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REVIEW: MANAGING WEED POPULATIONS THROUGH ALTERATION OF THE CROPPING PATTERN

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ABSTRACT. Alteration of the cropping pattern, such as manipulation of sowing date, increasing crop sowing rate, alteration in population density and row spacing, the use of cultivars that are more competitive and proper fertilization, particularly nitrogen application, have been the focus of many research studies. These studies aimed for the goal of boosting the crop's capacity to provide domination over weeds and surviving competitive stress. Modifications in sowing date might have tremendously influence on plants growth, but also have a prominent influence on weed infestation, crop development and yield. Changes in sowing dates are important to prevent the durations of considerable weed risks and consequently raise crop yield. High sowing rates increase the capacity of crops to overcome weeds and preserve yield loss under moderate weediness of the crop. Further, increased crop density, crop uniformity with alteration in row spacing had powerful and constant depressing outcomes on weed biomass and affirmative outcomes on biomass and yield of the crop. Competing varieties might be more efficient in the reduction of the capability of weeds throughout competitiveness for restricted sources. Finally, nutrient balance is frequently essential for crop-weed competition, and controlling the fertilizer applications in space and time might be a technique for useful weed suppression. Hence, the manipulation of certain agronomic integrated with competitive cultivar is a promising way to reduce weed interference in crops and to improve the sustainability of cropping systems through less reliance on herbicides.

Introduction

Weeds are the most severe obvious risk to sustain productive farming systems, responsible for imposing about 34% potential yield loss worldwide (Oerke, 2006). The use of herbicides is the most successful, profitable and useful system of weed control (Marwat *et al.*, 2006; Hussain *et al.*, 2008; Anwar *et al.*, 2012; Mehmeti *et al.*, 2018; Pacanoski, Mehmeti, 2018). Unfortunately, over-reliance on herbicides has led to the development of resistant weed biotypes (Moss *et al.*, 2011; Gage *et al.*, 2019; Heap, 2019), crop phytotoxicity (Begum *et al.*, 2008, El-Nahhal, Hamdona, 2017), environment pollution and public health hazard (Phuong *et al.*, 2005). The existing herbicide-founded weed control model is generally treated as unsustainable. Moreover, strict EU directives decrease the number of herbicide possibilities, and new mechanisms of action are seeming too ambitious and distant. Moreover, they increase the risk of the resistance evolvement to the remaining herbicides (Duke, 2012). Farmers are increasingly recognizing Integrated Weed Management (IWM) strategies to reinforce their weed control due to rising pressure on agriculture production from the herbicide resistance evolvement (Andrew, Storkey, 2017). Lindquist and Mortensen (1998) reported that managing weed populations throughout the modification of the cropping pattern is an important part of IWM. Several cultural practices have been investigated to increase the crop's capacity to provide an advantage concerning weeds and permanent competitive stress. This included the manipulation of sowing date (Duary, Yaduraju, 2006), increasing crop seeding rate (Chauhan, Johnson, 2011), alteration in population density (Nurse, Di Tommaso, 2005) and row spacing (Norsworthy, Oliveira, 2004), using of more competitive cultivars (Andrew, Storkey, 2017) and adequate fertilization which is particularly true for nitrogen (N) application (Blackshaw, Brandt, 2008).

Modifying sowing dates can adjust the growing season in sense of decreasing the weeds impact on crop growing, by altering the competitive superiority to the crops (Kwabiah, 2004). Berzsenyi (2000) stated that sowing date strongly relates with the preparation of the soil that has a significant effect on the weed seed dormancy and germination, whereas Williams (2006) noticed that sowing date influences crop yield losses caused by weeds. For example, delayed sowing has been reported to diminish yield losses caused by weeds in soybean (Buhler, Gunsolus, 1996) and dent maize (Gower et *al.*, 2002).

