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MINI-REVIEW: THE ROLE OF CROP ROTATION, INTERCROPPING, SOWING DATES AND INCREASED CROP DENSITY TOWARDS A SUSTAINABLE CROP AND WEED MANAGEMENT IN ARABLE CROPS

Panagiotis Kanatas

Agricultural Cooperative of Mesolonghi-Nafpaktia, 30200 Mesolonghi, Greece

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Vastutav autor: Corresponding author: Panagiotis Kanatas
E-mail: pakanatas@gmail.com

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ABSTRACT. The extended and in many cases unjustified use of herbicides has resulted in herbicide resistance development and serious environmental concerns. Therefore, the need for implementation and wider adoption of several agronomic and cultural practices is imperative. Ecologically-based crop management practices like crop rotation, intercropping, delay of sowing date and increased crop density can be also the basis for effective and sustainable weed management. In the present review, several cases are presented and the key points of each method are discussed. Special attention is given to the fact that the efficacy of each practice is depended on the specific soil and climatic conditions along with the field history of each site and crop. Alternative methods of weed management should be further studied and optimized to include them in both organic and conventional production systems and ensure the sustainability of agroecosystems.

Introduction

Among the different biotic factors negatively affecting crop yield in field crops, weeds are considered to be the most important ones (Oerke, 2006; Kanatas *et al.*, 2020[a]). Chemical control remains the "king" of weed management, however, the various negative effects make necessary the need for the development of alternative methods and strategies (Jabran *et al.*, 2017). Consequently, ecologically-based strategies for weed management are necessary.

During the next years, not many new modes of actions for chemical weed control are expected. Therefore, research focuses on the improvement and potential exploitation of several agronomic and cultural practices like crop rotation, intercropping, increased crop density, delayed sowing, mulching, green manure *etc*. towards a sustainable crop and weed management (Travlos *et al.*, 2014; Weerarathne *et al.*, 2017; Weisberger *et al.*, 2019; Kanatas *et al.*, 2020[a]). Decision support systems are expected to give significant help to the farmers of the near future with the precondition not only to optimize herbicides use but also to enhance weed management tactics less reliant on herbicides (Kanatas *et al.*, 2020[b]). Moreover, weed pressure associated with climate change is a major challenge for arable crops and therefore the implementation of several sustainable methods and practices could have positive crosscutting environmental benefits and be more climate-resilient (Ramesh *et al.*, 2017).

The objective of the present review was to highlight some examples on different ecologically based weed management methods such as crop rotation, intercropping and modified sowing date and crop density in arable crops.

Crop rotation

Monoculture or even simplified crop-rotations increase weeds' repeated exposure to the same set of ecological and agronomic conditions (Weisberger *et al.*, 2019) and therefore weed management cannot be achieved in the mid- and long-term. In general, crop rotations are considered to be the basis of sustainable agriculture since they allow the field to rest, they reduce the weed and pest pressure and they enhance the soil balance and water economy. Moreover, they usually implement changes in the tillage practices and therefore several weed species are suppressed. Weed management is feasible since the growth habits and life cycles of specific weeds are disrupted by employing different planting and harvest dates (Liebman, Staver, 2001). Employing diverse crop rotations can also provide higher flexibility in choosing herbicides with different modes of action and thus reduce the risk of selecting for herbicide-resistant weed biotypes. Research conducted in western Canada indicated that, in the absence of herbicides, cutting barley for silage was very effective for reducing wild oat populations, especially when the crop was cut at an early growth stage (Harker *et al.*, 2003). Each crop rotation may have a different influence on weed flora (Simic *et al.*, 2016). In a 3-yr study conducted in Serbia, maize-soybean-wheat rotation reduced biomass of perennial and annual weeds and significantly increased maize yield in comparison to maize monoculture or other crop rotation regimes (Simic *et al.*, 2016).

Rotations in organic production systems often include winter annual crops such as rye, hairy vetch, whose maximum growth occurs before the period of low Canada thistle (*Cirsium arvense*) carbohydrates reserves (HDRA, 2006). Combining cowpea (*Vigna unguiculata*) with sudangrass (*Sorgum sudanense*) produces a large amount of diverse residue which suppresses weeds (Creamer, Baldwin, 2000; Bicksler, Masiunas, 2009).

