Comparison between conventional and organic weed management: growth and yield of leek (*Allium porrum* L.)

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Abstract

Karkanis A., Bilalis D., Efthimiadou A., Katsenios N., 2012. **Comparison between conventional and organic weed management: growth and yield of leek (*Allium porrum* L.)**. Hort. Sci. (Prague), *39*: 81–88.

Leek is a weak competitor against weeds. A field experiment was conducted to determine the effects of herbicides and mulching on weed flora, growth and yield of a leek crop. A randomized complete block design was employed with five replicates per treatment (control, mulching with barley straw, post-transplant application of the herbicide oxyfluorfen at 360 g a.i./ha and pre-transplant application of pendimethalin at 1,650 g a.i./ha). The order of weed sensitivity to mulches was black nightshade (72–85%), venice mallow (80%) > redroot pigweed (70–74%), barnyardgrass (67–77%) > jimsonweed (65%) > common purslane (42–45%). Oxyfluorfen had the highest control of jimsonweed, venice mallow and common purslane. There were no significant effects of the pendimethalin treatment on weed control ratings of jimsonweed, venice mallow and field bindweed. Injury symptoms (small white spots) appeared on leek leaves exposed to oxyfluorfen. The highest yield of leek was recorded with the oxyfluorfen application. Our results indicate that mulching and oxyfluorfen application provides satisfactory control of weeds. The use of mulching is an option for the weed management in organic leek crop.

Keywords: herbicides; mulching with barley straw; injury symptoms; light interception; yield

Leek (*Allium porrum* L.) is a vegetable which, along with the onion and garlic, belongs to the Alliaceae family. Weeds represent one of the most important problems in leek production because of their ability to emerge rapidly, shading the crop and competing for water and nutrients (Gilreath et al. 2008). Leek is a weak competitor against weeds, thus requiring high costs for weed management. Tursum et al. (2007) reported that leek should be kept weed free between 7 and 85 days after transplanting to avoid yield losses. Yield reduction depends on multiple factors, including weed species, density and distribution, as well as soil type, moisture and fertility.

In Greece, pendimethalin is the only herbicide registered for pre-transplant application to manage broadleaved and grass weeds in leeks. Therefore, more herbicides need to be identified to widen the available options for leek growers. Onion and garlic labeled herbicides, such as oxyfluorfen, might be potential candidates for weed control in leeks (Gilreath et al. 2008). In Greece, the herbicide oxyfluorfen is registered for broadleaved and grass weed control in eggplant, cabbage, cauliflower, onion, cotton, sunflower and artichoke crops. Cohen et al. (2008) also reported that oxyfluorfen can be considered safe for grafted watermelon and effective for weed control in this crop.

Management methods that reduce the requirement for herbicides are needed to reduce adverse environmental impacts. Herbicides can cause crop injury (Bilalis et al. 2001). Moreover, there is a keen interest in developing alternative methods of natural weed control in organically grown crops (Bilalis et al. 2010), as weed control remain one of the most significant agronomic challenges in the production of organic crops. Weed management is often the most troublesome technical problem to be solved in organic farming, especially in poorly competitive crops like vegetables (Peruzzi et al. 2007). Cultivation and hand hoeing are common practices used in organically grown leek crops. In addition, a cover crop (living mulch) may contribute significantly to weed management (Folgart et al. 2011). Den Hollander et al. (2007) reported that the introduction of a cover crop has significant effects on both the leek crop and the weed infestation level. Mulch may take many forms: loose particles of organic or inorganic matter spread over the soil, or sheets of artificial or natural materials laid on the soil surface. Plant residues from preceding crops may also be used to form a mulch (Bond, Grundy 2001). Mulches on the soil surface are known to suppress weed emergence (Doring et al. 2005; Radics et al. 2006; Kristiansen et al. 2008), but the quantitative relationships between emergence and mulch properties have not been clearly defined (Teasdale, Mohler 2000). In order to be effective, soil cover must be greater than 60% to reduce population density and dry weed biomass (Bilalis et al. 2003). Karaye and Yakubu (2006) observed that for optimum weed control and bulb yield in garlic, 9 t/ha mulching should be used. There is little published information about the response of leek to application of herbicides. For this reason, the objective of this study was to evaluate the efficacy of herbicides in leeks (*Allium porrum* L.). Our study also investigated the effects of barley residues on weed density and biomass.

