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POTATO YIELD FORECAST BY USING GUTTATION TEST METHOD IN HOUSEHOLD LABORATORY CONDITIONS

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ABSTRACT. This paper aims to present the use of the guttation test method to establish the relationship between guttation and potato (*Solanum tuberosum* L.) yield. The laboratory tests (*in vitro* L.) under household conditions were carried out. To assess the state of the potato (variety 'Ando') yield the field (0.07 ha) of the family farm "Miili" were used. Assessment of the state of guttation plant barley (*Hordeum vulgaris* L.) variety 'Anni' by using of hydro-thermostat in conditions adapted hose hold laboratory (according to the generally known a bad epidemiological situation) were carried out. The test sites were located on a light sandy loam of Molli-Calcaric Cambisol (WRB) with areas of the field in the presence of soil samples No. 1 and 2. We have found that the maximum yield of potato 'Ando' on a plot of soil sample No. 1 (15 900 kg ha^{-1} or 1.00 of relative units) was obtained. At the same time, the minimum yield of soil sample No. 2 of the potato tubers was 3900 kg ha^{-1} (0.25 of relative units). To ranking score of the soil fertility level of the studied potato field, additional laboratory experiments were carried out, with extremely humus-rich soil (the guttation droplet imprint on the filter paper was 117.6 mm^2 to that was equated to 1.00 of relative units) and with sand the guttation droplet imprint – 37.0 mm^2 and 0.31 of relative units, respectively. The results of laboratory tests by using of guttation method with barley (variety 'Anni') carried out. The soil samples have been taken from the same areas of the field. In this case, for soil sample No. 1 the average area of the guttation droplet imprint on the filter paper was 55.1 mm^2 to that was equated to 0.47 of relative units and for soil sample No. 2 – 42.9 mm^2 or 0.36 of relative units, respectively. The results of the research have shown that concerning cultivating potatoes (variety 'Ando') and guttation experiments with barley (variety 'Anni') under conditions of soil samples No. 1 and 2 of the potato field a quite reliable relationship between guttation and the yield of potato tubers ($P < 0.001$, $R^2 = 0.98$) was obtained. To assess the different levels of soil fertility for soil samples No. 1 and 2 in the potato field taking as a reference soil with the highest possible fertility (humus-rich soil) and with the lowest possible fertility (clean sand) it was revealed that guttation of soil sample No. 1 of the potato field was 1.6 times inferior according to the results of guttation of the humus-rich soil. Analytical calculations have shown that if we are dealing with a humus-rich soil where potato 'Ando' cultivation would be carried out under the conditions of classical organic farming then the yield of potato tubers would be 22 880 kg ha^{-1} or 30 Mg ha^{-1} rounded. The novelty of our research was the development of a method for assessing the yield of potato by using the guttation test method.

Introduction

It is known that plants are capable of secret guttation fluid only under certain conditions of temperature and relative air humidity (Reppo, 1980). Moreover, not every plant has the inherent ability of guttation. It has been established that taking into account crops only cereal plants have this ability (Goatley, Lewis, 1966; Joachimsmeier, 2011). Unfortunately so far this ability has received too little attention.

One of the main problems is to forecast the yield of the crops (Caldeira *et al.*, 2016). Despite the modern and high level of agriculture, it is very difficult to predict what the upcoming yield will be given the variability of weather conditions (Meng *et al.*, 2017; Saue, Kadaja, 2010). As for potatoes, this crop is considered the most sensitive to soil conditions as well as to the variability of weather conditions in particular.

The guttation method eliminates this drawback since in this case; the soil-plant system functions under conditions of constant air temperature and at optimal soil water content (Jauneau *et al.*, 2020). So climate variability does not count here. Provided that all other conditions such as soil fertility its density and water content are the same as in the field. Moreover, it is natural that these conditions should be optimal.