In a 2-yr experiment conducted by Fisk *et al.* (2001), the influence of several annual cover crops on weed populations in a winter wheat-corn rotation system was studied. The density of winter annual weeds was between 41 and 78% lower following most cover crops when compared with the absence of cover crops, while dry weight was between 26 and 80% lower in all sites. There are several mechanisms responsible for the effect of cover crops on weeds.

In all cases, well-structured crop rotations can give the time and the flexibility to the growers to effectively control the important weeds (both annual and perennial) preferably using ecologically-based methods and with a certainly lower reliance on herbicide inputs. Long and justified crop rotations are very important in sustainable and ecologically based crop production systems. For instance, Anderson (2015) has found that some no-till, complex crop rotations improve nutrient cycling and soil porosity but also they can reduce or delay weed emergence, avoid yield losses and reduce invasion.

In a meta-analysis of 54 studies conducted by Weisberger *et al.* (2019), it was found that diversification of crop rotations using the addition of more crops can significantly reduce weed density (49%) and keep its high efficacy under varied environmental conditions and different crop production systems.

Intercropping

Intercropping is a system with two (or rarely more than two) crop species growing in the same field during the same cultivation period (Ofori, Stern, 1987). Intercropping can stabilize grain yield and reduce pest problems (Anil *et al.*, 1998) and globally, many organic and conventional farmers are already familiar with this practice (Entz *et al.*, 2001). Bulson *et al.* (1997) revealed that the 25% reduction of the recommended crop density for wheat and bean intercropping was more efficient than the monoculture of each crop. Another form of intercropping except a cereal together with a legume involves cover crops and promotes weed suppression (Liebman, 1986) and N supply to following crops (Thiessen Martens *et al.*, 2005).

Because the quality of cereal forage is usually lower than legumes, cereal forages (barley and oat) are often mixed with field pea and other legumes in many countries to increase protein content with no negative effect on total yield (Anil *et al.*, 1998; Chapko *et al.*, 1991; Hall, Kephart, 1991). Other benefits of these mixtures include greater use of light, higher absorption of water and nutrients and improved weed suppression (Anil *et al.*, 1998).

Additionally, using a winter cereal grain as a companion crop during legume establishment can provide a cash grain and straw (Exner, Cruse, 2001) and reduce soil erosion (Kaspar *et al.*, 2001), nitrate losses (Strock *et al.*, 2004), and weed competition (Hesterman *et al.*, 1992; Singer, Cox, 1998). Red clover is one of the best choices for winter cereal grain intercrops because it tolerates shading (Blaser *et al.*, 2006) and has similar feed value to alfalfa (Broderick *et al.*, 2001). Moreover, some potential benefits to the farming system of intercropping a legume in sunflower are nitrogen fixation, soil erosion control, and improvement of the soil structure and organic matter content (Biederbeck, Bouman, 1994). Intercropping may also improve snow trapping and green manure production during the year after the legume establishment (Lilleboe, 1991).

Furthermore, cover crops have long been used to reduce soil erosion and water runoff, reduce herbicide inputs and improve water infiltration, soil moisture retention, organic carbon and nitrogen (Teasdale, 1996; Yenish *et al.* 1996). Among the commonly used and studied cover crops there are many annual legumes such as crimson clover, hairy vetch and subterranean clover (Teasdale, Daughtry, 1993; Yenish *et al.* 1996).

According to Dhima *et al.* (2007), common vetch intercropped with cereals resulted in higher yields and profitability. Moreover, intercropping hairy vetch (*Vicia villosa*) at a specific growth stage (V4) of sunflower appears superior because it did not reduce sunflower yield, provided soil cover adding between 540 and 2400 kg ha^{-1} above-ground dry matter to the system, and increased $NO^{-}{}_{3}$–N levels at the beginning of the subsequent wheat season in several environments (Kandel *et al.*, 2000). Intercropping berseem clover (*Trifolium alexandrinum*) with cereals has increased the yield and quality of cereal forage crops in India (Singh *et al.*, 1989), increased total biomass production without reducing cereal grain yields in Mexico

(Reynolds *et al.*, 1994) and USA (Ghaffarzadeh, 1997; Holland, Brummer, 1999), and improved forage quality, reduced fertilizer needs, and increased subsequent crop yields in British Columbia (Stout *et al.*, 1997) and Iowa (Ghaffarzadeh, 1997). It has to be noted that in many cases intercropping may reduce crop yields compared to monoculture; however, land area is used more efficiently (Anil *et al.*, 1998; Pridham, Entz, 2008). This was also the case described by Szumigalski and Van Acker (2005), in which total yield of wheat and pea intercropping was similar (or lower) than the individual crops under monoculture. Legumes are also beneficial for intercropping, especially under low fertility conditions (Lunnan, 1989). Carr *et al.* (2004) revealed a significantly higher production for barley-pea intercrops in low N soils; while, the inclusion of pea had not any significant effect in rich soils. In many intercrops, modifications in canopy architecture are proposed for adequate weed management and reduction of their competitiveness (Weerarathne *et al.*, 2017).

