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Effects of cultural practices on weed flora in Virginia (flue-cured) organic tobacco (*Nicotiana tabacum* L.): green manure and irrigation systems

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Abstract: Organic tobacco is a new industrial crop. Field experiments were conducted, during 2005-2006, to determine the effects of irrigation system and green manure on weed flora in organic tobacco crops (*Nicotiana tabacum* cv. NC 71). The experiments were designed as a split plot design with 4 replicates, 2 main plots (drip and sprinkler irrigation), and 3 sub-plots (vetch and red clover as green manure, and control). The greatest number and dry weight of weeds was observed in sprinkler irrigation. Our results indicate that weed distribution under drip and sprinkler irrigation is related not only to the surface soil water content but also to competition from the crop for water and light. Moreover, there were no significant differences between vetch, red clover, and the control in terms of number of weeds at site 1. In addition, at site 2, the lowest number of weeds was found in red clover plots. The main reason for weed suppression at site 2 may be attributed to the amount of red clover incorporated into the soil, 390 kg ha^{-1} and 270 kg ha^{-1}, for site 2 and site 1, respectively. Red clover strongly inhibited germination and growth of barnyardgrass (*Echinochloa crus-galli* (L.) P.Beauv.) but only at the first sample date after transplanting of tobacco (35 days after transplanting). These results indicated that green manure and drip irrigation could be used for the suppression of weeds in organic row-crops.

Key words: Allelopathy, drip irrigation, green manure, organic tobacco, sprinkler irrigation, weed flora

Introduction

Weeds are an important variable in crop production, both economically and ecologically. There is strong interest in developing alternative methods of physical weed control in organically grown crops, because weeds remain one of the most significant agronomic problems in the production of organic crops. Cultural practices such as mulching (Bilalis et al. 2003), tillage (Bilalis et al. 2001), competitive cultivars (Korres and Fround-Williams 2002), rotation (Bond and Grundy 2001), irrigation systems (Sabra 2000; Karkanis et al. 2007), and allelopathic crops and cultivars (Khanh et al. 2005) influence weed density and distribution.

A number of crop plants have been reported to acquire allelopathic potential that affects the growth of other species. Allelopathic crops when used as cover crop, mulch, smother crops, green manures, or grown in rotational sequence are helpful in reducing noxious weeds. Those crops, particularly the legumes, incorporated at 1-2 t ha^{-1} (alfalfa, buckwheat), which can give weed reduction by 70%, are suggested for use

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as natural herbicides (Khanh et al. 2005). Higher plants with strong allelopathic properties are commonly incorporated into soil for weed-control purposes. Xuan et al. (2005a) reported that alfalfa (*Medicago sativa* L. cv. Rasen) and kava (*Piper methysticum* L.) strongly inhibited barnyardgrass (*Echinochloa crus-galli* (L.) P.Beauv. and pickerelweed (*Monochoria vaginalis* (Burm. F.) C.Presl ex Kunth) growth. Numerous growth inhibitors identified from allelopathic plants are responsible for their allelopathic properties and may be a useful source for the future development of bio-herbicides (Xuan et al. 2005b).

Vetch (*Vicia sativa* L.) and red clover (*Trifolium pratense* L.) are legume species well adapted to the soil and climate conditions of Greece. They can also be cultivated as plants for green manure, during the period between 2 major crops (intermediate crop) in the common rotation system of Greece, such as wheat/cotton and wheat/tobacco. Vetch and red clover can be seeded at the beginning of October and then cut and incorporated into the soil at the end of April. Green manuring of vetch and red clover before transplanting tobacco crops increase the yield and quality of tobacco (Bilalis et al. 2009). Vetch and red clover were found to exhibit allelopathic potential (Medeiros and Lucchesi 1993; Ohno et al. 2000).

Irrigation is critical for successful summer plant production in Mediterranean countries. Water management is an effective method to control weeds in crops. Irrigation level or frequency (Khalak and Kumuraswamy 1993; Panwar et al. 2000; Singh et al. 2002) influences weed density and growth. In Mediterranean countries, tobacco growers use sprinkler irrigation systems. In contrast, drip irrigation has not been widely used in tobacco production. The literature provides many examples of a shift in weed population in response to changes in irrigation systems (Sabra et al. 2000; Veeraputhiran and Kandasamy 2001; Karkanis et al. 2007).

The aim of this study was to analyze the effects a) of 2 irrigation systems and b) green manure on dry mass and density of weed species, as well as the species diversity of the weed population in an organically grown tobacco crop.