Higher sowing rate and row spacing is an important technique that facilitates crop competitive capacity about weeds (Lindquist, Mortensen, 1998; Gibson *et al.*, 2002; Chauhan, Johnson, 2011; Fahad *et al.*, 2015). Higher sowing rates promote brief canopy closure, which provides more efficiently weeds suppression. Significant decreases of relative weed density and weed biomass, as well as a significant increase of plant height, dry weight plant and seed yield of barley (O'Donovan *et al.*, 2001), wheat (Olsen *et al.*, 2005), and soybean (Place *et al.*, 2009), were recorded for the use of higher sowing rate.

For many crops, reducing row width has been found to increase the competitiveness of the crop because of an early canopy formation that results in improved yields and a reduction in the amount and frequency of herbicide use (Norsworthy, Oliveira, 2004). Murphy *et al.* (1996) observed increased corn yield and a light interception along with reduced weed biomass as row width was narrowed.

Further, diverse genotypes of the same crop acquire characteristics that may become a higher or lower competitive capacity with weeds. These characteristics are usually associated with earlier seed germination and crop plant emergence, prompt canopy development, and rapid growth in the young stages (Rasmussen, Rasmussen, 2000). Investigation of the crop capacity to suppress weeds by competition involves differences in competitive capability in cultivars and recognition of crop suppressive characteristics. This has been broadly recognized in many crops, such as wheat (Cosser *et al.*, 1997; Ogg, Seefeldt, 1999; Mason Spaner, 2006), barley (Dhima *et al.*, 2010), rice (De Vida *et al.*, 2006), and soybean (Vollmann *et al.*, 2010).

Finally, application timing and placement of N fertilizer can as well affect weed competition with crops. *Veronica hederifolia* competitive ability was greater when N was applied at the tillering than at the stem elongation stage of winter wheat (Angonin *et al.*, 1996).

Taking into account previously mentioned facts, the objective of this review is to recapitulate the existing material and to contribute for the successful weed-crop competitive interaction through modification of the cropping pattern.

Managing weeds through manipulation of sowing date

Modifications in sowing date might have tremendously influence on plants growth, but also have a prominent influence on weed infestation, crop development and yield (Hay, 1986). Changes in sowing dates are important to prevent the durations of considerable weed risks and consequently raise crop yield (Harper, 1999; Hussain *et al.*, 2017). Results of Bonis *et al.* (2010) reported that weed infestation was significantly affected by sowing date of wheat in Hungary. Spandl *et al.* (1998) detected that control of *Setaria viridis* in the spring-seeded wheat was more effective compared to fall-seeded wheat, due to the weed emergence in a single flush rather than many flushes. Delaying wheat drilling from September to the end of October decreased *A. myosuroides* populations by approximately 50% (Lutman *et al.*, 2013). As far as crop rotation is concerned, various rotations are more successful in suppressing weeds relative to simpler ones (Weisberger *et al.*, 2019). A six-year crop rotation containing lateness sowing in three years out of six caused an 87% reduction in *Avena fat* density, related to a 4% reduction in a wheat-fallow rotation only. Schoofs *et al.* (2005) found that *Avena fatua* infestations were decreased significantly by postponing sowing from early May to late May, without any crop yield consequences. Mulder and Doll (1994) reported that in row weed density decreased significantly in uncultivated treatments when corn planting was delayed from 25 April to 5 May. Delayed planting allows the corn to germinate after the peak emergence of many weed species (Regnier, Janke, 1990). Results of Rajablarijani *et al.* (2014) revealed that delayed sweet corn sowing (6 July) reduced weed dry weight by 46% (average for both years) compared with the 5 June sowing date without reducing crop yield. Similar, Williams and Lindquist (2007) reported an 80% lower weed biomass at harvest in late sown corn relative to early-sown corn. Rushing and Oliver (1998) reported a tendency for larger crop yield decrease from *Xanthium strumarium* competition in April-sowed soybean than in May or July sowings. Weed infestation is influenced by sowing time. In the study of Mubeen *et al.* (2014) higher weed infestation (51 to 59 plants m^{-2}) was noticed at late sowing compared to early sowing rice. For obtaining high yield and good kernels quality, rice sowing at the optimum time is crucial (Chauhan, Johnson, 2011). Bera *et al.* (2016) investigate four different dates of rice sowing, namely December 1^{st}, December 15^{th}, December 30^{th} and January 14^{th}. Rice sowing on December 15^{th} showed lowest weed infestation and biomass at both of the estimations, and highest per cent of productive tillers in comparison with other sowing dates. The highest grain and straw yields (5.19 and 5.65 t ha^{-1}, respectively) was collected from December 1^{st} sowing, it was narrowly succeeded by sowing at December 15^{th}. Regardless of weed control techniques, the rising tendency of weed infestation and weed dry weight were recorded with delaying of sowing date.

