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AKADEEMILISEL PÕLLUMAJANDUSE SELTSIL TÄITUS 100. JUUBEL

Põllumajandusteaduskonna üliõpilaste poolt ellu kutsutud Akadeemilise Põllumajanduse Seltsi põhikiri kinnitati Tartu Ülikooli Valitsuse poolt 2. detsembril 1920. Läbi sajandi on seltsi eesmärgiks olnud nii oma liikmete kui kodumaa põllumeeste harimine. Enne suurt ilmasõda andis selts välja ajakirju "Agronoomia" ja "Taluperenaine", mille tiraažid ulatusi kümnetesse tuhandetesse. Seltsi lipukirjaks oli "Töötada kodumaa põllumajanduse tõstmise tähe all Eesti edumeelse põllumehe vaimus!".

Täna koondab selts üle 220 põllumajandusteadlase ja spetsialist Eesti Maaülikoolist, Eesti Taimekasvatuse Instituudist ja erialaorganisatsioonidest, hoides kinni oma traditsioonidest. Selts annab välja ainukest emakeelset põllumajandusteaduste teadusajakirja "Agraarteadus" ning jätkab vankumatult nii liikmete kui siinsete põllumeeste harimist.

Pidupäeval ei tohi unustada, et lähikümnendil seisame silmitsi toidujulgeoleku riskide, uute taimehaiguste, loomataudide ja kliimamuutustega, sestap vajame enam põllumajandusteadlaste abi. Nii nagu sada aastat tagasi, nii ka täna, on oluline põllumajandusvaldkonnas loodud teadmust koguda ja jagada, et see parimal viisil rakendada.

Suur tänu seltsikaaslastele, et olete hoidnud akadeemilisust ning edendanud oma teadustöö ja õpetamisega Eesti põllumajandust läbi aastate. Täna tunneme rõõmu endiste aegade saavutustest, mis lubab vaadata lootusrikkalt tulevikku. Ma tunnustan igaüht, kes on kaasa rääkinud seltsielu eestvedamisel, konverentside korraldamisel, "Agraarteaduse" väljaandmisel, toimkondade töö organiseerimisel ja paljus muus. Kõiges selles, mille üle oleme täna eriti uhked ja võime õigustatult üksteile õlale patsutada ning tunnustavalt öelda: "Aitäh, et oled olnud meiega".

Suur tänu teile, et olete aidanud kaasa Akadeemilise Põllumajanduse Seltsi väärika ajaloo kirjutamisel.

Palju õnne, kogu seltsiperele!
Marko Kass, seltsi president

ESTONIAN ACADEMIC AGRICULTURAL SOCIETY IS CELEBRATED ITS 100TH OF ANNIVERSARY

The statute of the Estonian Academic Agricultural Society, established by the students of the Faculty of Agriculture, was approved by the Government of the University of Tartu on December 2, 1920. Throughout the century, the aim of the society has been to educate its members and farmers all over the country. Before the II World War, the society published numerous books and the journals "Agronoomia" and "Taluperenaine", which out-of-print works reached tens of thousands. The motto of the society was "To work under the rising star of the agriculture of our homeland in the spirit of a progressive Estonian farmer!".

Today, the society brings together more than 220 agricultural scientists and specialists from the Estonian University of Life Sciences, the Estonian Crop Research Institute and other professional organizations, to keep its traditions. The society publishes the only native-language scientific journal of agricultural sciences "Agraarteadus" and continues to educate both its members and local farmers.

On the day of the celebration, we must not forget that in the next decades, we will face food security risks, numerous plant and animal diseases and consequences of climate change; therefore, we need more help and knowledge from agricultural scientists. As a hundred year ago, it is essential today to compile and share the know-how created in the field of agriculture in order to make the best use of it in the future.

Many thanks to all members of society that you have maintained academicism and promoted Estonian agriculture through your research and teaching over the years. Today, we feel joy about the achievements of the past, which allows us to look to the future with hope. I commend everyone who has contributed to leading social activities, organizing conferences, publishing our journal, organizing the work of our committees and much more. In all that, we are particularly proud today, and we can approvely pat to each other shoulders and feel appreciation, saying to ourselves: "Thank you for being with us".

Congratulations to all of you!

Marko Kass, President of the Society

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PRECISION AGRICULTURE IN THE NORTH OF KAZAKHSTAN

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ABSTRACT. The precision farming system has been used in the North of Kazakhstan where specialized landfill on an area of 3000 ha was formed. In the fields of the landfill, detailed agrochemical survey (accuracy) of soil samples of the southern carbonate chernozem for grid cells 1 ha and 5 ha of fieldnet treatments with were conducted. Further differentiated fertilization was carried out both with the help of Amazone ZA-M and with the use of the Bourgault sowing complex. Monitoring of the state of the soil, plant development and work performed was carried out both by traditional methods and using modern remote sensing data. After the introduction of precision farming technologies in the North Kazakhstan from 2019 precision farming technologies has been used. As a result of the work carried out only from the introduction of one element of precision farming – differentiated rationing of fertilizer application, an increase in the yield of spring wheat 'Astana' by 9.6–19.2% to the standard economic technology was established. Research results have shown that the share contribution with a high yield of 2000 kg ha^{-1} was significant for a sampling grid cells 1 ha of fieldnet (40–47%) and less significant for a sampling grid cells 5 ha of fieldnet (15–20%). Hence it follows that the choice of a fieldnet with grid cells 1 ha is more preferable. Due to the use of a differentiated application system the savings from reducing the consumption of mineral fertilizers for the unit of the relay have had 69.26 EUR. Our novel research has shown that for characterizing the state of plants an assessment is given which was performed using test sites 1 and 5 ha grid cells of fieldnet treatments. In this case, we have used the vegetation indices NDVI – Normalized Difference Vegetation Index. At the same time, this index has changed relatively synchronously with the results of the yield of the spring wheat.

Introduction

It is known that wheat grown in Kazakhstan is the main crop for the republics of Central and Central Asia. The main wheat producer in this the region is Kazakhstan, which currently ranks 9th in production and 7th place in the export of wheat in the world (Fehér *et al.*, 2019). Other Asian countries, including Afghanistan, are the largest importers of Kazakhstan's wheat. Moreover, since 2004 imports in these countries have more than doubled. In countries such as Tajikistan and Kyrgyzstan, wheat accounts for over 60% of daily calorie intake (Satybaldin, 1997). Thus, food price surges are one of the main sources of food insecurity in Tajikistan and other republics (Morgounov *et al.*, 2018) in Asia.

Thus, wheat production in Kazakhstan serves as the food base for all of Asia. Moreover, the increase in yield and product quality is very relevant not only for Kazakhstan but also for many other countries (Abdullaev *et al.*, 2019).

One of the main ways to increase wheat productivity in Kazakhstan is the transition from extensive to highly intelligent farming systems. This path has already established itself all over the world where highly intelligent farming systems including farming technologies are being developed and introduced into production. However, before moving on to the introduction of precision farming technologies their adoption to new conditions is required (Irmulatov *et al.*, 2019; Truflyak *et al.*, 2017).

For the conditions of Kazakhstan, a very urgent task is the first stage of the introduction of high-intensity technologies of precision farming and precision plant growing aimed at increasing yields to 2000–2500 kg ha^{-1} which is the main task of the work of agricultural produces and scientists. Rational use of soil resources reproduction of soil fertility is the main condition for ensuring the stable development of an agro-industrial complex of the country and the most important source of expansion of agricultural production (Shortan, 2014). One of the main tasks of agriculture in North Kazakhstan is the realization of the productivity potential of arable soils at the level of productivity within above-mentioned yields of grain (first stage) and will reduce energy costs per unit of production (Agribusiness, 2020). The technology of precision farming and precision plant growing is a continuation of those innovative scientific and technological research that was carried out in the agro-industrial complex of Kazakhstan starting from the stage of "Virgin Land Upturned" and adaptive resource-saving production which lay down by A.I. Baraev and other scientists and production workers (Abdullaev, 2018).

The presented work was performed within the framework of the state program of Kazakhstan: "Transfer and adaptation of technologies for precision farming in the crop production on the principle of demonstration farms (polygons)". In this regard, our goal was to conduct this study.

Material and methods

For the introduction of new farming systems in Kazakhstan, it was necessary to develop new methodological foundations adapted to the conditions of the arid climate. For these purposes, the program "Transfer and adaptation of technologies for precision farming in the production of crop production according to the principle of demonstration farms (polygons)" was formed. The studies were carried out in the conditions of northern Kazakhstan (N51° 32'51.77"; E71° 03'27.50") since 2017 on the land use of non-profit institution LLP (Abdullaev, 2018)

To solve these problems a specialized test site on an area of 3000 ha was organized. The necessary equipment and agricultural machinery to carry out the work specialized for the precision farming system was purchased. All hardware and technical support were preliminarily adjusted, tested and adapted to production conditions. Equipping the test site with the necessary instruments, agricultural machinery and equipment made it possible to deploy precision research at the test site using both ground-based survey and Earth remote sensing (ERS) data (Komarov *et al.*, 2018). The following were carried out: agrochemical assessment of the field, application of fertilizers and fertilizing, sowing, caring for crops, harvesting, methodological approaches of the precision farming system was used (Yakushev, 2016). To clarify the heterogeneity of the supply of nutrients to the soils of the landfill, a detailed agrochemical survey of the landfill territory concerning soil samples per 1 ha and 5 ha with grid cells of fieldnet was carried out. The sampling of soil samples was carried out by an automated sampler based on a car with a GPS reference in the sub-zones of dark chestnut soils and southern carbonate chernozems which is typical for the above-mentioned region.

Fertilization was carried out in two ways: pre-sowing when fertilizers were applied together with sowing seeds in rows. This application was carried out using a Bourgault seeding complex equipped with a device (controller). Another method of fertilizing was spread surface. It was produced using an Amazone ZA-M solid bulk fertilizer spreader. At the same time, with the mineral fertilization 30 kg ha^{-1} of nitrogen and 20 kg ha^{-1} of phosphorus. Doses of nitrogen ranged from 0 to 60 kg, phosphorus – from 0 up to 50 kg. Potassium was not added, it is already in excess. An electronic operational map of fertilization (they were not evenly applied across the field) was in the memory of the on-board computer, which regulated the fertilization. Both complexes were equipped with on-board electronics and GPS receivers. Earth remote sensing (ERS) data were used in the assessment of orthophoto maps and the formation of a relief model, which was carried out using unmanned aerial vehicles (UAVs). So, field research, carried out using ground-based research and remote sensing, made it possible to develop a digital elevation model (DEM). It was a mathematical description of the earth's surface using a set of points located on it, connections between them, as well as a method for determining the heights of arbitrary points belonging to the modelling area by their plane coordinates. Complex display of ortho-mosaics shown in Fig. 1.

To assess the state of plants during the period of their growth and development, we used space images from satellites of the Sentinel 2 group. Using these images, it was possible to assess the change in the characteristics of large field objects (100 ha and more). The images were acquired in real-time using the Land Viewer service. It is generally known that Land Viewer provides free global satellite images and high resolutions satellite images. In our case, we used the vegetation indices NDVI – Normalized Difference Vegetation Index. This index described first time by B.J. Rose (1973) which as a simple indicator of the amount of photosynthetically active biomass (Sawyer, 1994). This is one of the most common and used indices for solving problems using quantitative estimates of vegetation cover. NDVI most correctly differentiates different types of vegetation according to optical characteristics (NASA, 2000). It is common knowledge that moderate values represent shrub and grassland (0.2–0.3), while high values are for tropical rainforests (0.6–0.8). The values of the index are also influenced by the species composition of vegetation, its closeness, condition, exposure and angle of inclination of the surface, and the colour of the soil under sparse vegetation. The index is moderately sensitive to changes in the soil background, except for cases when the vegetation density is below 30%. Based on a detailed assessment of various vegetation indices, the most informative indicators with a spatial resolution of 30 m were previously identified which were used in further studies (Komarov *et al.,* 2018). The need to analyze a digital elevation model for agricultural monitoring is associated with the possibility of taking into account the features of the relief, namely, taking into account slopes of different steepness (length, shape, exposure, and soil cover structure), height difference and detection of ravines, logs, watersheds (Fig. 1).

The obtained indicators were used in the implementation of a precision farming system at the landfill since the differentiated application of chemicalization agents should be based not only on the data of a detailed agrochemical survey with the preparation of maps of the agrochemical heterogeneity of the field but also take into account the relief features, characteristics of the agricultural landscape and the activity of watercourses, as well as the peculiarities of soils and ways of their transformation. This was the first time it was implemented in experimental fields.

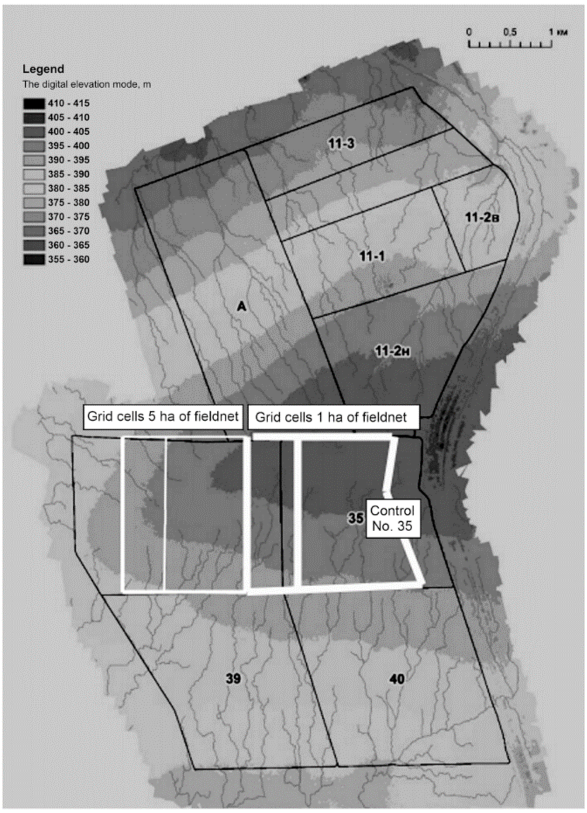

Figure 1. Value in numerals model of relief with streams and with corresponding highlighted fields, where field No. 35 is a control which represents as a control case with old extensive technology. Others numbers of the field are also represented as auxiliary experimental fields which are do not meet the objectives of this study

Statistical analysis was performed using the Stat and Microsoft Excel 2010 standard software packages. The reliability of the results of field experiments was assessed by the t-test.

Results

The results of the agrochemical characteristics of the precision farming landfill are shown in Table 1. It is noted that according to the sampling grid cells 5 ha of fieldnet, the reaction of the soil environment is moderately alkaline and the content of mobile potassium is high. The variation is also high, mostly for treatment grid cells 5 ha of fieldnet. The content of available phosphorus ranges from low to medium levels with an average of 28.6 mg kg^{-1} (LSD_{05} = 4.5 mg kg^{-1}) which is substantially higher compared with treatment grid cells 1 ha of fieldnet.

Table 1. Results of agrochemical characteristics of the soils in the arable horizon of the southern carbonate chernozem at a precision farming landfill

Treatments, *i.e.* grid cells of fieldnet, ha	Indices	Number of samples, n	Mean value of indices, mg kg^{-1}	$LSD_{05,}$ mg kg^{-1}
1	N-NO_3	318	15.2	1.1
1	P_2O_5	159	27.2	1.1
1	K_2O	159	733	23.9
1	pH	159	8.56	0.01
5	N-NO_3	122	13.1	1.9
5	P_2O_5	61	28.6	4.5
5	K_2O	61	793	38.4
5	pH	61	8.55	0.02

The results of the vegetation index (NDVI) for a precision farming landfill in comparison with control is shown (Fig. 2). At the same time, to assess the in the homogeneity of the state of the fields by the vegetation index, the method of dividing the fields by contrast zones into sectors was applied.

Vegetation indices for fields with different cell sizes show that the smaller the cell size, the more accurately the data is displayed. So, in a field with a cell size of 1 ha of fieldnet, the difference in the distribution of the vegetation index over the field is visible. The image with fieldnet a grid cells size of 5 ha of fieldnet shows a less contrasting distribution of the vegetation index. On the control field No. 35 indicators of the vegetation index are even more even and contrasting spots of heterogeneity are smoothed out.

Vegetation indices for fields with different grid cells sizes of fieldnet show that the smaller the grid cells size, the more accurately the data is displayed. So, in a field with a grid cells size 1 ha of fieldnet, the difference in the distribution of the vegetation index over the field is visible. The image with grid cell 5 ha of fieldnet size shows a less contrasting distribution of the vegetation index. On the control, field No. 35 indicators of the vegetation index are even more even and contrasting spots of heterogeneity are smoothed out.

Assessment of the state of the vegetation cover for each sector allows using cluster analysis to identify in more detail the zones of heterogeneity by the vegetation index. This, in turn, makes it possible to identify not only zones of heterogeneity, but also to determine the share (distribution) of the predicted yield in different parts of the field. As seen in Fig. 2 in the first sector, the predominant level of NDVI 0.5–0.6 occupies 46.00% of the sector's territory. The higher level of NDVI 0.6–0.7 is only 13.55%, while NDVI 0.7–0.8 accounts for only 0.56%. In sector 2, NDVI 0.5–0.6 covers 43.75 %. And a higher NDVI level of 0.6–0.7 covers a more significant area – 21.12%. There is an increase in the vegetation index and a higher significance. Thus, according to the NDVI indicator, it is seen that sector 1 has significantly lower indicators than sector 2. Even more significant differences in the vegetation index are recorded for sectors No. 3 and 4. However, evaluating the relationship between the distribution of vegetation index and yield the NDVI has changed relatively synchronously with the results of the yield of the spring wheat.

Concerning evaluating the yield data obtained using an electronic map (Fig. 3) it can be seen that there are zones in the field with both low and higher yield and this heterogeneity in yield practically coincides with the previously obtained data (Abdulaev *et al.*, 2019; Irmulatov *et al.*, 2019).

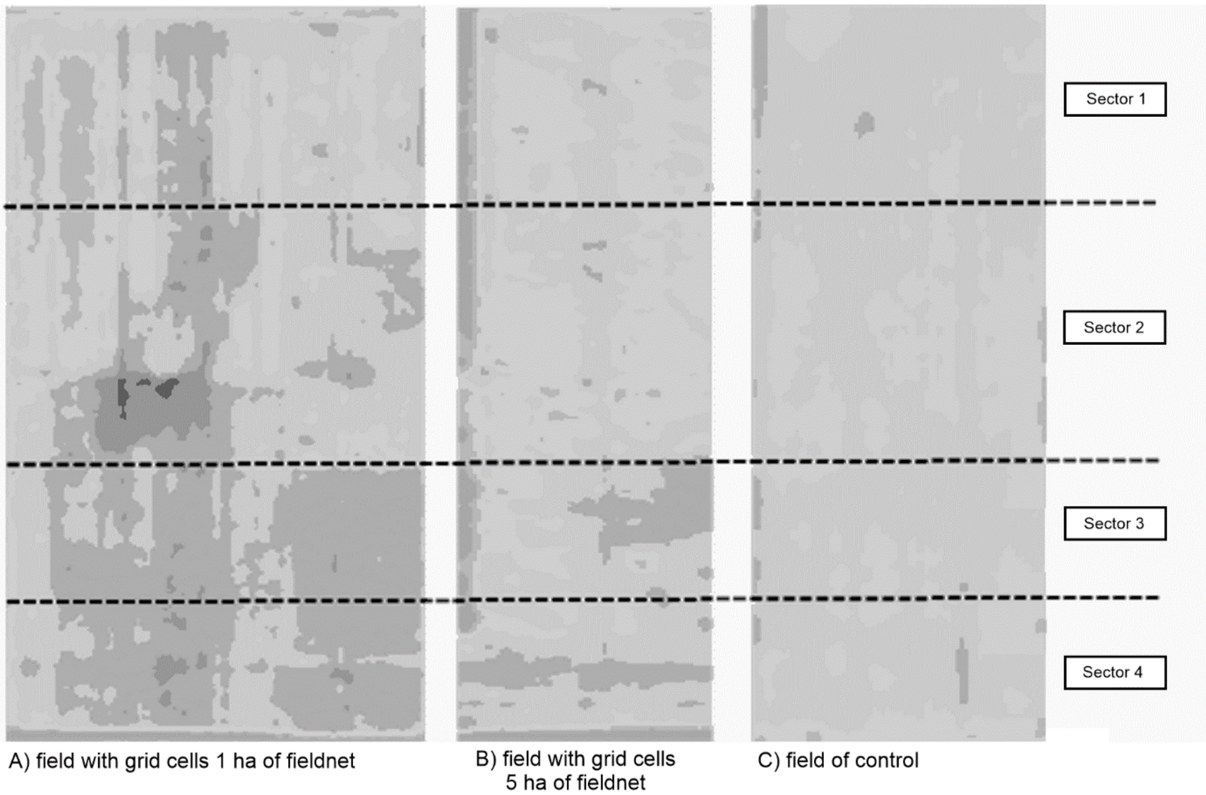

Figure 2. Distribution of the vegetation index (NDVI) over the territory of fields with different grid cells of fieldnet sizes and selected sectors of heterogeneity in the distribution of NDVI (comment: the order of the treatments is different compared to the order in Fig. 1 since this order of treatments was established depending on the intensity of changes of the NDVI. Moreover, the control is at number 35 of treatment).

The yield map data show (Fig. 3) that the applied elements of precision farming (differential fertilization) did not work to their full extent. According to the sampling grid cells 5 ha of fieldnet, the variation in yield indicators was in the range of 1000–2000 kg ha^{-1}, and according to the sampling grid cells1 ha of fieldnet, from 1000 kg ha^{-1} to 2500 kg ha^{-1} (Table 2). At the same time, the share participation of the minimum yield was significant both for the selection grid cells 1 ha of fieldnet (amounting to 30–37%), and with grid cells 5 ha of fieldnet – almost twice as much (70–75%). The share contribution with a high yield of 2000 kg ha^{-1} was significant for a sampling grid cells 1 ha of fieldnet (40–47%) and less significant for a sampling grid cells 5 ha of fieldnet (15–20%). Thus, an element of precision farming technology – differentiated fertilization – in the first year of the experiment provided an increase in yields not as much as expected. On the sampling grid cells 5 ha of fieldnet, the increase was 140 kg ha^{-1} or 9.6%, and on the sampling grid cells 1 ha of fieldnet, 280 kg ha^{-1} or 19.2%.

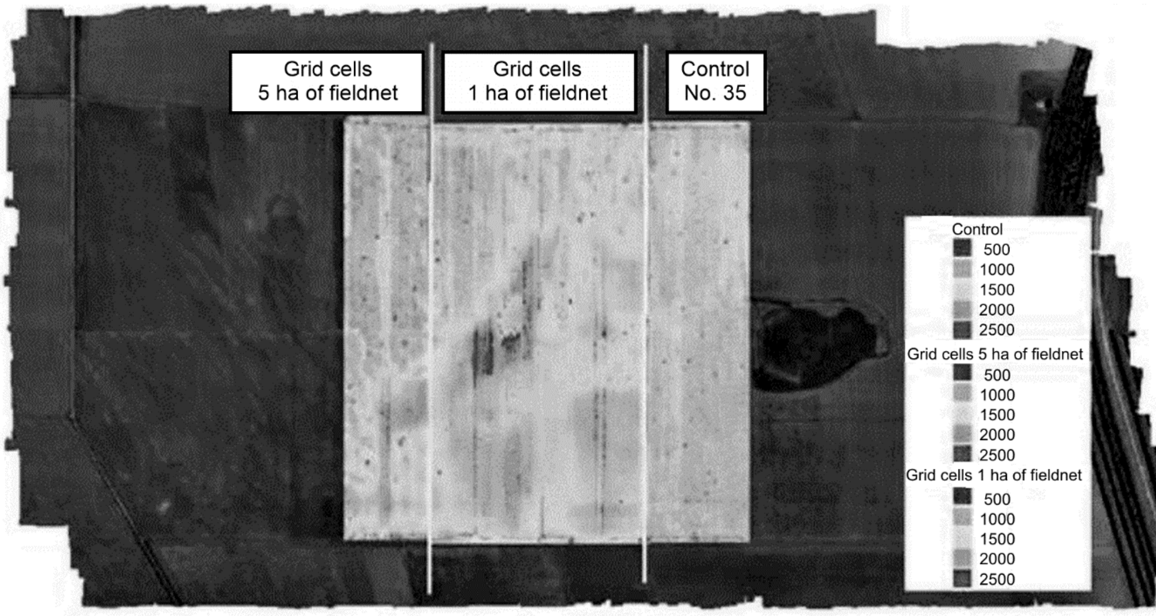

Figure 3. Yield map for the treatments under consideration

Table 2. The yield of spring wheat 'Astana' on the landfill of precision farming

Treatments, *i.e.* also elementary area of grid cells of fieldnet, ha	Sown area, ha	Yield, kg ha^{-1}	LSD_{05} kg ha^{-1}
1	174.4	1742	295
5	68.3	1596	254
Control	82.9	1463	349

Discussion

When comparing with grid cells 1 and 5 ha of fieldnet, there is low variability in pH and potassium (Table 1). The coefficients of variation for these parameters (pH and K_2O) between the elementary areas are comparable this was observed on a 5 ha with grid cells of fieldnet that with it, although according to some parameters the content of nutrients in the soil (P_2O_5 and K_2O) was higher, this difference was not statistically significant. In this case, one should take into account the fact that the coefficient of use of mineral fertilizers is important. This indicator (Smirnov *et al.*, 2014) depending on the type of fertilizer, has values for Northern Kazakhstan at N (0.55), at P_2O_5 (0.10) and K_2O (0.40). But yet indeed, it seems to us that such a potassium content is K_2O = 733–793 mg kg^{-1} in the soil not incorrect. There is no error regarding the potassium content in the soil because this content is typical in carbonate chernozems. There is an effusion regime (moisture evaporates and pulls salt through the pores), and not a flushing one, as we usually do (Haliniarz *et al.*, 2018). Therefore, salts in the conditions of Northern Kazakhstan do not go down the profile like we do, but accumulate at the top. Hence the high content of potassium, magnesium, calcium, and other alkaline elements in soils. Therefore, the pH in the soil is alkaline, more than 8.0 (Table 1). In general, taking into account the sufficient supply of nutrients in soils and their insignificant variability in the field, it was problematic to expect high efficiency from the introduction of the differentiated application of mineral fertilizers in precision farming technology.

Based on the analysis of the results of the experiment on the introduction of individual elements of precision farming in the conditions of Northern Kazakhstan, a positive effect from the introduction of technologies is noted (Table 2). Taking into account the possibility of further growth in yields from the differentiation of fertilization, as well as the use of other elements of precision farming, the introduction of a farming system in Kazakhstan is very promising.

It should also be especially emphasized that the prospects for wheat production in Kazakhstan are due to favourable natural and climatic conditions for the cultivation of cereals and leguminous crops and, first of all, food wheat with a high gluten content (Lu, 2017), which is in high demand in world markets (Bora *et al.*, 2014). In this regard, grain production is one of the strategic sectors of the republic, from the state of which food security of the country, income and employment of the population, development-related industries (livestock, poultry, food and processing industry).

Typical technologies for the cultivation of spring wheat using extensive technologies on southern carbonate chernozems showed a low (1460–1700 kg ha^{-1}) yield in the context of the variety 'Astana' (Table 2). At the same time, the variation in yield depended on the prevailing weather and climatic conditions and some other indicators (Meng *et al.*, 2017). At the same time, it is generally known that the Northern Kazakhstan stand is located in an arid climate zone were 220–350 mm of rainfall per year. There were 17 (42%) medium dry years, and only 12 years (30%) were there favorable conditions for grain production (Satybaldin, 1997).

In any case, extensive technology limited the growth of wheat productivity. To obtain high and sustainable yields required a transition from extensive to new technologies capable of increasing yields. These could be the precision technologies of precision farming, which have proven themselves all over the world.

The transition from extensive technologies to precision farming technology ensured a significant increase in productivity while reducing (due to differentiated rational use) doses of fertilizers applied by 10–30%.

We completely agree that the economic importance of cereals including spring wheat particularly arises from their role in the food industry and thus in ensuring national food security (Haliniarz *et al.*, 2018). At the same time, it is important to introduce new methods of a highly intelligent farming system and elements of farming systems used in agricultural practice (Anselin *et al.*, 2004).

As shown in the conditions of the Leningrad region of the Russian Federation (Matvejenko *et al.*, 2020), this task is quite feasible. It is also shown that by introducing new elements of precision farming, the yield of spring wheat can increase from 2500 up to 4000–4500 kg ha^{-1} and more. At the same time, due to the introduction of elements of precision farming, the grain of 2–3 classes was obtained for the first time in the North-West region of the Russian Federation. So, the main limiting factor in crop production in an arid climate (for example, for Kazakhstan) is lack of moisture (less than 300 mm per season), with an excess of solar radiation and high temperatures leading to drought.

With the achievement of cost savings per 1 standard relay of 69.26 EUR from the introduction of the system of differentiated fertilization, the return on investment of 2553.63 EUR is achieved with the production of about 36 standard relays.

In the structure of costs for the implementation of technological operations of sowing, the cost of a machine operator's work is about 24 EUR per standard relay. For a standard relay, fuel consumption is about 127.7 EUR. This imbalance creates conditions for excessive consumption of fuel and lubricants. The introduction of a control system for fuels and lubricants can provide savings of up to 30% of the specified cost item, which makes it possible to recoup the costs of using sensors in the first season of their use. In the structure of costs for growing wheat seeds, the share of fuels and lubricants can leave up to 14% of all direct production costs.

Saving 30% of fuel and lubricants due to the introduction of a precision farming system can be 8.42 EUR ha^{-1} or 4.0% of all production costs. In terms of a ton of products, this is 9.8% of all costs. Thus, the implementation of this system of precision farming in conditions of all Kazakhstan is very promising. Economic efficiency calculations showed that in the precision farming system, the total savings from the introduction of the automatic driving system on the Buhler Versatile 485 tractor for 1 standard relay amounted to 72.89 EUR.

Conclusions

The introduction of innovative farming systems, including precision farming technology, is very promising for the conditions of Kazakhstan. It is shown at a specialized precision farming landfill formed in North of Kazakhstan that the involvement of innovative technologies, new technology in the first year of implementation ensured the highest yield. Equipping the test site with the necessary instruments, agricultural machinery and equipment made it possible to deploy precision research at the test site using both ground-based survey and Earth remote sensing (ERS) data. We have used the vegetation indices NDVI – Normalized Difference Vegetation Index which has changed relatively synchronously with the results of the yield of the spring wheat 'Astana'. Also important is the fact that the share contribution with a high yield of 2000 kg ha^{-1} was significant for a sampling grid cells 1 ha of fieldnet within 40–47% and less significant for a sampling grid cells 5 ha of fieldnet within 15–20%. Hence the conclusion suggests itself that the choice of a field grid with cell sizes of 1 ha is more preferable Calculations of the economic efficiency of the introduction of elements of precision farming in Kazakhstan have shown their high efficiency and prospects for further developments.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publications of this paper.

Author contributions

KA – 30%, BI – 30%, AK – 30%, EN – 10% – study of the concept and design;
KA – 30%, BI – 30%, AK – 30%, EN – 10% – data collection;
KA – 15%, BI – 25%, AK – 50%, EN – 10% – analysis and interpretation of data;
KA – 15%, BI – 15%, AK – 50%, EN – 20% – writing a manuscript;
KA – 10%, BI – 10%, AK – 50%, EN – 30% – critical revision and approval of the final manuscript.

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SUBLETHAL EFFECT OF GLYPHOSATE [N-(PHOSPHONOMETHYL)GLYCINE] ON GROWTH PERFORMANCE AND BIOCHEMICAL ACTIVITIES IN SOME ORGANS OF *CLARIAS GARIEPINUS* (BURCHELL, 1822) FINGERLINGS

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ABSTRACT. The effect of the sublethal concentration of glyphosate [N-(phosphonomethyl)glycine] on growth and some biochemical indices in the organs of African catfish (*Clarias gariepinus*, Burchell 1822) fingerlings in a static bioassay setup was studied to provide information on the sublethal toxicity effect of glyphosate on *C. gariepinus* fingerlings. Two hundred and seventy (270) fingerlings of *C. gariepinus* (10.02 ± 0.20 g) randomly stocked at 30 fish per tank in triplicate were exposed to varying concentration (0, 2.75 and 5.00 ppm) of glyphosate for 70 days. The results of the study showed that the determined growth parameters decrease with increase glyphosate concentration (except specific growth rate). The highest mortality rate was recorded in the treatment with the highest phosphate concentration (5.50 ppm). The enzymatic analyses of the fish tissue revealed that Na^+/K^+-ATPase activity which ranged from 0.20 to 19.29 µM Pi min^{-1} mg^{-1} protein in all the fish tissues increase with increase glyphosate concentration in the fish muscle and liver, and decreases with increase in glyphosate concentration in the gills. However, the muscle and liver malate DH activities decreased with increase in glyphosate concentration while the lactate DH activity increases with increase intoxicant concentration in the muscle (with the highest treatment having a threefold increase). Generally, the enzymatic activities of fish tissues followed the order: Malate DH >Na+/K+-ATPase>Lactate DH. The study concluded that the glyphosate concentration negatively impacted the growth and survival of *C. gariepinus* and also had a pronounced effect on the enzymatic activities of the studied organs.

Introduction

Water bodies around the world are increasingly getting polluted, more than ever in history, due to human activities, especially with the use of an organic substance which directly or indirectly enter into the aquatic ecosystem through human perturbations (Scott *et al.,* 2000; Pérez *et al.,* 2011; Ayanda, Egbamuwo, 2012). The use of pesticide especially herbicide for destroying, preventing, or mitigating insects, rodents, nematodes, fungi, or weeds (as applicable), is on the increase worldwide in modern agricultural practices (Kellogg *et al.,* 2000; Tomlin, 2006; Steinmaus, 2010; Okayi *et al.,* 2010; Pérez *et al.,* 2011; Benbrook, 2016). Due to the chemical structure, toxicity, leaching through root zones, mobility and persistency of organic pesticides, several authors have reported them to possess a threat to the underground, surface water and aquatic lives (Artiola *et al*., 2004; Brusseau *et al*., 2006; Brusseau, Tick, 2006; Yusuf *et al.,* 2017).

Ikpe (2012) reported that since fish and other aquatic organisms only flourish when the biological and chemical conditions of the water are stable, the health of these aquatic organisms and even human consumers are therefore at risk when the aquatic ecosystem is polluted or contaminated. Several indicators have been used to study the effect of indiscriminate use, improper handling, accidental spillages or drifts of herbicide into natural waterways on aquatic organisms. Olaleye *et al.* (2005) reported the effect of glyphosate application to control *Eichhornia crassipes* on fish composition and abundance in Arabia Creek, Niger Delta, Nigeria while Ayanda, Egbamuwo (2012) reported the effect of glyphosate on histology of *Clarias gariepinus* liver and gill.

However, the effect of glyphosate on enzymes which are an organic catalyst that speeds up the rate of chemical reactions in a living cell (Michael, 2007), proteinous inactive and not used up during such biochemical reactions (Slenzka *et al*., 1994) have not been documented. Enzymes are known to play a very crucial role in the metabolic process in the fish body and are thus biochemical markers or indicators used to evaluate environmental contamination to avoid jeopardizing the health of aquatic lives (Barnhoorn, van Vuren, 2004). Moreover, the effect of toxicants on the enzymatic activity of fish is one of the vital biochemical parameters that are affected when under stress, and when an organ is diseased due to the effect of a toxicant, enzyme activity appears to be increased or it may be inhibited due to the active site(s) being denatured or distorted. Therefore, the increase or decrease in the levels of some enzymes which catalyze some steps in the metabolism of major macromolecules (such as carbohydrates and proteins) known to be present in most tissues, may be sufficient enough to provide information of diagnostic value (Adeyeni, 2010).

Some the enzymes that have been reported to have a close link between toxicants effects on organism include; glycolytic enzymes (Lactate Dehydrogenase, pyruvate kinase and phosphofructokinase); Trans-membraneATpases (sodium-potassium exchanger (Na^+/K^+ ATPases) and hydrogen-potassium ATPase – H^+/K^+ ATPase or gastric proton pump); Malate dehydrogenase (MDH) (Das *et al.,* 2004; Barnhoorn, van Vuren, 2004). These authors reported that increase or decrease in the level of these enzymes is enough bio-chemical indicators to qualify the damage done to an organism after exposure to a toxicant.

Glyphosate is widely used herbicides in Nigeria because of its efficacy for weed control (Miller *et al*., 2010). However, wholesale application of the herbicides for weed control in river catchment area ultimately result in the introduction of the herbicides and its residue into the aquatic ecosystem through erosion, spray drift and runoffs from the catchment areas and thus affect aquatic lives (Olaleye *et al*., 2005; Ayoola, 2009). Therefore, aquatic bioassays are necessary for water pollution control to determine whether a potential toxicant like glyphosate is harmful to aquatic lives, at varying concentrations (Olaifa *et al*., 2003). There is, therefore the need to evaluate the possible acute and sublethal toxic effect of glyphosate on aquatic life forms using fingerlings of *Clarias gariepinus,* which is the most widely cultured fish species in Nigeria due to its hardiness, economic values and ability to tolerate water of poor quality among others (Ayanda, Egbamuwo, 2012). The study aimed at determining the effect of sublethal concentration of glyphosate, popular herbicides on growth and oxidative enzymes of an important Nigeria food fish *Clarias gariepinus*.

Materials and methods

Range Finding and Acute Toxicity Test

The concentrations of the glyphosate used for the range finding test followed the methods described by Reish and Oshida (1986) and Obuotor (2004).

A stock solution of 4 gl^{-1} glyphosate was prepared by measuring 11.1 mL of Round-up® which was diluted to obtain 0.4, 0.04, 0.004, 0.0004 and 0.0 gl^{-1} glyphosate. 10 fingerlings of the test fish were randomly selected and introduced into each of the 10-litre tank containing 5 litres of dechlorinated tap water containing the test solution (toxicant). The containers labelled A to E contained the logarithmic concentration of 4, 0.4, 0.04, 0.004, and 0.0004 gl^{-1} glyphosate. Another tank labelled F which represented the control was without glyphosate addition. The exposure was carried out in triplicate. The fish were then observed for mortality after 1 hr, 3, 6, 12, 48, 72 and 96 hrs (Reich, Oshida, 1986). Toxicity range value was then estimated from the probit analysis and Spearman-Karber method of estimating mortality results (Carter *et al*., 2012). The result of the toxicity range obtained from the range-finding tests was used to prepare 8 graded concentration, 1.00, 4.00, 8.00, 12.00, 16.00, 20.00, 24.00 and 400.00 ppm of commercial glyphosate formulation (Roundup®) (containing isopropyl ammonium salt of glyphosate at 480 gl^{-1} as the active ingredient (equivalent to 360 g glyphosate per litre. The various concentrations were used for 96 hours acute toxicity bioassay in a static exposure system Obuotor, 2004). Ten (10) *Clarias gariepinus* fingerlings (10.02 ± 0.2 g) randomly selected were introduced carefully into each of the exposure tanks containing the test concentrations in triplicates. Mortality in each of the exposure chamber was monitored and recorded after 1 hour, 3, 6, 12, 24, 48, 72 and 96 hrs. Dead fish were promptly removed from the exposure chamber and the test was terminated after the 96 hrs period of exposure. The 96 hrs LC_{50} values were then calculated from the data collected using Trimmed Spearman-Karber Analysis (U.S.EPA, 1997).

Chronic toxicity testing

A total of two hundred and seventy (270) 6-weeks old African catfish (*Clarias gariepinus*) fingerlings (10.02 ± 0.2 g) obtained from Prime Aquaculture Ltd., Ikorodu, Lagos and transported to the Fish Culture Laboratory, Department of Zoology, Obafemi Awolowo University, Ile-Ife were acclimatized for two weeks in an aerated 150 L glass tanks. The fingerlings stocked in 30 fish per tank were fed with 2 mm Coppen's® feed containing (45% crude protein) at 4%

their body weight in two instalments. After acclimatization, the fish fingerlings randomly selected were carefully introduced into three exposure sets (*i.e.* control, 2.75 ppm (25% of the 96 hrs LC_{50} *i.e.* Lethal Dose 50%) and 5.50 ppm (50% of the 96 hrs LC_{50})) in triplicate at 30 fish per tank for 70 days. During these periods, the experimental test fingerlings were fed with Coppen's ® feed at the rate of 4% per body weight. The test solution in each tank was renewed every 72 hours with freshly prepared solutions. The water quality measured *in situ* daily were pH, temperature and Dissolved oxygen using a portable pH meter (Model with resolution 0.01 pH and accuracy of ± 0.05 pH), mercury in glass thermometer and Milkawauke D.O. meter respectively.

Fish growth performance was monitored fortnightly by collectively weighing and measuring the fish from each tank using a top-loading meter balance model P1210 (in grams). From the weight data collected and the quantity of the feed consumed, the growth performance and the feed utilization data were generated as follows:

Daily Feed Intake (DFI)

$$DFI\ (g\ fish^{-1}) = \frac{TFI}{t}, \quad (1)$$

where TFI = total feed intake (g),
t = rearing period of the experiment (days).

Mean Weight Gain (MWG)

This was calculated according to the method of Pitcher, Hart (1982) as:

$$MWG = W_f - W_i, \quad (2)$$

where W_f = final mean weight (g),
W_i = initial mean weight (g).

Daily Weight Gain (DWG)

The DWG was estimated according to the method of Pitcher and Hart (1982) as:

$$DWG\ (g) = \frac{MWG}{t}, \quad (3)$$

where: MWG = mean weight gained,
t = rearing period (days).

Percentage Weight Gain (PWG)

The percentage of weight gained was obtained according to the formula:

$$WG\ (\%) = \frac{MWG}{W_i} \times 100, \quad (4)$$

where: MWG = mean weight gain,
W_i = mean Initial weight.

Specific Growth Rate (SGR)

This was estimated from the logarithmic differences between the final and initial mean weight of fish (Brown, Guy, 2007).

$$SGR = \frac{100\ (Log_e W_f - Log_e W_i}{T}, \quad (5)$$

where W_f = final mean weight,
W_i = initial mean weight (g).
T = rearing period (days)

Feed Conversion Ratio (FCR)

The FCR was estimated according to the methods of Bruel *et al*. (2000) as:

$$FCR = \frac{Total\ feed\ intake\ (g)}{Total\ weight\ gain\ (g)}, \quad (6)$$

Percentage Survival

Survival was monitored daily by observing the experimental tanks each morning and recording the number of survivors and removing the dead fish. At the end of the experimental period, survived fish in each tank were counted and survival percentage was estimated as:

$$\%\ Survival = \frac{N_f}{N_i} \times 100, \quad (7)$$

where N_f = number of fingerlings at the end of the experiment,
N_i = number of fingerlings at the beginning of the experiment.

Biochemical Assay

After the 70th day of the experiment, five (5) fish from each tank were sacrificed and excised for the collection of liver, gills and muscle tissue. The tissues were rinsed in ice-cold 0.25M sucrose solution. The tissues were then weighed on a weighing balance, homogenized in iced-cold 0.15 M tris buffer, (pH 7.4) using a motor-driven glass-telfon potter-Elvejhem (TRI-R STIR-R K43) homogenizer, at 1000 rev min^{-1} to give a 10% homogenate. This resulting suspension was used for the assay of adenosine triphosphatase (ATPase), Malate Dehydrogenase and lactate dehydrogenase.

Enzyme Assays Procedure

The following oxidative marker enzymes were assayed for in the gills, liver and muscle homogenates for both the control and the experimental fish.

Malate Dehydrogenase (MDH) Assay

MDH was assayed for as described by Worthington Biochemical Corporation (1993). The assay mixture which consists of 0.1 ML oxaloacetate, 2.6 ml 0.1 M^{-1} phosphate buffer and 0.2 Ml NADH was incubated at temperature 25 °C in a Pharmacie Biotech Novaspec II spectrophotometer (Model 80-2088-64, Cambridge, England) at 340 nm for 3–4 minutes to achieve temperature equilibration and establish the blank rate. 0.1 ml of the liver homogenate sample was then added and a decrease in absorbance was read for 4 minutes at 30 seconds intervals. The $D_{340\,nm\,min^{-1}}$ was obtained from the linear curve of absorbance against time. The MDH activity was then calculated from the formula:

$$\mu l\ mg^{-1} = \frac{D_{340\,nm\,min^{-1}}}{6.22 \times mg\ enzyme\ ml\ reaction\ micture^{-1}}, \quad (8)$$

where $D_{340\,nm\,min^{-1}}$ = the slope from the graph of the absorbance against time.

Enzyme activity was expressed as u mg^{-1} where one unit of enzyme oxidizes 1.0 Nmol of NADH in 1 minute at 25 °C and pH 7.4 under the specified conditions.

Sodium, Potassium ATPase Assay (Na^+/K^+-ATPase)

The inorganic phosphate (P_i) liberated from the hydrolysis of the substrate adenosine triphosphate (ATP) at 37 °C was used for the measurement of Na, K – ATPase activities. Frozen gill filaments, (200 mg) was homogenized for 90 seconds in 0.3 m sucrose buffer (pH 7.4) were homogenized and centrifuged at 1000 g (r.m.p) for 10 minutes to remove debris. ATPase activity was monitored immediately on the resulting supernatant. Final assay concentrations of chemicals used were in (Mol l^{-1}) tris-HCL (pH = 7.4) 135, NaCl 100, KCl 10, $MgCl_2$ 6, ATP 3, EDTA 0.1 and Quabian 3.

After pre-incubation of the medium for 5 minutes, reactions were started by adding the samples and ATP appropriately. The reaction was continued for 30 minutes with the incubated medium shaken on a shaker using 100 rpm model of shaker. The reaction was terminated by putting the samples in ice and a Lubrol-molybdate mixture (1:1 w w^{-1}). The added sample was then vortexed to form the soluble yellow complex. An inorganic aliquot of the incubated mixtures. All assays were carried out in triplicate and ran with enzyme and reaction blanks. ATPase activity was expressed as Nmol Pi mg^{-1} protein hr^{-1} (Canli, Stagg, 1996; Obuotor, 2004).

Lactate Dehydrogenase (LDH) Assay

The assay for LDH was done on the gills, muscle and liver samples using the Randox Diagnostic Kit (Reitman, Frankel, 1957). The assay mixture contains either 0.04 ml gills, muscle or liver homogenate and 1.0 ml Randox buffer mixed at a temperature between 25–30 °C. The initial absorbance of the mixture was read at 340 nm after 30 seconds using a Pharmacia Biotech Novaspec II spectrophotometer, (Model 80-2088-64, Cambridge, England). The absorbance was then read every 30 seconds for 4 minutes. A regression line was obtained from the graph of absorbance against time while the slope was estimated. The LDH activity was calculated from the formula:

$$UI^{-1} = 4127 \times D_{340\,nm\,min^{-1}}, \qquad (9)$$

where $D_{340\,nm\,min^{-1}}$ is the slope from the graph of absorbance against time. Enzyme activities were expressed as UL^{-1}, where UL^{-1} is equal to the amount of enzyme required to convert 1.0 µmol of suitable to the product in 1 minute between 25–30 °C.

Data Analysis

Data generated were statistically analysed as a completely randomized design using each cage as an experimental unit. One-way ANOVA was used to determine if there were significant differences (P<0.05) among the treatments, followed by the Duncan test to identify where the differences occurred. The analytical tools used are SPSS software version 20.0 for statistical analysis, and Microsoft Excel for graphical representation.

Ethical Statement

The protocol and procedures employed in this study for the sacrifice of animal used were ethically reviewed and approved. The procedures also complied with directive 2010/63/EU of the European Parliament and of the Council on the protection of animals.

Results

The temperature, pH and dissolved oxygen measured during the experimental period were relatively stable ranging from 24.5 to 26.9°C, 6.24 to 7.62, and 4.00 to 8.00 mg L^{-1} respectively.

During the 96-hour acute toxicity test, fish mortality was recorded in each tank (Table 1). Swimming behaviour was observed to drastically change on introducing the fish into tanks treated with glyphosate. A first noticeable change in swimming pattern was observed in tanks with the highest treatments (Treatments F, G, H and I) which began with rapid sporadic movement characterized by darting movements in the tanks and lack of cruising movement. Vertical swimming, loss of balance, flaring of the opercula and gasping was later observed in the treatments before fish deaths which further increased the physiological stress of the fish. Feed avoidance was also noticed among the various treatments with very high glyphosate levels.

Table 1. The acute mortality rate of the experimental fish

Concentrations of glyphosate (ppm)	Time of Exposure (h)										Mortality rate	
	0.25	0.5	1	3	6	12	24	48	72	96	n	%
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	1	1	10
4	0	0	0	0	0	0	0	1	0	1	2	20
8	0	0	0	1	0	0	0	0	2	1	4	40
12	0	0	0	0	0	0	1	0	0	2	3	30
16	0	0	0	0	0	0	0	1	2	1	4	40
20	0	0	0	0	2	0	0	1	4	2	9	90
24	0	0	0	0	3	0	1	2	3	0	9	90
40	3	2	5	0	0	0	0	0	0	0	10	100

Fish in the control tanks and lowest treatment (Treatment A and B) maintained an initial short 'burst' movement and in a few minutes, began the regular cruising movement. As shown in Table 1, absolute (100%) fish mortality was first recorded in a tank with the highest concentration of glyphosate after one-hour exposure. Treatments F (20.00 ppm) and G (24.00 ppm) recorded 90% mortality rate on the 96 hr while Treatments C (8.00 ppm) and E (16.00 ppm) recorded 40% mortality rate after the 96 hours of exposure respectively (Table 1). Treatments A (1.00 ppm), B (4.00 ppm) and D (12.00 ppm) had a mortality of 10%, 20% and 30% rates respectively at the end of the 96 hours short term static bioassay (Table 1).

The daily feed intake (DFI), mean daily weight gain (MDWG), mean weight gain (MWG) and food conversion ratio (FCR) values of the fish in various tanks decreased with increase in the concentration of the glyphosate (Table 2). However, the specific growth rate (SGR) was independent of glyphosate concentration. The lowest SGR value was recorded in the fish exposed to 2.75 ppm glyphosate concentration while the highest SGR value was recorded in the control treatment tank. The mean weight gain of the exposed fish showed insignificant difference with the control treatment (P>0.05).

During the long term toxicity test, a highest mean mortality rate of 50% was observed at the end of the experiment in treatment with the highest concentration of glyphosate (5.50 ppm) while the control and treatment with 2.75 ppm had a mortality rate of 30% (Table 3).

Enzymatic Activities

Enzymatic activities of ATPase determined in various fish tissues (muscle, gill and liver) exposed in all the treatments tanks ranged from 0.20 ± 0.04 to 19.29 ± 1.86 µM Pi min^{-1} mg^{-1} protein. In all the tissue assayed, fish muscles recorded the lowest Na^+/K^+-ATPase activity which ranged between 0.20 ± 0.04 (control) and 0.43 ± 0.02 µM Pi min^{-1} mg^{-1} protein (5.50 ppm) while highest Na^+/K^+-ATPase activity was recorded in the gill with a range of 9.29 ± 1.33 (5.50 ppm) to 19.29 ± 1.86 µM Pi min^{-1} mg^{-1} protein (control) (Fig. 1). Among the treatments, Na^+/K^+-ATPase activity in the fish muscles and livers was observed to increase with an increase in glyphosate concentration while a decrease in the Na^+/K^+-ATPase activity with increasing concentration was observed in the gills of the exposed fish (Fig. 1). However, while the Na^+/K^+-ATPase activity in the muscle and liver of the exposed fish across the treatments showed no significant differences (P>0.05), the Na^+/K^+-ATPase activity level recorded in the gills of the exposed fish across the treatments were highly significant (P>0.05).

Malate DH activity in the muscle, gill and liver of the fish assayed in all the treatment tanks ranged from 5.50 ± 0.69 to 578.45 ± 33.47 µM Malate min^{-1} mg^{-1} protein (Fig. 2). In fish muscles, Malate DH activity significantly decreases (P<0.05) with the increasing concentration of glyphosate.

Table 2. Mean (±SE) Growth Performance* of *C. gariepinus* Juveniles Exposed to Variable glyphosate concentrations of for 70 days. Among-treatment comparisons are marked with different superscripts, which indicate significant differences (ANOVA Duncan test P<0.05).

Growth performance indices	Concentration of WSF		
	0% (control)	2.75 ppm	5.00%
Initial mean weight (g)	26.50^a ±0.42	28.50^a ±0.22	27.50^a ±0.53
Final mean weight (g)	138.10^a ±4.28	136.70^a ±2.82	132.40^a ±2.36
Mean weight gain (g)	111.50^a ±1.25	108.20^a ±2.24	104.00^a ±3.49
Mean daily weight gain (g)	1.59^a ±0.30	1.55^a ±0.17	1.49^a ±0.15
Specific Growth Rate (%)	0.31^a ±0.16	0.29^a ±0.12	0.30^a ±0.15
Feed Conversion Ratio	0.86^a ±0.08	0.86^a ±0.37	0.63^b ±0.60
% Mortality	30	30	50

Values with different superscripts are significantly different at P<0.05

Table 3. The mortality rate of the experimental fish during definitive exposure

Concent-rations of glyphosate (ppm)	Weeks of exposure										Mortality rate	
	1	2	3	4	5	6	7	8	9	10	n	%
0.00	0	0	0	0	0	0	1	0	0	1	2	20
0.00	0	0	0	0	0	0	0	0	0	1	1	10
0.00	0	0	0	0	0	0	0	0	0	0	0	0
2.75	0	0	0	0	0	0	0	0	0	0	0	0
2.75	0	0	0	0	0	0	0	2	0	0	2	20
2.75	0	0	0	0	0	0	0	1	0	0	1	10
5.50	0	0	0	0	0	0	0	3	1	0	4	40
5.50	0	0	0	0	0	0	0	3	1	0	4	40
5.50	0	0	0	0	0	0	0	0	6	1	7	70

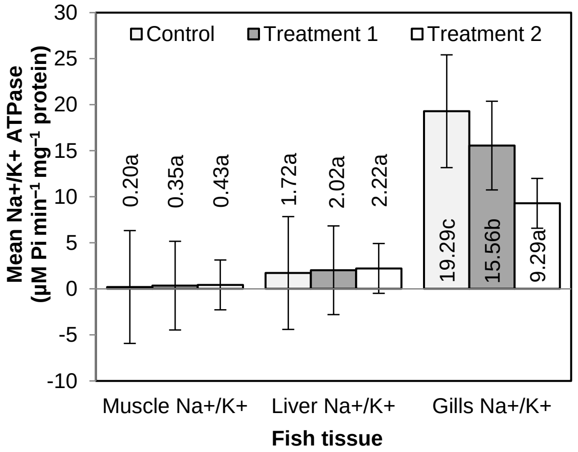

Figure 1. Comparative changes in the mean (±S.E.) Na^+/K^+ ATPase activity in the muscle, liver and gills of *C. gariepinus* following exposure to sublethal concentration of glyphosate. Treatment 1 – 2.75 ppm; Treatment 2 – 5.50 ppm.
*Bars of the same fish tissue with different superscripts were significantly different (P<0.05)

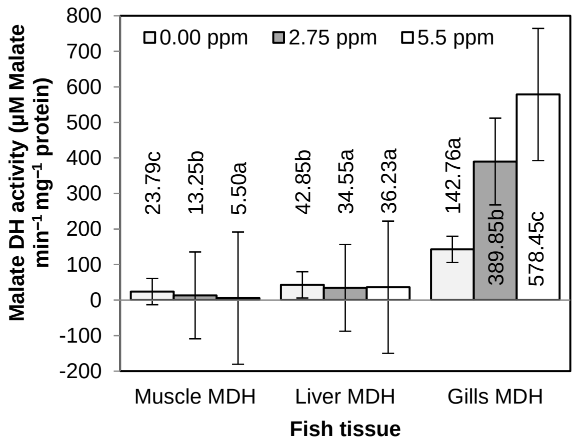

Figure 2. Changes in the mean (±S.E.) malate dehydrogenase activity in gills, muscle and liver of *C. gariepinus* fingerlings following exposure to sublethal concentration of glyphosate. Control – 0.00 ppm
*Bars of the same fish tissue with different superscripts were significantly different (P<0.05)

Highest mean Malate DH activity (23.79 ± 2.2 µM Malate min^{-1} mg^{-1} protein) was recorded in the control fish while the fish in 5.50 ppm treatment had lowest (5.50 ± 0.69 µM Malate min^{-1} mg^{-1} protein) Malate DH activity (Fig. 2). The Malate DH activity in the liver of the fish from various treatment tanks ranged narrowly from 34.55 ± 2.11 µM Malate min^{-1} mg^{-1} protein (2.75 ppm glyphosate) to 42.85 ± 2.65 µM Malate min^{-1} mg^{-1} protein (control). Malate DH activity in the liver of the exposed fish which were not significantly different (P>0.05) from each other was however significant (p<0.05) compared to the activity level recorded in the control fish (Fig. 2). In the gill tissues, Malate DH activity was generally higher than in other tissues and significantly increases with increasing concentration of glyphosate with a range of 142.76 ± 10.14 to 578.45 ± 33.47 µM Malate min^{-1} mg^{-1} protein (Fig. 2). Fish in the control tanks recorded the lowest mean value of Malate DH activity in their gills with a mean value of 142.76 ± 10.14 µM Malate min^{-1} mg^{-1} protein while treatment 5.50 ppm glyphosate recorded the highest activities of the enzymes in the gills with a mean value of 578.45 ± 33.47 µM Malate min^{-1} mg^{-1} protein.

The lactate DH activity of the fish tissues is shown in Figure 3. The Lactate DH activity of all the fish tissues assayed revealed that the activity of this enzyme in the gills was glyphosate concentration-dependent. Among the various fish tissue assayed for lactate DH activity, the liver had the highest Lactate DH activity (1.91 µM Lactate min^{-1} mg^{-1} protein) while the least Lactate DH activity (0.26 µM Lactate min^{-1} mg^{-1} protein) was recorded in the muscle. In the muscle of the fish from various treatment tanks, Lactate DH activity of the fish exposed to Treatment 2.75 ppm glyphosate recorded the lowest (0.26 µM Lactate min^{-1} mg^{-1} protein) while Treatment 5.50 ppm glyphosate had the highest muscles' lactate DH activity of over a threefold increase (0.99 µM Lactate min^{-1} mg^{-1} protein).

However, the activities of gill lactate DH in the control fish was the lowest with a mean value of 0.34 µM Lactate min^{-1} mg^{-1} protein, while the highest gill lactate DH activity was recorded in Treatment 5.50 ppm glyphosate with mean value 0.78 µM Lactate min^{-1} mg^{-1} protein (Fig. 3).

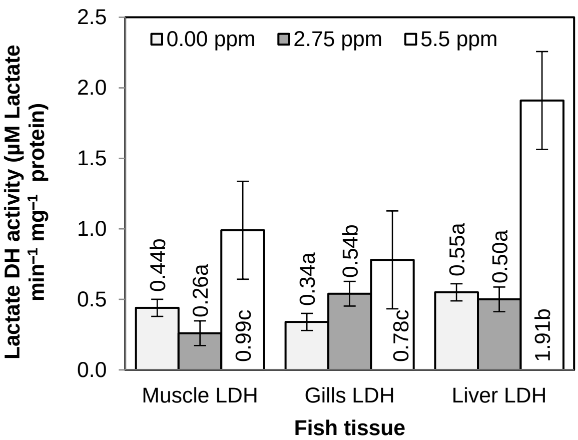

Figure 3. Changes in the mean (±S.E.) lactate dehydrogenase activity in gills, muscle and liver of *C. gariepinus* fingerlings following exposure to sublethal concentration of glyphosate. Control – 0.00 ppm
*Bars of the same fish tissue with different superscripts were significantly different (P<0.05)

The liver of the fish in treatment 2.75 ppm glyphosate had the lowest mean value of lactate DH activity (0.50 µM Lactate min^{-1} mg^{-1} protein) while the fish in the highest glyphosate treatment recorded a two-fold increase in the level of liver lactate DH activity with a mean value of 1.91 µM. Generally, significantly higher (P<0.05) lactate DH activity was recorded in all the tissues of the fish exposed to the highest concentration of glyphosate (Fig. 3).

Enzymatic activities of fish tissues followed the order viz malate DH > Na^+/K^+ ATPase > lactate DH.

Discussion

The overall mean water quality parameters determined in this study were within an acceptable range for aquaculture production (NSDWQ, 2007; Boyd, 1979).

The sporadic burst of movement, lacking cruising and balance, vertical swimming, flaring of opercula, gasping, and death of *C. gariepinus* fingerlings exposed during the acute toxicity test in this study is similar to the findings observed by (Annune *et al.*, 1994; Omitoyin *et al.*, 2006; Ayoola, 2008a) when fish are exposed to the higher concentration of glyphosate at 96 hr. Fish mortality was highest in treatments with glyphosate in the 96h acute toxicity test. This confirms the observation by Fryer and Makepeace (1997), that in all toxicants, a threshold is reached above which there is no drastic survival of the animal. Below the threshold, animal performance is not affected while above the tolerance zone is the zone of resistance. In the 96 h test, 100% of fish deaths were recorded in treatments ≥1.00 mg L^{-1}. This outcome was similar to reports by Okayi *et al.*, (2010) and Ayoola (2008a,b) in their study.

In sublethal toxicity test, fish mortality recorded the highest level with increasing glyphosate treatment. This is probably as a result of its toxicity to the gills and perhaps not necessarily decline in oxygen levels because the parameters had little variation and were evident that physicochemical properties of the water holding tanks were within the desirable range of fish culture (Boyd, 1979). Meleter *et al.* (1971) reported that herbicide affects the gas exchange of fish and other aquatic organisms.

Fish survival and growth performance indices which are useful tools to ascertain fish performance and condition(s) in a system were found to decrease with the increasing concentration of the glyphosate in this study. This corroborates the findings of Salbego *et al.* (2010) and Sweilum (2006) that herbicides concentration in the aquatic system cause physiological stress and have direct effects in decreasing the relative growth rate of fish. Several authors have reported that environmental stressors affect the biochemical and physiological capacities of fish to digest and transform the digested nutrients which in turn leads to a reduction in fish growth and feed efficiency (Adeyeni, 2010; Lazzari *et al.*, 2010; Fourie, 2006; Avoaj, Oti, 1997).

In this study, muscle Na^+/K^+-ATPase were lowest in the control compared to other treatments which indicate that glyphosate affected the increase in production of Na^+/K^+-ATPase. The decrease in Na^+/K^+-ATPase synthesis in the fish muscles suggests normal cruising efficient swimming patterns which do not require excessive enzymatic energy production as well as maintaining adequate resting potential while the increase in the muscle's Na^+/K^+-ATPase in the glyphosate treatments was due to response to the chemical stress which was, as a result, increased swimming and activities. The increased movement has also been characterized as fish's response to chemical stressors (Ayoola, 2008a; Ogundiran *et al.*, 2009; Hadi, Alwan, 2012).

Gill Na^+/K^+-ATPase was generally high among the control groups without glyphosate. The gills which are active respiratory organs in fish are required to be active to sustain respiration hence the high levels of Na^+/K^+-ATPase activities. This agrees with the work of Obuotor (2004). The decrease of Na^+/K^+-ATPase activity with increasing concentration of glyphosate in the fish gills recorded in this study might be a resultant effect of Na^+/K^+- pump disruptions, which allows unusual or inconsistent movement of Na^+/K^+ into the cell along the concentration gradient. Nowak (1992) also reported that a decrease in Na^+/K^+-ATPase of fish exposed to a toxic substance may be metabolic or ionic regulation. Another reason for the reduction of Na^+/K^+-ATPase activity in the gills of the exposed fish might be due to damages of the cells which allow the leakages of ATP into the bloodstream and pathological changes in tissue (Olurin *et al*., 2006).

Chemical toxicants affect normal organ functioning either by decreasing or increasing its cellular activities which is a dose-dependent response to the toxicant (Sullivan, Somero, 1983). Liver functions in the storage of glucose in the form of glycogen through a process of glycogenesis and a centre for detoxification (Barnhoorn, van Vuren, 2004). Liver Na^+/K^+ ATPase activity showed a corresponding increase with an increase in glyphosate. The Na^+/K^+ ATPase enzymatic activities in the liver were increased by the presence of glyphosate probably in response to stress created by the herbicides. The liver is largely responsible for the detoxification of toxins from the body and usually the organ that is first damaged due to toxic exposures. Chemical toxicants significantly affect the physiology of the liver by some histological alterations as recorded in earlier studies (Ayoola, 2008a,b; Ogundiran *et al.*, 2009)

Malate dehydrogenase plays an important role in the pathway of the tricarboxylic acid cycle which is also known as the Kreb's Cycle which is critical to cellular respiration in cells (Minárik *et al*., 2002). Malate DH which is a biomarker of cellular respiratory activities in animal tissues could be affected by pathological and toxic conditions which tend to decrease or upsetting cellular respiratory activities (Panepucci *et al.*, 2002). Muscles generally have higher cellular respiratory activities hence as seen in the fish tissues in this study compared to other tissues. Minárik *et al.* (2002) opined that cellular respiratory activities through the tricarboxylic acid cycle can be triggered by normal and abnormal environmental and physiological conditions such as stress. In this study, glyphosate exposure caused a decrease in muscle and liver tissues while gill tissues increased cellular respiratory activities with exposure to glyphosate.

Lactate dehydrogenase is another very important enzyme that plays a significant role in the interconversion of pyruvate, the final product of the glycolytic pathway to lactate in no or short supply of oxygen. At high concentrations, the enzyme exhibits feedback inhibition and the rate of conversion of pyruvate to lactate is decreased. Increased lactate dehydrogenase synthesis observed in all tissues of fish exposed to glyphosate is an indication of hypoxia in cells due to reduction in feed conversion and cellular respiration efficiency.

Conclusions

The study concluded that the increase in glyphosate concentration negatively impacted feed nutrient utilization by the fish which consequently affected their survival and growth, and also had a pronounced effect on the enzymatic activities of the studied organs.

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Conflict of interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions
AOA – conducted the research and investigation process, collected and analyzed the data;
HAA – formulated the research goals and aim, assisted in experimental procedures and interpretation of data, and draft the manuscript;
VFO – supervised the research work and reviewed the manuscript for final submission;
GEE – assisted in experimental procedures and interpretation of data.

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EFFECT OF WATER DEFICIT AND FOLIAR APPLICATION OF AMINO ACIDS ON GROWTH AND YIELD OF EGGPLANT IRRIGATED BY TWO DRIP SYSTEMS UNDER GREENHOUSE CONDITIONS

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ABSTRACT. Water deficit in semiarid areas limits eggplant (*Solanum melongena* L.) production and growth indicators. Suitable drip irrigation system and foliar application of amino acids may help overcome water deficit. In this work, the effects of drip irrigation system [Grand flow regulators (GR) and T-Tape], water deficit (50, 75, 100% based on field capacity) and foliar application of amino acids at 0, 100 and 200 mg L^{-1} on water relation of leaf's, yield and field water use efficiency (WUE_f) of eggplant were studied. The experiments were arranged in a split-split plot design within a completely randomized distribution each repeated three times. GR irrigation system treatment produced the highest relative water content (RWC), most yield (TY), WUE_f and the lowest of water saturation deficit (WSD) which were 74.71%, 6.50%, 5.97 t ha^{-1}, 2.11 kg m^{-3} and 23.09%, respectively. The lowest water uptake capacity (WUC) and relative membrane permeability (RMP) was obtained in T-Tape irrigation system treatment (0.43% and 59.45%, respectively). The 100% irrigation level revealed higher RWC (79.32%), WSD (7.38%), most TY (6.93 t ha^{-1}), the least of WSD (18.00%), WUC (0.28%) and RMP (39.40%). The maximum of WUE_f (2.37 kg m^{-3}) was obtained from 50% irrigation level. The foliar application of 200 mg L^{-1} Amino acids rate resulted in significantly maximum RWC (81.50%), WRC (7.19%), TY (6.75 t ha^{-1}) and WUE_f (2.51 kg m^{-3}) and least WSD (15.88%), WUC (0.33%), RMP (52.02%). GR drip irrigation system is best for water use efficiency; 200 mg L^{-1} Amino acids produced the best response for most studied traits.

Introduction

Water is a key determinant of plant productivity in agriculture in numerous world regions, particularly in dry and semi-dry regions (Tahi *et al.*, 2007). With increasing human population, urbanization and industrialization, competition for freshwater is increasing worldwide. The divergence between water availability and demand is widening. Worldwide, more than 40% of food production rely on supplementary irrigation (Ahmad, 2016). In Iraq, agriculture uses more than 93% of good quality freshwater (Aldulaimy *et al.*, 2019). There is a need to stretch freshwater resources to keep pace with the ever-increasing demand of varied users (Hsiao *et al.*, 2009, Wang *et al.*, 2010). Given the circumstance of not having much prospect of additional freshwater resources to be developed, the only choice is to control the available freshwater resources and improve management procedures (Haliński, Stepnowski, 2016). Since agriculture is the prime consumer of freshwater resources, any effort towards improving WUE_f in this sector will be worthwhile. Increasing WUE_f through upgraded irrigation technology and improving the efficiency of retaining soil productivity are complementary towards making the best use of irrigation water and conserving water for other uses. The average irrigation efficiency for surface irrigation is between 30–50% (Topcu *et al.*, 2007; Al-Shammari *et al.*, 2018a; Aldulaimy *et al.*, 2019). Poor irrigation efficiency provides an opportunity for improvement that will lead to additional water resource for agriculture or other uses; however, this should not be by negatively affecting yields.

It is proved that drought conditions damage cellular membranes, slow down water movement and nutrient absorption, reduce photosynthesis efficiency, respiration rate, enzyme activity and hormone balance, and increase reactive oxygen species production, which detrimentally production (Maloney *et al.*, 2010, Gupta, 2011). The loss of agricultural production is estimated by about 17% (Ahmad, 2016; Al-Shammari *et al.*, 2020a).

Amino acid applied to foliage or added to total soil have recently been used as a method to promote plant growth and productivity (Spann *et al.*, 2010). Amino acids have a direct function in increasing tissue protein content and enzyme activity necessary for metabolic antioxidant on-site events. Amino acids are precursors and proteins constituents which are necessary for cell growth. They contain acid and basic groups and act as buffers, which help maintain favourable pH within plant cells. Amino acids can influence physiological activities in plant growth and development (Sadak *et al.*, 2015; Al-Shammari *et al.*, 2018b).

Primarily housebroken by inhabitants of South and East Asia (Polignano *et al.*, 2010) and then transferred to Europe through Arab trade or migration around 600 CE (Daunay, 2008), eggplant is considered one of the most common vegetable crops grown in Iraq and other the world parts and its fruits are utilized as a staple food. Eggplant is only the third most important crop in consumption terms, behind potatoes and tomatoes, from the *Solanaceae* family. The varieties of eggplant show a wide range of fruit shapes and colours, ranging from oval or egg-shaped to long club-shaped; and from white, yellow, green through degrees of purple pigmentation to almost black. Eggplant fruits contain a considerable carbohydrates amount, proteins and some minerals (Raigón *et al.*, 2008, Mahmoud, 2000). Eggplant fruits are known for being low in calories and having a mineral composition useful for human health. They are also a wealthy source of potassium, magnesium, calcium and iron (Zenia, Halina, 2008). The eggplant fruit possesses antioxidant activities (Plazas *et al.*, 2013, San José *et al.*, 2013). This project was undertaken to determine effects of drip irrigation system type, irrigation levels and foliar application of Amino decanate® on leaf's Sprouts, yield and water use efficiency of eggplant under water deficit conditions.

Materials and methods

Experimental sites and description

Field experiments were conducted at a greenhouses experimental station of the College of Science, University of Diyala, Baqubah, Iraq, on 8 November 2018 to 3 April 2019. The area of the greenhouse was 450 m². The soil of the study site is classified as well-drained sandy loam. The chemical properties of the soil were: $CaCO_3$ (157.79 g kg^{-1}), $EC_{1:1}$ (13.17 dS m^{-1}), organic matter (OM) (0.91 g kg^{-1}), and nitrogen (N), phosphorous (P) and potassium (K) as 32.60, 9.70 and 160.6 mg kg^{-1}, respectively. Bulk density was 1.35 mg m^{-3}. Field capacity (F.C) was 25% (mass water content). The irrigation water EC was 0.82 dS m^{-1} (River water). Poultry litter was added at 1 kg m^{-2} during bed preparation.

Experimental design and treatments description

The experimental design was arranged in a 2 × 3 × 3 split-split plot, in a randomized complete block design, with 3 factors, replicated in 3 blocks. The first factor was the drip irrigation system type (GR and T-Tape). Surface drip irrigation GR (Grand flow regulators) diameter of the tube was 6.35 mm, plastic wall thickness is 1 mm, the distance between the emitters is 30 cm, the maximum capacity of water flow of the emitters is 4 L h^{-1} (Manufacturer: Universal for Industry of Drip Irrigation Pipes, Amman, Jordan). For surface drip irrigation T-Tape, a diameter of the tube was 6.35 mm, plastic wall thickness is 1 mm, the distance between the emitters is 11 cm, the maximum capacity of water flow of the emitters is 1 L h^{-1} (Manufacturer: Rivulis Reserve Drip Tape, USA). The second factor was the level of irrigation, 50, 75 or 100% of field capacity, each system was individual for levels irrigation, determined according to Allen (1998). The third factor was the level of Amino decanate® at 0, 100 or 200 mg L^{-1}. There were 18 treatments, totalling 54 plots. Amino decanate® was applied with a backpack sprayer 4 times at a 10-day interval beginning from flowering. Foliar treatment was applied early in the morning. The nutrients contents of the Amino decanate® are given in Table 1.

