HELIA, **33**, Nr. 52, p.p. 25-36, (2010) UDC 633.854.78:632.954
DOI: 10.2298/HEL1052025S

RESIDUAL EFFECTS OF SPRAYING IMIDAZOLINONE-FAMILY HERBICIDES ON CLEARFIELD®* SUNFLOWER PRODUCTION FROM THE POINT OF VIEW OF CROP ROTATION

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Received: March 18, 2010
Accepted: May 28, 2010

SUMMARY

This research was carried out to determine soil residual effects on stand establishment rate and yield in the rotation crops soft winter wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), winter oil seed rape (WOSR) (*Brassica napus* L.), maize (*Zea mays* L.) and sugar beet (*Beta vulgaris* L.) following Intervix® (33g Imazamox + 15g Imazapyr) spraying in Clearfield® (CL) sunflower (*Helianthus annuus* L.) production.

The experiments were conducted at the Trakya Agricultural Research Institute in Edirne between 2007 and 2009 using a randomized complete block design (stripe plots) with three replications. Five crops were evaluated in crop rotation after spraying Intervix® on Clearfield® sunflower. As the experiment materials, we used the sunflower hybrid Sanay-CL and the cultivars Gelibolu (soft winter wheat, SWW), Bolayir (barley), Elvis (winter oil seed rapeseed, WOSR), Brasco (maize), and Leyla (sugar beet). Nitrogen and phosphorus fertilization were applied according to soil analysis recommendations. Observations were made of the number of plants emerged per m^2, stand establishment, yield, time to flowering, time to physiological maturity, plant height, root length, head diameter, *etc.*, according to plants included in crop rotations.

Based on statistical analysis of the data from crop rotation experiments, CL sunflower plots followed by wheat, barley, and maize were not negatively affected to a significant degree by Intervix® residues in terms of stand establishment and seed yield in either year. In the first year of crop rotation, however, when planting WOSR four months after Intervix® application on CL sunflower plots, stand establishment and seed yield decreased significantly, by 35.7 and 23.7%, respectively. When planting sugar beet nine months after Intervix® application on CL sunflower plots, stand establishment and beet yield decreased by 26.7 and 11.6%, respectively. However, in the second year in the same crop rotations plots, stand establishment and yield of WOSR and

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sugar beet planted after CL sunflower were not affected significantly by Intervix® residues.

Key words: imidazolinone, Clearfield sunflower, wheat, barley, winter oil seed rape, maize, sugar beet, stand establishment

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the important oil seed crops in Turkey. The majority of Turkey's sunflower production (72%) is located in the Trakya-Marmara region. Sunflowers are also grown in the Çukurova region (15%), the Black Sea coast (6%), the Aegean coast (3%), Central Anatolia (3%), and South Eastern Anatolia (1%).

Based on 2008 FAO statistics, the Turkish sunflower acreage, production and yield was 577,958 ha, 992,000 t, and 1716 kg/ha, respectively. This oil seed sunflower production provides approximately 45% of edible oil in Turkey.

Historically, the first oil seed sunflower experiments in Turkey were conducted after the 1st World War and the crop reached a production area of 100,000 ha by 1946. Large-scale production of oil seed sunflower began in about 1943 and had reached 168,000 ha by 1956. This peak was followed by a decline to 81,000 ha in 1962, largely because of the weed problem caused by broomrape (*Orobanche cumane* Wallr.), a seed–producing root parasite. Resistance to this parasite was introduced with the Russian varieties VNIIMK 1646 and VNIIMK 8931. The new varieties led to a rapid recovery and an almost explosive increase in sunflower acreage to 495,000 ha in 1972. After the 1980s, open-pollinated sunflower cultivars like VNIIMK-8931 became susceptible to new races of broomrape in the Trakya region of Turkey (Süzer, 1998).