Referencing the authors (Joachimsmeier, 2011; Singh, Singh., 2013; Singh, 2014), it is noteworthy to note that the guttation method is efficient and was first described in detail back in 1676 by Abraham Munting (Ivanoff, 1963) already. Having such a rich experience in using the guttation method, a justified question arises why this method has not yet found wide application. It seems to us that apparently, this method requires special conditions in a well-equipped laboratory. On the contrary, using the example of this work, we can show that for this it is enough to have any suitable closed container where it will be possible to place any small containers with water and a couple of cylinders with soil where the germinated seeds of grain crops will be introduced. If at the same time it is possible to maintain a constant air temperature in this closed container, which will be different for different crops, then after 52 hours you can begin to collect guttation liquid from plant sprouts. It seems to us that this method is so simple that it can be used by any farmer.

Having already rich experience in the application of the guttation method, we have the right to confirm that using this method, the water constants (Reppo, 1981) of the soil (field capacity (FC) including) can be determined. It is also possible to use this method to determine the level and disposition of the negative impact of heavy agricultural machinery on the soil (Reppo, Nugis, 1983; Kuht, Reintam, 2001; Nugis *et al.*, 2020).

Since, according to the logic of the test crops, they also respond synchronously (through guttation) to soil fertility if certain crops also react to this, then the logical consequence is the forecast of the yield using the guttation method. The purpose of this first-time research on the example of potato cultivation was conducted.

Methods

The studies were carried out in the Lääne-Harju Community quite near of Klooga (N59° 19'; E24° 15') since 2020 on the land use of private family farm 'Miili'. To solve these subjects a specialized test site on an area of 0.07 hectares was organized. Display (by ArcGIS-online) of orthophoto shown in Fig. 1.

Assessment of the state of plant for guttation (spring barley variety 'Anni') by using of hydro-thermostat in conditions adapted hose hold laboratory (according to the generally known a bad epidemiological situation) were carried out. The test sites on a light sandy loam of Molli-Calcaric Cambisol (WRB) were located. For comparison, soil samples No. 1 and 2 within the same potato field were taken. Since it was impossible to determine the level of fertility for soil samples No. 1 and 2 under the conditions of a household, the laboratory tests on guttation with rich humus and cleanly sand were carried out.

In experiments *in vitro,* an old electric stove oven was used as a hydro-thermostat, the container of which was filled with 8 small plastic boxes (1012.5 cm^3 of one box) which also filled with water so that most of the oven would be occupied by these boxes. To provide a constant temperature in such a sealed oven and at the same time to provide the maximum relative humidity of the air, an additional heater with a fan was used. Warm fan air directed towards the oven door kept and in this result the temperature inside the oven constant at 21 °C. According to our preceding investigations in the laboratory of the Estonian Crop Research Institute, the temperature at box TPS-3 as hydro-thermostat was 23 °C (Nugis, Kuht, 2013).

In the same thermostat and under the same conditions of heat and relative air humidity (more than 90%), germination of seeds of barley of the 'Anni' variety was carried out. For this is needed 24 hours only. Germinated (*in vitro L.*) seeds 5 pieces per cylinder (geometric parameters of the cylinder are 270 cm^3 in volume; 6.4 cm in diameter and 8.4 cm in height) were according to the patent (Nugis, Kuht, 2013) to put in the soil of the cylinder which was then placed in a hydro-thermostat.

After 52 hours of keeping the cylinders in the hydro-thermostat, barley sprouts with an average length of 3 cm appeared on which droplets of water appeared. These droplets were collected (after every 3 hours) using dry filter paper pretreated in a 5% solution of copper sulfate. Thanks to this, an imprint or a blot of this droplet appeared on the filter paper. After the process of drying the guttate on filter papers, they were scanned. The scanned imprints were processed on a computer using Foxit Reader.

Previously, soil samples were taken from a potato field after harvesting potatoes, variety 'Ando'. Concerning experiments of guttation soil samples marked with crosses (Fig. 1) five replicates from a potato field with two contrasting soil samples No. 1 and 2 were taken.

The cylinders in which there was soil with the above soil samples (for differing treatment I and treatment II) and where guttational barley plants were grown have had a volume of 271 cm^3. The water content % (kg kg^{-1}) and bulk density (Mg m^{-3}) of the soil was also determined by the above-mentioned cylinders. Wherein, one cylinder was with humus-rich soil (III treatment) where the germinated seeds of 'Anni' barley were to put in soil, and the second – to put in clean sand (IV treatment). Everything else was done in the same way as described above.