Jadhav (2013) noticed stunted crop growth and higher weed density as a result of delaying in sowing.

Managing weeds through alteration in population density, higher seeding rate and narrow planting pattern

High sowing rates increase the capacity of crops outcompeting weeds and preserve yield loss under moderate weediness of the crop (Guillermo *et al.*, 2009). The use of higher sowing rates additionally might improve crop competition for light. The increasing sowing rate of wheat has a significant effect in decreasing the number of *Viola arvensis* and *Galium aparine* (Ona *et al.*, 2018). An increased wheat crop population had strong and persistent negative consequences on weed biomass and positive outcomes on crop biomass and yield. Kristensen *et al.* (2008) confirmed that in conditions of highest wheat plant density (721 seed m^{-2}), weed biomass was <50% than at the lowest wheat plant density (204 seed m^{-2}). It is reported that in maize through increased crops density, variety choice and sowing pattern all three factors had significant effects on both weed biomass and yield (Marin, Weiner, 2014). Also, increasing population density in sunflower crop showed practical management for weed control and higher yield (Dominschek *et al.*, 2019). Increased wheat crop density resulted in decreased weed biomass (59% and 58% for the 380 and 270 plant $m^{2\,-1}$ respectively) in comparison with crop densities of 125 plant $m^{2\,-1}$ (Korres, Froud-William, 2002). Weed population was significantly lower in wheat crop sown at higher seed rates of 150 kg ha^{-1} and 125 kg ha^{-1}as compared to the recommended seed rate of 100 kg ha^{-1} seed (Sharma, Singh, 2011). There are numerous examples where crop density manipulation has been shown to successfully reduce crop yield loss due to *A. fatua* interference (Kirkland, 1993; Wilson *et al.*, 1995). For example, Maxwell *et al.* (1994) reported that in competition with *A. fatua*, barley yield reductions were 54 and 23% at seeding rates of 67 and 134 kg ha^{-1}, respectively. Wilson *et al.* (1990) reported a lower detrimental effect from *A. fatua* on crop yield when seeding rate of both wheat and barley was increased from 135 to 337 and 134 to 443 plants m^{-2}, respectively. Evans *et al.* (1991) also reported that *A. fatua* reduced barley yield less at high than low crop densities. Furthermore, Barton *et al.* (1992), with *A. fatua* populations of 290 plants m^{-2}, observed that *A. fatua* biomass was reduced from 3,920 kg ha^{-1} to 2,460 kg $ha^{-1}$when barley seeding rate was increased from 180 to 355 seeds m^{-2}. Compared with the low seeding rate (175 plants m^{-2}) treatment, the high seeding rate (280 plants m^{-2}) reduce *A. fatua* interference and reduced percentage wheat yield loss from 26 to 32% (Stougaard, Xue, 2005). Also, O'Donovan *et al.* (2001) reported that *A. fatua* seed production was reduced when barley sowing rate was increased both with and without herbicide application. Similar, Yenish, Young (2004) noted that *Aegilops cylindrica* biomass decreased 27% per plant as sowing rate increased from 40 to 60 wheat seed m^{-2}. Tharp and Kells (2001) found that increasing corn population from 60,000 to 73,000 plants ha^{-1} reduced *Chenopodium album* L. biomass and fecundity and increased corn yield in the northern Corn Belt. In the same direction is an investigation of Nice *et al.* (2001) who found that increasing soybean populations from 245,000 plant ha^{-1} to 481,000 and 676,000 plants ha^{-1} coupled with reduced row spacing reduced *Senna obtusifolia* density and growth. The sowed single corn with higher plant population decreased weed occurrence and weeds has a low value of weed dry matter (Melo *et al.*, 2019). Increasing corn population from 33,000 to 133,000 plants ha^{-1} reduced *Cyperus esculentus* growth (Ghafar, Watson, 1983). Same, *Amaranthus retroflexus* vegetative biomass was reduced by increased corn population (McLachlan *et al.*, 1993). In aerobic rice systems sowing rates of 100–300 germinating seeds, m^{-2} increased rice yield significantly over weed biomass (Zhao *et al.*, 2007). According to Phuong *et al.* (2005), in lowland rice higher sowing rates advantaged rice towards weeds increasing yields under weedy conditions. When the rice sowing rate increased from 20 to 100 kg ha^{-1} weed biomass reduction ranged between 41 and 60%, and 54 and 56% at 35 days after sowing and at crop anthesis, respectively (Ahmed *et al.*, 2014).