However, it has to be noted that the potential effects of intercropping on weed control can vary according to the specific soil and climatic conditions and followed crop management practices. For instance, in an intercrop of sunflower/soybean in Argentina, it was found that richness and abundance of total, annual and perennial weeds were similar with sole crops (de la Fuente *et al.*, 2014). Therefore, the suggestion of Weerarathne *et al.* (2017) for further research on intercropping before endorsing it as an adequate alternative to herbicides seems rational. It has to be noted that such extensive research revealed that *e.g.* a higher planting density of maize in a cassava/maize intercrop can significantly reduce weed density (Muoneke, Mbah, 2007).

Sowing date, crop density and other agronomic practices

Varying seeding times can also be disadvantageous to weeds that tend to germinate at specific periods during the growing season. For example, late seeding of the crop may be an effective option with relatively early-germinating weeds such as wild oat. In the UK, a review of weed management options for organic cropping systems suggests waiting until various flushes of weeds emerge and then depleting the soil seed bank through tillage or other non- chemical methods (Bond, Grundy, 2001). A stale seedbed approach would be difficult to implement in conventional cropping systems in western Canada mainly due to the short growing season. In one study, delayed seeding resulted in a consistently high degree of control of wild oat, but also caused major losses in grain yield and quality (Hunter, 1983). In Greece, this delayed crop sowing was the basis of false and stale seedbed in barley and soybean and resulted in the satisfactory control of several kinds of grass and broadleaf weed species (Kanatas *et al.*, 2020[a,c]; Travlos *et al.*, 2020).

In a study conducted in the USA, seeding barley at relatively high rates enhanced the effects of reduced rates of tralkoxydim on wild oat control (O'Donovan *et al.*, 2001[b]). For example, there was little difference in the seed bank regardless the application of tralkoxydim at 50% or 100% of the recommended rate, with the only condition of barley sown at a rate of 175 kg ha^{-1}. However, when barley was seeded at a lower rate, much larger amounts of wild oat seed were present when the herbicide rate was reduced to 25% or 50% of the recommended rate. Other studies also indicate that herbicide activity can be improved considerably if the competitiveness of the crop is enhanced through planting competitive varieties and/or increasing the crop seeding rate. These results are in general agreement with similar studies conducted in the US (Wille *et al.*, 1998) and Europe (Christensen, 1994; Salonen, 1992).

Recommended crop seeding rates in western Canada have traditionally been based on the results of experiments conducted under relatively weed-free conditions. Several studies have shown that seeding crops at higher than recommended rates can improve competitiveness with weeds in barley (O'Donovan *et al.*, 1999). The importance of crop plant density as an IWM strategy was also evident from a study conducted in farmers' fields in Alberta (O'Donovan *et al.*, 2001[a]). Costs of barley and wheat seed tend to be low compared to the benefits associated with increasing the seeding rates (O'Donovan *et al.* 2001[b]) and that's why farmers often increase seed quantity at sowing. On the contrary, the high seed cost of herbicide-tolerant canola varieties, especially hybrids, maybe a major economic constraint to using increased canola seeding rate as an IWM strategy (O'Donovan *et al.*, 2004). It should also be taken into account that understanding the interactions between weeds, crops, crop and weed management methods and climate change is very important to avoid the expected ecological, environmental, and economic costs (Ziska, McConnell, 2016).

Conclusions

In the present study, agronomic practices like crop rotation, intercropping, delayed sowing and increased crop density were discussed and factors determining their efficacy against weeds were presented. Such practices ought to be the basis of integrated weed management systems and further studied and exploited in both organic and conventional production systems. Climate change is also something that should be taken into account and properly quantified to highlight the potential interactions between crops, weeds and management practices and ensure the overall sustainability. The frequent shift of strategy, the flexibility and the adaptation to the specific conditions of each farm and agroecosystem are crucial for the overall success and the satisfactory long-term crop and weed management in arable crops.

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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 contributed to the design and implementation of the research, to the analysis of the results and the writing of the manuscript.

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