MATERIAL AND METHODS

Study site

Field experiments were carried out in central Greece (Domokos, 230 km from Athens, 22°33'E and 39°03'N) in 2009 and 2010. Leek (*Allium porrum* L. cv. Bulgarian Giant) was planted. The experimental site had previously been cropped with organic wheat according to organic agriculture guidelines (EC 834/2007) and certified by DIO Certification Body. The soil was clay (50.7% clay, 23.3% silt and 26% sand) with pH = 7.6, 2.2% organic matter and EC 0.32 mS/cm. Some meteorological data of the experimental site are presented in Fig. 1.

Experimental design

A randomized complete block design was employed with five replicates per treatment. The experiment was set up over an area of 500 m^2. The plot size was 5.0 × 5.0 m. The treatments were: non-treated control [at 40 days after transplanting (DAT) the weeds were destroyed manually], mulching [barley residues were spread at soil surface (6 t barley straw/ha)], post-transplant application of oxyfluorfen (GOAL 48 SC, 48% SC; BASF, Athens, Greece) at 360 g a.i./ha and pre-transplant application of pendimethalin (STOMP 330 EC, 33% EC; BASF) at 1,650 g a.i./ha. Oxyfluorfen was applied at 20 DAT. Herbicides were applied with a hand-held field plot sprayer with a 2-m-wide boom with constant

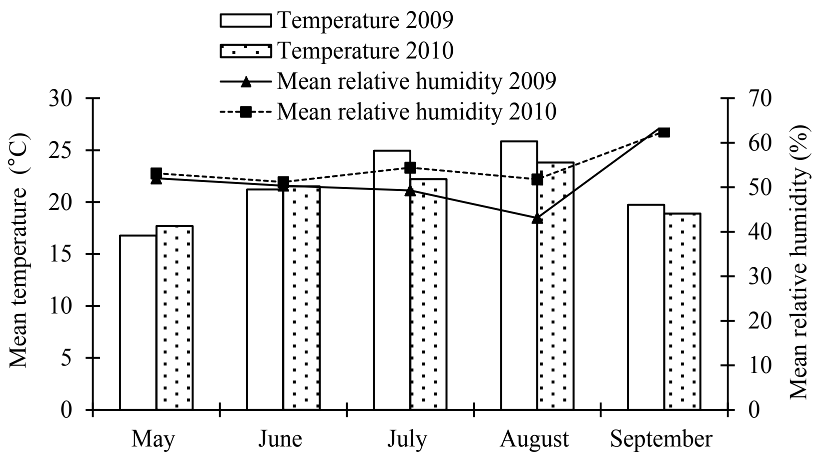

Fig.1. Meteorological data for the experimental site during the experimental periods (May–September, 2009 and 2010)

pressure at 250 kPa, using a total water volume of 300 l/ha and Teejet 8002 nozzles (TeeJet Technologies, Wheaton, USA). After application of oxyfluorfen, the experimental plots were irrigated using overhead sprinklers.

Planting and irrigation

Leek was sown on the 12th February 2009 and the 7th of February 2010 in a seedbed under plastic house conditions. In 2009 and 2010, after hardening, leek seedlings were transplanted on the same dates (2nd May 2009 and 2nd May 2010). Leek was transplanted at a 0.45 m row spacing and 0.10 m plant spacing, at an approximate density of 225,000 plants/ha. A sprinkler irrigation system (overhead irrigation) was used. Each irrigation dose was 50 mm (500 m^3/ha) with an irrigation frequency of 3–5 days, depending on temperature. Each irrigation lasted for 150 min.