Table 1. Composition of Amino decanate®

Material	Amount (wt./vol.)	Material	Amount (wt./vol.)
L-Leucine	5 g	L-Threonine	0.5 g
L-Valine		L-Phenylalanine	
L-Isoleucine		L-Tyrosine	
L-Glutamine		L-Asparagine	
L-Alanine	0.5 g	L-Aspartate	
L-Arginine		L-Cysteine	
L-Histidine		L-Lysine	
L-Proline		L-Serine	
L-Methionine		L-Tryptophan	
L-Threonine		Glycine	

Conduction of study

Seeds of eggplant (*cv*. Barcelona) was planted in cork trays with 200 cavities on 28 September 2018 using previously saturated peat moss as the substrate in a commercial nursery. When seedlings reached the 3 true leaf stage, they were established in a greenhouse on November 8, 2018. There was 1.25 m between rows and 0.4 m between plants, with 10 plants per experimental unit and a density equivalent to 20 000 plants ha^{-1}. To demonstrate effects of drip irrigation system type, water deficit, and foliar application of Amino decanate® in growth and yield on eggplant, the 20N-20P-20K was added in four split applications throughout the growth period with a dose of 240 kg ha^{-1} with irrigation water. After spraying the insecticides Carbaryl 85® at a dose 2 g L^{-1} of water and SITA JINTA® at a dose 1 ml L^{-1} of water, weeds were controlled manually. Irrigation was applied until the end of the last harvest; schedule irrigation was based on depletion of 50% of available water and water was added to the F.C. The process of sampling was conducted to estimate moisture content before each irrigation and according to the weight method and depth of 0–30 cm to the flowering stage and depth 0–60 cm to the end of the growing season.

Traits measured

Eight plants were randomly selected from each plot to determine relative water content in the leaves (RWC). The leaves were cut with scissors, then placed in polythene bags and transported to the laboratory as quickly as possible to minimize water losses due to evaporation. RWC was determined by the following equation:

$$RWC = \frac{(Fresh\ weight - Dry\ weight)}{(Turgid\ weight - Dry\ weight)} \times 100 \quad (1)$$

The water saturation deficit (WSD) was calculated by the following formula:

$$WSD = 100 - RWC \quad (2)$$

Water retention capacity (WRC) was estimated by the following formula:

$$WRC = \frac{Turgid\ weight}{Dry\ weight} \quad (3)$$

The water uptake capacity (WUC) was measured by the following formula:

$$WUC = \frac{(Turgid\ weight - Fresh\ weight)}{Dry\ weight} \quad (4)$$

For the relative membrane permeability (RMP), leaves were cut into small equal pieces and transferred into the test tube containing 20 mL of deionized distilled water. After shaking with a stirrer for 10 s, this solution was assessed for initial electrical conductivity (EC_0). For the (EC_1), these test tubes were kept at 4 °C for 24 hours and then assayed. Then these samples were autoclaved at 121 °C for 25 minutes for the determination of (EC_2), so RMP was calculated according to the following equation:

$$RMP = \frac{(EC1 - EC0)}{(EC2 - EC0)} \times 100 \quad (5)$$

Harvesting was done 76 days after the plantation. Sixteen harvestings were done. The fruits which have ripened were cut with a pruning shear and then weighed on an electronic scale in the treatment site. The yield obtained from each treatment was recorded (kg m^{-2}).

Values of field water use efficiency (kg m^{-3}) were calculated for different treatments after harvest based on the method specified by Jensen (1983), according to the following equation:

$$WUE_f = \frac{Total\ yield}{Water\ applied}, \quad (6)$$

where WUE_f is field water use efficiency.

Data analysis

Data were subjected to analysis of variance (ANOVA) using SAS (JMP ver. 9.1, SAS Institute, Cary, NC). If interactions were significant, they were used to explain results. If interactions were not significant means were separated with the Tukey-Kramer HSD test.

Results

Results in the variance analysis (table 2) show significant differences in all measured traits. Results in Table 2 display the effects of drip irrigation systems (GR and T-Tape) on all measured traits. Comparing with T-Tape drip irrigation system, GR drip irrigation system recorded higher values of RWC (74.71%), WRC (6.50 %), TY (5.97 t ha^{-1}), WUE_f (2.11 kg m^{-3}) and betters lower value of WSD (23.09 %). In all terms, GR drip irrigation system seems to be more performant than T-Tape.

Table 2. Effect of the main factors and their interference in all studied traits

Source of variation	df	Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Block	2	27.18	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation system (S)	1	1652*	1675*	5.13*	0.01*	157*	31.69*	1.68*
Error main plot	2	0.07	0.00	0.00*	0.00	0.00	0.00	0.00
Irrigation (I)	2	1887*	2192*	22.53*	0.47*	746*	55.47*	2.79*
S×I	2	46.54*	0.37*	0.45*	0.01*	111*	4.58*	0.05*
Error split plot	8	0.01	0.00	0.00	0.00*	0.00	0.00	0.00
Amino decanate (A)	2	2859*	2845*	20.02*	0.34*	128*	46.06*	6.15*
S×A	2	65.86*	5.95*	0.93*	0.00	509*	3.81*	0.28*
I×A	4	77.08*	12.32*	0.81*	0.02*	118*	2.47*	0.05*
S×I×A	4	15.01*	14.04*	0.40*	0.10*	185*	0.92*	0.03*
Error split-split plot	24							
Corrected Total	53							

* – significant at 0.05 level, ANOVA

Table 3 also illustrates the effects of irrigation levels and amino decanate® increments on the studied parameters. Increasing irrigation level from 50 and 75 to 100% of field capacity gradually and significantly improved the percentage of RWC, WSD and WRC as well as the mass of TY: these values evolved to the best status respectively from 58.84 and 69.38 to 79.32; from 40.03 and 27.94 to 18; from 5.09 and 6.5 to 7.32; and from 3.42 and 5.26 to 6.93. Inversely, WUC, RMP and WUE_f decreased whenever irrigation level increased.

Similarly, the same trend was observed from the amino decanate® doses which are in plus significantly increased the WUE_f from lower values of 1.34 and 1.96 to the highest value of 2.51 kg m^3 at 0, 100, and 200 mg L^{-1} respectively.

Respecting in Table 3 the interaction effect of GR drip irrigation system at full irrigation level resulted in a significant increase in RWC (86.50%), WRC (7.75%), TY (8.24 t ha^{-1}) and decrease in WSD (12.27%), while these parameters represented 53.38%, 4.96%, 3.11 t ha^{-1} and 45.49 % respectively, in T-Tape drip irrigation system at 50% irrigation level. The highest WUE_f was 2.50 kg m^{-3} for GR drip irrigation system at 50% irrigation level, while the lowest WUE_f (1.36 kg m^{-3}) for T-Tape drip irrigation system at full irrigation level. For the other traits, T-Tape drip irrigation system at 100% irrigation level had the minimum values of WUC (0.27%) and RMP (37.71%). While the maximum of WUC was (47.00%) for GR drip irrigation system at 75% irrigation level and RMP was (83.86%) for GR drip irrigation system at 50% irrigation level.

Plants treated with GR drip irrigation system and foliar treatment of 200 mg L^{-1} Amino decanate® resulted in a significant increase in total RWC (88.57%), WRC (7.23%), TY (7.93 t ha^{-1}) and WUE_f (2.80 kg m^{-3}), which decreased to a minimum 52.39%, 4.63%, 3.29 t ha^{-1} and 1.29 kg m^{-3} respectively, at the controlled treatment in T-Tape drip irrigation system.

T-Tape drip irrigation system and foliar treatments of 200 mg L^{-1} Amino decanate® had the minimum of WUC (0.31%) and RMP (44.32%), while Plants treated with GR drip irrigation system and no application (control treatment) had the maximum of WUC (0.64%), RMP (67.57%) comparing to plants treated with T-Tape drip irrigation system and no application (control treatment). Minimum of WSD (10.20%) treated plant was found in by GR drip irrigation system and foliar application of 200 mg L^{-1} Amino decanate®, and a maximum was obtained 45.96% by T-Tape drip irrigation system and foliar application of 200 mg L^{-1} Amino decanate®.

Table 3. Effect of drip irrigation systems, irrigation levels and Amino decanate® on factors in eggplant traits

Factors	Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Drip irrigation systems							
GR	74.71^a	23.09^b	6.50^a	0.47^a	59.45^a	5.97^a	2.11^a
T-Tape	63.65^b	34.23^a	5.88^b	0.43^b	56.03^b	4.44^b	1.76^b
Irrigation levels, %							
50	58.84^c	40.03^a	5.09^c	0.60^a	79.65^a	3.42^c	2.37^a
75	69.38^b	27.94^b	6.15^b	0.47^b	54.17^b	5.26^b	1.84^b
100	79.32^a	18.00^c	7.32^a	0.28^c	39.40^c	6.93^a	1.60^c
Amino decanate, mg L^{-1}							
0	56.31^c	41.01^a	5.08^c	0.60^a	67.45^a	3.56^c	1.34^c
100	69.73^b	29.09^b	6.29^b	0.41^b	53.76^b	5.30^b	1.96^b
200	81.50^a	15.88^c	7.19^a	0.33^c	52.02^c	6.75^a	2.51^a

Irrigation level and foliar application of Amino decanate® rate affected leaf characters and yield (Table 4). 100% irrigation level and foliar of 200 mg L^{-1} Amino decanate® treatments produced the highest RWC (87.45%), WRC (8.65%) and TY (9.17 t ha^{-1}), and the lowest WSD (6.87%) and WUC (0.16%), compared with other treatments. The highest WUE_f (3.06 kg m^{-3}) was for the combined treatment of 50% irrigation level and 200 mg L^{-1} Amino decanate®, compared with other treatments. For the least RMP (32.77%) was for full irrigation level and foliar of 100 mg L^{-1} Amino decanate®, compared with other treatments.

Results of analysis of variance in Table 5 showed that at GR drip irrigation system plant irrigated at 100% irrigated level and treated with 200 mg L^{-1} Amino decanate® had the highest relative water content (97.19%), water retention capacity (9.08%), most yield (11.26 t ha^{-1}) and the minimum of water saturation deficit (1.46%). For the best WUE_f (3.24 kg m^{-3}) was in a GR irrigation system by 50% irrigated level plants with 200 mg L^{-1} Amino decanate®. At each T-Tape and GR irrigation system by 100% irrigated level plants with 200 mg L^{-1} Amino decanate® had a minimum of water uptake capacity and relative membrane permeability (0.17 and 0.16% respectively).

Table 4. Interaction drip irrigation systems, irrigation levels and Amino decanate® on factors in eggplant traits

Factors		Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Drip irrigation systems	Irrigation levels, %							
GR	50	64.29^{e}	43.58^{b}	5.22^{e}	0.65^{a}	83.86^{a}	3.74^{e}	2.50^{a}
	75	73.34^{b}	22.41^{e}	6.52^{c}	47.00^{c}	53.40^{d}	5.93^{b}	2.01^{c}
	100	86.50^{a}	12.27^{f}	7.75^{a}	0.29^{d}	41.09^{e}	8.24^{a}	1.83^{d}
T-Tape	50	53.38^{f}	45.49^{a}	4.96^{f}	0.56^{b}	75.45^{b}	3.11^{f}	2.24^{b}
	75	65.41^{d}	33.46^{c}	5.78^{d}	0.47^{c}	54.94^{c}	4.58^{d}	1.67^{e}
	100	72.14^{c}	23.73^{d}	6.90^{b}	0.27^{e}	37.71^{f}	5.62^{c}	1.36^{f}
Drip irrigation systems	Amino decanate®, mg L^{-1}							
GR	Control	59.70^{e}	36.06^{b}	5.54^{e}	0.64^{a}	67.34^{b}	3.83^{e}	1.38^{e}
	100	75.87^{b}	23.01^{d}	6.71^{c}	0.41^{d}	51.30^{e}	6.16^{b}	2.15^{c}
	200	88.57^{a}	10.20^{f}	7.23^{a}	0.36^{e}	59.72^{c}	7.93^{a}	2.80^{a}
T-Tape	Control	52.92^{f}	45.96^{a}	4.63^{f}	0.57^{b}	67.57^{a}	3.29^{f}	1.29^{f}
	100	63.59^{d}	35.18^{c}	5.87^{d}	0.42^{c}	56.22^{d}	4.45^{d}	1.77^{d}
	200	74.43^{c}	21.56^{e}	7.14^{b}	0.31^{f}	44.32^{f}	5.58^{c}	2.21^{b}
Irrigation levels, %	Amino decanate®, mg L^{-1}							
50	Control	46.80^{i}	52.02^{a}	4.36^{i}	0.78^{a}	91.66^{a}	2.42^{i}	1.68^{f}
	100	57.83^{g}	41.17^{b}	5.24^{g}	0.54^{c}	75.44^{b}	3.39^{h}	2.36^{b}
	200	71.89^{d}	26.93^{f}	5.67^{f}	0.50^{d}	71.88^{c}	4.46^{f}	3.06^{a}
75	Control	53.45^{h}	40.86^{c}	4.87^{h}	0.60^{b}	64.59^{d}	364^{g}	1.27^{h}
	100	69.52^{e}	29.13^{e}	6.37^{d}	0.47^{e}	53.07^{e}	5.51^{d}	1.91^{e}
	200	85.15^{b}	13.84^{h}	7.22^{c}	0.34^{g}	44.86^{g}	6.63^{c}	2.53^{c}
100	Control	68.67^{f}	30.16^{d}	6.03^{e}	0.44^{f}	46.12^{f}	4.62^{e}	1.07^{i}
	100	81.83^{c}	16.99^{g}	7.27^{b}	0.24^{h}	32.77^{i}	7.01^{b}	1.61^{g}
	200	87.45^{a}	6.87^{i}	8.65^{a}	0.16^{i}	39.33^{h}	9.17^{a}	2.11^{d}

Table 5. Means comparison the interaction effects of drip irrigation systems, irrigation levels and Amino decanate® on factors in eggplant

Factors			Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Drip irrigation systems	Irrigation levels, %	Amino decanate®, mg L^{-1}							
GR	50	Control	51.69^{l}	47.30^{b}	4.81^{f}	0.83^{a}	93.75^{a}	2.65^{h}	1.77^{c}
		100	64.27^{j}	34.73^{c}	5.58^{de}	0.57^{c}	75.55^{c}	3.72^{fg}	2.49^{b}
		200	76.93^{e}	21.72^{ef}	5.27^{e}	0.56^{c}	82.28^{b}	4.85^{ef}	3.24^{a}
	75	Control	54.81^{k}	34.82^{c}	5.22^{e}	0.65^{c}	64.60^{d}	3.83^{fg}	1.28^{e}
		100	73.63^{fg}	25.02^{d}	6.99^{cd}	0.41^{de}	51.98^{ef}	6.29^{d}	2.10^{bc}
		200	91.58^{b}	7.41^{i}	7.36^{c}	0.35^{e}	43.62^{g}	7.69^{c}	2.66^{b}
	100	control	72.59^{g}	26.07^{d}	6.61^{d}	0.46^{d}	43.66^{g}	5.01^{e}	1.11^{ef}
		100	89.71^{c}	9.28^{h}	7.58^{c}	0.26^{f}	26.37^{hi}	8.47^{b}	1.88^{c}
		200	97.19^{a}	1.46^{j}	9.08^{a}	0.17^{fg}	53.26^{e}	11.26^{a}	2.51^{b}
T-Tape	50	Control	41.91^{m}	56.74^{a}	3.91^{g}	0.73^{b}	89.56^{b}	2.19^{i}	1.60^{d}
		100	51.39^{l}	47.60^{b}	4.60^{f}	0.51^{c}	75.33^{c}	3.07^{gh}	1.73^{c}
		200	66.86^{h}	32.14^{cd}	6.08^{d}	0.44^{d}	61.48^{de}	4.08^{f}	2.89^{b}
	75	Control	52.10^{l}	46.90^{bc}	4.52^{f}	0.56^{c}	64.58^{d}	3.45^{g}	1.26^{e}
		100	65.41^{i}	33.24^{cd}	5.76^{de}	0.53^{c}	54.15^{e}	4.73^{ef}	2.24^{bc}
		200	78.73^{d}	20.26^{f}	7.08^{c}	0.34^{e}	46.09^{fg}	5.58^{de}	2.04^{c}
	100	Control	64.75^{ij}	34.24^{c}	5.46^{e}	0.42^{d}	48.58^{f}	4.24^{ef}	1.03^{f}
		100	73.96^{f}	24.69^{e}	6.97^{cd}	0.23^{f}	39.17^{h}	5.56^{de}	1.35^{de}
		200	77.72^{de}	12.27^{g}	8.27^{b}	0.16^{g}	25.39^{i}	7.08^{c}	1.72^{cd}

Discussion

The foremost objective of this research was to determine the better irrigation system (GR or T-Tape) and foliar application rate of Amino decanate®, which could mitigate the adverse effects of water deficit (50, 75 and 100% of field capacity) on leaf characters, yield and WUE_f of eggplant.

The results of Table 3 show that the GR drip irrigation system had the highest values for the RWC, WRC, TY and WUE_f. This is due to the water application efficiency of the GR drip irrigation system, which provides water supply for the growth of the plant and to carry out all the physiological and vital processes.

This could be due to the maintenance of soil moisture allowing continued nutrient uptake (Al-Shammari *et al*., 2019, Ghazouani *et al*., 2019). This was probably due to full irrigation as long as water supply to the complete root area is consistent so that drench and dry-out conditions are reduced. Most biochemical, morphological and physiological processes related to plant development are come to terms pending water deficit and can result in poor photosynthesis, respiration, and nutrient metabolism. In the GR drip irrigation system, the amount of water is low and thus stresses the root zone, which leads to produced, ABA and transport it to leaves and adjust stomata aperture, reduce transpiration rate, when drought and wetness appeared by turns in different regions of root. In this experiment, it was found that irrigation levels inducing water deficit had a conspicuous effect on plant water status (Table 2). The water status change may be ascribed to, the transpiration in plants; water is thought to come from the soil out of osmosis process, and this water goes into the transpiration stream out of apoplastic and symplastic pathways. Water deficit is responsible for changing the situation on account of restricted transpiration. The reduction of transpiration hinders water uptake from the soils on account of injury in the root systems, which at the latest reasons the water status disparity in plants. Lower water uptake is thought to be accountable for lessening RMP rate (Table 3). The cell membrane, being at the interface between the cells and its surroundings, is the first organelle that is susceptible to water deficit and the capacity of maintaining its integrity is an important process related to plant resistance against water deficit (Hamdi, 2017; Shenia, Gangshuana, 2018; Ghazouani *et al*., 2019).

T-Tape drip irrigation system irrigates only planting row. Long-term water stress in the soil in a non-irrigated row would affect soil root distribution equality, to some extent and unfavourable to soil nutrient movement and absorption in the non-irrigation zone. Water amount of T-Tape drip irrigation system was so much that planting row and the working row was usually waterish, soil character becomes bad, reducing the absorbency of the root system, and affecting soil water and nutrient absorption and utilization (Díaz-Pérez, Eaton, 2015; Saddique, Shahbaz, 2019).

Water deficit caused significant reductions in yield. Full irrigation treatment (without water deficit) resulted in the maximum fruit yield (Table 3). Yield is affected by water deficit and it is significantly decreased by intensified water deficit conditions. Water deficit can progressively decrease CO_2 assimilation rates due to stomata closing and reduced leaf area, and consequently reduce photosynthetic pigment content and activity (Al-Sahmmari *et al.,* 2019b; Ghazouani *et al*., 2019). Drought stress also induces a decrease in the content and activity of photosynthetic carbon and enzymes cycle, including its key enzyme ribulose-1, 5-bisphosphate carboxylase/ oxygenase (Díaz-Pérez, Eaton, 2015; Abood *et al.,* 2019a; Saddique, Shahbaz, 2019). In the present study, using a foliar application of Amino decanate® in the presence and absence of water deficit induced level irrigation (50%, 75 and 100%), we showed that foliar application of 200 mg L^{-1} Amino decanate® had the best effect on enhancing eggplant tolerance to water deficit. Foliar application of Amino decanate® promote eggplant tolerance to water deficit, due to the improved water status, active osmotic adjustment, and mitigation of oxidative stress through efficient ROS scavenging by the enhanced activity of antioxidant enzymes (Tani *et al.,* 2018; Saddique, Shahbaz, 2019).

The first symptom of water deficit is the seizure of growth as a mechanism to preserve carbohydrates for unrelenting metabolism, for extended energy supply, and for improved recovery after stress relief (Bozkurt Çolak *et al*., 2015; Hamdi, 2017). However, poor water relations are the key reason responsible for plant growth reduction under water deficit (Bozkurt Çolak *et al.,* 2015; Ghazouani *et al.,* 2019). Plants keep water and reduce stress loading by reducing the transpiration rate, leaf water potential, and water use as well (Abood *et al.,* 2019b).

Foliar application of Amino decanate® showed a pronounced effect on leaf characters, TY and WUE_f of eggplant plants (Table 3) that eventually increased plant growth and biomass production in plants. The positive effects of the application of Amino decanate® may be due to osmoregulatory since it is soluble in water and increase concentrations of cellular osmotic components. Amino acids work is useful in withstanding adverse environmental conditions. Amino decanate® play an important role in the regulation of a variety of physiological processes, including cell division, morphogenesis, senescence (Al-Sahmmari *et al.,* 2020b).

Notably, foliar application of Amino decanate® is a common agriculture practice in vegetable cultivation that not only increases vegetable yield but also enhances plant tolerance to water deficit in arid and semi-arid areas. Therefore, agronomic management including the use of Amino decanate® has become one of the cutting-edge research topics to improve eggplant tolerance to water stress (Pandav *et al*., 2016; Abood *et al*., 2019a).

Conclusions

GR Drip irrigation system is the best and most efficient in providing the plants with the necessary water requirements to improve the qualities of vegetative growth and yield. Foliar application of Amino decanate® played a role in alleviating the negative impact of water deficit and improved plant growth, yield and water use efficiency.

Conflict of interest

The authors declare that they have no conflict of interest.
No funds from the public or private sector were used for this research. The authors covered all expenses.
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Author contributions

MA 50%, GH 50% – study conception and design;
MA 25%, BB 25%, SH 25%, SA 25% – acquisition of data;
GH 50%, MA 50% – analysis and interpretation of data;
GH 50%, MA 50% – drafting of the manuscript.
MA 50%, GH 50% – critical revision and approve the final manuscript.

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A THEORETICAL AND EXPERIMENTAL STUDY OF COMBINED AGRICULTURAL GANTRY UNIT WITH A MINERAL FERTILISER SPREADER

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ABSTRACT. Operations to apply mineral fertilisers to the soil are an important part of practically every form of agricultural technology. The current global trend of transitioning to bridge and gantry-type agricultural systems leaves the unanswered relevant question of the effectiveness of the technological process of applying mineral fertilisers to the soil. This is relevant because, in gantry agriculture, a section of the arable soil is separated as an engineering area. This is why the main difference in gantry agriculture from traditional methods of the bulk spreading of fertiliser onto a field is that, with gantry systems, the amount of fertiliser that lands within the engineering zone are limited. This significantly affects the manufacturing costs involved in the entire area of agricultural technology and, as a result, the production costs of the end product. This study aimed to research the patterns that are apparent in affecting the parameters involved in the use of gantry-type equipment when applying fertiliser with the parameters and operational modes of a specially-developed electric spreader of mineral fertilisers. The physical object of the study was the agricultural gantry equipment that had been developed by the authors. This equipment, which is used for spreading fertiliser, was in the form of a tractor-mounted, suspended, single-disc spreader which was known as JarMet, and which had especially been modified to run from an electrical supply. The study indicated that the biggest influence on the speed of rotation of the centrifugal disc in the mineral fertiliser spreader stems from its height above the ground, the distance of track of the agricultural gantry itself, and the aerodynamic coefficient of the fertiliser. It was determined that, for the agricultural gantry with a distance of tracks of 3.5 m, a sufficient angular speed of the single-disc centrifugal tool is 15.5 rad·s^{-1}, with a power demand for driving this at 0.35 kW·h. When using agricultural gantries of this type with an extended track width of up to 6 m, the necessary angular speed of the centrifugal tool for spreading fertiliser increases exponentially, to 318.2 rad·s^{-1}, with the power demand for driving it increasing to the third power.

Introduction

Operations to apply mineral fertilisers to the soil are an important part of practically every form of agricultural technology. The current global trend of transitioning to gantry-type agricultural systems (Nadykto *et al.*, 1997; Blackwell *et al.*, 2004; Gil-Sierra *et al.*, 2007; Jørgensen, 2012; Bindi *et al.*, 2013; Pedersen *et al.*, 2013; 2016; Chamen, 2015; Bulgakov *et al.*, 2019) leaves unanswered the relevant question of the effectiveness of the technological process involved in applying mineral fertilisers to the soil. This is relevant because, when it comes to gantry agriculture, a section of the arable soil is separated as an engineering area (Webb *et al.*, 2004; Uleksin, 2008; Bochtis *et al.*, 2010[a,b]; Önal, 2012; Antille *et al.*, 2015; Bulgakov *et al.*, 2017; 2018[a,b]; 2020). This area includes the transportation system for moving all items of mechanisation, energy, and water supply, plus communications and navigation equipment. This is why the main difference between gantry agriculture and traditional methods of bulk spreading fertiliser onto a field is that, with gantry systems, the amount of fertiliser that lands within the engineering zone are limited. This advance significantly affects the manufacturing costs involved in the entire area of agricultural technology and, as a result, the production costs of the end product.

Theoretical and experimental studies of centrifugal spreaders have been conducted by many of the world's scientists (Scheufle, Bolwin, 1991; Rainer, 2001; Villette *et al.*, 2005; Adamchuk, 2006; Olt, Heinloo, 2009; Van Liedekerke *et al.*, 2009; Villette *et al.*, 2010). They have studied the effect of the structural design of the discs, their vanes, and other elements of their construction, as well as their parameter and modes of operation, the physical and mechanical properties of the mineral fertiliser and other bulk materials, and the operating conditions for the equipment in terms of working width – in particular the spreading distance – along with the heterogeneity of applying the fertiliser, *etc.* The studies indicated that the biggest influence on the maximum flight distance of mineral fertiliser comes from the speed of rotation of the mineral fertiliser spreader's centrifugal disc, as well as from its height above the ground and the aerodynamic coefficient of the fertiliser (Villette *et al.*, 2008).

It is known that the effectiveness of using mineral fertilisers not only depends upon the fertilisers themselves but also on their manner of application (Adamchuk, 2002). Researchers are currently proposing various ways in which the effectiveness of that technological process can be improved. The world's most popular mechanical fertiliser spreaders are of a type that moves mineral fertilisers from a centralised technological bunker to spread it across the working width of the machine using the mechanical action of its operating elements on the fertiliser itself. More than 90% of the world's mineral fertiliser and chemical application-to-plant machines have disc-based spreader tools. In particular, machines of this type are made by Amazone, Bogballe, Bredal, Kuhn, Maschio, Rauch, Sulky, Titan, Vicon *etc.*

Also, disc-based centrifugal tools are widely used when applying granulated and bowdlerised fertilisers by sowing and planting machines, as well as by cultivators and plant nutrition machines. The latter's design incorporates a disc with vanes (Yasenetsky, Sheychenko, 2002; Dintwa *et al.*, 2004; Villette *et al.*, 2005) on its top surface. The disc itself is attached to a vertical shaft that is installed with the option of rotating it on the horizontal plane and which is connected to the driving mechanism. The operating process for the tool attachment of such a fertiliser spreader involves the fertiliser coming from the technological bunker, having first been grabbed by the vane and then pulled into rotating motion, and being moved along the vanes under centrifugal force towards the disc's edge. When reaching the ends of the vanes, the fertiliser slides off the tool at a certain pre-set speed. Thanks to its acquired kinetic energy reserve, the fertiliser particles overwhelm the aerodynamic resistance of the atmosphere. Thanks to this the fertiliser moves away from the centrifugal tool in a fan formation, along the equipment's working width. Under gravity, the fertiliser reaches the soil's surface, forming a continuous screen.

In the initial stages of the process of creating the machines for spreading mineral fertilisers, their designs incorporated tools with flat disks. The choice of the proper parameters and work modes for their centrifugal tools had an important role in ensuring the effectiveness of such machines.

Recently global manufacturers of machines for applying fertilisers and plant chemicals increased the diameter of the discs in their centrifugal spreader tools to 800 mm and their rotational speed to 1 000 min^{-1}. But any further increase of the tool disc's diameter has certain limits. In particular, the machine's design itself becomes a limitation for the diameter and strength of the mineral fertiliser's granules becomes a limitation for the rotational speed (Adamchuk, 2006). Correspondingly, to increase the machine's working width and to improve the quality of applying the fertiliser, a fertiliser spreader's working tool was created that had a cone-shaped disc with the cone's tip pointed towards the ground. Thanks to such a design in terms of the disc, the machine's working width was increased without increasing the disc's diameter or its rotational speed.

At one point in time, a fertiliser spreader with a centrifugal tool was created in Ukraine, which incorporated the good qualities both of a flat disc and a cone-shaped disc (Adamchuk, 2006). With that tool, the angle of the vanes was adjustable both on the plane of the horizontal disc in a vertical plane and along the radius of the disc on the horizontal plane. This design for the tool ensures an increase of the working width when it comes to applying mineral fertilisers, to 33 m, when compared with its analogues.

But this paper will not be discussing the advantages of these or other methods and technical means when it comes to applying mineral fertiliser by way of spreading. The authors discuss the problem of fertiliser spread in an agricultural gantry, which states that the possibility of mineral fertilisers landing within the engineering zone of the field is something that must be prevented, *i.e.* a particle of mineral fertiliser which has been distributed using the centrifugal disc tool at the required speed must perform free flight through the atmosphere and land on the surface of the arable (crop-bearing) area of the field without reaching the transport tracks within the field's engineering area.

The study aimed to research patterns when it comes to affecting the parameters of the tractor equipment in terms of applying fertiliser, and proper functioning using the principles of gantry-type equipment, with the parameters and operation modes of a specially-developed electric spreader of mineral fertilisers being taken into account.

Materials and methods

This theoretical study and the synthesis of design diagrams and parameters for an agricultural gantry system which will successfully apply mineral fertilisers to the soil were carried out using software-based modelling on a PC of its functioning conditions.

The physical object of the study was the agricultural gantry unit that had been developed by the authors Bulgakov *et al.* (2017).

For the experimental studies, a tractor-mounted, hanging, single-disc spreader of the Jar Met type was specially reconstructed to be driven by an electric motor, *i.e.* it was remodelled into being an electric spreader of mineral fertilisers, fully modelling the power take-off shaft from the tractor's front axle (Fig. 1a). For that end, an electric motor with a gearbox was placed under the disc-type fertiliser spreader. The rotational speed for the electric motor's shaft was electronically regulated (a frequency modulator) (Fig. 2). The parameters for the electrical current were documented using a measuring set of the K-505 type, which consisted of a portable unit that had been intended for measuring the current's strength, direction, and power in single-phase and three-phase AC circuits with three and four conductors during equal and unequal loading of the phases.

To prevent the mineral fertiliser from landing within the engineering area's track zone, the agricultural gantry unit was supplied with special screens on its left-hand and right-hand sides (Fig. 1b). The suspended technical system for the agricultural gantry unit is a serial-produced suspended mechanism that comes from a traditional tractor with a main hydraulic cylinder, and bottom and top rigidity elements. With its suspended system, the indicated mineral fertiliser spreader was connected to the elements of the agricultural gantry's suspended mechanism.

When conducting the experimental studies using the combined tractor and the mineral fertiliser spreader in an agricultural gantry system, Nitroamofoska mineral fertiliser was used as the bulk material to be spread.

Figure 1. Agricultural gantry while conducting experimental studies, with a mineral fertiliser spreader installed at the front: a) general view; b) view with protective screens installed on both sides

Figure 2. The measuring apparatus which consisted of a frequency modulator and a K-505 measuring instrument

Results

To be able to carry out theoretical studies concerning the flight of a mineral fertiliser particle with the mass of M after being thrown from the disc tool of the mineral fertiliser spreader, the equivalent scheme must first and foremost be determined (Fig. 3) to be able to indicate the forces affecting it and its linear dimensions.

Corresponding to the equivalent diagram indicated in Fig. 3, the fertiliser particle, after having separated from the disc's edge (or from the tip of a vane that may be located on the spreader disk), and having attained the necessary speed required when leaving the disc, performs a movement in a plane that coincides with the direction of the absolute speed of spreading. Having performed free flight through the atmosphere, the particle must land on the surface of the arable (crop-bearing) area of the field without reaching the transport tracks in the engineering area of the field. During that process, the material particle with a mass of M is subject to the forces of gravity $\bar{G}$ and air resistance $\bar{R}_x$.

The differential equation for the movement of a fertiliser particle during its flight in the direction of the axis x is as follows:

$$M \cdot \ddot{x} = -R_x \cdot \qquad (1)$$

Air resistance R_x can be determined as follows:

$$R_x = k \cdot \gamma \cdot F \cdot \dot{x}^2 , \qquad (2)$$

where k is the drag coefficient (Hijazi *et al.*, 2010); γ is the air's specific gravity, kg·m^{-3}; and F is the particle's largest cross-section, m^2.

With small assumptions, the authors estimate that $\dot{x} = V_x$. In that case, after inserting Eq. (2) into (1) and performing mathematical transformations, they get:

$$\frac{dV}{V_x} = -k_s \cdot dx , \qquad (3)$$

where k_s is the aerodynamic coefficient of the fertiliser particle, numerically equal to:

$$k_s = \frac{k \cdot F \cdot \gamma}{M} \cdot \qquad (4)$$

When integrating the Eq. (3), they get:

$$\ln V_x = -k_s \cdot x + \ln C_1 , \qquad (5)$$

where C_1 is the integration constant.

From Eq. (5), the expression of V_x is:

$$V_x = C_1 \cdot e^{-k_s \cdot x} . \qquad (6)$$

The integration constant C_1 is determined from the initial conditions, *i.e.* whereupon $x = 0$, the particle's speed is $V_x = V_r$ where V_r is the fertiliser particle's linear speed upon moving along the disc's circumference.

Having determined the constant C_1 and having integrated Eq. (6) by time t, they get:

$$\frac{e^{k_s \cdot x}}{k_s} = V_r \cdot t + C_2 , \qquad (7)$$

where C_2 is the integration constant.

The integration constant C_2 is also determined from the initial conditions, according to which upon $t = 0$, $x = 0$.

Then $C_2 = k_s^{-1}$. Accounting for that:

$$k_s \cdot x = \ln\left(k_s \cdot V_r \cdot t + 1\right) \cdot \qquad (8)$$

From that, the expression for the flight distance as a function of time looks like this:

$$x = \frac{\ln\left(k_s \cdot V_r \cdot t + 1\right)}{k_s} . \qquad (9)$$

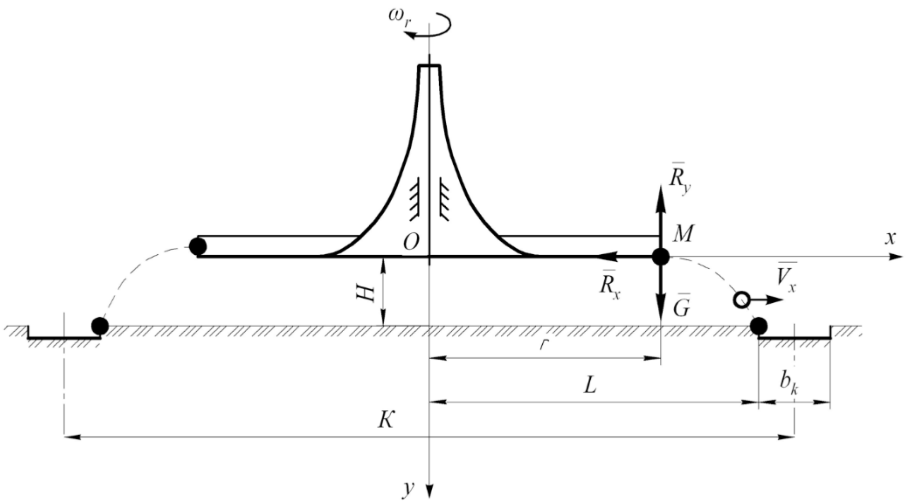

Figure 3. The equivalent diagram for the flight of a particle with the mass of *M*, as thrown from the disc-type tool when spreading mineral fertilisers.

To determine the flight time t of the fertiliser particle, its vertical movement is considered, *i.e.* along axis y under gravity and with air resistance R_y. As the movement speed of the material particle in that direction does not depend on its initial speed, and its falling height H has a negligible relation with the particle's flight distance, the effect of air resistance R_y can be neglected. Based on that, it can be assumed that when the fertiliser particle is in freefall, the height H is equal to:

$$H = \frac{g \cdot t^2}{2}, \tag{10}$$

where g is the freefall acceleration, m•s^{-2}.

From the expression (10), time t is expressed:

$$t = \left(\frac{2 \cdot H}{g} \right)^{\frac{1}{2}}. \tag{11}$$

When inserting the resulting expression (11) for time t in (9), the authors get the equation of the fertiliser particle's flying distance as follows:

$$x = \frac{\ln \left[k_s \cdot V_r \left(\frac{2H}{g} \right)^{\frac{1}{2}} + 1 \right]}{k_s}. \tag{12}$$

According to the equivalent scheme shown in Fig. 1, the flying distance of the mineral fertiliser particle must not reach the wheel tracks in the field's engineering zone, ie:

$$x \le L, \tag{13}$$

where L is half the width of the agricultural (crop-bearing) area of the field that is being served by the agricultural gantry unit, m:

$$L = \frac{1}{2}\left(K - b_k\right), \tag{14}$$

where K is the distance of tracks, m, and b_k is the width of the wheel tracks in the engineering zone, m.

The width of the agricultural zone in the field in question, with that zone being served by an agricultural gantry unit, is determined by the distance of tracks K, reduced by the width b_k for the wheel tracks. The latter depends mostly upon the parameters of its transport system, *i. e.* the agricultural gantry (Bulgakov *et al.*, 2018[a]). This means that the maximum flying distance x of a mineral fertiliser particle must be equal to:

$$x = \frac{1}{2}\left(K - b_k\right). \tag{15}$$

When inserting the expression Eq. (15) into (12), this expresses the speed V_r that a mineral fertiliser particle must possess so that it falls in the correct location and not in the wheel tracks in the engineering zone. The equation is:

$$V_r = \frac{e^{\frac{0.5 \cdot (K - b_k)}{k_s}} - 1}{k_s \cdot \left(\frac{2H}{g} \right)^{\frac{1}{2}}}. \tag{16}$$

When analysing the Eq. (16), it can be noted that the speed V_r which a mineral fertiliser particle must possess so that it does not reach the wheel tracks in the engineering zone, is affected by the following:

- distance K and width b_k for the engineering zone's wheel tracks;
- the installation height H of the centrifugal tool;
- the aerodynamic coefficient k_s of the fertiliser.

If the centrifugal spreader tool has a constant radius of r along its entire circumference then, for practical calculations, it should be assumed that the mineral fertiliser particle leaves the vane or the disc's edge at an absolute speed that is approximately equal to the speed V_r, ie:

$$V_r = \omega_r \cdot r, \tag{17}$$

where ω_r is the angular speed of the disc-based centrifugal fertiliser spreader tool.

Inserting Eq. (17) into (16) results in a mathematical model which relates to the parameters of the centrifugal tool that is used to spread fertiliser through its operating mode and the parameters of the wheel tracks of the agricultural gantry unit:

$$\omega_r = \frac{e^{\frac{0.5 \cdot (K - b_k)}{k_s}} - 1}{r \cdot k_s \cdot \left(\frac{2H}{g} \right)^{\frac{1}{2}}}. \tag{18}$$

The dependency analysis (18) indicates that the highest area of impact on the rotation speed at the circumference of the centrifugal tool being used to spread mineral fertilisers comes from its installation height, the track width of the agricultural gantry, and the aerodynamic coefficient of the mineral fertiliser particles.

The graph of dependence between the angular speed ω_r of the centrifugal spreading tool and the distance of track K of the agricultural gantry unit, which has been prepared using PC software and which corresponds to expression Eq. (18), has an exponential character (Fig. 4).

The dependence analysis that is shown in Fig. 4 indicates that, for this agricultural gantry unit with its distance of track of K = 3.5 m, it is sufficient to have the centrifugal tool's angular speed at its circumference set at 15.5 rad•s^{-1}, which corresponds to its rotational speed (revolution per second) of 2.47 rps. With the increase in the distance of track of the agricultural gantry unit to 6 m, the necessary angular speed of the centrifugal tool being used for spreading mineral fertilisers increases exponentially to 318.2 rad•s^{-1} (50.67 rps). Naturally, such an increase in the rotation speed of the centrifugal spreader tool requires a corresponding increase of the power demand for driving it (Adamchuk *et al.*, 2016). Therefore the authors will further discuss the dependence of the power demand that is required to drive the centrifugal tool for spreading fertiliser in terms of its rotational speed.

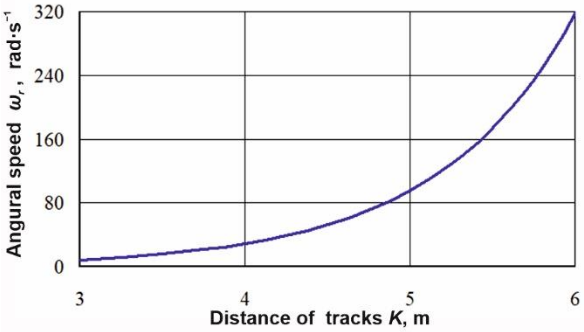

Figure 4. The dependence between the angular speed ω_r of the disc-shaped centrifugal tool for spreading mineral fertilisers and the distance of track K of the agricultural gantry

The total power N that is required to drive the centrifugal tool is presented as the sum of the power demand required to provide the fertiliser particles with the kinetic energy of N_1 so that they might exceed the air resistance upon moving along the vane and the disc N_2, to get past the impact on a vane at the position at which fertiliser is fed onto the disc N_3, and to exceed the resistance offered by the shaft's rotation on its supports N_4:

$$N = N_1 + N_2 + N_3 + N_4 . \quad (19)$$

The power demand N_1 is determined as the kinetic energy of the mass of the fertiliser being passed through the unit, per second:

$$N_1 = \frac{Q \cdot \omega_r^{\,2} \cdot r^2}{2} , \quad (20)$$

where Q is the mass consumption of fertiliser, kg·s^{-1}.

To allow it to exceed the friction caused by the particles moving along the disc of the centrifugal tool, the power demand N_2 can be determined with sufficient precision:

$$N_2 = Q \cdot l \cdot f \cdot \left(0.7 \cdot \omega_r^3 \cdot r + 0.5 \cdot \omega_r^2 \cdot r + g\right), \quad (21)$$

where l is the length of the spreader's vane, m; and f is the fertiliser's coefficient of friction on the disc.

The power demand N_3 is determined with the assumption that a vane's hit against the fertiliser stream is non-elastic:

$$N_3 = 2 \cdot \pi \cdot Q \cdot \frac{\omega_r^2 \cdot r^3}{L \cdot z} , \quad (22)$$

where z is the number of vanes on a spreader disc.

To ensure that the power demand N_4 exceeds the friction caused by the shaft's supports, the required values can be determined as follows:

$$N_4 = 0.5 \cdot \left(m_d + \frac{Q \cdot l}{\omega_r \cdot r} \right) \cdot g \cdot f_n \cdot d , \quad (23)$$

where m_d is the mass of the disc with its vanes, shaft, and driving wheel; f_n is the friction coefficient of the bearings; and d is the diameter of the groove on the bearing's inner ring, m.

When inserting the dependences Eq. (20) to (23) for the power demand for driving the spreader into Eq. (19) and solving the resultant dependence upon the speed ω_r for the centrifugal tool for spreading mineral fertiliser, the result is:

$$N = A_1 \cdot \omega_r^3 + A_2 \cdot \omega_r^{\,2} + A_3 \cdot \omega_r^{-1} + A_0 , \quad (24)$$

where $A_1 = 0.7 \cdot Q \cdot l \cdot f \cdot r$;

$$A_2 = 0.5 \cdot Q \cdot l \cdot f \cdot r + \frac{Q \cdot r^2}{2} + \frac{2 \cdot \pi \cdot Q \cdot r^3}{L \cdot z} ;$$

$$A_3 = 0.5 \cdot g \cdot f_n \cdot d \cdot \frac{Q \cdot l}{r} ;$$

$$A_0 = Q \cdot l \cdot f \cdot g + 0.5 \cdot g \cdot f_n \cdot d \cdot m_d .$$

An analysis of dependence (24) indicates that the power demands that are required to drive the centrifugal tool when spreading mineral fertiliser depend upon the disc's angular speed at its circumference to the third power. The graph to show that dependence is provided in Fig. 5.

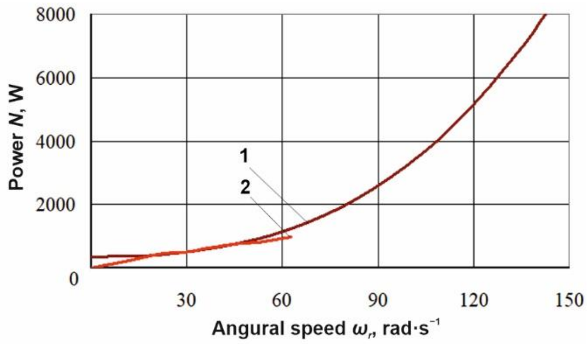

Figure 5. The dependence of the power demand N when driving the centrifugal tool for spreading mineral fertiliser in terms of the angular speed ω_r: 1) theoretical and 2) experimental dependence

An analysis of the graphs provided in Fig. 5 indicates that, for the physical object of the studies (the bulk material spreader on an agricultural gantry), the power demand required for driving the spreader is 0.35 kW. The result agrees quite accurately with the experimental data (Fig. 5). With an increase of the angular speed of the centrifugal tool for spreading fertiliser up to 140 rad·s^{-1} (22.2 rps), the power demand for driving the spreader increases to the third power and reaches 8.0 kW.

The results of these studies indicated that the individual power demand for driving the centrifugal tool for spreading mineral fertiliser in an agricultural gantry unit in comparison with the power demand for driving the agricultural gantry itself is negligible and makes up approximately 10% of the entire power demand.

Conclusions

1. As a result of the studies that have been carried out, it was determined that, for the automation of the process of applying technological bulk materials with an agricultural gantry unit, this purpose can be achieved when utilising an electric drive for the centrifugal fertiliser spreader. The highest impact on its angular speed at its circumference comes from its installation height above the soil, as well as from the agricultural gantry's track distance, and the fertiliser's aerodynamic coefficient.
2. The dependence of the angular speed of the spreader tool on the agricultural gantry's track distance has an exponential character. It was determined that, for an agricultural gantry with a distance of track of 3.5 m, it is sufficient to have the angular speed of a single-disc centrifugal tool be set at 15.5 rad•s^{-1} (2.47 rps). At such an angular speed of the spreader, the mineral fertilisers that are being spread onto the crop area of the agricultural gantry unit will not reach the wheel tracks of the engineering zone in the field. The power demand required for driving the spreader is 0.35 kW.
3. When using agricultural gantries unit with a track distance that was increased to 6m, the necessary angular speed of the centrifugal tool for spreading mineral fertiliser will exponentially increase to 318.2 rad•s^{-1} (50.67 rps). Naturally, such an increase in the angular speed of the centrifugal spreader tool requires the power demand to drive the spreader to be increased to the third power.
4. The results that have been accumulated from these theoretical and experimental studies have indicated that the individual power demand for driving the centrifugal tool for spreading mineral fertiliser from an agricultural gantry unit in comparison with the power demand required for driving the agricultural gantry unit itself is negligible and makes up approximately 10% of the total amount.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VB, VA – study conception and design;
VK, LS – acquisition of data;
VA, VK, JO – analysis and interpretation of data;
VB, JO – drafting of the manuscript;
JO – critical revision and approval of the final manuscript.

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SHORT COMMUNICATION: IMMUNOHISTOCHEMICAL STUDY OF SODIUM-DEPENDENT GLUCOSE CO-TRANSPORTERS IN OSTRICHES KIDNEYS

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ABSTRACT. Out of the two families of glucose transporters identified, the sodium-dependent glucose co-transporters contribute to renal glucose reabsorption. Due to the lack of knowledges of the localization of SGLTs in bird's kidneys, the present study aimed to immunolocalize Na+-glucose co-transporters SGLT1 and SGLT2 in ostrich's kidneys. In the study kidney material derived from five 14 days old female ostriches. Material 0.5–1.0 cm in diameter was fixed in 10% formalin, dehydrated, embedded into paraffin; thereafter slices 7 µm in thickness were cut and deparaffinized, followed by immunohistochemical staining with polyclonal primary antibodies Rabbit anti-SGLT1 and Rabbit anti-SGLT2 (Abcam, UK) according to the manufacturers' guidelines (IHC kit, Abcam, UK). Our study revealed the immunohistochemical localization of SGLT1 and SGLT2 in the proximal tubules of the renal cortex. The immunohistochemical locations of sodium-dependent glucose transporters resembled those in mammals.

Introduction

In the body, glucose is the central source of energy and the glucose homeostasis is of critical importance to health (Hruby, 1997). Kidneys play a role in glucose homeostasis in the body by ensuring that glucose is not lost in the urine (Ghezzi *et al.* 2018). Two families of glucose transporters have been identified: the facilitated-diffusion glucose transporter family (GLUT family), and the NA(+)-dependent glucose co-transporters (or sodium-glucose linked transporters, SGLT family) (Takata, 1996). Sodium-dependent glucose co-transporters are a family of glucose transporters found in the intestinal mucosa of the small intestine and the proximal tubule of the nephron (Miller, Bihler, 1961; Wright 2001). Membrane proteins which are responsible for glucose reabsorption from the kidney's glomerular filtrate are sodium-glucose co-transporters SGLT1 and SGLT2 (Vallon, Thomson 2012; Haas *et al.*, 2014).

SGLT2, the major co-transporter involved in glucose reabsorption in the kidney, is located in the beginning part of the proximal tubule and is responsible for reabsorption of 80–90% of the glucose filtered by the glomerulus (You *et al.*, 1995; Bonora *et al.*, 2020). Most of the remaining glucose absorption is carried out by SGLT1 in more distal sections of the proximal tubule (Horiba *et al.*, 2003; Vallon, Thomson, 2012) of the kidney. Failures of these transporters in kidneys result in the excretion of filtered glucose in the urine (Wright *et al.*, 2007).

As most of the experiments on kidney's SGLTs have been carried out in rats and mice, the renal locations of both transporters are well established in animals (Takata, 1996; Hussar *et al.*, 2004; Vrhovac *et al.*, 2015). However, due to the scarce information available on the molecular basis of glucose transport in bird's kidneys, the aim of the present study was the immunohistochemical localization of SGLT1 and SGLT2 in the kidneys of ostriches chicken.

Material and methods

The study was carried out on five 14 days old female ostriches *(Struthio camelus var. Domesticus)*. The commercial ostrich chicken's feed – Strus Premium-Strus 1 and water were available *ad libitum*. Tissue sections 0.5–1.0 cm in diameter were removed from renal cortex and medulla, fixed in 10% formalin, dehydrated in a tissue processor and embedded into paraffin according to the standardized tissue histological procedure (Carson, 1997). Slices 7µm thick were cut (microtome Microm HM360), floated on Poly-L-Lysine coated slides, deparaffinized with xylene and rehydrated in a graded series of ethanol followed by immunohistochemical staining with polyclonal primary antibodies Rabbit anti-SGLT1 and Rabbit anti-SGLT2 (Abcam, UK) in 1/1000 dilution, for 30 min at 37° C according to the manufacturer's guidelines (IHC kit, Abcam, UK). Biotinylated secondary antibody and streptavidin-conjugated peroxidase were used for detection using DAB as a chromogen. Negative controls contained antibody diluent (Dako, S0809) instead of primary antibodies. Photos of the slides were taken by the microscope Zeiss Axioplan-2 Imaging (Germany) and saved to the computer for analyzing by visual control using a camera (AxioCam HRc, Germany) connected to the microscope.

The experiments were carried out following the guidelines laid down by the European Communities Council Directive of 24 November 1986 (86/609/EEC) and the Ethical Committee of Latvian University of Agriculture has approved the experiments (protocol number 2014/2).

Results

The immunolocalization of SGLT1 and SGLT2 in 14 days old ostrich's kidneys was performed. SGLT1 was detected in the epithelial cells of the straight proximal tubules in medullary rays and outer stripe of the renal medulla (Figure 1a). SGLT2 was noted on the apical side of the epithelial cells in the renal cortical proximal tubules (Figure 1b). The epithelial cells of the collecting tubules as well as in the thin segment of the loop of Henle remained unstained for both antibodies.

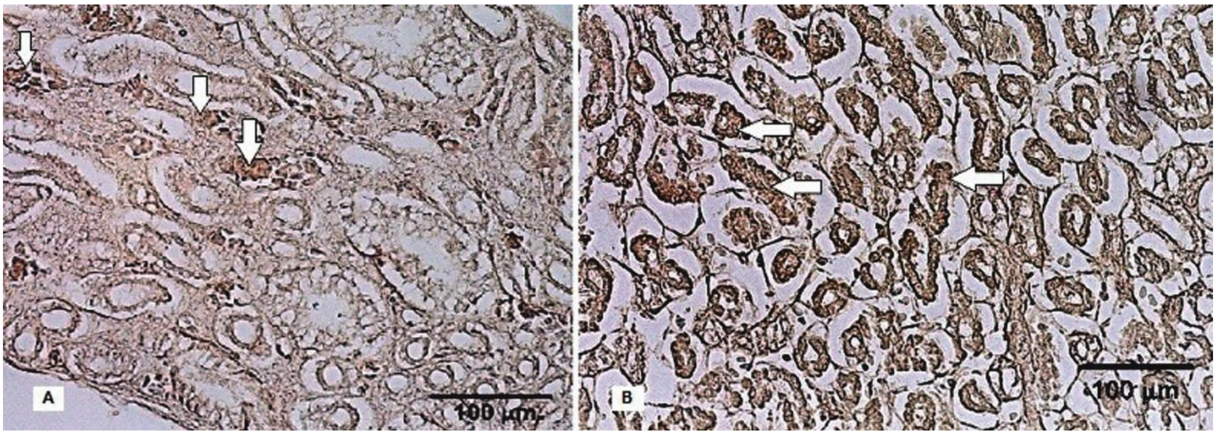

Figure 1. The immunolocalization of SGLT1 and SGLT2 in 14 days old ostriches kidneys: a) SGLT1 immunolocalized in straight proximal tubules in medullary rays (arrows). Bar:100 µm; b) SGLT2 in the renal cortical proximal tubules (arrows) of the 14 days old ostriches chicken. IHC, bar:100 µm.

Discussion

Kidneys contribute to glucose homeostasis by filtering and reabsorbing glucose (Mota *et al.,* 2015). In the kidneys, 100% of the filtered glucose in the glomerulus has to be reabsorbed along the nephron. Glucose is never secreted by a healthy nephron. If the plasma glucose concentration is too high (hyperglycemia), glucose is excreted in urine (glycosuria) because sodium-glucose co-transporters are saturated with the filtered glucose.

Among sodium-glucose co-transporters, SGLT1 and SGLT2 are responsible for glucose reabsorption from the glomerular filtrate. 'Knockout' of these transporters in mice and men results in the excretion of filtered glucose in the urine. SGLT1 is responsible for about 10% of the tubular glucose reabsorption (Wright *et al.*, 2007) and has been detected on the apical (urine) side of the proximal tubule where it facilitates the reabsorption of urinary glucose from the glomerular filtrate (Castaneda-Sceppa, Castaneda, 2011). In our study, SGLT1 was immunolocalized also in the proximal tubules in medullary rays and outer stripe in the kidneys of ostriches chicken.

Another member of the sodium-glucose linked transporters, SGLT2, detected in the early proximal tubules, is the primary renal glucose transporter. SGLT2 in conjunction with SGLT1 resorbs glucose into the blood from the forming urine. By inhibiting SGLT2, and not targeting SGLT1, glucose is excreted which in turn lowers blood glucose levels. Thus SGLT2 inhibitors, called *gliflozins*, are used in the treatment of type-2 diabetes (Song *et al.*, 2016). The selective SGLT1 inhibitor KGA 2727 has been developed as an antidiabetic agent, and it efficiently blocks the transporter function in cells overexpressing SGLT1 (Shibazaki *et al.*, 2012). LX4211, a dual SGLT1/SGLT2 inhibitor, improved glycemic control in patients with type-2 diabetes in a randomized, placebo-controlled trial (Zambrowicz *et al.*, 2012). LX4211 enhanced urinary glucose excretion by inhibiting SGLT2-mediated renal glucose reabsorption improving multiple measures of glycemic control, including fasting plasma glucose, oral glucose tolerance and significantly lowered serum triglycerides. In mammals, SGLT1 and SGLT2 have been noted in the brush border membrane of proximal tubule S1/S2 and S3 segments, respectively

(Aschenbach *et al.*, 2009). Different from rodents, the renal expression of SGLT1 has been noted to be absent in thick ascending limb of Henle (TALH) and macula densa in human (Vrhovac *et al.*, 2015). Our study revealed the renal locations of both transporters in 14 days old ostriches chicken resembled those in rats and mice – SGLT1 and SGLT2 were immunolocalized on the apical side of the cortical proximal tubules. By the previous studies, SGLT1 localized in straight proximal tubules in medullary rays corresponding to the S3 segment and SGLT2 in renal cortical proximal tubules corresponding to S1/S2 and S1 segments.

Conclusions

The current immunohistochemical study showed the SGLT1 and SGLT2 similar locations in the renal proximal tubules as previously detected in mammals. For a better understanding of the localization of the sodium-dependent glucose transporters in bird's kidneys, immunohistochemical studies on chicken in different ages should be carried out in future.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

PH, ID – conceptualization and planning;
ID – data collection;
PH, FP-P, TJ, ID – analysis and interpretation;
PH – writing – original draft preparation;
PH, FP-P, TJ, ID – writing – review and editing.
All authors have read and agreed to the final version of the manuscript.

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ÜLEVAADE NITRITITE JA NITRAATIDE SISALDUSTEST LIHATOODETES EESTIS

AN OVERVIEW OF THE NITRITE AND NITRATE CONTENTS IN MEAT PRODUCTS IN ESTONIA

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ABSTRACT. This study examined the nitrite and nitrate content in processed meat products in Estonia. The study shows the levels of nitrites and nitrates in meat products and compares the results with data from the previous study periods. All meat products, which needed heat treatment according to the manufacturer's instructions, were heat-treated prior analyses. Among analysed meat products (n=164), the highest nitrite concentration was 93.1 mg kg^{-1} and it was determined in uncooked meat preparation product. The overall mean nitrite concentration among nitrite contained meat products varied from 9.7–30.3 mg kg^{-1} depending on the meat product category. The highest mean nitrite concentrations were found in sausages and pates. There were large differences in the nitrite content of the products of different producers, ranging from the detection limit to 93.1 mg kg^{-1}. The largest differences in nitrite contents were observed in the cooked sausages of one manufacturer, in which the nitrite content was from the detection limit up to 61.5 mg kg^{-1} in the product. The nitrite and nitrate contents of different meat products also varied widely between producers and were different for each product group. By the Regulation (EC 1333/2008) taking into account the maximum levels for nitrites and nitrates allowed to be added to the meat products, there were no exceedances detected. In the comparison of previous and present study periods, it can be summarised that sodium nitrite ($NaNO_2$) levels are lower in cooked sausages, smoked sausages and wieners, and the content of sodium nitrate ($NaNO_3$) in various meat products is considerably decreased.

Sissejuhatus

Soola kasutamine liha ning lihatoodete konserveerimiseks on mitmete sajandite pikkune traditsioon, nt muistsed kreeklased kasutasid soola kala konserveerimiseks ning roomlased kasutasid liha ja kala säilitamiseks marinaade, mis sisaldasid nii soola kui ka teisi koostisaineid (Pegg, Shahidi, 2000). Nitritil on liha töötlemisel mitmeid olulisi funktsioone, nagu toote värvuse säilitamine, maitseomaduste parendamine, mikroobide kasvu pärssimine ning rääsumise aeglustamine (Gray, Pearson, 1984).

Toorestes soolamislisanditega töödeldud lihatoodetes on punane värvus tingitud nitrosüülmüoglobiinist. Viimane moodustub müoglobiini lämmastikoksiidiga reageerimisel. Nitritsool ($NaNO_2$) on lämmastikoksiidi põhiallikas ning lahustes on nitrit ioon tasakaalus dissotsieerimata lämmastikushappega. Nõrgalt happelistes tingimustes lagundatakse lämmastikushape lämmastikoksiidiks. Nitrit on ka oksüdeerija, mis kergesti muundab müoglobiini metmüoglobiiniks, mis omakorda taandatakse nitrosüülmetmüoglobiiniks. Müoglobiini muundamine nitrosüülvormiks on mittetäielik ega ole alati ühtemoodi kulgev protsess, kõikudes erinevates lihaproovides 35 ja 75% vahel. Eelnev protsess toimub mainitud ulatuses juhul, kui nitriti algne kogus on 100 kuni 150 ppm-i (ingl *parts per million*) (Ranken, 2000). Kuumutamise ajal nitrosüülmüoglobiin denatureerub roosakaks nitrosüülmüokromogeeniks, mida tuntakse ka kuumutatud lihapigmendi

(CCMP – ingl *Cooked Cured Meat Pigment*) nimetuse all. Seega, vaadeldes värvi tekitamist nitritsooladega töödeldud lihatoodetes, nitrit pigem seob roosakat värvust (Pegg, Shahidi, 2000). Oluline on teada, et soolamislisanditega töödeldud lihatoodete punase värvuse intensiivsus ei ole seotud niivõrd nitriti kontsentratsiooni, kuivõrd lämmastikoksiidi poolt stabiliseeritud müoglobiini kogusega lihastes. Näiteks, kui töödelda ühesuguse koguse soolamislisanditega veiselihakonservi ning sinki, siis konserveeritud veiselihale tekib oluliselt punakam värvus. Askorbiinhappe, askorbaatide või erütorbaatide lisamine kiirendab nitriti redutseerumist lämmastikoksiidiks ning lämmastikoksiidi reaktsiooni müoglobiiniga (Pegg, Shahidi, 2000; Sebranek, Bacus, 2007). Arvatakse, et askorbaat tugevdab soolamislisandite mõju, mistõttu selle kasutamisel koos nitritsoolaga oleks võimalik toodetes vähendada nitritite kogust ligikaudu ühe kolmandiku võrra. Samuti aitab askorbaat eemaldada hapniku jääke, mille olemasolu pärsib soolamislisanditega töödeldud lihatoodetes iseloomuliku värvi teket (Ranken, 2000). Samas nitritid avaldavad teatud lihatoodetes konserveerivat toimet, eelkõige seeläbi, et pärsivad mitmete ebasoovitavate mikroorganismide k.a bakteri *Clostridium botulinum* kasvu. Nitraadid ($NaNO_3$) võivad lõpptootesse sattuda toorainest, nt lihast (Ysart jt, 1999), veest ja teistest lisatavatest ainetest või tekkida nitriti muundumisel nitraadiks (Honikel, 2008). Toidus lubatud lisaainete kasutamise tingimused ja kord on sätestatud Euroopa Parlamendi ja nõukogu määruses (EÜ) nr 1333/2008. Nimetatud määrust on muudetud ja täiendatud mitmeid kordi. Vastavalt määrusele on enamike lihatoodete jaoks piisav kogus nitritsoola 50−100 mg kg^{-1} liha kohta. Teiste toodete jaoks, mille soolasisaldusi on vähendatud, kuid millistele on määratud pikad säilimisajad, on vaja *Clostridium botulinum*'i pärssimiseks lisada 50−150 mg nitrititsoola ühe kilogrammi liha kohta. Varasemalt teostatud uuringutest selgub, et nitriteid leidub erinevates lihatoodetes erineval määral. Näiteks Leth jt teostatud kümne aasta pikkuses uuringus leiti, et töödeldud lihatoodetes sisaldus nitriteid järgnevalt: maksapasteedis 0−4; pasteedis 4,1−7,6; rasvase lihaga võileivas 12,6−23,7; lahja lihaga võileivas 12−24,3; salaamivorstides 8,5−16,7; keeduvorstides 7−19,4 mg kg^{-1} kohta (Leth jt, 2008). Larsson jt (2011) poolt Rootsis teostatud uuringus toodi välja töödeldud lihatoodetes ka nitraatide ja nitritite sisaldused vastavalt: need olid peekonis 8,7 ja 2,2; keeduvorstis 15,3 ja 7,7; salaamivorstis 6,2 ja 0,7; kanalihavorstis 12,6 ja 34,1; suitsutatud kalkunilihas 6,9 ja 23,5; keedusingis 4,0 ja 0,6; suitsusingis 3,5 ja 1,1 ja maksapasteedis 18,4 ja 20,5 mg kg^{-1}. Rootsis teostatud uuringu alusel olid suurema nitritite sisaldusega tooted seega kanalihavorstid ja suitsutatud kalkuniliha (Larsson jt, 2011). Temme jt poolt Belgias teostatud uuringus leiti, et nitraatide ja nitritite sisaldused olid sinkvorstides 31,6 ja 34,4; keeduvorstides 35,3 ja 21,6; toorvorstides 40,4 ja 13,2; konservvorstides 23,5 ja 12,0; keedusingis 18,0 ja 6,6; maksapasteedis 57,3 ja 6,6; peekonis 85,9 ja 4,8 mg kg^{-1} (Temme jt, 2011). Belgia uuringu põhjal, nagu ka meie varasemalt Eestis koostatud uuringu põhjal (Reinik jt, 2005), saab tuua välja, et kõrgema nitriti sisaldusega lihatooted olid sinkvorstid ja keeduvorstid. Võttes arvesse eelnevalt Eestis teostatud uuringuid ning kirjanduses toodud andmeid, otsustati Eestis läbi viia lihatoodete nitritite sisalduste uuring. Antud töö eesmärk on selgitada välja nitritite ja nitraatide sisaldused Eestis toodetud ja müüdavates lihatoodetes ning teostada võrdlus nitritite sisalduse kohta sarnastes tootegruppides erinevate lihatööstusettevõtete lõikes.

Materjal ja metoodika

Proovide kogumine

Kokku analüüsiti 164 lihatoote proovi, mis olid toodetud Eestis 16 erineva tootja poolt. Tooted, mille nitritite sisaldust uuriti, olid järgmised: 36 toorvorsti ja küpsetamist vajavat lihatoodet, 53 viinerit ja sardelli, 29 keeduvorsti, 15 sinki, 5 poolsuitsuvorsti, 8 täissuitsuvorsti, 5 küpsetatud hakktoodet, 10 pasteeti koos teiste määretega ja 3 salaamivorsti (tabel 1). Kõiki tooteid, mis vajasid vastavalt tarbimisjuhendile kuumtöötlemist, kuumutati enne analüüside teostamist.

Proovide keemiline analüüs

Lihatoodete nitritite ja nitraatide analüüsid teostati Terviseameti Tartu laboris, kasutades ioonkromatograafilist meetodit T37-HPLC. Meetod põhineb standardil EVS-EN 12014-4:2005 ning on akrediteeritud Eesti Akrediteerimiskeskuse poolt. Nitraadid ja nitritid ekstraheeritakse peenestatud proovidest kuuma veega homogeniseerimise teel. Seejärel hoitakse proove ultrahelivannis, tsentrifuugitakse ning filtreeritakse. Nitritioonid (NO_2^-) ja nitraatioonid (NO_3^-) lahutatakse kolonni Waters Anion IC abil ning määratakse vedelikkromatograafi Shimadzu ja UV detektoriga lainepikkusel 205nm. Väikseim määratav kogus oli 5 mg kg^{-1} $NaNO_2$ ja 8 mg kg^{-1} $NaNO_3$.

Statistiline analüüs

Statistilise töötluse tegemiseks kasutati programmi R. Välja on toodud karpdiagrammidel mediaanid, kvartiilid ning analüüsitud lihatoodete nitritite kontsentratsioonide maksimaalsed ja minimaalsed väärtused.

Tulemused ja arutelu

Lihatoodete nitritite ja nitraatide sisaldused

Kokku uuriti käesolevas uuringus 164 lihatoodet. Kõigis lihatoodetes määrati nitritite ja nitraatide sisaldused, mille tulemused on esitatud tabelis 1.

Tabel 1. $NaNO_2$ ja $NaNO_3$ sisaldused erinevates lihatoodete gruppides
Table 1. *$NaNO_2$ and $NaNO_3$ content in different groups of meat products*

Tooteliik *Meat products*	Analüüside arv *No. of analyses*	$NaNO_2$ sisaldus mg kg^{-1} *$NaNO_2$ content mg kg^{-1}*			$NaNO_3$ sisaldus mg kg^{-1} *$NaNO_3$ content mg kg^{-1}*		
		Min	Max	Keskmine *Average*	Min	Max	Keskmine *Average*
Viinerid / *Francfurters*	46	<5,0	48,2	19	9,9	49,9	27,0
Sardellid / *Dinner sausages*	7	10,1	49,3	22,7	15,7	34,1	25,4
Lastevorstid / *Boiled sausages called "Lastevorst"*	9	14,6	61,5	29,0	14,9	37,0	18,1
Muud keeduvorstid / *Other boiled sausages*	20	<5,0	61,4	25,8	<8,0	36,6	26,7
Poolsuitsuvorstid / *Semi-smoked sausages*	5	10,7	23,7	18,9	23,4	38,1	21,7
Täissuitsuvorstid / *Fully smoked sausages*	8	<5,0	35,1	14,4	<8,0	59,8	37,2
Singid / *Hams*	15	<5,0	46,4	22,8	<8,0	52,7	12,7
Salaamivorstid / *Salami type sausages*	3	6,2	54,4	30,3	19,8	76,3	45,3
Pasteedid ja teised määrded / *Liver pate and other pates*	10	<5,0	56,0	26,7	<8,0	46,1	20,8
Küpsetamist vajavad toorvorstid / *Uncooked raw sausages*	22	<5,0	57,0	17,8	<8,0	41,2	21,1
Küpsetamist vajav liha jt sarnased tooted *Uncooked meat preparations and similar products*	14	<5,0	93,1	16,6	<8,0	34,8	5,8*
Küpsetatud hakktooted / M*eat patties and meatballs*	5	<5,0	34	9,7	<8,0	27,5	10,8

$NaNO_2$ määramispiir 5 mg kg^{-1} ning $NaNO_3$ määramispiir 8 mg kg^{-1} / *The quantification limit of $NaNO_2$ was 5 mg kg^{-1} and for $NaNO_3$ 8 mg kg^{-1}*
* Keskmiste arvutamisel alla määramispiiri analüüsi tulemused võrdsustati 0 mg kg^{-1}. / ** In the calculation of mean values, results under the limit of quantification were equalised to 0 mg.*

Esitatud on erinevate tootegruppide minimaalsed, maksimaalsed ja keskmised nitritite ja nitraatide sisaldused. Kõige suuremal hulgal teostati nitritite ja nitraatide analüüse viineritest (46 analüüsi), nende hulgas oli nii selliseid viinereid, mis sisaldasid nitriteid alla määramispiiri kui ka selliseid, mis sisaldasid nitriteid kuni 48,248,2 mg kg^{-1}. Võrreldes antud uuringu analüüsi tulemusi (tabel 1) Soomes aastal 2013 teostatud uuringu tulemustega (EVIRA, 2013), saab väita, et lihatoodete keskmised nitritite sisaldused on suhteliselt sarnased, nt sinkides oli antud uuringus nitriti keskmine ja maksimaalne sisaldus 22,8 ja 46,4 mg kg^{-1} ning Soome uuringus vastavalt 15,1 ja 43,6 mg kg^{-1}. Madalamate keskmiste nitritite sisaldusega tootegrupid olid küpsetatud hakktooted, küpsetamist vajav liha ja teised sarnased tooted. Üks erandlikult kõrge nitritisisaldusega toode (93,1 mg kg^{-1}) kuulus küpsetamist vajava liha tootegruppi, sellele järgnes "Lastevorst", mille ühest proovist tuvastati nitriteid 61,5 mg kg^{-1}. Teistes tootegruppides nii kõrgeid nitritite sisaldusi ei tuvastatud.

Tabelist 1 on näha, et kuigi lihatoodetesse lisatakse nitriteid, sisaldavad need ka nitraate. Nitraadid võivad lõpptootesse sattuda toorainest, nt lihast (Ysart jt, 1999), veest ja teistest lisatavatest ainetest või tekkida nitriti muundumisel nitraadiks (Honikel, 2008). Nitritid omakorda võivad muunduda lämmastikoksiidiks või seonduda amiididega ja amiinidega, moodustades nitrosoamiide ja -amiine. Euroopa Parlamendi ja nõukogu määrus (EÜ) nr 1333/2008 kehtestab eeskirjad toidu lisaainete kohta k.a lihatoodetes ja lihavalmististes kasutada lubatud lisaainete ja nende kasutamise tingimuste kohta. Võrreldes määrusega kehtestatud lihatoodetele lisada lubatud nitritite ja nitraatide piirmäärasid, võib vastavalt esitatud analüüsi tulemustele (tabel 1) väita, et lihatoodetesse ei lisata lubatud nitritite piirmääradest rohkem nitriteid, sest vastasel juhul oleks lõpptoodete nitritite sisaldused märkimisväärselt kõrgemad.

