

Synergy between Crop Competition, Agronomic Practices and Herbicides for Effective Weed Control in Plant Production

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SUMMARY

Interaction of herbicide application with the manipulation of certain agronomic practices for crop competition, including sowing date and seeding rate, row and plant spacing, and application of fertilizers have the potential to reduce the abundance of agricultural weeds and optimize herbicide use. Sowing date and herbicide application play a significant role in determining growth, development and seed yield of many crops, as well as reducing weed density and weed biomass. Narrow row spacing can improve weed control because weeds are smaller and more easily controlled with herbicides than they are in wide row spacing. Furthermore, the more rapid crop canopy development of narrow row spacing reduces problems with late emerging weeds and may allow POST EM herbicides to be applied earlier in the season, therefore improving effectiveness and allowing reduced rates to control small weeds. Finally, adequate fertilization increases the vigour and competitiveness of the crop. By altering the time and method of fertilizing with herbicide application, competitive advantage can be shifted in favour of the crop.

Keywords: agronomic practices, herbicides, fertilizers, weeds.

INTRODUCTION

In many agricultural systems around the world, competition with weeds is one of the major factors limiting profitable crop production (Avery, 1997). In developed countries, despite the availability of high-tech solutions (e.g. selective herbicides, GM and HR crops), the share of crop yield loss to weeds does not seem to reduce significantly over time (Cousens and Mortimer, 1995). In developing countries, herbicides are rarely accessible at a reasonable cost, therefore forcing farmers to often rely on alternative methods of weed management.

Weed management through physical and mechanical means often increases soil erosion rates, leading to deteriorating physical, chemical and biological properties of soil (Wall, 2007), reduced soil quality, i.e. soil structure, with consequences for water infiltration (Thierfelder and Wall, 2009), poor soil porosity, nutrient loss and low organic matter content (Kirschbaum, 1995), which leads to increased greenhouse gas emissions (Del Grosso et al., 2005). Furthermore, such weed management practices involve intensive labour and implement high costs, making them simultaneously more laborious, tiresome and expensive (Iqbal, 1994). On the other hand, reliance solely on chemical weed control involves excessive use of herbicides, resulting in pollution of the environment and inter- and intra-specific shifts (Hassan and Marwat, 2001), due to the development of more competitive herbicide-resistant biotypes within a plant population or a community, which are a threat for sustainable crop production (Shrestha et al., 2010; Chhokar et al., 2012).

Weed management programs should therefore not rely totally on either chemical or mechanical means, due to their respective potential risks and costs. One such strategy is the combination of cultural or ecological weed control with chemical weed control. Cultural weed control involves manipulation of the crop/weed environment so that the conditions become more favourable for crop plants than for weeds (Klein et al., 2006). Coordinating herbicide applications with the manipulation of certain agronomic practices for crop competition such as sowing date, seeding rate, row and plant spacing, as well as application of fertilizers, have the potential to reduce the abundance of agricultural weeds and optimize herbicide use (Conley et al., 2001; Filizadeh et al., 2007; Erfanifar et al., 2008; Hamouz et al., 2014; Woźniak and Soroka 2015).

Sowing date and herbicide application play a significant role in determining growth, development and seed yield of many crops. Results show that different sowing date and herbicide weed control method have a significant effect on relative weed density, weed biomass, weed control efficiency, plant height, dry plant weight and seed yield of soybean (Akter et al., 2016), rice (Mubeen et al., 2014), wheat (Duary and Yaduraju, 2006) and pearl millet (Arslan et al., 2018).

Narrow row spacing can improve weed control because weeds are smaller and more easily controlled with herbicides than they are in wide row spacing. Furthermore, the more rapid crop canopy development of narrow row spacing reduces problems with late emerging weeds and may allow postemergence herbicides to be applied earlier in the season, therefore improving their effectiveness and allowing reduced rates to control small weeds (Hartzler et al., 1996). Closer row spacing of 15 cm with 50% higher seed rate and cross sowing showed a distinct advantage in reducing the weed population and dry weight (Chhokar et al., 2012). Prakash et al. (1986) found closer row spacing (15 cm) and reduced dose of herbicide to be effective in reducing weeds and increasing wheat grain yield.