Samplings and measurements

The number and dry weight of the dominant weeds were assessed. A wooden square quadrate (0.45 × 0.45 m) was placed at random three times in each plot. Weeds in the 0.45 × 0.45 m area were counted for each species present, and fresh and dry matter determined. Weed assessments were made at 35 and 90 DAT as follows:

1. density per unit area (plants/m^2),
2. weed biomass [dry weight (g/m^2)]: weeds were cut and roots discarded. The remaining material was placed in paper bags in an oven at 65°C for 72 h. Dry matter was then determined,
3. weed control ratings: weed control ratings were assessed using a 0–100% scale, where 0% means no weed control and 100% total weed control. Weed control ratings were calculated as follows:

$$\text{Weed control rating} = \frac{(WDC - WDT) \times 100}{WDC}$$

where:

WDC – weed density obtained in the non-treated plots

WDT – weed density in treated plots

For the determination of height (m), stem diameter (mm) and yield of leek (kg/ha), 5 plants were randomly selected in each plot. Measurements of photosynthetic rate (mol CO_2/m^2s) were undertaken between the hours of 10.30 and 14.30 at 35 DAT, with five measurements per plot. Measurements were made using an LCi Leaf Chamber Analysis System (ADC BioScientific, Ltd., Hoddedson, UK).

Statistical analysis

The data were subjected to statistical analysis according to the randomized complete block design. Differences between treatment means were compared at $P = 5\%$ with ANOVA in order to find the statistically significant differences and then LSDs were used to compare the plots. Weed control ratings were transformed through arc sine square root prior to analysis of variance. The statistical analysis of the data was realized using the Statgraphics Plus 5.1 logistic package (Statpoint Technologies, Inc., Warrenton, USA).

RESULTS AND DISCUSSION

Weed control

The most common species during the two experiments were the broadleaved weeds redroot bigweed (*Amaranthus retroflexus* L.), field bindweed (*Convolvulus arvensis* L.), jimsonweed (*Datura stramonium* L.), venice mallow (*Hibiscum trionum* L.), common purslane (*Portulaca oleracea* L.) and black nightshade (*Solanum nigrum* L.), and the grass weed barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.). Most weeds were controlled by the herbicide oxyfluorfen except for field bindweed (Table 1). The herbicide oxyfluorfen had the best redroot bigweed, jimsonweed, venice mallow, common purslane, black nightshade and barnyardgrass control.

Little information is currently available on weed control in leek crop (Den Hollander et al. 2007; Gilreath et al. 2008). Gilreath et al. (2008) reported that the herbicides providing the most consistent season-long weed control were metolachlor, oxyfluorfen, prodiamine and pendimethalin. The herbicides metolachlor at 2.3 and 4.6 kg/ha, oxyfluorfen at 0.3 and 0.6 kg/ha and prodiamine at 1.7 kg/ha had the highest control of eclipta (*Eclipta alba* (L.) Hassk). In plots treated with metolachlor, oxyfluorfen, prodiamine and pendimethalin, American black nightshade (*Solanum americanum* P. Mill.) and slender amaranth (*Amaranthus viridis* L.) were effectively suppressed. Moreover, Gilreath et al.

Table 1. Effects of herbicides (pendimethalin and oxyfluorfen) and mulching on weed control ratings[1] (%) in leek crop (35 days after transplanting)