Järgnevas tabelis 2 on toodud nitritite ja nitraatide sisalduste võrdlus erinevatel uurimisperioodidel (2000−2001, 2003−2004 ja 2015−2017).

Tabel 2. $NaNO_2$ ja $NaNO_3$ sisalduste võrdlused erinevates lihatoodete gruppides erinevatel uurimisperioodidel (aastatel 2000−2001, 2003−2004 ja 2015−2017) (Noorsalu, 2001; Reinik jt, 2005; Reinik, 2007 ja käesoleva uuringu andmed)
Table 2. *Comparison of $NaNO_2$ and $NaNO_3$ concentrations in different groups of meat products between different study periods (years 2000 to 2001, years 2003 to 2004 and 2015 to 2017) (Noorsalu, 2001; Reinik* jt*, 2005; Reinik, 2007 and current study)*

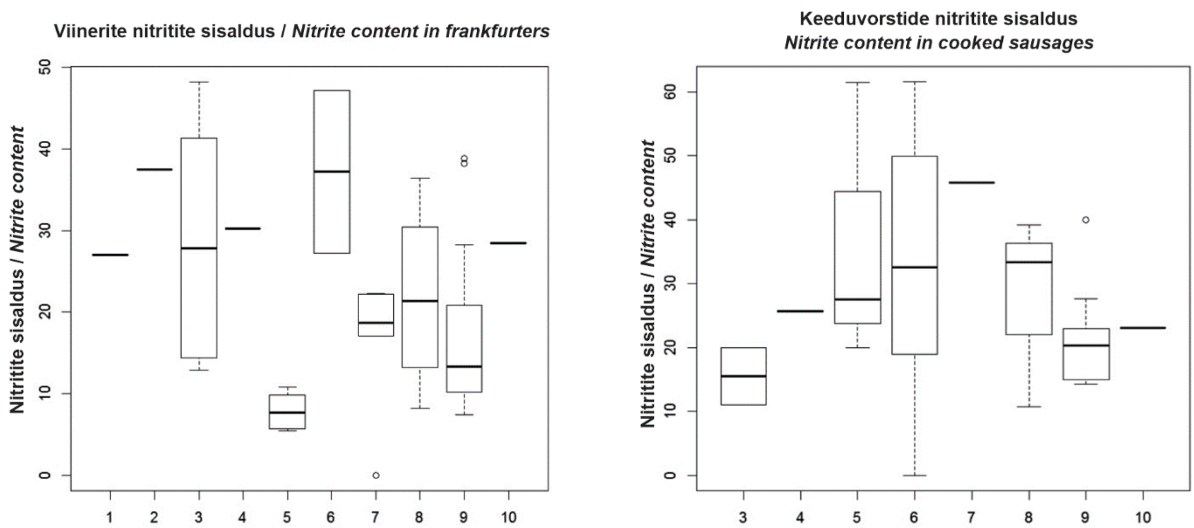
Tooteliik *Meat products*	Aasta *Year*	Analüüside arv *No. of analyses*	$NaNO_2$ keskmine sisaldus mg kg^{-1} *$NaNO_2$ average content mg kg^{-1}*	$NaNO_3$ keskmine sisaldus mg kg^{-1} *$NaNO_3$ average content mg kg^{-1}*
Keeduvorstid	2000−2001	116	35	59
Boiled sausages	2003−2004	81	28	52
	2015−2017	29	25	19
Suitsuvorstid	2000−2001	36	28	77
Smoked sausages	2003−2004	29	16	46
	2015−2017	13	17	30
Singid / *Hams*	2000−2001	44	22	63
	2003−2004	16	21	45
	2015−2017	15	23	13
Viinerid / *Frankfurters*	2001	18	34	76
	2015−2017	46	19	27
Salaami	2000−2001	4	4	138
Salami type sausages	2015−2017	3	30	45

Tabelist 2 selgub, et aastatel 2000−2001 teostatud uuringu (Reinik, 2007; Noorsalu 2001), aastatel 2003−2004 teostatud uuringu (Reinik jt, 2005) ja käesoleva uuringu nitritite ja nitraatide sisaldused lihatoodetes on erinevad. Varasematel perioodidel olid nitritite sisaldused kõrgemad keeduvorstides, suitsuvorstide ja viinerites. Sinkides oli nitritite tase kõigil uurimisperioodidel sarnane. Salaamivorstide kohta ei saa väheste analüüside tõttu kindlaid järeldusi teha, kuid on näha nitritite suuremat sisaldust. Nitraatide sisaldused on võrreldes kolme uurimisperioodiga kõigis lihatoodetes langenud. Seega, lihatööstused on teinud enda retseptuuris muudatusi ning lihatooted sisaldavad, võrreldes varasemate aastatega, vähem nitriteid ja nitraate.

Erinevate tootjate sarnaste toodete nitritite sisaldused

Joonistel 1 ja 2 on toodud erinevate tootjate toodangu nitritite sisalduste erinevused. Joonistel on toodud karpdiagrammid, mille vertikaalteljel on toodud $NaNO_2$ sisaldused milligrammides ühe kilogrammi toote kohta ning horisontaalteljel on tähistatud erinevate numbritega erinevad tootjad. Välja on toodud ka mediaanväärtus (tähistatud joonisel rasvase joonega), millest pooled nitritite sisalduste väärtused on suuremad ja pooled väiksemad. Seega on joonistel näha mediaan täpselt variatsioonirea keskel (on nn 50%-punkt). Nitritite sisalduste andmete esitamisel on näidatud mediaanväärtused, sest need on vähem tundlikud erandlikele väärtustele, võrreldes aritmeetilise keskmisega. Järgnevatel joonistel toodud kvartiilid (alumine kvartiil – 25%-punkt, ülemine kvartiil – 75%-punkt) näitavad seda, et variatsioonirida on jagatud proportsionaalselt nelja võrdsesse ossa, kus ülemisest kvartiilist suuremaid nitritite sisalduse väärtusi ja alumisest kvartiilist väiksemaid nitritite sisalduse väärtusi esines mõlemaid 25%. Kvartiilid märgivad joonistel nähtava karbi alumise ja ülemise serva. Väärtused, mis jäid alumisest või ülemisest kvartiilist kaugemale kui 1,5-kordne kvartiilide vahe (75%-punkt miinus 25%-punkt) loeti erandlikeks ja märgiti joonistele eraldi punktiga. Vurrude tipud või suurimad/vähimad erandlikud punktid vastavad analüüsitud nitritite kontsentratsiooni maksimaalsele ja minimaalsele väärtusele. Kui mingilt tootjalt on analüüsitud vaid ühte toodet või langevad kõikide analüüside tulemused kokku, on nii miinimum, maksimum, mediaan kui ka kvartiilid samad ja joonisel väljendub see vaid ühe horisontaalse joonena.

Joonisel 1 on toodud viinerite ja keeduvorstide nitritite sisaldused. Vaadeldes viinerite nitritite sisaldusi, on näha, et tootja nr 6 poolt toodetud viinerite korral ei ole karpdiagrammil vurrusid, kuna ülemisele ja alumisele kvartiilile järgnenud väärtused peale suurima olid sellega võrdsed. Seega, antud tootja toodetud viinerites olid nitritite sisaldused sarnases vahemikus, ilma suurte kõikumisteta. Samalt jooniselt on näha, et tootjate nr 1, 2, 4, 10 toodetest analüüsiti ainult ühte/mõningaid tooteid või sisaldasid need tooted nitriteid väga sarnastes koguses. Tootjate nr 3 ja 6 viinerid sisaldasid maksimaalsete kogustena kõige suuremal määral nitriteid, vastavalt 48,2 ja 47,2 mg kg^{-1}. Vaadeldes joonisel 1 toodud keeduvorstide nitritite sisaldusi, olid tootja nr 6 poolt toodetud erinevates keeduvorstides nitritite sisaldused (erinevad nimetused) väga kõikuvad. Tootjatel nr 4 ja 10 olid nitritite sisaldused keeduvorstides sarnase kontsentratsiooniga. Osad keeduvorstid sisaldasid nitriteid väga madalates kogustes (alla määramispiiri), kuid leidus ka tooteid, milliste nitritite sisaldused küündisid tootjate nr 5 ja 6 toodetes vastavalt 61,4 ja 61,5-ni mg kg^{-1}. Tootjate nr 7, 8 ja 9 toodete nitritite sisalduse mediaan jääb sarnasesse vahemikku.

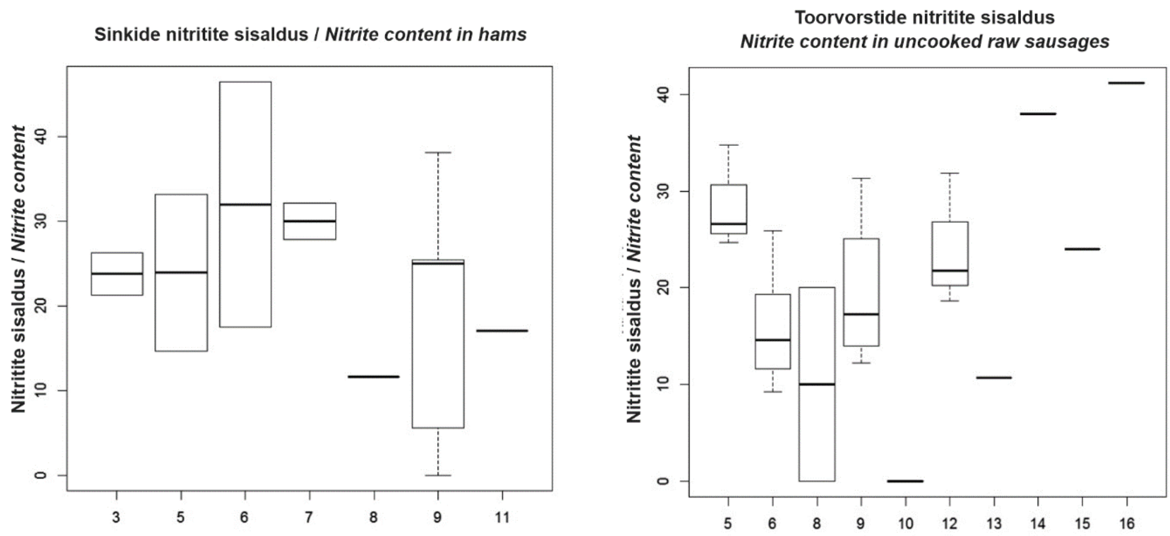


Joonis 1. Erinevate tootjate (1, 2, 3, 4, 5, 6, 7, 8, 9, 10) viinerite ja keeduvorstide $NaNO_2$ sisaldused mg kg^{-1}
Figure 1. *$NaNO_2$ contents (mg kg^{-1}) in frankfurters and cooked sausages produced by different manufacturers (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)*

Joonisel 2 on toodud erinevate tootjate poolt toodetud sinkide ja toorvorstide nitritite sisalduste andmed. Joonisel 2 on näha, et sinkide nitritite sisaldused tootja nr 9 poolt toodetud sinkides kõikusid võrreldes teiste tootjatega suuremal määral, olles mõningates toodetes alla määramispiiri kuni 38 mg kg^{-1}.

Lisaks on jooniselt 2 näha, et kuumtöödeldud toorvorstide nitritite sisaldused tootjate lõikes olid erinevad, kusjuures mitmed tootjad olid esindatud vaid üksikute toodetega. Kõige kõrgem nitritite sisaldus tuvastati tootja nr 16 toodetud toorvorstis – 41,2 mg kg^{-1}. Sellest tulenevalt on joonisel näha ilma karpideta mediaanväärtust (kontsentratsioon) tähistavat joont.

Tuleb lisada, et proovid koguti ning analüüsid teostati sügis-talvisel perioodil, seega oli toodete valik võrreldes kevad-suvise hooajaga tunduvalt väiksem. Kõik tooted, mis vajasid vastavalt tarbimisjuhendile kuumtöötlemist, kuumutati enne analüüside teostamist.

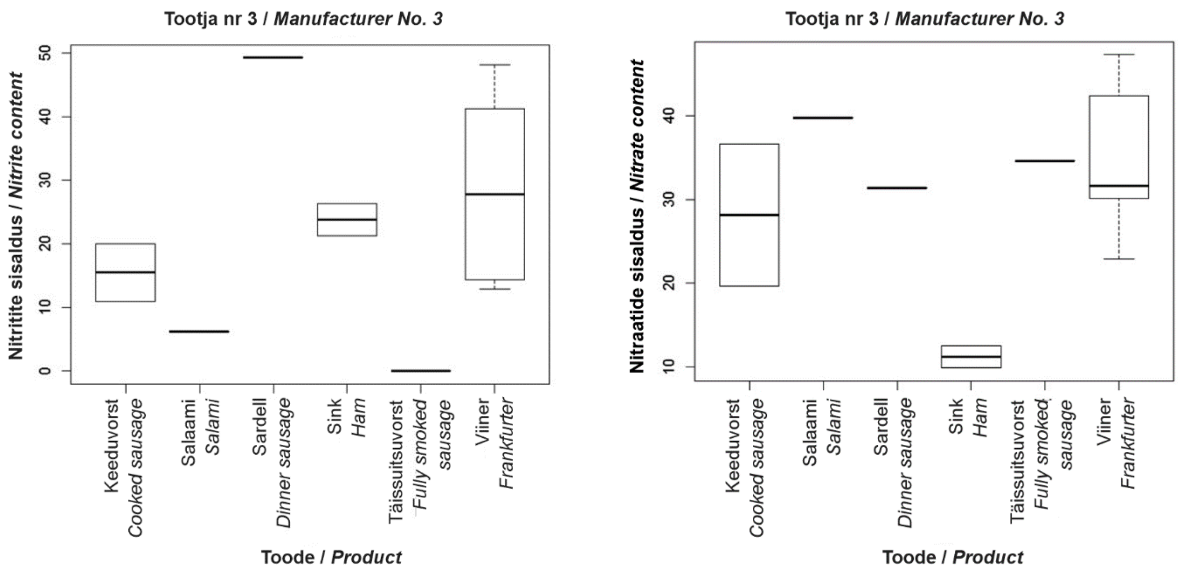


Joonis 2. Erinevate tootjate (3, 5, 6, 7, 8, 9, 11) sinkide ja toorvorstide $NaNO_2$ sisaldused mg kg^{-1}
Figure 2. *$NaNO_2$ contents (mg kg^{-1}) in hams and uncooked raw sausages produced by different manufacturers (3, 5, 6, 7, 8, 9, 11)*

Tootjate lõikes erinevate lihatoodete nitritite ja nitraatide sisaldused

Joonistel 3 kuni 7 on välja toodud need tootjad, kelle toodete sortimendis oli erinevatesse tootekategooriatesse kuuluvaid tooteid kuus ja enam. Joonistel on toodud erinevatesse tootekategooriatesse kuuluvate toodete nitritite ja nitraatide sisaldused. Kõrvuti asetsevad nitritite ja nitraatide sisalduste joonised annavad hea ülevaate iga erineva lihatoote grupi kohta.

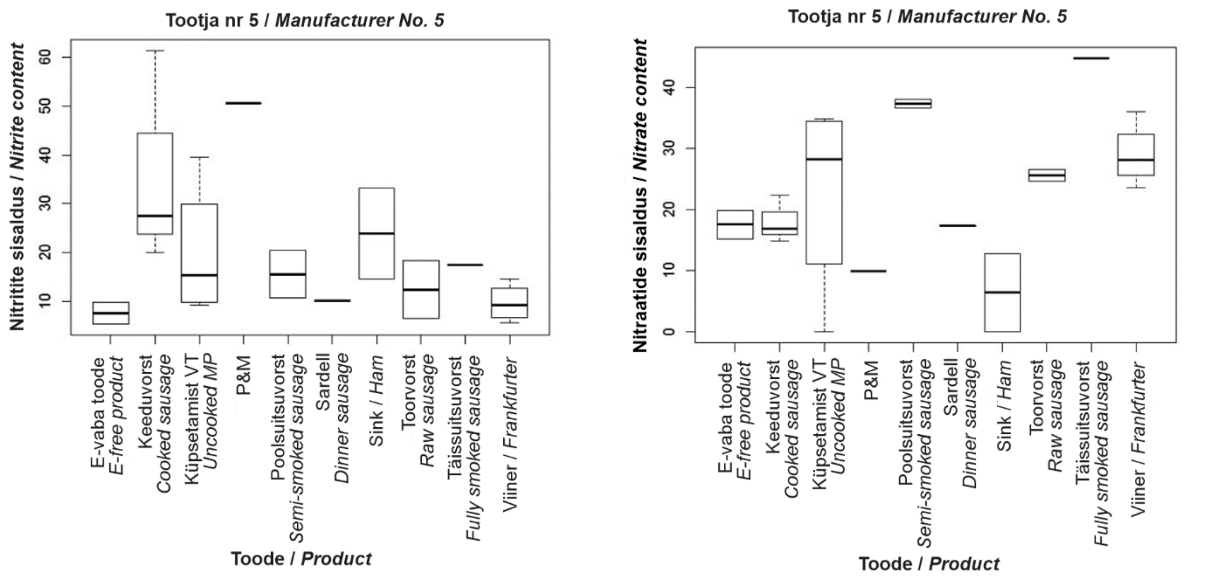
Tootja nr 3 poolt (joonis 3) toodetud toodetest on $NaNO_2$ sisaldused alates alla määramispiiri (täissuitsuvorst) kuni viinerite puhul 48,2 mg kg^{-1} lihatootes. $NaNO_3$ sisaldused olid alates 9,9 kuni 47,3 mg kg^{-1}. Vaadeldes tootja nr 3 poolt toodetud lihatoodetes nitritite ja nitraatide sisaldusi, siis vastavalt EÜ määrusele 1333/2008 ei ületatud lihatoodetesse lisada lubatud nitritite ja nitraatide koguseid.



Joonis 3. Tootja nr 3 poolt toodetud lihatoodete $NaNO_2$ ja $NaNO_3$ sisaldused mg kg^{-1}
Figure 3. *$NaNO_2$ ja $NaNO_3$ contents (mg kg^{-1}) in manufacturer No. 3 meat products*

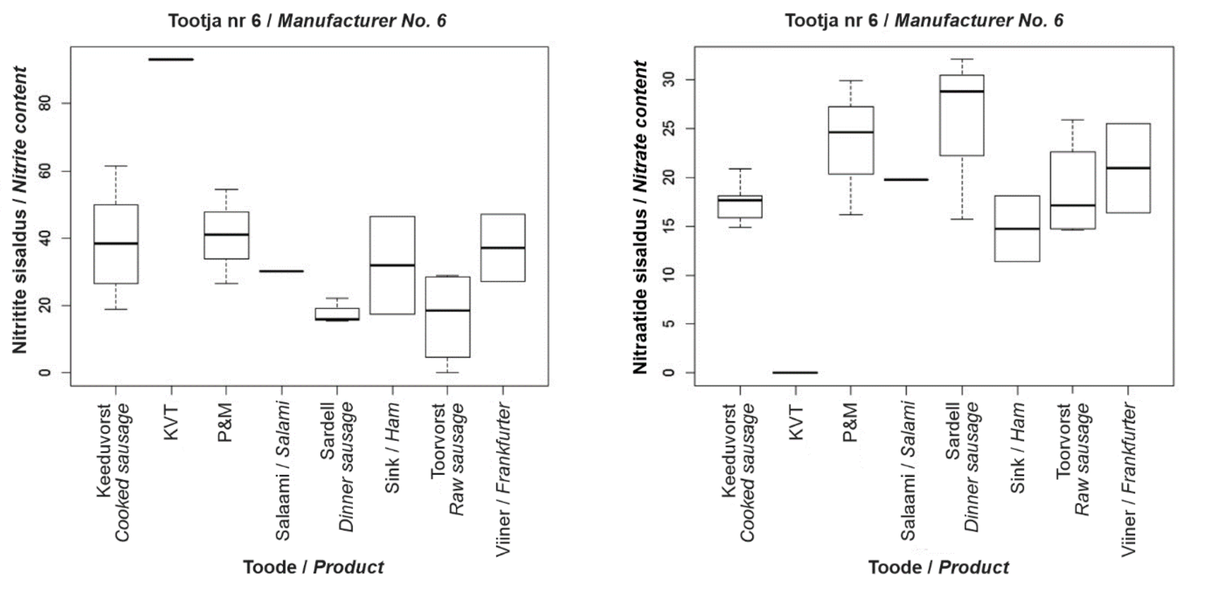
Joonisel 4 on toodud tootja nr 5 poolt toodetud kümne erineva lihatoodete grupi nitritite ja nitraatide sisaldused, seda ka E-ainete vabades toodetes. Oletuslikult võivad nitritid ja nitraadid E-ainete vabadesse lihatoodetesse sattuda juhul, kui toodetesse lisatakse joogivett või mõningaid looduslikke lisandeid, sest looduslikud lisandid võivad sisaldada naturaalsel kujul nitraate.

Küpsetamist vajavates toodetes on sarnastes kogustes nii nitriteid kui ka nitraate. Tootja nr 5 poolt toodetud keeduvorstidest on leitud üks üle 60 mg kg^{-1} nitriteid sisaldav toode, mille tõttu on joonisel näha vurrude tipu suurimat erandlikku punkti.



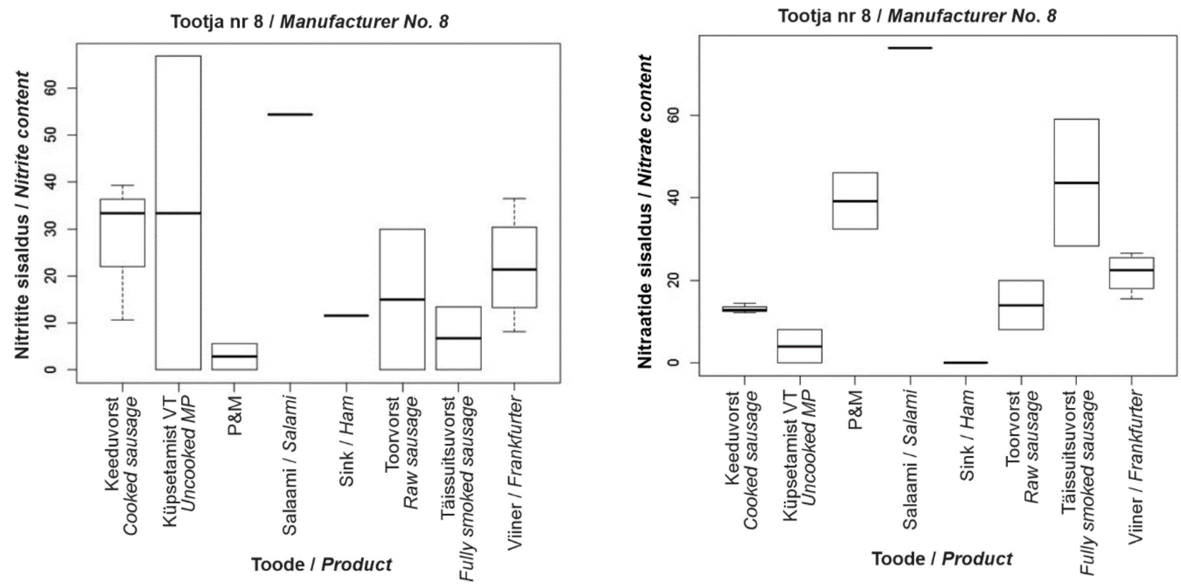
Joonis 4. Tootja nr 5 poolt toodetud lihatoodete $NaNO_2$ ja $NaNO_3$ sisaldused mg kg^{-1} (Küpsetamist VT – küpsetamist vajavad tooted; P&M – pasteedid ja määrded)
Figure 4. *$NaNO_2$ ja $NaNO_3$ contents (mg kg^{-1}) in meat products of manufacturer No. 5 (Küpsetamist VT – uncooked meat preparations which need cooking prior consumption; P&M – liver pate and other pates)*

Joonisel 5 on toodud tootja nr 6 poolt toodetud lihatoodete nitritite ja nitraatide sisaldused. Väga erandlikuna on tootja nr 6 toodete hulgas üks küpsetamist vajav lihatoode, mille nitritite sisaldus oli 93,1 mg kg^{-1}. Teiste lihatoodete nitritite ja nitraatide sisaldused jäid sarnastesse vahemikesse nagu teistel Eesti tootjatel.



Joonis 5. Tootja nr 6 poolt toodetud lihatoodete $NaNO_2$ ja $NaNO_3$ sisaldused mg kg^{-1} (KVT – küpsetamist vajavad tooted; P&M – pasteedid ja määrded)
Figure 5. *$NaNO_2$ ja $NaNO_3$ contents (mg kg^{-1}) in meat products of manufacturer No. 6 (KVT – uncooked meat preparations which need cooking prior consumption; P&M – liver pate and other pates)*

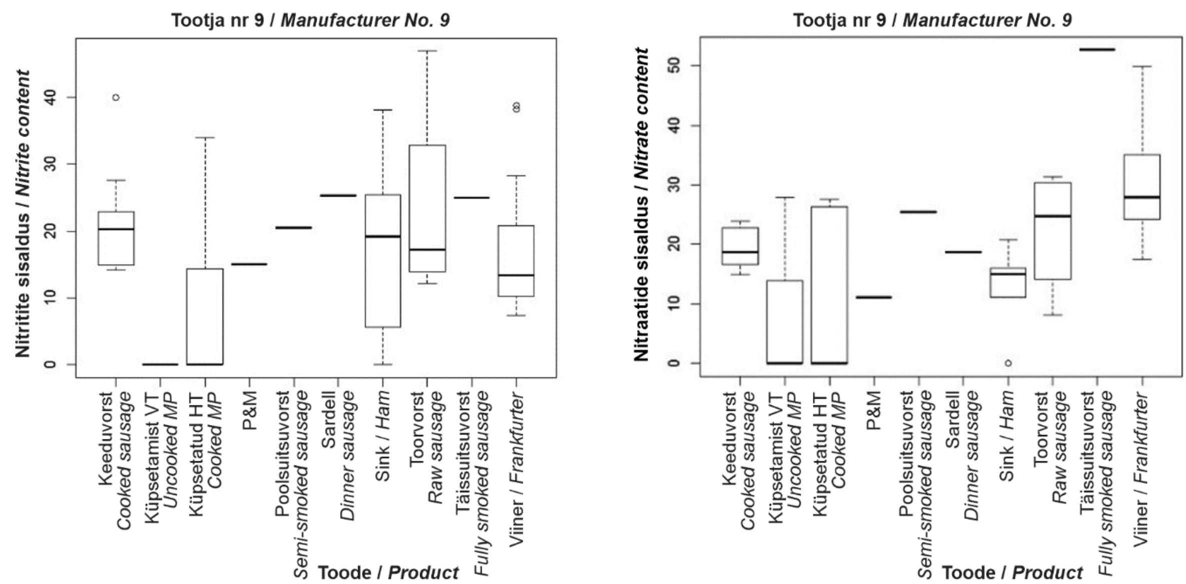
Joonisel 6 on toodud tootja nr 8 poolt toodetud lihatoodete nitritite ja nitraatide sisaldusi. Selle tootja lihatoodete hulgas leidus lihatooteid, mille nitritite ja nitraatide sisaldus oli kõrgem kui 60 mg kg^{-1}. Need sisaldused jäävad siiski EÜ määruse 1333/2008 kohaselt etteantud toodetes lubatu piiresse.



Joonis 6. Tootja nr 8 poolt toodetud lihatoodete $NaNO_2$ ja $NaNO_3$ sisaldused mg kg^{-1} (Küpsetamist VT– küpsetamist vajavad tooted; P&M – pasteedid ja määrded)
Figure 6. *$NaNO_2$ ja $NaNO_3$ contents (mg kg^{-1}) in meat products of manufacturer No. 8 (Küpsetamist VT – uncooked meat preparations which need cooking prior consumption; P&M – liver pate and other pates)*

Joonisel 7 on näha, et tootja nr 9 poolt toodetud lihatoodetes erinesid nitritite sisaldused küpsetamist vajavates lihatoodetes, sinkides ja toorvorstides suurel määral, kõige väiksem nitritite sisalduse kõikumine oli keeduvorstides. Nitraatide sisalduse poolest olid tootja nr 9 poolt toodetud lihatooted enamasti (erandina täissuitsuvorstid ja viinerid) madalamad kui teistel tootjatel.

Eelnevatelt joonistelt saab välja lugeda, et enamasti jäävad erinevate tootjate toodete nitritite ja nitraatide sisaldused madalamale kuni 50 mg kg^{-1}. Erandiks on nitritite sisalduse osas tootjate nr 6 ja 8 poolt toodetud küpsetamist vajavad tooted. Täiendavalt eristus ka tootja nr 5, kelle poolt toodetud keeduvorstide maksimaalsed nitritite sisaldused ulatusid 60 mg kg^{-1}.



Joonis 7. Tootja nr 9 poolt toodetud lihatoodete $NaNO_2$ ja $NaNO_3$ sisaldused mg kg^{-1} (Küpsetamist VT – küpsetamist vajavad tooted, Küpsetatud HT – küpsetatud hakktoode, P&M – pasteedid ja määrded)
Figure 7. *$NaNO_2$ ja $NaNO_3$ contents (mg kg^{-1}) in meat products of manufacturer No. 9 (Küpsetamist VT – uncooked meat preparations which need cooking prior consumption; Küpsetatud HT – cooked meat preparations)*

Kokkuvõte ja järeldused

Nitriteid kasutatakse lihatoodete säilivusaja pikendamiseks, et hoida ära nt *Clostridium botulinum*'st tulenevat terviseriski ning säilitada lihatoodetele iseloomulikku värvust ja maitset. Euroopa Parlamendi ja nõukogu määrus (EÜ) nr 1333/2008 kehtestab eeskirjad toidu lisaainete kohta k.a lihatoodetes ja lihavalmististes kasutada lubatud lisaainete ja nende kasutamise tingimuste kohta. Võrreldes määrusega kehtestatud lihatoodetele lisada lubatud nitritite ja nitraatide piirmäärasid, saab antud uuringus esitatud analüüsi tulemuste põhjal väita, et lihatoodetesse lisada lubatud nitritite piirmäärade ületamisi Eesti lihatoodetes suure tõenäosusega ei esinenud, sest vastasel juhul oleks lõpptoodete nitritite sisaldused märkimisväärselt kõrgemad. Võrdlusest mitme uurimisperioodi vahel saab samuti väita, et nitritite ja nitraatide sisaldused on enamikes lihatoodetes langenud. Vaadeldes ühe tootegrupisiseseid nitritite sisaldusi erinevate tootjate lõikes, selgus, et nitritite sisaldus kõigub nii sama tootja lõikes kui ka erinevate tootjate lõikes. Kui vaadeldi ühe tootja erinevate lihatoodete nitritite ja nitraatide sisaldusi, selgus, et sisaldused on iga erineva tootegrupi lõikes erinevad ning esineb ka tootegrupisiseseid nitritite ja nitraatide sisalduse kõikumisi. Sellest järeldub, et igal tootjal on igas tootegrupis olevate erinevate toodete jaoks erinev retseptuur ning erinevate tootegruppide toodetes kasutatakse erineval määral lisaaineid.

An overview of the nitrite and nitrate contents in meat products in Estonia

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Summary

The study aimed to find out the contents of nitrites and nitrates in meat products produced and sold in Estonia and to compare the content of nitrites in similar product groups of different meat industry companies.

A total of nitrite and nitrate contents were determined for 164 meat products. The product groups with lower average nitrite content were cooked minced meat products and non-ready-to-eat meat products (uncooked meat products). A single product with an exceptionally high nitrite content (93.1 mg kg^{-1}) was uncooked meat preparation product, followed by nitrite in boiled sausage ("Lastevorst") (61.5 mg kg^{-1}). In other product groups, the nitrite content was lower. The Regulation (EU) No 1333/2008 regulates the use of food additives in foods. Comparing the permitted nitrite and nitrate limits for meat products established by mentioned Regulation, and taking into account the results of the analysis of the present study (Table 1), it can be stated that meat producers are using nitrite salts in small quantities, which do not result in the exceeding's of the official limits in cured meat products.

Taking into account, the average results of nitrite contents, all cooked sausages, including boiled sausage "Lastevorst" and E-free products, contained as an average of 26.9 mg kg^{-1} sodium nitrite ($NaNO_2$). Nitrite content in most of the analysed meat products in the present study was comparable and similar to the results found in a study carried out in a neighbouring country, Finland (EVIRA, 2013). Comparing the concentrations of nitrites and nitrates in meat products in different study periods, it can be concluded (Table 2) that the average $NaNO_2$ contents of cooked sausages, smoked sausages and frankfurters have been decreasing. The content of sodium nitrate ($NaNO_3$) in various meat products has decreased more significantly. Nitrite contents within the same product group differed both within the same producer as well as for the same products produced by different meat industries. Nitrite and nitrate contents of different meat products of the same producer had also variations in nitrite and nitrate contents. Therefore, it can be summarized that each meat producer is adding nitrite salts according to their recipes. A most important finding is that generally, the use of nitrites in meat products has decreased in Estonia.

Tänuavaldused

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Huvide konflikt / *Conflict of interest*

Autor kinnitab artikliga seotud huvide konflikti puudumist.
The author declares that there is no conflict of interest regarding the publication of this paper.

Autorite panus / *Author contributions*

TE, MRo, SJ – uuringu kava ja planeerimine / *study conception and design*;
SJ, TE, MRo, MRe – andmete kogumine / *acquisition of data;*
SJ, MRo, MRe – andmete analüüs ja interpretatsioon / *analysis and interpretation of data;*
SJ, TE, MRo, MRe – käsikirja koostamine / *drafting of manuscript;*
TE, MRo, MRe, SJ – käsikirja ülevaatamine ja heaks kiitmine / *critical revision and approve the final manuscript*.

Kasutatud kirjandus

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NUTRIENT INTAKE, DIGESTIBILITY AND NITROGEN BALANCE OF WEST AFRICAN DWARF GOATS FED CASSAVA ROOT SIEVATE AND CASSAVA LEAF MEAL MIXTURE IN THEIR DIETS

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Keywords: nutrient intake, digestibility, utilization, body weight gain, cassava, goats.

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ABSTRACT. Four West African Dwarf (WAD) bucks averaging 7.62 kg and aged 8–10 months were used to determine the intake, body weight changes, digestibility and nitrogen balance of cassava root sievate-cassava leaf meal mixture based diets. The four experimental diets (T_1, T_2, T_3 and T_4) were formulated to contain palm kernel cake, brewers' dried grain, molasses, bone meal, limestone, meal, common salt and 0, 20, 40 and 60% cassava root sievate-cassava leaf meal mixture at the rate of 3:1 respectively. The diets were assigned individually to the four animals in metabolism cages in a 4×4 Latin square design experiment. Feed intake, body weight gain, dry matter intake (DMI), nutrient digestibility and the nitrogen balance status of each animal were measured. Results on proximate composition revealed that the nutrient requirements of the goats were adequate. The DMI for the supplement, total DMI, total DMI (g (kg $W^{0.75})^{-1}$), CF intake were highest ($P < 0.05$) for T_4. Average body weight gain (g day^{-1}) and average body weight gain (g (kg $W^{0.75})^{-1}$) were best ($P < 0.05$) for T_3 and T_4. Crude protein digestibility was best ($P < 0.05$) for T_4. Neutral detergent fibre and acid detergent fibre digestibilities were best for T_3 and T_4. Nitrogen intake (g day^{-1}), nitrogen balance (g day^{-1}) (g (W $kg^{0.75})^{-1}$), nitrogen retention (%), nitrogen absorbed (g day^{-1}) (g (kg $W^{0.75})^{-1}$), apparent N digestibility (%) and the efficiency of nitrogen utilization were all best ($P < 0.05$) for and T_4. The diet (T_4) containing 60% CRSCLM mixture was recommended among the other diets for feeding goats, as it had better performance concerning nutrient intake, body weight gain, nutrient digestibility and utilization.

Introduction

In addition to income generation, goat farming is an economic activity that sustains both rural and peri-urban families, in Nigeria and most West African countries. Despite this, the increase in the consumption of goat meat (chevon) in Nigeria is still poorly explored. This may be partly attributed to feeding. Feeding is a very essential part of goat farming and may constitute the highest expense of any goat production. Feed availability has been the major factor against the expansion of goat production here and elsewhere. The high cost of conventional feedstuffs and seasonal variation in Nigeria has necessitated the search for cheap and readily available feed ingredients (Jiwuba, Udemba, 2019) to enhance goat production. Ruminant nutritionist needs to concentrate their research interest on agro-wastes that have no direct nutritional value to man for feeding various classes of goats. Agro-wastes are mostly fibrous materials considered valueless as they are discarded as waste and hence have no economic value and may constitute an environmental nuisance when not properly disposed of. Ojebiyi *et al.* (2002) earlier noted that a potential alternative feed ingredient must not be a staple item that is directly eaten by man to avoid scarcity. Among such interest in this research is cassava root sievate and cassava leaves, which are hitherto not eaten by man. The high fibre content of cassava root sievate (Jiwuba *et al.*, 2018a) makes it to serve as both fillers and nutrient providers in ruminant nutrition. However, their efficient utilization by ruminants can better be achieved when mixed with a higher nitrogenous source to augment for nitrogen deficiency (Jiwuba *et al.*, 2016a). These materials are cheap and readily available all year round, as Nigeria is the world highest producer of cassava (Jiwuba *et al.*, 2018a). Nitrogen is very essential in the synthesis of microbial protein in the rumen, which is essential for the rumen function, and the general performance of the ruminant. Nitrogen balance status shows the extent to which the body is maintaining adequate protein balance (Min *et al.*, 2015). Positive nitrogen balance is an anabolic state for optimal muscle growth. This study aims to evaluate the nutrient intake, nutrient digestibility and nitrogen balance of West African Dwarf goats fed cassava root sievate and cassava leaf meal mixture in their diets.

Material and methods

This trial was carried out at the small ruminant unit of Animal Production Technology, Federal College of Agriculture, Ishiagu, Ivo L.G.A., Ebonyi State, Nigeria. The College is located at latitude 5.56° N and longitude 7.31^0 E, with an average rainfall of 1653 mm and a prevailing temperature condition of 28.50 °C and relative humidity of about 80% (FCAI, Meteorological station, 2017).

The cassava root sievate (variety TMS 419) (CRS) and cassava leaf (variety TMS 419) were sourced and harvested within the Ishiagu community. The cassava root sievate is a by-product of cassava root processing which is acquired after the cassava roots meant for fufu (a popular food in Nigeria) production are peeled or not, washed clean and soaked in clean water for 3–5 days to ferment to reduce the hydrogen cyanide and also to soften the roots to enable sieving (Jiwuba *et al.*, 2018a). Thereafter, the soaked cassava roots were sieved, the sievate (waste) collected and sundried for about 5 days to reduce the moisture contents and possible anti-nutrients that were not removed during the fermentation (retting) process. After which, the retted-sundried cassava root sievate were coarsely milled and stored in batches for future use. The cassava leaves were harvested from the College cassava farms after root harvesting. They were also coarsely milled using a hammer mill to encourage chyme chewing. The cassava root sievate meal (CRSM) and cassava leaf meal (CLM) were mixed in the ratio of 3:1 and used in the formulation of the experimental diet. The cassava root sievate-cassava leaf meal (CRSCLM) mixture was included at the rate of 0%, 20%, 40% and 60% for T_1, T_2, T_3, and T_4, respectively as presented in Table 1.

Table 1. Composition of the experimental diets for West African Dwarf goats

Ingredients	T_1 (0)	T_2 (20)	T_3 (40)	T_4 (60)
CRSCLM	0	20	40	60
Palm kernel meal	48.0	38.0	30.0	20.5
Brewer's dried grain	47.5	37.5	25.5	15.0
Molasses	2.0	2.0	2.0	2.0
Bone meal	1.0	1.0	1.0	1.0
Limestone	1.0	1.0	1.0	1.0
Salt	0.5	0.5	0.5	0.5
Total	100.0	100.0	100.0	100.0

CRSCLMM =cassava root sievate meal, cassava leaf meal mixture

Four WAD bucks of about 8–10 months of age and averaging 7.62 kg in weight were selected from the College flock for this experiment. The experimental animals were managed following the permission and stipulated guidelines of the Federal College of Agriculture, Ishiagu (FCAI) Animal Ethics Committee. The WAD bucks were subsequently transferred to previously disinfected individual metabolism cages provided with facilities for collecting faeces and urine. Feed offered was based on 3.5% body weight per day. Regular access to fresh drinking water was made available. They were fed the four experimental diets in a 4 × 4 Latin square design. Each animal received the experimental diets consecutively in 4 phases. In each phase, initial live weights of the animals were taken at the beginning of the feeding trial and weekly thereafter. Final live weight was obtained by weighing the goats at the end of the experiment. During phase 1 which lasted for 28 days, each animal received an assigned experiment diet for 21 days. During this period, each animal had access to free drinking water daily. Daily voluntary feed intake was determined. Total faeces and urine voided by the experimental animals were collected during the last 7 days (22–28). During phases 2–4, each animal was offered each of the remaining 3 experimental diets in rotational periods of 28 days each. The last 7 days in each of the feeding periods, was used for total urine and faecal collection. Each animal constituted a replicate while each feeding phase represented an observation. The quantity of each diet offered to the goats during each period ensured about 5% leftover. The leftovers were collected after 24 hours, then weighted and used to determine the voluntary intake. Total faeces collected in the mornings before feeding and watering during days 22–28 of each period. The faeces weighed fresh, dried and bulked for each animal. A sub-sample from each animal was dried in a forced draft oven at 100–105 °C for 48 hours and used for DM determination. Another sample was dried at 60 °C for 48–72 hours for determination of proximate composition. Total urine for each animal collected daily in the morning before feeding and watering. The urine trapped in a graduated transparent plastic container placed under each cage and to which 15 ml of 25% H_2SO_4 was added daily to curtail volatilization of ammonia from the urine. The total volume of urine output per animal was measured and about 10% of the daily outputs was saved in plastic bottles numbered and stored in a deep freezer at 5 °C. At the end of each 7-day collection period, the sample collections were bulked for each animal and sub-samples took for analysis.

All the sample of feed and test ingredients were analyzed for their proximate composition using the method of AOAC (2000). The following were determined and analyzed; dry matter content (DM), crude protein (CP), crude fibre (CF), ether extract (EE), nitrogen-free extract (NFE), ash, neutral detergent fibre (NDF) and acid detergent fibre (ADF) and hemicellulose. Gross energy was calculated using the formula:

$$T = 5.72Z1 + 9.50Z2 + 4.79Z3 + 4.03Z4 \pm 0.9\%; \quad (1)$$

where T – gross energy, Z1 – crude protein, Z2 – crude fat, Z3 – crude fibre, Z4 – nitrogen-free extract (Nehring, Haelein, 1973).

Data obtained were analysed using analysis of variance (ANOVA) as described by SAS (2008). Significant means were separated using the Duncan Multiple New Range Test.

Results and discussion

The proximate composition of the experimental diets, CRSM, CLM and *Panicum maximum* are shown in Table 2. The DM, CF and gross energy of the experimental diets tend to increase with increasing levels of CRSCLM while NDF and ADF decreased with increasing levels of CRSCLM. Ash, EE, CP, NFE and hemicellulose failed to follow a specific pattern across the treatment groups. The CLM is comparable with the DM, CP, ash and NFE values reported by Akinfala *et al.* (2002). The crude protein content of the CRSM is below the acceptable 7% CP for ruminant performance as recommended by ARC (1980) and 8% suggested by Norton (1994) for ruminal function. The fibre fractions (NDF, ADF and hemicellulose) imply the digestibility of plants. The NDF is a measure of the plant cell wall contents, used in determining the rate of digestion of feed. The NDF comprises mainly the cell wall fraction of forages and roughages and includes a complex matrix of lignin, small amounts of protein, and various polysaccharides. Odedire and Babayemi (2008) noted that the higher the NDF, the lower the plant's digestible energy. The values obtained for the CRSM may imply moderate cell wall content, moderate digestible energy and DM intake. The ADF consists mainly the lignin and cellulose. Hemicellulose has been reported to be more digestible than cellulose (Gillespie, 1998). The reportedly lower values of the fibre fractions are in agreement with the findings of Boonnop *et al.* (2009) for the same cassava by product. The high energy value reported for the CRSM is in agreement with Khampa *et al.* (2009) who noted that cassava roots contain high levels of energy and have been used as a source of readily fermentable energy in ruminant rations. The high dry matter value reported is favourably compared with the values of Boonnop *et al.* (2009). The proximate composition of the experimental diets revealed that the crude protein and the energy requirements are within the ranges reported for goats (ARC, 1980; NRC, 1981; Norton, 1994). The DM, ash NDF, ADF and hemicellulose were higher in the control but compared to the treatment groups. The proximate composition of *Panicum maximum* in this study is in comparison with the values reported by Odedire and Babayemi (2008), Onyeonagu and Eze (2013) and Jiwuba *et al.* (2016b) for the same forage.

Table 2. Proximate composition of the experimental diets, cassava root sievate meal, cassava leaf meal and *Panicum maximum*

Nutrients, %	Treatment				Cassava root sieviate meal	Cassava leaf meal	*Panicum maximum*
	T_1 (0)	T_2 (20)	T_3 (40)	T_4 (60)			
Dry matter	89.95	90.40	91.00	91.44	88.60	89.12	30.93
Crude protein	13.00	14.87	13.64	15.36	2.57	17.66	5.34
Crude fibre	18.96	18.96	19.65	20.11	18.96	5.38	12.64
Ash	5.44	5.59	4.91	4.50	1.80	9.87	4.01
Ether extract	2.15	3.26	3.38	2.90	2.71	3.93	3.17
Nitrogen free extract	48.04	42.72	50.14	50.93	68.14	52.28	26.37
Gross energy, MJ g^{-1}	3.94	3.89	4.07	4.04	3.79	3.76	2.27
Neutral detergent fibre	62.44	42.08	35.75	33.93	25.34	39.90	58.31
Acid detergent fibre	58.35	38.30	25.11	23.69	6.68	33.25	28.60
Hemi cellulose	4.09	3.78	10.64	10.24	8.66	6.65	19.17

Nutrient intake and body weight gain of West African Dwarf goats fed cassava root sievate and cassava leaf meal mixture in their diets is presented in Table 3. DM intakes were improved with the inclusion of 20, 40 and 60% CRSCLM in the diets with values ranging from 367.32–407.00 g day^{-1} observed in bucks fed 0 and 60% CRSCLM supplement respectively. The observed increased ($P < 0.05$) DM intake is in agreement with earlier reports of Odusanya *et al.* (2017) and Okah *et al.* (2019) who reported significant improvement for WAD rams fed cassava leaf meal concentrate diets and WAD bucks fed replacement levels of cassava peel meal (CPM) for maize offal respectively. The increased DM intake above 20–60% inclusion of CRSCLM may be attributed to the increased palatability of the feed. The reduced feed DMI observed in the control may be due to high levels of palm kernel cake and brewer's dried grain. A similar result was reported by Adu (1985). This may be partly be attributed to the fact that goat general relish cassava and its products. The total DMI range (83.90 and 90.69 g (kg $W^{0.75}$)$^{-1}$) obtained in this study are well above the recommended voluntary feed intake of 75 g (kg $W^{0.75}$)$^{-1}$ and 65 g (kg $W^{0.75}$)$^{-1}$ by AFRC (1998) and 68 g (kg $W^{0.75}$)$^{-1}$ by Kearl (1982) for goat breeds commonly raise in developing countries. Crude protein intake (CPl) ranged between 55.84 and 64.42 g d^{-1} which, is lower than the range reported by Okah *et al.* (2019) for WAD goats fed cassava peel meal. However, the CPI reported in this study fall within the range of CPI required for goats in the Tropics (Devendra, McLeroy, 1982). Crude protein intake is vital in the performance of goats due to increased availability of fermentable nitrogen needed by rumen microbes and chances of increased bypass protein. In an earlier study by Promkot and Wanapat (2003) noted that cassava leaf meal is similar to that of cottonseed meal as a source of by-pass protein. Crude fibre intake (CFl) increased significantly ($P < 0.05$) from values for T_I (77.52 g day^{-1}) to those of T_4 (89.60 g day^{-1}). Similar, non-significant ($P > 0.05$) increase were also observed in metabolic CFI (g (kg $W^{0.75}$)$^{-1}$). CFl (77.52–89.60 g day^{-1}) is lower than the range reported by Okah *et al.* (2019) for WAD goats fed cassava peel meal. The trend of the CFI is in agreement with an earlier report of Van Soest *et al.* (1991) which stated that the level of fibre in feed could be used to predict the intake. Hence, the CFI in this study followed a similar trend with DMI and CPI. Oni *et al.* (2010) noted that ruminants generally require ample coarse insoluble fibre for normal rumen function which is associated with adequate rumination and cellulose digestion. The higher fibre intakes reported for the treatment (T_2, T_3 and T_4) groups in this study may have facilitated colonization of ingesta by rumen microbes that in turn might induce higher fermentation rates, thus improved intake, digestibility and utilization of nutrients.

Average daily weight gain (ADWG) values ranged from 57.07 to 85.26 g day^{-1} across treatments. The variation could be attributed to the chemical constituents, a nutrient in the diet and age of animals. The higher weight gain observed in 40 and 60% inclusion of CRSCLM may suggest that higher levels of CRSCLM in the diet had a positive effect on the weight gain of the goats. The ADWG (57.07–85.26 g day^{-1}) obtained in the present study is higher than 33.8–52.9 g day^{-1} earlier reported by Oni *et al.* (2010) for WAD goats fed graded levels of dried cassava leaves but lower than the values (98.75–124.82 g day^{-1}) reported by Anya and Ozung (2018) for WAD goats fed diets containing African yam bean seed meal. The highest live weight gain obtained by goats on T_3 and T_4 diet may be attributed to the significant DM and CP intake of the goats. This is suggestive that increasing levels of cassava root sievate-cassava leaf meal mixture in the diets enhanced the growth rate of the goats. In an earlier study, Jiwuba *et al.* (2016b) reported that dry matter and crude protein intake as crucial to feed utilization and enhanced performance among goats. Feed conversion ratio although not ($P > 0.05$) affected were better for the T_3 and T_4 group. This could be attributed to the diets to overcome the nitrogen deficiency and boosted the multiplication of rumen microbes to enhance degradability and utilization of nutrients.

Table 3. Nutrient intake and body weight gain of West African Dwarf goats fed cassava root sievate and cassava leaf meal mixture in their diets

Parameters	Treatment				SEM
	T_1 (0%)	T_2 (20%)	T_3 (40%)	T_4 (60%)	
Daily feed intake, g day^{-1}	408.84	433.20	409.38	445.57	10.67
Dry matter intake (DMI), g day^{-1}					
Supplement	256.68^{c}	286.75^{b}	280.63^{b}	305.93^{a}	9.23
Forage	110.64	95.82	91.91	101.15	3.60
Total DMI	367.32^{c}	382.57^{b}	372.54^{b}	407.08^{a}	11.39
Total DMI, g (kg $W^{0.75}$)$^{-1}$	83.90^{c}	86.50^{b}	84.80^{b}	90.69^{a}	2.74
CP intake, g day^{-1}	55.84	62.80	57.92	64.42	4.69
CP intake, g (kg $W^{0.75}$)$^{-1}$	20.43	22.31	21.00	22.74	1.76
CF intake, g day^{-1}	77.52^{b}	82.10^{b}	80.44^{a}	89.60^{a}	3.56
CF intake, g $W^{0.75\,-1}$	26.12	27.27	26.86	29.12	1.23
Initial body weight, kg	5.85	6.96	6.90	7.15	0.26
Final body weight, kg	11.61	14.62	14.94	15.42	0.70
Total weight gain, kg	5.76	7.67	8.04	8.27	0.32
Average weight gain, g day^{-1}	59.38^{b}	57.07^{b}	82.89^{a}	85.26^{a}	7.74
Average weight gain, g (kg $W^{0.75}$)$^{-1}$	21.39^{b}	20.76^{b}	27.47^{a}	28.06^{a}	1.86
Feed conversion ratio	6.89	7.59	4.94	5.23	0.63

$^{a\text{-}c}$ means within the same row with different superscripts are significantly different ($P < 0.05$)

Generally, digestibility values were high and the highest DM digestibility of 68.32% was obtained in T_1 but the value is similar ($P > 0.05$) with other treatments (Table 4). Apparent digestibilities of CP, Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were significantly ($P < 0.05$) affected across the treatments, whilst dry matter (DM) and crude fibre (CF) were similar ($P > 0.05$) for all the diets. CP digestibility was least digested in T_1 (53.66%) and best digested in T_4 (71.33%). The highest ($P < 0.05$) digestibility coefficient of crude protein obtained in treatment T_4 showed that the dietary protein was better utilized by the animals fed diet T_4 relative to other treatments. This could be attributed to the addition of a higher proportion of cassava leaf meal, which may have improved the available amino acid content of the diet. The protein and amino acid profile of cassava leaves have compared with that of soybean (Eggum, 1970; Ravindran, 1991). The CP content of T_4 diet seems to have encouraged rumen motility and microbial functions, which resulted in high nutrient utilization and comparable performance with the control group T_1. Further, Ahamefule (2005) observed that dietary protein-enhanced digestibility; hence, the improved CP digestibility coefficient in the present study may be attributed to inclusion level of CRSCLM, which might have increased more protein availability to rumen microbes to catalyze the digestion process. The reported CP digestibility coefficient in this study compared with 56.07–66.33% for WAD bucks fed cassava peel-cassava leaf meal-based diets reported by Ukanwoko *et al.* (2009). NDF digestibility was lowest for goats fed T_1 (65.48%) diets and highest for goats on T_3 (71.10%) and T_4 (73.97%) diets. ADF digestibility followed a similar pattern as the NDF. The differences observed in digestibility values of the fibre fractions among the goats might be due to the lignin contents in the feed mixtures. The cassava root sievate had been reported to be high in fibre (Jiwuba *et al.*, 2018b) and this could inhibit digestibility. Mertens (1977) reported that changes of the composition of cell wall involving lignin and possibly silica limited the potential extent of digestion whereas the rate of digestion is limited by the chemical entities other than by the crystalline or physical nature of the fibre.

Table 4. Apparent nutrient digestibility of West African Dwarf goats fed cassava root sievate and cassava leaf meal mixture in their diets

Parameters, %	Treatment				SEM
	T_1 (0)	T_2 (20)	T_3 (40)	T_4 (60)	
Dry Matter	68.32	66.97	68.04	67.45	0.68
Crude protein	53.66[d]	64.78[b]	59.06[c]	71.33[a]	1.45
Crude fibre	59.66	58.92	60.22	56.99	1.11
Neutral detergent fibre	60.22[c]	67.67[b]	71.09[a]	73.97[a]	1.34
Acid detergent fibre	58.07[c]	63.77[b]	68.86[a]	69.56[a]	0.89

[a-c] means within the same row with different superscripts are significantly different (P < 0.05)

Nitrogen intake were 10.62, 12.11, 11.67 and 14.67 g day^{-1} for goats fed T_1, T_2, T_3 and T_4 respectively. Nitrogen intake (g day^{-1}) was (P < 0.05) best for goats fed T_4 diet. The values failed to follow any particular trend. However, the values of nitrogen intake (g (W kg$^{0.75}$)$^{-1}$) were not influenced (P > 0.05) by the diets. These values are comparable to the values of 9.92–15.35 g day^{-1} reported by Okah *et al.* (2019) for WAD goats fed cassava peel meal but higher than 5.07–6.32 g day^{-1} reported by Oni *et al.* (2010) for WAD goat fed dried cassava leaves. The high N intake observed for T_4 may be attributed to the higher incremental level of CRSCLM. Ravindran (1991) and Promkot and Wanapat (2003) compared amino acid and protein profile of cassava leaves in earlier studies with soybean and cottonseed respectively. Urinary N, faecal N and total nitrogen excreted did not differ significantly (P > 0.05) among treatment groups. However, goats fed T_1 diet had higher urinary nitrogen, and goats on T_3 had the highest faecal N. The non-significant faecal nitrogen and urinary nitrogen values reported in this study among the treatment groups are in agreement with the findings of Okah *et al.* (2019) and Odoemelam *et al.* (2015) who observed that faecal nitrogen and urinary nitrogen were not significantly affected by nitrogen intake. In an earlier study, Hadjipanayiotu *et al.* (1991) reported that diets high in protein result to the high concentration of rumen NH_3–N, which rumen microbes cannot efficiently utilize, and the NH_3 is excreted through the urine in the form of urea. Hence, the lower and non-significant (P > 0.05) value of urinary N reported in this study may have indicated that the rumen microbes efficiently utilized the protein in the CRSCLM containing diets.

Nitrogen balance, nitrogen absorbed and retention values were higher in the treatment diets (T_2, T_3 and T_4) showed the potentials of CRSCLM to enhance nitrogen utilization. Nitrogen balance values obtained in this study were higher than previously reported values in WAD goats fed dried poultry waste-cassava peel based diets (Ukanwoko, Ibeawuchi, 2009) and those fed graded levels of dried cassava leaves (Oni *et al.*, 2010). When nitrogen balance and nitrogen absorbed were expressed on a metabolic weight basis, the results showed significantly (P < 0.05) higher values for the treatment groups. This may indicate that the animals were all in positive nitrogen balance. This may also suggest high utilization of the CP in the diets by the animals especially the CRSCLM containing diets. The high nitrogen retention in comparison with the control supports the report of Sarwar *et al.* (2003) that nitrogen retention depends on the intake of nitrogen, the amount of fermentable carbohydrate of the diet. Cassava root sievate have been reported (Jiwuba *et al.*, 2018a) to be high in fermentable carbohydrate and cassava leave protein content have been reported (Khieu *et al.*, 2005) to range from 16.6 to 39.9%. The positive N balance obtained in this study indicates the positive influence of increasing proportions of urea with CRSCLM based diets in feeding WAD goats. The differences in the quantity and routes of nitrogen excretion with consequent influences on nitrogen retention could reflect treatment feed differences in nitrogen metabolism, in which nitrogen retention is considered as the most common index of the protein nutrition status of ruminants (Owens, Zinn, 2005). T_4 gave the highest apparent nitrogen digestibility. This could probably be attributed to high rumen degradability of cassava and its by-products (Jiwuba, Jiwuba, 2020). This is justified by the fact that none of the experimental animals lost weight during the study.

Table 5. Nitrogen utilization of West African Dwarf goats fed cassava root sievate and cassava leaf meal mixture in their diets

Parameters, %	Dietary levels				SEM
	T_1 (0)	T_2 (20)	T_3 (40)	T_4 (60)	
Nitrogen intake, g day^{-1}	10.62[c]	12.11[b]	11.67[bc]	14.67[a]	0.48
Nitrogen intake, g (W kg$^{0.75}$)$^{-1}$	5.88	6.49	6.31	7.50	0.52
Urinary Nitrogen, g day^{-1}	1.23	1.17	1.19	1.20	0.07
Faecal Nitrogen, g day^{-1}	4.42	3.39	4.46	3.99	0.09
Total Nitrogen excreted, g day^{-1}	5.65	4.56	5.65	5.19	0.14
Total Nitrogen excreted, g (W kg$^{0.75}$)$^{-1}$	3.66	3.12	3.66	3.44	0.08
Nitrogen balance, g day^{-1}	4.97[d]	7.55[b]	6.02[c]	9.48[a]	0.34
Nitrogen balance, g (W kg$^{0.75}$)$^{-1}$	3.33[d]	4.55[b]	3.93[c]	5.40[a]	0.29
Nitrogen retention, %	46.80[c]	62.35[a]	51.59[b]	64.62[a]	1.57
Nitrogen absorbed, g day^{-1}	6.20[d]	8.72[b]	7.21[c]	10.68[a]	0.59
Nitrogen absorbed, g (W kg$^{0.75}$)$^{-1}$	3.93[b]	5.07[ab]	4.40[ab]	5.91[a]	0.38
Apparent N digestibility, %	58.38[c]	72.01[a]	61.78[b]	72.80[a]	1.21
Efficiency of N utilization (ENU)	0.47[c]	0.62[a]	0.52[b]	0.65[a]	0.03

[a-d] means within the same row with different superscripts are significantly different (P < 0.05)

Conclusions

Incorporation of cassava root sievate-cassava leaf meal in concentrate diets fed as supplements to WAD bucks on *Panicum maximum* positively influenced dry matter intake (DMI), body weight gain, apparent N-digestibility, nitrogen balance and utilization. It could be concluded that cassava root sievate-cassava leaf meal could be included in the diets of goats up to 60% in a dry season supplement to enhance intake, body weight gain, nutrient digestibility and nitrogen balance of West African Dwarf goats. The use of cassava root sievate-cassava leaf meal-based diets is therefore recommended for enhanced goat production.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

PDCJ – conceptualization and planning; data collection, analysis and interpretation, original draft preparation, writing, review and editing.

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AROMATIC PLANT *MELISSA OFFICINALIS* EXTRACTS SELECTIVITY IN VARIOUS BIOMASS CROP AND LEGUME SPECIES

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ABSTRACT. Allelopathic effects of various plants can be exploited for use against weeds; however, the selectivity in different crops is also important. In the current study, the effects of lemon balm (*Melissa officinalis*) allelochemicals on seed germination and seedling emergence of three biomass crops and three legume species were evaluated. Seed germination of rapeseed was reduced by 19, 30, 56, and 80% in the concentrations of 1, 2, 5 and 10%, respectively, as compared to the control group, whereas sweet sorghum seeds showed a more intermediate response and sunflower germination was affected only by the highest concentration. Seed germination of common bean was by 25, 34 and 60% lower at 1, 2 and 5% extract concentrations, respectively, in comparison to the control whereas up to 85% reduction of seed germination was recorded in 10% concentration. Peanut seed germination percentage ranged between 72 and 47% of control in 5 and 10% concentrations, respectively, while soybean germination was least affected from *M. officinalis* leaf extracts since it was reduced by only 25 and 41% in 5 and 10% concentrations, respectively, as compared to the control. Seedling emergence of rapeseed was reduced by 14, 25, 46, and 79% in the concentrations of 1, 2, 5 and 10%, respectively, as compared to the control whereas lemon balm extracts showed increased selectivity on the sunflower. Soybean emergence was reduced by only 27 and 46% in 5 and 10% concentrations, respectively, in comparison to the control whereas common bean's seedling emergence was reduced up to 35% even in 2% concentration. Allelopathic response index values confirmed that sunflower and rapeseed were the least and most sensitive biomass crops to lemon balm allelochemicals, respectively, whereas sweet sorghum showed an intermediate response. Increased was the selectivity of the aqueous leaf extracts on soybean, whereas seed germination and seedling emergence of peanut were more affected and common bean was the most sensitive crop. Further research is needed to investigate the selectivity of *M. officinalis* and other aromatic plants' allelochemicals on various crops and under different soil and climatic conditions to optimize their efficacy as tools of more eco-friendly weed management strategies.

Introduction

Weed management is a crucial issue for overall crop growth and productivity. It has been documented that weed infestation is the reason for a 5% loss to agricultural production in most developed countries, a 10% loss in less developed countries and a 25% loss in the least developed countries (Oerke, Dehne, 2004). The extended use of plant protection products is often related to serious environmental issues and therefore, the promotion of ecologically-friendly practices is imperative.

Allelopathy is a noticeable phenomenon through which some plants exude organic compounds known as allelochemicals and affect seed germination, growth and survival, establishment and reproduction of other plants (Kanatas, 2020). Allelochemicals consist of a variety of organic compounds present in different plant parts such as simple polysaccharides, amino acids, organic acids and phenolic compounds. Phenolic compounds are of major importance in reducing seed germination growth and establishment of surrounding plants (Fan *et al.*, 1997; Inderjit, Duke, 2003; Wang *et al.*, 2014). There is a growing consideration regarding the potential use of allelochemicals in terms of weed management during the last two decades (Singh *et al.*, 2005; El-Rokiek, Eid, 2009; Puig *et al.*, 2013; Travlos *et al.*, 2018).

Allelopathy is something common in various aromatic plants and therefore important research has been conducted (Azirak, Karaman, 2008; Economou *et al.*, 2011). *Melissa officinalis*, a perennial aromatic plant, is already known to contain several allelochemicals with recent studies carried out in Greece and elsewhere revealing the effects of lemon balm on various grass and broadleaf weed species (Kato-Noguchi, 2001; Kanatas, 2020).

The selectivity of either natural or synthetic herbicides can be defined as the differential response level among species after the application of a particular molecule (de Oliveira, Inoue, 2001). Selectivity is mentioned as the capacity of a particular natural or synthetic herbicide to eliminate weeds in a crop, without affecting the yield or quality of the final product (Negrisoli *et al.*, 2004). Selectivity is directly related to the fact that plant species respond differently to the same natural or synthetic herbicide (Devine *et al.*, 1993). Although the herbicidal effects of the allelochemicals as derived from the tissues of aromatic plants is well established, there is not much evidence regarding the selectivity of such allelochemicals on crops and the response of the crops to their application. After the evaluation of the allelopathic potential of *M. officinalis* against different weeds (Kanatas, 2020), the objective of the current study was to evaluate the selectivity of lemon balm aqueous leaf extracts in three biomass and three leguminous crop species and find out which were the most and the least affected from the allelochemicals' application in four different concentrations.

Materials and methods

M. officinalis plants were collected at flower stage (2018), from a field located in Etloakarnania prefecture in Greece (20º 53′54″ E, 38º 53′38″ N) as previously described by Kanatas (2020). Leaves were washed, cut, ground and mixed with distilled water. After the overnight maintenance at room temperature, the mixture was filtered and diluted with distilled water, to have different aqueous extracts (1, 2, 5 and 10%). Five replicates for each aqueous extract were used, whereas the untreated seeds were used as the control group for each experiment as described by Kanatas (2020). Twenty seeds of three biomass crop species (sunflower, sweet sorghum and rapeseed), as well as three leguminous crop species (soybean, peanut and common bean) (Table 1), were placed in Petri dishes on the surface of two Whatman No. 1 sheets of filter paper. An untreated control group was moisturized only with distilled water. The emergence of the radicle one week after incubation was considered to be germination (Bewley, Black, 1994).

Table 1. List of the crops tested in the present study

Crop	Species	Family
Sunflower	*Helianthus annuus* L.	Asteraceae
Sweet sorghum	*Sorghum bicolor* (L.) Moench.	Poaceae
Rapeseed	*Brassica napus* L.	Brassicaceae
Soybean	*Glycine max* L.	Fabaceae
Peanut	*Arachis hypogaea* L.	Fabaceae
Common bean	*Phaseolus vulgaris* L.	Fabaceae

Allelopathic response index (RI) was also calculated as suggested by Williamson and Richardson (1988):

$$RI = 1 - \left(\frac{C}{T}\right)\ (when\ T > C) \qquad (1)$$

and

$$RI = \left(\frac{C}{T}\right) - 1\ (when\ T < C), \qquad (2)$$

where T and C were the germination percentages (%) of the treated and the untreated seeds, respectively.

To evaluate the effects of the extracts on the first growth of the plants and consequently crop establishment, the emergence was also measured outdoors in two pot experiments. Twenty pregerminated seeds of each treatment having a radicle of 1–2 cm length were sown at 1–3 cm depth in four pots filled with 3 l of a sandy clay loam (SCL) soil of pH = 7.1 and organic matter of 1.2%.

Regarding the statistical analysis, ANOVA was performed for all data and differences between means were compared using Fisher's Protected LSD test ($P < 0.05$). The Statsoft software package (Statsoft, Inc. 2300 East 14th Street, Tulsa, OK 74104, USA) was used.

Results

The results of the *in vitro* experiments revealed that *M. officinalis* aqueous leaf extracts showed their maximum allopathic effects on all the biomass and leguminous crops studied when applied in the concentrations of 5 and 10% whereas sensitive crops were affected even in lower concentrations. For example, seed germination of rapeseed was reduced by 19, 30, 56, and 80% in the concentrations of 1, 2, 5 and 10%, respectively, as compared to germination percentage recorded for the untreated seeds. Also, sweet sorghum showed an intermediate response to *M. officinalis* aqueous leaf extracts since seed germination was not affected in the low concentrations but in 5 and 10%, germination percentage was decreased by 31–55% in comparison to the untreated check. It is worth mentioning that lemon balm extracts showed increased selectivity on sunflower given that seed germination reduction did not surpass the level of 53% compared to the control even in the case where the greatest concentration was applied (Table 2).

Table 2. *M. officinalis* extracts' effect on seed germination (%) of three biomass crop species

Species	Control	Concentration of *M. officinalis* leaf extract			
		1%	2%	5%	10%
Sweet sorghum	93[a]	84[a]	82[a]	64[b]	42[c]
Sunflower	97[a]	95[a]	98[a]	75[a]	59[b]
Rapeseed	91[a]	74[b]	64[b]	40[c]	18[d]

Different lower case letters in the same row denote statistically significant differences ($P < 0.05$) between the means

Regarding leguminous crops, the common bean was the most sensitive to the allopathic extracts of lemon balm. In particular, 25, 34 and 60% fewer seeds did germinate in 1, 2 and 5% extract concentrations, respectively, in comparison to the control whereas up to 85% reduction of seed germination was recorded in 10% concentration. Peanut seed germination percentage ranged between 72 and 47% of control in 5 and 10% concentrations, respectively, while it was not influenced by the low concentrations. Soybean germination was least affected by *M. officinalis* leaf extracts. For instance, it was reduced by only 25 and 41% in 5 and 10% concentrations, respectively, as compared to the control (Table 3).

Table 3. *M. officinalis* extracts' effect on seed germination (%) of three legumes species

Crop	Control	Concentration of *M. officinalis* leaf extract			
		1%	2%	5%	10%
Soybean	94[a]	94[a]	88[b]	71[b]	55[c]
Peanut	92[a]	90[a]	89[a]	66[b]	43[c]
Common bean	93[a]	70[b]	61[b]	37[c]	14[d]

Different lower case letters in the same row denote statistically significant differences ($P < 0.05$) between the means

For the biomass crops studied, it was noticed that the majority of the values of the RI were negative apart from the case where sunflower was treated with the aqueous leaf extracts of lemon balm in 1 and 2% concentration. This outcome indicates the increased selectivity of lemon balm extracts on this crop. Moreover, the sunflower was slightly affected even from the highest concentration of extract (10%). Regarding sweet sorghum, its RI value ranged between –0.004 and –0.019 in 1 and 2% extract concentration. Treatment with a 5% concentration increased RI over the level of 80% as compared to lower concentrations whereas the response of sweet sorghum was even greater in the highest concentration. The results of the *in vitro* experiments clarified that rapeseed was the most sensitive biomass crop to lemon balm extracts since its allelopathic response index value was –0.144 in the concentration of 1% whereas, in 2% concentration, RI value was increased by 35% as compared to the value mentioned above (Table 4).

Table 4. *M. officinalis* extracts' effect on the allelopathic response index (RI) of three biomass crop species

Crop	Control	Concentration of *M. officinalis* leaf extract			
		1%	2%	5%	10%
Sweet sorghum	–	–0.004[a]	–0.019[a]	–0.098[b]	–0.204[c]
Sunflower	–	0.045[a]	0.007[a]	–0.069[b]	–0.192[c]
Rapeseed	–	–0.144[a]	–0.222[b]	–0.329[c]	–0.468[d]

Different lower case letters in the same row denote statistically significant differences ($P < 0.05$) between the means

The estimated RI values of the leguminous crops showed that soybean was the species least affected by the application of lemon balm allelochemicals. In particular, its RI was positive (0.017) in 1% concentration whereas it was –0.221 in the highest concentration of the aqueous extracts and this value was lower than the corresponding estimated for either peanut or common bean. Peanut showed an intermediate response in the application of *M. officinalis* leaf extracts. It was noticed that the RI value estimated in 5% concentration was by 64 and 93% greater than the corresponding values estimated in 1 and 2% concentrations, respectively. Regarding common bean, it was validated that this crop was by far the most sensitive of the three legumes studied. This outcome is derived from RI values which ranged between –0.158 and –0.344 in extract concentrations between 1 and 5% whereas, in the highest concentration, RI value surpassed the value of –0.5. In 10% concentration, the response of common bean to allelochemicals was by 32, 53 and 69% greater than the response observed in 5, 2 and 1% concentrations, respectively (Table 5).

Table 5. *M. officinalis* extracts' effect on the allelopathic response index (RI) of three legume species

Crop	Control	Concentration of *M. officinalis* leaf extract			
		1%	2%	5%	10%
Soybean	–	0.017[a]	–0.028[a]	–0.103[b]	–0.221[c]
Peanut	–	–0.011[a]	–0.059[a]	–0.166[b]	–0.277[c]
Common bean	–	–0.158[a]	–0.236[b]	–0.344[c]	–0.505[d]

Different lower case letters in the same row denote statistically significant differences ($P < 0.05$) between the means

The results of the current study indicated that seedling emergence of rapeseed was reduced by 14, 26, 53, and 79% in the concentrations of 1, 2, 5 and 10%, respectively, as compared to the emergence percentage recorded for the untreated check. Moreover, *M. officinalis* aqueous leaf extracts put an intermediate effect on sweet sorghum seedling emergence since it as much in the low concentrations of the allelochemical extracts. However, in 5 and 10% concentrations, seedling emergence was reduced by 30–55% as compared to the control. Lemon balm extracts showed great selectivity on sunflower given that seedling emergence of this crop was affected from the allelochemicals' application only in the highest concentration where the reduction percentage was only 36% (Table 6).

