

Effect of Tillage System and Rimsulfuron Application on Weed Flora, Arbuscular Mycorrhizal (AM) Root Colonization and Yield of Maize (*Zea mays* L.)

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Abstract

Field experiments were conducted to determine the effects of tillage system and rimsulfuron application on weed flora and growth of maize (*Zea mays* L. Mitic F1) at a site with no history of pesticide use for the last 5 years. A randomized complete block design was employed with three replicates per treatment (conventional tillage without rimsulfuron application (control), no-tillage with rimsulfuron application (NT+Rim) and conventional tillage with rimsulfuron application (CT+Rim)). The lowest leaf area index, dry weight and yield of maize were recorded in NT+Rim plots. In addition, the highest soil bulk density was determined in NT+Rim plots. Moreover, the rimsulfuron application resulted in significant reduction in the root growth and arbuscular mycorrhizal (AM) colonization. The lowest root biomass, root length density, root surface and AM root colonization was found in CT+Rim plots. The lowest weed number and biomass was also observed at CT+Rim plots. Sustainability yield index (SYI) shown that the maize crop is more stable under conventional tillage compared with no-tillage. Our results indicated that root growth was reduced significant by rimsulfuron application but statistically significant lower maize yield was obtained in no-tillage system.

Keywords: conventional tillage, growth, herbicides, maize, no-tillage, sustainability

Introduction

Rimsulfuron is a sulfonylurea herbicide for post emergence use in maize to control grasses and some broadleaves weeds. Similar to other sulfonylureas, the site of action of rimsulfuron is acetolactate synthase (ALS), an enzyme in branched-chain amino acid biosynthesis (Koeppel *et al.*, 2000). Data obtained by other researchers clearly demonstrated the beneficial effects of rimsulfuron application on weed control and yield of maize (Auskalniene and Auskalnis, 2003; Chikoye *et al.*, 2007; Sikkema *et al.*, 2007). Moreover, Triantafyllidis *et al.* (2006) reported that rimsulfuron application decreased in growing of root system. Alla *et al.* (2007) have also observed that recommended field dose of rimsulfuron reduced shoot fresh and dry weight of 10-day-old maize plants as well as leaf protein content. In addition, Chikoye *et al.* (2007) reported that rimsulfuron did not cause any visible phytotoxicity on the maize at any dosage. Moreover, there are limited published

data on the combination effects of tillage and herbicides application on weed flora and growth of crops (Rapp *et al.*, 2007; Ritter and Menbere, 2001; Streit *et al.*, 2002).

Tillage systems affect soils properties (Bilalis *et al.*, 2011). Bhattacharyya *et al.* (2009) reported that no-tillage increase bulk density, mean weight diameter and the proportion of macroaggregate fractions in soil compared with conventional system (CT). No tillage has been adopted worldwide as a strategy to reduce the negative effects of soil erosion in conventional system (Cavaliere *et al.*, 2009). Moreover, Cavaliere *et al.* (2009) reported that the long-term use of no-tillage resulted in increases of organic carbon and pore connectivity. Fabrizzi *et al.* (2005) have also found that penetration resistance showed differences between tillage systems, being higher under no-tillage at all sampling depths.

Moreover, tillage practices that reduce soil disturbance affect weed community dynamics and crop-weed interference (Efthimiadou *et al.*, 2009). Bilalis *et al.* (2001 a) re-

ported that perennial weeds had higher density under the no-tillage system. Moreover, tillage intensity influences growth and yield of maize (Banda, 1997; Fabrizzi *et al.*, 2005; Karumatilake *et al.*, 1997; Materechera and Mloza-Qin *et al.*, 2006).

Arbuscular mycorrhizal (AM) fungi are ubiquitous in agricultural soils. These fungi play an important role in plant nutrition and soil conservation (Kabir, 2005). AM fungi improve the host plants ability to absorb nutrients, especially phosphorus and several other macronutrients (Shabani *et al.*, 2011). Data obtained by other researchers clearly demonstrated the effects of tillage intensity (Borie *et al.*, 2006; Kabir, 2005; Mozafar *et al.*, 2000) on AM root colonization. In addition, there is a lack of information on how herbicides affect the AM root colonization (Abd-Alla *et al.*, 2000; Rejon *et al.*, 1997). Inhibition of mycorrhizal colonization by herbicide may influence crop growth and productivity (Stoklosa *et al.*, 2011).

The main objective of this study was to evaluate the effects of tillage system and rimsulfuron application on weed flora, growth and yield of maize (*Zea mays* L. Mitic F1). Also, we intended to evaluate the effects of tillage intensity and rimsulfuron application on mycorrhizal root colonization of maize.