Today, newly developed sunflower hybrids genetically resistant to broomrape and Clearfield® (CL) sunflowers are grown in Turkey. CL sunflower varieties occupy about 25% of Turkey's sunflower acreage. The features of Clearfield® technology in sunflower production can provide a broad spectrum of post-emergence control of weeds and all broomrape races in all tillage systems. Clearfield® technology offers many advantages to growers, particularly with the control of flushing and late-emerging weeds. However, severe drought in some years raises concerns for carryover problems on rotational crops.

In field conditions, soils with a higher organic matter and clay content tend to have a higher moisture holding capacity. Generally, the population of soil microbial flora and fauna is larger and more active in soils with a higher soil moisture level, organic content, and temperature. The breakdown of herbicide residues is accelerated in situations where microbial populations flourish. With Clearfield® technology, the amount and distribution of moisture (precipitation plus irrigation) received during the growing season(s) between the herbicide applications and re-cropping to susceptible plants is the most important factor determining the rate of residue degradation. Degradation is accelerated in soils with a high moisture content. Higher precipitation and/or irrigation amounts increase available soil moisture, which in turn increases soil microbial activity and the rate of herbicide breakdown.

The rate of pesticide breakdown in field conditions depends on soil moisture and temperature, which are very important factors in determining the rate of pesticide breakdown. There are different mechanisms which determine the environmental fate of a herbicide such as volatilization, breakdown from sunlight (photolysis), leaching, *etc*. However, the two main mechanisms of herbicide degradation are microbial and chemical hydrolysis. These two processes are dependent on soil water and temperature. However, soil moisture is more critical with herbicides that require microbes for degradation (Streck, 2005). Soil microbes thrive in warm, moist soils, which results in faster degradation. It is estimated that there is a two- to three-fold increase in chemical half-life with a 10°C decrease in temperature and a one-and-a-half to two-fold increase in chemical half-life if soil moisture content is reduced by a factor of two (Walker, 1987).

In field conditions, soil properties such as organic matter content, soil moisture, soil texture, and soil pH play an important role in the carryover potential of residual herbicides (Walker, 1987). With Clearfield® technology, herbicide adsorption to organic matter may reduce its bioavailability and the moisture holding capacity of high organic matter soils makes them conducive to increased microbial activity. The importance of soil organic matter in reducing carryover potential has been shown in studies conducted on sulfosulfuron and flucarbazone (Moyer and Hamman, 2001; Eliason *et al*., 2002). The effect of clay content on herbicide residues is similar to organic matter in that it tends to adsorb the herbicide as well as improve the water-holding capacity.

Soil pH is another factor affecting the residual characteristics of some herbicides in field conditions. A low soil pH (less than 7.0) tends to increase the persistence of imidazolinone herbicides such as imazethapyr, imazamethabenz, and imazamox. Imidazolinone herbicides tend to be more adsorbed under acidic (low soil pH) conditions, which reduces their availability for microbial degradation (Loux and Reese, 1992). Extended carryover of imidazolinone herbicides in acidic soils may also be related to their sorption-desorption characteristics.

Rotating to different crops such as oil seed sunflower after wheat, barley, maize and sugar beet usually results in higher grain yields in field production. Even greater benefits are usually obtained by rotating two distinctly unrelated crops, such as oil seed sunflowers planted on land where the previous crop was a cereal. Some of the more important beneficial effects that can be obtained from a well-planned sunflower crop rotation are reduced broomrape and pest problems, beneficial residual herbicide carryover, improved soil fertility, improvements in soil tilth and aggregate stability, soil water management, reduction of soil erosion, and reduction of allelopathic or phytotoxic effects.

In sunflower production, crop rotations can be used to cause shifts in weed populations. Certain weed species in field conditions can be suppressed by competition from the crop raised or by the selective use of herbicides. For example, wild mustard populations can be reduced by selective treatment of cereals grown in rotation with row crops such as CL sunflower. Grass weed populations, which often cause problems in cereals, can be reduced by the use of the appropriate herbicide in the previous row crop such as CL sunflower.

In crop rotations, herbicides can have both beneficial and harmful carryover residual effects on a subsequent crop. Therefore, planning the correct sequence of herbicide usage together with crop selection has become a necessary part of rotation management in agriculture.