Table 6. *M. officinalis* extracts' effect on the emergence (%) of three biomass crop species

Crop	Control	Concentration of *M. officinalis* leaf extract			
		1%	2%	5%	10%
Sweet sorghum	87[a]	85[a]	80[a]	61[b]	39[c]
Sunflower	90[a]	88[a]	84[a]	71[b]	58[c]
Rapeseed	86[a]	74[b]	64[b]	40[c]	18[d]

Different lower case letters in the same row denote statistically significant differences ($P < 0.05$) between the means

From the leguminous crop species studied, the common bean was the most sensitive to the leaf extracts of *M. officinalis*. In particular, 26, 37 and 64% fewer seedlings emerged in 1, 2 and 5% concentrations, respectively, as compared to the control whereas up to 89% reduction of seed germination was recorded in 10% concentration. Peanut seedling emergence ranged between 50 and 31% of control in 5 and 10% concentrations, respectively, while it was slightly affected by the low concentrations of 1 and 2%. Soybean emergence was least affected by lemon balm allelochemicals. In particular, it was reduced by only 27 and 47% in 5 and 10% concentrations, respectively, in comparison to the untreated check (Table 7).

Table 7. *M. officinalis* extracts' effect on the emergence (%) of three legume species

Crop	Control	Concentration of *M. officinalis* leaf extract			
		1%	2%	5%	10%
Soybean	88[a]	80[a]	81[a]	64[b]	47[c]
Peanut	85[a]	72[a]	74[a]	50[b]	31[c]
Common bean	89[a]	66[b]	56[b]	32[c]	10[d]

Different lower case letters in the same row denote statistically significant differences ($P < 0.05$) between the means

Discussion

The growth-inhibiting effects of lemon balm aqueous leaf extracts on the different crops showed variation dependent on species level. From the biomass crops evaluated, rapeseed was the most sensitive whereas from the leguminous crops common bean was most affected by the application of the allelochemicals. Such findings highlight the susceptibility of some crops in the allelochemical compounds derived from other plant species. This outcome is validated by the corresponding of Souto *et al.* (2001) who noticed that soil bioassays revealed the allelopathic effects of *Acacia* spp. Allelochemicals on the growth of lettuce (*Lactuca sativa* L.) and white clover (*Trifolium repens* L.) under the soil and climatic conditions of the Mediterranean region. Also, the findings of another study have established that aqueous leaf extracts derived from the tissues of allelopathic species can reduce seed germination of important forage and pasture crops up to 80% (Hussain *et al.*, 2011). Csiszár (2009) noticed that seed germination and root length of white mustard (*Sinapis alba L.)* was reduced at either the 0.01 or the 0.001 probability levels, respectively, due to the application of allelochemical extracts as derived from invasive plant species notorious for their allelopathic potential. Sweet sorghum and peanut had an intermediate response to lemon balm allelochemicals since they were slightly affected by the low concentration but more influenced by the allelochemicals' application in the concentrations of 5 and 10%. This outcome is in a common direction with the study of Uddin *et al.* (2010) where lettuce and cucumber (*Cucumis sativus* L.) were slightly affected by the application of sorgoleone. The same authors also noticed that major food crops such as wheat, barley, rice, corn and soybean were tolerant to sorghum root allelochemical extracts whereas other crop species showed a slight susceptibility (Uddin *et al.* 2010). This is validated from the results of the present study where soybean's seed germination ability, seedling emergence was slightly affected by *M. officinalis* aqueous leaf extracts. Furthermore, similar observations were made regarding sunflowers' tolerance to the allelochemicals applied as it is indicated from the values of the RI estimated in the different concentrations. Regarding RI, the observed variability among either the biomass or the leguminous crops has also been demonstrated in the recent study of Scavo *et al.* (2018).

The facts that growth inhibition was very low for two crops and intermediate for others means that *M. officinalis* leaf extracts contained allelopathic compounds and that their phytotoxicity remained lower in the case of the least sensitive crop species. Hill *et al.* (2007) showed that although germination and radicle growth of various weed species was significantly reduced by methanol and ethyl acetate extracts of hairy vetch extracts, corn, tomato and cucumber were not affected from the presence of the allelochemicals. The same authors also mentioned that corn and cucumber radicle elongation was stimulated at low concentration of the extracts (Hill *et al.*, 2007). Also, Uddin and Pyon (2010) demonstrated that rotation crop residues can have intense herbicidal effects on weeds without inhibiting the growth of crop species which was found in our study. Furthermore, the same scientists observed no growth inhibition in plants like red pepper and lettuce at any incorporation rates, but tomato, cucumber and corn were slightly inhibited in a few cases at their highest incorporation levels (Uddin, Pyon, 2010). The observed differences could be probably explained by the different concentration of the allelochemicals' in the several extracts. The positive values of RI, as well as the stimulation of seed germination observed for sunflower and soybean at the rates of 1% and 2%, are in full accordance with findings reported by other researchers (Travlos, Paspatis, 2008; Economou *et al.*, 2011). The results of the *in vitro* experiments carried out during the present study indicated that the phytotoxicity of lemon balm allelochemicals was a matter of concentration. There is much evidence in direct conformity with this outcome observed from the current study. For example, radicle length of perennial grass weed species *Eragrostis curvula* (Schrad.) Nees was by 44 and 74% reduced when treated with 10 and 20 g l^{-1} of aqueous leave extracts as compared to the control treatment in the study of Fatunbi *et al.* (2009). Furthermore, there is evidence that flower methanol extracts derived from highly allelopathic plants can reduce *Hordeum murinum* (L.) germination by 56–87% when applied at the concentrations of 5 and 10 g l^{-1} as compared to control treatments whereas the corresponding effect of methanol leaf extracts on this monocotyledonous species' seed germination can reach the level of 75% (Abd El Gawad *et al.*, 2015).

As mentioned above, there is much evidence derived from the literature regarding the herbicidal effects of several aromatic plants on various grass and broadleaf weed species' seed germination, seedling emergence and growth. For instance, oregano can be used as a source of natural herbicides (Azirak, Karaman, 2008; Economou *et al*., 2011). Azizi and Fuji (2006) noted that the undiluted hydro-alcoholic extracts of both perforate St John's-wort (*Hypericum perforatum* L.) and common sage (*Salvia officinalis* L.) did put a strong inhibitory effect on seed germination percentage for *Amaranthus retroflexus* L. The herbicidal effects of lemon balm on either broadleaves or grasses have been evaluated and highlighted (Kato-Noguchi, 2001; Kanatas, 2020). However, apart from the herbicidal potential of *M. officinalis* extracts, there is a growing concern regarding the selectivity of such allelochemicals in crops and crop response to their application has not been widely studied. Under that concept, the present study is of major importance.

Conclusions

In the present research, the effects of aqueous extracts of *M. officinalis* on various biomass and leguminous crops were evaluated. From the study on seed germination and seedling emergence percentages, it can be concluded that sunflower and rapeseed were the least and most sensitive biomass crops to lemon balm allelochemicals, respectively, whereas sweet sorghum showed an intermediate response. Regarding leguminous crops, increased was the selectivity of the aqueous leaf extracts on soybean whereas seed germination and seedling emergence of peanut were more affected and common bean was the most sensitive crop. These results can be further explained from the estimated values of RI for each crop in each concentration. RI values were negative, apart from the cases where sunflower and soybean were exhibited to the low concentrations of the allelochemicals. In any case, the impact of the *M. officinalis* extracts on the crops was concentration-dependent and of course, the effect was species-specific. In particular, the higher the concent‘ration, the greater the inhibiting effects of the allelochemicals on each crop. Due to these species-specific effects, the use of *M. officinalis* extracts for weed management is suggested only on particular crops and not in all species. Further research is needed to investigate the selectivity of *M. officinalis* and other aromatic plants' allelochemicals on various crops and under different soil and climatic conditions to optimize their efficacy as tools of more eco-friendly weed management strategies.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

PK, IG, IK and PP contributed equally to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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APPLICATION OF THE DIFFERENTIAL SCANNING CALORIMETRY METHOD IN THE STUDY OF THE TOMATO FRUITS DRYING PROCESS

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ABSTRACT. Structural changes in the process of heating fresh fruit, sun-dried fruits and powder obtained from the dried tomato fruits were studied by differential scanning calorimetry method application. The kinetics of the shredded fruits in the dryer proves the prospects for using convective drying, which is performed for 295 minutes. The kinetic coefficients of drying and critical moisture content in the crushed fruits of tomato were determined. The kinetic coefficients were determined by the graphical-analytical method: a = 0.839, ln(α) = 1.3 and α (1 s^{-1}) = 0.262. It was determined that the critical maximum moisture content for drying the shredded fruits of tomatoes is 1.503% mm^{-1}, after what the process of combustion of vegetable tissue begins. The application of the differential scanning calorimetry (DSC) method allowed the fuller study of the mechanism of drying the fruits of tomato in different condition: fresh, sun-dried and dried. It was determined that the greatest amount of energy is consumed to remove free moisture (1 993 J g^{-1}) from the fresh tomatoes. At the same time, when being cooled, crystallization in plant tissue occurs with the release of energy in the amount of 0.03922 J g^{-1}. When drying the previously sun-dried tomatoes the process of moisture removal and the partial decomposition of the compounds that are unstable to temperature is completed. At the same time, at the 129.61 °C temperature in the powder obtained from the fruits of tomatoes, melting of carbohydrates and other compounds occurred. Thus, this confirms the need to observe the normalized value of the mass fraction of moisture in the powders in the process of their packaging, storage and use. The basic technological system of production of powder from dried fruits of tomatoes is offered.

Introduction

With the increasing demand for natural products of high biological value, the demand for powders of plant products rises every year. Powders provided by the optimum drying mode, are well stored and are convenient for the use in food production (Petrova, 2013; Khomichak *et al.*, 2019). Among those products the powder obtained from the dried tomato fruits, known as carotene-containing products, take the leading place.

Carotenoids are required for the normal functioning of the organs of vision, cell growth, skin, hair, teeth, and respiratory mucous membranes. (Mukherjee *et al.*, 2011) found that vitamin A has a protective effect against malignant processes. Vitamin A and its derivatives may prevent carcinogenesis of epithelial tissues, and β-carotene may prevent carcinogenic or ultraviolet skin cancer (290–320 nm). Zhuzha (2013), Shutyuk *et al.* (2016), Gloria *et al.* (2014) and Kuznetsova (2013) confirms the anticancer action of vitamin A and certain carotenoids (quartetin and lycopene).

In the current conditions, the production and creation of new types of food with the use of carotene-containing ingredients are relevant and necessary for the nation's health. The use of lycopene-containing products is also becoming more important. Lycopene is a substance of the carotenoid group, which determines the dietary value and the degree of maturity of the fruit. It is not synthesized in the human body, and consumption of fresh tomatoes or tomato products provides 50–80% of the body needs in the total consumption of food. Entering the human body, lycopene can enhance protective functions of it, inhibit degenerative processes in the tissues, and reduce the risk of initiation and development of cancer, cardiovascular and other pathologies. According to the Nutrition and Bioactive Substance Consumption Guidelines, the optimal dose of lycopene intake is 5 mg per day and the maximum intake is 10 mg per day. Also, lycopene "blocks" the negative effect of free radicals on the human body and its antioxidant action is three times higher than β-carotene (Gloria *et al.*, 2014). This contributed to the growing interest in lycopene in the medical field, what is reflected in the works of medical scientists, such as (Gloria *et al.*, 2014; Mukherjee *et al.*, 2011) and others. In particular, it was found that the average concentration of lycopene in blood plasma at a healthy person is about 0.5 μmol l^{-1}, and the maximum level is reached in the period from May to October.

Taken into consideration the importance of the functional capacity of tomato fruits, particular attention is paid to their preservation for a certain period to provide people with the required amount of compounds necessary for the human body and ensure continuous operation of the processing plant. Therefore, it is important to develop and improve technologies for lycopene-containing products processing and their further use in functional food production.

Materials and methods

Tomato fruits of the Popilna variety, which were grown in a subzone of insufficient moisture at the experimental plots of the Institute of Horticulture of the NAAS (Borky village, Kyiv region), were used. The tomato fruits were purified, shredded and dried in a convective TSO-type dryer at the Institute of Technical Thermophysics of the NAS of Ukraine.

The sizes of tomato fragments were selected in a way that provides their uniform drying along with the tray. Also, smaller parts accelerate the drying process which reduces energy consumption.

The raw material was dried down to the constant weight in laboratory automatic dryer. The following methodology was used for the experiment. The temperature was brought to the necessary one, then a container with the material was loaded into the receiver (net basket). The parameters of the thermometer and electronic scale were scanned in equal time intervals and under the constant temperature. The experiment lasted until the difference between the previous and the next scale parameter became unchanging during several tests.

Drying mode parameters: drying agent temperature (air) – t = 60 °C, drying agent movement rate – v = 2.5 m s^{-1}, moisture content – d = 10 g kg d.p.$^{-1}$, layer thickness – 15 mm. Drying process parameters can change depending upon the peculiarities of the product that is supplied into convective drying.

The experimental stand (Fig. 1) is a system of the isolated air ducts with the devices for heat treatment and circulation of the heating agent, drying chambers, measuring circuits and devices for controlling the parameters of the drying process and measuring the values characterizing the drying process of the test material. The stand is equipped with three drying chambers: one horizontal (air blasting model – parallel airflow) and two vertical (expulsion model).

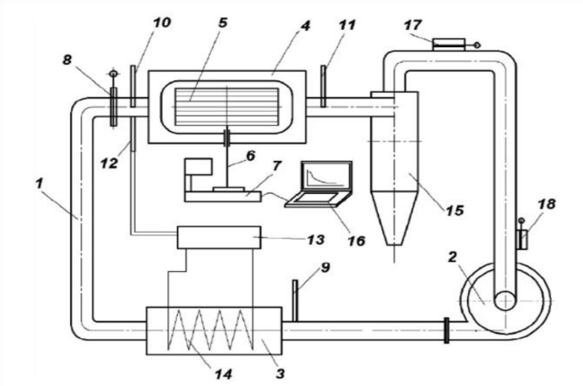

Figure 1. Experimental stand for convective drying process (developed by I. Kuznietsova, V. Paziuk; working principle is explained in the text)

Drying unit (Fig. 1) is thermally insulated circulation metal loop 1, with the airflow generated by fan 2 and flowing consecutively through the electric metal radiator 3 and drying chamber 4, which contacts with the material through the supply of heat and removal of evaporated moisture. Then the waste air moves from the drying chamber through cyclone 15, where caught product particles are removed, to the fan input 2, which provides air circulation in the dryer's circulation loop. The material that is being dried, is placed in a net box 5 (the inner space of the drying chamber), connected with electronic scale 7 through bar 6. The net box is removable. It can be disconnected from the bar and taken out of the drying chamber through a side hatch, locked with a slide glass gate. One can observe the status of the material through this gate during the drying. The consumption and respective heated airspeed in the drying chamber are regulated by gate 8 and controlled by anemometer; air temperatures before radiator t0, after radiator t1 and after drying chamber t2 are controlled by thermometers 9, 10, 11. The set (target) air temperature t1 at the chamber input is regulated by electronic contact thermometer 12 through blocking relay 13 which is connected to electric heater 14 of radiator 3. A part of the waste heat agent is removed through a nozzle with gate 17. Fresh air is supplied through the nozzle with gate 18. The mass of the product in the basket is measured on the scale and registered by computer 16 through set time intervals. The experimental error didn't exceed 5% and comprised 2.4%. Based on experimental findings, we calculated current moisture content of the material W and drying speed ΔW/Δτ, built dependency diagrams W = f(τ) and ΔW/Δτ = f(W), that is demonstrated on Fig. 2.

The obtained dried tomato fruits with a 7.2% mass fraction of dry matter. The output dried tomato fragments were crushed into powder. A portion of 100 ± 0.1 g of dried tomato fragments was milled in a lab mill. Then the product was weighed, which identified 0.83 g loss. Milled dried tomatoes were bolted through a lab bolter applying a set of 5 bolters. Of the portion of 100.05 g of the product, the mass sample with the particle size of less than 0.2 mm (powder) comprised 98.48 g. Thus, the loss was 1.57 g (1.6%). The plant tissues sample was sealed in a special aluminium capsule and placed in a QDSC-20 Termo Fisher SCIENTIFIC calorimeter measuring unit.

The thermal center of the DSC system consists of two trays: a control tray and a sample tray. The equipment is adjusted to sustain a constant temperature in the trays in the course of the heating process. During DSC measurements the control tray is filled with buffer solution first and then the sample tray is filled with a sample solution. Then they are heated with constant scanning frequency. The heat absorption that takes place during the biomolecule spreading results in the temperature difference (TD) in the trays, which causes temperature gradient in Peltier units with the voltage establishing which is turned into energy and used to control the Peltier unit to bring the TD (temperature difference) to 0 °C. The DSC signal is proportional to the heat capacity of constant pressure, which is the derivative of temperature enthalpy.

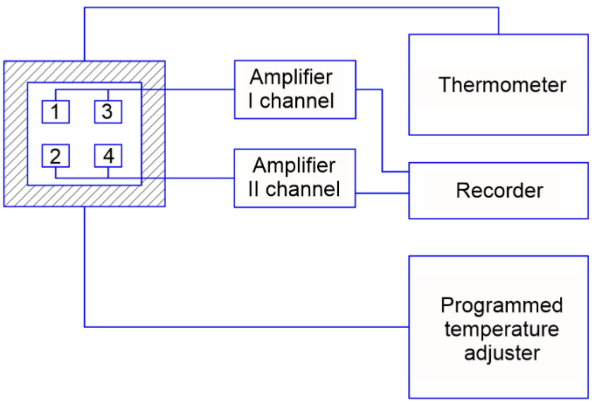

Figure. 2. Flowsheet of differentiating scanning calorimeter: 1–4 slots with thermal sensors

The reduction of measurement error was reached by finding the lowest scanning speed for this model of 10 °C min^{-1}. The planned experimental temperature range was 20–105 °C. They are peculiar to convective drying. The range of 105–250 °C was planned for studying the process of pulp biomolecule melting. High precision (to the hundredth) of the temperature and enthalpy calculations during thermal impact on biomolecule was provided through automated data processing of the equipment with the help of STAR^e software by Mettler Toledo (Switzerland).

Results and discussion

Thus, the study of the drying process is an important task of the research, which will help to substantiate the physical and chemical processes that occur in plant tissue provided by increasing the temperature in the product.

Kinetics of the crushed fruits in the drier (Fig. 3) shows the prospects for convective drying, which is being performed for 295 minutes (Paziuk *et al.*, 2018, 2019; Khomichak *et al.*, 2019).

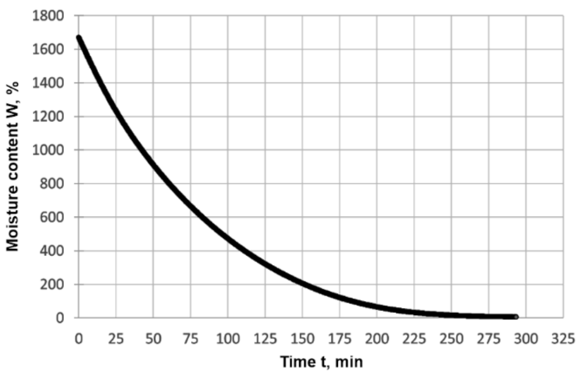

Figure 3. Kinetics of the tomato fruits drying

Regression equation (1) was calculated based on the characteristic curve and according to the expression that describes S-curves of drying plant raw material. The mathematical relation obtained allows describing plant raw material drying curves and can be used to process drying curves under constant temperature.

The kinetics of moisture removal (*W*, %) from the pulp of tomato fruits is described by the dependence:

$$W = 2\,897.8 \times e^{-0.389 \times \tau}, \quad (1)$$

where τ – duration of the drying process, min.

The experimental results obtained laid the basis for generalized curves for the studied raw material. They can be used for any temperature modes of drying.

The rate of drying (*V*, % s^{-1}) the crushed tomato fruits is described by the regression equation:

$$V = 2.1083W + 1.6806 \quad (2)$$

Approximation of the experimental data by the linear function made it possible to obtain the following calculated dependence of the internal diffusion coefficient (*D*) on the temperature (*T*) for the crushed tomato fruits:

$$D^t = 0.0039D^{293} + 0.0015 \times (T - 293\ °C) \quad (3)$$

Determination of the critical humidity, duration and coefficient of drying was carried out by the graphical-analytical method. The results of the studies are presented as a graphical dependence:

$$L_g(W - Wr) = f(\tau), \quad (4)$$

where W – is the running humidity, %; W_r – equilibrium humidity, %; τ – duration of drying, s.

To describe the kinetics of fragmented tomatoes drying under the experimental data and the characteristic curve obtained (Fig. 4) was define kinetic coefficient ln(a) and coefficient α a slope of a line to an absciss (Khomichak *et al.*, 2019; Kindzera *et al.*, 2014).

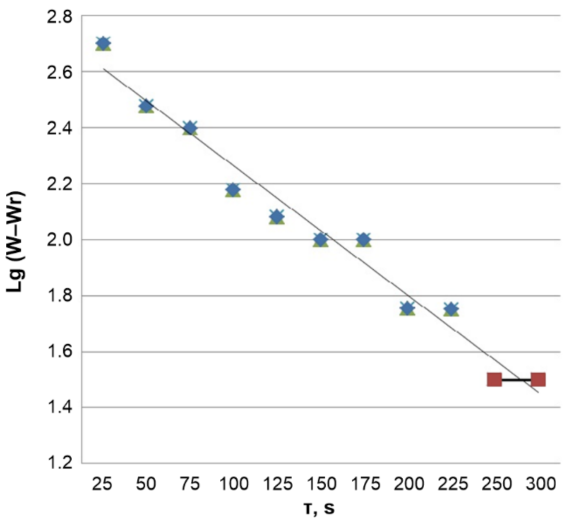

Figure 4. Logarithmic dependence of fragmented tomatoes drying kinetics

Thus, the kinetic coefficients have the values: α (1 m^{-1}) = 0.839, ln(α) = 1.3, α (1 s^{-1}) = 0.262.

The critical moisture content (°C, %) in the crushed tomato fruits will be determined as the square root of the ratio of the kinematic coefficient α to the product of the kinetic coefficient a (1 m^{-1}) and the thickness of the raw material layer. After calculation, it was defined that the critical maximum moisture content for the crushed tomato fruits drying is 1.503% per mm, after what the process of combustion of plant tissue began.

Removal of moisture from the plant tissue is accompanied by destruction of its structure, weakening of intermolecular forces and the hydrogen bonds breaking. The moisture-holding capacity of plant cells depends on the general physiological condition of the plants. Method of the differential scanning calorimetry (DSC) allows studying water transformations in plant tissues under the influence of thermal action. The DSC method for determining the state of water is based on distinguishing the properties of free and bound water. In this case, the bound water is identified as non-freezing water. The bound water does not experience a first-order phase transition when cooled below 0 °C. And only free water crystallizes when cooling or heating in the negative temperatures range. Application of the DSC method for the study of the structural properties of food is outlined in the works devoted to the study of stevia leaves (Roik *et al.*, 2015; Kuznetsova, 2014), chocolate, and the like.

The process of drying vegetables takes place at different temperatures (in particular 50 °C, 110–130 °C) depending on the intended purpose of the final product, design and principle of operation of the dryer. The final moisture content of the fruits of vegetables makes up 6–10%, but drying is possible right up to 2%. The fruits contain both free and bound moisture. Free moisture has the same properties as pure water. The bound moisture is tightly joined to other components of the product and exhibits properties different from those of free moisture. Almost all the moisture in plant products is kept in bound condition but is held by tissues with different strengths.

Corresponding thermograms for tomato fruits when dried fresh, previously sun-dried and powdered are presented. During the initial phase of the substances mixtures, transformation heat is released. Comparison of the DSC-grams (Fig. 5) of the fresh and sun-dried tomato samples shows that the minimum endothermic peaks of the two samples differ.

The tomato thermogram curve (Fig. 5) shows that at the temperature of 20–97 °C excess moisture is removed from the tomato fruit, after that the process is stabilized without disturbing the structure of the main components of the fruit. Increasing the temperature to 96.5 °C facilitates the opening of pores of the intermolecular space and the rate of the process is limited by the transfer of mass in macropores. Endopeak at the temperature of 97.54 °C shows the achievement of the maximum possible removal of moisture from the fruit. In case of the crushed sun-dried tomato fruit (Fig 5, curve 2) two peaks are observed at such temperatures:

- 98.34 ºC, which causes removal of the free part of moisture and decomposition of tomato fruit compounds which are not resistant to high temperatures;
- 107.29 ºC, at which some of the bound moisture is removed and then melting of the sun-dried tomato compounds takes place. An acute peak at this temperature indicates crystalline rearrangements, syntheses, or solid-state transitions of relatively pure compounds.

The study of drying the tomato powder shows the smoothness of the thermo-gram curve (Fig. 6), which indicates the even removal of moisture from the powder. That is, during the second temperature treatment, some of the free and capillary moisture is removed from the tomato fruits. Increase in the temperature of heating contributes to the increase of the energy of separation the molecules from the hydrated film surface and the rate of diffusion of moisture in plant tissue macro-pores.

Fig. 4 shows the DSC curve of a sample of tomato powder having one expressed temperature peak at 129.61 °C and another at 148.33 °C, what indicates the removal of bound moisture from plant cells and partial decomposition of certain compounds which are not resistant to high temperatures.

The aggregated data on the temperature peaks of tomato fruits drying are presented in Table 1, which demonstrates the uniform removal of free moisture from fresh and sun-dried tomatoes and indicates the remains of it in the plant tissue of the fruits after the fresh tomatoes drying. Removal of the adsorbed moisture from the polymolecular and monomolecular layers promotes the increase of the energy of the physical and mechanical bonds of the moisture in the microcapillaries and the solid phase of the sample, what increases the consumption of energy up to 1,993 J g^{-1} at the fresh tomato fruit.

In addition, drying fresh tomatoes results in the highest energy consumption the plant tissue structure change.

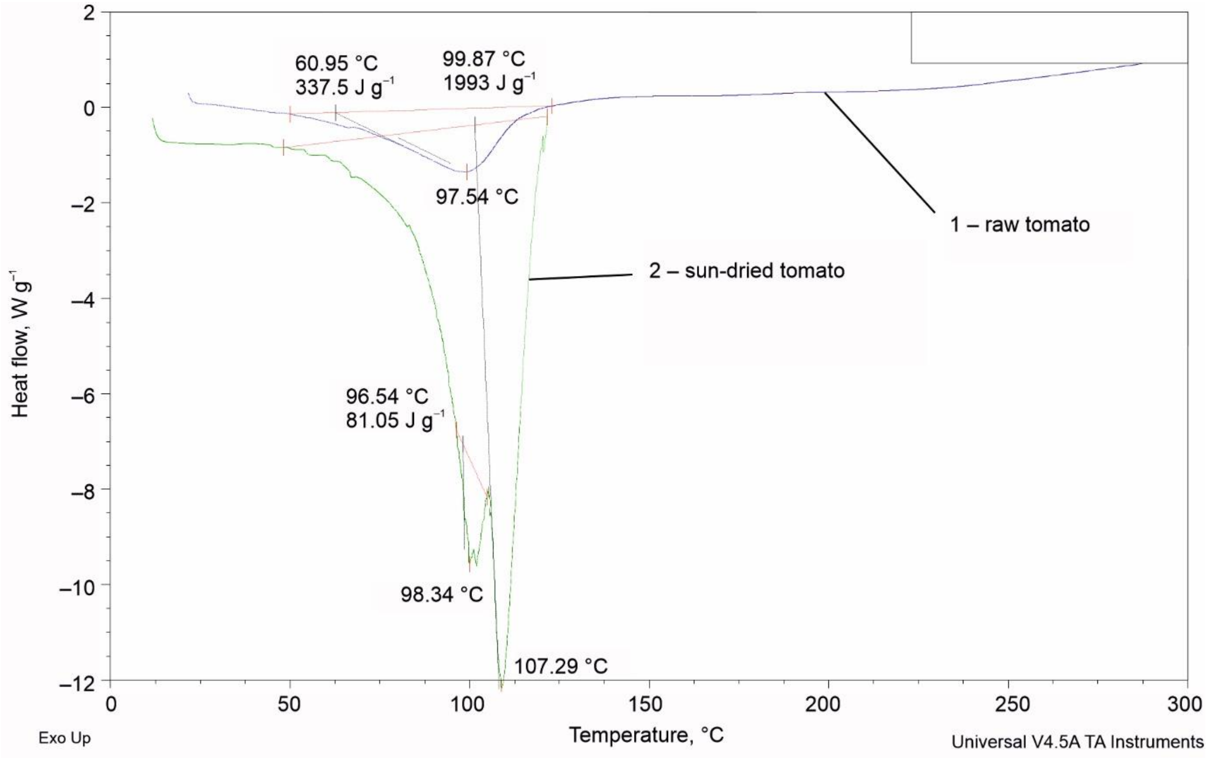

Figure 5. Fresh and sun-dried tomato fruits drying

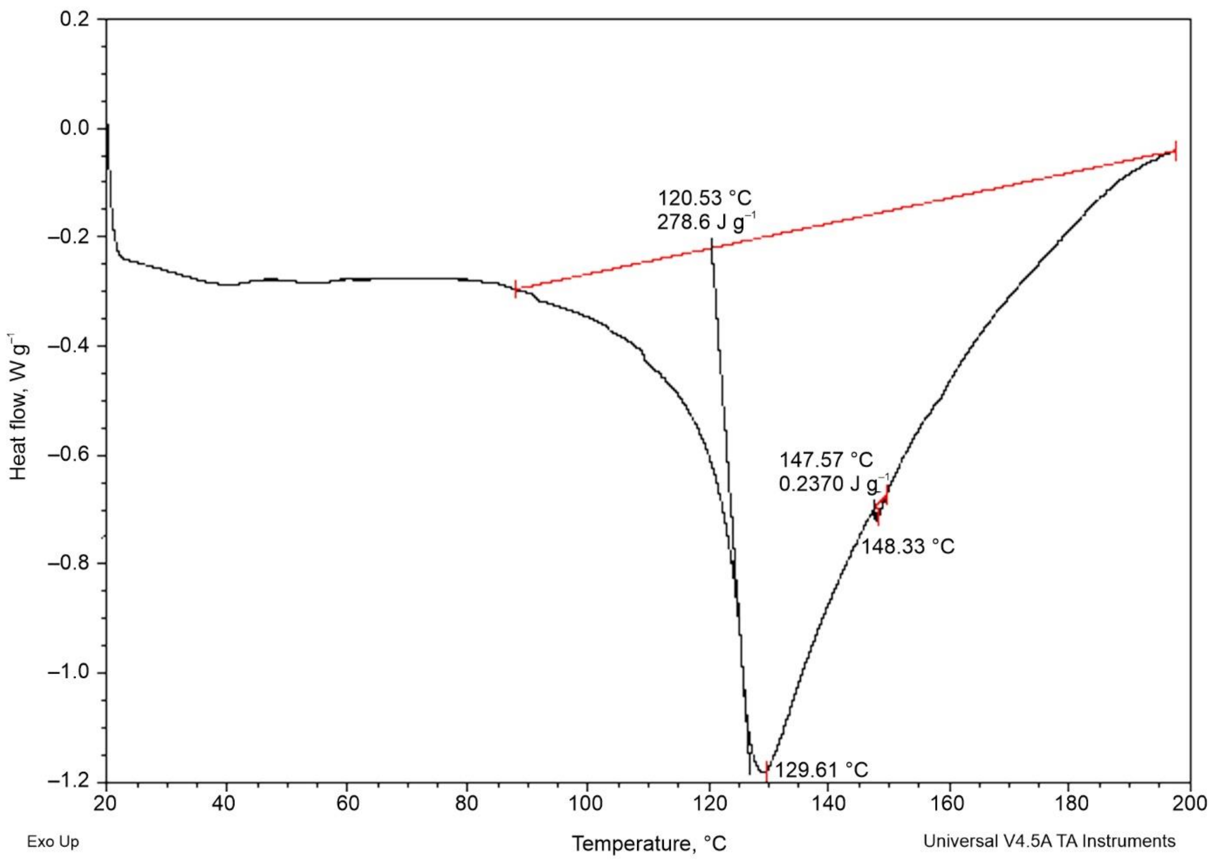

Figure 6. Tomato fruits powder drying

Table 1. Characteristics of the drying process of tomato samples with various dry matter contents

Tomato fruit samples	Temperature of moisture, °C	Melting temperature, °C	Enthalpy, J·g^{-1}
Fresh	97.54; 99.81	–	1 993
Sun-dried	98.34; 107.29	–	133.5
Powder	–	129.61; 148.33	278.6; 0.237

Part of the capillary moisture is also removed when drying the sun-dried tomato. When drying tomato powder the melting process of certain compounds takes place, which is accompanied by the process of energy consumption initially at the level of 278.6 J per g of the raw materials, and then a smaller amount of energy – 0.237 J per g, which indicates the plant tissue structure breaks down.

According to the Lavoisier-Laplace law (Pecal *et al.*, 2011), decomposition of a complex compound into simple ones absorbs a certain amount of energy that is consumed to form the same compound. When the dried tomato fruit is cooled (Fig. 7), crystallization of acids occurs in vegetable tissues, what is evidenced by the 20.78 °C temperature peak. At the same time, energy in the amount of 0.03922 J per g was spent for the crystalline structure formation.

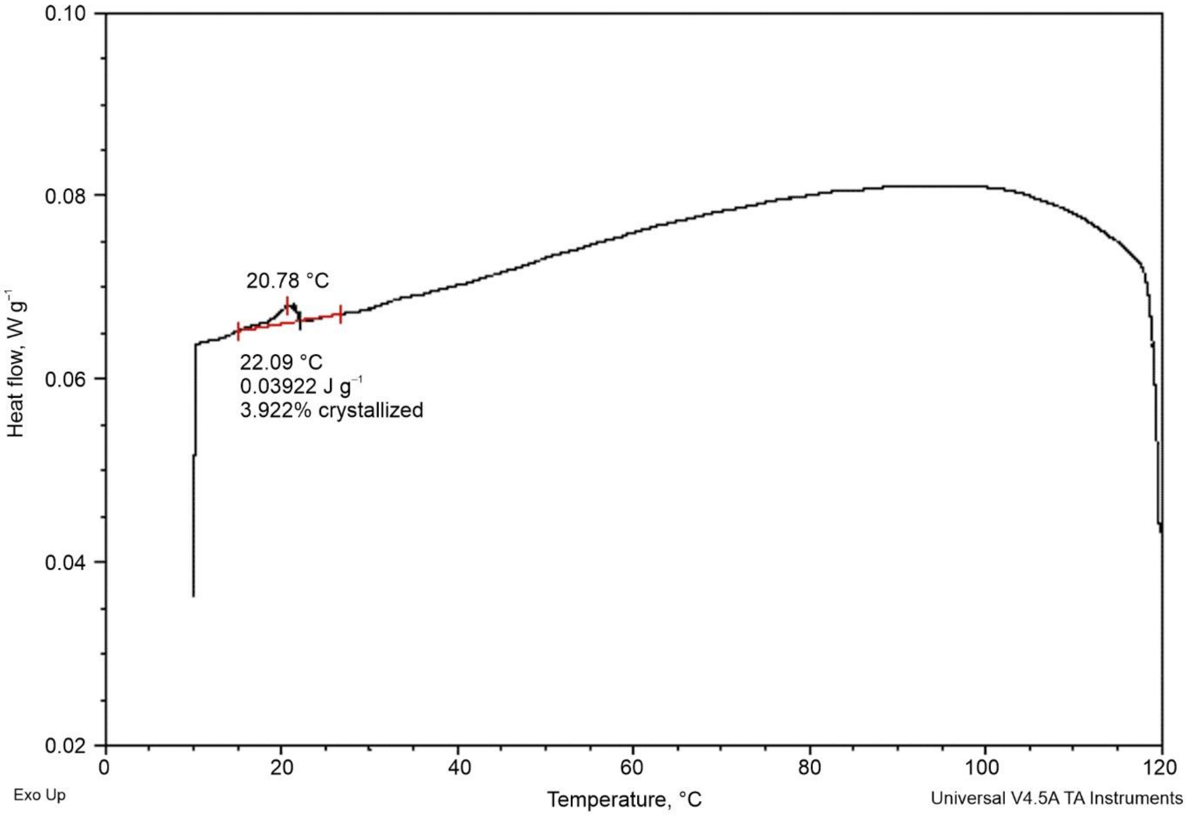

Figure 7. Cooling of the dried tomato fruit

For industrial applications, it is recommended to use a TSU convective type dryer (Fig. 8), which will provide a dried product of guaranteed quality.

Based on the in-depth research of tomato fruits drying, a basic technological model is submitted (Fig. 9).

Thus, the basic technology for obtaining powder from the fruits of tomatoes involves the following processes:

- receipts of ripe, red fruits of tomatoes for production;
- washing and green mass selection from the fruits;
- shredding to the 5×5×5 mm size particles;
- convective drying under conditions: layer thickness – 15 mm, drying agent temperature (air) – t = 60 °C, drying agent movement rate – v = 2.5 m s^{-1}, moisture content – d = 10 g kg d.p.$^{-1}$, duration – 225 minutes;
- grinding on a ball mill to a powdered state;
- storage and delivery to consumers.

Figure 8. The TSU convective drier

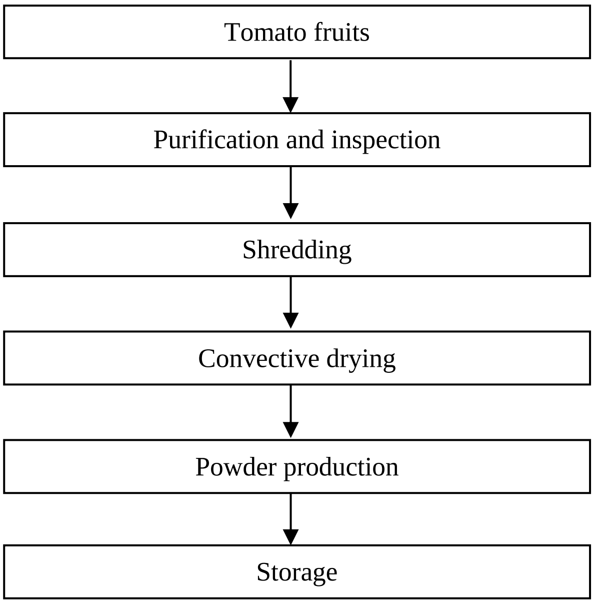

Figure 9. Basic model of the dried tomato fruits powder production

Conclusions

It has been proved that convective drying of shredded tomato fruits is one of the promising ways of producing tomato powder. The values of kinematic coefficients (α = 0.839, ln(α) = 1.3, α(1 s^{-1}) = 0.262) and the critical boundary moisture content (1.503% per mm) were determined.

The application of the DSC method allowed the fuller study of the mechanism of drying the fruits of tomato of different state: fresh, sun-dried and dried. This gives a clear idea of the temperature and energy transformations in tomato fruits with a high content of dry matter during technological operations. It is determined that the most energy is consumed to remove free moisture (1 993 J h^{-1}) in processing fresh tomato fruit. At the same time, when it is cooled, crystallization occurs in plant tissue with the 0.03922 J g^{-1} energy release.

Further drying of the sun-dried tomato fruits results in the completion of moisture removal and partial decomposition of the compounds that are temperature unstable. At the same time, the 129.61 °C temperature causes melting of carbohydrates and other compounds of the powder obtained from tomato fruits. It should be noted that the availability of excess moisture in the product weakens the carbohydrate bonds and accelerates their melting under high temperatures. Thus, this substantiates the need to adhere to the normalized value of the mass fraction of moisture in the powders during their packaging, storage and use.

The basic technological pattern of production of tomato powder is offered.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

InK – study conception and design;
VB, VP, OT, IK – acquisition of data;
VB, VP – analysis and interpretation of data;
VP, OT – drafting of the manuscript;
IK – editing the manuscript;
InK, VP – critical revision and approval of the final manuscript.

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EESTI EROSIOONIST HÄIRITUD MULDADE ORGAANILISE SÜSINIKU- JA LÄMMASTIKUSISALDUS

ORGANIC CARBON AND NITROGEN CONTENT IN ESTONIAN EROSION-AFFECTED SOILS

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ABSTRACT. The work is dedicated to the characterization of erosion-affected soils' (EAS) humus status (HS) in pedo-ecological conditions of South-Eastern Estonia. For understanding HS of EAS their organic carbon (OC) and total nitrogen (NT) sequestration capacities and the ratio C:N was studied by separate soil layers. The average data about soil OC and NT contents (g kg^{-1}) and superficial densities (Mg ha^{-1}) are given by arable soil species. The analysis of reflecting EAS HS on four research areas (Valgjärve, Otepää, Haanja and Mooste) was carried out based on four different origin databases. The analysis of OC content is done by Tjurin and NT by Kjeldahl. In soil associations of erosion-affected areas' the following groups of soils were distinguished: eroded (E), deluvial (D), neutral (N) and non-eroded (En) soils.

The HC thicknesses of research area Valgjärve E soils are in limits 18–23 cm, D soils 30–65 cm and of En soils 22–27 cm. The medians of same soils OC concentrations are accordingly 9.4, 11.2 and 10.9 g kg^{-1} and ratios C:N accordingly 9.8, 9.4 and 10.2. The OC stocks given in the limits of quartiles are in E soils 24–36, D soils 51–143 and En soils 32–49 Mg ha^{-1}. Therefore on eroded areas, the perpetual continuums of soil properties' (among these HS) changes may be followed and it is very complicated to separate soil contours on 1:10 000 soil maps. In this work, the transitional areas between E and D soils are characterized via N soils.

On erosion-affected areas the E and D soils form different soil associations with auto- and hydromorphic normally developed non-eroded soils, where very commonly as well the fluvial (abnormal) soils are presented. The relatively high pedodiversity caused by the areas high geodiversity is requisite to the high biodiversity. In erosion-affected regions is extremely important to maintain agricultural activity, as with this is ensured the persistence of naturally beautiful landscapes. The soil cover with EAS acts as an accumulator of formed on the same area soil OC.

Sissejuhatus

Erosioonist häiritud muldades (EHM) on bioloogilise olemusega normaalne mullatekkeprotsess häiritud erosioonist kui geoloogilisest protsessist. Kiirendatud vee- ja tuuleerosioon ei ole olulisteks muldkatet degradeerivateks teguriteks Eestis üleriigiliselt, kuid muldade erosioon koos EHM tekkega on eluliselt tähtsad regionaalselt ja seda ennekõike Kagu-Eestis. Eestis tuleks muldade erosiooni käsitleda kui teatud regioonidele omast väga olulist põllumajandusmaa kasutamise ja kaitsega seotud probleemi.

Nii nagu kõigi mistahes piirkonna muldkatete puhul, ei ole mõeldav muldkattes olevate eriilmeliste muldade määramine ja omaduste tundmaõppimine ilma muldade klassifikatsiooni kui töövahendit kasutamata. Eesti EHM käitlemisel kasutame loomulikult Eesti muldade klassifikatsiooni (EMK), kus anormaalsete muldade hulgas on eristatud 14 EHM liiki (Astover, 2013). Juhul kui ei olda veel hästi kursis EMK-ga, oleks heaks abiks EMK mullanimetuste ja nende koodide (antud juhul EMK ühe osa – anormaalsete EHM muldade) nimestiku käepärast olek. Seda põhjusel, et mullaliikide täisnimede esitamise asemel kasutame EHM nimetamisel nende koode.

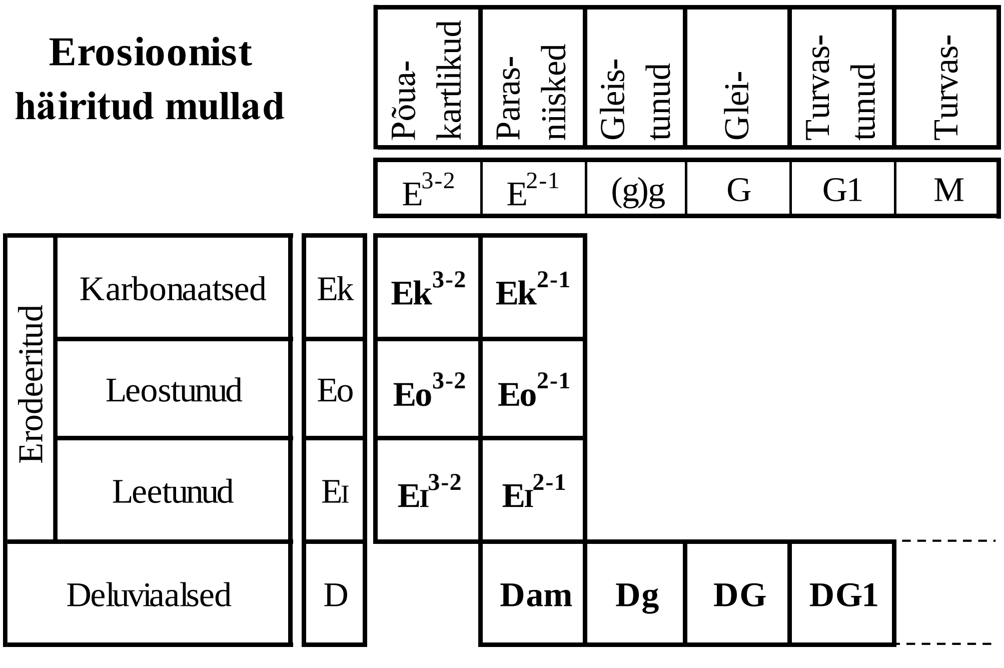
Üldiselt on Eestis EHM levik ja peamised morfoloogilised parameetrid võrdlemisi hästi fikseeritud suuremõõtkavalise mullastiku kaardistamise käigus (Maa-amet, 2001; Maa-uuringud, 2009). Samas vajab täiendavat uurimist ja üldistamist EHM huumusseisund (HS), mis on vajalik nende talitlemise ja agronoomilise kvaliteedi hindamisel. Mulla HS all mõistetakse mulda sattunud orgaanilise aine voogu läbi muldkatte (sisend → lagunemine/muundumine → väljund) ja selle kvaliteeti, millede olulisteks talitlemist määravateks komponentideks on mulla orgaanilises aines (MOA) olev orgaaniline süsinik (OC) ja üldlämmastik (NT). Nii ongi käesoleva töö ülesandeks käsitleda OC- ja NT-sisaldust ja varu erinevates EHM kihtides ning nende omavahelist suhet (C:N) ja seoseid teiste EHM ökoloogiliste parameetritega. OC kontsentratsioonid EHM-des on määratud Tjurini ning NT Kjeldahli meetodite järgi (Tjurin, 1935; Vorobyova, 1998).

Muldade klassifikatsioon kui EHM tundmaõppimise ja käitlemise töövahend

EHM hulka kuuluvad ühelt poolt erodeeritud (E) ehk ära uhutud mullad ja teiselt poolt deluviaalsed (D) ehk peale uhutud mullad. EMK-s on eristatud 11 E mulla ja 3 D mullaliiki (EPP, 1982; Astover, 2013). EMK-s on E mullad jaotatud erosiooni (ärauhte) intensiivsuse järgi, mis kajastub hästi nende muldade erodeeritud huumushorisondi (Ae) ülesehituses. Nii võivad E mullad olla nõrgalt (E1 või indeks e), keskmiselt (E2), tugevasti (E3) või väga tugevasti (E4) erodeeritud. E muldade geneesi ja karbonaatsuse järgi eristatakse E1 puhul automorfsete erosioonist mõjutamata (En) muldadega analoogsed liigid (Ke, Koe, KIe, LPe ja Lke), kuid E2 ja E3 muldade puhul – karbonaatsed (Ek), leostunud (Eo) või leetunud (El) mullaliigid E4 ei käsitleta mullaliigina, vaid erosioonist väga tugevasti rikutud pinnasena.

D mullad on jaotatud veerežiimi ja deluviaalse (pealeuhutud) mullakihi (Ad) tüseduse järgi. Mullaveeolude järgi võivad nad olla parasniisked ehk automorfsed (Dam), ajutiselt liigniisked ehk gleistunud (Dg) või alaliselt liigniisked ehk märjad (DG), kuid Ad horisondi tüseduse järgi nõrgalt, keskmiselt või tugevasti pealeuhutud D mullad. Määrates EMK järgi mullaliike saavad mulla nimetuste kaudu sedastatud ka olulisemad mulda iseloomustavad tunnused.

EHM omavaheline seos on kujutatud anormaalsete muldade maatriksil (joonis 1). Sellel maatriksil kajastub hästi ka mullakoodide ülesehituse põhimõte, kus põhinimetus on antud suurte tähtedega, kuid eri aspekte kajastavad indeksid väikeste tähtede või numbritega. Vastavad indeksid leiab ülalpool olevast tekstist. E ja D muldade arengu selgitamisel ja agronoomiliste omaduste hindamisel on suureks abiks anormaalsete EHM muldade maatriksi võrdlus normaalsete muldade maatriksiga, mille mullad on tunduvalt põhjalikumalt uuritud. E muldade huumuskatte (HK) tüüpide ehk humipedoni või huumusvormide kvaliteedi järgi saab väita, et Ek mullad on omadustelt lähedased rähksetele (K) muldadele, Eo mullad leostunud (Ko) ja leetjatele (KI) ning El - kahkjatele (LP) ja leetunud (Lk) muldadele. Kui E mullad asetsevad litoloogilis-geneetilise skalaari suhtes positsioonil või ridadel 10–60, siis D mullad asuvad peamiselt positsioonil või ridadel 30–50 s.t üleminekualal karbonaatse ja karbonaadivaese alusmullaga muldkatete vahel.



Joonis 1. Erosioonist häiritud mullad (EHM ehk E ja D mullad) Eesti anormaalsete muldade maatriksil. Muldade täisnimed saab tuletada koodide järgi (vt. tekst) või kasutada selleks Eesti muldade nimestikku (Astover jt, 2013)

Figure 1. *Estonian erosion-affected soils (EAS or E&D soils) presented on abnormal soils matrix. The soils' full names presented in the list of Estonian soils (Astover* jt*, 2013) may be deducted after their codes*

Erosioonist mõjutatud muldade levik ja seos pedo-ökoloogiliste tingimustega

EHM osatähtsus Eesti muldkattes on kõige suurem Kagu-Eestis. Võru ja Valga maakonnas moodustavad nad põllumaa muldkattest 25–27% ja haritavast maast 32–37% (Kõlli jt, 2010). Ka Põlva maakonnas on EHM osatähtsus küllaltki suur – vastavalt 12 ja 15%. Nendest kolmest põhja pool asuvate Tartu, Viljandi ja Jõgeva maakondades EHM osatähtsus järk-järgult väheneb põllumaa suhtes vastavalt 6%-lt 1%-ni ja haritaval maal 7%-lt 2%-ni.

Eesti EHM-dele rajatud Haanja (Hnj), Otepää (Otp) ja Valgjärve (Vlg) HS selgitamise uurimisalad (UA) esindavad hästi moreenküngastike ja moreenkattega mõhnastike domineerimisega Kagu-Eesti maastikke (Arold, 2005). Taolisi maastikke leidub peamiselt Võru, Valga ja Põlva, kuid vähemal määral veel ka Tartu ja Viljandi maakondades. Valdavaks muldade lähtekivimiks nendel aladel on punakaspruun karbonaatne või karbonaadivaba liivsavi ja saviliiv moreen. Neljanda UA Mooste (Mst) mullastik on iseloomulik Kagu-Eesti lavamaade moreenitasandike või ka uhutud moreenitasandikega maastikele, milliste taustal esineb ka nii orulaadseid kui ka moreenikühmudest koosnevaid pinnavorme. Peale Põlva, Tartu ja Viljani maakondade esineb taolisi maastikke vähemal määral ka Valga ja Võru maakondades. Kagu-Eesti lavamaade En mullad on kujunenud kas erineva karbonaatsusega punakaspruunil saviliiv või liivsavi moreenidel, liustiku sulamisvetest pärinevatel põimjaskihilistel mõhnaliivadel või mitmekihilistel lõimisega lähtekivimitel. Kõigi erosioonist mõjutatud mullastikuga aladel esineb D muldade lähtematerjaliks olevat nõlva ehk deluviaalset setet.

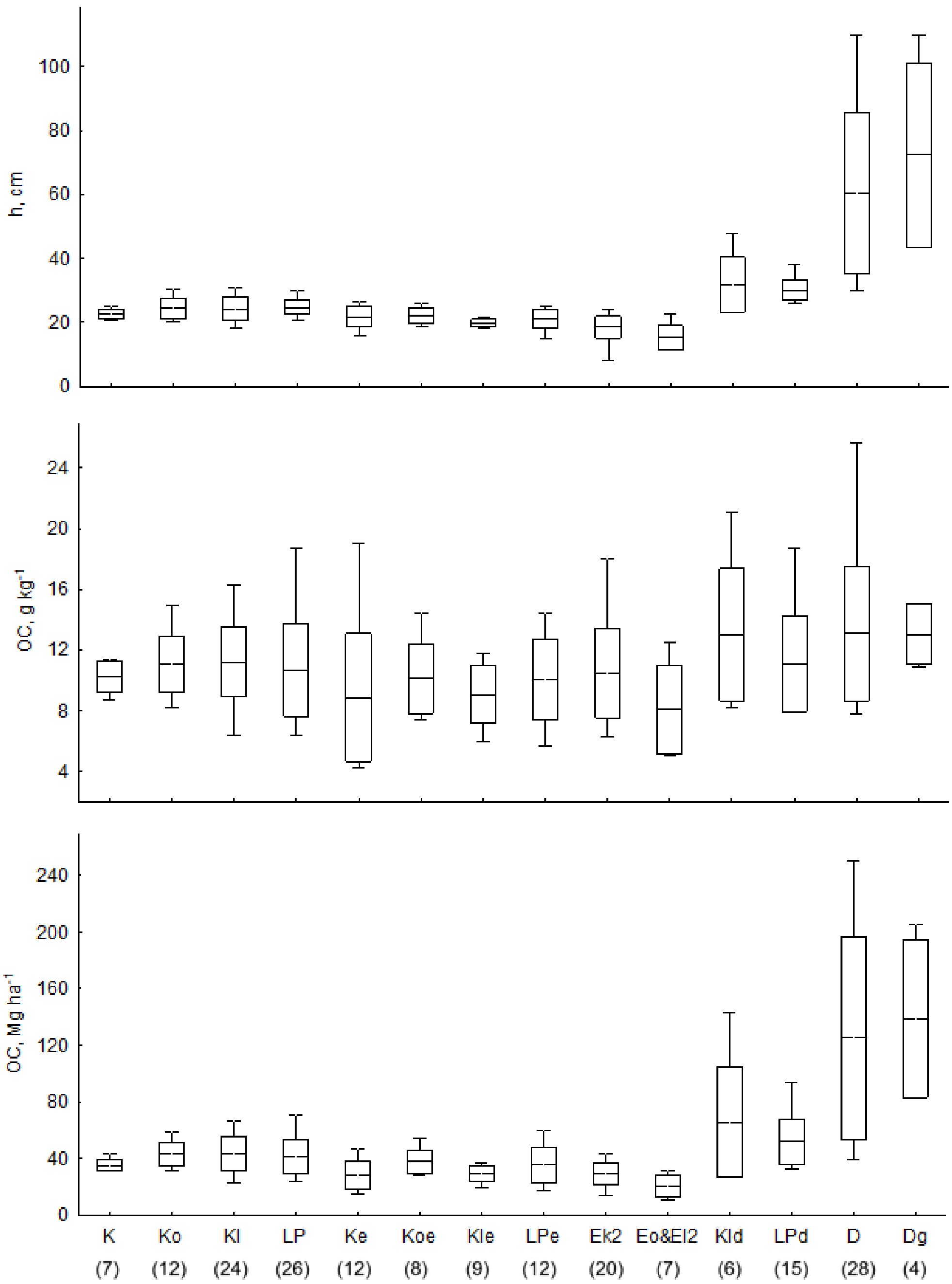
Hnj, Otp ja Vlg UA E mullad levivad künklike põllumaade kühmude, künniste, kuplite ja seljakute lagedel ning nende nõlvade ülemistel kumeratel osadel. UA Mst E mullad esinevad tugevasti liigestatud tasandike orulaadsete pinnavormide nõlvade ülemistel servadel. E muldadele kaasnevad D mullad esinevad positiivsete pinnavormide alumistel nõgusatel nõlvadel, jalamitel ja lohkudes või E muldadega vahetult piirnevatel kallakutel või tasandike madalamatel osadel. Selgub, et EHM võivad erineda väga suurtes piirides oma HS, veeolude ja agrokeemiliste omaduste poolest ning järelikult ka viljakuse ja kasutussobivuse poolest.

Erosioonist mõjutatud maastike kõrgematel osadel domineerivad E1 ja E2 mullad ning madalamatel aladel Dam või Dg mullad. Piiratud ulatuses esineb kõigi UA-de haritava maa kõrgemate aladel E3 ja madalatel DG muldasid. EHM moodustavad koos En muldadega väga mitmesuguseid kohalikele mullatekketingimustele vastavaid muldade kooslusi. Nii kaasneb EHM-dele maastiku madalamatel osadel olulises mahus madalsoomuldi. Märgadele aladele omaselt esineb ka mõne protsendi ulatuses glei- (2–3%) ja rabamuldi (1–3%) ning vooluvee sängidele moodustunud lammimuldi (<1%). Parasniiskete ja gleistunud En muldade osakaal oleneb erosiooni toimumise eeldustest UA-l, olles suurem vähema erosiooniohtlikkusega aladel. Kui Hnj UA on En muldade osakaal väga väike (<1%), siis tunduvalt suurem on see Otp UA-l (12%) ja veelgi suurem Mst UA-l (>70%). UA-de mineraalsete muldade lõimiste, mis on erosiooniprotsesside toimumise üheks eelduseks, võrdlusest selgub, et lõimise poolest on kõige erosiooniohtlikum Mst UA, millele järgneb Hnj UA, kuid kõige vastupidavamad on Otp ja Vlg UA-d, kus on rohkem liivsavi ja saviga alasid.

Uurimusest tulenevad EHM huumusseisundi kvantitatiivsed näitajad

EHM leviku muster ja HS suur mitmekesisus on tingitud peamiselt erosiooni astmest, ära- ja pealeuhte iseloomust, mulla lõimisest, karbonaatsusest ja happesusest. EHM mitmekesisus on põhjustatud veel ka ala geomorfoloogilisest mitmekesisusest, hüdroloogilistest tingimustest, ala ekspositsioonist ilmakaarte suhtes, asukohast maastikul ja maaharimise tehnoloogiast. Paremaks muld- ja taimkatte vastastikuste seoste mõistmiseks käsitleti EHM seisundit ökosüsteemi tasemel regioonile tüüpilistel mullaliikidel ja majandamise tingimustes.

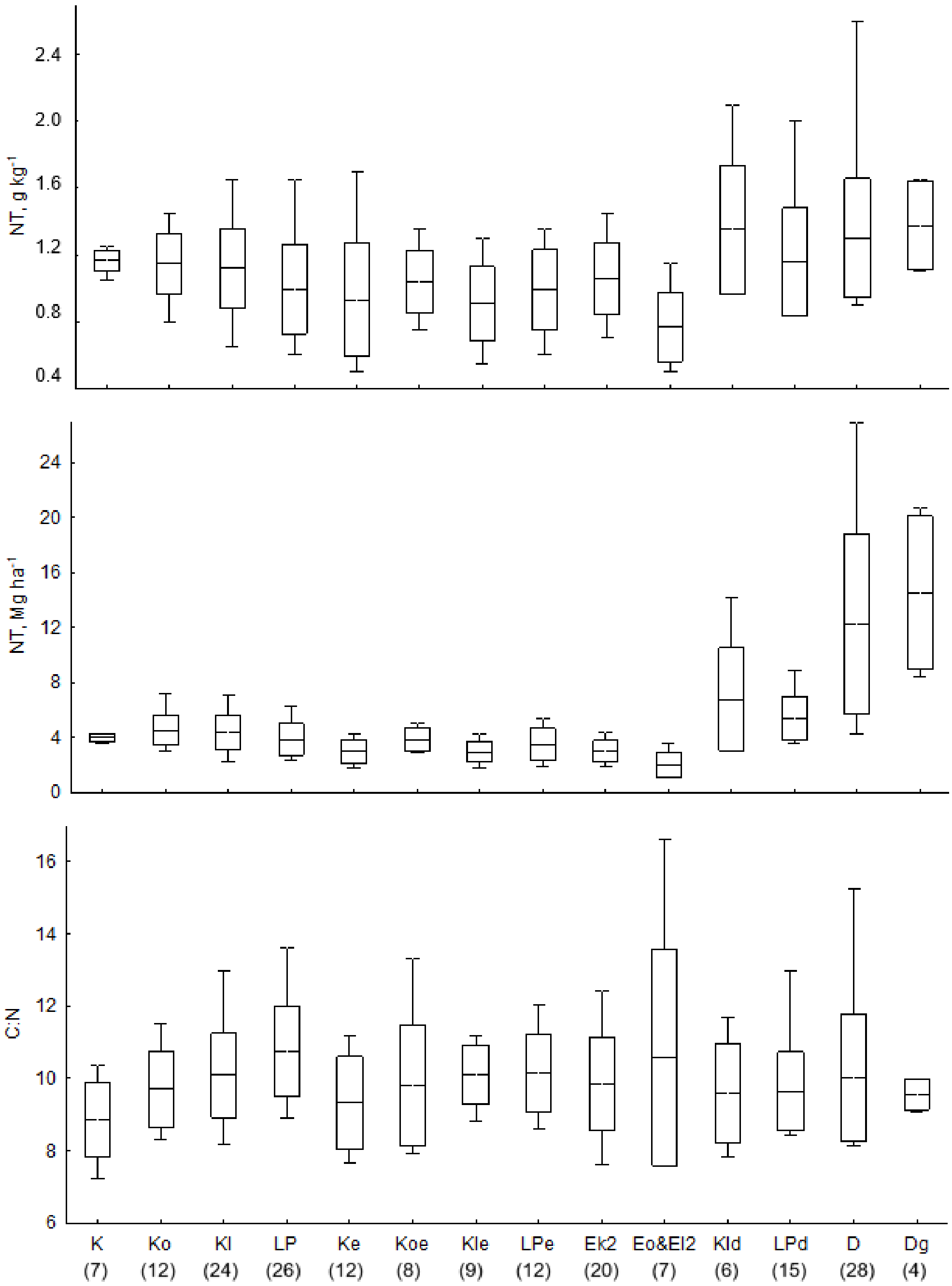
Erosioonist mõjutatud muldkatete omadusi iseloomustavad näitajad varieeruvad sõltuvuses nende formeerumise tingimustega (joonis 2). Võttes aluseks kvartiilid selgub, et EHM HK tüsedused varieeruvad E muldadel piirides 18–23 cm, D muldadel 30–65 cm ja erosioonist mõjutamata En muldadel 22–27 cm. OC-sisaldused varieeruvad erosioonist häiritud maastikel tunduvalt vähemal määral, kusjuures E, D ja En muldade OC-sisalduse mediaansuurused on vastavalt 9,4, 11,2 ja 10,9 g kg^{-1}. EHM kvaliteedi ja kasutussobivuse hindamisel on siiski oma sisu poolest parimaks ja enamal määral integreeritud näitajaks OC varu. Olgugi, et jooniselt 2 selguvad OC varude erinevused E ja D muldade ning justkui etaloniks oleva En mullagruppide vahel, esitame siinjuures ka vastavate mullagruppide huumuskatte OC varud ülemise ja alumise kvartiili piires, mis on E muldadel 24–36, D muldadel 51–143 ja En muldadel 32–49 Mg ha^{-1}.



Joonis 2. Erosioonist häiritud põllumullaliikide huumuskatte tüsedused (h, cm) ning mulla orgaanilise süsiniku (OC) kontsentratsioonid (g kg^{-1}) ja varud ehk pindtihedused (Mg ha^{-1}) Valgjärve uurimisalal. Joonisel on esitatud: — aritmeetiline keskmine, ☐ keskmine ±SD, ⌶ min−max ning sulgudes mõõtmiste arv.

Figure 2. *Depth of humus cover (h, cm), and concentration (g kg^{-1}) and stock densities (Mg ha^{-1}) of soil organic carbon (OC) in different arable soil species' humus cover on Valgjärve research area. On the figure are presented: — Mean, ☐ Mean ±SD, ⌶ min−max and in brackets below the figure the number of samples.*

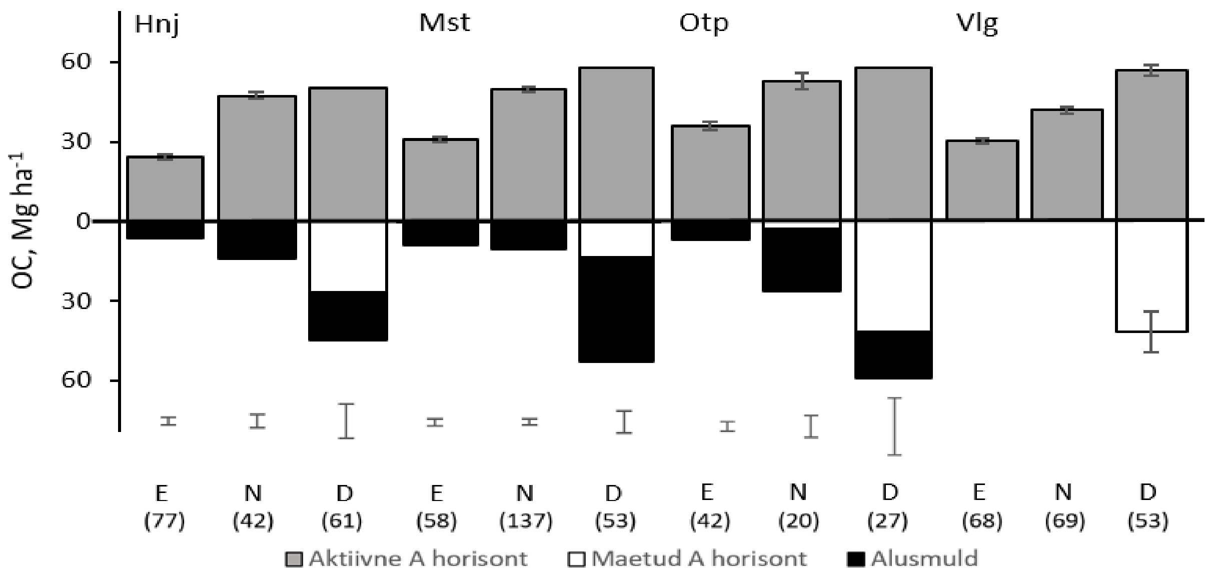
Kuna muldade lämmastikuseisund on sarnaselt OC-ga seotud MOA-ga, on ka NT kontsentratsioonides ja mulla HK NT varudes mullaliikide kaupa sarnased seaduspärasused (joonis 3). Ennekõike näitab seda suhte C:N võrdlemisi väike varieeruvus EHM-des, kusjuures C:N suhte mediaansuurused E, D ja En muldades on vastavalt 9,8, 9,4 ja 10,2. Samas on En muldade puhul näha suhtarvu suurenemise tendentsi minnes karbonaatsetelt muldadelt happelisematele muldadele. On näha, et C:N suhtarvu laienemine En muldades on tingitud NT kontsentratsiooni vähenemisest HK-s. Kui jooniselt 2 on näha, et EHM kolme mullagrupi OC varude omavahelist suhet iseloomustab valem D > En > E, siis jooniselt 3 selgub, et sama seaduspärasus kehtib ka NT varude kohta.



Joonis 3. Eesti erosioonist häiritud põllumullaliikide huumuskatete üldlämmastiku (NT) kontsentratsioonid (g kg^{-1}) ja varud ehk pindtihedused (Mg ha^{-1}) ning C:N suhe. Joonisel on esitatud: — aritmeetiline keskmine, □ keskmine ±SD, ⌶ min−max ning sulgudes mõõtmiste arv.

Figure 3. *Total nitrogen (NT) concentrations (g kg^{-1}) and stock densities (Mg ha^{-1}), and the ratio C:N in humus cover of different arable soil species of erosion-affected soils. On the figure are presented: — Mean, □ Mean ±SD, ⌶ min−max and in brackets below the figure the number of samples*

Kõigi uurimisalade E muldade huumusvarud on erosiooni tagajärjel vähenenud, mida näitab nende OC varu, mis on kõigil neljal uurimisalal piirides 17–39 Mg ha^{-1} (joonis 4). Nii E ja D vahelistel üleminekualade muldade (46–56 Mg ha^{-1}) kui ka normaalsete erosioonist häirimata muldade (Vlg, 40 Mg ha^{-1}) OC varud on vastavalt 1,7 ja 1,4 korda suuremad E muldade näitajatest. Märkimisväärsed OC kogused esinevad erosioonist häiritud aladel ka alusmullas, millised võivad õhukesema Ae korral osaleda aktiivses bioloogilises ringes. Erosiooniala muldade negatiivseks ilminguks agronoomilisest aspektist on maetud Ad horisondi varud koos sellest veelgi sügavamal asuvate alusmulla OC varudega. Nende maetud varude (UA mediaanid E muldades 5–8, N muldades 10–24 ja D muldades 16–40 Mg ha^{-1}) tekkimine, mis on agronoomilisest aspektist negatiivne nähtus, on samas süsinikupoliitika aspektist hinnatuna positiivne.



Joonis 4. Orgaanilise süsiniku (OC) keskmised (±SE) varud (Mg ha^{-1}) erosioonist häiritud muldade erinevates muldkatte kihtides. Uurimisalad: Hnj – Haanja, Mst – Mooste, Otp – Otepää ja Vlg – Valgjärve; mulla kihid: 1 – aktiivne A horisont, 2 – maetud A horisont ja 3 – alusmuld; mullad: E – erodeeritud, N – üleminekuala ehk neutraalsed mullad, D – deluviaalsed mullad; NB! Vlg uurimisalal on N puhul esitatud erodeerumata (En) mullaliikide keskmised; joonise kohal olevad vuntsid iseloomustavad aktiivse A horisondi varu standardviga (SE), all olevad aga orgaanilise süsiniku (OC) koguvaru varieerumist; joonise all sulgudes olevad arvud kajastavad mõõtmiste arvu

Figure 4. *Mean (±SE) soil organic carbon (OC) stocks in different layers of erosion-affected soils' (EAS) species. Research areas: Hnj – Haanja, Mst – Mooste, Otp – Otepää and Vlg – Valgjärve; soil layers: 1 – active A horizon, 2 – buried A horizon and 3 – subsoil; soils: E – eroded, N – neutral or transitional, D – deluvial soils; NB! on research area Vlg by N the uneroded normal soils (En) are presented; the vertical bars on columns indicate the standard error (SE) of active A horizon, but under the columns – the same of the whole soil cover OC stock; in brackets below the figure a sample size is given. Legend: Aktiivne A horisont – Active A horizon; Maetud A horisont – Buried A horizon, Alusmuld – Subsoil*

Kuigi OC ja NT kontsentratsioon E1 muldades on lähedane võrreldes analoogse geneesiga En muldadega, väljenduvad nende erisused siiski selgelt OC ja NT varudes. Enamuses juhtudel on OC ja NT kontsentratsioon madalaim E2 muldades ning kõrgeim D muldades. Taoline seaduspärasus leiab kinnitust ka nende varude kaudu haritava maa HK-s. Mullaerosiooni mõju mulla HS-le väljendub kõige selgemalt OC ja NT varude kaudu, mis vähenevad tunduvalt E2 ja E1 muldades võrreldes En muldadega. Samas suurenevad nõrgalt pealeuhutud (KId, LPd) muldade OC ja NT varud kuni vastavalt 50–70 ja 5–7 Mg ha^{-1} ning keskmiselt ja tugevasti pealeuhutud (Dam, Dg) D muldade varud kuni 120–140 ja 12–14 Mg ha^{-1}.

C:N suhe on enamjaolt piirides alates 9 kuni 11, olles pisut suurem enam erodeeritud ja happelisemates muldades. Olulist mõju huumuse formeerumisele ja varude kujunemisel avaldab NT-sisaldus, mis on tähtsaks komponendiks huumuse koostises, mõjutades selle kvaliteeti (Christopher, Lal, 2007; Poeplau jt, 2018). Muldade HS, sh OC ja NT kontsentratsioon, varud ja omavaheline suhe, on seisundit määrava tähtsusega näitajad, sest nendest sõltub muldade produktiivsuse tase ja sobivus erinevatele kultuuridele. Analüüs EHM maatriksi taustal näitab, et HS näitajad seostuvad hästi muldade erosiooni astme ja karbonaatsusega.

