Available online at www.notulaebotanicae.ro

Print ISSN 0255-965X; Electronic 1842-4309

Not. Bot. Hort. Agrobot. Cluj 38 (3) 2010, 117-123

Notulae Botanicae Horti Agrobotanici Cluj-Napoca

Rye Cover Crop Management Affects Weeds and Yield of Corn (*Zea mays* L.)

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Abstract

In recent years, increasing application of chemical herbicides has raised concerns over their destructive impacts on living organisms and environmental health and it requires studies on non-chemical weed management methods. As a result, this experiment was initiated in November 2008 at experimental field of Islamic Azad University, Karaj Branch, in order to evaluate weed-suppressive ability of winter rye cover crop and mulch, and its effects on following corn yield production. Treatments included three rye seeding rates (500, 750 and 1000 kernels/m^2) and three rye kill dates (29/3/2009, 15/4/2009 and 3/5/2009). In the fall 2008 rye was planted, then in the above three dates have been killed and left on the soil surface to provide mulching effect. Then in middle of June 2009, corn plants planted on the same plots of winter rye. Weeds density and biomass production were monitored in the fourth, sixth and eighth weeks after planting (WAP) corn. Corn yield production was also measured in late October 2009. Results showed that rye seeding rate has not affected weeds significantly but rye kill date had significant effect. The first kill date stimulated weeds germination and growth. The third kill date reduced density of all weeds in the fourth WAP on average 28.73% and their biomass production in the sixth WAP on average 21.38%. This treatment also increased corn grain production 7.89% at the end of the season. Finally, results of the experiment indicate that using cover crops should be combined with other methods to control weeds efficiently and to prevent yield production loss.

Keywords: allelopathy, fallow, herbicide, mulch, weed

Introduction

Since human began to cultivate crops, weeds have caused lots of problems to agriculture. During this long period of time, weed control methods have changed from hand weeding and primary tools to animal and then mechanical powered implements, biological control and finally chemical control (Heap and LeBaron, 2001; Monaco *et al.*, 2002; Zimdhal, 2007). After introducing herbicides to agriculture, their efficacy and cost-effectiveness led to heavy reliance on them. Nevertheless, they are not such reliable. Herbicides, like other pesticides, are toxic materials and in recent years there has been increased concern about residues and associated food safety issues and their adverse impact on the environment and human health. Sudden death, birth deficit, various kinds of cancers, respiratory system diseases, and too many other health problems are associated with herbicides application specially in developing countries (Liebman *et al.*, 2004; Lynge, 1998; Shanahan *et al.*, 2003). On the other hand, the widespread occurrence of herbicide resistant weeds is another problem that has reduced the efficacy of herbicides. Until April 2010, 347 biotypes from 195 plant species, in 340,000 fields around the world had been reported as herbicide resistant weeds (Anonymous, 2010; Monaco *et al.*, 2002).

Mentioned problems require weed scientists to work on non-chemical weed management techniques and integrated weed management (IWM). Using cover crops and mulches are useful methods to suppress weeds which have other positive impacts rather than weeding. They protect soil against water and wind erosion, improve soil properties and organic matter content, enhance soil fertility by fixing N and increasing soil nutrients, boost crop yield, recycle and prevent soil nutrients leaching, provide extra forage or raw materials for biofuel, and of course they eliminate weeds (Blanco and Lal, 2008; Teasdale *et al.*, 2007; Winch, 2006). In two experiments cover crops reduced soil erosion to 3.70 from 41.3 Mg/ha^{-1} (Martin and Cassel, 1992) and improved soil penetration resistance to 0.1 from 0.2 MPa (Obi, 1999).

Cover crops and mulches inhibit weeds germination and growth through different mechanisms. Physical suppression, reducing light penetration to soil surface and decreasing soil temperature, competing for resources such as light and nutrients, releasing allelopathic compounds and promoting activity of weed seed predators are examples of these mechanisms (Creamer *et al.*, 1996; Menalled *et al.*, 2007; Monaco *et al.*, 2002; Putnam and DeFrank, 1983). Results of these interactions show an inhibitory effect which is greater for small-seeded than large-seeded plants. Weeds usually have smaller seeds than crops so crops will tolerate the condition better than weeds (Mohler, 1996). In a study on weed seed predators, *Harpalus rufipes* beetles were marked and released in cover crop and non-cover crop plots and when recaptured, percent of marked beetles in plots with cover crop were two times more than fallow plots (18 and 8%, respectively) (Shearin *et al.*, 2008).