	Treatments			
	control	mulching	pendimethalin	oxyfluorfen
2009				
Amaranthus retroflexus	0^{c}	70^{b}	92^{a}	97^{a}
Datura stramonium	0^{c}	65^{b}	0^{c}	89^{a}
Echinochloa crus-galli	0^{c}	67^{b}	80^{a}	87^{a}
Hibiscus trionum	0^{c}	80^{b}	0^{c}	98^{a}
Portulaca oleracea	0^{c}	42^{b}	53^{b}	96^{a}
Solanum nigrum	0^{c}	85^{b}	79^{b}	91^{a}
Convolvulus arvensis	0^{a}	0^{a}	0^{a}	0^{a}
2010				
Amaranthus retroflexus	0^{d}	74^{c}	86^{b}	96^{a}
Datura stramonium	0^{c}	65^{b}	0^{c}	90^{a}
Echinochloa crus-galli	0^{c}	77^{b}	86^{a}	86^{a}
Hibiscus trionum	0^{c}	80^{b}	0^{c}	96^{a}
Portulaca oleracea	0^{c}	45^{b}	50^{b}	95^{a}
Solanum nigrum	0^{c}	72^{b}	76^{b}	96^{a}
Convolvulus arvensis	0^{a}	0^{a}	0^{a}	0^{a}

[1]weed control rating per species is obtained by using 0–100% rating scale, where 0% = no control and 100% = total control; means in each row followed by the same letter are not significantly different

(2008) observed that cinmethylin is not a viable option for weed control in leeks.

The highest population density of weeds was recorded with the control treatment (Table 2). In the control plots, the most frequent weeds were redroot pigweed, venice mallow and common purslane. The herbicide pendimethalin had no effect on jimsonweed and venice mallow population density. The order of weed sensitivity to mulches was black nightshade, venice mallow > redroot pigweed, barnyardgrass > jimsonweed > common purslane. Teasdale and Mohler (1991) reported that the success of emergence through mulches was related to the capacity of seedlings to grow around obstructing mulch elements under limiting light conditions. There were no statistically significant differences between mulching and pendimethalin concerning the population density of weed species common purslane and black nightshade. Both treatments had no effect on field bindweed emergence. Anzalone et al. (2010) found that most weed species were controlled by the mulching materials except purple nutsedge (*Cyperus rotundus* L.). Covering or mulching the soil surface can prevent weed seed germination or physically suppress seedling emergence, but is not effective against the establishment of perennial weeds (Bond, Grundy 2001). Anyszka and Dobrzanski (2006) reported that the early weed suppression provided by cover crop residues can reduce herbicide inputs. Leek can be grown in cover crop residues left on the soil surface, but this requires strong and well-developed transplants.

Crop residues mainly affect the light interception (red to far-red ratio), temperature (diurnal soil temperature) and moisture of the soil. Teasdale and Mohler (1991) reported that spectral analysis from 400 to 1,100 nm showed a slight increase in transmittance through residue as wavelength increased, resulting in a slight lowering of the red (660 nm) to far-red (730 ratio) relative to that of unobstructed sunlight. Seeds perceive light through phytochromes (Kruk et al. 2006). Phytochromes have two photo-interconvertible forms: Pfr (usually the active far-red absorbing form), with maximum absorption at 735 nm; and Pr (the inactive red-absorbing form), with maximum absorption at 665 nm. Exposure of seed to light with a high red to far-red ratio leads to increase of Pfr:Pr

Table 2. Effects of herbicides (pendimethalin and oxyfluorfen) and mulching on population density (plants/m^2) of weeds in leek crop (35 days after transplanting)

	Treatments				LSD*
	control	mulching	pendimethalin	oxyfluorfen	
2009					
Amaranthus retroflexus	26.50^a	8.00^b	2.25^c	0.75^d	0.26
Datura stramonium	9.25^a	3.25^c	8.50^b	1.00^d	0.42
Echinochloa crus-galli	7.50^a	2.50^b	1.50^c	1.00^d	0.29
Hibiscus trionum	13.50^a	2.75^b	11.25^a	0.25^b	2.41
Portulaca oleracea	11.25^a	6.50^b	5.25^b	0.50^c	1.35
Solanum nigrum	8.50^a	1.25^c	1.75^b	0.75^d	0.28
Convolvulus arvensis	2.50^a	2.25^a	2.75^a	2.50^a	0.76
Total	79^a	26.5^c	33.25^b	6.75^d	11.29
2010					
Amaranthus retroflexus	22.50^a	5.75^b	3.25^c	1.00^d	0.32
Datura stramonium	7.75^a	2.75^c	6.75^b	0.75^d	0.56
Echinochloa crus-galli	8.75^a	2.00^b	1.25^c	1.25^c	0.45
Hibiscus trionum	11.25^a	2.25^b	9.75^a	0.5^c	1.57
Portulaca oleracea	9.50^a	5.25^b	4.75^b	0.5^c	0.61
Solanum nigrum	6.25^a	1.75^b	1.50^b	0.25^c	0.35
Convolvulus arvensis	1.50^a	1.25^a	1.5^a	1.75^a	0.55
Total	67.5^a	21^c	28.5^b	6^d	9.25