Erosioonist häiritud muldkatte kasutamine ja kaitse

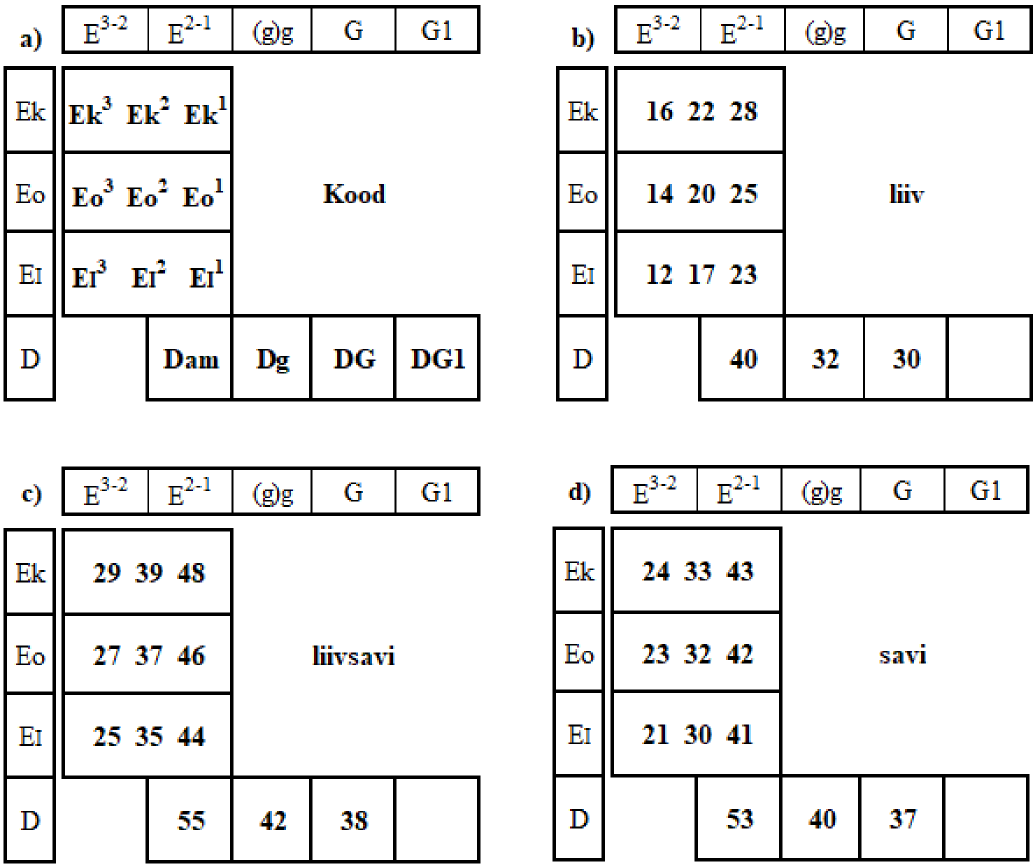
Eestis peetakse igati mõistlikuks maaelu säilimist ka EHM levikuga aladel, seega ei ole otstarbekas loobuda seal ka tegelemisest kohalikke vajadusi rahuldava põllumajandusega. Mullakaitse häid tavasid arvestav põllumajanduslik tootmine tagab samas ka künkliku pinnamoega looduskaunite põllumajandusmaastike säilimise. Muldade minimaalse degradeerumise huvides on vaja neid majandada erosiooni ärahoidvalt või seda vähendavalt (Lutsar, 1982; Hellin, 2006; Spaan jt, 2006). Kui klassikalise mullakaitse seisukohalt on kõige õigem võtta erosioonist enam häiritud mullad kasutusele ennekõike rohumaadena, siis maaelu edendamisel on vaja EHM-dega aladel leida võimalusi ka teravilja ja rühvelkultuuride kasvatamiseks. Selleks enamsobivate muldade väljavalimisel on oluliseks toeks ülevaated nii üksikute mullaerimite ja/või mullaliikide kui ka mullakoosluste OC ja NT seisunditest. Eesti maastike mitmekesisuse ja rekreatsiooni eesmärkideks sobivuse huvides tuleks künklikel aladel vältida laialdast metsastumist. Selles plaanis on osutunud efektiivseimaks võtteks niidetavate rohumaade rajamine, mis ühtaegu kaitseb kiirendatud erosiooni eest ja takistab metsastumist (Fullen jt, 2006). Künkliku maastiku looduslikud rohumaad kaitsevad mulda hoides ära kiirendatud erosiooni. Taoliste erosiooniohtlike alade haritavateks muutmisega kaasneb reeglina kiirendatud mullaerosioon. Kuna mullaerosiooni ärahoidvate ja/või leevendamise võtete kasutamine lokaalselt s.o erosiooniohtlikes piirkondades, nõuab asjaosalistelt täiendavaid kulutusi on ühiskond leidnud võimalusi taoliste kulude kompenseerimiseks (PMKT, 2019).

EHM-ga maastikel on selgemini kui mujal tajutav muldade pidev ühest mullast teiseks muutumise (kontiinuumi) printsiip (Kokk, Rooma, 1971; Heinsalu, 1982; Kõlli, 1993). Selle nähtuse võimalikult adekvaatsemaks kajastamiseks kasutati HS uurimise transektide (HT) meetodit. Maastikele rajatud HT-de abil selgitati põhjalikumalt mullaliikide varieeruvust ehk heterogeensust ning täpsustati E ja D muldade üleminekualal olevate ehk neutraalsete (N) muldade esinemise seaduspärasusi, morfoloogiat ja huumusseisundit. Kõiki nimetatud näitajaid ei ole võimalik kajastada suuremõõtkavalisel (1:10000) mullastiku kaardil.

EHM-dele rajatud HT uurimine on näidanud suhteliselt suuri HS muutusi piki transekti, mis on osaliselt põhjustatud ka mullaharimisest. Maaharimisest põhjustatud tehnoloogilise erosiooni olemasolu näitavad suuremad A horisondi tüsedused nõgusatel ja põldude madalamatel osadel ning väiksemad põldude kumeramatel osadel (Van Oost jt, 2006). Kui Lõuna-Eestis on põllumuldade HS degradeerumisel juhtivaks teguriks vee-erosioon, siis Kesk- ja Põhja-Eestis on selleks tehnoloogiline erosioon. Üldiselt on teada, et maaharimise kaudu toimunud mullamassi ümberpaiknemised on selgemini väljendunud kruusakatel liivadel ja saviliivadel, mis oma hea vee-läbilaskvuse tõttu on vähem häiritud vee-erosioonist. MOA kadu erosiooni läbi ja tema kiirendatud mineraliseerumine kitsendavad C:N suhet mullas olevas orgaanilises aines (Shaffer, Ma, 2001). Erosiooniohtlike muldade degradeerumise riski aitab vähendada ka minimeeritud pinnapealne maaharimine ja otsekülv. Üldiselt on soovitatav siiski mitte kasutada E3 muldasid haritava maana, vaid püsirohumaadena, kuigi levinud võtteks nende kaitsmise huvides on metsastamine või jätmine looduslikku olekusse nagu seda on valdavalt tehtud E4 muldade korral.

Arutlused ja märkused Eesti erosioonist häiritud muldade kohta

EHM OC ja NT kontsentratsioon, varu ja C:N suhe on töös antud valdavalt haritavate maade HK kohta. Tingituna erosiooniprotsessidest on erosioonist mõjutatud muldkatete heterogeensus tunduvalt suurem võrreldes normaalselt arenenud muldkatetega. Üheks parimaks põllumajanduslikult kasutatavate muldade indikaatoriks ehk kvaliteedi näitajaks on tema agronoomilisest seisukohast lähtuv mulla boniteet (Kask, 1975), mis kajastab potentsiaalset viljakust ja tuleneb mullaliikide HS-st (sh OC ja NT seisundist) ning taimekasvatusliku potentsiaali määrast (joonis 5). EHM süsinik- ja lämmastikseisundid on otseselt seotud muldade produktiivsusega. Et suur osa MOA koostise talitlusest määratakse ära OC- ja NT-sisaldustega, on vastavad andmed olulised mulla huumusseisundi, ökoloogia ja produktiivsuse mõistmise seisukohalt.



Joonis 5. Erosioonist häiritud muldade boniteet hindepunktides olenevalt mulla lõimisest (Maa-amet, 1992)
Figure 5. *Quality of erosion-affected soils in points as a dependent of their texture (Maa-amet, 1992). EAS's codes and texture: kood – code, liiv – sand, liivsavi – loam, and savi – clay*

Mulda läbiva MOA voo (sisend → olek → väljund) iseloomustamisel on heaks kvantitatiivseks näitajaks aasta fütoproduktiivsus ja sellega seoses olev uue MOA sisend mulda. Mõlemad need näitajad on tihedalt seotud ökosüsteemis toimuvate OC ja NT voogude ja ringetega (Chapman jt, 2013). Need protsessid on seotud muldkatte koosseisus olevate erinevate mullaliikide OC ja NT akumuleerimise võime ning C:N suhtega. Ökosüsteemse lähenemise printsiibi järgi tuleks muldkatte omaduste kõrval arvestada ka taimkatte, muldadele kohandunud organismide koosluste ja ümbritseva ala hüdroloogiliste oludega.

Muldade mitmekesisus (*pedodiversity*), mis on suuresti tingitud maa-ala geomorfoloogilisest ja geoloogilisest mitmekesisusest (*geodiversity*) determineerib omakorda ökoloogiliselt sobiva taimestiku ja sellega kaasneva elustiku (*biodiversity*). Koos EHM ehk E ja D muldadega esinevad maastike kõrgematel tasastel osadel erosioonist mõjutamata normaalse arenguga erinevad automorfsed mullad nagu K, Ko, KI, LP ja Lk ning madalamatel osadel hüdromorfsed glei-, turvastunud glei-, madalsoo- või lammimullad. Seega moodustuvad erosioonist häiritud aladel üksteisest suuresti erinevad, kuid ala mullatekketingimustega kooskõlas olevad muldade kooslused.

Nähtub, et Ae horisondi tüsedus ei sobi hästi E mulla erosiooniastme määramiseks, sest muld võib olla küntud sügavamalt kui seda on põhjustanud erosioon. Ei sobi ka OC kontsentratsioon (g kg^{-1}), sest muld võib olla lahjendatud huumusesisalduse suhtes liialt sügava künniga. Heaks erosiooni astmete eristamise aluseks on OC varu või pindtihedus (Mg ha^{-1}) HK kohta. Ka D muldadel sobib põhinäitajaks OC varu. Samas iseloomustab keskmiselt ja tugevasti pealeuhutud D muldasid hästi ka Ad tüsedus, sest sel juhul on piir maetud ja pealeuhutud mulla vahel morfoloogiliste tunnuste järgi kergemini määratav. Nõrgalt pealeuhutud D muldade ei saa Ad tüsedus olla objektiivseks näitajaks.

Liialt sügava künni tõttu toimub E muldadel OC ja NT kontsentratsiooni vähenemine, kuna olemasolev varu on lahjendatud alt ülestoodud huumusvaesema mullaga. Huumusevaesemaks võib olla muutunud ka E ja D muldade üleminekuala N mullad. D muldadest on sügava künni tõttu olnud mõjutatud vaid nõrgalt peale uhutud D mullad. Tavaliselt on D muldade OC-sisaldus veidi kõrgem E muldadest tänu peenestunud orgaanilise aine osiste lisandumisele mulda. Samas on E3 muldadele kaasnevad D mullad tunduvalt vaesemad OC poolest võrreldes vähemal määral erodeeritud muldadele (E2, E1) kaasnevate D muldadega.

Erosioonist häiritud alade huumusbilanss on tervikuna positiivne ehk need alad talitlevad OC akumuleeriva muldkattena. Nii ulatub keskmiselt ja tugevasti pealeuhutud D muldade OC varu, mis on kõrvaldatud bioloogilisest aineringest ehk on maetud varu, piiridesse 17–37 Mg ha^{-1}. Seda näitab ka lineaarsest aspektis arvutatud E mulla ümberpaiknemise koefitsient D mulda, mis on piirides 2,1–2,7. EHM-dega maa-alade OC akumulatsiooni mehhanism seisneb selles, et teatud osa igal aastal E mulda sattunud uuest taimsest varisest kantakse (nii tugevasti peenestatud kui ka humifitseerunud kujul) erosiooni käigus koos mulla mineraalsete osistega (millised võivad olla seotud stabiilse huumusega) maastiku madalamatele osadele, kus nad moodustavad D mulla. Järjestikuste uute D mulla kihtide ladestumisega maetakse eelmised järjest sügavamale kuni nende väljalülitumiseni aktiivsest bioloogilisest aineringest. Seega moodustub D mulla alla suhteliselt suur huumuse (või OC) varu, mis võib seal säilida aastakümneid muutumatul kujul.

Euroopa vaatepunktist lähtudes, peetakse muldade erosiooni osas tähtsaimaks asjaks piirkondlike (sh riikide lõikes) erosiooni intensiivsuste erisuste või sarnasuste väljaselgitamist, tehes seda 1:250000 ja veelgi üldisemate mullakaartide ja andmebaaside põhjal (Montanarella, 2003; Bullock, Montanarella, 2005). Erinevate üle-euroopaliste koondandmete järgi on EHM osatähtsus Eestis ja erosiooniprotsesside intensiivsus suuresti varieeruv, kuid keskmisena suhteliselt tagasihoidlik ca 0,4 Mg ha^{-1} a^{-1}, ulatudes vähestel aladel piiridesse 1–2 Mg ha^{-1} a^{-1} (Kask jt, 2006; Cerdan jt, 2010; Panagos jt, 2014). Samas ulatub see näitaja tugevasti erosiooniohtlike muldkatetega riikides piiridesse 2–5 Mg ha^{-1} a^{-1}. Köster jt (2010) andmetel on Eesti keskmine erosiooni intensiivsus loodusliku taimkatte korral ligikaudu 0,04 t ha^{-1} a^{-1}, kuid haritavatel muldadel *ca* 0,43 Mg ha^{-1} a^{-1}.

Kokkuvõtteks

- Kagu-Eesti erosioonist häiritud põllumajandusmaastike muldkattes varieeruvad E muldade OC varud piirides 24–36 Mg ha^{-1} ja D muldade varud piirides 51–143 Mg ha^{-1}.
- Eesti erosioonist mõjutatud regioonides tuleks toetada kohalikke vajadusi rahuldavat põllumajanduslikku tegevust, mis on samal ajal looduskauni ja mitmekesise maastiku säilimise eeltingimus.
- EHM suure osakaaluga muldkate talitleb kui OC akumulaator seoses E muldadel toodetud huumuse ümber paiknemise ja mattumisega D muldadesse ehk väljalülitumisega pikaks ajaks aktiivsest bioloogilisest ringest.
- Suur mullastiku mitmekesisus *(pedodiversity)* erosioonist häiritud aladel, mis on tingitud selle ala suurest geomorfoloogilisest ja geoloogilises mitmekesisusest *(geodiversity)*, on peamine tegur selle ala bioloogilise mitmekesisuse *(biodiversity)* kujunemisel.

Organic carbon and nitrogen content in Estonian erosion-affected soils

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Summary

Erosion-affected soils (EAS) are abnormal or synlithogenic agriculturally used mineral soils, where

normal soil-forming processes have been influenced by soil erosion. In the work, their forming conditions and the nomenclature of EAS are treated. The main criteria of eroded (E) soils determination are the intensity or stage of erosion and calcareousness of soils, but of deluvial (D) soils the water regime and the thickness of formed colluvial horizon. Neutral (N) soils are transitional soils between E and D soils and non-eroded (En) soils are those where is absent the denudation and sediment accumulation.

Humus status (HS) of soil reflects the whole soil organic matter presented in various soil horizons and being in various stages of decomposition embracing all links of soil organic matter flow throughout the soil. The essential compartments of soil HS are its organic carbon (OC) and total nitrogen (NT) contents and ratio C:N in soil. For characterization of EASs' HS, their OC and NT contents (g kg^{-1}), superficial densities (Mg ha^{-1}) and ratio C:N were studied by soil layers of arable soil species.

Quantitative parameters treated in the work were derived from (1) Database (DB) of arable EAS monitoring on the Valgjärve research area; (2) DB Estonian soils in numbers, formed in the course of large scale soil survey of Estonia; (3) DB Pedon about soil profiles' horizons created during 1967–1985 by us, and (4) DB on humus transects established for research of arable soils HS.

Using as a base of comparing data's quartiles it reveals, that EAS's HC thicknesses of research area Valgjärve E soils are in limits 18–23 cm, D soils 30–65 cm and of En soils 22–27 cm. The concentrations of OC in influenced by erosion landscapes vary only in modest extent, whereas the E, D and En soils' OC contents medians are accordingly 9.4, 11.2 and 10.9 g kg^{-1}. The OC stocks given in the limits of quartiles is in E soils 24–36, D soils 51–143 and En soils 32–49 Mg ha^{-1}. The medians of C:N in E, D and En soils are accordingly 9.8, 9.4 and 10.2. Therefore, on eroded areas, the perpetual continuums of soil properties' (among these HS) changes may be followed and it is very complicated to separate soil contours on 1:10 000 soil maps. In this work, these transitional areas between E and D soils are characterized as N soils.

On erosion-affected areas, the E and D soils form different soil associations with auto- and hydromorphic normally developed non-eroded soils, where very commonly as well the fluvial (abnormal) soils are presented. The relatively high pedodiversity caused by the areas high geodiversity is requisite to the high plants and soil organisms' biodiversity. In erosion-affected regions is extremely important to maintain agricultural activity, as with this is ensured the persistence of naturally beautiful landscapes. The soil cover with EAS acts as an accumulator of formed on the same area soil OC.

Huvide konflikt / *Conflict of interest*

Autor kinnitab artikliga seotud huvide konflikti puudumist. *The author declares that there is no conflict of interest regarding the publication of this paper.*

Autorite panus / *Author contributions*

RK, KK, TT – artikli kontseptsioon ja planeerimine / *study conception and design*;
RK – andmete kogumine / *acquisition of data*;
KK, RK – andmete analüüs / *analysis of data*;
KK – illustreeriva materjali vormistamine / *design of figures*;
RK – käsikirja mustandi kirjutamine / *drafting of manuscript*;
RK, KK, TT – lõpliku käsikirja toimetamine ja heaks kiitmine / *critical revision and approve the final manuscript*.

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BIO-FERTILIZER ACTIVITY OF *TRICHODERMA VIRIDE* AND *PSEUDOMONAS FLUORESCENS* AS GROWTH AND YIELD PROMOTER FOR MAIZE

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ABSTRACT. The bio-fertilizer potential of *Trichoderma viride* and *Pseudomonas fluorescens* on growth and yield performance of open-pollinated maize variety Rampur Composite was studied at the research farm of Agriculture and Forestry University (AFU), Rampur, Chitwan, Nepal during the winter season of 2018/19. The experiment was laid out in randomized complete block design with seven treatments (T1: recommended dose of NPK (120:60:40 kg NPK ha^{-1}), T2: *T. viride* only, T3: *P. fluorescens* only, T4: *T. viride* + 50% NPK; T5: *P. fluorescens* + 50% NPK; T6: *T. viride* + *P. fluorescens* + 100 % NPK, T7: control) and replicated thrice. The package of agronomic practices was followed as per national recommendation. The result revealed that *T. viride* + 50% NPK enhanced most of the growth components like plant height (103%), leaf number (9.77%), stem diameter (73.98%), root length (40.57%), leaf area index (173.28%), leaf biomass (83.36%) and stem biomass (127.72%) of maize compared to the control. Similarly, the higher cob biomass (641 g), yield (5708 kg ha^{-1}) and thousand kernel weight (295 g) were recorded in the plot applied to *P. fluorescens* + 50% NPK. The use of *Trichoderma viride* and *Pseudomonas fluorescens* with a half-dose of recommended fertilizers may increase the vegetative growth and yield of maize and may also help to reduce the rate of chemical fertilizers in maize.

Introduction

Maize (*Zea mays* L.) is the second important staple food crop in terms of area (954 158 ha) and production (2 555 847 t) with a productivity of 2 679 kg ha^{-1} in Nepal (MoALD, 2018). The productivity of maize in Nepal is very low compared to global yield with wide yield gap due to various biotic and abiotic factors (Subedi, 2015). Among yield-limiting factors, the management of fertilizers, particularly nitrogen, is crucial to increase the yield of maize. Chemical fertilizers have been used indiscriminately and have contributed to severe disequilibrium in agroecosystems due to pollution of soil, water, air and food, causing soil degradation and pest resistance, and a threat to human health (NMRP, 2016). Today, it is of great interest to reduce synthetic fertilization and to recover soil microflora utilizing strategies that make it possible to improve agricultural productivity in a non-polluting manner. Bio-fertilization with microorganisms (like *Trichoderma* and *Pseudomonas*) is a common method used in various crops in different parts of the world to improve the growth and yield components. *Trichoderma* and *Pseudomonas* are fungi and bacteria, respectively, considered very potent biological control agents against a wide range of pathogens of different crops (Subedi *et al*., 2015), using different control mechanisms such as antibiosis, lysis and mycoparasitism (Subedi *et al*., 2019). The strength of *Trichoderma and Pseudomonas* spp. as opportunistic microflora are well-known bio-stimulants (Candelero *et al*., 2015), characterized by their rapid growth, the ability to assimilate a wide range of substrates (Chen *et al*., 2006) and the production of a variety of microbial compounds, which stimulate the growth rate, yield and vegetal development of the crop. The maize roots colonized by microflora like *Trichoderma* and *Pseudomonas* spp. require 40% less nitrogen fertilizer in comparison to non-colonized roots, reducing fertilizers' application costs and improving the environment (Páez *et al*., 2006;

Harman, 2006). Bhusal *et al.* (2018) recorded that the application of *Trichoderma viride* was effective for leaf blast management in rice. Mahato *et al.* (2018) found that the application of *Trichoderma viride* as biofertilizer increased the grain yield in wheat. In this study, the effect of commercial formulation with *T. viride* and *P. fluorescens* applications alone or in combination with different doses of chemical fertilizer on maize growth and yield components were investigated. The study aimed to evaluate *T. viride* and *P. fluorescens* as biofertilizers for their ability to promote growth and yield of maize crop.

Materials and methods

The experiment was conducted at the research farm of Agriculture and Forestry University (AFU), Rampur, Chitwan, Nepal during the winter season of 2018/19. The latitude, longitude and altitude of the experimental site was 27° 40’N 84° 19’ E, and 228 masl respectively. The experiment was laid out in randomized complete block design (RCBD) with seven treatments and replicated thrice. The treatment combinations were T1: Recommended dose of NPK (120:60:40 kg NPK ha^{-1}), T2: *Trichoderma viride* only, T3: *Pseudomonas fluorescens* only, T4: *Trichoderma viride* + 50% NPK; T5: *Pseudomonas fluorescens* + 50% NPK; T6: *Trichoderma viride* + *Pseudomonas fluorescens* + 100 % NPK and T7: control. The micro-floras used in the experiment were the commercial formulation of Biocide Trivi (*Trichoderma viride* – 1×10^9 cfu ml^{-1}) and Guard (*Pseudomonas fluorescens* – 1×10^9 cfu ml^{-1}) received from Agricare Nepal Private Ltd, Bharatpur, Chitwan. The commercial formulation of micro-floras was prepared separately at 2.5 ml each in 5% sugar solution on 1 litre of water and inoculated with the seed of open-pollinated variety Rampur Composite at 2.5 ml kg^{-1} of seed. The unit plot size was 6 rows of 6.5 m length with a row spacing of 0.60 m and plant spacing of 0.25 m. All agronomic practices were followed as per standard of National Maize Research Program, Rampur (NMRP, 2016). In the case of fertilizer, Di-ammonium phosphate (DAP) and Murate of potash (MoP) were applied as basal whereas urea was top-dressed in three splits to the doses mentioned in the treatments. Five plants from each experimental plot were randomly selected for data collection. Data on growth and yield attributing components like plant height (cm), leaf number, stem diameter (cm), root length (cm), leaf area index, leaf biomass per plant (g), stem biomass per plant (g), cob biomass per plant (g), grain yield (kg ha^{-1}) and thousand kernel weight (g) were recorded (CIMMYT, 1985). Leaf area index was calculated dividing leaf area (m^2) by ground coverage of maize (m^2). Grain yield was adjusted to 80% shelling recovery and 15% moisture level. The growth and yield parameters increased over the control was calculated. The soil samples were collected from two different depths (15 and 30 cm) from the experimental field and analyzed in the laboratory of soil science division, NARC, Khumaltar, Lalitpur. The pH, organic matter, nitrogen, phosphorus, and potash content of the soil samples were analyzed (Motsara, Roy, 2008). Microsoft Excel was used for tabulation of data and simple calculation. Data were analyzed statistically by performing analysis of variance (Steel, Torrie, 1980) by using GenStat software (18th edition) and the means were separated by using Duncan's Multiple Range Test (DMRT) at 5% level of significance.

Results

The growth parameters like plant height, stem diameter, root length and leaf area index differed significantly among the treatments (Table 1). The higher plant height (250 cm), stem diameter (2 cm) root length (28 cm) and leaf area index (4) of maize were recorded in the plot with *Trichoderma viride* + 50% NPK whereas the lower plant height (123 cm), stem diameter (1 cm) root length (20 cm) and leaf area index (2) of maize were recorded in control plot (Table 1).

Significant differences were revealed in the biomass and yield variables of maize among the treatments (Table 2). The higher leaf biomass/plant (845 g) and stem biomass/ plant (2637 g) of maize were recorded in the plot with *Trichoderma viride* + 50% NPK whereas higher cob biomass/plant (641 g), grain yield (5708 kg ha^{-1}) and thousand kernel weight (295 g) was recorded in the plot with *Pseudomonas fluorescens* + 50% NPK. The lower leaf biomass per plant (461 g), stem biomass per plant (1158 g), cob biomass per plant (150 g), grain yield (4965 kg ha^{-1}) and thousand kernel weight (267 g) of maize were recorded in control plot (Table 2).

Table 1. Effect of treatments on growth traits of maize at Rampur, Chitwan during winter 2018

Treatment	Plant height, cm	Leaf number per plant	Stem diameter, cm	Root length, cm	Leaf area index
Recommended dose of NPK (120:60:40 kg NPK ha^{-1})	175^b	11	2^d	26^b	3^b
Trichoderma viride (1×10^9 cfu ml^{-1}) only	177^b	10	2^b	26^c	2^d
Pseudomonas fluorescens (1×10^9 cfu ml^{-1}) only	169^b	11	2^c	24^d	3^c
Trichoderma viride + 50% NPK	250^a	11	2^a	28^a	4^a
Pseudomonas fluorescens + 50% NPK	172^b	10	2^d	24^d	3^{cd}
Trichoderma viride + *Pseudomonas fluorescens* + 100% NPK	132^{bc}	10	2^e	23^e	2^e
Control	123^c	10	1^f	20^f	2^f
Grand mean	171	10	2	24	3
Significance with F-test	**	NS	**	**	**
LSD (0.05)	41.97	1.57	0.03	0.76	0.20
CV, %	13.80	8.50	1.00	1.70	4.40

Means in the column with the same superscript are not significantly different by DMRT $_{(P<0.01)}$, ** – significant at 0.01 level, NS – not significant

Table 2. Effect of treatments on biomass and yield of maize at Rampur, Chitwan during winter 2018

Treatment	Leaf biomass per plant, g	Stem biomass per plant, g	Cob biomass per plant, g	Yield, kg ha^{-1}	Thousand kernel weight, g
Recommended dose of NPK (120:60:40 kg NPK ha^{-1})	828^a	1568^e	621^a	5451^a	285^b
Trichoderma viride (1×10^9 cfu ml^{-1}) only	663^c	1860^b	537^b	5547^a	274^d
Pseudomonas fluorescens (1×10^9 cfu ml^{-1}) only	643^c	1759^c	428^c	5539^a	278^c
Trichoderma viride + 50% NPK	845^a	2637^a	451^c	5667^a	283^b
Pseudomonas fluorescens + 50% NPK	696^b	1749^c	641^a	5708^a	295^a
Trichoderma viride + *Pseudomonas fluorescens* + 100% NPK	562^d	1636^d	430^c	5496^a	284^b
Control	461^e	1158^f	150^d	4965^b	267^e
Grand mean	671	1767	466	5482	281
Significance with F-test	**	**	**	*	**
LSD (0.05)	22.48	47.75	39.99	356.80	2.27
CV, %	1.90	1.50	4.80	3.70	0.50

Means in the column with the same superscript are not significantly different by DMRT $_{(P<0.01)}$, * – significant at 0.05 level, ** – significant at 0.01 level

Growth parameters increased over the control

The result revealed that *T. viride* +50% NPK enhanced most of the growth components like plant height (103%), leaf number (10%), stem diameter (74%), root length (41%) and leaf area index (173%) of maize crop compared to control plot (Fig. 1).

Biomass and yield components increased over the control

The plot treated with *T. viride* + 50% NPK enhanced biomass like leaf biomass (83%) and stem biomass (128%) of maize compared to control. Similarly, the increased cob biomass (329%), grain yield (15%) and thousand kernel weight (11%) over the control was recorded in the plot applied to *P. fluorescens* +50% NPK (Fig. 2).

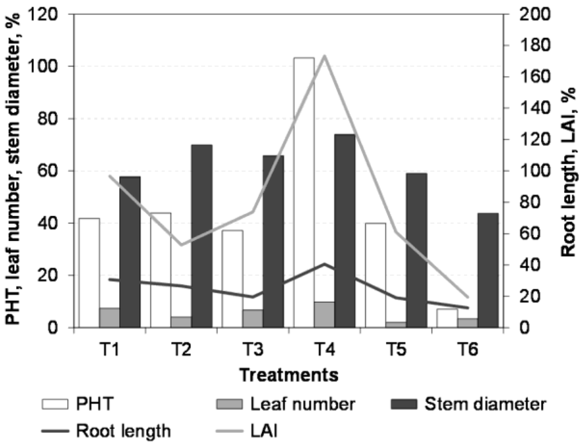

Figure 1. Effect of treatments on growth components increased over control plot at Rampur, Chitwan during winter 2018. (T1: recommended dose of NPK (120:60:40 kg NPK ha^{-1}), T2: *T. viride* only, T3: *P. fluorescens* only, T4: *T. viride* + 50% NPK; T5: *P. fluorescens* + 50% NPK; T6: *T. viride* + *P. fluorescens* + 100% NPK)

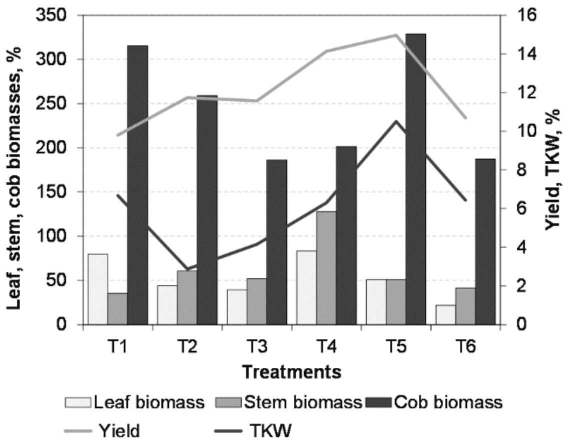

Figure 2. Effect of treatments on biomass and yield components increased over control plot at Rampur, Chitwan during winter 2018. (T1: recommended dose of NPK (120:60:40 kg NPK ha^{-1}), T2: *T. viride* only, T3: *P. fluorescens* only, T4: *T. viride* + 50% NPK; T5: *P. fluorescens* + 50% NPK; T6: *T. viride* + *P. fluorescens* + 100% NPK)

Soil analysis

The laboratory analysis of soil sample up to 15 cm depth revealed that the increased organic matter (23.25%), nitrogen (25%) and phosphorous (50%) over the control was recorded in the plot applied to *T. viride* + 50% NPK and *P. fluorescens* + 50% NPK (Table 3). Similarly, in 30 cm soil depth, the plot treated with *T. viride* + 50% NPK increased the amount of organic matter (35.99%), nitrogen (35.29%) and phosphorous (67.80%) over the control (Table 3). The amount of potassium was found higher in control plot both in 15 and 30 cm soil depth.

Table 3. Analysis of soil sample from the plots treated with *Trichoderma viride* and *Pseudomonas fluorescens* in combination with chemical fertilizer at 15 and 30 cm soil depths during winter 2018

Treatment	pH	Organic matter	Nitrogen	Phosphorus	Potassium
Soil depth (15 cm)					
Recommended dose of NPK (120:60:40 kg NPK ha^{-1})	4.7	2.78	0.14	51.75	39.65
Trichoderma viride + 50% NPK	5.2	3.14	0.16	94.35	28.32
Pseudomonas fluorescens + 50% NPK	4.8	3.14	0.16	94.81	22.66
Control	4.8	2.41	0.12	48.09	90.62
Soil depth (30 cm)					
Recommended dose of NPK (120:60:40 kg NPK ha^{-1})	4.5	2.84	0.14	39.85	28.32
Trichoderma viride + 50% NPK	5.2	3.39	0.17	54.04	28.32
Pseudomonas fluorescens + 50% NPK	4.9	2.29	0.16	50.84	22.66
Control	4.8	2.17	0.11	17.4	90.62

Discussion

The results obtained in this study are in agreement with López-Valenzuela *et al.* (2019) and García-Reyna *et al*. (2005), both of whom reported that, when inoculating maize seeds with soil micro-flora as growth and yield promoters, the average dry weight of maize foliage increased by 30% on an individual basis compared to the control plot and also reduced the nitrogen fertilization rate to 50%. Harman (2006) reported that maize roots colonized by *Trichoderma* spp. need 40% less nitrogen fertilizer in comparison to non-colonized roots. The findings of this study are also consistent with Páez *et al.* (2006) on inoculation with *Trichoderma* spp., which reduced the rate of nitrogen required by maize plants and, as a result, the cost of achieving appreciable environmental improvement. The result of the experiment is also in line with the findings of many studies conducted with various bacterial promoters of vegetable growth and yield in different soils, environments and crops of agronomic significance showed a 5 to 30% increase in yields, as well as a 25 to 50% decrease in the dosage of chemical fertilizers, such as nitrogen and phosphorus (Hernández-Escareño *et al*., 2015; García Crespo *et al*., 2012; Adesemoye *et al*., 2009; Aguado, Moreno, 2008). The findings achieved with soil microflora in this study can be attributed to the participation of these microorganisms in the biotransformation of cellulose, the acceleration of cell reproduction, the mineralization of nitrogen and the solubilization of phosphorus present in the soil, but also the increase in the volume of roots, the enhancement of their space for exploration and, as a result, obtaining more nutrients and water present in the soil favouring both growth and yield of the crops (Subedi *et al*., 2019; Santana *et al*., 2003).

Conclusions

Both microflora *Trichoderma viride* and *Pseudomonas fluorescens*, fertilized with a half dose (50%) of recommended fertilizers showed the effectiveness in growth and yield promotion of maize crop and proved as potential biofertilizers. The use of such microorganisms as biofertilizers may be an alternative source of biofertilizers because they minimize the usage of chemical fertilizers, the cost of production and soil pollution from the unnecessary use of synthetic fertilizers.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

BN – acquisition of data, drafting of the manuscript;
SS – analysis and interpretation of data, critical revision and approval of the final manuscript;
SB – study conception and design;
SM – drafting of the manuscript;
DB – study conception and design;
JS – analysis and interpretation of data, critical revision and approval of the final manuscript.

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INFLUENCE OF FERTILIZING WITH MODERN COMPLEX ORGANIC-MINERAL FERTILIZERS TO GRAIN YIELD AND QUALITY OF WINTER WHEAT IN THE SOUTHERN STEPPE OF UKRAINE

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ABSTRACT. This article presents the results of using different varieties, variants of nutrition and their impact on the yield and grain quality of winter wheat. Experimental studies were conducted during 2011–2016 on the experimental field of the Mykolayiv National Agrarian University, Ukraine. The technology of growing winter wheat in the experiment, except the studied factors, was generally accepted to the existing zonal recommendations for the southern steppe of Ukraine. The predecessor was peas (*Pisum sativum* L.) It was determined that the higher grain yield and slightly better quality indicators differed grain of the studied winter wheat varieties with the joint use of pre-sowing application of $N_{30}P_{30}$ and foliar fertilizing of winter wheat crops twice during the vegetation season by Escort-bio. Thus, for this variant of nutrition, the crude gluten content of winter wheat grain was 24.2 up to 25.1%, the protein content was 12.9 up to 13.2%, and the conditional protein yield of from 1 ha of sowing area was 0.58–0.66 t depending on the studied variety. At the same time, on average, according to the nutrition factor, plants of the 'Zamozhnist' variety in comparison with the 'Kolchuga' variety formed more by 9.3% of the grain, which had the best quality indicators.

Introduction

For millennia, human beings have been aware of the importance of agricultural products in their life and have benefited from plants and their different parts like fruits, leaves, and seeds, for food, clothing, medicine, and animal feed (Erturk *et al.*, 2010; Canan *et al.*, 2016; Hricova *et al.*, 2016). Wheat is an important cereal crop, because of its high productivity and diverse usage possibilities (Filipcev *et al.*, 2017; Erben *et al.*, 2017; Abera *et al.*, 2017; Adams *et al.*, 2016; Altinel, Unal, 2017; Antov, Dordevic, 2017; Barber *et al.*, 2017; García-Molina *et al.*, 2019). The main purpose of wheat is to provide people with bread, bakery products, cereals and other grain processing products. The value of wheat bread is determined by the favourable chemical composition of the grain, in particular, a combination of proteins, carbohydrates, fats, amino acids, minerals and other preparations (Ulich *et al.*, 2014; Janić Hajnal *et al.*, 2019). Wheat provides about 20% of the calories and it is an important protein source for a large portion of the world's population (FAO, 2018). Therefore, global wheat production needs for increasing in the upcoming decades to cover the rising demand for this grain (Hernández-Espinosa *et al.*, 2018).

Wheat production in Europe countries is particularly dependent on synthetic fertilizers because the use of animal manure is very limited, many of the soils are naturally low in levels of soil organic matter and there are only a few legumes present in main crop rotations that could supply symbiotically fixe nitrogen (Biel *et al.*, 2016).

Mineral fertilizers are an important element for achieving stable high grain yields with high-quality indicators (Delogu *et al.*, 1998; Pan *et al.*, 2006; Panfilova *et al.*, 2019; Shi *et al.*, 2012).

According to some studies, mineral fertilizers are better absorbed by plants in certain periods of growth and development.

Nitrogen fertilizers have been a key factor in the increased yields achieved by modern agriculture and the last 30 years, the use of mineral nitrogen to fertilize crops has widely increased (Marinciu *et al.*, 2018).

According to Sommer and Scherer (2009), the nitrogen fertilizer should not be applied using the CULTAN (Controlled Uptake Long Term Ammonium Nutrition) system to cereals until the end of tillering. However, according to the findings of Kozlovsky *et al.* (2010) the nitrogen injection just at the end of tillering leads, under conditions of the Czech Republic, to the deterioration of baking quality of grain of CULTAN-treated winter wheat compared to the winter wheat treated with nitrogen split into three doses. Therefore, according to the findings of Kozlovsky *et al.* (2010), the nitrogen fertilization by the CULTAN system should be carried out at an earlier date in spring.

There is a growing global interest in the use of organic farming and in increasing grain production using low levels of mineral fertilizers (Petrenko *et al.*, 2018). Reducing the dose of mineral fertilizers, especially nitrogen, is possible with the use of growth-regulating preparations.

Modern intensification of crop production in the conditions of acute deficiency of organic fertilizers and too high prices for mineral fertilizers involves the development of alternative measures of technology of crop cultivating, including growth-regulating preparations (Panfilova *et al.*, 2020). That is why the research presented in this article is relevant.

Materials and methods

Experimental studies were conducted during 2011–2016 on the experimental field of the Mykolayiv NAU, Ukraine. We studied the following varieties of winter wheat – 'Kolchuga' and 'Zamozhnist'. The variety 'Kolchuga' (variety-lutescens) refers to the early maturing varieties, its vegetation period is 275–278 days. The height of the plant is medium-sized (96 cm). In the field conditions during the testing years, winter hardiness was 8.8 points, resistance to lodging was 8.7 points, resistance to shedding was 8.9 points, and drought resistance was 8.1 points. It is the variety of intensive type, universal use. The variety 'Zamozhnist' (variety – erythrospermum) is mid-ripening. The vegetation period is 282–287 days. Plant height is 94–104 cm, the variety is highly resistant to lodging and shatter, frost and winter hardiness above average, it is characterized by high drought and heat resistance. It is the variety of high-intensity type and universal use on different agricultural backgrounds.

The technology of growing winter wheat in the experiment, except the studied factors, was generally accepted to the existing zonal recommendations for the southern steppe of Ukraine, which has a temperate continental climate and chernozem soils (black soil of the South, light clay-loam soil on loess).

The experiment scheme included the following variants:

Factor A – variety: 1. 'Kolchuga'; 2. 'Zamozhnist'.

Factor B – nutrition: 1. Control (without fertilizers); 2. $N_{30}P_{30}$ for pre-sowing cultivation; 3. $N_{30}P_{30}$ and urea K1 (1 l ha^{-1}); 4. $N_{30}P_{30}$ and urea K2 (1 l ha^{-1}); 5. $N_{30}P_{30}$ and Escort-bio (0.5 l ha^{-1}); 6. $N_{30}P_{30}$ and urea K1 and urea K2 (0.5 l ha^{-1}); 7. $N_{30}P_{30}$ and organic D2 (1 l ha^{-1}). Fertilizing of crops with preparations was carried out at the beginning of the resumption of spring vegetation (BBCH 21) and the beginning of the winter wheat stooling (BBCH 31).

Preparations to be used for foliar application of barley crops were listed in the list of pesticides and agrochemicals authorized for use in Ukraine. Preparations of Urea K1 and Urea K2 are registered as fertilizers containing respectively N as 11–13%, P_2O_5 as 0.1–0.3%, K_2O as 0.05–0.15%, micronutrients as 0.1%, succinic acid as 0.1% and N as 9–11%, P_2O_5 as 0.5–0.7%, K_2O as 0.05–0.15%, sodium humate as 3 g L^{-1}, potassium humate as 1 g L^{-1}, trace elements as 1 g L^{-1}. Organic D2 is organo-mineral fertilizer containing N as 2.0–3.0%, P_2O_5 as 1.7–2.8%, K_2O as 1.3–2.0%, total calcium as 2.0–6.0%, organic matter as 65–70% (in terms of carbon). Escort-bio is a natural microbial complex that contains strains of microorganisms of genera Azotobacter, Pseudomonas, Rhizobium, Lactobacillus, Bacillus, and biologically active substances produced by them.

In the process of research the method it was used the state variety testing of crops (Volkodav *et al.*, 2001). The crop structure was analyzed by the sheaves, which were taken before harvesting from the sites of 1 m^2. The yield was determined by the method of continuous harvesting of each registration area (Sampo - 130 combine harvester).

Technological and biochemical indicators of quality of soft wheat grain intended for food needs use were established by DSTU 3768:2010 "Wheat. Technical conditions", regarding the standards: the crude gluten content by a manual method according to DSTU ISO 21415-1:2009, "Wheat and wheat flour"; the protein content of grain according to DSTU 4117:2007; the nature of grain according to DSTU 4234:2003 "Crops".

The statistical analysis (repetition was three times during 5 years of growing grain) of the research were processed using the method of multivariate disperse analysis. The obtained data were compared using analysis of variance. All statistical analyses were performed with Agrostat New and Microsoft Excel.

Results and discussion

Wheat yields vary from year to year under the influence of climatic conditions, the grown variety, introduced nutrients, the presence of pests and pathogens (Suciu *et al.*, 2018; Panfilova, Mohylnytska, 2019).

Our research also found the yield of winter wheat grain varied under the influence of varietal characteristics, background nutrition and climatic conditions of the cultivation year, in particular, the provision of plants with moisture during the vegetation season (Table. 1).

Table 1. The yield of winter wheat depending on the variety and nutrition, t ha^{-1}

Variety	Nutrition variant	Years					Average for 2012–2016
		2012	2013	2014	2015	2016	
'Kolchuga'	Control	1.71	1.85	2.71	4.02	4.15	2.89
	$N_{30}P_{30}$	2.23	2.36	3.13	4.71	4.78	3.44
	$N_{30}P_{30}$ and Urea K1	2.73	3.29	3.78	5.64	5.69	4.23
	$N_{30}P_{30}$ and Urea K2	2.79	3.37	3.90	5.78	5.82	4.33
	$N_{30}P_{30}$ and Escort-bio	3.04	3.49	3.97	5.93	5.99	4.48
	$N_{30}P_{30}$ and Urea K1 and Urea K2	2.91	3.44	3.94	5.82	5.77	4.38
	$N_{30}P_{30}$ and Organic D2	2.97	3.42	3.98	5.74	5.98	4.42
'Zamozhnist'	Control	1.86	1.99	2.90	4.20	4.28	3.05
	$N_{30}P_{30}$	2.35	2.47	3.35	4.86	4.89	3.58
	$N_{30}P_{30}$ and Urea K1	3.32	3.74	4.21	5.96	5.99	4.64
	$N_{30}P_{30}$ and Urea K2	3.54	3.95	4.42	6.09	6.13	4.83
	$N_{30}P_{30}$ and Escort-bio	3.76	4.14	4.55	6.24	6.28	4.99
	$N_{30}P_{30}$ and Urea K1 and Urea K2	3.71	4.11	4.46	6.21	6.25	4.95
	$N_{30}P_{30}$ and Organic D2	3.72	4.20	4.39	6.20	6.31	4.96
LSD 05	Factor A	0.07	0.10	0.11	0.09	0.11	
	Factor B	0.13	0.12	0.14	0.13	0.14	
	Factor AB	0.15	0.14	0.16	0.17	0.18	

For all years of cultivation, the increase in grain yield under the influence of fertilizers in the context of varieties was determined by statistical analysis to be reliable.

Thus, the lowest grain yield of winter wheat was formed in 2012 – 1.71 up to 3.04 t ha^{-1} by 'Kolchuga' variety and it was 1.86 up to 3.76 t ha^{-1} by a variety of 'Zamozhnist' depending on the nutrition. Favourable weather conditions in 2015 and 2016 during the vegetation season provided the highest yield of winter wheat, regardless of the studied factors. Thus, on average, for both varieties and nutrition variants, in 2015, it was formed grain yield as 5.53 t ha^{-1}, and in 2016 was 5.59 t ha^{-1}, which exceeded the level of 2012, which was the least favourable, by 2.63 up to 2.69 t ha^{-1} or by 90.7 up to 92.8%.

The level of grain yield varied depending on the variety taken for study. According to our studies, on average over the cultivation years on the nutrition factor, slightly higher yields were formed by plants of the 'Zamozhnist' variety as 4.43 t ha^{-1}, which exceeded the yields of the 'Kolchuga' variety by 0.41 t ha^{-1} or 10.2%.

In all the years of research, it was observed a positive effect of the main pre-sowing application of moderate doses of mineral fertilizers and foliar application in the main periods of vegetation of winter wheat varieties. Thus, on average, over the years of research, the winter wheat grain yield as 3.44 up to 3.58 t ha^{-1} was obtained on the background of $N_{30}P_{30}$ depending on the variety, which exceeded the control by 0.53 up to 0.55 t ha^{-1} or 17.4 up to 19.0%. The use of $N_{30}P_{30}$ contributed to a slight increasing of the winter wheat grain yield in all years of research, regardless of the variety. At the same time research (Ammanullah, 2014; Sedlar *et al.*, 2017) showed that moderate doses of nitrogen fertilizers had little effect on grain yield.

The maximum grain yield in the experiment was formed by winter wheat plants of the variety 'Zamozhnist' in the background + Escort – bio nutrition variant in the range from 3.76 to 6.28 t ha^{-1} depending on the weather conditions of the year.

The quality of wheat grain is influenced by the interaction of several factors, including variety, soil, climate, grain cultivation practices and grain storage conditions (Buráňová *et al.*, 2016).

As a result of our research, it was found that the quality indicators of winter wheat grain depended on the variety and the plant nutrition variant (Table 2).

Table 2. Influence of nutrition optimization on grain quality of winter wheat varieties (average for 2012–2016)

Variety	Nutrition variant	Crude gluten content, %	Protein content, %	Condi-tional protein content, t ha^{-1}
'Kolchuga'	Control	21.4	11.2	0.32
	$N_{30}P_{30}$	22.8	12.0	0.41
	$N_{30}P_{30}$ and Urea K1	23.0	12.2	0.52
	$N_{30}P_{30}$ and Urea K2	23.2	12.3	0.53
	$N_{30}P_{30}$ and Escort-bio	24.2	12.9	0.58
	$N_{30}P_{30}$ and Urea K1 and Urea K2	23.6	12.5	0.55
	$N_{30}P_{30}$ and Organic D2	23.9	12.7	0.56
'Zamozhnist'	Control	22.0	11.6	0.35
	$N_{30}P_{30}$	23.4	12.4	0.44
	$N_{30}P_{30}$ and Urea K1	23.7	12.6	0.58
	$N_{30}P_{30}$ and Urea K2	24.1	12.6	0.61
	$N_{30}P_{30}$ and Escort-bio	25.1	13.2	0.66
	$N_{30}P_{30}$ and Urea K1 and Urea K2	24.6	12.8	0.63
	$N_{30}P_{30}$ and Organic D2	24.9	13.0	0.64
LSD 0.05	factor A	0.18	0.12	
	factor B	0.24	0.14	
	factor AB	0.27	0.18	

When optimizing nutrition in the grain of the studied varieties the content of raw gluten, protein, and conditional protein collection from the conditional area significantly increased.

Variety selection is a key factor in obtaining high technological grain quality, although recently it is associated with a decrease in yield (Visioli *et al.*, 2018). In the 'Kolchuga' variety, the crude gluten content of non-fertilized plants was by 6.1 relative per cent less compared to the version of the main application of mineral fertilizers in the dose of $N_{30}P_{30}$. Carrying out foliar fertilizing of plants on the background of fertilizer contributed to the increase of this indicator by 7.0–11.5 relative per cent to the control.

The gluten content in the grain of 'Zamozhnist' variety plants also increased under the influence of optimization of nutrition. Thus, on average, over the years of research, the increasing of this quality indicator only from the background application of mineral fertilizers amounted to 6.0 relative per cent, and from the use of compatible with modern growth-regulating preparations, it was by 7.2–12.4 relative per cent compared to the control.

It is known that the protein content in the grain, is influenced by weather and climatic conditions, especially the provision of moisture during the grain loading, varietal characteristics, the presence and time of application of nutrients, especially nitrogen (Buráňová *et al.*, 2016). This also was observed in our studies. Thus, the protein content in winter wheat grain of both varieties studied by us in 2012 was lower in comparison with its content in 2016, which was more favourable in terms of moisture content of crops. During the spring-summer period of winter wheat vegetation in 2016, precipitation was 173.0 mm, while in 2012 was only 73.3 mm, while in the interphase period "earing – full maturity of the grain" the amount of precipitation was 86,0 and 52.0 mm. Favourable weather and climatic conditions in 2012 for the formation of winter wheat grain quality indicators facilitated the conglomeration in the grain of 'Kolchuga' variety on average by a nutritional factor of 14.0% protein, and 'Zamozhnist' variety – 14.1%, which exceeded the indicators of 2016 by 20.6–21.4 relative points.

On average, over the years of research, in the control of the experiment, the grain of the 'Kolchuga' variety contained 11.2% protein, the grain of 'Zamozhnist' variety contained 11.6%, then the application of only mineral fertilizers before sowing ensured increasing of this indicator by 6.5–6.7%, and carrying out on their background foliar fertilizing increased by 8.2–13.2 and 7.9–12.1% depending on the variety.

It is established that the variants of the research affected both the protein content of winter wheat grain and its conditional yield from the sowing area. So, when introducing of moderate doses of mineral fertilizers under winter wheat the conditional protein yield of 'Kolchuga' variety compared to non-fertilized control increased by 22.0%, and the yield of 'Zamozhnist' variety increased by 20.5%. The foliar application increased this indicator of 'Kolchuga' variety by 38.5 up to 44.8% and it increased this indicator of 'Zamozhnist' variety by 39.7 and 47.0%.

It was determined that some better quality indicators were differed by the grain of both studied winter wheat varieties when used together with the pre-sowing application of $N_{30}P_{30}$ and foliar dressing of winter wheat crops twice during the vegetation season with Escort-bio. Thus, the crude gluten content in winter wheat grain for this variant of nutrition was 24.2–25.1%, the protein content was 12.9–13.2% and the conditional protein yield from 1 ha of sowing area was 0.58–0.66 t depending on the studied variety.

According to the research results, it was found that on average for 2012–2016, the cultivation of the 'Zamozhnist' variety contributed to the production of the grain of the highest quality compared to the 'Kolchuga' variety. So, on the average on nutrition variants, the gluten content in grain of winter wheat was 3.3% higher than 'Kolchuga' variety, and the protein content was higher by 2.4 relative per cent. In this case, the conditional protein yield from the sown area increased by 12.5%.

Conclusions

In the conditions of the South of Ukraine optimization of winter wheat plant nutrition on the principles of resource-saving, ensures the increase of grain yield and significantly improves its quality. It was established that double application of fertilizing with modern complex organic-mineral fertilizers (Organic D2 and Escort-bio) for foliar fertilizing of crops at the beginning of the resumption of spring vegetation and at the beginning of the winter wheat stooling on the background of $N_{30}P_{30}$ allowed optimizing the nutrition of this crop and due to this combination, it allowed to reduce (replace) a certain amount of nitrogen fertilizer.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

AP – study conception and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript;
VG – drafting of the manuscript, critical revision and approval of the final manuscript;
IS – analysis and interpretation of data.

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EXPERIMENTAL RESEARCH INTO IMPACT OF KINEMATIC AND DESIGN PARAMETERS OF A SPIRAL POTATO SEPARATOR ON QUALITY OF PLANT RESIDUES AND SOIL SEPARATION

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ABSTRACT. The experimental investigations carried out in field production conditions have proved that the process of cleaning potato tubers from extraneous material with the use of a spiral separator takes place due to the active conveyance of the heap by the turns of the cantilever mounted cleaning spiral springs. The cleaning spiral springs not only rotate at the set angular velocity, but simultaneously their cantilevered ends perform oscillatory motion, which arises due to the deflection of their longitudinal axes under the action of the weight of the potato heap fed into the work zone of the separator. The results obtained in the process of the field experiment investigations carried out by the authors have provided for obtaining the relations that enable selecting the optimum design and kinematic parameters of the spiral-type potato cleaning devices for the targeted separation rate and, accordingly, estimating their impact on the quality of the performed work process.

Introduction

During the mechanised harvesting of potatoes with the use of combine harvesters, the separation of the large amount of the tubers from soil and plant residues is one of the major problems (Feller *et al*., 1987; Misener, McLeod, 1989; Peters, 1997; Bishop *et al*., 2012; Ichiki *et al*., 2013; Wang *et al*., 2017). Various cleaning devices, separators, clod smashers, elevators, screens *etc*. are employed to remove directly the considerable mass of soil and plant residues from the potato tubers (Petrov, 1984; Holland-Batt, 1989; Vasilenko, 1996; Feng *et al*., 2017; Guo, Campanella, 2017; Wei, Sun, 2017; Ye *et al*., 2017; Nowak *et al*., 2019).

Another important aspect in the potato harvesting is the separating of the tubers from soil and plant residues without inflicting damage on them. Therefore, the development of machines for cleaning potatoes from extraneous material directly after lifting from the soil the complete tuber-bearing bed (potato tubers, stuck soil, solid soil buildups, rhizomae, haulm debris, stones *etc*.) is an important topical scientific and technical problem in the field of agricultural engineering.

The aim of the study is to improve the quality indices of the process of cleaning potato tubers from soil and plant residues during their lifting from the soil by means of validating the rational design and kinematic parameters of the spiral separator.

The authors have developed a new design of the potato heap separator comprising four cantilevered power-driven spirals (Bulgakov *et al*., 2018a, 2018b, 2018c), which constitute an active undulated cleaning surface, onto which the lifted heap is fed (Fig. 1). At the same time, the design provides for changing the angle α of inclination of the said cleaning surface relative to the horizon, which increases the separation rate and ensures the progression of the tubers towards the discharge elevator. All these arrangements also promote better distribution of the heap over the working surface of the separator, more intensive disintegration of soil clods and, consequently, improved sieving down of the soil impurities and plant debris and reduced clogging of the cleaning spirals with the residues. Eventually, higher cleaning efficiency and productivity of the device for cleaning potatoes from soil and plant residues is achieved.

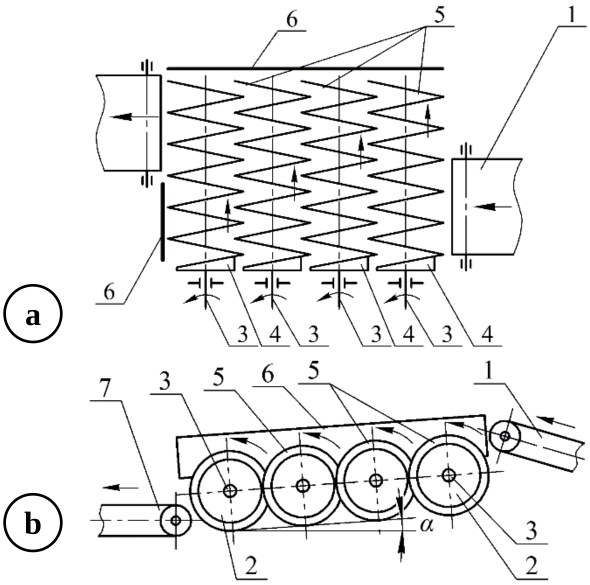

Figure 1. Design layout of spiral-type potato cleaning device: a – top view; b – side view: 1 – feeding elevator; 2 – spirals of cleaning rolls; 3 – shafts actuating rotary motion of spirals; 4 – hubs; 5 – free ends of spirals; 6 – screens; 7 – discharge elevator; *α* – inclination angle

The design of the spiral separator for separating potatoes from soil and plant residues comprises several power-driven spiral rolls 2 made in the form of spiral springs, which are cantilever supported and form an undulated separating surface. On one side this cleaning surface is connected with the loading (feeding) elevator 1, on the opposite side it is connected with the discharge elevator 7. The design also includes screens preventing the loss of potato tubers during their cleaning. The first flat screen 6 is fixed on a frame over the above-mentioned cleaning surface, the second screen 6 is fixed beside the discharge elevator 7. The spiral rolls 2 comprise the hubs 4 and the cleaning spirals cantilevered on the hubs. The hubs, in their turn, are connected to the drive shafts 3 that actuate the rotary motion of the spirals.

The cleaning spirals of the rolls 2 have mutual overlapping. The position in space of the whole cleaning surface formed by the cleaning spirals of the rolls 2 can be changed, that is, the angle α of its inclination relative to the horizon can be adjusted as required. The rotation of the cleaning spirals of the rolls 2 actuated by the drive shafts 3 can be set at different angular velocities, which would result in different circumferential velocities of rotation of the spiral turns. The sense of the rotary motion performed by the cleaning spirals of the rolls 2 is the same for all spirals. The cleaning spirals of the rolls 2 are mounted with mutual overlapping, while their free ends 5 can perform oscillatory motion under the action of the variable load of the potato heap lifted from the soil and fed onto the spirals by the feeding elevator 1.

The proposed design of the spiral potato separator envisages also the use of more than four spirals of the cleaning rolls and they can have different lengths, which, overall, provides for configuring the active cleaning surface of any area in the cleaning device. That said, the pitch of the cleaning roll spirals and their mutual overlapping must rule out the trapping of even small-size potato tuber bodies, *i.e.* prevent their loss and damaging.

Such a design solution (Fig. 2) of the proposed potato heap cleaning device provides openings of significant areas in its cleaning surface, which are formed by the spaces between the turns within each spiral and the clearances between the windings of the adjacent cleaning spirals. That increases the area, through which the separation of the soil impurities and plant debris down and outside the cleaning machine is performed.

At the same time, the described design features such an advantage as the absence of any shafts on the centrelines of the cleaning spirals. That allows to ensure the unobstructed passage down of all extraneous material and also prevents the undesirable wrapping of the shafts with plant debris. The hollowness of the internal space inside each cleaning spiral spring provides for the improved ability to transport positively all the mass of soil and plant residues entering that space towards the outlet (cantilever) end of the spiral and discharge it through the free end face onto the field surface.

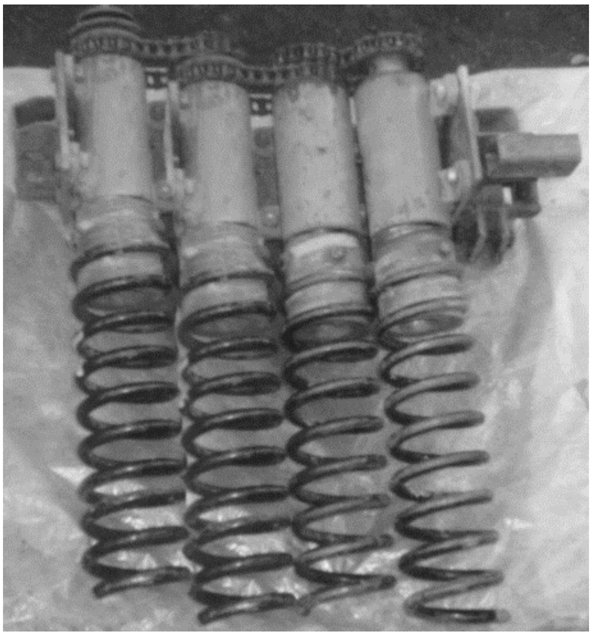

Figure 2. Design solution of separation module in experimental unit

The cantilever mounting of the spiral ends results in their forced oscillations, which materially activates the process of separating the extraneous material from the potato tubers.

In order to prevent the soil from sticking to the cleaning spirals and sealing the clearances between the spiral windings (especially in case of wet soil), the spiral springs are mounted with mutual overlapping, which implies the turns of one of the spirals partially entering the spaces between the turns of the second spiral. For the purpose of ensuring the progression of the potato tubers along the cleaning surface that has an undulated shape, the design includes the possibility to change the angle α of its inclination relative to the horizon. Each cleaning spiral features eccentricity, which makes the spiral perform forced oscillatory motion during its operation. The said motion promotes the agitation of the potato heap fed onto the spiral.

Materials and methods

In accordance with the earlier prepared programme (Bulgakov *et al*., 2019a, 2019b, 2020a, 2020b) of a multiple-factor experiment, the authors carried out the experimental research into the impact that the main design and kinematic parameters of the spiral potato separator had on the intensity, with which it separated soil impurities and plant debris from potatoes. As regards the parameters of the spiral potato separator that could influence the separation process most of all, within the framework of the experimental investigations, the task of the greatest interest was the research into the impact that had: the angle α of the cleaning surface inclination relative to the horizon; the circular velocity V of the rotary motion performed by the cleaning spirals; the eccentricity ε, with which the cleaning spiral were mounted; and the material feeding rate Q, *i.e*. the rate, at which the potato heap was fed for separating it from soil and plant residues. Such design parameters as the diameter of the cleaning spiral (d_s = 133 mm), the angle of lead of its helical line (γ = 12 deg), the diameters of the bars, from which the cleaning spirals were wound (d_p = 11 mm) had earlier been determined by the authors theoretically, therefore, in the experimental investigations they were assumed as known constant values.

For the purpose of carrying out the described experimental research, the authors implemented a fractional factorial experiment of the $2^{4\text{-}1}$ design with a test replication number of 3. The model that described the impact of the factors on the optimisation parameter was assumed to be a linear relation (Brandt, 2014):

$$y = b_0 + b_1\,\alpha + b_2\,V + b_3\,\varepsilon + b_4\,Q\ . \qquad (1)$$

After obtaining the initial experimental data, they were processed with the use of the Microsoft Excel application software. The results of the experimental data processing were presented in the form of a regression equation, which was the mathematical model of the work process under consideration relating its parameters to each other.

The mathematical model in the form of the following linear regression equation was generated after processing the results of the experimental data obtained during the research into the impact that the above-mentioned parameters have on the intensity of the soil and plant residues separation with the use of a multiple correlation coefficient of $R = 0.789$ and a number of experiments of 8:

$$I_S = 126.334 + 1.086\alpha - 43.107V + 0.975\varepsilon - 0.081Q \qquad (2)$$

At the same time, the following correlations of the separation intensity had been observed: with the angle α of the separator inclination relative to the horizon – 0.505, with the circular velocity V of the cleaning spiral rotation – 0.562, with the eccentricity ε of the spiral mounting – 0.527, with the material feeding rate Q – 0.019.

It was concluded on the basis of the above-mentioned experimental research that the factors that had a significant effect on the course of the process included the circular velocity V of the cleaning spiral rotation, the eccentricity ε of the spiral mounting and the angle α of the inclination of the whole cleaning surface relative to the horizon. The eccentricity ε as a design parameter is usually set depending on the conditions of operation of the potato heap cleaning device (its value is set at the maximum, when the fed potato heap has a large moisture content). For that reason, the further experimental research was focused on exploring the impact of the circular velocity V of the rotary motion of the cleaning spirals and the angle α, at which the cleaning surface was inclined relative to the horizon, on the extraneous material separation intensity I_S at constant values of the cleaning spiral mounting eccentricity ε and the rate Q of feeding the material, that is, the separated potato heap.

The above-mentioned further research was implemented in the form of a complete factorial experiment of the 3^2 design with 4 additional points, in which the cleaned potato mass rate was set at 20 kg s^{-1} and the cleaning spirals were mounted with an eccentricity of 7 mm.

The statistical analysis of the data obtained as a result of the experiments was carried out with the use of the PC equipped with the "Statistica" application software, version 5.0.

Results and discussion

The obtained experimental data were used for carrying out multivariate regression analysis with the use of various kinds of functions.

The data obtained during the research into the impact of the separator tilt angle α and the circular velocity V of the cleaning spirals in their rotary motion on the separation intensity I_S were processed.

The mathematical models were obtained in the form of regression equations for different types of functions (at a probability of P = 0.95, $t_{\alpha cr}$ = 2.17):

– for the linear function, in the following form:

$$I_S = 146.596 + 1.712\alpha - 49.905V\ , \tag{3}$$

at D = 0.893, R = 0.945, s = 6.175;

– for the power function, in the following form:

$$I_S = 233.279 \cdot \alpha^{0.037} \cdot V^{-1.865}\ , \tag{4}$$

at D = 0.936, R = 0.967, s = 0.092;

– for the exponential function, in the following form:

$$I_S = 262.9707 \cdot 1.0338^{\alpha} \cdot 0.4094^{V}\ , \tag{5}$$

at D = 0.848, R = 0.921, s = 0.142;

– for the logarithmic function, in the following form:

$$I_S = 138.191 + 1.805 \cdot \ln\alpha - 104.367 \cdot \ln V\ , \tag{6}$$

at D = 0.918, R = 0.958, s = 5.39;

– for the inverse function, in the following form:

$$I_S = -38.340 - \frac{0.00003}{\alpha} + \frac{216.389}{V}\ , \tag{7}$$

at D = 0.902, R = 0.95, s = 5.897;

– for the multivariate second-degree polynomial, in the following form:

$$I_S = 246.317 + 4.642\alpha - 155.297V - 0.105\alpha^2 - 0.395\alpha V + 26.158V^2\ , \tag{8}$$

at D = 0.978, R = 0.989, s = 3.35.

The selection of the function to be eventually used for the adequate description of the mathematical model was carried out by means of comparing their coefficients of multiple determination D. The function with the greatest value of the coefficient would prevail. In the case under consideration the multivariate second-degree polynomial was such a prevailing function.

Proceeding from the conditions described above, the authors chose the multivariate second-degree polynomial (Table 1) with the number of factors equal to 3, the number of variables equal to 6, at a probability level of P = 0.95, t_{α} = 2.17, for a second-degree polynomial.

The response surface of the relation between the extraneous material separation intensity on the one hand and the separator inclination angle α and the circular velocity V of the rotary motion of the cleaning spirals on the other hand (Fig. 3) as well as its two-dimensional section (Fig. 4) were plotted with the use of the above-mentioned application programme "Statistica", version 5.0.

The extremum value of the tilt angle α was determined with the use of the method of two-dimensional sections by differentiating the regression equation with respect to the separator inclination angle α and equating the derivative to zero. The following was obtained as a result:

$$\frac{dI_S}{d\alpha} = 3.709 - 0.199\alpha = 0\ , \tag{9}$$

which gives $\alpha \approx$ 18.56 deg.

Table 1. Results of regression analysis

Variable	Correlation	Linearized coefficient of regression	Statistical error of regression coefficient	t_{α}	Coefficient of elastisity	Significance of regression coefficient
Dependent (outcome) variable						
I_S		+246.317				
Independent (predictor) variable						
α	+0.732	+4.642	+1.392	+3.51	+0.78	significant
V	–0.597	–155.297	+109.822	–1.41	–5.46	not significant
α^2	+0.605	–0.105	+0.021	–5.14	–0.27	significant
$\alpha \cdot V$	–0.639	–0.395	+0.598	–0.66	–0.14	not significant
V^2	–0.592	+26.158	+26.209	+1.00	+1.94	not significant

The obtained results provided for analysing in more detail the impact that the angle α of the separator inclination and the circular velocity V of the cleaning spirals had on the percentage of the sieved soil and the separation intensity I_S. For that purpose, the obtained experimental data were used for plotting the diagrams of the relations between the separation intensity I_S on the one hand and the separator inclination angle α and the circular velocity V of its rotating cleaning spirals on the other hand.

As is seen in the presented diagrams, the separation intensity I_S. depends on the separator inclination angle α and the circular velocity V of the cleaning spiral rotation (Fig. 3) in such a way that, when the separator inclination angle α increases up to 12 deg, significant growth of the optimisation parameter is observed. In case of the further increase of the angle α, at which the spiral tool's separating surface is inclined with respect to the horizon, the change in the said parameter is already insignificant, which can be explained by the potatoes rolling down without being cleaned from extraneous material.

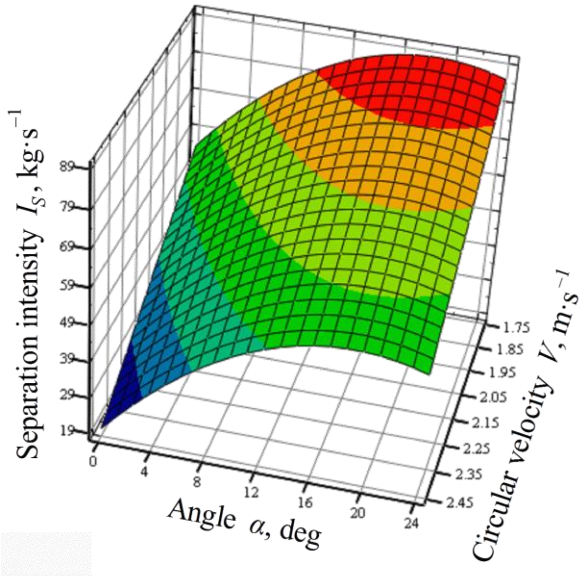

Figure 3. Response surface of relation between separation intensity I_S on the one hand and separator inclination angle α and circular velocity V of cleaning spiral rotation on the other hand.

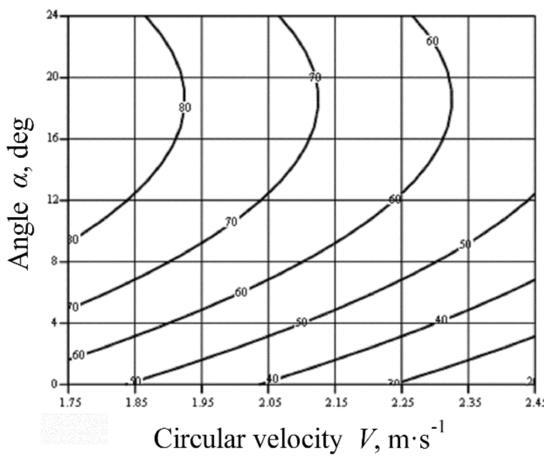

Figure 4. Two-dimensional section of response surface of relation between separation intensity I_S on the one hand and separator inclination angle α and circular velocity V of cleaning spiral rotation on the other hand.

When the circular velocity V of the cleaning spirals in their rotary motion (Fig. 4) increases up to 2 m s^{-1}, while the separator inclination angle α is at its rational value of 12 deg, the separation intensity I_S shows high values – in excess of 70 kg s^{-1}, but after reaching 2 m s^{-1}, its substantial decrease is observed.

That is due to the fact that, with the increase of the circular velocity V of the cleaning spiral rotation, the time of contact between the components of the potato heap and the spiral surfaces of the tool in the cleaning machine is reduced and also many potato tubers as well as larger soil particles, having obtained from the cleaning spirals sufficient initial velocities, just fly over the whole working surface of the cleaning tool and its screens. Such circumstances place limitations on the increase of the said circular velocity V of the cleaning spiral rotation.

Conclusions

1. A novel design of a device for separating potatoes from plant residues and soil has been developed, which offers an active separating surface of undulated shape formed by power-driven cantilevered spirals that are mutually eccentric positioned so as to permit the angle of their inclination to the horizontal to be readily adjusted.
2. Field experiment investigations have been carried out and the obtained data have been used for generating the model of a full factorial experiment. The results of the experiment have been statistically processed, which provided for performing the correlation and regression analysis of the obtained data with the use of the Microsoft Excel application software.
3. The completed research resulted in obtaining the relations for the intensity of the separation process. The said relations provide for determining the optimum design and kinematic parameters of the spiral-type machine for cleaning potatoes from extraneous material, which can be used in the design and development of new potato combine harvesters.
4. When the circular velocity V of the separating spirals increases up to 2 m s^{-1} and the separator inclination angle α is at a rational value of 12 deg, the separation intensity I_S has high values, reaching more than 70 kg s^{-1}.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

VA, VB – study conception and design;
VK, YI – acquisition of data;
AB, ZR – analysis and interpretation of data;
JO, VB – drafting of the manuscript;
JO – critical revision and approval of the final manuscript.

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SHORT COMMUNICATION: CHANGES OF COMPATIBLE SOLUTES CONTENT IN *TRITICUM AESTIVUM* AND *TRITICUM DICOCCUM* SEEDLINGS IN RESPONSE TO DROUGHT STRESS

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ABSTRACT. The influence of drought stress modelling by polyethene glycol (PEG) on water status, total soluble protein, proline and carbohydrates content in the roots and leaves tissues of three drought resistance wheat genotypes – *Triticum aestivum* L. ('Podolianka', 'Favorytka') and *Triticum dicoccum* Schrank. ('Holikovska') have been studied. Tested varieties of bread wheat and emmer wheat presented the resilience-anisohydric strategy for water balance regulation retaining a high level of relative water content, great variability in organic solutes with osmoprotective properties (total soluble protein, total carbohydrates and free proline) accumulation and retaining the level of low molecular weight proteins in response to drought with noticeable distinctions amid the varieties. However, drought stress increased the efficiency of accumulation of osmoprotectants either protein or carbohydrate nature in all three tested varieties of wheat seedlings.