Cover crop plants are different. Hairy vetch (*Vicia villosa* Roth), sorghum-sudangrass (*Sorghum bicolor* L.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), black oat (*Avena strigosa* Schreb), cowpea (*Vigna unguiculata* L.), various clovers (*Trifolium* spp.) and many other plants can be used as cover crop and mulch crop (Hartwig and Ammon, 2002; Reeves *et al.*, 2005; Teasdale *et al.*, 2007). Several studies indicated that above mentioned cover crops and mulches can improve soil quality, suppress weeds and decrease the need for herbicides to some extent in large range of field crops like soybean (Reddy, 2001; Ruffo *et al.*, 2004), cotton (Reeves *et al.*, 2005; Vasilakoglou *et al.*, 2006), corn (Malik *et al.*, 2008), sweet potato (Treadwell *et al.*, 2007), cabbage (Mochizuki *et al.*, 2008), pumpkin (Rapp *et al.*, 2004), vineyard (Baumgartner *et al.*, 2008) as well as in fallow (Blackshaw and Moyer, 2001). Among different plants, rye is a commonly used cover crop especially in cooler climates. This popularity is because of its potential to establishing in late fall and is able to withstand cold winter temperatures, it can germinate and grow rapidly, produce abundant biomass in early spring, scavenge the remaining soil nitrogen and produce allelochemicals (Creamer *et al.*, 1996; Helm and Zollinger, 1991; Johnson and Hoyt, 1999). Two main allelopathic compounds in rye are defined as BOA, (3H)-benzoxazolinone), and DIBOA, 2,4-dihydroxy-1,4-(2H)benzoxazine-3-one (Barnes *et al.*, 1987). An experiment tested BOA and DIBOA for their inhibitory effect on several weeds and crops seed germination and plant growth (Burgos and Talbert, 2000). Results showed that on average, DIBOA is about seven times more inhibitor to root growth and four times more inhibitor to shoot growth than BOA.

Corn (*Zea mays* L.) is one of the three major cereals in the world (Winch, 2006). According to FAO statistics (2007), United States, China, Mexico, Brazil and Argentina are the top five producers of corn. Corn area harvested in Iran is 210,000 ha and production quantity is 1,588,000 tons per year. Like other crops, weed management in corn is important and more experiments should be done to understand if cover crops and mulches can effectively inhibit weeds in corn fields. These experiments should answer some key questions like: (1) Can cover crops and mulches provide full season-long weed suppression without reducing yield production? (2) When is the best time to kill the cover crop to obtain the optimal weed control and to prevent interference of residues in following crop cultivation and growth? So the objective of this study was to determine the best seeding rate and killing date of winter rye cover crop to suppress weeds and increase corn yield production.

Materials and methods

Site and Treatments Description

Field experiment was initiated in 2008 at the research farm of Islamic Azad University Karaj branch, Iran, located in 50° 49' E, 35° 43' N, elev: 1170 m. Soil type was Sandy Loam (sand: 67%, silt: 15%, clay: 18%) with pH of 7.94 and organic matter (OM) content of 0.71%. The field was under sunflower (*Helianthus annus* L.) cropping in the previous spring of the experiment. Natural weed infestation at the time of samplings included redroot pigweed (*Amaranthus retroflexus* L., Bayer Code: AMARE), jimsonweed (*Datura stramonium* L., Bayer Code: DATST), common purslane (*Portulaca oleracea* L., Bayer Code: POROL), common lambsquarters (*Chenopodium album* L., Bayer Code: CHEAL) and field bindweed (*Convolvulus arvensis* L., Bayer Code: CONAR).

The experiment was conducted in split plot arrangement of treatments in the form of randomized complete block design (RCBD) with four replications. The size of sub plots were 3×4 m. 1 m between sub plots and 3 m between main plots were left uncultivated to prevent treatments interference. Treatments included three kill dates (in main plots) and three seeding rates of rye (in sub plots). Normal recommended seeding rate for rye by the Seed and Plant Improvement Institute of Iran was 500 kernels/m^2 so 500, 750 and 1000 kernels/m^2 were set for rye seeding rate treatment. Three kill dates of rye were started in early spring with intervals of two to three weeks, depending on climatic and field condition (29/3/2009, 15/4/2009 and 3/5/2009). In each main plot, one additional sub plot was kept fallow (rye wasn't seeded) as control. When corn was planted, each control plot was divided into two parts, one weed free and the other weed infested all the season. This was to enable comparison between improvement of corn yield compared with weed infested control and reduction of corn yield compared with weed free control.