Some researchers (Weiner *et al.*, 2001; Olsen, Weiner, 2005; Olsen *et al.*, 2012) noted that increased crop uniformity harmed weed biomass. Acciaresi and Zuluaga (2006) and Blackshaw *et al.* (1999) found that narrow row square planting pattern suppressed weed growth more effectively than wide-row planting pattern in beans. Moreover, Mashingaidze *et al.* (2009) reported that narrow rows in cornfields reduce biomass and seed production of weeds. Furthermore, weed biomass (Mickelson, Renner, 1997) and the total leaf area of *Amaranthus retroflexus* (Legere, Schreiber, 1989) were reduced by 20% when soybean was planted in a 19 cm compared to 76 cm row spacing. The increasing the soybean sowing rate in 76 cm rows, from 185,000 to 432,000 seeds ha^{-1} significantly reduced *Solanum ptycanthum* dry weight (Rich, Renner, 2007). Soil residual herbicides or sequential applications of glyphosate to control late-emerging weeds may not be necessary for narrow-row soybean because shade inhibits the growth of many, but not all weeds (Ritchie *et al.*, 1997; Ateh, Harvey 1999).

Managing weeds through crop genotype choice

One of the key elements of an IWM strategy is to promote crop cultivars with increased capacities either to compete with or tolerate weeds (Mohler, 1996). Competitive cultivars are a possibly interesting choice because they do not acquire any extra costs. These types of cultivars are more competent in reducing the capability of a weed species throughout the struggle for restricted resources (Christensen, 1995), may excrete allelochemicals that disturbed weed growth (Wu *et al.*, 1999; Olofsdotter, 2001; Pacanoski, Mehmeti, 2019) and lessen the economic stress of weeds by resisting crop loss (Vandeleur, Gill, 2004). Competitive cultivars can lessen the weed seed getting back into the soil and allow moderate to durable weed management programs, decreasing the pressure on chemical and mechanical weed control methods (Christensen *et al.*, 1994; Blackshaw *et al.*, 2006) and promoting the sustainability of agro-ecosystems. For instance, in Greece, it has already been demonstrated that the use of competitive cultivars alone reduced recommended rates of herbicides in wheat by 50% (Travlos, 2012). The differences in competitive capacity among varieties of winter wheat and spring barley have been described contrary to volunteer oilseed rape (Christensen *et al*., 1994; Christensen, 1995). Similar results have been reported in wheat contrary *Aegilops cylindrica* (Ogg, Seefeldt, 1999), *Lolium rigidum* (Lemerle *et al*., 2001), *Galium aparine* (Mennan, Zandstra, 2005b) and weed mixtures (Cosser *et al*., 1997; Korres, Froud-William, 