Materials and methods

Experimental design

The experiment field was established in the Agrinio area at West Greece, during 2006 and 2007 and in a site with no history of pesticide use for the last 5 years. The soil type was a silt loam (46.6% sand, 34.1% silt, and 19.3% clay) with 1.68% organic matter and a pH of 6.24. The total area of the field was approximately 2500 m². The crop cultivated before maize was wheat (*Triticum durum* cv. 'Simeto'). The experiment design was completed randomized block with 3 replications. Each block was divided in three subplot (control: conventional tillage without rimsulfuron application, No-tillage with rimsulfuron application (NT+Rim) and conventional tillage with rimsulfuron application (CT+Rim)).

During the experiment the following tillage systems were adopted:

a) conventional tillage (CT), i.e. mouldboard ploughing at a depth of 20-25 cm on the 10th and 13th of August (in 2005 and 2006 respectively), followed by one rotary hoeing at 5-10 cm on the 15th and 20th of April (in 2006 and 2007 respectively);

b) no-tillage (NT), i.e. seeding in 5 cm-wide slots cut with a hand tool. In this tillage system wheat mulch was remained on soil surface.

Maize (*Zea mays* L. Mitic F1) was sown by hand in rows of 75 cm apart at a depth of 3 cm. Maize was planted at an approximate density of 88,000 plants ha⁻¹. The field was sown on 20 April 2006 and 25 April 2007. Rimsulfuron (Rush 25WG: DuPont) was applied 35 days after

the sowing date (DAS) of maize in dose of 12.5 g active ingredient ha⁻¹. Weeds, in control plots, were controlled by hand, at 35 DAS.

Irrigation and fertilization

The irrigation was begun in early-June and, until early September; the field area was irrigated 9 times. A drip irrigation system was set up on plots. The drip system consisted of laterals with 20 mm diameter with in-line drippers and at 0.40 m distance. The drippers had a discharge rate of 4 l h⁻¹ under an operation pressure of 1 atm. According to soil analysis (NO₃-N 10.3 mg kg⁻¹ soil, P 17.1 mg kg⁻¹ soil, K 251 mg kg⁻¹ soil), in the conventional plots, 800 kg ha⁻¹ of fertilizer (20-10-10: N-P₂O₅-K₂O) was applied before sowing.

Sampling and measurements

Soil bulk density (BD) was determined, at 140 days after sowing, for each plot by collecting undisturbed soil cores from 0-35 cm depth using 100 cm³ -cylinders (5 cm height and 5.04 cm diameter) (Lutz, 1947).

For the computation of dry weight of plants, 10 plants were randomly selected at in each plot, 140 days after sowing. The dry weights of all plant parts were determined after drying for 48 h at 70°C. Leaf area measurements were taken, 140 days after planting. Plants were destructively sampled and leaf area was measured by using an automatic leaf area meter (Delta-T Devices Ltd). The results on a per plant basis were converted into leaf area index (LAI) by multiplying by the average crop density of each plot. To define yield the plants were harvested at 2 m in two different places of each plot, 140 days after sowing at 14% seed moisture.

The quantitative assessment of the sustainability of the agricultural practice developed by Singh *et al.* (1990). The sustainable yield index (SYI) was calculated as follows:

$$SYI = \frac{Y_m - S_d}{Y_{max}}$$

where Y_m is the mean yield, 'S_d' the standard deviation and Y_{max} is the maximum yield obtained under a set of management practices.

Root samples were collected 140 days after sowing and from the 0-35 cm layer by using a cylindrical auger (25 cm length, 10 cm diameter) at the midpoint between successive plants within a row. Firstly, roots were separated from the soil by soaking the samples overnight in 30 ml of a 0.5% solution of sodium hexametaphosphate. Afterwards, the samples were stirred for 5 min and washed over a 5 mm mesh-sieve. The roots thus held on the sieves were decanted into a 0.1% trypan blue FAA staining solution (mixture of 10% formalin, 50% ethanol and 5% acetic acid solutions). For the determination of root length density (RLD) and root surface (RS), the stained root samples were placed on a high resolution scanner (Hewlett Packard 4c, Palo Alto, CA, USA) and images captured using Delta-T software was used, (Delta-T Scan version 2.04;

Delta-T Devices Ltd, Burwell, Cambridge, UK). The root dry weight (RDW) was determined after drying for 48 h at 70°C.