*(P = 0.05) for treatments are shown; means in each row followed by the same letter are not significantly different

Table 3. Effects of herbicides (pendimethalin and oxyfluorfen) and mulching on weed dry matter production (kg/ha) in leek crop (90 days after transplanting)

	Treatments				LSD*
	control	mulching	pendimethalin	oxyfluorfen	
2009					
Amaranthus retroflexus	202.3^a	112.4^b	29.6^c	8.2^d	3.8
Datura stramonium	29.1^a	14.7^b	30.9^a	4.5^c	2.2
Echinochloa crus-galli	57.8^a	17.8^b	6.2^c	2.3^d	0.9
Hibiscus trionum	22.6^a	8.9^b	23.6^a	1.2^c	3.7
Portulaca oleracea	386.4^a	210.4^b	245.2^b	14.8^c	50.7
Solanum nigrum	26.7^a	15.2^b	12.3^c	2.6^d	2.3
Convolvulus arvensis	15.5^a	13.2^a	17.4^a	18.7^a	6.4
Total	740.4^a	392.6^b	365.2^b	52.3^c	44.7
2010					
Amaranthus retroflexus	194.7^a	105.9^b	32.1^c	7.6^d	3.4
Datura stramonium	25.3^b	16.7^c	34.5^a	4.0^d	2.5
Echinochloa crus-galli	62.5^a	15.6^b	8.1^c	2.5^d	1.2
Hibiscus trionum	18.6^a	6.5^b	20.6^a	1.0^c	3.4
Portulaca oleracea	473.5^a	227.8^b	253.4^b	15.7^c	47.8
Solanum nigrum	21.3^a	14.3^b	10.6^c	2.4^d	1.6
Convolvulus arvensis	14.5^{bc}	10.7^b	18.5^{ac}	20.4^a	5.2
Total	810.4^a	397.5^b	377.8^b	53.6^c	32.3

*(P = 0.05) for treatments are shown; means in each row followed by the same letter are not significantly different

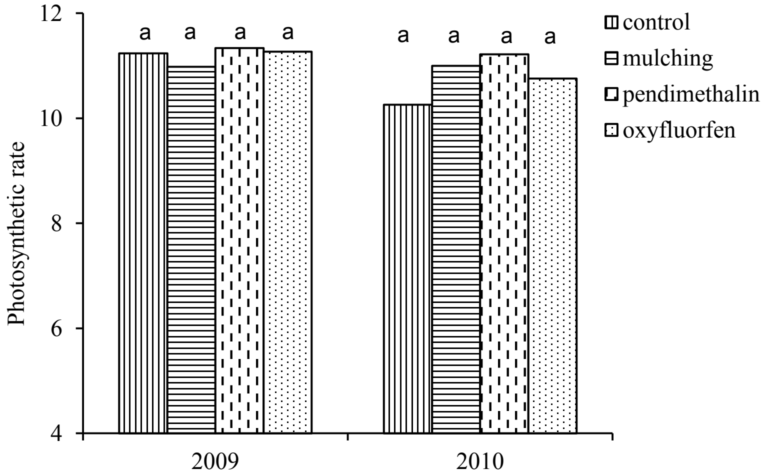

Fig. 2. Effects of herbicides (pendimethalin and oxyfluorfen) and mulching on the photosynthetic rate (μmol CO_2/m^2s) of leek (15 days after oxyfluorfen application). Mean values are shown, and did not differ significantly between treatments in each year

ratios that might be high enough to trigger germination. Teasdale et al. (1991) reported that under no-tillage treatment, rye or hairy vetch residue reduced total weed density by an average of 78% compared to the treatment without cover crop, when cover crop exceeded 300 g/m^2 and when residue covered more than 90% of the soil. Moreover, Jodaugiene et al. (2006) reported that wood chips, peat, and straw mulches had the strongest influence on the decrease of weed germination; however, it is important to ensure that mulches are not infected with weed seeds.