Introduction

Crops yield is highly susceptible to water stress and constantly balancing between drought survival and mortality. Plants iso/anisohydric strategies of water status regulation might play a role in their ability to tolerate drought conditions. An overall mechanism for plants with an isohydric strategy of water balance regulation arises from the deviation of drought-induced hydraulic insufficiency throughout stomatal closure, resulting in a reduction in net photosynthetic rate (McDowell *et al*., 2008).

By decreasing hydraulic and stomatal conductance to retain an invariable water status, the isohydric plants minimized the exposure of their leaf tissues to water deficit, but also reduced their ability to fix carbon for growth and to ensure productivity in drought conditions. Unlike, the plants with anisohydric strategy conserved a high assimilation rate while leaves tissue water potential decreased, which should resolve higher productivity in the anisohydric plants, but also made those more assailable to damage from extended drought impact (Attia *et al*., 2015). Resilience-anisohydric strategy strikes a balance between plants reaction to water deficit with a rapid closure of stomata to prevent further water wastage via transpiration and ability to keeping a high level of internal osmotic potential by synthesizing various osmoprotectants and osmoregulators.

Therefore, this work aimed to investigate the biochemical adaptive stress response at the level of soluble osmoregulators and low molecular weight protein patterns in leaves of common bread wheat varieties (*Triticum aestivum* L.) and emmer wheat (*Triticum dicoccum* Schrank.), grown under PEG-induced drought stress.

Materials and methods

The objects of the study were three wheat varieties – *Triticum aestivum* ('Podolianka', 'Favorytka') and *Triticum dicoccum* Schrank. ('Holikovska'). Seedlings were grown in a growth chamber at 25 °C with photoperiod 16 h of light, at 200 μmol photons $m^{2\ –1}$ $s^{–1}$ of photon flux density during 7 days. Control variant of seedlings was grown on distilled water. Experimental seedlings were grown on distilled water with polyethene glycol (PEG) 6000 with an osmotic potential of –0.3 MPa.

Total soluble protein content was determined by the method of Bradford (1976) using BSA as standard. Proline colourimetric determination proceeded according to Bates *et al.* (1973). Total soluble carbohydrates content was measured by phenol-sulfuric acid method Jain *et al.* (2017) using glucose for standard curve plotting.

Electrophoresis was carried out using dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE) in vertical slab gel discontinuous buffer system following the method of Laemmli (1970) with minor modifications (Vítámvás *et al*., 2015).

The experiment was conducted with three biological and analytical repeats. The data were subjected to analysis of variance (ANOVA) with subsequent Duncan's multiple range test. Data are expressed as means of replicates + standard deviation and were considered reliable at a significance level of $P < 0.05$.

Results

In response to water imbalance, majority of physiological and biochemical plant functions are disordered. Investigation of the multiple mechanisms by which plants react to drought stress is an invocation to enhancing plant drought tolerance (Soltys-Kalina *et al*., 2016). Parameter relative water content (RWC) shows the balance between water supply to the leaf tissue and transpiration rate. Water deficit (WD) is known as the percentage of water shortage of its total amount in plant tissues when it is fully absorbed. It can occur by the disturbance of the water supply of the plant and cause changes in the progress of physiological and biochemical processes, affecting the productivity of crops (Osmolovskaya *et al*., 2018). These plant water balance traits were previously studied by Smirnov *et al.* (2020). RWC of the leaves tissues of 'Podolianka' and 'Favorytka' varieties were decreased beside 15%, in variety 'Holikovska' – by 7%.

Data analysis revealed that experimental water deficit has increased threefold in varieties 'Podolianka' and 'Favorytka', while in variety 'Holikovska' water deficit has increased by 50%. The authors claim that among tested wheat cultivars large differences in plant water balance were observed as a result, plant architecture parameters differ (Smirnov *et al*., 2020). Thus, increasing of dry matter can be explained so the next step was the comparative analysis of total soluble protein, carbohydrates and free proline contents (Fig. 1).

Comparative analysis of soluble protein content showed a slight decreasing of its level within the limits of 10–15% in roots and leaves tissues of 'Podolianka' and 'Favorytka' varieties under stress condition. In 'Holikovska' variety protein content increased by 30% in roots tissues and remained at the level of the control variant (Fig. 1 A). In response to water deficit in studied varieties, a decrease in protein content usually resulted in a compensatory increase in carbohydrates and/or proline content to maintain a high level of cell turgor (Fig. 1 B, C). There were no significant differences concerning the total soluble protein, carbohydrates and proline contents in the leaves of 'Holikovska' variety.

The alteration of low molecular weight protein synthesis is one of the most basic metabolically stimulated processes that may influence drought tolerance. Analysis of the leaf protein by SDS polyacrylamide gel electrophoresis did not show significant fluctuation levels of polypeptides in stressed leaves (Fig. 2).

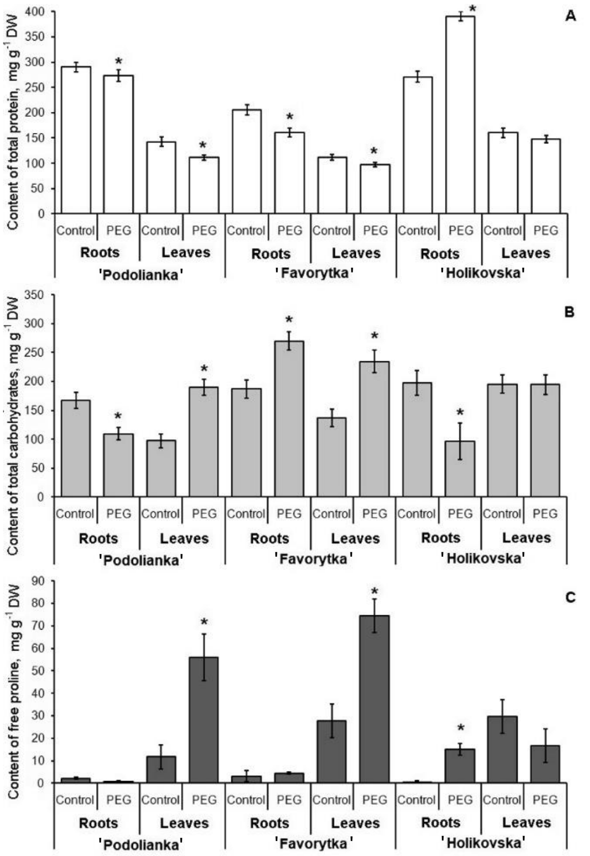

Figure1. Soluble protein (A), carbohydrates (B) and proline (C) content in the roots and leaves tissues of wheat different varieties under the drought stress; n = 15 (PEG – polyethene glycol treatment variant; * – data represent mean values with standard deviation; significant difference at P < 0.05 comparing to control level for each variety)

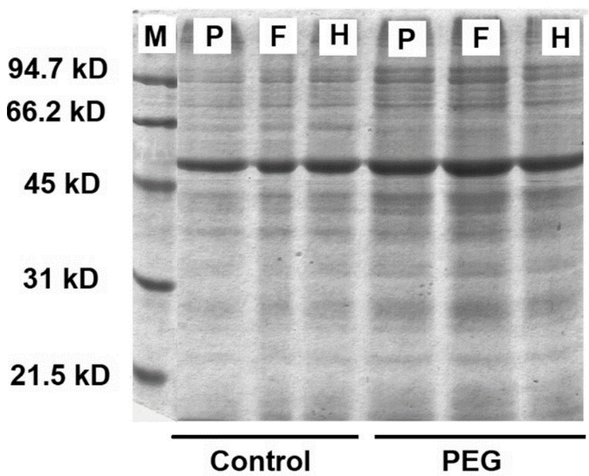

Figure 2. The sodium dodecyl sulphate polyacrylamide gel electrophoresis profile of low molecular weight proteins in the leaves tissues of wheat different varieties under the drought stress; n = 5 (PEG – polyethene glycol treatment variant, M – markers of molecular weight, P – 'Podolianka', F – 'Favorytka', H – 'Holikovska'

Discussion

Osmoregulators accumulation in response to water deficit is important for maintaining cell turgor by reducing water potential (Silva *et al.*, 2009) and certainly, several organic solutes are participating in this process as soluble proteins, sugars, free proline, and others soluble low molecular weight solutes. In this research, it was verified, if there is a variation in the pattern of accumulation of solutes among studied varieties in response to drought stress. Such resilience-anisohydric response suggesting that the synthesis and mobilization of soluble proteins or sugars and proline in wheat leaf and root tissues is a key strategy to cope with prolonged stress and the enhanced risk of osmotic imbalance (Dal Santo *et al*., 2016).

Committed metabolic changes, including the production of compatible soluble organic solutes used to maintain the tissue hydration. Amid the varied mechanisms used by plants to mitigate the negative impacts of drought stress, many plant species accumulate organic compatible solutes, such as osmoregulators and osmoprotectants. This mechanism is known as osmotic adjustment and it is allowed as an important adaptive responsive reaction, which supposes the maintenance of intracellular turgor and favours the water absorption (Medeiros *et al.*, 2012).

Previously studies showed drought stress relative decreasing of levels of soluble proteins whit high molecular weight, while soluble proteins with low molecular weight increases in bread wheat and Egyptian barley genotypes (Moradpour *et al.*, 2014; Hellal *et al.*, 2018). Sustentation of functionally active conformation is especially important for cell survival under stress. Heat shock proteins and late embryogenesis abundant proteins (10–100 kD) are responsible for protein folding; assembling, moving and degrading in many normal cellular processes stabilize protein and membranes and can help in protein refolding under stressful conditions. They can play a crucial role in maintaining the adaptive potential of plants by restoring normal protein conformation and therefore cellular homeostasis (De Britto *et al*., 2011).

Conclusions

Tested varieties of common wheat (*Triticum aestivum* L.) and emmer wheat (*Triticum dicoccum* Schrank.) presented resilience-anisohydric strategy at the level of the biochemical adaptive stress response. Great variability in organic solutes with osmoprotectants properties accumulation and maintaining the level of low molecular weight proteins in response to drought with marked differences among the varieties. However, drought stress increased the efficiency of accumulation of osmoprotectors either protein or carbohydrate nature in all three tested varieties of wheat seedlings. All tested *Triticum* varieties showed diversity in their ability to tolerate chemical dehydration induced by PEG keeping a high level of internal osmotic potential.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

OS – author of the idea, guided the research, and is the corresponding author.
AZ, L-AK – performed the biochemical assays and calculation of the results and data statistical analysis.
MK, NT – performed the literature data analysis and discussion of the results.
All authors read and approved the final manuscript.

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ANALYTICAL STUDY OF SOIL STRAIN RATE WITH A PLOUGHSHARE FOR UNCOVERING SLIT

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ABSTRACT. The article is devoted to solving one of the most important tasks of substantiating rational design and technological parameters of the working body for the installation of elements of subsurface irrigation. To reduce the frictional resistance during pulling of intra-soil irrigation communications, it becomes necessary to form a cavity inside the soil. The energy efficiency of such a process is determined by the traction resistance and directly depends on the normal and shear stresses of the soil as a result of its relative deformation during interaction with a special working body – the share of a mole plough. The geometric shape and kinematic parameters of the share, together with the mechanical characteristics of the soil, have the greatest influence on the nature of the relative deformation. Therefore, the purpose of the article is to determine the functional dependences of the components of the soil deformation rates on the geometric and kinematic parameters of the working body surface. These equations are necessary to determine the stress components in the soil, which make it possible to determine the compaction of the soil on the walls of the formed cavity (molehill), as well as the components of the forces of resistance to the movement of the working body.

Introduction

There is a necessity of laying moisturizers together with an impervious screen for maintaining the moisture and best spread it in the horizontal direction under in-soil irrigation of agricultural plants (Akutneva, 2014; Terpigorev *et al.*, 2017; Al-Khazaali, Kovbasa, 2016a).

For this purpose, share mole plough can be used. Substantiation of that tool's geometrical parameters and modes of operation is an actual scientific problem.

The solution of this problem allows us to determine the functional dependences of the effect of the tool's geometric parameters and soil's mechanical properties on the distribution of its strain rates and stress components. This makes it possible, when share mole plough interacts with the soil, to predict the location of zones in which the ratio of the stress components corresponds to a transition to the plastic state up to the disruption of the continuity for a certain plasticity criterion.

Analysis of researches and publications (Bagirov, 1963; Vyalov, 1978; Johnson *et al.*, 1979; Kushnarev, 1980; Cullen *et al.*, 1986; Contreras *et al.*, 2013; Zhao *et al.*, 2016; Ahmadi, 2016) shows that the solution of this problem requires the formalization of the soil, as a medium, on which the tool's action is directed, and the formalization of the soil – tool interaction. There are used most often models that are more like as the interaction with a rigid body or are the models used in the classical theory of soil mechanics and are based on the mechanics of granular media (Sokolovsky, 1960). Besides, when modelling of interaction, typically use one-dimensional models, or at best two-dimensional that do not always adequately depict the actual process of changes of soil properties under the action of the tool (Contreras *et al.*, 2013; Lurie, 1955). Recent publications show that the soil often represented as a viscoplastic or plastic medium. For this, either experimental research methods or numerical simulation methods using finite element methods are used (Zhu *et al.*, 2017; Gürsoy *et al.*, 2017; Zhang *et al.*, 2018; Solona *et al.*, 2019).

However, the use of such methods does not provide a real display of the change in the stress-strain state in zones close to critical, namely within the tool point, where there are zones of both fracture and strain hardening.

Also, with such research methods, it is impossible to obtain functional dependences of the connection between the strain rate and stress components, depending on the geometric parameters of a tool, and therefore numerous physical or numerical experiments are necessary.

It should be noted that the soil density under the tool's effect varies as a function of changes in all six components of strain or stresses which cannot be obtained in the plane problem, and even more so in a one-dimensional one. Furthermore, such formulation does not allow determining all three components of the resistance to movement of the tool in the soil medium.

Therefore, the problem of the soil – tool interaction in a three-dimensional formulation with the determination of the relation the geometric parameters and operating modes of the tool itself, as well as the properties of the soil, with components of the traction resistance is urgent and requires a solution.

In this regard, as one of the aims of the investigation was to determine if the strain rates in the contact zone of share mole plough with the soil, depending on its geometric and kinematic parameters. This will allow us to determine the values of the stress components and the soil density functions, depending on them. Besides, this will allow us to determine the soil force resistance to the movement of the share mole plough.

Methods

The use of the method of differential components of bi-harmonic potential functions in the contact zone of soil with share mole plough.

For the formation of the cavity in which the screen will be placed, using the method of broach can be used to share mole plough, a scheme of movement of which is illustrated in Fig. 1.

The following notation is adopted in Fig. 1: the coordinate system xyz represents the coordinates of the soil half-space and coincides with the share mole plough coordinate system $\xi\eta\zeta$, H – the ploughshare running depth relative to the field surface fs , B_l – the working width of the ploughshare, N_l – the normal to the plane of the ploughshare.

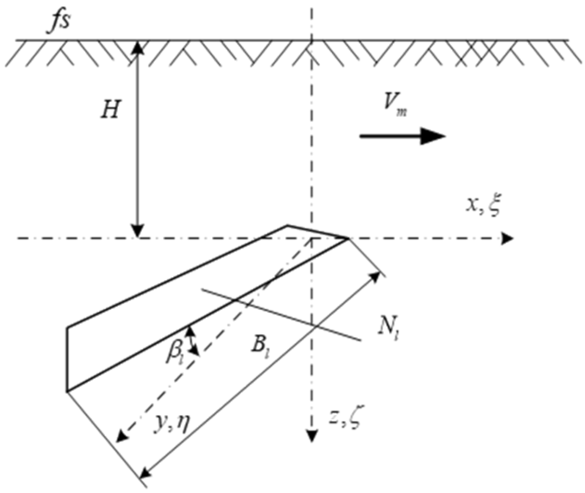

Figure 1. Scheme of the share mole plough motion

The equation of the working part of the surface of the ploughshare in the coordinate system idem has the form of the equation of plane:

$$f_l = \frac{\xi}{a} + \frac{r-\eta}{b} + \frac{(r/2)-\zeta}{c} = 0$$

where a, b, c – the coefficients that determine the inclination of the plane to the corresponding coordinate axes $o\xi, o\eta, o\zeta$; r – the height of the share's vertical projection, which is due to the mounting height at the attachment point.

The introduction of this height to equation defines the displacement of the centre of the plane to the origin in the direction of the axis $o\zeta$.

The cosines of the inclination angles of the surface normal to the coordinate axes expressed by the dependencies:

$$l_l = \frac{\partial f_l/\partial\xi}{\sqrt{(\partial f_l/\partial\xi)^2 + (\partial f_l/\partial\eta)^2 + (\partial f_l/\partial\zeta)^2}} = 1\Bigg/\left(a\sqrt{\frac{1}{a^2}+\frac{1}{b^2}+\frac{1}{c^2}}\right);$$

$$m_l = \frac{\partial f_l/\partial\eta}{\sqrt{(\partial f_l/\partial\xi)^2 + (\partial f_l/\partial\eta)^2 + (\partial f_l/\partial\zeta)^2}} = -1\Bigg/\left(b\sqrt{\frac{1}{a^2}+\frac{1}{b^2}+\frac{1}{c^2}}\right);$$

$$n_l = \frac{\partial f_l/\partial\zeta}{\sqrt{(\partial f_l/\partial\xi)^2 + (\partial f_l/\partial\eta)^2 + (\partial f_l/\partial\zeta)^2}} = -1\Bigg/\left(\sqrt{\frac{1}{a^2}+\frac{1}{b^2}+\frac{1}{c^2}}\,c\right).$$

The displacements velocities of the soil on the ploughshare surface are determined based on the fact that the projection of the velocity on the normal to the ploughshare surface has the form: $V_{Nl} = V_m / l_l$:

$$v_{l0} = V_{nl}\, m_l = -aV_m/b\; ;\; w_{l0} = V_{nl}\, n_l = -aV_m/c\; ;\; u_{l0} = V_{nl} l_l = V_m\; .$$

Analytical solutions of contact problems are possible only in the elastic or elastic-viscous formulation. Moreover, these solutions are allowed only for the case when successive substitutions of geometric equations in the physical equations of stress-strain relations and further substitution of the resulting stress components into the equations of statics (dynamics) of the continuous medium will lead to equations of elliptic type. In this case, the solution can be found when using the bi-harmonic potential functions that satisfy the

conditions on the body surface (coordinate system ξ, η, ζ) and medium with which it interacts (coordinate system x, y, z). In this case, when $x-\xi=0,\ y-\eta=0,\ z-\zeta=0$, the components of the velocities (displacements) are equal to their initial values.
For our case this means that the components of velocity for the ploughshare take the form:

$$u_l\big|_{x-\xi=0,y-\eta=0,z-\zeta=0}=u_{l0}\ ;$$
$$v_l\big|_{x-\xi=0,y-\eta=0,z-\zeta=0}=v_{l0}\ ;$$
$$w_l\big|_{x-\xi=0,y-\eta=0,z-\zeta=0}=w_{l0}\ .$$

The second condition, which must satisfy the biharmonic potential functions to determine the composition of the velocity has the form:

$$u_l\big|_{x-\xi=\infty,y-\eta=\infty,z-\zeta=\infty}\to 0\ ;$$
$$v_l\big|_{x-\xi=\infty,y-\eta=\infty,z-\zeta=\infty}\to 0\ ;$$
$$w_l\big|_{x-\xi=\infty,y-\eta=\infty,z-\zeta=\infty}\to 0\ .$$

Such bi-harmonic potential functions, according to (Lurie, 1955; Kovbasa *et al.*, 2015; Al-Khazaali, Kovbasa, 2016b) are of the form:

$$\begin{aligned}
u_l &= \int_r^B\int_{-r}^r \frac{a_0\,u_{l0}(x-\xi_l+\delta)}{((x-\xi_l+\delta)^2+(y-\eta_l+\delta)^2+(z-\zeta_l+\delta)^2)^{3/2}}\mathrm{d}\zeta_l\mathrm{d}\eta_l\,;\\
v_k &= \int_{-r}^r\int_0^{L_k} \frac{a_0\,v_{l0}(y-\eta_k+\delta)}{((x-\xi_l+\delta)^2+(y-\eta_l+\delta)^2+(z-\zeta_l+\delta)^2)^{3/2}}\mathrm{d}\xi_l\mathrm{d}\zeta_l\,;\\
w_l &= \int_r^B\int_0^{L_l} \frac{a_0\,w_{l0}(z-\zeta_l+\delta)}{((x-\xi_l+\delta)^2+(y-\eta_l+\delta)^2+(z-\zeta_l+\delta)^2)^{3/2}}\mathrm{d}\xi_l\mathrm{d}\eta_l\,,
\end{aligned} \tag{1}$$

where $L_l=-B\,Cos(1/a)$ – the projection length of the ploughshare in the direction of the axis $o\xi$; B – the projection length of the ploughshare in the direction of the axis $o\eta$.

$a_0=\dfrac{1}{\pi}\dfrac{4}{Log[-\delta+\sqrt{3}\sqrt{\delta^2}]-Log[\delta+\sqrt{3}\sqrt{\delta^2}]}$ – factor that enforces initial conditions with the introduction of a small magnitude δ. This magnitude eliminates the singularity of the expressions (1). Bi-harmonic potential functions should satisfy the equation $\Delta^2 f=0$, where Δ – Laplacian, $f=\{u_l, v_l, w_l\}$.

Due to the complexity of integration of the equations (1), which represent the components of the displacement velocities of soil in space in front of the share mole plough, in the general form, it is possible to solve the problem of finding the distribution of displacement velocities, strain rates and the stress components in a differential form, as it was proposed in (Vyalov, 1978; Zhao, 2016).

The essence of the method consists in the fact that to find the components of strain rates it is necessary to the differentiation of equations (1).

For this, equations (1) can be transformed in such a way that as a result, the components of the differential components of the soil displacement velocities in front of the share mole plough will be obtained. In this case, due to the cumbersome of the equations at the last stage, it is possible to apply numerical methods of integration:

$$\begin{aligned}
du_l &= \frac{d^2}{d\eta_l d\zeta_l}\int_0^B\int_{-r}^r \frac{a_0\,u_{l0}(x-\xi_l+\delta)}{((x-\xi_l+\delta)^2+(y-\eta_l+\delta)^2+(z-\zeta_l+\delta)^2)^{3/2}}\mathrm{d}\zeta_l\mathrm{d}\eta_l =\\
&= \frac{15\,a_0V_m(z+\delta-\zeta_l)(y+\delta-\eta_l)(x+\delta-\xi_l)}{((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2+(x+\delta-\xi_l)^2)^{7/2}};\\
dv_l &= \frac{d^2}{d\zeta_l d\xi_l}\int_{-r}^r\int_0^{L_l} \frac{a_0\,v_{l0}(y-\eta_k+\delta)}{((x-\xi_l+\delta)^2+(y-\eta_l+\delta)^2+(z-\zeta_l+\delta)^2)^{3/2}}\mathrm{d}\xi_l\mathrm{d}\zeta_l =\\
&= -\frac{15a\,a_0V_m(z+\delta-\zeta_l)(y+\delta-\eta_l)(x+\delta-\xi_l)}{b((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2+(x+\delta-\xi_l)^2)^{7/2}};\\
dw_1 &= \frac{d^2}{d\eta_l d\zeta_l}\int_r^B\int_0^{L_l} \frac{a_0 w_{l0}(z-\xi_l+\delta)}{((x-\xi_l+\delta)^2+(y-\eta_l+\delta)^2+(z-\zeta_l+\delta)^2)^{3/2}}d\xi_l d\eta_l =\\
&= -\frac{15aa_0V_m(z+\delta-\zeta_l)(y+\delta-\eta_l)(x+\delta-\xi_l)}{c((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2+(x+\delta-\xi_l)^2)^{7/2}}.
\end{aligned} \tag{2}$$

From equations (2) the differential components of the strain rates of the soil using geometric equations (cauchy equations) can be obtained:

$$d\dot{\epsilon}_{xl} = \frac{d}{dx}du_l = \frac{15a_0V_m(z+\delta-\zeta_l)(y+\delta-\eta_l)((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2-6(x+\delta-\xi_l)^2)}{((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2+(x+\delta-\xi_l)^2)^{9/2}};$$

$$d\dot{\epsilon}_{yl} = \frac{d}{dy}dv_k = \frac{105a\,a_0V_m(z+\delta-\zeta_l)^2(y+\delta-\eta_l)(x+\delta-\xi_l)}{c((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2+(x+\delta-\xi_l)^2)^{9/2}} - \frac{15a\,a_0V_m(y+\delta-\eta_l)(x+\delta-\xi_l)}{c((z+\delta-\zeta_l)^2+(y+\delta-\eta_l)^2+(x+\delta-\xi_l)^2)^{7/2}};$$

$$d\dot{\epsilon}_{zl} = \frac{d}{dz}dw_l = 15a_0V_m(\delta-\zeta_l+z)\times$$
$$\times\frac{\left(\frac{7a(\delta-\xi_l+x)^2(\delta-\eta_l+y)}{b} - \frac{a(\delta-\eta+y)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)}{b} - \\ -7(\delta-\xi_l+x)(\delta-\eta_l+y)^2+(\delta-\xi_l+x)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)\right)}{((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)^{9/2}};$$

$$d\dot{\gamma}_{xyl} = \frac{d}{dy}du_l + \frac{d}{dx}dv_l = 15a_0V_m(\delta-\zeta_l+z)\times$$
$$\times\frac{\left(\frac{7a(\delta-\xi_l+x)^2(\delta-\eta_l+y)}{b} - \frac{a(\delta-\eta_l+y)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)}{b} - \\ -7(\delta-\xi_l+x)(\delta-\eta_l+y)^2+(\delta-\xi+x)((\delta-\xi+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)\right)}{((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)^{9/2}}; \tag{3}$$

$$d\dot{\gamma}_{xzl} = \frac{d}{dz}du_l + \frac{d}{dx}dw_l = 15a_0V_m(\delta-\eta_l+y)\times$$
$$\times\frac{\left(-\frac{a(\delta-\zeta_l+z)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)}{c} + \frac{7a(\delta-\xi_l+x)^2(\delta-\zeta_l+z)}{c} + \\ +(\delta-\xi_l+x)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)-7(\delta-\xi_l+x)(\delta-\zeta_l+z)^2\right)}{((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)^{9/2}};$$

$$d\dot{\gamma}_{yzl} = \frac{d}{dy}dw_l + \frac{d}{dz}dv_l = 15a_0V_m(\delta-\eta_l+y)\times$$
$$\times\frac{\left(-\frac{a(\delta-\zeta_l+z)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)}{c} + \frac{7a(\delta-\xi_l+x)^2(\delta-\zeta_l+z)}{c} + \\ +(\delta-\xi_l+x)((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)-7(\delta-\xi_l+x)(\delta-\zeta_l+z)^2\right)}{((\delta-\xi_l+x)^2+(\delta-\eta_l+y)^2+(\delta-\zeta_l+z)^2)^{9/2}};$$

where $d\dot{\epsilon}_{xl}$, $d\dot{\epsilon}_{yl}$, $d\dot{\epsilon}_{zl}$, $d\dot{\gamma}_{xyl}$, $d\dot{\gamma}_{xzl}$, $d\dot{\gamma}_{yzl}$ – differential components of the velocities of relative normal and shear strains of soil in front of the ploughshare.

To understand how the share mole plough, namely its geometric shapes and sizes affects the changes of the strain components in the area of direct contact with the soil, the expressions can be integrated (3), according to expressions (1).

But the same time it should be taken into account that the zone of direct contact will be analyzed, namely the conditions: $\{\zeta_l - z = 0,\ \eta_l - y = 0,\ \xi_l - x = 0\}$. This greatly simplifies the expression (3):

$$\dot{\epsilon}_{xl} == \int_r^B\int_{-r}^r d\dot{\epsilon}_{xl}\,\mathrm{d}\zeta_l\,\mathrm{d}\eta_l = \int_r^B\int_{-r}^r \frac{\partial u}{\partial x}\mathrm{d}\zeta_l\,\mathrm{d}\eta_l\,;\dot{\epsilon}_{xl} = \int_{-r}^r\int_0^{L_k} d\dot{\epsilon}_{yl}\,\mathrm{d}\xi_l\,\mathrm{d}\zeta_l = \int_{-r}^r\int_0^{L_k}\frac{\partial v}{\partial y}\mathrm{d}\xi_l\,\mathrm{d}\zeta_l\,;$$
$$\dot{\epsilon}_{zl} = \int_r^B\int_0^{L_l} d\dot{\epsilon}_{zl}\,\mathrm{d}\xi_l\,\mathrm{d}\eta_l = \int_r^B\int_0^{L_l}\frac{\partial w}{\partial z}\mathrm{d}\xi_l\,\mathrm{d}\eta_l\,;$$
$$\dot{\gamma}_{xyl} = \int_{-r}^r\int_0^{L_k}\frac{\partial u_l}{\partial y}\mathrm{d}\xi_l\,\mathrm{d}\zeta_l + \int_r^B\int_{-r}^r\frac{\partial v_l}{\partial x}\mathrm{d}\zeta_l\,\mathrm{d}\eta_l\,;\ \dot{\gamma}_{xzl} = \int_r^B\int_0^{L_l}\frac{\partial u_l}{\partial z}\mathrm{d}\xi_l\,\mathrm{d}\eta_l + \int_r^B\int_{-r}^r\frac{\partial w_l}{\partial x}\mathrm{d}\zeta_l\,\mathrm{d}\eta_l\,; \tag{4}$$
$$\dot{\gamma}_{yzl} = \int_r^B\int_0^{L_l}\frac{\partial v_l}{\partial z}\mathrm{d}\xi_l\,\mathrm{d}\eta_l + \int_{-r}^r\int_0^{L_k}\frac{\partial w_l}{\partial y}\mathrm{d}\xi_l\,\mathrm{d}\zeta_l\,.$$

Results and discussion

Unfortunately, the final expression of strain rates components in its complete form $\dot{\epsilon}_{xl}$, $\dot{\epsilon}_{yl}$, $\dot{\epsilon}_{zl}$, $\dot{\gamma}_{xyl}$, $\dot{\gamma}_{xzl}$, $\dot{\gamma}_{yzl}$ is not possible lead within the paper, because of their cumbersomeness. Graphical interpretation of these expressions is shown in Figs. 2 and 3.

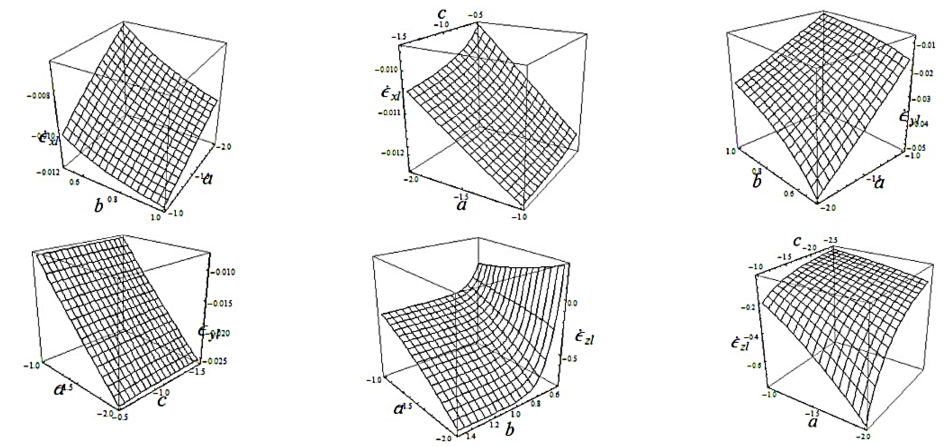

Figure 2. Graphs of the normal strain rate components of the soil $\dot{\epsilon}_{xl}, \dot{\epsilon}_{yl}, \dot{\epsilon}_{zl}$, depending on the coefficients *a, b, c* of the equation of the plane

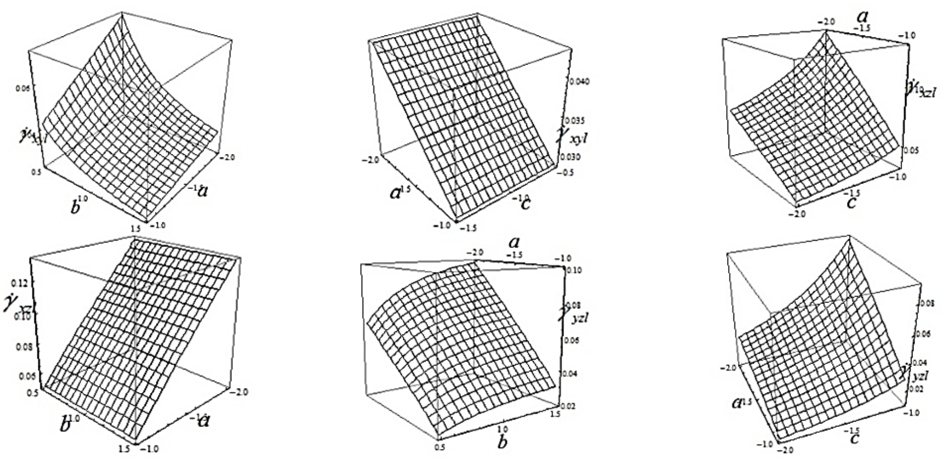

Figure 3. Graphs of the shear-strain rate components of the soil $\dot{\gamma}_{xyl}, \dot{\gamma}_{xzl}, \dot{\gamma}_{yzl}$, depending on the coefficients *a, b, c* of the equation of the plane

The analysis showed that the effect of the plane equations coefficients a, b, c on the change in the components (Fig. 2) of normal strain rates by such functions is characterized:

1) the decrease in the slope of the normal of the plane to the axis ox that is longitudinal to the direction of motion (magnitude $1/a$), leads to an increase in the normal strain rate components $\dot{\epsilon}_{xl}, \dot{\epsilon}_{zl}$ (compression) and a decrease in the component $\dot{\epsilon}_{yl}$ that is transverse to the direction of motion;

2) the increase in the slope of the normal of the plane to the axis oy that is transverse to the direction of motion (magnitude $1/b$), leads to a decrease in the normal strain rate components $\dot{\epsilon}_{xl}, \dot{\epsilon}_{yl}, \dot{\epsilon}_{zl}$;

3) the increase in the slope of the normal of the plane to the axis oz that is vertical to the direction of motion (magnitude $1/c$), leads to a decrease in the normal strain rate components $\dot{\epsilon}_{xl}, \dot{\epsilon}_{zl}$, and the component $\dot{\epsilon}_{yl}$ remains unchanged.

It should be noted that:

1) the decrease in the slope of the normal of the plane to the axis ox (magnitude $1/a$), leads to an increase in all three shear-strain rate components $\dot{\gamma}_{xyl}, \dot{\gamma}_{xzl}, \dot{\gamma}_{yzl}$;

2) the decrease in the slope of the normal of the plane to the axis oy (magnitude $_{1/b}$), leads to an increase in components $\dot{\gamma}_{xyl}$, $\dot{\gamma}_{yzl}$ and does not affect the change $\dot{\gamma}_{xzl}$;

3) the increase in the slope of the normal of the plane to the axis oz (magnitude $1/c$), leads to an increase in the $\dot{\gamma}_{yzl}$, $\dot{\gamma}_{xzl}$, while component $\dot{\gamma}_{xyl}$ remains unchanged (Fig. 3).

Conclusions

The research results of the interaction of share mole plough with the soil are presented in the paper. As a result of the analysis, the strain rate components of the soil at the contact zone with share mole plough were obtained.

These expressions are the starting point for the further determination of the stresses components in the soil that determine the soil compaction on the walls of the formed of the cavity for impervious screen and components of resistance forces to the movement of share mole plough. In the future, this will make it possible to determine the geometric parameters of the tool, under various mechanical properties of the soil, to ensure the stability of the cavity walls with minimum energy costs.

The solution is common for a certain class of problems of the kinematics of the contact interaction of a rigid body with a deformable medium.

The proposed solution makes it possible to determine the changes in the components of the soil's strain rates as a function of the slope of the ploughshare plane.

In the future, this allows us to determine the dynamic components of the contact interaction of the ploughshare with the soil.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

OS, VK – study conception;
VK, IK – analysis and interpretation of data;
OS, IK– drafting of the manuscript;
IK – editing the manuscript;
VK – critical revision and approval of the final manuscript.

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MODULAR-VITALITY AND IDEOTYPICAL APPROACH IN EVALUATING THE EFFICIENCY OF CONSTRUCTION OF OILSEED RADISH AGROPHYTOCENOSISES (*RAPHANUS SATIVUS* VAR. *OLEIFERA* PERS.)

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ABSTRACT. The paper provides the results of a multi-year study of the peculiarities of phytocoenology of oilseed radish agrophytocenosises using various methods of its condition assessment and studying the tactics of plant vitality strategy. A comprehensive assessment was made of the impact of changes in inter-row spacing width, sowing rates and fertilizer on the formation of different plant ideotypes, the variability of their morphological features and general indicators of viability.

Three ideotypes of oilseed radish plants in the vertical study of agrophytocenosises were identified, based on which a detailed analysis of the variability of each group and a statistical assessment of the reliability of its existence was made. The peculiarities of morphological integration of each tier were analyzed and its influence on the formation of the overall field capacity was assessed. Based on the modular and vitality grouping, the efficiency and feasibility of combining different stand density and fertilizer options in the range of 30–90 kg of primary material per 1 hectare were evaluated.

Due to the application of regression analysis, the impact of climatic conditions on the formation of different morphological types of plants and the nature of relationships between oilseed radish plants in cenosises of different stand densities with different fertilizer options was assessed. The main perspective directions of further research on the peculiarities of the creation of highly productive and highly adaptive agrophytocenosises of oilseed radish are outlined.

Introduction

The agrophytocenosis assessment of any crop species has two typologically different approaches. The first one is based on using the average cenosis value for a certain indicator, for example, the height of plants, the individual mass of the plant, *etc*. This approach implies the use of a certain selection from which the average value of the indicator is statistically determined. The second one is based on the phytocoenological approach to the structure of agrophytocenosises in various forms – vertical and horizontal architecture of the spatial orientation of the cenosis plants, assessment of the level of coenotic tension, considering the density of cenosis, the level of fertilization, hydrothermal factors of vegetation. According to many researchers, in modern agrotechnological scientific practice, the second approach is more rational and essential, as it answers the urgent questions of the optimal construction of the cenosis already conducted at the sowing technological stage. Further, it is decisive in plants' growth and physiological processes, being determinative in implementing their genotypic potential. (Zlobin, 1989, 1993, 2009; Isaacs *et al*., 2016; Burstin *et al*., 2018).

The aspects of the idiotic structure of sowing, the formation of its high-altitude layering and the plant stand differentiation into the corresponding plant ideotypes are also based on the same approach (Zeven, 1975; Martre *et al*., 2015; Barot *et al*., 2017). Ensuring a certain ratio between plants idiotypes defined for each agricultural crop is crucial in ensuring optimal plant growth formats, since ensuring uniformity of agrophytocenosises, even considering modern selection practice and genetic uniformity of plants is a very problematic issue (Zhang, 1999; Anten, Vermeulen, 2016).

It should also not be forgotten that modern approachhes to mineral nutrition of major crops should be adaptive and correspond to both hydrothermal conditions of the territory and specific biological features of the crop itself, considering the plant variety architecttonics. In recent years, the format for evaluating fertilizer performance has been moving in the phytocoenological direction. Phytocoenological approaches are technologically introduced into the strategy of precision farming, as they transform the concept from general to the individual, allowing treating the agrophytocenosis of a certain crop from the standpoint of individual development considering the stress factors that arise when certain technological regulations of cultivation are observed (Shanda, 2017). Mineral fertilizers in the phytocoenological assessment approach are considered as a stress-regulating factor and are evaluated in the format of a stimulant for ensuring the receipt of plants of different vitality class, different idiotype (Debaeke, Quilot-Turion, 2014).

Although the issue of the vitality strategy of agrophytocenosises is relatively well researched, aspects of their application in the development of technologies for growing certain crops, including such basic elements as sowing rate, plant nutrition area and fertilizer, which should effectively combine and intensify the previous two factors. This approach is especially important and appropriate for crops that have high rates of modifiable variability at the level of reproductive effort and individual parameters of seed productivity, and are sensitive to changes in sowing parameters at technological setting and formation of agrophytocenosises. Given the fact that oilseed radish can be classified as such crop varieties (Tsytsiura, 2018, 2019), the application of a system of phytocoenological fertilizer assessment will be relevant and reasonable.

TA number of researchers in their studies covers the issue of vitality strategy of formation of agrophytocenosises in crops of the different development cycle. Thus, it is noted (Jeuffroy *et al*., 2014; Van der Meulen, Chauhan, 2017) that it is necessary to consider the aspects of inter- and intraspecies competition in the technologies of main crops growing. On their basis, the approaches to the productive efficiency of agrophytocenosises are formed, and a possible conclusion about the expediency of the corresponding basic elements of the technology is drawn. It is pointed out (Hamblin, 1993) the necessity of the phytocoenological approach to the construction of productive crop cenosises with the evaluation of their structure and general coexistence of components.

It is mentioned (Heslot *et al*., 2014) the complex biological aspect of growth processes of plants in artificially separated cenosises which are certain fields with single-species sowing of crops. The dynamics of this growth has a complex combinatorial nature and cannot be effectively described using only a group or average approach. It is important to highlight the individual characteristics of plants, which should be combined into a system of corresponding dependencies. We've developed the approach (Mangin *et al*., 2017) using a correlation-block system of corresponding technological measures efficiency estimation by forming certain plants' morphotype in sowing, the existence of corresponding correlation dependences between morphological features vegetative and generative parts. In their turn, they provide reception of the corresponding level of biological productivity of a plant organism at a combination of corresponding nutrition area, fertilizer and other measures on a background of corresponding reaction norm. At the same time, the existence of certain morphotypes of plants as a part of single-species cenosis was specified in the '70s of last century in the concept of the plant idiotype and its importance in heterogeneous selection (Donald, 1968; Mock *et al*., 1975). Further, the concept of the plant idiotype started to include features of plant morphometry by key parameters of the ratio of separate organs and their general development. The concept also considered the average indicator typical for the cenosis at the given technological parameters of its pre-sowing formation and the corresponding additional mineral nutrition. (Haverkort, Kooman, 1997; Semenov, Stratonovitch, 2013; Martre *et al*., 2015; Vincourt, Carolo, 2018). Ideotypical approach to plant morphometry assessment allows to conduct appropriate levels of modelling of physiological and growth processes and determine the efficiency of use of hydrothermal and physiological and genetic factors of plant growth and development by plants (Ishbirdin *et al*., 2005; Qia *et al*., 2010; Van Tassel *et al*., 2017; Tonin *et al*., 2018). It's also noted that the said different plant morphotypes have different reproductive tactics and corresponding indicators of reproductive effort (Samson, Werk, 1986; Dickmann *et al*., 1994; Ly *et al*., 2018). Moreover, the plant idiotype (morphotype) can be attributed to the respective modelled level of plant development with an assessment of their suitability for the respective level of technology (Ellisséche *et al*., 2002; Cilas *et al*., 2006), can be used in the options of pest and disease resistance assessment (Le May *et al*., 2009; Calonnec *et al*., 2013; Andrivon *et al*., 2013), as well as in the assessment of the stress tolerance and adaptability level of varietal agrotechnologies (Loison *et al*., 2017; Gauffreteau, 2018) and the assessment of allelopathic resistance (Grodzinskiy, 1973; Rais, 1978). It is further noted (Zhilyayev, 2005) that the format of the relevant technological components will be effective as a whole if it is based on the viability properties of the population or agrophytocenosis. This indicator should be interpreted as a general plant architectonics in single-species coenopopulations, which include field-planting crops. The very implementation of the vital strategy of the cultivated plants will be determined by the level of competitiveness of the plants, primarily with each other and to the vegetation of other species groups. Under these conditions, an effective option for the plant cenosis construction will be one that guarantees a weaker variant of intra-species competition against the background of optimization of the growth processes of plants.

The consistency of studying the issue of the vitality strategy of cenosises, considering their construction and application of respective regulators, which may include mineral fertilizers, is reflected in numerous scientific papers by Zlobin (1989, 2009). Based on the generalization of various scientific hypotheses and numerous research carried out by various scientists, the author has formulated the basic regularities of coeno-population relations of different levels, and peculiarities of formation of plant morphotypes. He has also described the basic components of plant vitality strategy and has outlined the main tactics of the general methodology of assessment of the viability of plants co-enopopulations and agrophytocenosises. Despite the multiplicity of covered and discussed problematic issues, the role of plant stands density and its corresponding individual nutrition area in interaction with additional mineral nutrition is a determining factor model in the regulation and expression of intra-species variability, weakening or strengthening of single-species competition and ensuring the desired vitality strategy in the formation of signs of productive morphology, both in terms of leaf mass and seed yield indicators. It is a matter that requires further scientific study and generalization with the development of recommendations for optimizing the mineral nutrition of crops (using the example of oilseed radish) based on the phytocoenological approach.

Materials and methods

The research was conducted on the experimental field of the Vinnytsia National Agrarian University on dark grey forest soils (Luvic Greyic Phaeozem soils (IUSS Working Group, 2015)). The agrochemical field potential according to the main agrochemical indicators defined by the National Standard of Ukraine 4362:2004: Soil quality. Indicators of soil fertility. (2006) meets the general characteristics of this soil type and is as follows: humus content: 2.02–3.2%, lightly hydrolyzed nitrogen 67–92, mobile phosphorus 149–220, exchangeable potassium 92–126 mg kg^{-1} of soil at pH_{KCl} 5.5–6.0. Technological parameters for the formation of oilseed radish agrophytocenosises were carried out in the interval of recommended variants in terms of common row (row spacing of 15 cm) and wide-row (row spacing of 30 cm) sowing methods. The variants are selected considering the uniformity of seed placement along the length of the row from 15 to 60 similar seeds per linear meter in a row (Table 1).

The climate of the region is moderately continental (Dfb according to the Köppen-Geiger climate classification (Pivoshenko, 1997)). The hydrothermal parameters of the oilseed radish vegetation period differed, forming certain typological features of the years of study.

The 2013–2014 conditions (Fig. 1) can be classified as the most optimal for growth processes of oilseed radish due to the combination of slow growth rates of average daily temperatures and uniform precipitation at the end of May-mid-June. In the study area, it's phenologically corresponds to active vegetation of oil-seed radish and coincides with the interphase phenological period of stooling-flowering (BBCH 30-65) (Test Guidelines…, 2017).

Table 1. Scheme of the experiment under wide-spread variants of oilseed radish agrophytocenosis formation

Factors of the trial (A – conditions of the year)		
B – planting method	C – seeding rates (mln germinable seeds ha^{-1})	D – fertilization
B_1 – row method (15 cm)	B_1 – 1.0 (15 seeds m^{-1} per row*) B_2 – 2.0 (30 seeds m^{-1} per row) B_3 – 3.0 (45 seeds m^{-1} per row) B_4 – 4.0 (60 seeds m^{-1} per row)	C_1 – without fertilizers C_2 – $N_{30}P_{30}K_{30}$ C_3 – $N_{60}P_{60}K_{60}$ C_4 – $N_{90}P_{90}K_{90}$
B_2 – wide-row method (30 cm)	B_5 – 0.5 (15 seeds m^{-1} per row) B_6 – 1.0 (30 seeds m^{-1} per row) B_7 – 1.5 (45 seeds m^{-1} per row) B_8 – 2.0 (60 seeds m^{-1} per row)	

The conditions of 2015 and 2018 for the research period based on the of precipitation uniformity and the nature of the average daily temperature rise curve ratio should be considered as stressful for the physiological and growth processes of oilseed radish plants.

Thus, in 2015, the precipitation distribution was uneven, with no precipitation during the second decade of May to the second decade of June, with an intensive and rapid rise in average daily temperatures during the same period and a high amplitude of values. As a result, there was a double effect of general stress of the environmental factor during the interphase period of the beginning of budding-flowering (BBCH 38-64) concerning oilseed radish plants and it allowed to effectively evaluate the studied indicators in the system of environment-forming features.

For the conditions in 2018, there was a prolonged atmospheric and soil drought with slight moistening by the second decade of June against the background of low average daily temperatures, in contrast to the conditions in 2015, which affected the value of the architectonics of the oilseed radish plants starting from the rosette formation phase and its subsequent stooling (BBCH 19-38). These are the reasons why the 2018 vegetation year is the most indicative of stress assessment.

The 2016 and 2017 research years on hydrothermal regime parameters should be classified as intermediate in a six-year study cycle with a similar dynamic regime of average daily temperatures and irregular atmospheric moistening. Meanwhile, the 2016 conditions are close to the 2013–2014 period, and the 2017 conditions are similar to the 2015 conditions. Thus, an increase in the overall favorable hydrothermal vegetation regime for the oilseed radish towards reducing weather risks in terms of optimality for the growth and development of the oilseed radish should be placed in the following order: 2018–2015–2017–2016–2013–2014.

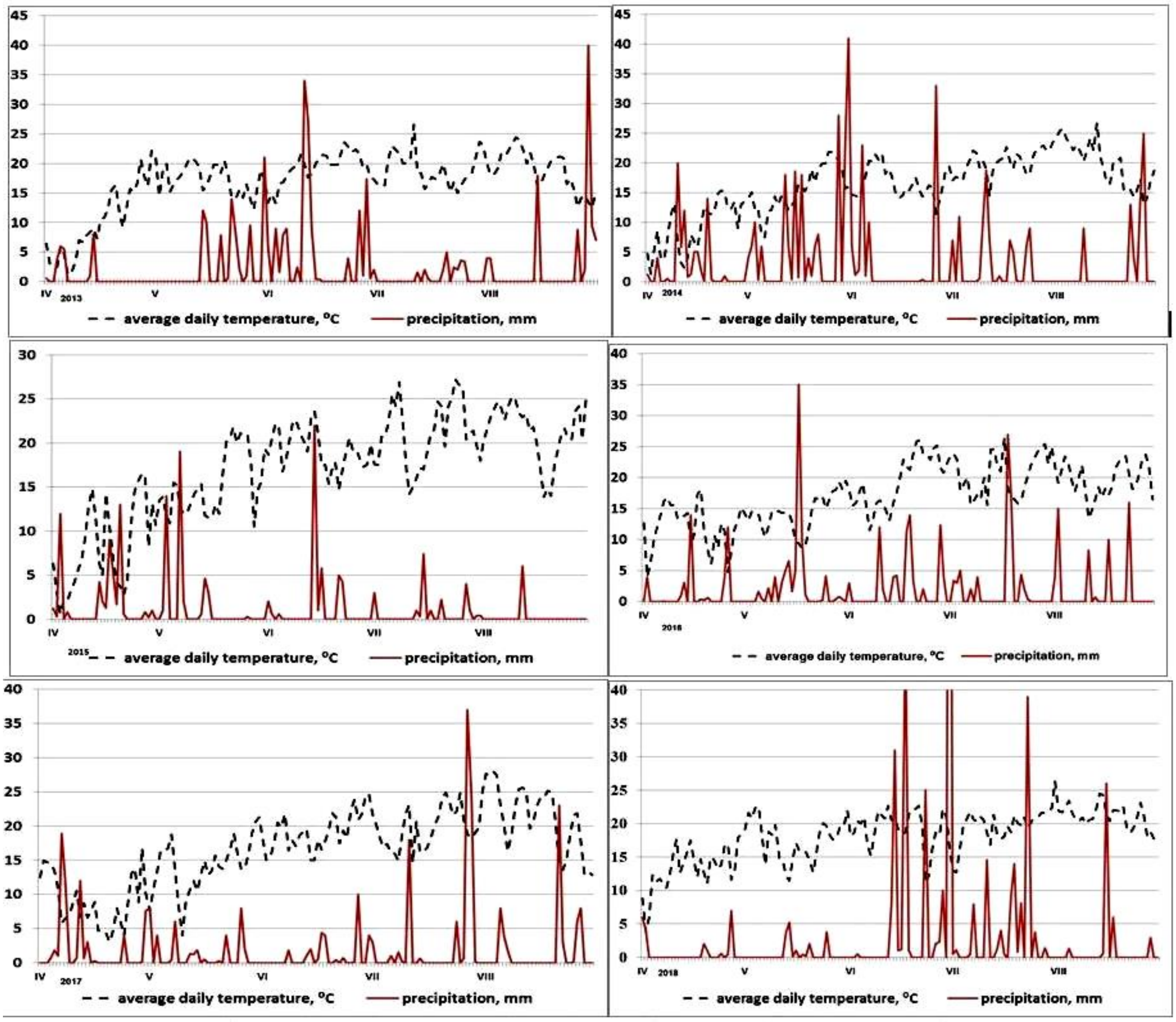

Figure 1. Hydrothermal conditions for April–August (2013–2018 period) (sequentially left-right and top-down: 2013–2014–2015–2016–2017–2018)

At the same time, the impact of environmental parameters on the studied indicators was analyzed in the paper using the hydrothermal coefficient (HTC) developed by Selyaninov (Mukhortov, Ryabchikova, 2012), which was calculated using the Formula 1:

$$HTC = \frac{\sum R}{0.1 \times \sum t_{>10}}, \quad (1)$$

where the amount of precipitation (ΣR) in mm for the period with temperatures, above 10 °C, the sum of active temperatures (Σt>10 °C) for the same period reduced by 10 times.

The assessment of the oilseed radish vitality strategies against the background of the technological regulations for the pre-sowing construction of its agrophytocenosises was carried out using modular-distinctive and vitality approaches, considering the fertilizer options as stress-regulating and corrective factors in the light of changes in oilseed radish cenosis density combined with sowing rates and row spacing. The study was conducted on basic area-specific oilseed radish genotypes, namely 'Zhuravka', 'Lybid' and 'Raiduha'.

Given the similarity of the identified regularities and peculiarities, the materials presented in this paper relate to the 'Zhuravka' variety with relevant practical conclusions regarding the general species of oilseed radish (*Raphanus sativus* var. *oleifera* Pers.).

The following indicators were used to systematically evaluate the formation of vital strategies of oilseed plants.

Vitality coefficient (calculated according to defined methods (Zlobin, 1989; Ishbirdin *et al*., 2004), using the Formula 2:

$$IVC = \frac{1}{N} \times \sum_{i=1}^{N} \frac{x_i}{X_i}, \quad (2)$$

where IVC – agrophytocenosis vitality index; N – total number of features that are determined in agrophytocenosis; x_i – the value of the i-th feature in agrophytocenosis with certain cultivation technology parameters; X_i – the average of the i-th feature for all agrophytocenosises in the interval of cultivation technology parameters under study.

Morphological variability module according to recommendations (Glukhov, Prokhorov, 2008) using Formula 3:

$$Mod_x = \frac{CV}{CV_{St}} \qquad (3)$$

where Mod_x – morphological variability module of the respective plant parameter, CV – coefficient of variation of a feature from the variant under the study, CV_{st} – coefficient of variation in the variant of maximum morphological development.

Modified morphological integration index (I_{mmi}) was determined by the recommendations (Zlobin, 2009; Sherstyuk, 2017) using Formula 4:

$$I_{mmi} = \frac{1B \leq 0,5 + 2B > 0.5... < 0,8 + 3B \geq 0,8}{(n^2 - n)/2} \qquad (4)$$

where I_{mmi} – modified morphological integration index; B≤0.5 – the number of statistically reliable (at the probability level of 0.95) correlation coefficients in the matrix, the values of which by the module are in the range from 0 to 0.5 inclusive; B>0.5…<0.8 – the number of statistically reliable (at the probability level of 0.95) correlation coefficients in the matrix, the values of which by the module are higher than 0.5 and lower than 0.8; B≥0.8 – the number of statistically reliable (at the probability level of 0.95) correlation coefficients in the matrix, the values of which by the module are equal to or greater than 0.8; n – total number of morphometric parameters that have been assessed.

The degree of integrated connection of plant morphological features was assessed using the weight correlation graph method in two interpretations using Formula 5 and 6:

$$G = \sum_{|r_{ij}| \geq \alpha} |r_{ij}| \qquad (5)$$

where r_{ij} – correlation coefficient between *i*-th and *j*-th indicator. Reliable correlation coefficients are considered.

$$G' = (\sum_{|r_{ij}| \geq \alpha} |r_{ij}|)/n \qquad (6)$$

n – number of statistically significant correlation coefficients.

To assess the vitality of oilseed radish agrophytocenosises, a quality index (Q) was used for the various study options by the recommendations (Rasevich, 2008) using Formula 7:

$$Q = \frac{(A+B)}{2} \qquad (7)$$

The vitality classes have been interpreted in terms of the idiotype of oilseed radish plants, which were mentioned earlier in our publications on the specifics of the layering formation of the crop's agrophytocenosis. Given these conditions, in the formula, A and B, respectively, represent the number of species of the first and second ideotype, *i.e.* the upper and middle dominating tier. The resulting average between the first and second plant ideotype was compared to the third plant ideotype (lower-tier) (C). The principle of comparison provided for the use of equation in the following format: Q>C, cenosis has growth and development-friendly structure for species, Q<C – regressive, Q = C – equilibrium-dynamic.

The agrophytocenosis flourishing index (I_Q) was determined by the recommendations (Ishbirdin *et al.*, 2005) using Formula 8:

$$I_Q = \frac{(A+B)}{2C} \qquad (8)$$

Phytocoenotic plasticity index I_p was determined by the recommendations (Zlobin, 1989) using Formula 9:

$$I_p = \frac{(A \cdot B)}{A} \qquad (9)$$

where A and B – respectively the maximum and minimum average value of the feature by year of observation.

The ecological amplitude of the technological variant of oil radish cultivation was assessed based on the size plasticity index, which was calculated using Formula 10 (Ishbirdin *et al.*, 2004):

$$ISP = \frac{IVC_{\max}}{IVC_{\min}} \qquad (10)$$

where IVC_{max} – vitality index for plants with signs of the most distinct morphotype; IVC_{min} – vitality index for plants with signs of the least distinct morphotype.

Morphological features were assessed by sampling typical plants at five locations along the length of a row in a stochastic manner along the width of the area, with row horizontal displacement in non-contiguous repetitions at four single repetitions. The morphological features were registered in the following phenological phases: flowering (BBCH 65), green pod (BBCH 75-78), and yellow pod (BBCH 79-83). To register the features, the plants were marked and numbered for the non-destructive recording of the relevant indicators. Those indicators, which required the selection of a part of the plants (area of leaves, the weight of separate parts, the weight of fruits, *etc*.), were recorded on parallel plants which were the closest to the main (numbered) plants in the records. Such a system of conditional comparison of the integrity of typical plants applied in the evaluation of the system of matrix correlations of plant features in dynamics (Rostova, 2002) has allowed us to compile a matrix of correlations that connects the full range of morphological vegetative features of plants and individual basic indicators of their seed productivity. The system of morphological features used in the assessment results was divided into blocks (Table 2).

Table 2. Modular blocks for morphological and productive analysis of oilseed radish plants (grouping)

Modular and morphological block	Feature and dimension of its evaluation	Trivial designation
Stem and root block	Stem height, cm	H
	Stem diameter at the base, mm	D
	Stem height to the first branching, cm	H_1
	Stem morphology index, cm mm^{-1}	HDR
	Weight of the stem part of the plant, g	w_1
	Root weight, g	WR
Block of the leaf part	Number of leaves on the stem, pcs.	n
	Leaf length, cm	l
	Leaf width, cm	a
	Area of plant leaves, cm^2	S
	Average leaf area, cm^2	$S\ n^{-1}$
	Thickness of 10 leaves, mm	h
	Weight of leaves from the plant, g	w_2
	Elongation of the leaf blade	$l\ a^{-1}$
	Leaf area per unit of leaf phytomass, $cm^2\ g^{-1}$	SLA
Block of the generative part	Number of flowers on the plant, pcs.	N_1
	Total weight of the inflorescence, g	w_3
	Number of reproductive branching of the stems, pcs.	R
	Number of pods on the plant, pcs.	N_2
	Number of seeds in the pod, pcs.	g
	Total weight of pods from a plant at green pod phase, g	w_4
Productive block	Total weight of the plant, g	W $(WR + w_1 + w_2 + w_3 + w_4)$
	Photosynthetic effort (leaf weight per unit of phytomass)	LWR
	Reproductive effort RE (flower),%	$w_3\ w_1^{-1}$
	Reproductive effort RE (fruit),%	$w_4\ w_2^{-1}$
	Reproductive effort RE assimilation,%	$w_3\ (w_4)\ S^{-1}$
	Ratio of leaf surface area to plant weight, $cm^2\ g^{-1}$	LAR
	Ratio of leaf surface area to stem diameter, $cm^2\ cm^{-1}$	ADR
	Relative increase in height, cm g^{-1} $(H\ (w_1+w_2+w_3+w_4)^{-1})$	HWR
	Weight of 1000 seeds, g	m
	Seed projection surface area, mm^2	s
	Seed yield from the plant, g	Y

Tier structure of agrophytocenosises along with the determination of plant ideotypes was registered and analyzed at selected parts of the experimental plots in each repetition. The main morphological features were registered using standardized and widely accepted methods for a group of cruciferous crops (Sayko, 2011). Also, we used methodological descriptive recommendations of classification rank tables of species expertise (Test Guidelines…, 2017) with experimental statistical approaches (Zaytsev, 1984; Rumsey, 2016) in the format of four-factor dispersion analysis (Multivariate Analysis of Variance (MANOVA) and a pack of statistical programs Statistica 10 and MS Excel 2013. The correlation coefficient values $r < 0.5$ were considered as weak, $0.7 > r \geq 0.5$ – as moderate, $0.9 > r \geq 0.7$ – as strong (Rumsey, 2016). The level of variability of morphological features and grouped indicators was based on the Zaytsev H.N. scale (Zaytsev, 1984): very low (CV < 7%); low (CV = 8–12%); medium (CV = 13–20%); elevated (CV = 21–30%); high (CV = 31–40%); very high (CV > 40%).

Results and discussion

Modern practical approaches to the formation of agrophytocenosises of agricultural plants are aimed at the maximum realization of their genetic potential and are expressed in the formation of a specific, desirable ideological structure of sowing. Today, the "ideotype" term is defined as a "biological model", which results in programmed plant productivity under specific cultivation conditions due to a combination of the respective habitus project and the biological properties of the genotype, which should, in the resulting variant, ensure maximum yield of the plants with the corresponding high indicators of its quality (Donald, 1968; Zeven, 1975; Foltyn, 1977; Ma *et al*., 2014; Zhang, 1999; Rötter *et al*., 2015; Skliar *et al.*, 2016; Gauffreteau, 2018, Mangin *et al.*, 2017). The modern interpretation of the term is a search for appropriate plant microbiotypes that form the agrophytocenosis of any agricultural plant to make the most efficient use of growth resources under the respective physiological needs of the plant and agro-climatic resources of the territory (Tandon *et al*., 2004, Andrivon *et al*., 2013; Bassu *et al*., 2014). On the other hand, it is noted that when assessing such microbiotypes in general cenosis, it is necessary to determine the correlation between morphometric parameters and individual plant productivity indicators, considering the respective soil and climate resources of the territory against the background of their abiotic adaptation (Zhuchenko, 2001, Rostova, 2002; Tandon *et al*., 2004; Araus, Cairns, 2014). The integrity of these microbiotypes and the predominant expression of some of them determine, by their very nature, the life strategy of cenosis and its corresponding ideotype structure, the analysis of which is an indicator of performance at both the individual and general levels (Rasmusson, 1991; Abuelgasim, 1991; Thurling, 1991; Notov, 1999; Dolotovsky, 2003; Rostova, 2002; Desclaux, 2008; Rötter, 2015; Van Oijen, 2016; Van Tassel *et al.*, 2017; Anderson, 2019).

In our system of assessments, the integrity of the morphological features of oilseed plants was assessed by three criteria mentioned above: modified morphological integration index (I_{mmi}), weight correlation graph method (G) and morphological variability module (Mod_x). The first of the two indicators are based on a system of pairwise correlations by the methodology used to determine them. Correlation analysis on basic morphological features, by the conclusions on the influence of abiotic factors and technological aspects of the cultivation of crops on the materiality of dependencies (Labana *et al*., 1976; Rostova, 2002) was carried out in the format of the annual correlation matrix in the context of the studied options of oilseed radish cultivation (Table 1). The paper presents pairwise correlation coefficients for two types of vegetation years concerning hydrothermal supply (2014 and 2018, respectively (Table 3)) and for two radically different technological variants of sowing rates (4.0 and 0.5 million pcs ha^{-1} of germinable seed respectively, against the background of the two fertilizer limit systems – fertilizer-free and $N_{90}P_{90}K_{90}$ application (Tables 4, 5)). A general stress assessment of the correlation matrix for radically different vegetation years showed several features. Firstly, oilseed radish can be classified as plant species with a sufficiently high level of morphological integration, taking into account the average level of cohesion, according to an average value of $G^{'}$ 0.533 for the year with the lowest (2014), and $G^{'}$ 0.639 for the year with the highest stress (2018). Secondly, under conditions of 2018, the average correlation coefficient in the sum of morphological features was 19.8% higher than in 2014, which according to the hydrothermal regime was considered to be the most favourable year for physiological growth processes of oilseed radish plants. This means that abiotic pressure, by limiting the intensity of growth processes, both radial and linear, ensures the formation of distinct pleiades in the basic characteristic plant blocks that characterize their morphological integrity. In the case of the moistening limit against the background of intensively rising temperatures (conditions of 2018), an overall miniaturization effect is observed for oilseed radish plants – a significant reduction in species by linear size, size of the assimilation surface and mass of the generative part. Under the same conditions, the tendency described in several studies is typical (Grime, 1979, 1988; Usmanov, 1990; de Kroon *et al.*, 2005; Murren, 2002; Sultan, 2004; Zlobin, 1993, 2009), namely the specific reaction to the complex stress of allometric parameters: the photosynthetic effort (LWR) of plants naturally increases and the reproductive effort (RE) significantly decreases. In other words, the overall ontogenetic tactics are maintained, and plant survival becomes an important factor in their reproductive tactics. Given these conditions, the narrowness of the variability of the morphological features in terms of the variation coefficient increases the contingency in their combinatorial variation in the ratio of pairs of features. For the oilseed radish, such features can be seen between the following pairs of features: stem diameter (D) – the weight of the plant (W), stem diameter (D) – the area of plant leaves (S), area of plant leaves (S)-leaf morphological parameters (length (l) and width (a)) and others. In the optimal combination of abiotic growth and development parameters, there is an opposite situation to stress conditions, which ensures the growth of the interval of values of plant morphological parameters of both allometric and reproductive nature and reduces the overall integration of plant morphological development. However, there is general preservation of the nature of pleiad pairs in terms of reducing the materiality of the correlation link of the features that form them, by the values of the correlation graph correlated by the number of significant correlation coefficients ($G^{'}$). Due to certain facts, the morphological and weight integrity of oilseed radish plants in a single system of comparison of technological variants, under conditions of significant abiotic stress, is substantially higher than under an optimal combination of environmental factors.

At the same time, in terms of the value of the correlation graph (G), the formation of correlation dependencies for various features has its peculiarities when comparing stressful and optimal conditions. Thus, the highest degree of integration of the connection for indicator G, significant stress conditions of vegetation, was noted for such features as the area of plant leaves (S) and weight of the plant stem (w_1) – 12.57 and 12.53 respectively. Substantially higher morphological and weight integration values were also recorded for leaf length (l) 11.99, the weight of the inflorescence (w_3) 11.84, the weight of leaves from the plant (w_2) 11.79 and stem diameter (D) 11.53. These are the features that form the middle and high-level pleiade correlation structures by the bond materiality. Low integration values were noted for the features of stem height to the first branching (H_1) and seed projection surface area (s) – 7.64 and 8.14, respectively. The weight 1000 seeds (m) should also be attributed to the group of indicators with a low level of integration, both because of the intermediate effects of interaction in the formation of the indicator and because of the corresponding level of its genetic determinacy. Under the conditions of 2014, with a decrease in abiotic pressure, the overall integration in terms of the value of the correlation graph of features (G) decreased by 16.4% for the group as a whole, with a maximum decrease for features of leaf width (a) 28.4%, plant height (H) 28.1%, number of pods on the plant (N_2) 25.0%, number of leaves on the plant (n) 23.0%, root weight (WR) 22.4%. The minimal decrease in the value of the correlation graph was observed with a decrease in abiotic pressure for the features of the weight of leaves from the plant (w_2) 5.1%, number of seeds in the pod (g) 6.7%, the total weight of pods from a plant at green pod phase (w_4) 7.9%, weight of 1000 seeds (m) 11.5%. This nature of change indicates a change in the correlation structure between the oilseed radish organs due to more intense linear and radial growth, the overall increase in the linear size of the assimilation apparatus. At the same time, the ratio between the above-ground system and the root system is disproportionate, and the total number of reproductive elements of flowers and pods has less reproductive effort than in stressful conditions. In this case, the conditions of assimilation feeding require an appropriate area of leaf apparatus to support growth processes. This is the reason for the minimal decrease in the correlation graph by the feature of the weight of leaves from the plant and the intensive decrease in the graph by the features of the number of leaves on the plant and leaf width. Again, the intensive growth of above-ground plant biomass with a decrease in abiotic pressure contributes to the associated changes in the reproductive effort (with a certain proportional formation of plant weight and pod weight) and to an increase in the correlative determinacy of the indicator. The nature of changes in the number of seeds in the pod and weight of 1000 seeds is determined by the same genetic determination in cruciferous crops highlighted in several publications (Zhuchenko, 2001). It should be noted that the expression of the pleiade structure of the bonds in 2014 for indicator D' shifts towards such features as stem diameter (D), area of plant leaves (S) and its weight (w_2), the weight of the stem plant (w_1) and weight of pods from a plant (w_4).

Preliminary conclusions are also confirmed in the evaluation of the correlation matrix for features of oilseed radish plants in different technological variants of oilseed radish cultivation (Tables 4, 5). Given that the plant stand density per unit of feeding area should be considered as an option for the agrophytocenosis regulation (Rabotnov, 1998; Rostova, 2002; Shanda, 2017), and the additional use of mineral fertilizers as a factor to increase or decrease plant stress, especially at cenosises of different density (Sinyagin, 1975; Chapin, 1980; Poluektov, 2006) analysis of the obtained data allows us to assess the degree of morphological integration of plants at different fertilization and stand density. It should be noted that the results we have obtained indicate certain stability in the system of correlation bonds at different cenosis densities of the oilseed radish. This is evidenced by the results of assessing the weight of the average correlation graph G on comparable technology variants. Thus, with a sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground this indicator was 8.20, on the ground with the application of $N_{90}P_{90}K_{90}$ kg ha^{-1} – 6.97. The same indicators for the same types of fertilizer with a sowing rate of 0.5 million pcs. ha^{-1} were 8.47 and 7.05, respectively, for the survey period. The similarity was also determined for the examined system of plant features and the indicator of the corrected correlation graph on the materiality of the bond: for both density and fertilizer comparisons, they were 0.513 and 0.482 and 0.507 and 0.459, respectively. Thus, with lower stand density on a nonfertilized ground, there is a greater weight of the graph than in the variant with significantly higher stand density. On the contrary, mineral fertilizers, within the studied options, contributed to a 17.3% reduction in morphological integration with a sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds and a 20.3% reduction with a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds. Thus, for the oilseed radish, we have established the stability of integration of the general morphogenesis, where the reduction of the bond density in one pair of features with changes in the agrophytocenosis construction technology is balanced by an increase in its materiality in another system of features. At the same time, with the relative stability of the bonding tendencies and the existence of relatively stable correlation pleiades in the system, they are being reformatted. Thus, the constancy of the bonds between such features as stem diameter (D), root weight (WR), area of plant leaves (S), leaf length (l) for both dual variants of comparison with the relatively constant range of the pairwise correlation coefficients in the range of 0.397–0.968 (Tables 4, 5) is heterogeneously compensated or, conversely, weakened by the specificity of the interaction of the total reduction of the oilseed radish plant's habitus. It's accompanied by the increase in cenosis density (Tsytsiura, 2018, 2019) and an increase in the overall variability of morphological features and associated weight characteristics of oilseed radish plants with different fertilizer variants. Thus, for the variant of 4.0 million pcs. ha^{-1} of germinable seeds, on a nonfertilized ground, significant correlation bonds were noted in the system of integration of such features as plant height, stem diameter, root weight, stem weight, number of leaves, morphological features of the leaf itself, individual features of the seeds. For the technological variant of assessment of 0.5 million pcs. ha^{-1} of germinable seeds, the bond intensity of the above-mentioned features is reduced, especially concerning the height of the plants, but due to the growth of the total branching of plants in the variants of oilseed radish sowing rate of 0.5–1.0 million pcs. ha^{-1} of germinable seeds in the variant of wide-row sowing (Tsytsiura, 2018) the role of the height of plants to the first branching (H_1) in the morphological integration of the plants is increased.