Rye

After preparing the field in conventional method (moldboard plow-disk-leveler), rye (*Secale cereale* L. var. Danko, untreated seed) seeds broadcasted according to different seeding rate treatments on Nov. 9th, 2008. Quickly after that, broadcasted seeds were incorporated into the soil using a furrower (50 cm of between row spacing) and then field was irrigated. In fall and winter, rye growth and stand was regularly observed and in mid March, when air temperature increased, rye began to grow again. Totally, four irrigations were enough during rye growth period from November 2008 to May 2009 as rainfall provided sufficient water.

The first kill date of rye was on Mar. 29th, 2009, when rye height was about 50 cm (at stem elongation stage). Rye was cut by hand and left on the soil to provide mulch but it could not fully cover the soil surface which caused a weak mulching. In order to measuring rye aboveground biomass production, 1 m^2 was harvested at kill time and its fresh and dry weight (oven dried at 75°C for 3 days) obtained (Tab. 1). After 21 days, on Apr. 19th rye mulch of the first kill date was incorporated into the top soil layer using a rotivator. At this time, mulch had been dried under the sun and rye regrowth was small.

The second kill date of rye was done 17 days after the first one, on Apr. 15th when rye height was about 100 cm (spike was about to appear in some stems). This time, mulch covered the soil surface completely and inhibited rye regrowth. 1 m^2 was again harvested to measure biomass production (Tab. 1) but it took 5 days at 75°C oven to get dry because stems were thicker. Incorporating mulch into the soil by rotivator has been done on May 9th, 24 days after the second kill date.

Finally, the third kill date of rye was on May 3rd, 18 days after the second kill date, and rye height was more than 160 cm (at anthesis). This mulch was very heavy and thick. Another 1 m^2 of rye was harvested to measure biomass production (Tab. 1) and oven dried at 75°C for 5 days. This time, incorporation of mulch into the soil was done 28 days after third kill date, on May 31st, because of soil moisture condition.

Corn

To prepare the field for corn cultivation, furrower (60 cm of between row spacing) just used instead of conventional method to prevent movement of soil between plots. On Jun. 8th, 2009, field was irrigated before seeding corn to ensure proper germination. Then on Jun. 12th, corn (*Zea mays* L. var. Zola 450, treated with fungicide and insecticide) planted with 20 cm of spacing and after 1 day was irrigated. Totally, 14 irrigations were required during corn growth period from June to October.

Data Collection

Biomass and density of the mentioned weeds was measured in the 4th, 6th and 8th weeks after planting (WAP) corn by using 50×50 cm fixed quadrates. In the 4th WAP, density of all 5 weeds was measured in treat and control plots but their biomass was not. Quadrates remained fixed in all plots until the 6th WAP. Then, density of all 5 weeds was counted again and weeds were harvested and separated by species to measure their biomass. Samples were oven dried at 75°C for 7 days. In the 8th WAP, quadrates were displaced because weeds had been harvested in the 6th WAP. This time, density and biomass of just 2 weed species (redroot pigweed and jimsonweed) were measured because both corn and weeds were fully grown and it was too difficult to work in plots. Harvested samples were again separated by species and oven dried at 75°C but this time for 14 days.

After finishing weeds sampling, when corn plants were fully maturated, yield and yield components were measured on Oct. 25th, 2009. Samples were taken from middle rows of all plots and their following traits measured: plant height, stem diameter, number of ears per plant, ear length and diameter, number of rows per ear and kernels per row, aboveground biomass, ear weight, grain production, 1000 kernels weight and harvest index (HI).

Statistical Analysis

First, increasing or decreasing effect of treatments compared with controls was evaluated as percent for collected data. Then, all data were subjected to analysis of variances (ANOVA) using PROC GLM (SAS 2002) to test the main effect of treatments on weed control and corn yield production. At last, means were separated using Duncan's multiple range tests, at the 5% level of significance. Data of weed free controls were not analyzed and their average was just taken.

Results and discussion

Rye Biomass Production

Both higher seeding rate and later killing date of rye increased rye biomass at kill time. The only exception was in the 3rd kill date that seeding rate 3 produced less biomass than seeding rate 2 (Tab. 1). Differences in biomass production caused by kill dates which were higher than by seeding rates, as expected. In other experiments, legume and cereal cover crops biomass production ranged from 2,180 to 11,000 kg/ha (Haramoto and Gallandt, 2005; Reddy, 2001; Reddy, 2003).