The second root samples were cleaned and stained with trypan blue in lactophenol, according to the method of Phillips and Hayman (1970). The percentage of root length colonized by AM fungi was determined microscopically with the gridline-intersection method at a magnification of $\times 30-40$ (Giovannetti and Mosse, 1980).

The number and dry weight of weeds were also assessed. Weeds were measured 20 days after herbicide application. A 1 m \times 1 m quadrat was used, 3 times per plot. All weeds were collected from the measured area and weighted in order to determine the dry matter. The species diversity of weed groups was characterized using Shannon-Weiner's (H) and Simpson's indices (D) (Booth *et al.* 2003; Krebs, 1978):

$$H = -\sum (P_i)(\ln P_i)$$

$$D = 1/\sum P_i^2$$

where P_i is the fraction of the weed density belonging to the i^{th} species in a given group. The indices are increased either by having additional unique species, or by having greater species evenness. The population has a maximum index only when each species in the population is evenly represented. For calculation of this indices the software Species Diversity and Richness III (Pisces Conservation Ltd., 2002) was used.

Statistical Analysis

For calculating analysis of variance and comparisons of means the software Statsoft was used. The LSD test was used to detect and separate the mean treatment differences. All comparisons were made at the 5% level of significance.

Results and discussion

Weed flora

Rimsulfuron is a sulfonylurea herbicide for post emergence use in maize to control grasses and some broadleaves weeds. Our results indicate that the highest weed density (47.25 weeds m^{-2} and 39.76 weeds m^{-2} , in 2006 and 2007, respectively) and weed biomass were determined for the control treatment (Tab. 1). Also, there were significant differences between CT+Rim and NT+Rim ($p < 0.05$) treatments. The lowest weed density and biomass was recorded in CT+Rim plots. Rimsulfuron application provides excellent control of *Amaranthus retroflexus* L. and *Echinochloa crus-galli* (L.) P. Beauv. which has the highest density.

Chikoye *et al.* (2007) reported that there was a rapid increase in weed control as the dosage of rimsulfuron increased from 0 to 20 g ha^{-1} . Weed control was not improved at rates higher than 20 g ha^{-1} . Also, Auskalniene and Auskalnis (2003) observed that rimsulfuron was effective against *Echinochloa crus-galli*. Koeppe *et al.* (2000) have also reported that maize metabolized rimsulfuron rapidly, with a half-life of $< 1\text{h}$, while the sensitive species *Sorghum halepense* (L.) Pers., *Amaranthus retroflexus* L. and *Digitaria sanguinalis* (L.) Scop. metabolized rimsulfuron slowly, with half-lives of 38, > 48 and 27 h, respectively.

The density of weeds in NT+Rim treatment was lower than in control (conventional tillage) and higher than in CT+Rim. The main reasons for lower efficacy of rimsulfuron in no-tillage system may be attributed to wheat residues. The wheat residues were left on the field in no-tillage but were incorporated into the soil in conventional tillage. Thus, wheat mulch appeared to protect some weeds by rimsulfuron action. There is a lack of information on how tillage systems, especially no-tillage, affect the herbicide efficacy. Streit *et al.* (2000) observed that post-emergence

Tab. 1. Influence of tillage system and rimsulfuron application (Control: conventional tillage without herbicide application, NT+Rim: no-tillage with herbicide application, CT+Rim: conventional tillage with herbicide application) on weed density (no m^{-2}), weed biomass (kg ha^{-1}), Shannon-Weiner index and Simpson index of maize crop

Treatments	Weed density		Weed biomass	
	2006	2007	2006	2007
Control	47.25a	39.76a	50.21a	48.43a
NT+Rim	18.45b	17.54b	22.87b	21.67b
CT+Rim	5.87c	6.32c	7.65c	8.34c
LSD ($p=0.05$)	8.98	11.21	4.54	3.67
Treatments	Shannon-Weiner's index		Simpson index	
	2006	2007	2006	2007
Control	2.89a	2.94a	1.38a	1.48a
NT+Rim	3.32b	3.21b	1.54b	1.63b
CT+Rim	3.87c	4.02c	1.87c	1.91c
LSD ($p=0.05$)	0.23	0.19	0.14	0.21

Means in each column followed by the same letter are not significantly different. The LSD ($p=0.05$) are also shown

weed control was more efficient than pre-emergence weed control regardless of the tillage system. In addition, Krausz *et al.* (2000) observed that grass control in no-till maize was affected by application time rather than herbicide. Rimsulfuron plus thifensulfuron applied post-emergence provided 90 to 97% control of giant foxtail (*Setaria faberi* (L.) P. Beauv.) and barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.).