Concerning the above, the guttation experiments in three replicates were carried out.

The obtained indicators were used in the implementation of a guttation method, as well as the peculiarities of the young sprout of barley and ways of their discharge of guttation fluid. This was the first time it was implemented in household's conditions.

The statistical estimation of data of the areas of a splotch of the guttation fluid and corresponding yield of potato tubers has been carrying out by Student T-test at 0.05 levels. The least significant difference (LSD) test as of right was used. In addition, the correlation coefficient (r) was calculated through the coefficient of determination (R^2) taking from it the square root.

Figure 1. Orthophoto of test site of a potato field in the private family farm "Miili", borough town Klooga, Lääne-Harju Community

Note: the signs on the orthophoto show the location of soil sample No. 1 and guttation treatment I in the potato field after harvesting the potatoes (variety 'Ando') and at the other end part of the field the soil sample No. 2 and guttation treatment II. (concerning more and less fertile soil, it was an initial valuation only).

Results

As a result of our investigations it was found that after harvesting of potato tubers in the soil sample No. 1 (I treatment) the yield on average was 14 150 ± 800 kg ha^{-1} or 0.89 relative units (highest yield was 15 900 kg ha^{-1} or 1.00 relative units) and on the less fertility part (II treatment) of the field − 6200 ± 1000 kg ha^{-1} or 0.39 relative units (smallest yield was 3900 kg ha^{-1} or 0.25 relative units). As for the area of an imprint of the guttation droplet on the filter paper, these indicators had average values for soil sample No. 1 − 55.1± 3 mm^2 (or 0.47 relative units) and for soil sample No. 2 − 42,9 ± 4,8 mm^2 (or 0.36 relative units), respectively. With all three replications taking into account the growth and development of barley sprouts (variety 'Anni') it was possible to collect water droplets on the barley sprouts only for one and a half days. If the barley sprouts could continue to grow then the plant roots would reach the bottom of the cylinder and after that, the data of the above-mentioned droplets would have already distorted values. How the relationship between the value of the relative area on the filter paper of the guttation droplet and the potato yield looks can be seen in Fig. 2.

Concerning water content (WC) and bulk density (BD) related above mentioned treatments they are: I treatment WC = 24.4 ± 1.0% (kg kg^{-1}), BD = 1.07 ± 0.04Mg m^{-3}, II treatment WC = 19.8 ± 1.1% (kg kg^{-1}), BD = 1.12 ± 0.05 Mg m^{-3}. At the same time we have had for humus-rich soil (III treatment) WC = 20.5 ± 1.4% (kg kg^{-1}), BD = 0.92 ± 0.06Mg m^{-3} and for clean sand (IV treatment) − WC = 19.2± 1.3% (kg kg^{-1}), BD =1.16 ± 0.03Mg m^{-3}, respectively.

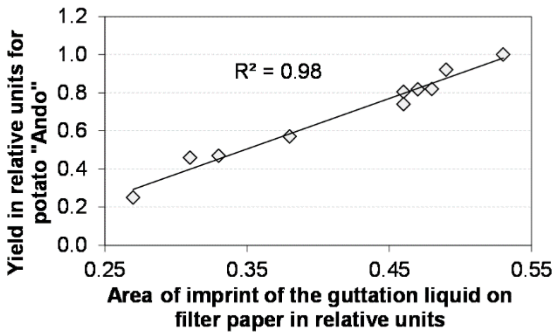

Figure 2. Relationship between the area of the imprint of guttation liquid (in relative units) and yield of potato 'Ando' (P <0.001, R^2 = 0.98).Note: concerning yield of potato for soil sample No. 1 soil LSD_{05} = 2 530 kg ha^{-1} (0.16 relative units) and for soil sample No. 2 LSD_{05} = 3170 kg ha^{-1} (0.20 relative units). At the same time concerning the area of the imprint of guttation liquid on filter paper LSD_{05} = 2 mm^2 (0.03 relative units)