Weeds Density and Biomass Control

According to ANOVA, main effect of rye cover crop seeding rate and interaction of kill date by seeding rate were not significant (data not shown). Mean comparisons also showed that only kill date treatments have controlled weeds significantly and seeding rates have not (Tab. 2 to 5). It could be possible, because of the effect of seeding

Tab. 1. Rye cover crop and mulch biomass and other properties as affected by different seeding rate and kill date treatments

	Growth period (days)	Days between kill and corn cultivation	Days between incorporating into soil and corn cultivation	Average rye height at kill time (cm)	Rye biomass at kill time (kg/ha)		
					Seeding rate 1 [b]	Seeding rate 2	Seeding rate 3
Kill 1[a]	139	75	54	50	3,100	3,300	3,350
Kill 2	156	58	34	100	6,400	6,500	6,750
Kill 3	174	40	12	160	9,700	10,150	10,050

[a] 1: Mar. 29th, 2: Apr. 15th and 3: May 3rd; [b] 1: 500, 2: 750 and 3: 1000 (kernels/m^2)

Tab. 2. Effect of different kill date treatments on percent of weeds density control in 4th, 6th and 8th WAP [a,b]

Treatment	4th WAP (control %)					6th WAP (control %)					8th WAP (control %)	
	AMARE[e]	DATST	POROL	CHEAL	CONAR	AMARE	DATST	POROL	CHEAL	CONAR	AMARE	DATST
K. 1[c]	- 26.39 b	- 26.39 c	- 11.46 c	-11.67 b	- 10.08 c	- 18.77 c	- 19.94 c	- 12.32 c	- 9.41 c	- 6.25 c	- 5.51 b	- 2.35 c
K. 2	21.69 a	12.22 b	17.69 b	20.70 a	14.39 b	12.24 b	7.08 b	13.60 b	13.20 b	11.67 b	9.90 a	5.40 b
K. 3	27.62 a	32.16 a	26.85 a	27.05 a	29.99 a	21.42 a	27.68 a	22.08 a	25.33 a	20.97 a	14.15 a	12.95 a

Tab. 3. Effect of different seeding rate treatments on percent of weeds density control in 4th, 6th and 8th WAP [a,b]

Treatment	4th WAP (control %)					6th WAP (control %)					8th WAP (control %)	
	AMARE	DATST	POROL	CHEAL	CONAR	AMARE	DATST	POROL	CHEAL	CONAR	AMARE	DATST
SR. 1[d]	6.65 a	- 2.30 a	10.24 a	9.67 a	11.73 a	4.28 a	- 1.36 b	4.97 a	8.44 a	10.56 a	4.32 a	4.99 a
SR. 2	1.08 a	11.11 a	7.08 a	13.88 a	11.42 a	2.00 a	12.30 a	8.83 a	9.80 a	8.22 a	5.14 a	4.28 a
SR. 3	15.19 a	9.18 a	15.76 a	12.53 a	11.16 a	8.62 a	3.88 ab	9.56 a	10.88 a	7.60 a	9.08 a	6.72 a

Tab. 4. Effect of different kill date treatments on percent of weeds biomass control in 6th and 8th WAP [a,b]

Treatments	6th WAP (control %)					8th WAP (control %)	
	AMARE	DATST	POROL	CHEAL	CONAR	AMARE	DATST
K. 1	- 4.97 c	- 4.12 c	- 6.54 c	- 3.14 c	- 4.50 c	- 1.52 c	- 0.25 c
K. 2	14.13 b	9.18 b	13.14 b	9.53 b	13.70 b	5.66 b	6.39 b
K. 3	19.30 a	22.33 a	24.61 a	17.83 a	22.85 a	9.25 a	8.98 a

Tab. 5. Effect of different seeding rate treatments on percent of weeds biomass control in 6th and 8th WAP [a,b]

Treatments	6th WAP (control %)					8th WAP (control %)	
	AMARE	DATST	POROL	CHEAL	CONAR	AMARE	DATST
SR. 1	8.61 a	6.41 b	9.27 ab	7.44 b	9.94 a	4.13 a	5.08 a
SR. 2	8.16 a	7.90 b	8.16 b	8.32 a	11.14 a	4.46 a	4.86 a
SR. 3	11.70 a	13.09 a	13.79 a	8.48 a	10.97 a	4.80 a	5.18 a