2002). Winter wheat varieties altered in their capacity for detrimental influence on the appearance and following growth of *Portulaca oleraceae*, *Amaranthus retroflexus*, *Eragrostis ciliogenesis*, and *Echinochloa crus-galli* (Wicks *et al*., 1986). In this research, reduction of weeds was between 59 and 96% compared to treatments where the winter wheat had been eliminated by cultivation before May. Choosing more competitive cultivars could decrease *A. myosuroides* heads $m^{2\ -1}$ by 22% (Lutman *et al.*, 2013). Furthermore, some wheat cultivars could provide enhanced *A. myosuroides* suppression (Andrew, Storkey, 2017). Further, high wheat tillering capability provided suppression of dry matter production in mixed weed flora population (Korres, Froud-William, 2002). In that context, Challaiah *et al.* (1986) approved the negative correlation between several wheat tillers and *B. tectorum* seed production. Similar, in Australia higher wheat tillering capacity also reduced *L. rigidum* seed production (Lemerle *et al*., 1996). Tastan (1988) concluded that wheat cultivars 'Haymana 79' and 'Kunduru 79' can suppress *Bifora radians* more effectively than other wheat cultivars in the Central Anatolia region of Turkey. *Bifora radians* biomass and seed numbers were reduced not only by an increase in the wheat seeding rate but also by cultivars. *Bifora radians* seed production in Bezostaja, Kate A-1, Momtchill, and Panda were diminished 60, 53, 54, and 46%, respectively, at the seeding rate of 250 kg ha^{-1} compared with *Bifora radians* alone at a density of 350 plants m^{-2} (Mennan, Zandstra, 2005a).

Wicks *et al.* (1986), Lemerle *et al.* (1996) and Grundy *et al.* (1997) agreed that height is a major characteristic contributing to cultivar competitiveness. This aspect is associated with light penetration within the crop canopy and shading ability (Blackshaw, 1994; Seavers, Wright, 1995). Although in weed-free fields their yield is usually lower, taller varieties commonly tolerate higher weed pressure and, in the same time, enhance reduction of weed growth (Ogg, Seefeldt, 1999; Vandeleur, Gill, 2004). The benefit of height, in terms of shading weeds, has been reported in *Bromus tectorum*-infested wheat (Challaiah *et al*., 1986), in winter wheat in competition with *A. cylindrica* (Ogg, Seefeldt, 1999), spring barley against *B. napus* (Christensen, 1995) as well as oats, barley and wheat in relation with *G. aparine* (Brain *et al*., 1999).The tall wheat 130 cm reduced mature *A. cylindrica* biomass 46 and 16% compared with short 100 cm wheat in years 1 and 2 of the experiment, respectively (Yenish, Young, 2004).