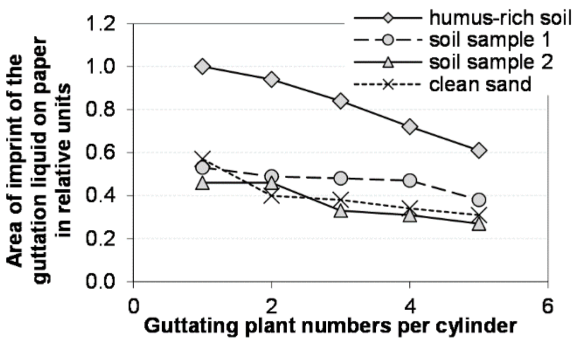

Figure 3. Results of comparing soil sample 1 (treatment I) and soil sample 2 (treatment II) of a potato field with the extreme level of fertility, i.e. humus-rich soil (treatment III) and clean sand (treatment IV)
Note: concerning area of imprint of guttation liquid on filter paper for humus-reach soil LSD_{05} = 73.5 mm^2 (0.63 relative units), but for clean sand − LSD_{05} = 22.1 mm^2 (0.19 relative units)

According to the above task, in connection to compare the degree of soil fertility of parts of a potato field with extreme levels of fertility (humus-rich soil and clean sand); the results are shown in Fig. 3. It can be seen from this figure that the highest value of the guttation droplet imprint on the filter paper was in the humus-rich soil which was equal to 117.6 ± 30.0 mm^2 or 1.00 relative units (average 89.1 ± 3.2 mm^2 or 0.76 relative units), while for pure sand, on the contrary, it was 37± 9 mm^2 or 0.31 relative units (but average 47.1 ± 5.2 mm^2 or 0.40 relative units).

Discussion

When considering the method of gutting the main problem until now was not the yield of this plant, but the description of the process of releasing a droplet of water under certain conditions by this plant (Eaton, 1943; Ivanoff, 1963). In this regard, there are various studies (Takeda *et al.*, 1991; Hughes, Brimblecombe, 1994; Joachimsmeier *et al.*, 2011) on how many guttation droplets are emitted by a plant, while guttation is closely correlated with temperature and humidity. Also, the study of guttation after the germination of spring wheat in dense soil (over 1.4 Mg m^{-3}) showed somewhat lower assimilation of water from the soil. This was revealed in the lower percentage of guttation water that was pressed out of hydathodes by the root pressure of plants (Nugis, 2017; Kuht, Reintam, 2001).

We could thus reach the depths of the xylem structure which is the vascular tissue of the plant that conducts water and dissolved nutrients up from the root to the end of the plant sprout (Komarnytsky *et al.*, 2000). If we go even deeper into the problem of guttation then it is known that the xylem plays a double role (Fisher *et al.*, 1997) providing 1) the gradient of the water potential (transpiration); 2) gradient of osmotic potential (root pressure of the fluid). In this case, this work would have a completely different purpose. Be that as it may, but we decided to use a simple method to determine the relationship between the guttation of the test culture and the potato yield. The fact that such a result was obtained (Fig. 2) and such a close rectilinear relationship (P <0.001, R^2 = 0.98), we could not even expect. It can be emphasized here that a large difference in the natural fertility of the soil of the potato field played a certain role here. The natural fertility of the soil of this potato field was formed as a result of the 4-year rest of the field under black fallow. Weed control was the only challenge to keep the black fallow. However, about the marginal part of the potato field (Fig. 1 and 3), as a result of long-standing reclamation work, a large amount of gravel was carried out to the surface where even weeds did not want to grow. Therefore, the soil of this part of the field, as shown by the results of experiments on guttation. It differs little in fertility from clean sand (Fig. 3).

The next problem for us was how to assess the level of soil fertility in a potato field. Since it is known that everything is cognized in comparison it seems to us that in practice the chosen method has fully justified itself in this (Fig. 3). As can be seen from this figure that such part of the soil of the potato field which was soil sample No. 1 (treatment I) is 1.6 times inferior to the humus-rich soil (treatment III) according to the results of guttation which can be compared with chernozem. The fact that single sprouts of 'Anni' barly numbered in the order of decreasing area of the imprint of a droplet of water on filter paper (Fig. 3) vary relatively more in humus-rich soil (treatment III) than in soil sample No. 1 (treatment I) soil of a potato field which is apparently due to the quality of the seed, which was impossible foresee.