Adequate fertilization increases the vigour and competitiveness of the crop. By altering the time and method of fertilizer and herbicide application, competitive advantage can be shifted in favour of the crop. The initial crop growth will be better if the fertilizer is made more available to the crop instead of weeds and, in the same time, the efficacy of herbicides

is increased when it coincides with the application of the fertilizer (Sosnoskie *et al.*, 2009). Synergism between herbicides and fertilizers in control of broadleaved weeds in wheat and barley were reported by Prishchepa (1999). Application of isoproturon at 1.5 or 1.0 kg a.i. ha⁻¹, followed by a top dressing with N at 35 DAS, resulted in lowest accumulation of weeds dry matter, highest number of effective tillers per meter length, spikelet's spike, straw and grain yield ha⁻¹ of wheat (Saini and Angiras, 1998).

Taking into consideration what has been said before, the objective of this report is to summarize the available information and bring together advantages of effective weed control through interaction between crop competition, agronomic practices and herbicides.

SYNERGY BETWEEN HERBICIDES, SOWING DATE AND SEEDING RATE

The use of herbicides to control weeds has facilitated the adoption of several important agronomic practices and has major impacts on all phases of crop production. Seeding date manipulation for weed control involves trying to increase the crop's competitive ability, compared to that of the weeds. The timing of weed emergence relative to the crop is the main factor to consider, since weeds that emerge before the crop compete more aggressively with the crop than those that emerge after the crop. Until the 1950s, delayed seeding in interaction with herbicides was the most effective way of controlling weeds in spring-sown crops. Early sowing, as is common today, was impossible because weeds would outcompete the crop. Spring cultivation, after weed emergence, removed weeds before crop planting, but delayed planting by approximately three weeks (Weller *et al.*, 2014). Earlier planting, as now practiced, reflects the availability of hybrid seeds with a higher cold tolerance and decreased need for spring tillage, made possible by the use of herbicides (Warren, 1998). In the U.S. Midwest, corn planting occurs two weeks earlier today than it did in the late 1970s, and in the mid-southern part of the United States for the 50% of corn the planting date has moved earlier by about a month (from early May to early April) during the past 30 years (Kucharik, 2006). In northern Alberta, a six-year crop rotation including delayed seeding and POST EM herbicides in three years out of six resulted in a 87% decrease in *Avena fatua* populations, compared to a 4% decrease in a wheat-fallow rotation (Anonymous, 1968). In another Alberta study, allowing *Avena fatua* to grow to the two-leaf stage and then destroying it with either tillage or herbicides prior to seeding rapeseed resulted in good control, with little or no crop yield loss (Darwent and Smith, 1985). Waiting until *Avena fatua* was in the three- to four-leaf stage resulted in good control, but some yield loss. A Manitoba study on oat found that *Avena fatua* populations were reduced drastically by POST EM herbicides and delayed seeding from early to late May, without sacrificing crop yield (Schoofs *et al.*, 2005). Gürsoy *et al.* (2014) found that late plantings of lentil (November 23), where cultivator and POST EM herbicides were used after rainfall, reduced weed density and dry weight biomass, and gave significantly more lentil seeds than early planting (October 19).

Increased seeding rate and use of herbicides are two important components of integrated weed management program. Planting late-planted wheat at higher seeding rates improves yield and weed competitiveness of the crop. In many areas in Jordan high seeding wheat rates of 140 kg ha⁻¹, in interaction with herbicides, are used as a form of control of high competitive wild oats and broadleaved weeds (Munir et al., 2002). Findings of Marwat et al. (2011) revealed that integrating line wheat sowing with higher seed rate (150 kg ha⁻¹) and Buctril super suppressed weeds by more than 90%. In investigation of Jhala et al. (2008) interaction effect of seed rates and weed management treatments revealed that treatment combinations 160 kg ha⁻¹ and 180 kg ha⁻¹ with pendimethalin applied PRE EM recorded lowest weed presence in wheat crop. Combining the highest seeding rate (200 seeds m⁻²), and the earliest time of weed removal (two-leaf stage of canola) led to a 41% yield increase, compared with the combination of the lowest seeding rate (100 seeds m⁻²) and the latest time of weed removal (six-leaf stage of canola), with glufosinate applied at 500 g a.i. ha⁻¹ (Harker et al., 2003). Higher seeding rate favors rice more than weeds and increases yield under weedy conditions (Phuong et al., 2005). *Echinochloa crus-galli* and *Leptochloa chinensis* densities were reduced at higher rice seeding rates of 200 kg ha⁻¹ and POST EM herbicide application, when compared with 100 kg ha⁻¹ seeding rate with the same herbicides (Hiraoka et al., 1998). Similarly, according to Ahmed et al. (2014) weed biomass decreased significantly (by 55%) when seeding rice rate increased from 20 to 100 kg ha⁻¹. Ridge sowing in combination with pendimethalin + prometryne applied at 875 g a.i. ha⁻¹ was the best method in terms of controlling weeds, reducing dry weight of weeds, increasing monopodial and sympodial branches per plant, total number of bolls per plant, number of mature bolls per plant, seed cotton weight and seed cotton yield (Nadeem et al., 2013). When herbicide was not applied in lentil and seed rate was increased by 1.5 times, this resulted in a 70% weed control, compared with 90% when seeding rate was the same and herbicides were used (Boerboom and Young, 1995).