The lowest weed biomass was recorded with oxyfulorfen treatment (Table 3). There were significant differences between mulching and pendimethalin concerning weed biomass. For the weeds jimsonweed, venice mallow, common purslane and field bindweed, the plots treated with barley straw gave lower biomass than those under pendimethalin treatment. In contrast, in the plots treated with pendimethalin, redroot bigweed, black nightshade and barnyardgrass gave lower biomass than in those treated with barley mulch.

Crop growth and yield

The lowest height (0.596 m), stem diameter (25.02 mm) and yield (32,340 kg/ha) of leek were recorded for the control (Table 4). At 45 DAT, injury symptoms (small white spots) appeared on leek leaves exposed to oxyfluorfen application. Ghosheh (2004) also observed that injury symptoms, of necrosis or burning, appeared on onion leaves exposed to post-emergence applications oxyfluofen. Loken and Hatterman-Valenti (2010) reported that applications of oxyfluorfen resulted in approximately 15% injury to onion crop, regardless of the herbicide rate or the number of

Table 4. Effects of herbicides (pendimethalin and oxyfluorfen) and mulching on height (m), stem diameter (mm) and yield (kg/ha) of leek (120 days after transplanting)

	Treatments				LSD*
	control	mulching	pendimethalin	oxyfluorfen	
2009					
Height	0.596^c	0.725^b	0.745^b	0.834^a	0.341
Stem diameter	25.02^c	30.23^b	31.05^b	33.72^a	1.31
Yield	32,340^c	47,580^b	51,040^b	62,500^a	3,972.3
2010					
Height	63.7^c	77.9^b	76.3^b	89.6^a	4.56
Stem diameter	26.78^d	29.85^c	31.46^b	35.23^a	1.45
Yield	34,520^c	51,200^b	53,750^b	67,400^a	4583.1

*(P = 0.05) for treatments are shown; means in each row followed by the same letter are not significantly different

applications. Onion treated with oxyfluorfen had the greatest total yield. Moreover, Norsworthy et al. (2007) reported that oxyfluorfen applied after crop emergence caused less than 10% injury in both years to green onion. Injury from oxyfluorfen had no effect on photosynthetic rate (Fig. 2), growth nor yield of leek (Table 4). The highest height (0.896 m), stem diameter (35.23 mm) and yield (67,400 kg/ha) were recorded with the oxyfluorfen application. Moreover, there were no statistically significant differences between mulching and pendimethalin application concerning the height, stem diameter and yield of leek. Gilreath et al. (2008) reported that plants treated with oxyfluorfen (both at 0.3 and 0.6 kg/ha) performed similarly to those in the weed-free control in two out of the three seasons.

CONCLUSIONS

Our results show that the herbicide oxyfluorfen provided the most consistent season-long weed control. There were statistically significant differences between mulching and pendimethalin application concerning the total weed density and biomass. Plots treated with oxyfluorfen had the highest leek yields and plant vigor during all seasons. Application of oxyfluorfen caused small white spots on leaves of leeks, likely due to herbicide toxicity. The order of weed sensitivity to mulches was black nightshade (72–85%), venice mallow (80%) > redroot pigweed (70–74%), barnyardgrass (67–77%) > jimsonweed (65%) > common purslane (42–45%). The use of mulching is an option for the reduction of herbicide inputs in leek cultivation practices.

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Received for publication August 2, 2011
Accepted after corrections October 15, 2011

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