As for the results obtained in relative units, we took as the basis for the potato yield its maximum value of 15 900 kg ha^{-1}, which was equated to one. All other yield data were individually divided by 15 900 and thus a corresponding numerical series of indicators in relative units was obtained. The same was done with the data of guttation where the largest area of the imprint of a droplet of guttation liquid on filter paper was taken 117.6 mm^2 or 1.00 as a relative unit. This largest area of the imprint belonged to humus-rich soil about which all other data on the areas of the imprints of a droplet of guttation liquid on filter paper for experimental treatments I, II, III and IV were calculated (Fig. 2 and 3).

Approaching our main goal which is associated with the forecast of the potato (variety 'Ando') yield if it were cultivated on a highly humus-rich soil then this can be done analytically by calculating through a simple ratio between the above-average indicators of guttation results in mm^2 and the average yield of potato tubers in a field with soil sample (No. 1) then if 14 150 kg ha^{-1} * 89.1 mm^2 / 55.1 mm^2 = 22 880 kg ha^{-1} which would be the logical result. If this figure is rounded up to 30 Mg ha^{-1}, then taking into account the fact that if we are dealing only with black fallow where potato cultivation will be carried out without the introduction of mineral and organic fertilizers then with such classic organic farming. Finally, we can ultimately consider that this hypothetical yield of potato is a very real result.

Conclusions

The results of our research have shown that the guttation method is an economical, cheap and efficient method for predicting potato yield. These studies have shown that taking into account the existing epidemiological situation it is quite feasible to carry out the necessary laboratory experiments in household laboratory conditions. On the example of the cultivation of potatoes (variety 'Ando') and guttation experiments with barley (variety 'Anni') in conditions of soil samples No. 1 and 2 parts of the potato field as a result of laboratory and field experiments a completely reliable ($P < 0.001$, $R^2 = 0.98$) relationship between guttation and the yield of potato tubers was obtained.

To assess the different levels of soil fertility in the potato field taking as a reference soil with the highest possible fertility (humus-rich soil) and with the lowest possible fertility (clean sand) it was revealed that guttation of soil sample No. 1 was 1.6 times inferior according to the results of guttation of the humus-rich soil which can be identified with chernozem. The corresponding analytical calculations showed that if with black fallow we were dealing with humus-rich soil where potato cultivation would be carried out without the introduction of mineral and organic fertilizers which would naturally correspond to the conditions of classical organic farming then the yield of potato tubers is about 22 880 kg ha^{-1} or roughly 30 Mg ha^{-1} which is a probable entirely a real result.

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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

EN − 40%, JK − 40%, AK − 20% − study of the concept and design;
EN − 60%, JK − 20%, AK − 20% − data collection;
EN − 40%, JK − 30%, AK − 30% − analysis and interpretation of data;
EN − 60%, JK − 30%, AK − 10% − writing a manuscript;
EN − 30%, JK − 40%, AK − 30% − critical revision and approval of the final manuscript.

References

Caldeira, J.F., Moura, G.V., Santos, A.P. 2016. Predicting the yield curve using forecast combination. – Computational Statistics & Data Analysis, 100:79−98. DOI: 10.1016/j.csda.2014.05.008.

Goatley, J.L., Lewis, R.W. 1966. Composition of guttation fluid from rye, wheat, and barley seedlings. − Plant Physiology, 41:373−375.

Eaton, F.M. 1943. The osmotic and vitalistic interpretations of exudation. − American Journal of Botany, 30:663−674.

Fisher, J.B., Angeles, G., Ewers, F.W., López-Portillo, J. 1997. Survey of root pressure in tropical vines and woody species.− International Journal of Plant Sciences, 158(1):44−50. DOI: 10.1086/297412

Hughes, R.N., Brimblecombe, P. 1994. Dew and guttation: formation and environmental significance. − Agricultural and Forest Meteorology, 67(3−4):173−190. DOI: 10.1016/0168-1923(94)90002-7

Ivanoff, S.S. 1963. Guttation injuries of plants. − The Botanical Review, 29:202−229.