Table 3. Correlation matrix for morphological and productive analysis of oilseed radish plants of "Zhuravka" variety in the system of technological variants for the construction of its agrophytocenosises, in the consolidated system of technological variants – years of cultivation, 2013–2018 (for N in total annual group 480)

Year	Graph of feature (G)	Graph of feature (G')	Features	H	D	H_1	w_1	WR	n	l	a	S	w_2	N_1	w_3	N_2	g	w_4	m	s	Y	Features	Graph of feature (G)	Graph of feature (G')	Year
2018	10.05	0.591	H	1.000	0.762	0.380	0.373	0.482	0.152	0.355	0.256	0.29	0.463	0.592	0.578	0.417	0.509	0.579	0.415	0.317	0.312	H	7.23	0.425	2014
	11.53	0.678	D	0.724	1.000	–0.621	0.805	0.709	0.529	0.572	0.474	0.785	0.597	0.694	0.639	0.531	0.319	0.609	0.459	0.207	0.402	D	9.71	0.571	
	7.64	0.449	H_1	0.314	–0.714	1.000	–0.622	–0.412	–0.561	–0.358	–0.249	–0.215	–0.329	–0.259	–0.39	–0.369	–0.308	–0.292	–0.356	–0.254	–0.517	H_1	6.49	0.382	
	12.53	0.737	w_1	0.855	0.935	–0.801	1.000	0.637	0.711	0.728	0.659	0.741	0.827	0.629	0.714	0.727	0.407	0.707	0.629	0.358	0.525	w_1	10.80	0.635	
	10.72	0.630	WR	0.615	0.852	–0.693	0.852	1.000	0.501	0.517	0.505	0.491	0.609	0.396	0.488	0.515	0.392	0.535	0.336	0.318	0.423	WR	8.27	0.486	
	11.49	0.676	n	0.489	0.804	–0.562	0.805	0.653	1.000	0.309	0.367	0.859	0.902	0.571	0.505	0.609	0.517	0.529	0.367	0.319	0.544	n	8.85	0.521	
	11.99	0.705	l	0.819	0.755	–0.615	0.858	0.761	0.712	1.000	0.892	0.875	0.745	0.621	0.711	0.505	0.519	0.693	0.459	0.412	0.51	l	9.78	0.575	
	10.44	0.614	a	0.703	0.681	–0.522	0.751	0.602	0.651	0.928	1.000	0.838	0.410	0.504	0.413	0.351	0.219	0.305	0.218	0.329	0.322	a	7.31	0.430	
	12.73	0.749	S	0.715	0.892	–0.675	0.853	0.774	0.719	0.922	0.901	1.000	0.890	0.814	0.809	0.743	0.706	0.633	0.458	0.391	0.692	S	11.23	0.661	
	11.79	0.693	w_2	0.674	0.631	–0.506	0.909	0.609	0.951	0.808	0.712	0.928	1.000	0.712	0.751	0.701	0.56	0.854	0.614	0.601	0.623	w_2	11.19	0.658	
	11.11	0.654	N_1	0.307	0.814	–0.503	0.708	0.412	0.703	0.691	0.528	0.805	0.631	1.000	0.909	0.597	0.507	0.628	0.562	0.439	0.505	N_1	9.94	0.585	
	11.84	0.696	w_3	0.652	0.855	–0.568	0.801	0.669	0.735	0.752	0.654	0.827	0.677	0.851	1.000	0.394	0.389	0.639	0.502	0.456	0.378	w_3	9.67	0.569	
	10.96	0.645	N_2	0.584	0.809	–0.455	0.655	0.555	0.714	0.587	0.509	0.611	0.755	0.714	0.705	1.000	0.569	0.817	0.511	0.467	0.596	N_2	8.22	0.483	
	10.82	0.636	g	0.825	0.684	–0.494	0.515	0.618	0.622	0.693	0.569	0.752	0.582	0.613	0.557	0.628	1.000	0.526	0.463	0.491	0.815	g	10.09	0.593	
	10.95	0.644	w_4	0.488	0.886	–0.505	0.610	0.701	0.691	0.571	0.412	0.602	0.781	0.762	0.789	0.701	0.608	1.000	0.612	0.42	0.711	w_4	10.09	0.593	
	9.38	0.552	m	0.396	0.624	–0.623	0.607	0.354	0.551	0.603	0.501	0.557	0.551	0.589	0.554	0.565	0.612	0.509	1.000	0.709	0.625	m	8.30	0.488	
	8.14	0.509	s	0.202	0.509	–0.089	0.459	0.406	0.502	0.505	0.407	0.5	0.51	0.556	0.536	0.512	0.715	0.55	0.618	1.000	0.522	s	7.01	0.412	
	11.27	0.663	Y	0.687	0.791	–0.514	0.554	0.589	0.629	0.607	0.411	0.693	0.571	0.927	0.658	0.903	0.733	0.786	0.563	0.653	1.000	Y	9.02	0.531	

Levels of significance: $p \le 0.05$: $0.09 \le r \le 0.116$; $p \le 0.01$: $0.117 \le r \le 0.148$; $p \le 0.001$: $r \ge 0.148$.

Table 4. Correlation matrix for morphological and productive analysis of oilseed radish plants of 'Zhuravka' variety at a sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds with different fertilizer options for the 2013–2018 period (for N in technological variant 60)

Variant	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Features	H	D	H_1	w_1	WR	n	l	a	S	w_2	N_1	w_3	N_2	g	w_4	m	s	Y	Features	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Variant
4.0 million pcs. ha^{-1} of germinable seeds against the $N_{90}P_{90}K_{90}$ ground	0.444	0.548	7.10	H	1.000	0.411*	0.525	0.114	0.405	0.156	0.562	0.442	0.521	0.507	0.365	0.411	0.511	0.402	0.409	0.283	0.401	0.612	H	0.451	0.711	6.77	4.0 million pcs. ha^{-1} of germinable seeds fertilizer-free
			9.31			0.793**	0.521	0.684	0.683	0.883	0.824	0.672	0.765	0.708	0.814	0.771	0.837	0.632	0.761	0.411	0.603	0.727				12.09	
	0.489	0.599	6.85	D	0.287	1.000	–0.089	0.612	0.542	0.519	0.456	0.473	0.618	0.634	0.526	0.511	0.452	0.265	0.414	0.225	0.311	0.315	D	0.471	0.646	7.06	
			8.99		0.592		–0.432	0.785	0.756	0.654	0.726	0.528	0.819	0.909	0.637	0.654	0.705	0.302	0.639	0.429	0.609	0.605				10.98	
	0.366	0.436	3.66	H_1	0.464	–0.257	1.000	–0.165	–0.112	–0.169	–0.108	–0.087	–0.205	–0.315	–0.167	–0.257	–0.236	–0.107	–0.152	–0.237	–0.151	–0.251	H_1	0.366	0.438	1.10	
			4.80		0.586	–0.305		–0.326	–0.507	–0.412	0.473	–0.485	–0.569	–0.507	–0.374	–0.492	–0.452	–0.308	–0.354	–0.412	–0.391	–0.429				7.44	
	0.437	0.540	6.56	w_1	0.326	0.623	0.096	1.000	0.564	0.267	0.404	0.361	0.518	0.414	0.39	0.495	0.453	0.301	0.419	0.417	0.239	0.311	w_1	0.395	0.631	5.93	
			8.64		0.404	0.817	0.157		0.801	0.651	0.723	0.625	0.719	0.709	0.617	0.631	0.682	0.524	0.659	0.612	0.429	0.543				10.72	
	0.503	0.525	5.03	WR	0.512	0.603	–0.236	0.624	1.000	0.312	0.409	0.328	0.412	0.392	0.304	0.417	0.515	0.251	0.408	0.319	0.303	0.322	WR	0.396	0.649	5.95	
			7.87		0.633	0.704	–0.192	0.813		0.719	0.761	0.634	0.725	0.709	0.652	0.639	0.624	0.469	0.669	0.529	0.602	0.551				11.03	
	0.428	0.507	6.00	n	0.296	0.527	–0.411	0.425	0.409	1.000	0.105	0.091	0.529	0.614	0.294	0.368	0.455	0.482	0.426	0.456	0.198	0.400	n	0.380	0.669	5.32	
			8.11		0.451	0.609	–0.558	0.569	0.507		0.709	0.589	0.845	0.854	0.669	0.629	0.809	0.669	0.811	0.505	0.357	0.612				11.38	
	0.416	0.585	6.71	l	0.633	0.512	–0.523	0.428	0.394	0.211	1.000	0.822	0.751	0.702	0.369	0.41	0.318	0.353	0.31	0.327	0.205	0.387	l	0.446	0.664	6.69	
			8.78		0.708	0.617	–0.456	0.583	0.552	0.316		0.908	0.901	0.814	0.652	0.658	0.501	0.508	0.604	0.602	0.395	0.525				11.28	
	0.458	0.511	5.03	a	0.402	0.352	–0.239	0.335	0.421	0.302	0.732	1.000	0.812	0.364	0.257	0.307	0.242	0.214	0.362	0.287	0.203	0.289	a	0.400	0.562	5.20	
			7.15		0.509	0.496	–0.320	0.452	0.519	0.369	0.893		0.907	0.626	0.498	0.469	0.503	0.419	0.507	0.415	0.354	0.411				9.55	
	0.549	0.620	8.24	S	0.509	0.523	–0.294	0.529	0.507	0.622	0.828	0.802	1.000	0.625	0.574	0.521	0.504	0.369	0.542	0.257	0.303	0.459	S	0.501	0.699	8.02	
			10.54		0.631	0.781	–0.369	0.635	0.587	0.701	0.968	0.889		0.893	0.734	0.718	0.668	0.599	0.712	0.429	0.451	0.627				11.89	
	0.528	0.635	8.44	w_2	0.632	0.805	–0.322	0.524	0.451	0.702	0.751	0.529	0.816	1.000	0.407	0.521	0.521	0.269	0.587	0.421	0.25	0.459	w_2	0.485	0.662	7.75	
			10.16		0.702	0.921	–0.478	0.603	0.551	0.809	0.908	0.612	0.968		0.647	0.627	0.619	0.428	0.713	0.509	0.356	0.622				11.25	
	0.419	0.510	6.71	N_1	0.414	0.631	–0.329	0.429	0.319	0.362	0.528	0.419	0.469	0.362	1.000	0.587	0.429	0.298	0.557	0.369	0.305	0.452	N_1	0.405	0.585	6.48	
			8.66		0.529	0.745	–0.450	0.56	0.451	0.451	0.612	0.54	0.594	0.427		0.733	0.592	0.387	0.613	0.405	0.352	0.569				9.95	
	0.460	0.531	6.90	w_3	0.369	0.527	–0.269	0.429	0.456	0.502	0.524	0.327	0.563	0.527	0.638	1.000	0.452	0.303	0.51	0.289	0.326	0.412	w_3	0.417	0.585	7.10	
			9.03		0.473	0.704	–0.308	0.581	0.561	0.592	0.608	0.451	0.691	0.638	0.702		0.611	0.383	0.601	0.397	0.417	0.522				9.95	
	0.489	0.579	8.14	N_2	0.52	0.527	–0.367	0.524	0.511	0.409	0.492	0.412	0.527	0.554	0.503	0.529	1.000	0.516	0.741	0.369	0.321	0.562	N_2	0.385	0.505	5.38	
			9.85		0.592	0.63	–0.457	0.611	0.602	0.567	0.569	0.517	0.637	0.701	0.616	0.624		0.554	0.811	0.417	0.439	0.691				8.58	
	0.387	0.421	3.10	g	0.425	0.132	–0.102	0.236	0.152	0.328	0.169	0.169	0.306	0.155	0.219	0.165	0.364	1.000	0.402	0.512	0.362	0.551	g	0.457	0.615	7.31	
			5.47		0.587	0.254	–0.189	0.354	0.211	0.403	0.287	0.291	0.412	0.219	0.357	0.301	0.472		0.504	0.605	0.469	0.818				10.45	
	0.395	0.469	5.13	w_4	0.361	0.284	–0.056	0.326	0.217	0.269	0.147	0.103	0.41	0.427	0.389	0.452	0.616	0.374	1.000	0.41	0.325	0.489	w_4	0.457	0.615	7.31	
			6.57		0.471	0.351	–0.102	0.411	0.327	0.39	0.196	0.151	0.502	0.512	0.487	0.55	0.719	0.401		0.502	0.419	0.569				10.45	
	0.346	0.389	3.46	m	0.214	0.051	–0.163	0.325	0.196	0.234	0.259	0.136	0.202	0.344	0.287	0.263	0.451	0.332	0.357	1.000	0.523	0.627	m	0.391	0.510	5.87	
			5.45		0.302	0.104	–0.211	0.418	0.269	0.312	0.401	0.213	0.269	0.413	0.321	0.32	0.52	0.442	0.415		0.653	0.841				8.67	
	0.340	0.384	3.06	s	0.429	0.145	–0.103	0.269	0.208	0.169	0.11	0.129	0.209	0.269	0.301	0.214	0.32	0.359	0.329	0.417	1.000	0.628	s	0.373	0.471	4.11	
			4.99		0.505	0.289	–0.198	0.3	0.294	0.214	0.19	0.201	0.297	0.354	0.369	0.319	0.408	0.455	0.418	0.521		0.715				8.01	
	0.454	0.527	7.26	Y	0.524	0.387	–0.422	0.439	0.451	0.433	0.329	0.174	0.537	0.427	0.327	0.529	0.518	0.607	0.537	0.429	0.365	1.000	Y	0.455	0.610	7.28	
			8.96		0.633	0.425	–0.511	0.529	0.502	0.508	0.403	0.296	0.612	0.562	0.451	0.605	0.607	0.709	0.62	0.531	0.459					10.38	

*Levels of significance: $p \le 0.05$: $0.255 \le r \le 0.330$; $p \le 0.01$: $0.331 \le r \le 0.418$; $p \le 0.001$: $r \ge 0.418$; * – minimum and ** maximum correlation value for years of assessments.*

Table 5. Correlation matrix for morphological and productive analysis of oilseed radish plants of 'Zhuravka' variety at a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds with different fertilizer options for the 2013–2018 period (for N technological variant 60)

Variant	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Features	H	D	H_1	w_1	WR	n	l	a	S	w_2	N_1	w_3	N_2	g	w_4	m	s	Y	Features	Graph $(G')_{minm}$	Graph $(G')_{max}$	Graph (G)	Variant
0.5 million pcs, ha^{-1} of germinable seeds against the $N_{90}P_{90}K_{90}$ ground	0.278	0.355	0.83 5.33	H	1.000	0.318* 0.471**	0.092 0.252	0.214 0.367	0.268 0.442	0.186 0.306	0.278 0.379	0.275 0.409	0.290 0.403	0.365 0.487	0.284 0.419	0.274 0.419	0.327 0.495	0.351 0.476	0.315 0.475	0.161 0.279	0.139 0.333	0.301 0.489	H	0.288	0.416	3.74 6.65	0,,5 million pcs, ha^{-1} of germinable seeds fertilizer-free
	0.475	0.580	7.12 9.87	D	0.228 0.402	1.000	–0.708 –0.760	0.531 0.673	0.469 0.640	0.336 0.539	0.469 0.712	0.409 0.589	0.531 0.679	0.604 0.806	0.463 0.640	0.490 0.644	0.528 0.701	0.351 0.513	0.611 0.854	0.530 0.668	0.333 0.517	0.424 0.559	D	0.477	0.645	8.11 10.97	
	0.453	0.490	7.25 8.33	H_1	0.055 0.276	–0.732 0.803	1.000	–0.530 –0.562	–0.589 –0.678	–0.497 –0.565	–0.527 –0.628	–0.314 –0.382	–0.428 –0.501	–0.608 –0.653	–0.501 –0.597	–0.331 –0.408	–0.555 –0.740	–0.429 –0.633	–0.478 –0.507	–0.529 –0.561	–0.612 –0.657	–0.527 –0.579	H_1	0.486	0.554	8.26 9.41	
	0.452	0.579	7.23 9.84	w_1	0.203 0.342	0.462 0.605	–0.602 –0.698	1.000	0.502 0.674	0.515 0.582	0.680 0.775	0.587 0.664	0.602 0.759	0.612 0.857	0.523 0.751	0.550 0.701	0.469 0.653	0.402 0.567	0.644 0.878	0.412 0.663	0.269 0.539	0.305 0.471	w_1	0.478	0.655	8.13 11.14	
	0.390	0.523	6.23 8.90	WR	0.262 0.409	0.351 0.512	–0.525 –0.566	0.352 0.521	1.000	0.523 0.659	0.517 0.666	0.419 0.609	0.455 0.597	0.447 0.604	0.312 0.537	0.420 0.562	0.512 0.655	0.314 0.489	0.602 0.801	0.441 0.565	0.317 0.471	0.402 0.551	WR	0.442	0.600	7.51 10.20	
	0.432	0.529	5.61 8.47	n	0.226 0.401	0.429 0.608	–0.403 –0.439	0.512 0.654	0.352 0.541	1.000	0.307 0.509	0.352 0.511	0.551 0.801	0.533 0.765	0.529 0.704	0.519 0.701	0.469 0.641	0.504 0.655	0.528 0.677	0.220 0.351	0.118 0.319	0.307 0.492	n	0.462	0.575	6.47 9.78	
	0.397	0.516	5.17 8.77	l	0.115 0.319	0.421 0.587	–0.420 –0.501	0.513 0.655	0.418 0.567	0.309 0.453	1.000	0.759 0.856	0.732 0.835	0.528 0.734	0.447 0.572	0.531 0.734	0.520 0.694	0.317 0.521	0.502 0.561	0.320 0.483	0.302 0.497	0.338 0.478	l	0.475	0.626	8.07 10.63	
	0.360	0.488	5.40 8.29	a	0.208 0.361	0.463 0.604	–0.310 –0.319	0.420 0.551	0.402 0.557	0.202 0.364	0.769 0.802	1.000	0.718 0.844	0.401 0.550	0.512 0.657	0.454 0.573	0.335 0.469	0.321 0.524	0.417 0.552	0.262 0.378	0.202 0.341	0.317 0.524	a	0.403	0.555	6.85 9.43	
	0.490	0.580	6.86 9.87	S	0.226 0.410	0.559 0.695	–0.496 –0.502	0.513 0.708	0.420 0.546	0.531 0.704	0.704 0.816	0.698 0.781	1.000	0.705 0.858	0.515 0.654	0.515 0.668	0.533 0.731	0.441 0.569	0.442 0.578	0.269 0.451	0.297 0.376	0.414 0.559	S	0.470	0.625	7.98 10.63	
	0.430	0.526	5.59 8.94	w_2	0.206 0.347	0.511 0.702	–0.502 –0.574	0.424 0.553	0.531 0.662	0.405 0.570	0.412 0.565	0.302 0.455	0.521 0.755	1.000	0.393 0.511	0.513 0.700	0.532 0.690	0.357 0.459	0.590 0.779	0.321 0.491	0.202 0.348	0.315 0.454	w_2	0.472	0.632	8.03 10.75	
	0.414	0.540	5.80 9.18	N_1	0.302 0.465	0.269 0.517	–0.469 –0.474	0.539 0.702	0.351 0.454	0.415 0.583	0.332 0.537	0.420 0.559	0.392 0.543	0.205 0.351	1.000	0.532 0.663	0.644 0.876	0.221 0.408	0.654 0.874	0.321 0.519	0.330 0.469	0.530 0.709	N_1	0.468	0.621	7.49 10.56	
	0.405	0.507	5.67 8.62	w_3	0.135 0.270	0.424 0.552	–0.307 –0.419	0.447 0.589	0.456 0.552	0.487 0.561	0.432 0.579	0.335 0.547	0.312 0.498	0.432 0.559	0.411 0.574	1.000	0.502 0.701	0.332 0.509	0.538 0.806	0.321 0.459	0.220 0.389	0.405 0.553	w_3	0.452	0.599	7.23 10.19	
	0.446	0.571	7.13 9.70	N_2	0.269 0.351	0.469 0.588	–0.552 –0.598	0.460 0.570	0.392 0.558	0.432 0.553	0.415 0.605	0.447 0.552	0.524 0.655	0.418 0.631	0.574 0.789	0.462 0.564	1.000	0.614 0.800	0.602 0.842	0.388 0.504	0.311 0.456	0.539 0.777	N_2	0.327	0.545	5.57 9.26	
	0.391	0.499	5.86 8.48	g	0.212 0.319	0.344 0.452	–0.469 –0.468	0.421 0.528	0.332 0.455	0.458 0.581	0.224 0.424	0.328 0.468	0.532 0.652	0.412 0.564	0.347 0.476	0.351 0.497	0.469 0.659	1.000	0.304 0.526	0.212 0.441	0.220 0.395	0.529 0.774	g	0.588	0.655	8.24 11.14	
	0.410	0.560	6.55 8.96	w_4	0.136 0.252	0.532 0.756	–0.452 –0.269	0.574 0.750	0.428 0.589	0.409 0.584	0.331 0.510	0.229 0.442	0.317 0.497	0.432 0.585	0.525 0.755	0.501 0.673	0.487 0.691	0.269 0.405	1.000	0.456 0.575	0.296 0.406	0.257 0.447	w_4	0.484	0.654	8.24 11.14	
	0.353	0.435	3.53 6.97	m	0.027 0.219	0.455 0.555	–0.452 –0.459	0.387 0.558	0.332 0.504	0.139 0.312	0.221 0.357	0.256 0.359	0.211 0.371	0.224 0.404	0.203 0.421	0.169 0.356	0.259 0.365	0.344 0.458	0.385 0.513	1.000	0.525 0.663	0.429 0.578	m	0.325	0.508	5.52 8.63	
	0.351	0.384	2.47 6.14	s	0.118 0.319	0.352 0.467	–0.411 –0.417	0.325 0.455	0.221 0.402	0.101 0.246	0.167 0.301	0.169 0.256	0.204 0.271	0.169 0.258	0.225 0.401	0.111 0.311	0.106 0.271	0.301 0.408	0.352 0.479	0.404 0.572	1.000	0.430 0.559	s	0.248	0.455	4.22 7.74	
	0.360	0.498	5.76 8.46	Y	0.245 0.335	0.351 0.462	–0.451 -0.543	0.281 0.402	0.329 0.501	0.471 0.559	0.269 0.446	0.309 0.453	0.342 0.464	0.291 0.406	0.451 0.583	0.312 0.521	0.503 0.701	0.487 0.669	0.329 0.459	0.256 0.403	0.324 0.551	1.000	Y	0.398	0.652	6.77 9.55	

*Levels of significance: $p \le 0.05$: $0.255 \le r \le 0.330$; $p \le 0.01$: $0.331 \le r \le 0.418$; $p \le 0.001$: $r \ge 0.418$; * – minimum and ** maximum correlation value for years of assessments.*

Thus, in our opinion, the specificity of the variability of morphological features of a plant in a certain technological variant and the specificity of pairwise correlations in each pleiade combination will determine a reliable situation of morphological integration of plants, which is confirmed by the summary data in Table 6. A comparison of the morphological variability module (Mod_x) with sowing rate, row width and fertilizer variants (as compared to the basic variant of 0.5 million pcs. ha^{-1} of germinable seeds) confirmed our conclusions on reducing overall plant variability by comparing the fertilizer rate of the control variant with the application of $N_{90}P_{90}K_{90}$ kg ha^{-1} of the primary material against the background of row sowing with a gradual reduction in coenotic tension towards a reduction in sowing density from 4 to 1 million pcs. ha^{-1} of germinable seeds.

For wide-row sowing, an increasing role in the morphological variability of plants in cenosis at a fertilizer rate of 90 kg ha^{-1} of the primary material is noted in the range of 1.5 million pcs. ha^{-1} of germinable seeds (in years favourable by hydrothermal coefficient – HTC) – 1.0 million pcs. ha^{-1} of germinable seeds. As a result, the maximum variability of morphological features of plants was noted in the variant of 0.5 million pcs. ha^{-1} of germinable seeds with a peak value for the same variant when fertilizing $N_{90}P_{90}K_{90}$ kg ha^{-1}, which in the evaluation system became a reference for comparable variability of morphological features. The gradual growth of fertilizer rates from 0 to 60 kg ha^{-1} provides an overall average variability growth of 3.0–13.0%. At the same time, this growth rate is characterized by a gradual decrease with an overall decrease in cenosis density in the range of fertilizer application from 30 to 60 kg ha^{-1} of the primary material. A further increase in the fertilizer rate to 90 kg ha^{-1} of the primary material has a specific manifestation for various variants of cenosis density: a 2.0% increase of the morphological variability module has only been observed on variants of 1.0 and 0.5 million pcs. ha^{-1} of germinable seeds for wide-row sowing, and a constant decrease of 1.0–14.0% in other variants. Given that, the maximum level of reduction has been noted on variants of 2.0–4.0 million pcs. ha^{-1} of germinable seeds, the fertilizer rate of 60 kg ha^{-1} of the primary material is a threshold value for ensuring the morphological integrity of plants and ensuring a biologically permissible level of coenotic pressure. Crossing this threshold results in both an overall reduction in plant architecttonics and a reduction in the overall morphological and weight integration of plants according to the I_{mmi} indicator. The application of a modified morphological integration index (I_{mmi}), in our assessments, enabled us to assess the integrity of oilseed radish plants in a more differentiated way at various technologies of construction of its agrophytocenosises. Thus, its constant interval decrease from a variant with a density of 4.0 million pcs. ha^{-1} of germinable seeds to a variant of 1.0 million pcs. ha^{-1} of germinable seeds for row sowing and from a variant of 2.0 million pcs. ha^{-1} of germinable seeds to a variant of 0.5 million pcs. ha^{-1} of germinable seeds indicates that the specific manifestation of morphological integrity of oilseed radish plants and statistical significance of the correlation connection of features increases with the overall growth of coenotic tension. At the same time, mineral fertilizers provide an overall increase in the variation of morphological features, especially those related to the stem and leaf morphology block (Table 2), which becomes essential when the density is below 2.0 million pcs. ha^{-1} of germinable seeds in the variant of row sowing and 1.5 million and less pcs. ha^{-1} of germinable seeds in the variant of wide-row sowing. On the other hand, the range of values of the I_{mmi} indicator is higher in the technological variants of row sowing than in the variants of wide-row sowing, and the lower limit of this interval has a higher threshold value exactly in the case of wide-row sowing. In our opinion, this points to the greater specificity of developing the potential for morphological and weight integration of plants due to the reduced level of coenotic tension. This statement is also confirmed by two-interval levels in the value of the I_{mmi} interval at a rate of 4.0 million pcs. ha^{-1} of germinable seeds of the row sowing and 2.0 million pcs. ha^{-1} of germinable seeds of the wide-row sowing.

It should be noted that an overall analysis of the morphological integrity of plants is not complete if it does not cover an important aspect of the formation of the ideotype structure of the agrophytocenosises of a particular crop (Donald, 1968). Any agrophytocenosis as an artificially created and supporting the population of cultivated plants is characterized by the formation of differentiation with the appearance of different categories of plants both in terms of phenological and ontogenetic features and morphological development. The first of these is based on the different phenorhythms of the development of individual plants against the background of the different quality of the seed material itself and subsequent differences in the phenological stages of the plants. The other is based on the nature of plant development, the intensity of biomass growth and the overall development of morphometric.

In the system of these regularities, the most typical features of the distribution of agrophytocenosis into individual groups of plants are the size of the plants with their derivative characteristics, their calendar age and the difference in the vitality state of the plants as a certain morphological and structural state of the representation of ontogenetic strategies (Zlobin, 1989; Usmanov, Martynova, 1990).

Table 6. Modular and morphological and ideotypical assessment of oilseed radish plants of 'Zhuravka' variety considering final morphological features of plants during the yellow pod phase (BBCH 79-83) in the context of individual study variants taking into account ideotypes (classes of vitality) of plants (average for 2013–2018) (for N attribute groups = 22 at n = 15…n (linear meter)$^{-1}$ *(for 2 non-contiguous repetitions))

Sowing rate and method (B, C factors)	Fertilizer (D factor) (A factor–year conditions)	Range of average values by years (R)		Q	Average fraction of life class plants (ideotype), %			I_Q	IVC	ISP
		Mod_x	I_{mmi}		A (upper-tier)	B (middle-tier)	C (lower-tier)			
4.0 million, row	Fertilizer-free	0.41–0.64	0.525–1.179	31.3	9.2	53.4	37.4	0.84	0.536	1.235
	$N_{30}P_{30}K_{30}$	0.49–0.61	0.519–1.103	30.9	13.6	48.2	38.2	0.81	0.568	1.284
	$N_{60}P_{60}K_{60}$	0.55–0.74	0.517–0.997	32.0	13.2	50.8	36.0	0.89	0.576	1.269
	$N_{90}P_{90}K_{90}$	0.46–0.60	0.512–0.827	32.6	10.4	54.7	34.9	0.93	0.477	1.218
3.0 million, row	Fertilizer-free	0.48–0.69	0.512–1.117	32.1	10.9	53.2	35.9	0.89	0.631	1.352
	$N_{30}P_{30}K_{30}$	0.44–0.72	0.505–1.078	33.3	11.8	54.8	33.4	1.00	0.735	1.396
	$N_{60}P_{60}K_{60}$	0.42–0.75	0.493–0.974	33.9	12.5	55.2	32.3	1.05	0.815	1.440
	$N_{90}P_{90}K_{90}$	0.51–0.67	0.478–0.806	32.2	11.8	52.6	35.6	0.90	0.779	1.531
2.0 million, row	Fertilizer-free	0.56–0.68	0.509–1.102	32.0	12.4	51.5	36.1	0.89	0.672	1.225
	$N_{30}P_{30}K_{30}$	0.53–0.82	0.497–1.024	32.7	13.2	52.1	34.7	0.94	0.788	1.192
	$N_{60}P_{60}K_{60}$	0.54–0.85	0.454–0.952	33.6	13.8	53.4	32.8	1.02	0.888	1.162
	$N_{90}P_{90}K_{90}$	0.53–0.76	0.426–0.801	33.4	14.2	52.5	33.3	1.00	0.867	1.179
1.0 million, row	Fertilizer-free	0.59–0.75	0.492–1.082	35.9	13.9	57.8	28.3	1.27	0.739	1.236
	$N_{30}P_{30}K_{30}$	0.61–0.79	0.436–0.984	36.6	14.5	58.6	26.9	1.36	0.921	1.241
	$N_{60}P_{60}K_{60}$	0.63–0.86	0.425–0.918	37.4	14.9	59.8	25.3	1.48	1.033	1.256
	$N_{90}P_{90}K_{90}$	0.62–0.83	0.422–0.873	38.4	15.1	61.6	23.3	1.65	1.082	1.250
2.0 million, wide-row	Fertilizer-free	0.59–0.78	0.710–1.114	34.8	14.2	55.4	30.4	1.14	0.712	1.241
	$N_{30}P_{30}K_{30}$	0.62–0.84	0.684–1.096	36.0	14.8	57.1	28.1	1.28	0.854	1.154
	$N_{60}P_{60}K_{60}$	0.66–0.85	0.641–1.019	37.0	15.2	58.7	26.1	1.42	0.902	1.131
	$N_{90}P_{90}K_{90}$	0.61–0.70	0.639–1.004	35.4	15.0	55.7	29.3	1.21	0.917	1.117
1.5 million, wide-row	Fertilizer-free	0.69–0.84	0.674–1.092	37.6	15.8	59.4	24.8	1.52	0.850	1.180
	$N_{30}P_{30}K_{30}$	0.75–0.87	0.640–1.042	38.9	16.5	61.2	22.3	1.74	1.028	1.166
	$N_{60}P_{60}K_{60}$	0.72–0.94	0.608–1.002	40.4	17.2	63.6	19.2	2.10	1.201	1.101
	$N_{90}P_{90}K_{90}$	0.69–0.91	0.567–0.904	40.9	17.6	64.2	18.2	2.25	1.226	1.057
1.0 million, wide-row	Fertilizer-free	0.65–0.86	0.665–1.061	39.6	15.1	64.0	20.9	1.89	0.888	1.244
	$N_{30}P_{30}K_{30}$	0.74–0.91	0.618–1.008	40.6	15.6	65.5	18.9	2.15	1.049	1.188
	$N_{60}P_{60}K_{60}$	0.81–0.94	0.571–0.924	41.8	16.2	67.4	16.4	2.55	1.186	1.167
	$N_{90}P_{90}K_{90}$	0.75–0.96	0.520–0.879	41.0	15.8	66.2	18.0	2.28	1.223	1.170
0.5 million, wide-row	Fertilizer-free	0.86–0.93	0.643–1.023	40.2	13.5	66.8	19.7	2.04	1.072	1.204
	$N_{30}P_{30}K_{30}$	0.84–0.96	0.596–0.971	40.6	13.9	67.3	18.8	2.16	1.269	1.257
	$N_{60}P_{60}K_{60}$	0.81–0.98	0.502–0.907	42.0	14.7	69.3	16.0	2.63	1.480	1.302
	$N_{90}P_{90}K_{90}$	1.00⁺	0.440–0.835	42.8	15.0	70.6	14.4	2.97	1.516	1.320

LSD_{05} (factors in the dispersion system)	*For morphological features in the group Fisher's criterion (F)$F_ф$ = 92.1–487.9; F_m = 1.78–6.90*	*LSD_{05}* (factors in the dispersion system)			*F value Pr(>F) (655.6 <2e-16 C p 0.001)*
A value/share of influence in the formation of the indicator, %		*0.0009* (45.00)	*0.0023* (26.73)	*0.0014* (19.16)	*0.025* *(20.19)*
B		*0.0005* (23.34)	*0.0013* (12.68)	*0.0008* (48.44)	*0.015* *(31.70)*
C		*0.0008* (6.25)	*0.0019* (3.23)	*0.0012* (20.91)	*0.0021* *(29.35)*
D		*0.0008* (7.81)	*0.0019* (1.08)	*0.0012* (1.96)	*0.0021* *(12.16)*
AB		*0.0013* (0.46)	*0.0033* (15.47)	*0.0020* (1.24)	*0.0036* *(0.37)*
AC		*0.0019* (0.68)	*0.0047* (15.74)	*0.0028* (0.89)	*0.0050* *(0.56)*
AD		*0.0019* (0.25)	*0.0047* (0.74)	*0.0028* (0.20)	*0.0050* *(0.23)*
BC		*0.0011* (10.90)	*0.0027* (2.13)	*0.0016* (4.69)	*0.0029* *(0.47)*
BD		*0.0011* (0.84)	*0.0027* (0.22)	*0.0016* (0.05)	*0.0029* *(1.40)*
BC		*0.0015* (1.68)	*0.0038* (0.26)	*0.0023* (0.45)	*0.0041* *(2.29)*
ABC		*0.0026* (0.47)	*0.0066* (15.73)	*0.0040* (0.27)	*0.0071* *(0.61)*
ABD		*0.0026* (0.16)	*0.0066* (0.71)	*0.0040* (0.16)	*0.0071* *(0.08)*
ACD		*0.0037* (0.34)	*0.0093* (2.17)	*0.0056* (0.22)	*0.0101* *(0.26)*
BCD		*0.0022* (1.57)	*0.0054* (0.95)	*0.0033* (1.15)	*0.0058* *(0.19)*
ABCD		*0.0053* (0.26)	*0.0132* (2.17)	*0.0080* (0.19)	*0.0142* *(0.13)*

*Notes 1. * – for the number of plants corresponding to actual plant density per 1 linear metre in the experiment variant; 2.+– variant of maximum morphological development of plants (Mod_x ~ 1.00).*

In this perspective, the ideal state of construction of any sowing in the long term provides for such a density of plants that ensures a minimum part of different plant morphotypes and would ensure the same growth process rates of the species per area unit based on a single stage and harmony. This goal is one of the modern strategies for the successful cultivation of a particular crop, as it not only guarantees the agro-technological consistency of sowing but also reduces intra-species competition and guarantees an overall increase in the efficiency of application by correcting resources such as mineral fertilizers, stimulants, protective means, *etc*. (Zlobin, 2009).

Unfortunately, it is not possible to achieve the maximum desired effect of avoiding the appearance of different plant ideotypes in sowing, even with the best possible ideal placement of plants both in the row zone and in the inter-row zone, which results in appropriate differentiation of sowing of a certain crop into tiers (Vijaya Kumar *et al*., 1996; Zhilyaev, 2005; Zlobin *et al*., 2013; Skliar, Sherstuk, 2016).

On the other hand, it is noted that each agrophytocenosis has its specific limit on the density of species, which depends on both varietal characteristics and edaphic conditions of growth and development, as well as on many climatic, biological, and physiological factors. In most cases, self-regulation of intra-species alignment of effective productivity of species within the same area occurs in the cenosises due to the two accompanying directions – the extinction of the species and its self-liquefaction and miniaturization because of a significant reduction in all sizes of plant parts. Under these conditions, plant sizes can be reduced from hundreds to thousands of times while maintaining minimal levels of generative development with minimal ability to produce fully productive seedlings (Rabotnov, 1998; Zhilyaev, 2005; Zlobin, 2009, 2013; Temesgen *et al*., 2015; Skliar, Sherstuk, 2016). It should not be forgotten about the well-known indicator of agrophytocenosis differentiation – the Sukachev effect (Sukachev, 1956): in single-species and single-stage agrophytocenosises, there is the differentiation of individuals into small and large ones when the density increases, which is especially noticeable in fertile soil variants and when the sowing density increases to a certain limit - until the plants die off completely. It is further stated that the evaluation of the efficiency of the arrangement of species in cenosis should be carried out using a systematic approach, forming a certain model of its density given the altitude gradient of plants, which the author defines as volume density (Laman *et al*., 1999). In general, cruciferous crops are distinguished by the formation of plants of different ideotype by the value of morphological parameters (Yadav, 1978; Thurling, 1991; Vijaya Kumar *et al*., 1996; Khan, 2006; Ana *et al.*, 2008; Mamun *et al.*, 2014). In our studies, we have identified certain regularities in the formation of oilseed radish agrophytocenosis layering. Given this formation of different tiers of plants and their corresponding morphotypes, we considered their morphological integration as a continuation of a certain protective ontogenetic strategy of the plant body under the influence of changing stress factor. We considered the enhancement of morphological integration as a protective ontogenetic strategy and its reduction as a level of stress adaptability of the technology variant and fertilization. In our research variant, the stress factors were divided into three groups: general additive nervousness of climate factors, changes in the number of individuals due to changes in sowing rates and row width, and changes in fertilizer rates in conjunction with other factors of research. For the period 2013–2018, we have identified morphological development groups of plants that belong to three tiers in the vertical projection. These plants were grouped into three main ideotypes (vitality classes), the main statistical assessment of which is presented in Table 7 and Fig. 2. It should be noted that oil radish agrophytocoenosis is considered to be sensitive from the point of view of the reaction to changes in both the density of plants per area unit and from the point of view of optimization of mineral nutrition conditions. An important aspect of assessing the ideotype sowing structure is the differing level of variability of features. Given the coefficient of variation of morphological features, we've established that it's significantly higher for plants of the upper-tier (class of plant vitality A – with the average CV 38.2% – a high level against CV 24.8% – an increased level – for the class of vitality B (middle-tier)). Thus, we believe it's due to the dominant nature of such plants' growth processes and a gradual reduction of phenotypic tension for them due to more intensive growth rates in the early stages of vegetation. By analogy with these conclusions for oilseed radish plants of lower-tier (vitality class C), due to phenotypic pressure from more competitive species and the general slowdown in growth processes, the result is a minimization of plant architectonics and the emergence of atypical morphotypes in terms of their development. The same conclusions are confirmed by the index of phytocoenotic plasticity (I_p) in terms of morphological parameters within the selected oilseed radish plant ideotypes. The value of this indicator differed for different morphological features.

At higher maximum stability with lower I_p for middle vitality class plants (middle-tier of agrophytocenosis) and minimum stability with higher I_p for lower-tier plants, the minimum value of ecological scope of values is noted in the system of all selected ideotypes for such feature as the height of plants (at I_p 0.47), and the maximum value for the individual weight of plants (at I_p 0.80). Thus, the magnitude of changes in plant morphotypes within their defined ideotypes behind the vertical gradation tiers of agrophytocenosis is distributed in the following order: C>A>B. The system of morphological indicators that we have chosen to distribute the vertical of agrophytocenosis is indicative in the morphological plant development. Actually, ideotypical types of plants of corresponding tiers had distinctive features, which allowed to effectively determine the percentage of each tier in the cenosis of the corresponding technological variant of its construction, which is confirmed in Fig. 2–5. The degree of differentiation of the agrophytocenosis by the indicators determining the grouping had both significant differences in the comparison of the technological variants and within the technological variant itself. So, we provide, for example, data concerning interval distribution of 60 plants, which were used in our estimations on such indicator as stem diameter for one year of research on a nonfertilized ground according to the criterion of less variable component (2016, Fig. 7). Histograms for all technological variants under study have revealed a complete variability of the indicator from the smallest value, which is significantly distant from the dominant indicator for the general population to, respectively, the largest value. It should be noted that the specified number of interval groups of the indicator is the minimal one in the variants of the maximum density of oilseed radish agrophytocenosis both for row sowing (4.0 million pcs. ha^{-1} of germinable seeds – 5 interval groups) and for wide-row sowing (2.0 million pcs. ha^{-1} of germinable seeds – 6 interval groups).

Figure 2. Ideotypes of oilseed radish plants of the 'Zhuravka' variety against the ground of $N_{90}P_{90}K_{90}$ (successively positions 1, 9 – 4.0 million pcs. ha^{-1} of germinable seeds, 2, 8 – 2.0 million pcs. ha^{-1} of germinable seeds (row sowing); 3, 7 – 1.5 million pcs. ha^{-1} of germinable seeds (wide-row sowing); 4 – 1.0 million pcs. ha^{-1} of germinable seeds (wide-row sowing); 5, 6, 11 – 0.5 million pcs. ha^{-1} of germinable seeds (wide-row sowing); 10 – 4 million pcs. ha^{-1} of germinable seeds (row sowing), 2017

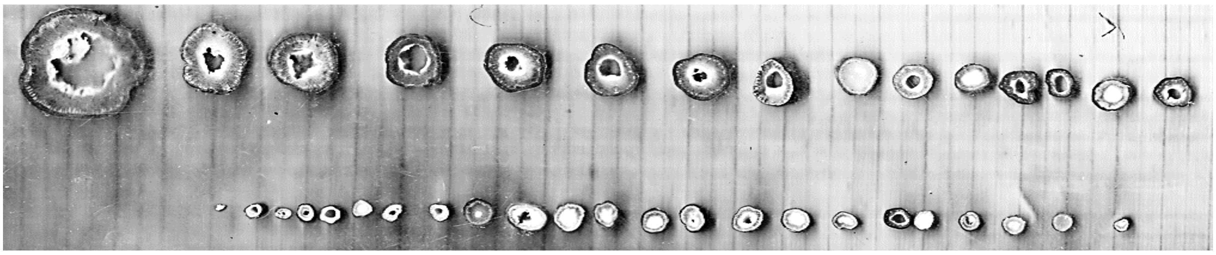

Figure 3. Dynamic stem diameter range (upper position for plants of the upper-tier, lower position for plants of the lower-tier), 2016

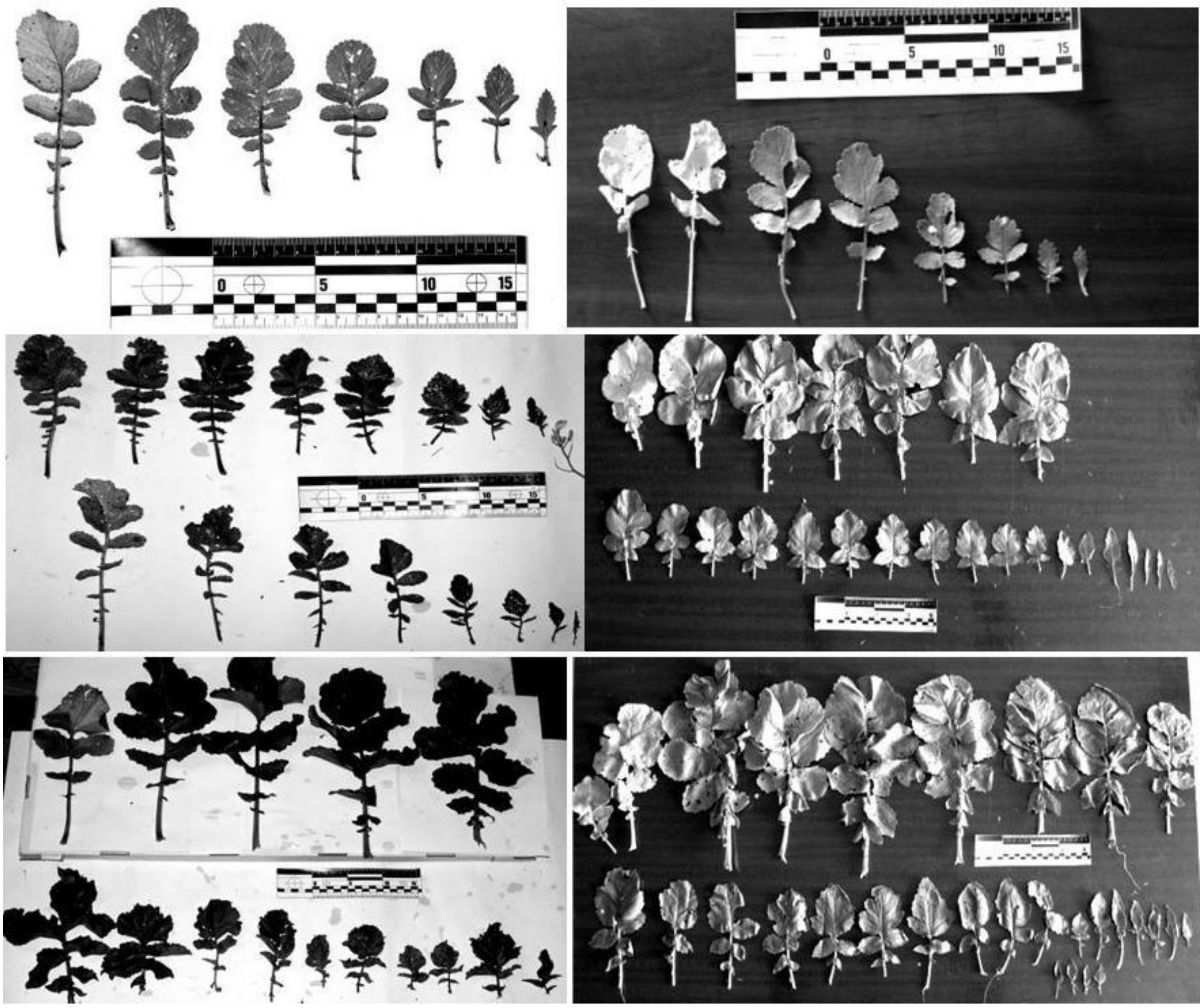

Figure 4. Morphological features and area of leaf area of plants of different ideotypes upper position 1: for plants of variant 4.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants); middle position 2: for plants of variant 1.0 million pcs. ha^{-1} of germinable seeds (row sowing) against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants); lower position 3: for plants of variant 0.5 million pcs. ha^{-1} of germinable seeds (row sowing) against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants), 2017

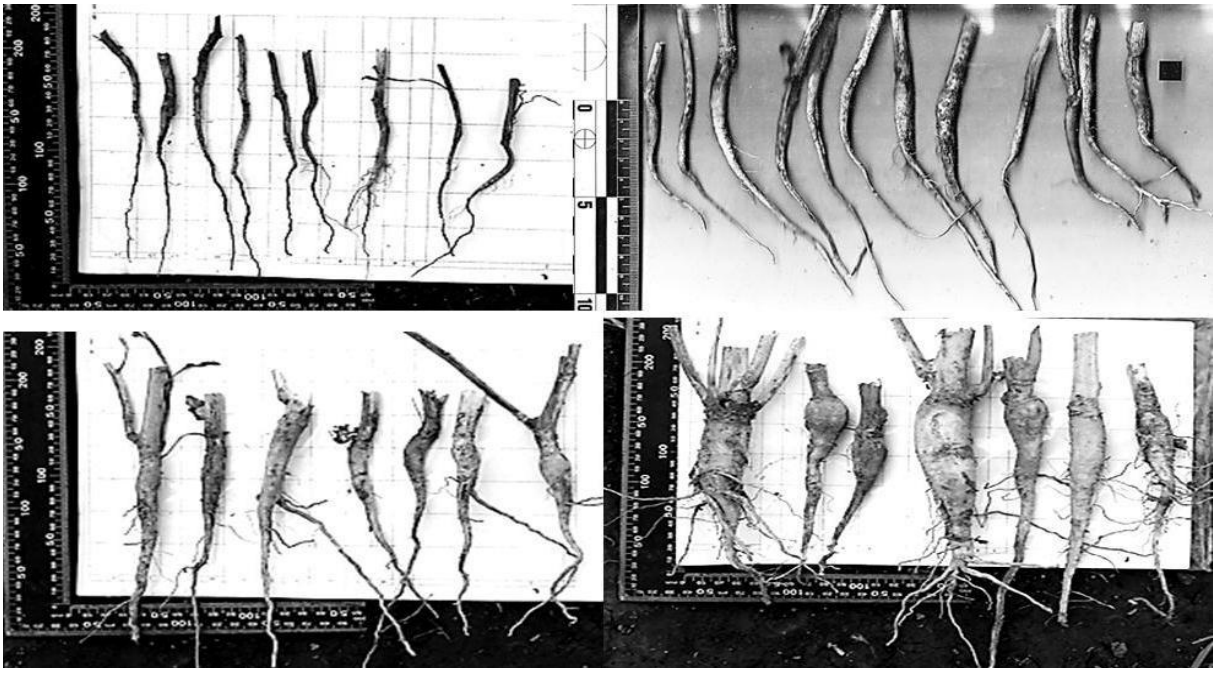

Figure 5. The root system, upper position 1: for plants of variant 4.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants); lower position 2: for plants of variant 0.5 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ (on the left – lower-tier plants, on the right – upper-tier plants), 2018

Table 7. Morphometry of oilseed radish plants ideotypes in the context of the general selection of variants for the 'Zhuravka' variety during the flowering phase (BBCH 65) and the yellow pod phase (BBCH 79-83) (on average for the 2013–2018 period (for N=60 plants in each variant of x years of research)

Morphological parameters of plants of the corresponding tier	Lower (vitality class C)				Middle (vitality class B)				Upper (vitality class A)			
	X_{av}	R^{+}	CV, %	I_P	X_{av}	R	CV, %	I_P	X_{av}	R	CV, %	I_P
Height of plants in the yellow pod phase, cm	60.8^{**}	29.6–102.3	32.5	0.71	100.7	72.9–111.6	28.4	0.35	114.5^{**}	90.8–143.4	35.9	0.37
Stem diameter at the base in the yellow pod phase, mm	6.1^{**}	3.2–8.9	26.4	0.64	9.1	6.5–12.9	23.5	0.50	12.3^{**}	8.7–21.5	40.2	0.60
Leaf area on the plant during the flowering phase, cm^2	169.4^{**}	82.9–211.7	20.6	0.61	292.3	108.7–313.9	22.3	0.66	425.7^{***}	256.9–1024.3	43.5	0.75
Individual weight of plants during the yellow pod phase, g	11.6^{**}	2.3–15.7	28.2	0.85	15.8	5.7–21.3	25.8	0.73	19.4^{**}	11.3–61.7	42.9	0.82
Number of side branches in the inflorescence during the yellow pod phase, pcs	3.7^{**}	2.5–6.2	19.9	0.60	6.2	3.3–8.6	20.9	0.62	8.5^{***}	5.4–11.4	28.7	0.53

*Notes. 1. $^{+}$ The range of values (R) is shown in the context of the years of study, as well as the format of the ratio of morphological features of plants of different tiers according to the methodology of one-type vegetative comparison. 2. Lower and upper-tier parameter values in relation to the middle-tier *P < 0.05, **P < 0.01, ***P < 0.001.*

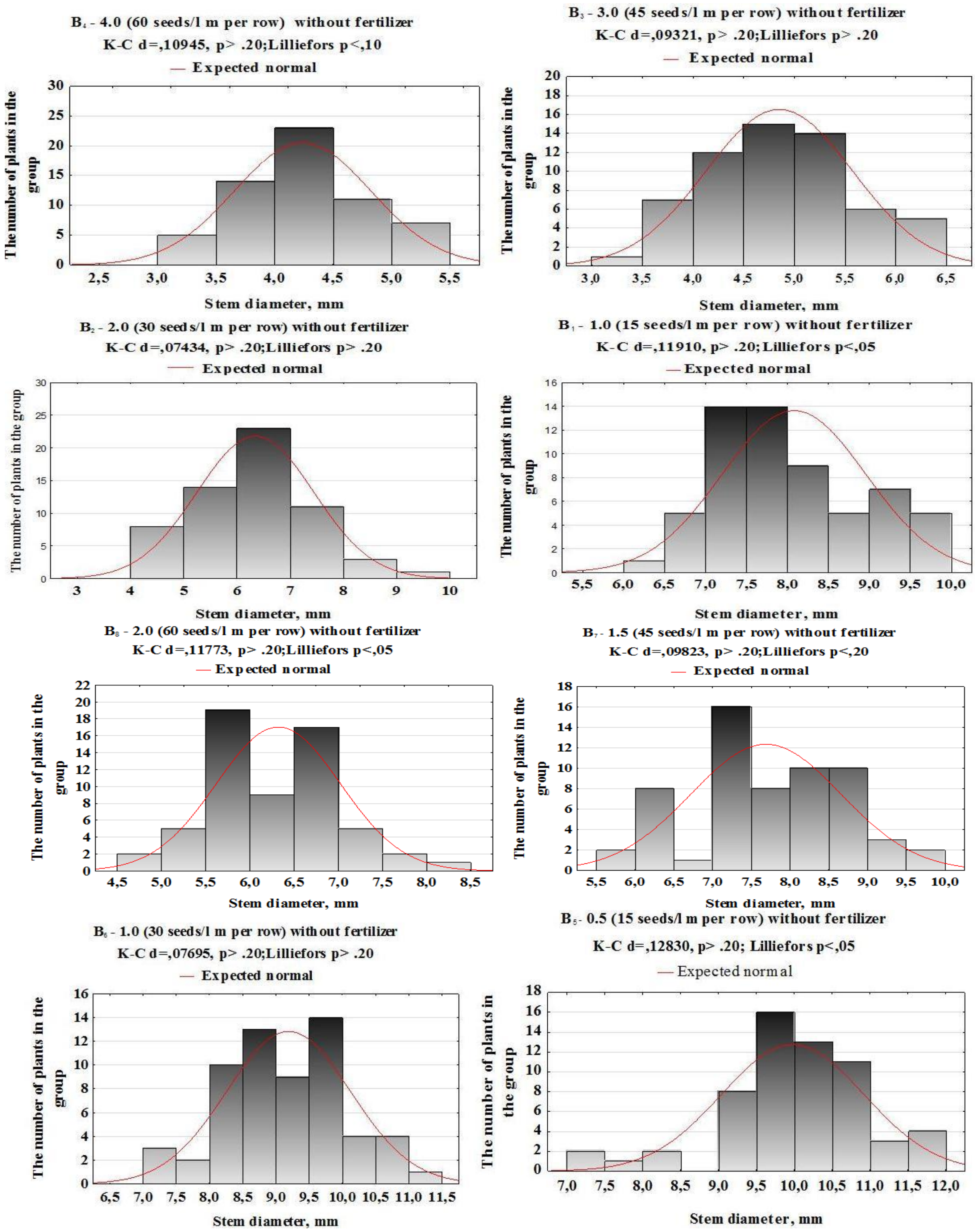

Figure 6. Histogram of the distribution of the stem diameter value of oilseed radish plants in the context of the studied technological variants consistently from left to right and from top to bottom variants: B_4, B_3. B_2, B_1, B_8, B_7, B_6, B_5 (Table 1), 2016

The maximum number of variants is noted in the variants of the lowest density for both sowing methods, respectively (1.0 and 0.5 million pcs. ha^{-1} of germinable seeds – 9 and 10 interval groups, respectively). This confirms our conclusions regarding morphological integration and morphological variability module depending on the variants under study. Thus, the intensive coenotic tension in the variant of 4.0 million pcs. ha^{-1} of germinable seeds leads to an overall decrease in the range of variation, which leads to a decrease in the area of the interval distribution curve with the simultaneous growth of the chart height. On the contrary, at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds, there is an expansion of interval differentiation of agrophytocenosis, the growth of the total number of intervals, which leads to a decrease in the height of the extremum of the distribution curve chart.

Using approaches to schematization of the representation of ideotypical types of plants, applied to mustard (Vijaya Kumar *et al*., 1996) and spring rapeseed (Khmelyanchyshyn, 2005), we also proposed schemes of oilseed radish plants ideotypes of different tiers presented as an example for two cardinally distant technological variants of construction of oilseed radish agrophytocenosis (Figure 7).

The features of morphogenesis, which we discovered, naturally determined the distribution of oilseed radish agrophytocenosis into corresponding classes of vitality (ideotypes). According to the conditions of the identity of the quality index comparison (Zhilyaev, 2005; Zlobin, 1989, 2009; Mirkin *et al*., 1985, 1999) (Q) in the format: $Q > C$, cenosis has a favourable structure for growth and development of species, $Q < C$ – regressive, $Q = C$ – balanced-dynamic – favorability of oilseed radish cenosis to growth and development (Table 6) is regressive in the interval to the variant of 2.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{30}P_{30}K_{30}$, and balanced-dynamic for the variant of 2.0 million pcs. ha^{-1} of germinable seeds when fertilizing in the interval of $N_{60-90}P_{60-90}K_{60-90}$ kg of the primary material ha^{-1}. All other variants should be referred to as favourable for growth and development of oilseed radish plants. The mentioned gradation of technological variants is also confirmed by the I_Q index (agrophytocenosis flourishing index) whereby the value of the indicator more than 1.5 (Zlobin, 1989), the variant with the sowing rate of 1.0 million pcs. ha^{-1} of germinable seeds with the row sowing and variants in the interval of 1.5–0.5 million pcs. ha^{-1} of germinable seeds are classified as "flourishing" (highly favourable) for the development of individual species of agrophytocenosis.

It is also important to note that the already mentioned general additive stress of climatic factors is defined as a component of the dispersion analysis of the studied variants (factor A – conditions of the year) that indicates different determinacy of abiotic conditions in the formation of the tier structure of oilseed radish agrophytocenosis by the selected ideotypes. Thus, the part of plants of the upper-tier by 45% is determined by abiotic factors of the year, and the part of plants of the middle and lower-tier by 26.73% and 19.16% respectively. A significant factor in the formation of the part of different plant ideotypes was also determined as the agrophytocenosis density – the percentage of the influence of this indicator consistently from the upper to lower-tier plants was 23.34%, 12.68% and 48.44% respectively. The sowing method factor had the greatest influence in the formation of lower-tier plants ideotypes (20.91%), and the influence of fertilizer had the maximum effect in the formation of upper-tier plants ideotypes (7.81%).

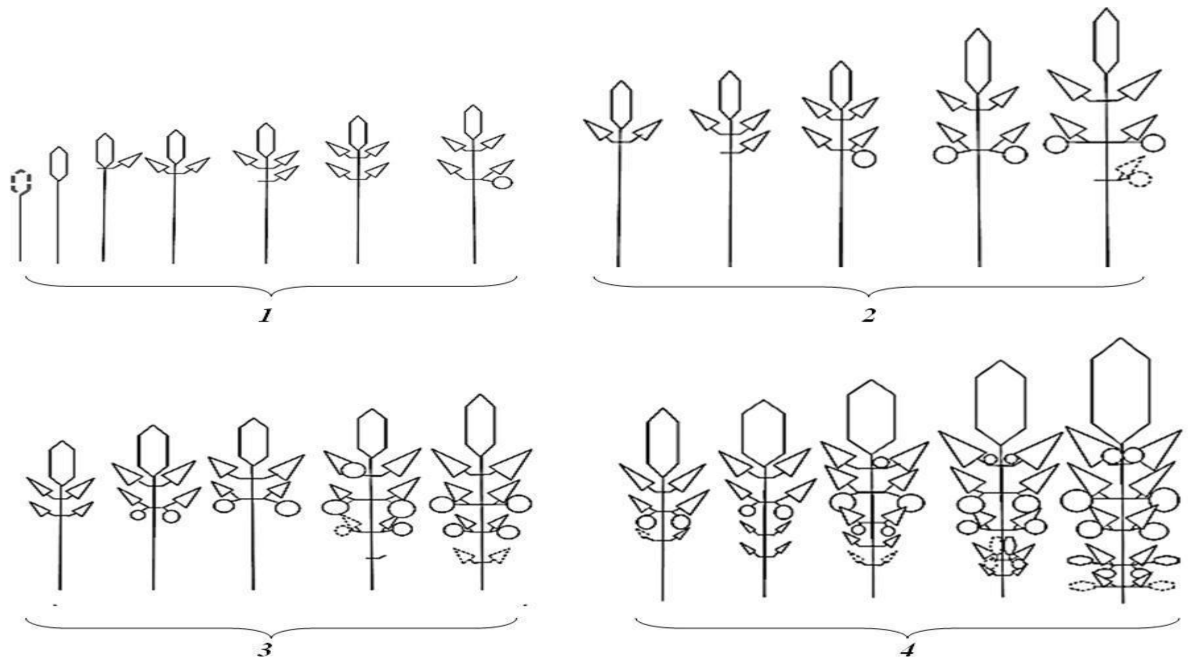

Figure 7. Ideotypical rows of oilseed radish plants of the 'Zhuravka' variety of different tiers of agrophytocenosis at different variants of its technological construction (1 – at the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground; 2 – at the sowing rate of 4.0 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$; 3 – at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds on a nonfertilized ground; 4 – at the sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds against the ground of $N_{90}P_{90}K_{90}$ based on the results of multi-year assessments for the 2013–2018 period (conventional symbols: – main stem inflorescence; – inflorescences of lateral branches of the first tier; – inflorescences of branches of the second tier; – inflorescences of branches of the second tier; the striation of structures determines the presence of a structural element in individual plants, the size of structures – relative morphological development

At the same time, the maximum impact of the interaction of the conditions of the year and technological parameters of the formation of agrophytocenosis is noted in the variant of the middle-tier plants ideotypes. The statistical significance of the interaction between individual environmental parameters (by a hydrothermal coefficient (HTC)), agrophytocenosis and fertilizer density expressed in index terms (0 – fertilizer-free; 1 – $N_{30}P_{30}K_{30}$; 2 – $N_{60}P_{60}K_{60}$; 3 – $N_{90}P_{90}K_{90}$)) is shown in the Figures 8, 9.

The analysis of the above graphic dependencies shows that at both low and high HTC values, mineral fertilizers have a significant stress-regulating effect (in the index format of rates) on plant morphogenesis. Thus, with an increased density of agrophytocenosis – 4.0 million pcs. ha^{-1} of germinable seeds – the growth of the part of plants in the lower-tier was observed both with a decrease in HTC in the variants of simultaneous growth of fertilizer rates and against the background of significantly high HTC (> 1.2) again in the variants of increasing the rates of mineral nutrition. Optimal technological niche to reduce the part of the lower-tier plant's ideotype, as the least productive in the structure of agrophytocenosis, at this level of plant stand density is set by HTC in the range of 0.8–1.1 at 30–60 kg ha^{-1} of the primary material. At a sowing rate of 0.5 million pcs. ha^{-1} of germinable seeds, the minimum part of plants in the lower-tier of oilseed radish agrophytocenosis is set in the HTC range of 1.2–1.4 and fertilizer in the range of 60–90 kg ha^{-1} of the primary material.

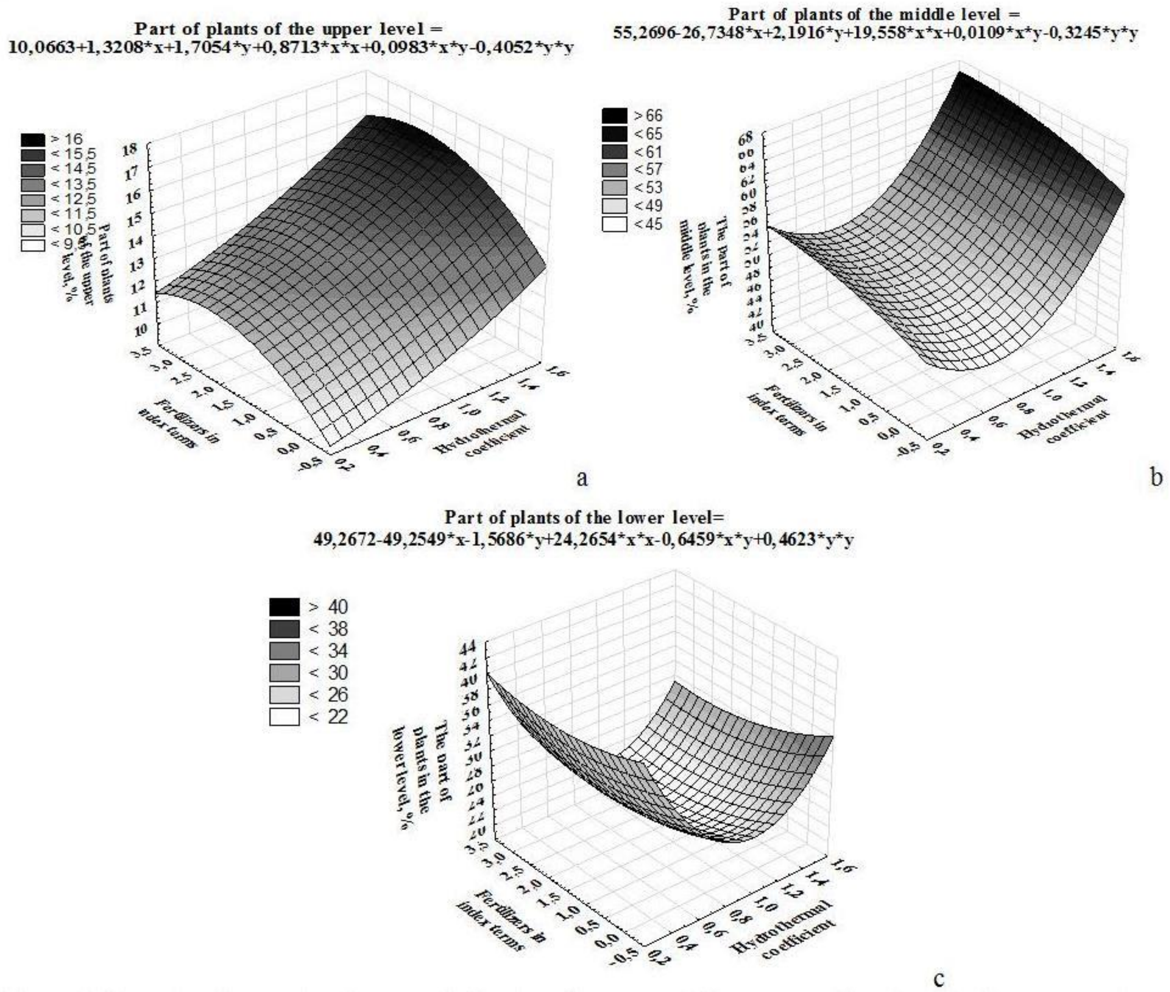

Figure 8. Dependencies graphs of a part of the plant ideotypes of the corresponding tier (Z-axis: a – upper, b – middle, c – lower) depending on the hydrothermal coefficient (HTC, X-axis) and fertilizer doses expressed in index terms (Y-axis), 2013–2018

It should also be noted that the impact of mineral fertilizers is weakening concerning intra-species competition, but according to our estimates to a certain level of the interaction system of nutrition and fertilizer area. It is demonstrated by the character of reaction curves on the Figs. 8 and 9, in particular for ideotypes of plants of upper and lower-tiers. Based on the data obtained over the years, we found that the rate of fertilizer more than 60 kg ha^{-1} of the primary material is justified with the stand density in the interval of 1.0–2.0 million pcs. ha^{-1} at row sowing and 0.5–1.0 million pcs. ha^{-1} at wide-row sowing. At technological stand densities of plants over established intervals, additional mineral nutrition is a factor of intensification of intra-species competition (which in turn, as shown by the analysis performed previously, increases at low values of HTC), which leads both to the appearance of plants with ultra-low vitality, and to the emergence of morphotypes, which significantly exceed typical plants by the average value of morphological parameters in the agrophytocenosis of oilseed radish. The latter factor is due to the general positive stimulating effect on all components of the cenosis and immobilization of growth processes in plants with supra-competitive vitality strategy.

Thus, from the perspective of plant ideotype formation, mineral fertilizers are active components of the system for regulating the degree of plant stand differentiation into morphotypes of plants of different tiers. In high-density oilseed radish cenosis, it is reasonable to increase the fertilizer rate only at a certain density, and in low-density and liquefied cenosis, only if the increased rates of fertilization are combined with the optimum moisture content. So, with the overall growth of sowing density, additional mineral nutrition only enhances the process of interspecific antagonism and provides a clear differentiation of the vertical projection of sowing to significantly different ideotypes of oilseed radish plants.

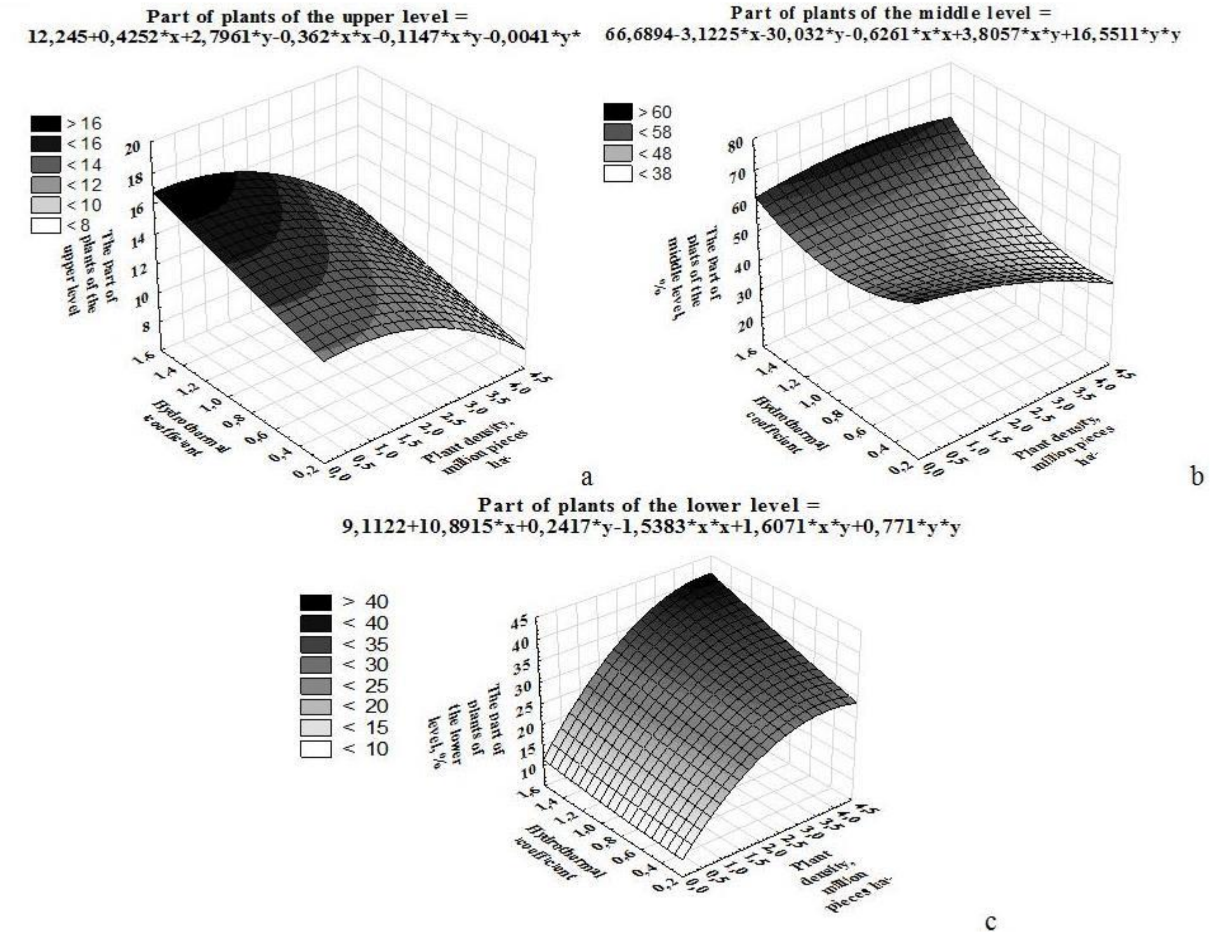

Figure 9. Dependencies graphs of a part of the plant ideotypes of the corresponding tier (Z-axis, positions: a– upper, b – middle, c – lower) depending on the hydrothermal coefficient (HTC, X-axis) and stand density (Y-axis, million pcs. ha^{-1} of germinable seeds), 2013–2018

On the other hand, the comparison of morphological integration index, vitality index (IVC) and size plasticity index (ISP) (Table 6) testifies to the complex ontogenetic tactics of oilseed radish plants in the context of the studied variants, as the dynamic growth of variability of features with the increase of inter-row spacing, reduction of sowing rate and fertilizer growth provides the general growth of vitality index and size plasticity index, allows to state the differentiated divergent ontogenetic tactics of plants. In turn, strengthening the formation of over-dominant plant morphotypes on liquefied agrophytocenosises in the fertilization variants of 90 kg ha^{-1} of the primary material gives us reason to recommend the optimal variant of oilseed radish fertilizer for the research area with a fertilization rate of $N_{60\text{-}90}P_{60\text{-}90}K_{60\text{-}90}$ kg of the primary material ha^{-1} with a sowing rate of up to 1.7–2.0 million pcs. ha^{-1} of the germinable seeds at the row sowing and 1.5 million pcs. ha^{-1} of the germinable seeds at the wide-row sowing. The choice of optimum sowing rates and fertilizer options is also based on the value of size plasticity index (ISP): stable growth of its value with the growth of fertilizer rates is noted in the grading of options 1.0–2.0 of the row sowing and 0.5–1.5 of the wide-row sowing.