[a] Abbreviations:. WAP, weeks after planting; K, kill date; SR, seeding rate; [b] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$; [c] K1: Mar. 29th, K2: Apr. 15th, and K3: May. 3rd; [d] SR1: 500, SR2: 750 and SR3: 1000 (kernels/m^2); [e] Bayer codes of *Composite List of Weeds* by Weed Science Society of America (WSSA). Available online at www.wssa.net. AMARE, *Amaranthus retroflexus* L.; DATST, *Datura Stramonium* L.; POROL, *Portulaca oleracea* L.; CHEAL, *Chenopodium album* L.; CONAR, *Convolvulus arvensis* L.

rate treatments on rye biomass production which was too low (Tab. 1) and it is known that mulch mass is an important factor to inhibit weeds (Smeda and Weller, 1996). In other word, in each of the 3 kill dates, effect of seeding rates on rye biomass production and consequently mulch mass, was not noticeable so weed control was not changed significantly. In another experiment conducted by Teasdale and Mohler (2000), weed emergence declined when mulch rate increased.

Among three kill dates of rye which had significant effects on weeds germination and growth, effect of the first kill date was stimulatory instead of inhibitory. It means, this treatment surprisingly increased density and biomass of weeds (Tab. 2 and 4). This could be again described as a function of mulch qualities. As mentioned in Tab. 1, on one hand mulch mass of the first kill date is low (Ranged from 3,100 to 3,350 kg/ha) and on the other hand there is a 76 days interval between rye kill and corn cultivation. As a result, decomposition of rye mulch and leaching will leave very small amount of rye residue and its allelopathic compound in soil. In other studies, stimulatory effect of low rates of allelochemicals on seeds germination and growth is defined. For example, Randhawa *et al.* (2002) tested 4 concentrations of sorghum water extract (SWE) on germination and growth of *Trianthema portulacastrum*. Although concentration of 100% decreased the germination percent to 60 from 75% (control: distilled water), but concentration of 25% increased the germination percent to 80%. Root and shoot length followed the same trend as germination percent at different concentration of SWE. Teasdale and Mohler (2000) also observed that redroot pigweed emergence will be stimulated at mulch mass lower than 2,000 kg/ha and will be decreased at higher mulch rates. So increased germination and growth of weeds in the first kill date of this experiment is probably caused by low mulch mass and low rate of allelopathic compounds.

The second and the third kill dates could effectively control weeds density and biomass (Tab. 2 and 4). As the third kill date was closer to corn cultivation and had the highest biomass (ranged from 9,700 to 10,150 kg/ha), it showed the most inhibiting ability on weeds. These results are in agreement with the results achieved in other experiments. Treadwell *et al.* (2007) found out there is a significant correlation between weeds density and cover crop residue dry weight.

The overall results of this experiment show that although rye cover crop and mulch can control weeds in corn fields, but in order to obtain higher level of weed control to ensure suitable yield production, this method should be combined with other weed management techniques like chemicals or mechanicals. Malik *et al.* (2008) conducted experiments to evaluate the effect of wild radish (*Raphanus raphanistrum*) and rye cover crops, alone and in conjunction with herbicides, on weed control and sweet corn yield. Wild radish and rye cover crops without herbicides reduced total weed density by 35 and 50%, respectively at 4 WAP, but when they were in conjunction with half or full rate of atrazine and s-metolachlor, controlled > 95% of three weed species. Reeves *et al.* (2005) also showed that conjunction of cover crops with herbicides is necessary to control weeds effectively.

Results of this experiment indicate two other reasons that require cover crops and mulches to be combined with other methods for perfect weed management. One reason is that in most of the cases, biomass of weeds was controlled less than their density (Fig. 1). It means that