Changes in sowing date can strongly affect plant development and have noticeable effects on weed intensity, crop growth and yield, as well (Hay, 1986). Sowing dates can be manipulated to avoid the periods of greatest risk from weeds and hence increase the crop yield (Harper, 1999). Furthermore, high seeding rates improve the ability of crops to suppress weeds and can reduce yield loss under partially-weedy conditions (Guillermo et al., 2009). Also, crop competition for light can be further improved with the use of higher seeding rates.

SYNERGY BETWEEN HERBICIDES AND ALTERATION IN POPULATION DENSITY AND ROW SPACING

Crop competitiveness against weeds can be improved by using higher crop population densities. Use of higher planting densities can accelerate canopy closure, thus promoting interception of radiation by the crop canopy and hence weed suppression (Andrade et al., 2002; Mashingaidze, 2009). Furthermore, increased crop density increases the degree of “size-asymmetric competition”, to the advantage of the crop, which almost always has an

initial size advantage in competition with annual weeds (Weiner et al., 2001). Finally, increased crop density and uniformity can contribute to weed management in many crops, potentially reducing the need for herbicides or mechanical weed control (Marin and Weiner, 2014). Closer row spacing and higher plant populations per hectare are common practices for peanut, soybean and vegetable crops where, after introduction of herbicides, crop yields increased in snap beans (45%), sweet corn (50%), carrots (22–33%) and broccoli (65%) (Mack, 1969). In the study by Safdar et al. (2011), the 22.5 cm single row sowing in combination with chemical weed control proved to be the best option, regarding weed control (87.23%), wheat grain yield (4073 kg ha^{-1}) and number of fertile tillers m^{-2} (509.5). The effect of narrow row spacing and interaction of herbicides on weeds and wheat grain yield was recorded by Ashrafi et al. (2009). Minimum number of weeds (8 m^{-2} grasses and 10 m^{-2} broadleaf), as well as the highest grain yield (5.35 t ha^{-1}) was recorded in 20 cm row spacing treated with 2,4-D butyl Ester 72 EC + isoproturon 75 WP. Maize weed control by hoeing or herbicide treatments resulted in smaller weed biomass and greater maize yield in narrow-, when compared to wide-spacing maize (Hussein et al., 2008). Teasdale (1995) found that, when herbicide was applied at a standard rate, zero weeds emerged when row spacing was halved (from 76 cm to 38 cm) and maize density doubled (from 58,000 to 109,000 plants ha^{-1}), when compared with 3% weed cover at standard row spacing and planting density. Dalley et al. (2004) investigated the effects of glyphosate application timing coupled with reduced row spacing in glyphosate-resistant maize. When glyphosate was applied sequentially at five different weed growth stages over four seasons, the higher light interception by the maize canopy resulted in 60% less weed biomass, compared to wider rows. In the same study, a single application of glyphosate at the beginning of the season, coupled with halved row spacing, reduced weed biomass by 39% over four seasons. In a study by Teasdale (1995), the use of narrower rows and increased plant population by only 25% of the recommended herbicide rate showed no significant differences in weed control, when compared with the recommended herbicide rates, applied under conventional row spacing and maize population. Intra-row spacing of 15 cm and the use of pre-emergence application of metolachlor + prometryne at $1.6 \text{ kg a.i. ha}^{-1}$, followed by one supplementary hoe-weeding at 6 WAS, controlled weeds effectively, with consequent high groundnut pod yield, when compared to those of two hoe-weeding (Ojelade et al., 2018). Adigun et al. (2016) cit. by Ojelade et al. (2018) also reported that intra-row spacing of 15 cm and application of probaben and butachlor at $2.0 \text{ kg a.i ha}^{-1}$, followed by supplementary hoe weeding at 6 WAS. gave better weed control than either of the herbicides applied alone in groundnut. Higher than 90% control of *Panicum dichotomiflorum*, *Eleusine indica*, *Digitaria sanguinalis*, *Amaranthus* spp. and *Ipomoea* spp. was obtained in narrow-row cotton with glufosinate applied early POST and mid-POST EM to two- and six-leaf cotton, respectively (Wilson et al., 2007). Among soybean planting systems, narrow with high plant density soybeans in combination with PRE and POST EM herbicide programs reduced total weed biomass by 81–100%, when compared to wide-row spacing with low soybean plant density (Koger et al., 2002). Shading by the soybean canopy in 10-in rows reduced the survival of late-emerging *Setaria faberi* and improved late-season control ratings to 84% (Hartzler et al.,