It should also be noted that, given the established features of the formation of layering of the oilseed radish agrophytocenosis in case of changes in HTC – at its value of more than 1.1, it is necessary to limit the dose of nitrogen fertilizers to 60 kg ha^{-1} of the primary material on oilseed radish sowing constructed at a rate of more than 2.0 million pcs. ha^{-1} of germinable seeds to avoid lodging by increasing competition and reducing the vitality index.

Conclusion

In the prognostic assessment approach, the vitality and coenotic tactics of oilseed radish plants in terms of variability of morphological features of all three basic blocks defined by us, both in the vertical and horizontal directions, will be enhanced with the growth of plant stand density and a decrease in the width of the row spacing with an interval factor of difference between the minimum value of morphological development of plants of the lower and upper-tiers. In an ideal combination we must ensure the growth of part of the plants of the middle-tier (the most productive component of the cenosis, which together with the part of plants of the upper-tier determines the level of productivity of sowing), should grow at a decrease in atypical plant morphotypes, especially with an extremely low vitality level.

The results of our multi-year studies have confirmed the complex vertical-spatial structure of oilseed radish agrophytocenosises. The approach we applied in our research, which is based on the basic principles of phytocoenology and its regularities, is effective in evaluating the technological feasibility of cenosis construction at the stage of sowing of crops in general and oilseed radish in particular. The analysis of the vitality strategy, which was based on the in-depth analysis of the modular and morphological, and ideotypical blocks, made it possible to comprehensively assess the efficiency of the studied technological variants of oilseed radish cultivation and select for the production implementation the most appropriate of them from the position of productive ontogenetic tactics of oilseed radish plants with strengthening the function of mineral fertilizers in the format of the regulator of agrophytocenosis quality coefficient.

The study of dynamic aspects of the formation of the vitality strategy of oilseed radish agrophytocenosises is promising for further research, considering climatological models of the vegetation period of the crop.

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GROWTH AND YIELD RESPONSES OF POTATO (*SOLANUM TUBEROSUM* L.) TO BIOCHAR

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ABSTRACT. The response of five types of biochar (*Lantana camara*, *Ipomoea carnea*, rice husk, sawdust, no biochar) on growth and yield attributes of potato was evaluated. The experiment was laid out in randomized complete block design with six replications in rainfed areas of two different environments (Jiri in 2018 and Pawati in 2019) of Nepal. The popular early maturing potato variety 'Desiree' was used in the experiment. The spacing was maintained 60 cm between rows and 25 cm between plants in the plot size of 7.2 m^2. Seed tubers were planted in the 1st week of February and harvested in the 4th week of May. Recommended fertilizers (100:100:60 kg ha^{-1} NPK + 20 t ha^{-1} farmyard manure) and biochars at 2 t ha^{-1} were applied to the soil. Seed tubers were completely covered with an equal amount of biochar before covering with the soil. The results revealed that the total yield and marketable yield of potato varied with biochars types. The potato tuber yield was found higher and red ants infestation was lower in plots applied with biochars as compared to control plots (without biochars). The use of biochars derived from *Lantana camera* produced the highest number of tubers (6.1 tubers $plant^{-1}$), the greatest weight of tubers (286.1 g $plant^{-1}$) and the least damage of red ants on tubers (4.7%) followed by sawdust (6.0 tubers $plant^{-1}$, 263.6 g tuber weight $plant^{-1}$ and 7.8% damaged tubers by red ants). The findings provide new information on the understanding of biochar effect on increased marketable yield of potato in rainfed lands by reducing damage from red ants.

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important parts of the vegetable recipe of Nepalese cuisine throughout the country and a staple food source for the residents of high hills and mountains. It is commercial non-cereal produce of Nepal and an important source of income for the farmers. However, its productivity is low (14.7 t ha^{-1}) in the country (MoALD, 2019). This low productivity of potato in Nepal is constrained by various factors. The factors identified by National Potato Research Program (NPRP) were low yielding varieties, inadequate cultivation practices with the soil-cultivars-climate complex, inadequate control measures for major diseases and insect pests, insufficient soil fertility management practices (NPRP, 2015). Specifically, drought, red ants, post-harvest losses due to insect pests and diseases and poor performance of varieties in specific microclimate are some of the major threats in country's potato industry (NPRP, 2019).

To reduce the productivity of potato, red ants (*Dorylus orientalis* Westwood) play an important role in causing damage to the potato tubers. Red ants are the most destructive insect pests of potato in the field (Sharma *et al*., 2019). Previous studies showed that the pest could cause 15 to 82% tuber damage in potato fields (Joshi, 1998; Bhandari, 2011). About 35 to 90% damage of potato tubers by this pest was reported in India and Bangladesh (Mishra *et al*., 1993; Konar *et al*., 2005; Alam, 2012). Entomology Research Division of NARC has recommended applying resistant varieties but no variety is perfectly resistant (no damage) yet, however, there were some less damaged clones (Sharma *et al.*, 2017). Earlier studies had identified some local cultivars such as Sabet local, Chisapani Rato and Khumbule as less damaged by red ants in Lumle, Bhitri, and Kabre (Dolakha) in Nepal (Joshi, 1998). However, these cultivars are very old and degenerated now and need to be validated for their performance. In a separate experiment, varietal resistance of potato against red ant was studied in Nepal by Sharma *et al.* (2015) and showed that the potato genotypes CIP 385499.11, CIP 393077.54, PRP 056267.9, PRP 056267.1, CIP 395112.32, and PRP 016567.12 were found the least damaged types but none of them was released.

Similarly, lack of irrigation is a major problem in potato producing upland areas of the hills. Reduction of carbon through reduced application and replenishment of organic matter is also prevalent in these areas (Tripathi, 2015). In the hills, many soils are acidic by nature due to various reasons (Vista, Adhikari, 2015). Potato producing areas of Dolakha districts such as Jiri and Pawati are also in such categories. Considering this fact, the possibility of application of biochar was considered as a researchable issue by NPRP in 2016.

Biochar is a black carbon manufactured through pyrolysis of biomass (Lehmann *et al*., 2006; Upadhyay, 2015). It is effective for improvement of cation exchange capacity, the durability of soil aggregates, microbial activity, bioenergy production and water retention capacity; reduction of nitrous oxide and methane emissions from soils, leaching, soil erosion and need of fertilization and thereby enhancement of soil fertility and crop yields (Brandstaka *et al.,* 2010; Upadhyay, 2015) and adsorption of anions and cations to prevent leaching of applied nutrients (Major *et al*., 2009, Upadhyay, 2015). Biochars may also have some pesticidal activity with potential for the formulation of biopesticides (Sayed *et al*., 2018), for example, lower concentrations (≤1%) of biochar often suppress several diseases (Frenkel *et al*., 2017). Yet, the longevity of the biochar effect on disease severity is unknown (Graber *et al*., 2014)

In recent years, biochar effects are concerned with their economic value. In Australian condition, biochar mixed with NPK increased 53% crop yield led into an increase in farmer net benefits by the US $8 000 per hectare, at a biochar cost of US $160 per hectare (Robb, Joseph, 2019). In an estimate conducted in Canada, biochar application did not cover average total costs for potatoes showing average annualized net returns of US $965.48 ha^{-1} over variable costs (Keske *et al.*, 2019). In another estimate done in Canada, potato production yields average annualized net returns of US $965.48 ha^{-1} over variable costs. In a recent study (Farooque *et al.*, 2020), the maximum net benefit (US $4 433.98 ha^{-1}) was achieved by the combination of the recommended dose of fertilizer and biochar in comparison with control treatment that had a net loss of US $–2621.49 ha^{-1} in Canada. To know the further benefits from the commercialization of biochar, a comprehensive market study is required.

In Nepal, little works have been undertaken to test the biochar on soil fertility and crop growth but the outstanding results are yet to be explored. Vista *et al*. (2015) suggested its potentiality in Nepalese agri-culture after gaining farmers' positive response when it was tested in potato, maize, onion, sugarcane, zinger, barley and tomato. Rice husk biochar was effective for the growth and development of garden pea (Bhattarai *et al*., 2015). However, the studies on the influence of on yield, biotic and abiotic stresses are inadequate. Therefore, the present experiment was conducted to assess the effectiveness of biochar on yield response and red ant infestation in potato cultivar 'Desiree' in two ecological conditions of Dolakha district in 2018 and 2019. The present study aimed to assess the efficacy of biochar to improve potato yields in rain-fed uplands where soil moisture was inadequate for crop growth. The other objective of the study was to evaluate the biochars against red ants to reduce yield loss by the insect pest.

Materials and methods

Site description

An experiment was conducted at Jiri and Pawati villages of Dolakha district in 2018 and 2019, respectively. Jiri village was situated at 27°38'0" N and 86°14"0' E with an altitude of 1 900–2 500 meters above mean sea level while the experimental site was in 1950 masl. Its climate was a temperate type where a crop of potato could be grown in a year during spring-summer. The cultivable lands were uplands, rain-fed and dry where winter frost provided moisture for germination of potato tubers. Similarly, Pawati village was situated near Tamakoshi river, 40 km west from Jiri. The altitude of Pawati was 1 200–1 500 meters above mean sea level with a subtropical climate and upland terraces where two crops of potato could be grown in a year during October–January and March–June. The monthly average maximum temperatures were 16, 18, 22, 33, 28 and 28 °C and minimum temperatures were 7, 9, 11, 15, 18 and 23 °C from January to June in 2019, respectively (HCRP, 2020 Fig. 1). In 2018, the monthly average maximum temperatures were 19.3, 24.3, 24.5, 26.5, 28.5 and 28.8 °C and minimum temperatures were 5.5, 7, 9.3, 12.5, 13.3 and 13.0 °C in the same months. Monthly total rainfall was 3, 7, 5. 10, 80 and 60 mm in 2019 whereas it was 6.2, 3, 32, 36, 180.3 and 181.2 mm in 2018 during the same months, respectively. The soils of Jiri and Pawati were characterized by the acidic, well-drained sandy loam in texture based on the World Reference Base for Soil Resources (FAO, 2014). The soil pH of Jiri and Pawati ranged 5.0–5.4 and 4.8–5.2, respectively.

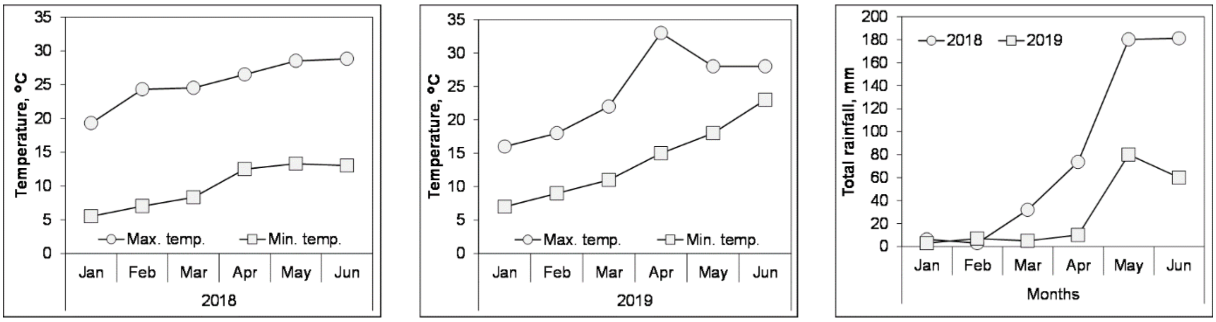

Figure 1. Monthly average temperatures and rainfall during cropping season at Kabre, Dolakha

Preparation of biochar

Biochar produced from *Lantana camara*, *Ipomoea carnea* var. *fistulosa*, rice husk and sawdust were used for the experiment. Plant materials of Lantana and Ipomoea were collected from wastelands and dried under the sun for 15 days. Wood dust was received from a sawmill, whereas rice husk was obtained from a rice mill in Lalitpur district. These materials were pyrolysed in a Kon-Tiki Flame Curtain kiln prepared by Soil Science Division of NARC according to the design recommended in previous reports (Schimidt *et al*., 2015; Cornelissen *et al*., 2016). The temperature in the main pyrolysis zone of the kiln ranged 680–750 °C (Schmidt, Taylor, 2014; Schmidt *et al*., 2015; Cornelissen *et al*., 2016) and cooled down slowly below the main pyrolysis zone when new feedstock layers were added to 150–450 °C depending on the duration of the batch before final quenching (Cornelissen *et al*., 2016).

Char particles of two plant materials were further ground in a grinding machine to make it fine powder with the char size similar to chars of sawdust and rice husk. Biochars were assessed for contents of nitrogen, phosphorus, potassium, total ash, electrical conductivity, pH and water holding capacity at the Chemical Laboratory of Nepal Academy of Science and Technology (NAST) in July 2017. Details of the biochar properties are presented in Table 2. The pH was determined by 1:2.5 biochar water suspension (Jackson, 1967). Organic matter content (Walkley, Black, 1934), Nitrogen (Micro-Kjeldahl, Bremner, Mulvaney, 1982), available phosphorus (Olsen *et al*., 1954) and available potassium (Ammonium acetate method; Jackson, 1967) were analyzed in the laboratories.

Water holding capacity of biochar was determined by Keen Raczkowski method (Piper, 1942). In this method, the Keen's box fitted with a filter paper was weighed on an electronic balance. The Keen's box was then packed with biochar sample by adding small quantity at a time. Excess biochar was removed with a spatula to bring the biochar inside the box to the level of the top of the box. The Keen's box with air dry biochar was weighed. The box with biochar placed in a Petri dish containing water to a depth of ¼ inch and it was left overnight. The next day the box was removed from the Petri dish and the excess water was allowed to drain out. Then the Keen's box was weighed. The water holding capacity was calculated from the gain in weight and the result was expressed in percentage (Baruah, Barthakur, 1999).

Experimental setup

The experiment was conducted to assess the effectiveness of biochars of different feedstock on the yield and yield attributes of potato; yield loss by the red ants and economic benefit. An experiment was conducted at Jiri in 2018 and Pawati in 2019 during the spring-summer season. An early variety 'Desiree' (Urgenta × Depesche) was used in the experiment. Potato tubers were planted in the first week of February and harvested in the fourth week of May in both the years. The experimental design was a randomized complete block with 6 replications and five treatments (Table 1). Plot size of 7.2 m^2 was maintained with the spacing of 60 cm for rows and 25 cm for plants, row length 3 m including 12 plants per row and 4 rows per plot. Thus, the whole plot was selected for yield and yield attributes. Fertilizers at the rate of 100:100:60 kg N : P_2O_5 : K_2O with 20 t ha^{-1} of FYM were applied on the rows and mixed with soil before planting. Biochars were applied at the rate of 2 t ha^{-1}. After planting, seed tubers were covered with an equal amount of biochar (Fig. 2). Without disturbing biochar, seed tubers were covered with the soil making ridges of 15 cm height. Seed sized tubers (25–50 g size) planted at a depth of 10 cm in the ridges.

Table 1. Treatment details for the experiment in 6 replications

Serial Number	Treatments
1	No Biochar
2	*Ipomoea carnea* var. *fistulosa*
3	*Lantana camara*
4	Rice husk
5	Saw dust

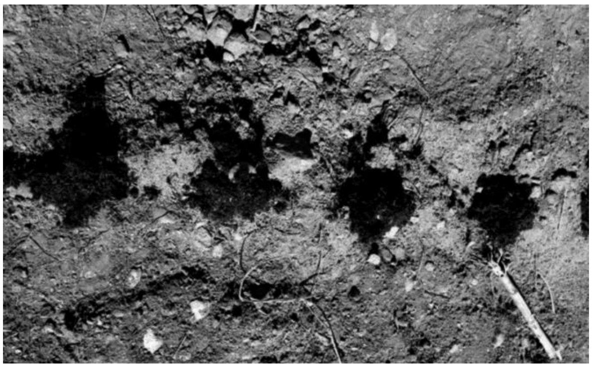

Figure 2. Method of biochar application in the field

Data observation

Observations were recorded on plant uniformity, ground cover, plant height, number of main stems per plant, percentage of number and weight of undersize, seed size and oversize tubers, number of tubers per plant, the weight of tubers per plant, total yield, and yield loss by the red ants and marketable yield. Plant and tuber attributes were recorded according to the field book of NPRP (NPRP, 2014). For example, plant uniformity (1–5 scale, 5 is 100% of plants uniform), ground cover (%), plant height, number of main stems per plant were recorded on 75 days of planting whereas rest of the parameters were recorded at harvesting.

For red ant infestation, number of damaged tubers, the weight of damaged tubers, percentage of damage, number of injuries per kg tubers, and tubers damage index (TDI) were recorded as the procedure applied by Sharma *et al*. (2017). Tubers Damage Index (TDI) value (0.00 to 1) was calculated based on the percentage of damaged tubers and the number of injuries per kilogram of tubers. Lower the TDI value, higher is the resistance against red ants. A formula developed by Sharma *et al*. (2015) was used to calculate the TDI value (Eq. 1).

Data analysis

Data were managed in a spreadsheet and analyzed with GenStat version 18 (VSN International, 2015) software for windows. Analysis of variance was used to determine statistically significant differences between means. Post hoc analysis was done by Duncan's Multiple Range Test. Standard errors of the means were determined for all significant data. At first, separate analysis for two locations was done and combined analysis was undertaken to determine conclusive results.

$$TDI\ value = \frac{Percentage\ of\ damaged\ tubers\ (a) + Number\ of\ injuries\ on\ per\ kg\ of\ tubers\ (b)}{The\ highest\ value\ of\ a\ sum\ of\ (a)\ and\ (b)\ of\ the\ same\ replication} \quad (1)$$

Results

Properties of biochar

Laboratory analysis of biochar showed that the biochar produced from *Lantana camara* L. contained higher water holding capacity, phosphorus and total nitrogen than the other biochars (Table 2). Total ash, potassium and electrical conductivity were higher in sawdust biochar compared to others. The pH value was the greatest in the biochar produced from *Ipomoea carnea* var. *fistulosa*. Nutrients and other properties may vary with the type of biochar (Kochanek, 2014). The nutrient content, ash content and other properties greatly differed when biochars were produced from Sugarcane Trash and Green Wastes (Upadhyay, 2015).

Table 2. Properties of biochar used in the experiment in 2018 and 2019

SN	Parameters	LC	IC	RH	SD
1	Water holding capacity, %	17.4	12.8	13.2	9.9
2	pH	9.6	9.9	8.03	9.2
3	Electrical conductivity, dS	3.8	3.1	3.3	8.5
4	Total ash, %	11.0	10.0	8.0	12.0
5	Potassium, ppm	10.4	5.3	8.0	12.7
6	Phosphorus, ppm	3.41	3.37	2.46	2.13
7	Total nitrogen, %	0.43	0.28	0.32	0.38

LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = saw dust

Biochar effects on yield attributes of potato at Jiri in 2018

Among the plant characteristics (Table 3), significant differences (P = <0.05) were observed for ground cover, plant height and the number of main stems per plant. The differences were also observed for the percentage of the number of undersized tubers, percentage of the weight of oversize tubers and weight of tubers per plant (Table 4), total yield, yield loss by red ants and marketable yield (Fig. 3). Plant uniformity (Table 3), per cent of the weight of undersized tubers, number of seed size tubers, the weight of seed size tubers, number of oversize tubers and number of tubers per plant remained statistically non-significant (Table 4). The effect of no biochar was greater on ground cover followed by *Ipomoea carnea* whereas all biochars had similar but greater positive effect on plant height and the number of main stems per plant compared to the effect of no biochar. Undersize, seed size and oversize tubers were further measured to their number and weight (Table 4). The minimum percentage of the number of undersized tubers was recorded in the plots treated with *Lantana camara* biochar. The percentage of the weight of oversize tubers was higher in biochar-added plots compared no biochar-added plots except rice husk biochar applied plots. Weight of tubers per plant was greater in biochar treated plots compared to no biochar. Among the biochars, biochar produced from *Lantana camara* produced a significantly greater weight of tubers per plant compared to other biochars. Biochars were also effective for increasing total yield compared to no biochar. However, the influence of all biochars was similar for total yield. Yield loss by red ants was less in the plots treated with *Lantana camamra* and rice husk biochars. Marketable yield was higher in biochar-added plots showing *Lantana camara* biochar the most effective to produce marketable yield followed by rice husk and sawdust biochar.

Table 3. Effect of biochar on plant characteristics of potato at Jiri in 2018

Treatment	Uniformity (1–5)	Ground cover, %	Plant height, cm	No. of main stems plant^{-1}
NB	4.0	90±0.0 d	32.0±0.00 a	3.0±0.00 a
IC	3.7	84.2±0.03 c	27.7±0.16 b	4.5±0.63 b
LC	4.2	75.8±0.02 a	27.5±0.24 ab	3.8±0.21 ab
RH	3.7	82.5±0.01 bc	27.2±0.28 b	4.1±0.33 b
SD	3.8	79.2±0.0 2 ab	26.4±0.23 b	4.2±0.31 b
LSD (0.05)α0.05	0.71	3.9	3.09	0.79
CV (%)	15.2	4.0	9.1	16.9

NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = sawdust. The means followed by the same letter on the same column are not significantly different at α 0.05 by Duncan's Multiple Range Test. The ± values represent standard error of the mean.

Table 4. Effect of biochar on tuber characteristics of potato at Jiri in 2018

Treatment	Tuber size distribution, %						No. of tubers plant^{-1}	Weight of tubers plant^{-1}
	Undersize (<20 g)		Seed size (20–50 g)		Oversize (>50 g)			
	No.	Weight	No.	Weight	No.	Weight		
NB	37.3 ± 1.26 b	15.1	49.1	59.2	13.6	25.7 ± 3.62 a	5.1	267.1 ± 14.72 a
IC	36.3 ± 0.91 b	11.1	44.6	51.4	19.0	37.6 ± 2.61 b	5.6	309.8 ± 17.14 b
LC	29.2 ± 2.19 a	10.3	54.6	56.9	16.2	32.8 ± 2.49 b	5.6	326.6 ± 24.64 c
RH	37.2 ± 1.78 b	13.8	49.2	54.4	13.6	31.8 ± 3.02 ab	5.4	276.7 ± 15.02 b
SD	35.7 ± 1.83 b	13.3	44.9	50.5	19.4	36.2 ± 2.80 b	5.7	302.5 ± 17.13 b
LSD (0.05)	5.22	3.95	8.22	8.68	6.24	6.18	3.3	17.35
CV (%)	12.3	25.8	14.1	13.2	31.7	15.6	9	10.1

NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = sawdust. The columns of the same series followed by the same letter are not significantly different at α 0.05 by Duncan's Multiple Range Test. The ± values represent standard error of the mean.

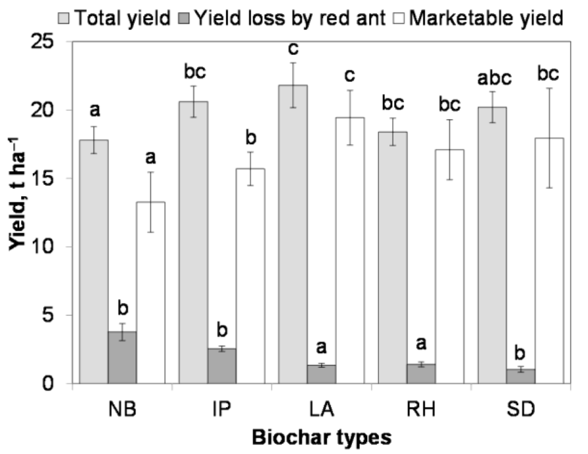

Figure 3. Effect of biochar on yields of potato at Jiri in 2018. NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = sawdust. The columns of the same series followed by the same letter are not significantly different at α 0.05 by Duncan's Multiple Range Test. The bars represent standard error of the mean.

Biochar effects on red ant infestation on potato at Jiri in 2018

The number of tubers per plot was greater in the plots treated with biochars of *Ipomoea carnea*, *Lantana camara* and no biochar (Table 5). The percentage of damaged tubers was less in plots with biochar than the plots with no biochar; indicating a beneficial effect of biochar on red ant management. Biochars of *Lantana camara*, rice husk and sawdust produced less per cent of damaged tubers and weight of damaged tubers. The number of injuries per kg of tubers and Tubers damage index was less in the plots treated with *Lantana camara* and rice husk biochar. The TDI value showed that the tubers were less damaged in *Lantana camara* (TDI value = <0.5), medium damaged in rice husk (TDI value = 0.5–0.75) and highly damaged (TDI value = >0.75) in remaining treatments, according to the categories developed by Sharma *et al*. (2015). The variety 'Desiree' was characterized as highly susceptible to red ants with 49.7 to 77% of damaged tubers (Joshi, 1998).

Table 5. Effect of biochar on red ant infestation on potato at Jiri in 2018

Treatment	No. of tubers plot^{-1}	% of damaged tubers	Weight of damaged tubers, kg	No. of injuries kg^{-1}	Tubers damage index
NB	313.5 ± 16.65 b	23.3 ± 1.43 c	2.72 ± 0.450 c	43.2 ± 3.94 bc	0.97 ± 0.023 b
IC	326.7 ± 18.97 b	9.6 ± 0.84 b	1.83 ± 0.143 b	47.6 ± 4.00 c	0.85 ± 0.056 b
LC	303.8 ± 14.37 b	4.7 ± 0.81 a	0.97 ± 0.099 a	26.4 ± 4.86 a	0.48 ± 0.096 a
RH	252.7 ± 18.01 a	5.3 ± 1.15 a	1.02 ± 0.130 a	30.3 ± 3.18 ab	0.55 ± 0.081 a
SD	240.5 ± 9.50 a	7.4 ± 1.85 ab	0.75 ± 0.152 a	45.8 ± 6.89 c	0.78 ± 0.070 b
LSD (0.05)	47.99	3.373	0.707	31.66	0.194
CV (%)	13.9	27.8	31.6	29.4	22.2

NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = sawdust. The means followed by the same letter on the same column are not significantly different at α 0.05 by Duncan's Multiple Range Test. The ± values represent standard error of the mean.

Biochar effects on yield attributes of potato at Pawati in 2019

In Pawati, significant differences (P = <0.05) were observed for ground cover, plant height and the number of main stems per plant (Table 6). The differences were also observed for the percentage of the number of undersized tubers, percentage of the weight of undersized tubers, number of tubers per plant, the weight of tubers per plant (Table 7), total yield, yield loss by red ants and marketable yield (Fig. 4). Plant uniformity (Table 6), percentage of the number of seed size tubers, the weight of seed size tubers, number of oversize tubers and weight of oversize tubers remained non-significant. The effect of no biochar was greater on ground cover and plant height whereas all biochars had similar but greater positive effect on the number of main stems per plant compared to the effect of no biochar. The minimum percentage of the number of undersized tubers and the percentage of the weight of undersized tubers was recorded in the plots treated with *Lantana camara* biochar. *Lantana camara* biochar also produced the highest number of tubers per plant and weight of tubers per plant. The effects of *Lantana camara*, sawdust and rice husk biochars were greater on total yield. Yield lossless in biochar-added plots compared to no biochar. Among the biochars, *Lantana camara* showed less yield loss by red ants followed by rice husk and sawdust biochar. Biochars were also beneficial for producing marketable yield showing *Lantana camara* biochar the most effective to produce marketable yield followed by sawdust and rice husk biochar.

Table 6. Effect of biochar on plant characteristics of potato at Pawati in 2019

Treatment	Uniformity (1–5)	Ground cover, %	Plant height, cm	No. of main stems plant^{-1}
NB	4.3	90.5 ± 0.0 d	32.0 ± 0.00 b	3.0 ± 0.00 a
IC	3.7	84.7 ± 0.03 c	27.7 ± 0.16 a	3.7 ± 0.63 b
LC	4.2	77.3 ± 0.02 a	27.5 ± 0.24 a	3.7 ± 0.21 b
RH	3.7	83.3 ± 0.01 bc	27.2 ± 0.28 a	3.8 ± 0.33 b
SD	3.8	79.5 ± 0.02 ab	26.4 ± 0.23 a	4.2 ± 0.31 b
LSD (0.05)	0.71	4.40	3.09	0.616
CV (%)	15.0	4.4	9.1	13.7

NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = saw dust. The means followed by same letter on the same column are not significantly different at α 0.05 by Duncan's Multiple Range Test. The ± values represent standard error of the mean.

Table 7. Effect of biochar on tuber characteristics of potato at Pawati in 2019

Biochar	Tuber size distribution, %						No. of tubers plant^{-1}	Weight of tubers plant^{-1}
	Under size (<20 g)		Seed size (20–50 g)		Oversize (>50 g)			
	No.	Weight	No.	Weight	No.	Weight		
NB	34.3 ± 1.26 b	14.6 ± 0.79 b	48.9	47.9	16.8	37.5	5.3 ± 0.27 a	240.4 ± 14.72 a
IC	35.6 ± 0.91 b	13.3 ± 0.38 b	44.8	45.2	19.6	41.5	5.6 ± 0.34 ab	252.1 ± 17.14 a
LC	29.7 ± 2.19 a	9.8 ± 0.43 a	48.0	48.3	22.3	42.0	6.1 ± 0.26 b	286.1 ± 24.64 b
RH	35.5 ± 1.78 b	13.8 ± 1.07 b	44.7	45.3	19.7	40.9	5.7 ± 0.21 ab	259.1 ± 15.02 ab
SD	32.3 ± 1.83 ab	12.8 ± 0.85 b	47.9	45.0	19.7	42.2	6.0 ± 0.29 b	263.6 ± 17.13 ab
LSD (0.05)	3.98	1.81	4.62	5.11	4.55	5.66	0.52	27.99
CV (%)	9.9	11.7	8.2	9.2	19.3	11.5	7.3	8.9

NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = sawdust. The means followed by the same letter on the same column are not significantly different at α 0.05 by Duncan's Multiple Range Test. The ± values represent standard error of the mean.

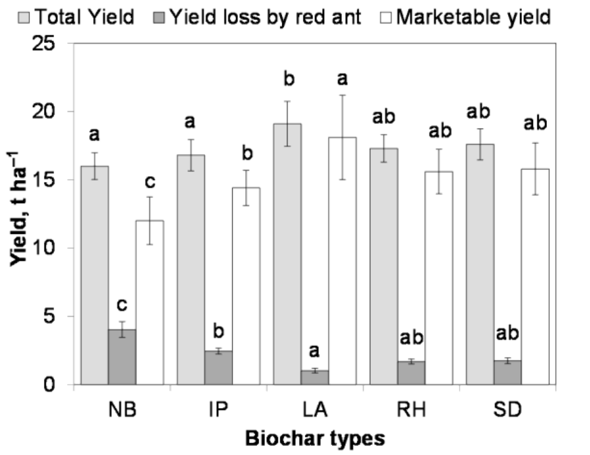

Figure 4. Effect of biochar on yields of potato at Pawati in 2019. The columns of the same series followed by the same letter are not significantly different at α 0.05 by Duncan's Multiple Range Test. The bars represent standard error of the mean

Biochar effects on red ant infestation on potato at Pawati in 2019

The results revealed that the greatest number of tubers per plot was produced by *Ipomoea carnea* followed by *Lantana camara* and no biochar (Table 8). The per cent of damaged tubers was less in biochar-added plots than no biochar plots. Biochar produced from *Lantana camara* had a significantly greater positive effect on the percentage of damaged tubers, weight of damaged tubers. The number of injuries per kg of tubers was less in the plots treated with sawdust followed by *Lantana camara* biochar. The TDI value was the least for sawdust followed by *Lantana camara* whereas it was significantly larger for no biochar. According to the category, the TDI value showed that the less damage (TDI value = <0.5) tubers were observed in sawdust and *Lantana camara*, medium damaged in rice husk (TDI value = 0.5–0.75) and high damage (TDI value = >0.75) in remaining treatments.

Table 8. Effect of biochar on red ant infestation on potato at Pawati in 2019

Biochar	No. of tubers plot^{-1}	% of damaged tubers	Weight of damaged tubers	No. of injuries kg^{-1}	Tubers damage index
NB	280.3 ± 13.07 b	25.2 ± 1.07 d	2.90 ± 0.421 c	49.2 ± 3.43 c	0.96 ± 0.038 d
IC	292 ± 11.72 b	12.6 ± 0.83 c	1.77 ± 158 b	46.5 ± 3.90 c	0.77 ± 0.055 c
LC	282 ± 13.41 b	4.6 ± 0.39 a	0.73 ± 0.126 a	28.3 ± 4.55 a	0.42 ± 0.051 a
RH	233 ± 10.48 a	9.2 ± 1.05 b	1.22 ± 0.128 ab	35.3 ± 4.93 b	0.57 ± 0.045 b
SD	230.2 ± 7.04 a	7.8 ± 1.28 b	1.25 ± 0.150 ab	21.8 ± 2.43 c	0.38 ± 0.041 a
LSD (0.05)	34.3	2.939	0.647	10.92	0.142
CV (%)	10.8	20.5	30.3	25	18.9

NB = no biochar, LC = *Lantana camara*, IC = *Ipomoea carnea*, RH = rice husk, SD = sawdust. The means followed by the same letter on the same column are not significantly different at α 0.05 by Duncan's Multiple Range Test. The ± values represent standard error of the mean.

Discussion

Biochar effects were encouraging on yield attributes of potato. Yields were higher in 2018 than in 2019. It should be linked with the consistent trend of temperatures and higher rainfall during March-April in 2018 (Fig. 1), when the tuber initiation and development stage was started. The dry nature of the soil in Jiri received more moisture during the tuber formation period in 2018. The biochar produced from *Lantana camara* was more effective, possibly due to favourable water holding capacity, ash content and NPK content (Table 2).

Effect of biochar may rely on growth conditions and composition of soil medium. For instance, biochar application may not bring significant soil quality and crop productivity improvements to high-input agricultural systems (Boersma *et al*., 2017). The number of stems per hill, the number of tubers per hill, weight of tubers per hill and yield were increased with the application of biochar plus recommended fertilizer dose (Ali, 2017). Our study results were also in line with these results. Similarly, adding biochar to potato plants grown in sandy soil improved plant growth, plant chemical compositions, tuber yield and its components, with good tuber quality (Youssef *et al*., 2017). Adding biochar to the soil with the fully irrigated condition without phosphorus fertilizer and arbuscular mycorrhiza increased the biomass of potato (Liu *et al*., 2016).

On the other hand, a single rotation of wood biochar to soil did not affect growth or harvest yield of potato (Jay *et al*., 2015). There was no consistent effect of green waste biochar on growth of true potato seedlings and node cuttings of true potato seedlings when biochar was applied to sand medium nourished with additional nutrient solution (Upadhyay *et al*., 2014). Nair *et al*. (2014) also found no significant effect of biochar on growth and marketable number and weight of potato. Application of plantain peel biochar to potato under freshwater and wastewater did not increase yield (Nzediegwu *et al*., 2019) whereas it varied between biochars in the present study. For example, the effect of biochar produced from *Ipomoea carnea*, rice husk and sawdust was similar to the influence of no biochar; and biochar of *Lantana camara* was effective for increasing the yields.

In a recent study carried out by Robb and Joseph (2019), biochar mixed with NPK increased the total yield per hectare of potatoes from 38.8 tonnes to 58.1 tonnes, a 53 % increase in which the 20% biochar substitution delivered both the highest yield and highest tuber productivity per plant. According to Liu *et al*. (2013), biochar applications increased potato yields approximately 19%, based upon a meta-analysis of 59 pot experiments from 21 countries and 57 field experiments from 21 countries. When situation favours to 19% yield increase in present yield (14.7 t ha^{-1}) of potato in Nepal, it will reach 17.5 t ha^{-1} which could be a significant contribution to substitute import of potato from neighbouring countries. In the fiscal year 2018/19, about 347 309 metric tonnes of potatoes were imported to Nepal (TEPC, 2019). Thus, the increased production will be 539 049 metric tonnes when 19% yield increase will occur by biochar application. If not the same but 50% of the 19% yield increase could be added, a considerable amount of import would be reduced.

Likewise, Farooque *et al*. (2020) showed that the maximum potato yields (30.5 t ha^{-1}) could be achieved by the combined application of biochar and recommended dose of synthetic fertilizers in comparison with the control treatment. Our study showed a significant increase in potato yield by biochar in combination with recommended dose of fertilizers. A recent study showed that if potato crop irrigated fully with phosphorus addition to soil and not inoculated with AM fungi, then the addition of biochar can increase potato yield (Spudsmart, 2020). In the present study, results indicate the positive effect of biochar on yield increase.

Biochar could be a useful additive in the production and formulation of biopesticides (Sayed *et al*., 2018). Some findings have been reported on the influence of biochar on the occurrence of insect pests. For instance, biochar amendment to rice fields had negative impacts on the rice brown planthoppers when applied at the level of 200 g kg^{-1} of soil (Hou *et al*., 2015). Elad *et al*. (2015) indicated that biochar induced systemic resistance to the broad mite pest (*Polyphagotarsonemus latus* Banks) on pepper. The abundance of soil insects was reduced due to the increased rate of rice husk biochar in potato fields (Meilin, Rubiana, 2018). Some preliminary observations on charcoal effects on small red ants showed that brinjal seeds in the 6 pots with 30% charcoal plus soil were untouched by small red ants while the seeds in control pots were eaten (Reddy, 2007). The ant distribution could be connected to the properties of biochar amended soil (Castracari *et al*., 2015). However, these ants were different from red ants of potato and their damaging behaviour was different. Yet, the literature on the efficacy of biochar to control potato red ants are very limited. Our findings would be an avenue for further confirmation of the influence of biochar on red ant infestation on the potato.

The impact of biochar needed to be observed in succeeding years since the impact of biochar is long-term. We did not examine the effects of biochar application in soil fertility; however, it was important for developing a long-term soil management plan. We also did not evaluate soil and plant nutrients before planting and after harvest so that the information on soil nutrient status could not be explained. We observed it in two locations where farmers were facing the problem of red ants. The results emphasized that the application of biochar was beneficial for saving yields where the considerable loss of potatoes is occurred due to red ant infestation. The reason behind the low infestation of red ants with the biochar application is a matter of study. In our case, there was a possibility that some compounds might be left in the biochar from the pyrolysis process (Kon-Tiki 680–750 °C) which acted as a repellent. Besides, there could be an indirect impact of biochar that it improved the immunity of the plants through increased water availability, hence making them more resistant to pests and other threats. Yet, is there any specific chemical inherent to the biochar may toxic or repel the red ants? Or its powdery mass may suffocate to the ants or absorb water from their body? Nepalese traditional farmers apply wood ash to control ants and aphids in the kitchen garden; they believe ash powder suffocates and absorbs water from their body. Can we expect similar effects of fine biochar on red ants? These are the questions that should be answered from future experiments.

Conclusions

Biochar application with the rate of 2 t ha^{-1} an in combination with recommended farmyard manure and NPK fertilizers increased total yield and marketable yield. Among the biochars, *Lantana camara*, sawdust and rice husk showed less yield loss by red ants compared to no biochar. Tubers damage index was less in the plots with the biochar of *Lantana camara* followed by rice husk and sawdust. The yields saved from red ants with the application of biochar, specifically the biochar from *Lantana camara*, were significantly higher than no biochar. Thus, biochar application to potato fields in red ant prone areas could increase marketable yield.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author contributions

KPU – study conception and design, analysis and interpretation of data, drafting of the manuscript and approval of the final manuscript;
NBD – carried out the experiment on outreach site of Kabre, Dolakha;
PNS – acquisition of data of insects;
JDN – acquisition of data of experiment;
JS – critical revision and approval of the final manuscript.

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TUTVUSTAV LÜHIÜLEVAADE EESTI TAIMEKASVATUSE INSTITUUDI JUUBELI PUHUL ILMUNUD RAAMATUST

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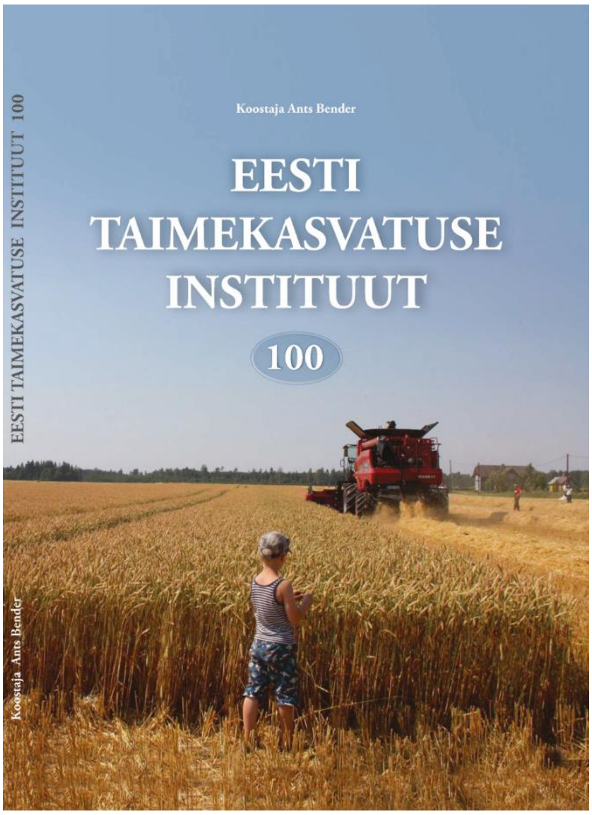
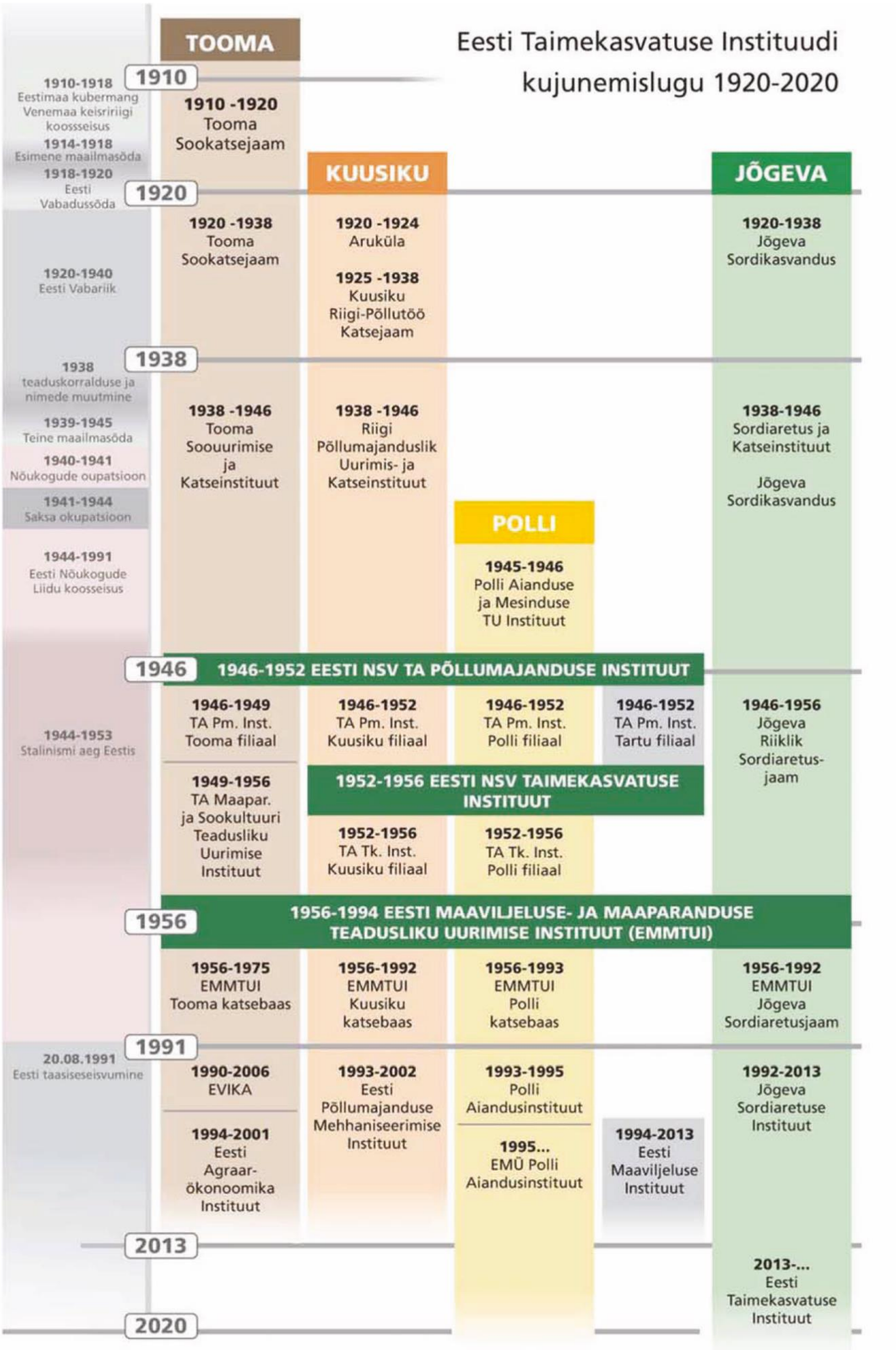


Raamatus on püütud anda ülevaade tähtsamate kultuurigruppide (teraviljad, kartul, söödakultuurid, köögi- ja puuviljad, tehnilised kultuurid) sordiaretuse ja agrotehnoloogia arengust möödunud 100 aasta jooksul. Raamatu mahukates lisades tuuakse ära: 1. taimekasvatusteadlaste poolt eri aegadel välja antud olulisemate publikatsioonide loetelu; 2. Jõgeval, Pollis, Kuusikul ja Sakus aretatud põllu- ja aiakultuuride sortide nimistu; 3. töötajatele omistatud tunnustused (aunimetused, riiklikud preemiad, teenetemärgid Eesti Vabariigi Presidentidelt, põllumajandusministeeriumilt ja maaeluministeeriumilt); 4. tuuakse Eesti Taimekasvatuse Instituudis (mõeldud koos eelkäija-asutustega) töötanud 100 kõige enam põllumajandust ja põllumajandusteadust mõjutanud teadlase lühielulood. Siia on kaasatud ka väljapaistvad teadlased-instituutide juhid Jaak Ümarik, Kaarel Liidak, Mihkel Pill, Leo Rinne, Aleksander Raidla, Ilmar Jürisson, Hans Küüts, Edgar Tõnurist, Ilmar Aamisepp, Arnold Piho, Arvi Kallas jt.

Huvilistel on võimalik raamatut tellida Eesti Taimekasvatuse Instituudist.

Pm-dr Arvo Sirendi


Eesti Taimekasvatuse Instituudi kujunemislugu 1920-2020
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1918-1920 Eesti Vabadussõda
1920-1940 Eesti Vabariik
1938 teaduskorralduse ja nimede muutmine
1939-1945 Teine maailmasõda
1940-1941 Nõukogude oupatsioon
1941-1944 Saksa okupatsioon
1944-1991 Eesti Nõukogude Liidu koosseisus
1944-1953 Stalinismi aeg Eestis
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1920-1938 Jõgeva Sordikasvandus
1938 -1946 Tooma Soouurimise ja Katseinstituut
1938 -1946 Riigi Põllumajanduslik Uurimis- ja Katseinstituut
1938-1946 Sordiaretus ja Katseinstituut
Jõgeva Sordikasvandus
1945-1946 Polli Aianduse ja Mesinduse TU Instituut
1946-1952 EESTI NSV TA PÕLLUMAJANDUSE INSTITUUT
1946-1949 TA Pm. Inst. Tooma filiaal
1946-1952 TA Pm. Inst. Kuusiku filiaal
1946-1952 TA Pm. Inst. Polli filiaal
1946-1952 TA Pm. Inst. Tartu filiaal
1946-1956 Jõgeva Riiklik Sordiaretus-jaam
1949-1956 TA Maapar. ja Sookultuuri Teadusliku Uurimise Instituut
1952-1956 EESTI NSV TAIMEKASVATUSE INSTITUUT
1952-1956 TA Tk. Inst. Kuusiku filiaal
1952-1956 TA Tk. Inst. Polli filiaal
1956-1994 EESTI MAAVILJELUSE- JA MAAPARANDUSE TEADUSLIKU UURIMISE INSTITUUT (EMMTUI)
1956-1975 EMMTUI Tooma katsebaas
1956-1992 EMMTUI Kuusiku katsebaas
1956-1993 EMMTUI Polli katsebaas
1956-1992 EMMTUI Jõgeva Sordiaretusjaam
1990-2006 EVIKA
1994-2001 Eesti Agraar-ökonoomika Instituut
1993-2002 Eesti Põllumajanduse Mehhaniseerimise Instituut
1993-1995 Polli Aiandusinstituut
1995... EMÜ Polli Aiandusinstituut
1994-2013 Eesti Maaviljeluse Instituut
1992-2013 Jõgeva Sordiaretuse Instituut
2013-... Eesti Taimekasvatuse Instituut

TOIVO UNIVER – 80

24. detsembril 2020 tähistab oma 80-ndat juubelit Eesti üks populaarsematest puuviljandusteadlastest põllumajanduskandidaat Toivo Univer. Ta on sündinud (24.12.1940) omaaegses Mäe vallas Petserimaal, lõpetanud Räpina Aiandustehnikumi (1958), EPA kaugõppeteaduskonna agronoomia erialal (1967), õppinud EMMTUI juures aspirantuuris (1970–1973, juhendaja professor A. Siimon), kaitsnud põllumajanduskandidaadi kraadi teemal "Õunapuusortide ja -vormide uurimistulemused ENSV-s" (1981, Moskva Mittemustmullavööndi Tsonaalne Aianduse TUI), täiendanud teadmisi Moskva RÜ-s (puuviljakultuuride selektsioon, 1985), Ukraina Taimekasvatuse, Selektsiooni ja Geneetika TUI-s (Harkov, matemaatilised meetodid geneetikas, 1986), Mitšurinskis Geneetika laboratooriumis (matemaatilised meetodid puuviljanduses, 1987) ja mujal. Omaaegne Kõrgem Atestatsioonikomisjon on Toivo Univerile omistanud vanemteaduri kutse selektsiooni ja seemnekasvatuse erialal (1989).

Toivo Univer on läbi elu olnud põhjalik ja järjekindel. Seda võib välja lugeda jälgides juubilari karjäärialast edenemist teadus- ja õppeasutustes. Pärast Räpina Aiandustehnikumi lõpetamist alustas tööd EMMTUI Polli katsebaasis aiandus-oskustöölisena (1958), olnud samas aiabrigadir (1966–1967) ja aiandusagronoom (1967–1970), aspirantuuri järel jätkanud nooremteaduri (1973–1986) ja vanemteadurina (1986–1995), pärast Polli liitumist EPMÜ-ga Polli Aiandusinstituudi teadusdirektorina (1995–1998) ning direktorina (1998–2003). Hiljem on töö jätkunud vanemteaduri (2003–2015) või erakorralise teaduri ametikohtadel (2016…) olles ühtlasi õunviljaliste töörühma projektijuht Pollis. Õpiaastatel EPA kaugõppeteaduskonnas (1958–1968) on juubilar töötanud õpetajana Hallistes, aednikuna Luual, aiandusagronoomina Tõrva sovhoosis ja teeninud Nõukogude armees.

Toivo Univer on kohakaasluse alusel viinud läbi õppetööd. Oli Halliste 7-kl kooli bioloogiaõpetaja (1958–1960), EPMÜ Agronoomiateaduskonna aiandusinstituudi lektor (1987–1989), dotsent (1989–1992) ja professor-instituudi juhataja (1992–1994), edasi dotsent (1994–2002). Õppejõuna on Toivo Univer EPMÜ-s lugenud üliõpilastele puuviljakultuuride ja pomoloogia loengukursuseid, juhendanud arvukalt bakalaureuse ja magistritöid.

Toivo Univeri vastutusvaldkonda Pollis kuuluvad õunapuu, pirnipuu ja astelpaju uurimine. Õunapuudel ja pirnipuudel uuritakse geenivaramu raames kollektsioonaeda kogutud Eestis aretatud või introdutseeritud sorte ja aretisi, millele lisandub pookealuste kollektsioon. Samal ajal tegeleb ta aretustööga. Tema osalusel on aretatud sort 'Punane talvenauding'. Viimase paarikümne aasta vältel on peatähelepanu kulunud maailma kärntõvekindlate õunasortide uurimisele ja kohapealse oma sordi loomisele. Sellesuunalise töö resultaadina on perspektiivsed omamaised õuna- ja pirnipuu aretusnumbrid olnud juba väljas aiandusnäitustel. Parimad neist on paljundamisel ja esitatakse UPOV-i katsetusse, mis toimuvad Poolas. Pollis jätkuvad uurimistööd astelpaju ja kultuurpihlaka kasvatamise alal. Projektipõhise finantseerimise tulemusena on tulnud osaleda ka paljudes kõrvalvaldkondi käsitlevais uurimisprojektides, mistõttu arvukas teaduspublikatsioonide ampluaas leiavad käsitlemist puuviljanduse väga erinevad tahud. On raamatute "Eesti puuvilja- ja marjasordid" (2006) ja "Puuviljad ja marjad Eestis". "Pomoloogia" (2010 ja 2012) üks autoritest, kirjutanud puuviljanduse peatüki koguteosele "Eesti põllumajandus XX sajandil" aastad 1900–1940 (2006) ning ajaloolise ülevaate puuviljandusalasest uurimistööst Pollis 75 tegevusaasta vältel raamatus "Eesti Taimekasvatuse Instituut 100″ (2020). Osaleb Eesti esindajana puuviljandusvaldkonna rahvusvahelistes teadus- ja arendustegevuse projektides, on hinnatud esineja nii kodu- kui välismaistel teaduskonverentsidel.

Sügavalt eriala tundva spetsialistina on Toivo Univer kuulunud hinnatud liikmena Eesti Põllumajandusülikooli, Taimebiotehnoloogia Uurimiskeskuse EVIKA ja loomulikult ka Polli Aianduse Instituudi teadusnõukogusse. Ta on Eesti Aiandusliidu puuviljanduse ekspertkomisjoni liige ning maaeluministeeriumi konsulentide atesteerimiskomisjoni ekspert.

Toivo Univer on Eesti Looduskaitse Seltsi, A. Kitzbergi Sõprade Seltsi ja Akadeemilise Põllumajanduse Seltsi (samas kauaaegne eestseisuse) aktiivne liige. On aastakümneid mänginud puhkpilliorkestrites klarnetit, edendanud loodushoiu põhimõtteid, uurinud kodulugu ja puuviljandushariduse ning -teaduse arengulugu. Teinud tänuväärset tööd õunasorte tutvustavate näituste korraldamisel – alati koos degusteerimisega. On sellega märkimisväärselt mõjutanud (kiirendanud) uute aretiste jõudmist kodu- ja tootmisaedadesse.

Pikaaegse tulemusliku töö ja ühiskondliku aktiivsuse eest on Toivo Univer pälvinud Viljandimaa Vapimärgi, Eesti Maaülikool on tunnustanud teda teenete medaliga, Eesti Põllumajandusministeerium hõbedase teenetemärgiga.

Koos abikaasa Irenega on peres üles kasvatatud kolm tublit last, kellest poeg Neeme on astunud isa jälgedes puuviljandusteadusesse. Aastal 2004 kaitses Neeme Univer edukalt teadusmagistri kraadi väitekirja teemal "Õunapuu nõrga- ja keskmisekasvuliste kloonaluste uurimise tulemusi". Vanavanemate elutarkust ja hellust on jagada kuuele lapselapsele, kellest viis on poisid. Viimane asjaolu seab selles tänuväärses töös just vanaisa rolli juhtpositsioonile.

Soovime juubilarile tugevat tervist, kordaminekuid teaduslikus uurimistöös ja jätkuvat energiat teadusüritustel kaasa löömiseks!

Ants Bender

ENDEL TURBAS – *in memoriam*

13.02.1929–†10.12.2020

10. detsembril 2020. aastal lahkus meie hulgast agrokeemik kauaaegne EPA õppejõud Endel Turbas.

Endel Turbas sündis 13. veebruaril 1929. aastal Mulgimaal tolleaegses Abja vallas talupidajate pere teise lapsena. Isa surma tõttu jäi talutööde tegemine juba varakult Endli õlgadele. Majanduslikele raskustele vaatamata astus ta pärast Abja Keskkooli lõpetamist 1947. aastal Tartu Ülikooli põllumajandusteaduskonda, 1951. aastast jätkusid õpingud vastloodud Eesti Põllumajanduse Akadeemia agronoomiateaduskonnas. Endel lõpetas EPA I lennu õpetatud agronoomina kiitusega.

Endel Turbas osutus professor Osvald Halliku poolt väljavalituks ja esimeseks töökohaks sai tal EPA mullateaduse ja agrokeemia kateeder, kus Endel töötas kuni 1990. a pensionile siirdumiseni. Kateedris töötamisel läbis Endel kogu ametiredeli tehnik-agrokeemikust kuni dotsendini. Õppejõu tööga alustas ta 1953. aastal. 1958–1961. aastani oli ta aspirandiks. Pärast kandidaadidissertatsiooni edukat kaitsmist 1952. a happeliste muldade lupjamise alal edutati Endel 1964. a vanemõpetajaks, aasta hiljem dotsendi kohusetäitjaks ja 1966. a dotsendiks. Dotsendina õpetas Endel agrokeemiat ligi 25 aasta jooksul. Endel oli tasakaalukas täpsust ja korda nõudev õiglane õppejõud.

Pärast prof O. Halliku surma tuli Endel Turbasel 1964. a üle võtta oma õpetaja ootamatult katkenud õppe- ja teadustöö. Teadustöö põhisuunaks jäi Endlil kuni pensionile siirdumiseni happeliste muldade lupjamine ja korduslupjamine. Erialast täiendõpet sai Endel Moskvas Timirjazevi nimelises Põllumajanduse Akadeemias kahel korral aastatel 1968 ja 1987. Mullateaduse ja agrokeemia kateedris kujundas Endel kiiresti välja toimeka muldade lupjamise alase töörühma, kellest said nimekad teadlased ja õppejõud. Neist on tänaseks kahjuks Valter Hiis, Paul Kuldkepp ja Ervi Lauk läinud juba manalateele.

Endel oli üleliidulise muldade lupjamise alase koordineerimise nõukogu, NSVL Lääne osakonna maaviljeluse, mullateaduse ja agrokeemia sektsiooni liige ja osales Üleliidulise Väetuskatsete Võrgu uurimistöös. Eestis oli ta ENSV Põllumajandusministeeriumi teaduslik-tehnilise nõukogu maaviljeluse, agrotehnika, agrokeemia ja sordiaretuse uurimistöö koordineerimiskomisjoni ning söötade analüüsi metoodika vabariikliku koordineerimiskomisjoni liige.

Eesti Vabariigi taastamisel jäid happeliste muldade lupjamise küsimused unustusehõlma. Viimastel aastatel on need probleemid taas päevakorrale kerkinud, sest lupjamise mõju kestus on ju ainult 5–7 aastat. Tegelema on hakatud ka tülikalt tolmava ja raskesti doseeritava tolmpõlevkivituha granuleerimise võimaluste selgitamisega – selle probleemiga tegeles Endel juba aastakümneid tagasi.

Endel oli ka viljakas kirjamees, tal on avaldatud üle 300 trükise, sh oli ta raamatute-õppevahendite "Agrokeemia laboratoorne praktikum", "Agrokeemia alused", "Lupjamisalase uurimistöö tulemused ja soovitused muldade korduslupjamiseks", "Taimede toitumise ja väetamise käsiraamat" kaasautoriks. Ta oli mitmete EPA teaduslike tööde kogumike toimetaja, kirjutas hulgaliselt ENE ja EE artikleid, oli aktiivne Postimehe arvamuslugude kirjutaja ning ühe viimase aja suurema tööna kogus kokku Lõuna-Eesti piirkonna põllumajanduse edendajate elulood.

Akadeemilise Põllumajanduse Seltsi liige oli Endel 1990. aastast, samal ajal jäi ta ka tervislikel põhjustel pensionile. Eesti Maaülikooli emeriitdotsent oli ta 2008. aastast. Nooruslikku särtsu aitas tal aastakümnete jooksul sees hoida osalemine EPA Meeste Turnimise Seltsis. Kodutalu taastamist ei võtnud Endel enam ette, sest selle tagastamise ajaks oli ta juba liialt eakas, kuid hobiaednikuna tegutses ta Eerikal peenramaal kuni viimase ajani.

Kolleegid ja paljud õpilased jäävad mälestama suurepärast õppejõudu, teadlast ja kirjameest Endlit. Olgu Eestimaa muld sulle kerge.

Mullateaduse õppetooli nimel Endli õpilane
Enn Leedu.

VALVE JAAGUS – 100

15. detsembril 2020. a möödub 100 aastat Eesti ühe pikaaegsema ja tulemuslikuma sordiaretaja Valve (Aamisepp) Jaaguse sünnist. Sündis ta Jõgeval tuntud sordiaretaja Julius Aamisepa peres, kus kasvas lisaks Valvele üles veel kaks tulevast põllumajandusteadlast. Vanemast vennast, põllumajandusdoktor Ants Aamisepast (s 1918) sai Rootsi Põllumajandusülikooli dotsent, nooremast vennast, põllumajanduskandidaat Ilmar Aamisepast (s 1927) aga kauaaegne Eesti põllumajandusministri esimene asetäitja ja aastatel 1984–1988 Eesti Maaviljeluse ja Maaparanduse Teadusliku Uurimise Instituudi direktor.

Valve Jaagus lõpetas Jõgeva 6-kl algkooli (1935), Tartu Eesti Noorsoo Kasvatuse Seltsi Tütarlaste Gümnaasiumi (1941), Kehtna Aiandusinstituudi (1944, *cum laude*) ja Eesti Põllumajanduse Akadeemia kaugõppeteaduskonna agronoomia erialal (1956).

Valve isa, Julius Aamisepp, oli laialdaste teaduslike huvidega teadlane. Tema põhitööks Jõgeva Sordiaretusjaamas oli kartuli, juur- ja kaunviljade sordiaretus. Tööst vabal ajal huvitus aga ka köögiviljade ning isegi viljapuude ja marjakultuuride sordiaretusest. Sellesse töösse oli Valve Jaagus kaasatud juba lapseeas. Isa on vormistanud teda kaasautoriks aedhernesortidele N 10/3b (vormistatud 1935. a) ja Jõgeva varane 22 (1936. a). Marjakultuuride aretuses saavutati edu karusmarja ja mustsõstraga. Esimesel on tootmises levikut omanud sort 'Aamisepa viljakas', teisel sort 'Anneke'. Mõlema aretajateks on märgitud samuti isa koos tütrega.

Iseseisva aretajana alustas Valve Jaagus tööd Jõgeva Sordiaretusjaama köögiviljade töögrupis kohe pärast Kehtna Aiandusinstituudi lõpetamist 1944. a. Juba 1945. a nimetati ta vanemteaduriks, millisel ametikohal töötas 50 aastat, sh 29 aastat köögiviljade aretusgrupi juhina. Selle aja jooksul jõudis ta tegeleda seitsme köögiviljaliigi sordiaretusega, peatähelepanu seejuures aedhernel ja tomatil. Tema või tema osalusel on jõudnud riiklikku katsetusse 27 köögiviljasorti, millest 18 on tootmises kasutusel käesolevalgi ajal. Need on aedherned 'Aamisepp' (aretatud koos J. Aamisepaga), 'Looming' (V. Jaagus), 'Erme' (koos M. Raudsepingu ja K. Kasega), 'Valma' (koos M. Raudsepinguga), 'Herko' (koos M. Raudsepinguga); valge peakapsas 'Jõgeva' (koos R. Tamme ja M. Liiasega); söögiporgand 'Jõgeva Nantes' (koos R. Tamme ja M. Liiasega); redis 'Jõgeva 169' (koos R. Tamme ja M. Liiasega), söögisibul 'Jõgeva 3' (koos J. Aamisepaga); aeduba 'Vaia' (koos M. Raudsepinguga); tomat 'Koit' (V. Jaagus), 'Visa' F1 (koos L. Kase, K. Kase ja I. Ojaga), 'Erk' (koos M. Raudsepingu ja K. Kasega), 'Mato' (koos K. Kase ja P. Sooväljaga), 'Vilja' (koos M. Raudsepinguga), 'Terma' (koos M. Raudsepinguga), 'Valve' (koos M. Raudsepingu ja K. Kasega) ning 'Maike' (koos M. Raudsepingu ja K. Kasega). Ajal mil Eesti kuulus Nõukogude Liidu koosseisu olid Valve Jaaguse osalusel aretatud aedherne, redise ja tomatisordid rajoonitud paljudes impeeriumi kliimapiirkondades. Suurima levikuga nendest oli aedhernesort 'Tasuja' (sün. 'Ovostsnoi 76'), mis oli rajoonitud 34 piirkonnas (üldse oli piirkondi 35).

Sordiaretuse kõrvalt uuris Valve Jaagus köögiviljade ja maitsetaimede kasvatamise agrotehnikat. Ulatuslikumad olid need söögisibulaga. Sellealase katsematerjali baasil valmis tal 1965. aastal edukalt kaitstud kandidaadiväitekiri teemal "Agrotehnilisi aluseid söögisibula 'Peipsi-äärne' agroökotüübi kasvatamiseks" ning valmis raamat "Söögisibul" (Tallinn, 1968, 64 lk). Ta on "Köögiviljanduse käsiraamatu" (Tln, 1964, 372 lk) autoreid. Kokku on trükis avaldanud 135 tööd. Eriala tunnustatud asjatundjana oli ta oodatud esineja teaduskonverentsidel, õppepäevadel ja aiandusseltsi üritustel. Aastatel 1977–1984 täitis ta EPA-s õppeülesannet: pidas üliõpilastele 12-tunniseid loenguid köögiviljade sordiaretuse alal. Tema juhendamisel on valminud üks doktoritöö (M. Raudseping, kaitstud 1994). Kutsetöö kõrvalt oli ta pikka aega Eesti Aianduse ja Mesinduse Seltsi Jõgeva osakonna juhatuse liige, valitud ka nimetatud seltsi teeneliseks liikmeks (1980) ja auliikmeks (1985). Ta on olnud paljude aiandus- ja kodundusnäituste korraldaja ja ise neil ka aktiivne osaleja. Kohalikus klubis lavastas näidendeid, osales isetegevusliku näitlejana. Tegi mitme tasandi omavalitsusorganites rahvasaadiku ja rahvakohtuniku kaasistuja ühiskondlikku tööd.

Kõige muu kõrvalt jätkus Valve Jaagusel aega ja entusiasmi tegeleda ilutaimedega. Tal oli kaks lemmiklille: aediirised ja nartsissid. Mõlemast liigist olid tal koduaias tähelepanuväärsed sordikollektsioonid, mis võimaldasid korraldada mahukaid näitusi Jõgeval ja kaugemalgi. Lahke, sõbraliku inimesena jagas ta tuttavatele oma aiast ilutaimede istikuid, aidates nii kaasa ilu ja heakorra edenemisele alevikus.

Tähelepanuväärsete teadussaavutuste eest on Valve Jaagust autasustatud Üleliidulise Rahvamajanduse Saavutuste Näituse hõbe- ja pronksmedaliga, 1980. aastal omistati talle teenelise teadlase aunimetus.

Valve oli abielus liblikõieliste heintaimede sordiaretaja Mart Jaagusega (1921–2009).

Valve Jaagus suri 10. juunil 1995 aastal ning on maetud Tartus Raadi kalmistul Aamisepa perekonna matmispaigale.

Valve Jaaguse varasemaid bibliograafilisi andmeid võib leida: ajakiri "Agraarteadus" 1990, nr 4, lk 462; "Agraarteadus" 1995, nr 4 lk 502; "Eesti aianduse biograafiline leksikon", Tln, 1998, lk 40; "Eesti Põllumajandusentsüklopeedia" I köide, Tln, 1998, lk 309; "Eesti teaduse biograafiline leksikon" I köide, Tln, 2000, 435 lk; "Eesti Entsüklopeedia" 14. köide, Tln, 2000, lk 103; "Puuviljandus Eestis. Sordid ja aretajad", Tartu, 2010, lk 170–171.

Ants Bender

PROFESSOR, AKADEEMIK LOIT REINTAMI NIMELINE PINK

4. juulil 2020. aastal toimus Loit Reintami nimelise pingi avamine tema kodukohas endise Kernu valla rahvamaja juures olevas pargis.

12. novembril 2019. a möödus 90 aastat Loit Reintami sünnist ja 17. jaanuaril 2020. a 10 aastat tema surmast.

Loit Reintam astus TRÜ põllumajandusteaduskonda 1949. a ja jätkas 1951. a õpinguid vastavatud EPA agronoomiateaduskonnas ning lõpetas selle 1954. a õpetatud agronoomina kiitusega. Pärast lühiajalist agronoomina töötamist astus ta samal aastal aspirantuuri mullateaduse erialal. 1960. a kaitses Loit kandidaadi kraadi, 1973. a doktorikraadi, 1989. a on ta teeneline teadlane ja 1990. a akadeemik. Üle 50 aasta Loidi elust möödus aktiivse, viljaka ning sisutiheda teadusliku, pedagoogilise, administratiivse ja ühiskondliku tegevusega. Loit oli osalejaks-esinejaks-organisaatoriks ligi 350 teaduskonverentsil Eestis, endistes NSV Liidu piirkondades ja teistes riikides üle maailma. Trükis jõudis ta ilmutada ca 600 kirjatööd ja toimetada ligi 50 kogumikku, populaarteaduslike loengutega jõudis ta esineda üle 2000 korra. Oponendi-eksperdi hinnanguid andis Loit ca 700 doktori- ja kandidaadiväitekirjale. Mullateadust ja ökoloogiat õpetas ta Eesti Põllumajanduse Akadeemias ja selle järeltulijas EPMÜ-s kuni 1999. aastani, lisaks TRÜ-s aastatel 1958–1993 ja Juhtimise Kõrgemas Koolis 1986–1992. aastani. Õppetööd tegi ta kokku 100 semestri jooksul ja tema loengutelt on läbi käinud mitu tuhat tudengit, nende hulgas ligi pooled APS-i liikmetest.

Oma elu viimastel aastatel pensionipõlves hooldas Loit oma isakodu Mälivere talu Harjumaal Kernu vallas ja oli aktiivseks osalejaks koduvalla tegemistes.

Tänutäheks organiseeris pikaaegne Kernu vallavanem ja tema kunagine õpilane Enn Karu Loit Reintami nimelise tahvliga pingi. Pingi avamine lükkus Covid-19 tõttu 2020. a juuli algusse ja jäi kehtivate kogunemise piirangute ning vihmase ilma tõttu suhteliselt tagasihoidlikuks.

Enn Leedu,
Loit Reintami aspirant aastatel 1970–1973

35 AASTAT DOTSENT HARRY MAURINGU LAHKUMISEST

Harry Mauring (6.09.1914–25.11.1985) lõpetas Tartu Ülikooli Põllumajandusteaduskonna 1939. aastal õpetatud agronoomina ning asus tööle assistendina samas teaduskonnas. Pärast magistrieksamite sooritamist ja magistritöö koostamist omistati 1942. aastal talle agronoomiateaduse magistrikraad.

Aastatel 1942–1944 oli Harry Mauring Vasula Kodumajanduskooli juhataja. 1944. aastal asus ta tööle Tartu Riikliku Ülikooli Põllumajandusteaduskonnas assistendina, hiljem töötas samas teaduskonnas veisekasvatuse ja hobusekasvatuse kateedri vanemõpetajana.

Eesti Põllumajanduse Akadeemia moodustamisel 1951. aastal asus Harry Mauring tööle vanemõpetajana EPA Zootehnikateaduskonna eriloomakasvatuse kateedris (juhataja dots C. Ruus) ja töötas nimetatud ametikohal 1958. aastani. 1958. aastal valiti ta dotsendi kt-ks ning 1959. aastal dotsendiks.

Harry Mauring õpetas algul lambakasvatust, hiljem põllumajandusloomade söötmist ja aretust, hobuse- ning veisekasvatust. Ta on avaldanud töid peamiselt hobusekasvatuse alal, kuid ka veise-, sea- ja karusloomakasvatuses, samuti põllumajandusloomade söötmisest.

1957. aastal kaitses ta põllumajandusteaduste kandidaadikraadi teemal "Hobuste kasutamine töödel ja sobiv põllumajandusliku hobuse tüüp Eesti NSV-s". Harry Mauring osales mitme põllumajandusloomade pidamisega ja aretusega seotu käsiraamatu/õpiku koostamisel. Õpikus "Loomakasvatuse alused" kirjutas ta peatükid: põllumajandusloomade kehaehitus ning hobusekasvatus.

Tema hing kuulus hobusekasvatusele, uurimistööle ja õpetamisele. 1960. aastal oli ta käsiraamatu "Hobuste pidamine ja kasutamine" kaasautor, 1982. aastal ilmus tema sulest õpik "Hobusekasvatus ja ratsasport".

Harry Mauring oli ASPS-i aktiivne liige.

Mäletan Harry Mauringut kui soliidset ja sõbralikku kolleegi, kes pidas lugu heast huumorist ning seltskonnaüritustel võttis alati laulu üles. Siiani on meeles tema soov, kui olime põllumajandusloomade aretuse kateedri kolleegidega EPA bussiga tagasiteel Väike-Maarja kolhoosist Tartusse, et me seltskonnas ei unustaks laulu üles võtta…

Harry Mauringu õppejõutee lõpetati varem, kui ta ise oleks seda soovinud… Läks mööda paar aastat, ja me saatsime ta ära lõplikult…

Anne Lüpsik
Harry Mauringu õpilane ja hilisem kolleeg

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THESIS DEFENDERS ESTONIAN UNIVERSITY OF LIFE SCIENCES IN 2020

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