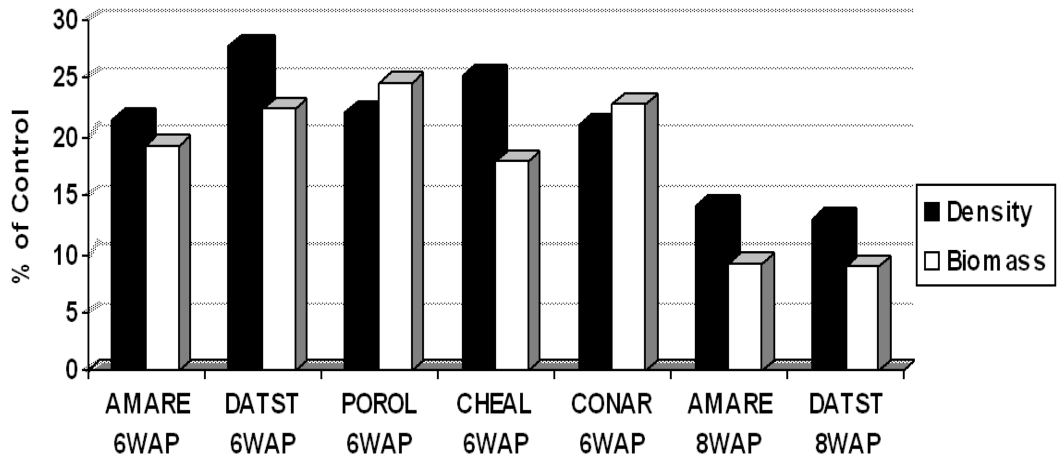

Fig. 1. Comparison of the controlling effect of rye cover crop and mulch (3rd kill date) between weeds density and biomass in 6th and 8th WAP

Abbreviations: WAP, weeks after planting; AMARE, *Amaranthus retroflexus* L.; DATST, *Datura stramonium* L.; POROL, *Portulaca oleracea* L.; CHEAL, *Chenopodium album* L.; CONAR, *Convolvulus arvensis* L.

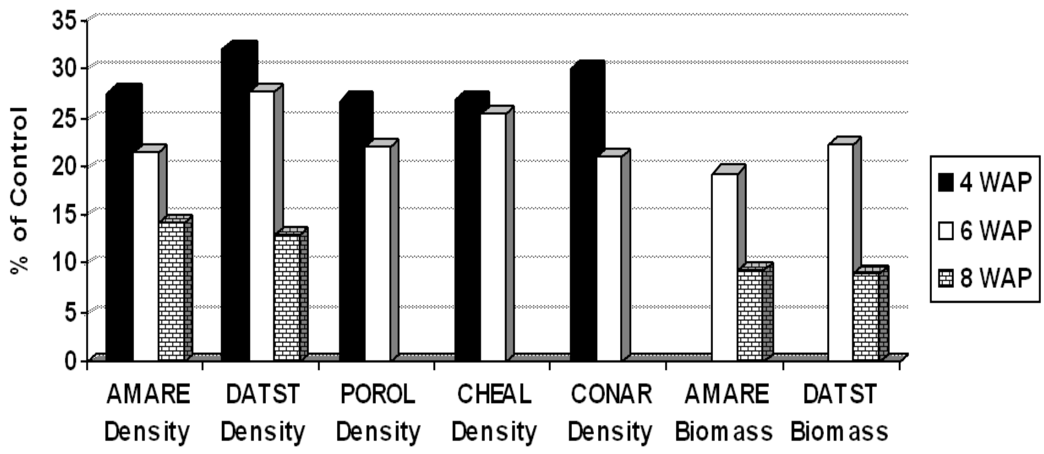

Fig. 2. Reduction of the controlling effect of rye cover crop and mulch (3rd kill date) on weeds density and biomass, in **4th**, **6th** and **8th** WAP

Abbreviations: WAP, weeks after planting; AMARE, *Amaranthus retroflexus* L.; DATST, *Datura stramonium* L.; POROL, *Portulaca oleracea* L.; CHEAL, *Chenopodium album* L.; CONAR, *Convolvulus arvensis* L.

Tab. 6. Effect of different kill date treatments on corn yield and yield components (as percent of improvement compared with weed infested control)[a,b]

Treatments	Plant height	Stem diameter	# Ears per plant	Ear length	Ear diameter	# Rows per ear	# Kernels per row	Aboveground biomass	Ear weight	Grain production	1000 kernels weight	Harvest index (HI)
K. 1[c]	-0.06c	-0.27c	0.00b	-0.22c	0.14c	0.00a	-0.19c	-0.34c	-0.84c	-1.09c	-0.53c	-0.61a
K. 2	4.93b	1.84b	0.00b	4.72b	3.40b	0.26a	5.19b	4.52b	4.53b	4.18b	1.85b	-0.06a
K. 3	10.24a	4.08a	6.67a	8.05a	5.73a	0.48a	9.39a	8.20a	7.98a	7.89a	3.50a	-0.28a
W.F.[d]	19.91	20.41	43.30	34.02	16.82	1.12	42.78	42.71	37.13	39.58	18.66	-2.12

[a] Abbreviations: K, rye kill date; #, number; WF, weed free control; [b] Means in a column followed by the same letter are not significantly different at $P \leq 0.05$;
[c] K1: Mar. 29[th], K2: Apr. 15[th], and K3: May. 3[rd]; [d] Not analyzed, average was taken over 4 replications

cover crops and mulches inhibit weeds germination better than growth. In fact, when fewer weeds seeds germinate, each germinated seed has more available place (otherwise known as niche) to grow. Of course, crops will use some parts of this niche to grow, but weeds will occupy the rest. In an experiment with some similar results, Vasilakoglou *et al.* (2006) concluded that some rye, barley (*Hordeum vulgare* L.) or triticale (*Triticosecale*) cover crops have the ability to suppress germination of weeds seeds, but none of them have any effect on the initial growth of survived annual grasses.