1996). *Ambrosia artemisiifolia* and *Chenopodium album* control by all herbicide treatments was enhanced in narrow-, when compared to wide-row soybean 56 DAT as was *Amaranthus retroflexus* control by CGA-277476 treatment. POST EM herbicide treatments resulted in less weed biomass and greater soybean yield in narrow-, when compared to wide-row soybean (Nelson and Renner, 1998).

SYNERGY BETWEEN HERBICIDES AND FERTILIZER APPLICATION

Furthermore, the benefits of fertilization depend on weed control. The application of fertilizers causes more weeds to grow, if they are not controlled properly. By controlling the weed problem with herbicides, farmers will be more likely to use fertilizers for an even greater crop yield increase (Manda, 2011). The use of subnormal herbicide doses (50%) and N fertilization may be useful in wheat production systems (conventional and no tillage systems) as a strategy to manage natural weed populations (Ashrafi et al., 2010). Soltani and Saeedipour (2015) revealed that effects of graminaceous herbicide, in combination with ammonical nitrogen on silty clay soil, resulted in a remarkable increase in grain yield of wheat crop. Najafi and Ghadiri (2012) reported that there is a synergy created by foramsulfuron 0.06 kg a.i. ha⁻¹ in the presence of nitrogen 50 kg ha⁻¹ to ensure good control of *Convolvulus arvensis* L., *Amaranthus retroflexus* L. and *Physalis alkekengi* L. in barley crop. Mesosulfuron-methyl plus iodosulfuron-methyl decreased weed dry matter by 86.2% with highest level on nitrogen (304 kg urea ha⁻¹) when compared to the respective weedy check treatments (Sheibani and Ghadiri, 2012). The results of Sepahvand et al. (2014) show improved efficiency of nitrogen utilization by banding herbicide application. Grain yield, harvest index, seed rows per cob, seeds per row and cob weight were increased by weed control. In the application of foramsulfuron + hand weeding (HW) treatment corn grain yield was increased 126% in comparison with weedy control. Such results are a representation of the intense affects of weed competition with corn. The highest corn grain yield (6758 kg ha⁻¹) was related to the application banding of nitrogen fertilizer and foramsulfuron + once HW (Sepahvand et al., 2014). Similarly, in maize production, grain yield increases after the application of 3% urea as NPK (160-80-50), in combination with 1125 g a.i. ha⁻¹ foramsulfuron applied POST EM, having reduced the density of three invasive species: *Trianthema portulacastrum*, *Cyperus rotundus* and *Coronopus didymus* (Nadeem et al., 2008). Maize grain yield gain and better control of *Echinochloa crus-galli*, *Sorghum halepense*, *Cynodon dactylon*, *Digera muricata*, *Portulaca oleracea*, *Convolvulus arvensis* and *Cyperus rotundus* was induced by atrazine 1 kg a.i. ha⁻¹ and 160 kg N ha⁻¹, compared to stomp 0.75 kg a.i. ha⁻¹ subjected to the same conditions and 2.4 D-72 (ester) 0.80 a.i. kg ha⁻¹ applied in post-emergence or 25 days after sowing (Khan et al., 2012a). The lowest weed density (30.83 weeds m⁻²) and the lowest dry weed biomass (6.80 g m⁻²), as well as the greatest grain yield production (1.5 t ha⁻¹) was recorded in plots treated with atrazine 38 SC, followed by the application of 160 kg ha⁻¹ N (Khan et al., 2012b). Applying the two herbicides alone at the recommended doses was good enough for controlling both types of weeds, broad and narrow