Jauneau, A., Cerutti, A., Auriac, M.-C., Noël, L.D. 2020. Anatomy of leaf apical hydathodes in four monocotyledon plants of economic and academic relevance. – PLoS ONE, 15(9):e0232566. DOI: 10.1371/journal.pone.0232566

Joachimsmeier, I., Pistorius, J., Heimbach, U., Schenke, D., Kirchner, W., Zwerger, P. 2011.

Frequency and intensity of guttation events in different crops in Germany. − 11th International Symposium of the ICP-BR Bee Protection Group, Wageningen (The Netherlands), November 2−4, pp. 87−90. DOI: 10.5073/jka.2012.437.020

Komarnytsky, S., Borisjuk, N.V., Borisjuk, L.G., Alam, M.Z., Raskin, I. 2000. Production of recombinant proteins tobacco guttation fluid. − Plant Physiology, 124(3):927−933. DOI: 10.1104/pp.124.3.927

Kuht, J., Reintam, E. 2001. The impact of deep rooted plant growth on the qualities of compacted soils. – Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting, May 24–29, 1999, West Lafayette, Indiana, USA, pp. 632–636.

Meng, T., Carev, R., Florkowski, W.J., Klepacka, A. 2017. Analyzing temperature and precipitation influences on yield distributions of canola and spring wheat in Saskatchewan. − Journal of Applied Meteorology and Climate, 56:897–913. DOI: 10.1175/JAMC-D-16-0258.1

Nugis, E. 2017. Determination of the level of soil compaction by method of gutta-diagnostical indication. − Journal of Agriculture and Environment, 1(1):23–28.

Nugis, E., Tamm, K., Võsa, T., Plakk, T., Palge, V. 2020. Express-diagnostics method for assessment of soil compaction for different cultivation methods. − Agraarteadus, 1(31):53−65. DOI: 10.15159/jas.20.04.

Nugis, E., Kuht, J. 2013. Method for assessment of soil physical properties by means of guttated plant. Patent nr 05682 B1 (EE). − https://www1.epa.ee/patent/kirjeldus/05682.pdf Accessed on 10/05/2021.

Reppo, E. 1981. Patent nr 866471 (SU). Metoda okreslenia granicznego, dopuszalnego zageszczenia gleba automorficznych dla roslin wskaznikowych zwlaszczajeczmienia. − Biuletyn Informacyjny, 35.

Reppo, E. 1980. Ocenka vlazhnosti avtomorfnyh pochv Jestonii. [Assessment of humidity of the Estonian automorphic soils]. − In Collection of Theoretical bases and methods for determination of optimum soil properties parameters. − Docuchaiev’s Soil Research Institute, Moscow, 99−104. (in Russian)

Reppo, E., Nugis, E. 1983. Soil productive capability determination method. Patent nr 1018013 A1 (SU) – https://ee.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=1&ND=3&adjacent=true&locale=ee_EE&FT=D&date=19830515&CC=SU&NR=1018013A1&KC=A1# Accessed on 10/05/2021.

Saue, T., Kadaja, J. 2010. Simulated potato crop yield – an indicator of climate variability in Estonia. − In Climate Change and Variability (Ed. S. Simard). IntechOpen, pp. 365−388.

Singh, S., Singh, T.N. 2013. Guttation 1: chemistry, crop husbandry and molecular farming. − Phytochemistry Reviews, 12:147–172. DOI: 10.1007/s11101-012-9269-x.

Singh, S. 2014. Guttation: New insights into agricultural implications. – Advances in Agronomy, 128:97–135. DOI: 10.1016/B978-0-12-802139-2.00003-2

Takeda, F., Wisniewski, M.E., Glenn, D.M. 1991. Occlusion of water pores prevents guttation in older strawberry leaves. − Journal of the American Society for Horticultural Science, 116(6):1122−1125. DOI: 10.21273/JASHS.116.6.1122