The objective of this research was to determine the soil residual effects on rotation crops, soft winter wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), winter oil seed rape (WOSR) (*Brasscica napus* L.), maize (*Zea mays* L.) and sugar beet (*Beta vulgaris* L.) stand establishment rate and yield after spraying with the imadazolinone-family herbicides Intervix® (33 g Imazamox + 15 g Imazapyr) in Clearfield® (CL) sunflower (*Helianthus annuus* L.) production.

MATERIALS AND METHODS

This research was conducted over a period of three years (2007-2009) in a stationary experiment area at the Trakya Agricultural Research Institute, which is located in the European part of Turkey. The main properties of soil used in the field experiments are presented in Table 1. The fertilizer used in the experiment area was in accordance with the results of soil analyses. The experiment was established in a Randomized Complete Block Design (stripe plots) with three replications and 30 plots in total. Each plot was set up in planting at 5.0 m × 10 m = 50.0 m^2 in all rotation crops.

As the experiment materials, we used the sunflower hybrid Sanay-CL and the cultivars Gelibolu (soft winter wheat (SWW)), Bolayir (barley), Elvis (winter oil seed rapeseed (WOSR)), Brasco (maize), and Leyla (sugar beet).

In the first year of the crop rotation experiment, Sanay-CL was planted on all 30 plots (15 treatments + 15 standards). Planting was done on April 4, 2007 using a pneumatic sunflower planter with an intra-row spacing of 30 cm and a row-to-row spacing of 70 cm. Intervix® was sprayed in 15 treatments at a dose of 1.25 l/ha when plants reached the eight-leaf stage on May 21, 2007.

Table 1: Main properties of soil used in the field experiments

Year	Depth	Dry/ Wet	Water saturation	pH	Texture class	P_2O_5	K_2O	Ca	Zn	Organic matter
	(cm)		(%)			(ppm)	(ppm)	(ppm)	(ppm)	(%)
2007	0-30	Dry	45	6.16	Silt	24.0	321.0	2442	0.867	1.52
2008	0-30	Dry	40	6.24	Silt	28.0	326.0	2665	0.459	1.61
2009	0-30	Dry	45	6.03	Silt	25.0	336.0	2612	0.659	1.72

After spraying Intervix® on Clearfield® sunflowers in the first year, in the next two growing seasons five crops were evaluated on rotation with five stripe blocks:

1. SWW (soft winter wheat)-WOSR (winter oil seed rape),
2. barley-SWW,
3. WOSR-barley,
4. maize-sugar beet, and
5. sugar beet-maize.

Each block contained three Intervix® treated plots and three untreated control plots.

In the second growing season of the crop rotation experiment Intervix® treated and untreated control plots were WOSR-planted after 4 months, SWW- and barley-planted after 5 months, sugar beet-planted after 9 months, and maize-planted after 11 months. Planting was done randomly in stripe blocks with three replications.

In the third growing season of the crop rotation experiment Intervix® treated and untreated control plots were WOSR-planted after 16 months, SWW- and barley-planted after 17 months, sugar beet-planted after 21 months, and maize-planted after 23 months. Planting was done randomly in stripe blocks with three treated and three untreated replication plots.

In each growing season, observations such as the number of plants emerged per m^2, stand establishment, yield, time to flowering, time to physiological maturity, plant height, spike number per 1 m^2, pods number per plant, root length, head diameter, *etc.*, were taken in all plants included in the crop rotations.

Mean values of crop yields were determined in each plot and analyzed using ANOVA and 1 and 5% levels used for the F-test according to the JMP 5.0.1a statistics program. The mean values were compared with each other using the least significant difference (LSD) method at 5% (Little and Hills, 1978; Russel, 1986).

RESULTS AND DISCUSSION

Shown in Tables 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 are the residual effects spraying imidazolinone-family herbicides on Clearfield® sunflowers had on the rotation crops (winter soft wheat, barley, winter oil seed rape (WOSR), maize, and sugar beet) and stand establishment rate and yield between 2007 and 2009.