leaved ones. However, using both of them in combination with different fertilizers (i.e., urea and diammonium phosphate) was much more effective (Abouziena, 2007). The presence of adjuvant MSO, especially with nitrogen fertilizer, AMN and UAN, improved the half rate (30 g ha⁻¹) nicosulfuron activity in the control of *Chenopodium album*, *Viola arvensis*, *Polygonum convolvulus*, *Polygonum aviculare* and particularly *Echinochloa crus-galli* in maize (Idziak and Woznica, 2013). Mesotrione + nicosulfuron in 50 cm row distance and standard urea application provided 96.65% control of weeds in maize (Simić et al., 2017). Increasing N application rate up to 150 kg ha⁻¹ caused significant improvement in grain rice yield when the weeds were well controlled either by pendimethalin + bispyribac Na or by pendimethalin + bispyribac Na + 1 HW, respectively (Mahajan and Timsina, 2011). Increased application of N up to 90 kg ha⁻¹, and complementary weed control by pre-transplant application of butachlor (50% w/v) or proababen* (metolachlor 20% w/v + prometryn 20% w/v) each at 2.0 kg a.i. ha⁻¹, followed by supplementary hoe weeding at 6 weeks after transplanting (WAT), significantly reduced weed density by at least 15% and increased fruit yield of tomato by at least 32%, compared to the use of pre-transplant herbicides alone, across both years of study (Adigun et al., 2018).

Nutrient level is often important for crop–weed competitive interactions (Lintell-Smith et al., 1992) and managing the application of fertilizers in both space and time can be a tool in managing weeds (Angonin et al., 1996; Liebman and Mohler 2001). Manipulation of crop fertilization is a promising cultural practice to reduce weed interference in crops (Di Tomaso, 1995; Evans et al., 2003). In conclusion, manipulation of certain agronomic practices for crop competition, such as sowing date, seeding rate, row and plant spacing and the application of fertilizers in synergy with herbicide applications, led to high levels of crop production, reductions in the abundance of agricultural weeds, optimal herbicide use and reduction of herbicide dependence, increase in net returns, and the adoption of more integrated weed management systems. Such a strategy also offers an environmentally friendly alternative to mechanical weed control, reducing traffic on the field, soil erosion, nutrient loss, labour, fuel consumption and CO₂ emissions.

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Sinergizam kompeticije, agrotehničkih mera i primene herbicida za efikasno suzbijanje korova u biljnoj proizvodnji

REZIME

Zajednička primena herbicida i agrotehničkih mera za jačanje kompetitivne sposobnosti useva, pored ostalog, uključuje pravovremene rokove setve, setvenu normu i primenu đubriva koji potencijalno mogu umanjiti zakorovljenost useva i optimizirati primenu herbicida. Datum setve i primjena herbicida imaju značajnu ulogu za rast, razvoj i prinos mnogih useva, kao i smanjenje brojnosti i biomase korova. Manje međuredno rastojanje može doprineti lakšem i efikasnijem hemijskom suzbijanju korova iz razloga izraženijeg kompetitivnog pritiska useva u odnosu na veći međuredni razmak. Pored toga, brži rast i razvoj useva sa manjim međurednim razmakom smanjuje kasniju pojavu korova i omogućava raniju primenu POST EM herbicida, čime se obezbežuje čist usev kao preduslov za visok prinos. Takođe, adekvano đubrenje pozitivno utiče na brži rast i razvoj useva a time i kompetitivnu snagu u odnosu na korove. Dakle, dobrim rokovima i gustom setve, đubrenjem i primenom herbicida jača se kompetitivna prednost useva u odnosu na korove.

Ključne reči: agrotehničke mere, herbicidi, đubrivo, korovi.