Moreover, the lowest values of Shannon-Weiner's and Simpson indices were determined for the control treatment (Tab. 1). These indices are increased either by having additional unique species, or by having greater species evenness. Mas and Verdu (2003) noted that the highest Shannon-Wiener diversity index was obtained for the no-tilled weed community, and was related to the highest richness and highest evenness. In the CT+Rim treatment, was recorded the highest values, so weed flora in this treatment was shown high species evenness because rimsulfuron was controlled the weeds, *Amaranthus retroflexus* L. and *Echinochloa crus-galli* (L.) P. Beauv., which has the highest density in other treatments.

Maize growth and Yield

Tillage intensity and the application of rimsulfuron had a significantly effect on maize root growth. In both years, the highest dry weight of roots, root length density (16.87 cm cm⁻³ and 20.11 cm cm⁻³, in 2006 and 2007, respectively) and root surface were determined for the control treatment (Tab. 2). Also, there were significant differences between CT+Rim and NT+Rim ($p < 0.05$) treatments. Root parameters tended to be higher in NT+Rim than in CT+Rim treatment.

Moreover, Qin *et al.* (2006) noted that within soil profile, maize root length density was significant higher under NT than under CT at a depth of 5 cm, whereas it was higher under CT than under NT below 10 cm. Below 50 cm, there was no difference in root length density between

the tillage systems. The limited root system in NT+Rim treatment is attributed to the phytotoxicity of rimsulfuron. There is a lack of information on how herbicides affect root growth (Bilalis *et al.*, 2001 b, Triantafyllidis *et al.*, 2006). Triantafyllidis *et al.* (2006) reported that the rimsulfuron phytotoxicity in root system of maize was higher in plots at the slope of 4% in comparison with the plots at the slope of 0%.

The tillage intensity influenced growth and yield of maize. The application of rimsulfuron had also a significant effect on maize growth. The lowest dry weight (27040 kg ha⁻¹ and 28030 kg ha⁻¹, in 2006 and 2007, respectively) and leaf area index was determined for the NT+Rim treatment (Tab. 3). The dry weight and leaf area index tended to be higher in CT+Rim than in control. Dry weight of maize plants had positive and significant correlation with weed density and weed biomass ($r=0.79^{**}$, $p < 0.01$ and $r=0.87^{**}$, $p < 0.01$, respectively).

Tillage intensity and the application of rimsulfuron had a significantly effect on maize yield. In both years, the lowest yield (11500 kg ha⁻¹ and 10,980 kg ha⁻¹, in 2006 and 2007, respectively) and sustainable yield index was determined in NT+Rim plots (Tab. 3.). Yield tended to be higher in CT+Rim than in control treatment. Yield had positive and significant correlation with weed density and weed biomass ($r=0.81^{**}$, $p < 0.01$ and $r=0.93^{***}$, $p < 0.001$, respectively). Karunatilake *et al.* (2000) found that maize yield was significantly higher under moldboard plow till in 1992, but similar to NT in 1993. Moreover, Ojeniyi and Adekayode (1999) observed that no-tillage could be substitute for mechanized tillage without significant loss in yield of cowpea and maize and soil fertility. The lowest sustainable yield index (SYI) was determined in NT+Rim plots (Fig. 1.). The main reason for lower SYI in no-tillage system may be attributed to dissimilarity of wheat residues on soil surface.

Tab. 2. Influence of tillage system and rimsulfuron application (Control: conventional tillage without herbicide application, NT+Rim: no-tillage with herbicide application, CT+Rim: conventional tillage with herbicide application) on root dry weight (kg ha⁻¹), root length density (cm cm⁻³ of soil), root surface (cm² cm⁻³ of soil) and AM root colonization (% of root surface) of maize crop

Treatments	Root length density		Root Surface	
	2006	2007	2006	2007
Control	16.87a	20.11a	0.95a	0.96a
NT+Rim	14.25b	17.22b	0.84ab	0.78b
CT+Rim	12.10c	13.12c	0.74b	0.66b
LSD ($p=0.05$)	1.32	2.45	0.11	0.16
Treatments	Dry weight of roots		AM root colonization	
	2006	2007	2006	2007
Control	4125a	4235a	32a	35a
NT+Rim	3665b	3782b	22b	23b
CT+Rim	3456b	3501b	18c	16c
LSD ($p=0.05$)	256	342	2.11	3.35

Means in each column followed by the same letter are not significantly different. The LSD ($p=0.05$) are also shown