The second reason for the need to combine cover crops and mulches with other methods of weed control is that the effect of rye cover crop and mulch in this study was short-term rather than season-long (Fig. 2). The inhibitory effect on weeds germination and growth declined during weeks after corn planting as decomposition of residues and leaching of allelopathic compounds took place. Similar results were obtained in other experiments. Malik *et al.* (2008) represented that although total weed density was significantly different among cover crop and control treatments in the 4[th] WAP, but in the 8[th] WAP it was the same. Yenish *et al.* (1996) also reported rye cover crop will increase short-term weed control in no-till corn but not season-long control.

Corn Yield Production

Result of ANOVA (data not shown) for corn yield was mostly similar to weeds. Effect of different seeding rates of rye, unlike kill dates, was also non-significant in most of the measured traits. As mentioned previously, effect of rye cover crop and mulch on weeds was short-term and decreased over time in weeks after planting corn. Consequently, it caused a slight improvement in corn yield production compared with weed infested control (Tab. 6.). The third kill date treatment increased grain production 7.89% but weed free treatment increased it 39.58%. It shows a great yield loss caused by weed competition and requires cover crops and mulch to be combined with other weed control methods. Vasilakoglou *et al.* (2006) concluded that some winter cereals have the ability to suppress germination of annual grass weeds and in combination with inter-row cultivation will enhance cotton yield. However using herbicides is essential to maximize cotton yield and to satisfy producers.

Conclusions

Finally, overall results of the experiment show that winter rye cover crop and mulch can help to control weeds. The third kill date of this experiment reduced density of all weeds in the fourth WAP on average 28.73% and their biomass in the sixth WAP on average 21.38%. However, to obtain adequate weed suppression and to prevent corn yield loss, rye cover crop and mulch should be used along with other methods such as chemicals and mechanicals.

References

Anonymous (2007). Crop production statistics. http://www.faostat.fao.org. Accessed: May 9, 2010.

Anonymous (2010). International survey of herbicide resistant weeds. http://www.weedscience.org. Accessed: Apr. 18, 2010.

Barnes, J. P., A. R. Putnam, B. A. Burke and A. J. Aasen (1987). Isolation and characterization of allelochemicals in rye herbage. Phytochemistry 26:1385-1390.

Baumgartner, K., K. L. Steenwerth and L. Vielleux (2008). Cover-crop affect weed communities in a California vineyard. Weed Sci. 56:596-605.

Blackshaw, R. E. and J. R. Moyer (2001). Yellow sweetclover, green manure, and its residues effectively suppress weeds during fallow. Weed Sci. 49:406-413.

Blanco, H. and R. Lal (2008). Principles of soil conservation and management. US., Springer.

Burgos, N. R. and R. E. Talbert (2000). Differential activity of allelochemicals from *Secale cereale* in seedling bioassays. Weed Sci. 48:302-310.

Creamer, N. G., M. A. Bennett, B. R. Stinner, J. Cardina and E. E. Regnier (1996). Mechanisms of weed suppression in cover crop-based production systems. Hortscience 31:410-

413.

Haramoto, E. R. and E. R. Gallandt (2005). Brassica cover cropping: I. effects on weed and crop establishment. Weed Sci. 53:695-701.

Hartwig, N. L. and H. U. Ammon (2002). Cover crops and living mulches. Weed Sci. 50:688-699.

Heap, I. and H. LeBaron (2001). Introduction and overview of resistance. In: Herbicide resistance and world grains, CRC Press pp.1-22.

Helm, J. L. and R. K. Zollinger (1991). Weed control with winter rye. http://www.ag.ndsu.edu. Accessed Aug. 27, 2008.

Johnson, A. M. and G. D. Hoyt (1999). Changes to the soil environment under conservation tillage. HortTechnology 9:380-392.

Liebman, M., C. L. Mohler and C. P. Staver (2004). Ecological management of agricultural weeds. Cambridge, UK., Cambridge University Press.