Managing weeds through adequate fertilization

Nutrient balance is frequently essential for crop–weed competition (Lintell-Smith *et al.*, 1992), and controlling the fertilizer applications in space and time might be a technique for useful weed-suppressing (Angonin *et al.*, 1996; Liebman, Mohler, 2001). Crop fertilization management is a favourable cultural practice to decrease weed infestation in crops (Di Tomaso, 1995; Evans *et al.*, 2003; Jiang *et al.*, 2018). Application of fertilizers influences on competitive interactions crop–weed of interest in the oat crop (Blackshaw, Brandt, 2008) and emphasizes oats as a usually competitive and resourceful crop. Nitrogen (N) is the major nutrient added to increase crop yield (Raun, Johnson, 1999; Wang *et al.*, 2016). Pre-seeding N application might enhance competing crop capacity compared to weeds in high growth rate crops at early stages, but this outcome depends on the dominant weeds in the crop. For example, Paolini *et al.* (1998) noticed that pre-planting N fertilization in sunflower improved the suppression of summer-emerging weeds such as *Solanum nigrum*, *Xanthium strumarium*, and *Chenopodium album*, in comparison with the split application (50% pre-planting and 50% top-dressing). Also, early or delay top-dressing with N fertilizer improved sugar beet competitive capacity against of early- or late-emerging weeds, respectively (Paolini *et al.*, 1999). Study of Evans *et al.* (2003) showed that weeds have a lower consequence on crop yield when N is applied in early growth stages whiles at amounts lower than recommended for optimum yield. N use in early growth stages also led to a reduction of weed biomass than N applications occurring in advanced growing stages (Hoeft *et al.*, 2000; Sweeney *et al.*, 2008). *Avena fatua*, *Sinapis arvensis*, *Chenopodium album*, and *Setaria viridis* density and biomass in wheat crop were at times reducing with spring than with autumn-applied N (Blackshaw *et al.*, 2004). According to the same authors, the technique of N application usually had bigger and more permanent outcomes than the timing of application on weed biomass and wheat yield. With subsurface banded or point-injected N, shoot N concentration and weed biomass were often reduce than with surface broadcast N, and concomitant growth in yield of spring wheat generally followed with these N placement applications. As a conclusion of the 4-year research project, without taking into account the weed population, the reduction of weed seed bank was between 25% and 63% with point-injected compare to broadcast N fertilization. Nitrogen fertilizer placed as narrow in soil bands, rather than surface broadcast, has been documented to reduce the competitive ability of several grass weed species (Blackshaw *et al.*, 2000; Mesbah, Miller 1999; Rasmussen 1995). Hodge *et al.* (1999) suggested that there may be competitive advantages to nutrient placement through a localized increase in root-length density of the competing species. Uptake of N by *Setaria viridis* in competition with wheat was greater when N was surface broadcast compared with surface pooling or point injection of ammonium nitrate solution (Blackshaw *et al.*, 2002). Nitrogen formulation also influences the outcome of the weed–crop competition (Blackshaw *et al.*, 2002; Di Tomaso, 1995; Kirkland, Beckie, 1998). For example, differences in the growth of corn and *Amaranthus retroflexus* were greater when N was applied as nitrate, $Ca(NO_3)_2$, than as ammonium, $(NH_4)_2SO_4$ (Teyker *et al.,* 1991). Ammonium exhibited some detrimental effects on *Amaranthus retroflexus* such as leaf chlorosis and crinkling, reduced shoot dry weight, and reduced total N accumulation.

Conclusion

The highest diversification of the cropping system (*i.e.* growing more competitive cultivars integrated with a range of other cultural control strategies) designed on agro-ecological fundamentals is crucial for successful weed management in any circumstances. In this relation, a strategy based on the manipulation of sowing date, increasing crop sowing rate, alteration in population density and row spacing, using of more competitive cultivars and adequate fertilization can improve the sustainability of cropping systems through less reliance on herbicides. This approach also provides an environmentally friendly substitute for mechanical weed control, decreasing soil erosion, nutrient loss, labour, traffic on the field, fuel consumption, and CO_2 emissions. This indicates that education of growers is obliged to gain a higher rank of proficiency and technical competence. Unilaterally decisions, like mechanical weed control and over-reliance on herbicides as the simply direct weed-control techniques may be effective in the short term but are never productive in the long term. Nowadays, many different models are used to search cropping system scenarios and to predict their effects on weed populations. Applying these measures to control weeds will reduce the use of herbicides, and this will have a greater impact on the protection of the environment which is in line with EU directives. Also, by reducing the use of herbicides and applying the measures included in the IWM, the biotypes of resistant weeds can be avoided. Therefore, alteration of the cropping pattern is very important in the development of sustainable and environmentally safe strategies for weed control.

Conflict of interest

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

Author contributions

ZP and AM – contributed equally to the preparation, creation and/or presentation of the manuscript.

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