Table 2: Mean seed yield and yield components of CL sunflower on Intervix® treated and untreated plots (2007)

No	Treatments	Seed yield	Oil content of seed	Oil yield	Flowering time	Physiological maturity	Plant height	Head diameter	1000 seed weight	Orobanche
		(kg/ha)	(%)	(kg/ha)			(cm)	(cm)	(g)	(%)
1	Intervix® Treatment	2097 a	35.6	729	22.6.07	21.8.07	190	22.0	72.4	0.0
2	Untreated Standard	1952 b	34.7	684	22.6.07	21.8.07	190	21.5	72.0	26.4
LSD (0.05)		98**								
C.V. (%)		4.1								

**: significant at 0.01 level

Oil seed CL sunflower

As seen in Table 2, spraying imidazolinone family herbicides on Clearfield® sunflowers affected seed yield significantly (p≤0.01). In terms of mean values, Intervix® treated plots gave higher seed yields than the untreated control plots. This yield increase in Intervix® treated plots occurred due to better control of broomrape and weeds in the soil.

Soft winter wheat

As seen in Tables 3 and 4, there were no significant differences in seed yield per hectare between the Intervix® treated and untreated control plots for soft winter wheat that was planted according to crop rotation plans after Intervix® application on CL sunflower plots in 2007 and 2008. In 2007, soft winter wheat was planted after 5 months of CL sunflower on Intervix® treated and untreated control parcels, whereas in 2008 it was planted after 17 months.

Table 3: Mean seed yield and yield components of soft winter wheat planted after five months of CL sunflower on Intervix® treated and untreated plots (2007-2008)

No	Treatments	Seed yield	Emerged plants number	Plant height	Flowe-ring time	Spike number	Seed number	1000 seed weight	Test weight	Protein
		(kg/ha)	(1 m²)	(cm)		(1 m²)	(1 spike)	(g)	(kg/hl)	(%)
1	Intervix® Treatment	7013 a	398.6	105	1.5.08	408.6	44	40.15	81.3	12.4
2	Untreated Standard	7159 a	397.6	105	1.5.08	415.0	44	41.36	81.8	12.7
LSD (0.05)		207 ns								
C.V. (%)		4.8								

ns: not significant

Table 4: Mean seed yield and yield components of soft winter wheat planted after 17 months of CL sunflower on Intervix® treated and untreated plots (2008-2009)

No	Treatments	Seed yield	Emerged plants number	Plant height	Flowe-ring time	Spike number	Seed number	1000 Seed weight	Test weight	Protein
		(kg/ha)	(1 m²)	(cm)		(1 m²)	(1 spike)	(g)	(kg/hl)	(%)
1	Intervix® Treatment	6030 a	419.3	105	6.5.09	482.3	40.3	35.44	80.9	11.0
2	Untreated Standard	6126 a	417.3	105	6.5.09	483.3	40.6	37.55	79.9	11.4
LSD (0.05)		1203 ns								
C.V. (%)		5.6								

ns: not significant

Barley

With barley, as seen in Table 5 and 6, there were no significant differences in seed yield per hectare between Intervix® treated and untreated control parcels that were planted according to crop rotation plans after Intervix® application on CL sunflower plots in 2007 and 2008. In 2007, the barley crop was planted after 5 months of CL sunflower on Intervix® treated and untreated control plots. In 2008, it was planted after 17 months.

Table 5: Mean seed yield and yield components of barley planted after five months of CL sunflower on Intervix® treated and untreated plots (2007-2008)

No	Treatments	Seed yield	Emerged plants no.	Plant height	Flowe-ring time	Spike number	Seed number	1000 seed weight	Test weight	Protein
		(kg/ha)	(1 m^2)	(cm)		(1 m^2)	(1 spike)	(g)	(kg/hl)	(%)
1	Intervix® Treatment	6215 a	444.6	95	25.4.08	543	32	38.17	60.3	11.4
2	Untreated Standard	6298 a	447.0	95	25.4.08	545	33	38.50	61.4	11.8
LSD (0.05)		335 ^{ns}								
C.V. (%)		4.5								

ns: not significant

Table 6: Mean seed yield and yield components of barley planted after 17 months of CL sunflower on Intervix® treated and untreated plots (2008-2009)