Tab. 3. Influence of tillage system and rimsulfuron application (Control: conventional tillage without herbicide application, NT+Rim: no-tillage with herbicide application, CT+Rim: conventional tillage with herbicide application) on soil bulk density (g cm^{-3}), dry weight (kg ha^{-1}), leaf area index (LAI) and yield (kg ha^{-1}) of maize crop

Treatments	Soil Bulk Density		Yield	
	2006	2007	2006	2007
Control	1.24a	1.23a	12500a	13340a
NT+Rim	1.45b	1.51b	11500b	10980b
CT+Rim	1.25a	1.19a	13250a	14230a
LSD ($p=0.05$)	0.11	0.09	802.3	984.1

Treatments	Dry Weight		LAI	
	2006	2007	2006	2007
Control	30450a	31540a	2.75a	2.81a
NT+Rim	27040b	28030b	2.28b	2.37b
CT+Rim	32570c	33870c	3.32c	3.41c
LSD ($p=0.05$)	1563	1863	0.35	0.27

Means in each column followed by the same letter are not significantly different. The LSD ($p=0.05$) are also shown

Arbuscular mycorrhizal root colonization

The highest AM root colonization was determined in control plots. The application of rimsulfuron had a significant effect on the AM root colonization, reducing it by up to 43% at conventional system (Tab. 2). The lowest AM root colonization (32% and 35%, in 2006 and 2007, respectively) was determined for the CT+Rim treatment. The AM root colonization tended to be higher in NT+Rim than in CT+Rim. Borie *et al.* (2006) observed that AM spore number and active hyphen length were highest under NT having the greatest incidence on AM root colonization. Maize roots were colonized to a greater extent by mycorrhizal fungi with NT than with CP (chisel plow) or CT treatments (Mozafar *et al.*, 2000). The main reason for lower phytotoxicity of rimsulfuron in no-tillage system may be attributed to soil properties and root growth. In both years, the highest bulk density (1.45% and 1.51%, in 2006 and 2007, respectively) was determined for the NT+Rim treatment (Tab. 3). In addition, there were no significant differences between control and CT+Rim. Also, root parameters were higher under NT+Rim treatment than under CT+Rim. AM root colonization had positive and significant correlation with root length density and root surface ($r=0.81^{**}$, $p<0.01$ and $r=0.94^{***}$, $p<0.001$, respectively).

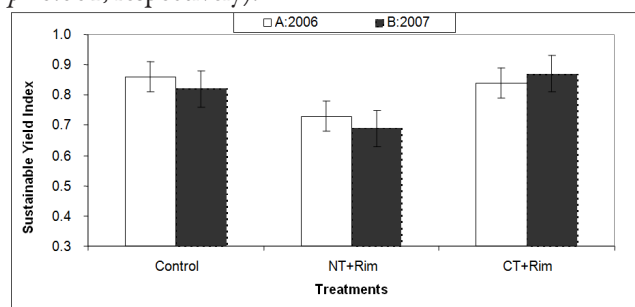


Fig. 1. Influence of tillage system and rimsulfuron application (Control: conventional tillage without herbicide application, NT+Rim: no-tillage with herbicide application, CT+Rim: conventional tillage with herbicide application) on sustainable yield index of maize crop. Error bars indicate $\text{LSD}_{5\%}$.

There is a lack of information on how herbicides affect the AM root colonization (Abd-Alla *et al.*, 2000). Rejon *et al.* (1997) reported that diclofop inhibited root colonization by *Glomus deserticola* in wheat. Santos *et al.* (2006) have also observed that mycorrhizal colonization was affected by the herbicides (flusafop-p-butyl and fomesafen), while the highest value of AM colonization was found under NT. In addition, Stoklosa *et al.* (2011) reported that the isoxaflutole did not inhibit mycorrhizal colonization of maize roots. Moreover, Pasaribu *et al.* (2011) observed that the application of alachlor or glyphosate herbicide at their recommended field application rate were not harmful to mycorrhizal development and symbiotic colonization of plant roots.

Conclusions

The present results indicate that rimsulfuron application had greatly affected the weed density and biomass. Also, the lowest values of Simpson and Shannon-Weiner indices were recorded in control plots. The lowest yield of maize was observed in no-tillage with rimsulfuron application treatment. Sustainability yield index (SYI) shown that the maize crop is more stable under conventional tillage compared with no-tillage. Finally, all the parameters of the root system (root length density, surface and AM root colonization) were negatively influenced by the rimsulfuron.

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