Lynge, E. (1998). Cancer incidence in Danish phenoxy herbicide workers, 1947-1993. Environmental Health Perspectives 106:683-688.

Malik, M. S., J. K. Norsworthy, A. S. Culpepper, M. B. Riley and W. Bridges, Jr (2008). Use of wild radish (*Raphanus raphanistrum*) and rye cover crops for weed suppression in sweet corn. Weed Sci. 56:588-595.

Martin, C. K. and D. K. Cassel (1992). Soil loss and silage yield for 3 tillage management systems. Production Agriculture 5:581-586.

Menalled, F. D., R. G. Smith, J. T. Dauer and T. B. Fox (2007). Impact of agricultural management on carabid communities and weed seed predation. Agriculture, Ecosystems and Environment 118:49-54.

Mochizuki, M. J., H. M. Van Es and T. Bjorkman (2008). Rye mulch management affects short-term indicators of soil quality in the transition to conservation tillage for cabbage. Hortscience 43 (3):862-867.

Mohler, C. L. (1996). Ecological bases for the cultural control of annual weeds. Production Agriculture 9:468-474.

Monaco, T. J., S. C. Weller and F. M. Ashton (2002). Weed science (4^{th} ed) - principles and practices. New York, US., John Wiley and Sons.

Obi, M. E. (1999). The physical and chemical responses of a degraded sandy clay loam soil to cover crops in southern Nigeria. Plant Soil 211:165-172.

Putnam, A. R. and J. DeFrank (1983). Use of phytotoxic plant residues for selective weed control. Crop Prot. 2:173-181.

Randhawa, M. A., Z. A. Cheema and M. A. Ali (2002). Allelopathic effect of sorghum water extract on the germination and seedling growth of *Trianthema portulacastrum*. International Journal of Agriculture and Biology 4 (3):383-384.

Rapp, H. S., R. R. Bellinder, H. C. Wien and F. M. Vermeylen (2004). Reduced tillage, rye residues, and herbicides influence weed suppression and yield of pumpkins. Weed Technol. 18:953-961.

Reddy, K. N. (2001). Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean (*Glycine max* L.). Weed Technol. 15:660-668.

Reddy, K. N. (2003). Impact of rye cover crop and herbicides on weeds, yield, and net return in narrow-row transgenic and conventional soybean (*Glycine max* L.). Weed Technol. 17:28-35.

Reeves, D. W., A. J. Price and M. G. Patterson (2005). Evaluation of three winter cereals for weed control in conservation-tillage nontransgenic cotton. Weed Technol. 19:731-736.

Ruffo, M. L., D. G. Bullock and G. A. Bollero (2004). Soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agron. J. 96:800-805.

Shanahan, M., C. Jordan, S. Trent and J. Williams (2003). What's your poison? Environmental justice Foundation: http://www.ejfoundation.org. Accessed: Jan. 7, 2008.

Shearin, A. F., S. C. Reberg-Horton and E. R. Gallandt (2008). Cover crop effects on the activity-density of the weed seed predator *Harpalus rufipes* (Coleoptera: *Carabidae*). Weed Sci. 56:442-450.

Smeda, R. J. and S. C. Weller (1996). Use of rye cover crops for weed management in processing tomatoes. Weed Sci. 44:596-602.

Teasdale, J. R. and C. L. Mohler (2000). The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci. 48:385-392.

Teasdale, J. R., L. O. Brandsaeter, A. Calegari and F. Skora Neto (2007). Cover crops and weed management. In: M. K. Upadhyaya and R. E. Blackshaw (Eds), Non-chemical weed management-principles, concepts and technology. UK., CABI pp.49-64.

Treadwell, D. D., N. G. Creamer, J. R. Schultheis and G. D. Hoyt (2007). Cover crop management affects weeds and yield in organically managed sweetpotato systems. Weed Technol. 21:1039-1048.

Vasilakoglou, I., K. Dhima, I. Eleftherohorinos and A. Lithourgidis (2006). Winter cereal cover crop mulches and inter-row cultivation effects on cotton development and grass weed suppression. Agron. J. 98:1290-1297.

Winch, T. (2006). Growing food - a guide to food production. Netherlands, Springer.

Yenish, J. P., A. D. Worsham and A. C. York (1996). Cover crops for herbicide replacement in no-tillage corn (*Zea mays* L.). Weed Technol. 10:815-821.

Zimdhal, R. L. (2007). Fundamentals of weed science (3^{rd} ed). US., Elsevier.