No	Treatments	Seed yield	Emerged plants no.	Plant height	Flowe-ring time	Spike number	Seed number	1000 Seed weight	Test weight	Protein
		(kg/ha)	(1 m^2)	(cm)		(1 m^2)	(1 spike)	(g)	(kg/hl)	(%)
1	Intervix® Treatment	7334 a	480.6	100	21.4.09	534.0	27	40.78	60.1	9.9
2	Untreated Standard	6771 a	476.6	100	21.4.09	535.0	26	42.87	63.9	10.0
LSD (0.05)		2029^{ns}								
C.V. (%)		8.5								

ns: not significant

Winter oil seed rape

For winter oil seed rape (WOSR), as seen in Table 7, significant differences were observed in seed yield per hectare between Intervix® treated and untreated control plots that were planted according to crop rotation plans four months after Intervix® application on CL sunflower plots in 2007. In the first year of crop rotation, when winter rapeseed was sown four months after Intervix® application on CL sunflower plots, stand establishment and seed yield decreased significantly, by 35.7 and 23.3%, respectively.

However, in the second year, 16 months after Intervix® spraying on CL sunflower plots in 2008, stand establishment and seed yield of winter rapeseed were not affected significantly by herbicide residues (Table 8). This was because Intervix® herbicide decomposition occurred due to enough rainfall during the 16 months. Herbicides decomposition takes a lot of time if soil organic mater is less than 1%, especially in sandy soils.

Table 7: Mean seed yield and yield components of winter oil seed rape planted after four months of CL sunflower on Intervix® treated and untreated plots (2007-2008)

No	Treatments	Seed yield	Oil content of seed	Oil yield	1000 seed weight	Emerged plants number	Full flowering	Physiological maturity	Plant height	Number of branches per plant	Number of pods per plant	Number of seeds per pod
		(kg/ha)	(%)	(kg/ha)	(g)	(1 m^2)			(cm)			
1	Intervix® Treatment	2777 ab	41.3	1146	3.84	47	12.04.08	11.06.08	155	7	127	26
2	Untreated Standard	3621a	46.2	1672	3.60	73	12.04.08	11.06.08	170	6	125	26
LSD (0.05)		947*										
CV(%)		8.4										

*: significant at 0.05 level

Table 8: Mean seed yield and yield components of winter oil seed rape planted after 16 months of CL sunflower on Intervix® treated and untreated plots (2008-2009)

No	Treatments	Seed yield	Oil content of seed	Oil yield	1000 seed weight	Emerged plants number	Full flowering	Physiological maturity	Plant height	Number of branches per plant	Number of pods per plant	Number of seeds per pod
		(kg/ha)	(%)	(kg/ha)	(g)	(1 m^2)			(cm)			
1	Intervix® Treatment	2780 a	41.3	1148	2.78	119	16.04.08	12.06.08	175	5	129	24
2	Untreated Standard	2808 a	43.6	1224	2.61	120	16.04.08	12.06.08	175	5	130	24
LSD (0.05)		274 ^{ns}										
CV(%)		2.8										

ns: not significant

Maize

For maize, as seen in Table 9 and 10, there were no significant differences in seed yield per hectare between Intervix® treated and untreated control plots that were planted according to crop rotation plans after Intervix® application on CL sunflower plots in 2008 and 2009. In 2008, the maize crop was planted after 11 months of CL sunflower on Intervix® treated and untreated control plots. In 2009, the planting was done after 23 months.

Table 9: Mean seed yield and yield components of maize planted after 11 months of CL sunflower on Intervix® treated and untreated plots (2008)

No	Treatments	Seed yield	Emerged plants number	Tassel emer-gence	Physio-logical maturity	Plant height	Ear height	Harvest time seed moisture	1000 seed weight
		(kg/ha)	(1 m^2)			(cm)	(cm)	(%)	(g)
1	Intervix® Treatment	8016 a	10	25.7.08	8.9.08	1.90	95	18	271.9
2	Untreated standard	8000 a	10	25.7.08	8.9.08	1.90	95	18	262.3
LSD (0.05)		240 ^{ns}							
CV(%)		5.2							

ns: not significant

Table 10: Mean seed yield and yield components of maize planted after 23 months of CL sunflower on Intervix® treated and untreated plots (2009)

No	Treatments	Seed yield	Emerged plants number	Tassel emer-gence	Physio-logical maturity	Plant height	Ear height	Harvest time seed moisture	1000 seed weight
		(kg/ha)	(1 m^2)			(cm)	(cm)	(%)	(g)
1	Intervix® Treatment	8191 a	10	22.7.09	30.8.09	1.95	95	17	264.5
2	Untreated Standard	8178 a	10	22.7.09	30.8.09	1.95	95	17	255.9
LSD (0.05)		1030 ns							
CV(%)		3.6							

ns: not significant

Sugar beet

For sugar beet, as seen in Table 11, there was a significant difference in root yield per hectare between Intervix® treated and untreated control plots that were planted according to crop rotation plans 9 months after Intervix® application on CL sunflower plots in 2008. In the first year of crop rotation, when sugar beet was planted nine months after Intervix® application on CL sunflower plots, stand establishment and root yield decreased significantly, by 26.7 and 11.6%, respectively. It can be concluded that if Intervix® is applied on CL sunflower plots, re-cropping with canola and sugar beet should be avoided in the growing season that follows (Bresnahan *et al.*, 2000).

However, in the second year of planting (2009), 21 months after Intervix® spraying on CL sunflower plots, stand establishment and root yield of sugar beet were not affected significantly by the herbicide residues (Table 12), because Intervix® herbicide decomposition occurred due to enough rainfall during the 21 months. In Trakya conditions, herbicides decomposition takes a lot of time if soil organic mater is less than 1%, especially in sandy soils.

Table 11: Mean seed yield and yield components of sugar beet planted after nine months of CL sunflower on Intervix® treated and untreated plots (2008)

No	Treatments	Root yield (kg/ha)	Emerged plants no. (1 m^2)	Leaf number per plant	Root diameter (cm)	Root length (cm)
1	Intervix® Treatment	50600 ab	11	20	8	30
2	Untreated Standard	57200 a	15	25	8	33
LSD (0.05)		6450 *				
CV (%)		11.5				

*: significant at 0.05 level

Table 12: Mean seed yield and yield components of sugar beet planted after 21 months of CL sunflower on Intervix® treated and untreated plots (2009)

No	Treatments	Root yield (kg/ha)	Emerged plants no. (1 m^2)	Leaf number per plant	Root diameter (cm)	Root length (cm)
1	Intervix® Treatment	57530 a	14	27	8	29
2	Untreated Standard	58000 a	14	27	8	29
LSD (0.05)		6071^{ns}				
CV (%)		3.0				

ns: not significant

CONCLUSIONS

Five major conclusions can be drawn from the results of this three-year study.

Based on statistical analysis of the data from crop rotation experiments, CL sunflower plots followed by soft winter wheat, barley, and maize were not affected significantly by Intervix® residues in terms of stand establishment and seed yield in either year.

In the second year of crop rotation, however, when winter oil seed rape was planted four months after Intervix® application on CL sunflower plots, stand establishment and seed yield decreased significantly, by 35.7 and 23.3%, respectively.

Also, when planting sugar beet nine months after Intervix® application on CL sunflower plots, stand establishment and beet yield decreased by 26.7 and 11.6 %, respectively.

In the third year, in the same crop rotation plots, stand establishment and yield of winter oil seed rape and sugar beet planted after CL sunflowers were not affected significantly by Intervix® residues.

It can be concluded that if Intervix® is applied on CL sunflower plots, winter rapeseed and sugar beet should not be sown in the following growing season.

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