Materials and methods

Experimental design

The experiment was performed twice in 2005-2006. A tobacco crop (*Nicotiana tabacum* L. cv. NC71) was established in the experimental "organic" field of the Agricultural University of Athens (23.43E, 34.58N). Before setting up this experiment, the field had been under organic agriculture since 2001. The soil was clay loam (29.8% clay, 34.3% silt, and 35.9% sand) with pH 7.24, 1.87% organic matter, and 0.54 dS m^{-1} of EC. In parallel, a tobacco crop was established in the Domokos (Central Greece) district (22.33E, 39.03N) 200 km north of Athens. The soil was clay (50.7% clay, 23.3% silt, and 26% sand) with pH 7.6, 2.2% organic matter, and EC of 0.32 dS m^{-1} of EC. The crops cultivated before tobacco were vetch (*Vicia sativa* L. cv. Alexandros) and red clover (*Trifolium pratense* L. cv. Nemaro), which was incorporated into the soil, during the flowering stage, according to organic agriculture common technique. Prior to this study the field had been under wheat cultivation. The management of the field follows the organic production legislation EN 2092/91.

The experiment was set up in an area of 1200 m^2 according to the split plot design, with 4 replicates, 2 main plots (irrigation systems), and 3 sub-plots (green manure treatments). The green manure treatments were vetch and red clover as green manures and green manure-free plots (control). The main plot size of each irrigation system was 15 × 10 m and the sub-plot size was 5 × 10 m. The meteorological information was obtained from the nearest weather station and it is presented in Figure 1. The precipitation during the growing season (May-September) in Domokos (42 mm) was higher than that in Athens (13.6 mm).

Irrigation systems

Overhead sprinkler and drip irrigation systems were set up on adjacent blocks within the same field, but far enough away to avoid cross irrigation. Moreover, irrigation intervals ranged from 3 to 7 days, depending on daily temperature. In the drip system, irrigation was applied for 3 h for each application, and, in the overhead system, irrigation was applied for 2 h.

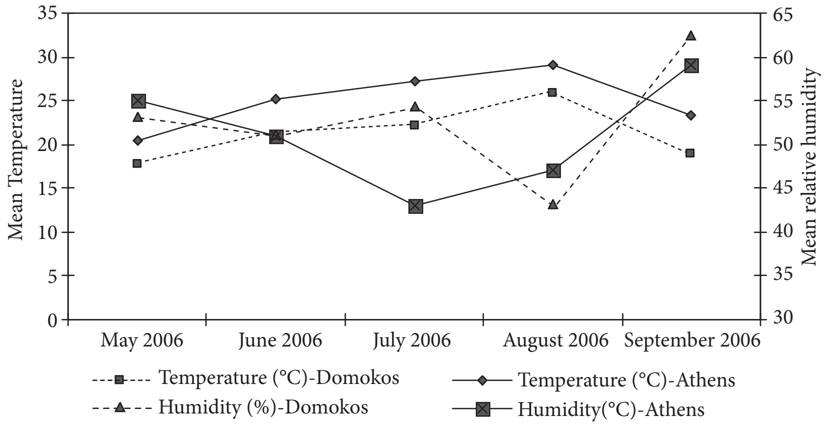

Figure 1. Meteorological data in the experimental sites during experiment period.

The drip system consisted of laterals with 20 mm diameter and laterals with in line drippers and at 0.40 cm distance. The drippers had a discharge rate of 4 L h^{-1} under an operation pressure of 1 atm. The sprinkler irrigation system consisted mainly of pipes 40 mm in diameter, laterals pipes also 40 mm in diameter, and rotor-type sprinklers (radius: 5 m, discharge rate: 16.35 L min^{-1}) with 2 m risers. The laterals pipes were 15 m long with sprinklers spaced at 5 m in each lateral.

At sites 1 and 2, the numbers of irrigations were 10 and 8 for both systems, respectively. The total amount of water at site 1 was 260 mm and 410 mm for the drip and sprinkler system, respectively. The total amount of water at site 2 was 210 mm and 357 mm for the drip and sprinkler system, respectively.

Planting, fertilization, and weed control

Vetch and red clover were sown by hand in rows 20 cm apart, at a depth of 1.5 cm. The field in Domokos district was sown on 1 October 2005 and the one in Athens was sown on 4 November 2005. The rate was 100 kg ha^{-1} and 20 kg ha^{-1} for vetch and red clover, respectively. Vetch and red clover were incorporated into the soil at the beginning of May. Seeds of tobacco were sown on 5 March 2006 in a seedbed under plastic house conditions (to protect the seedlings from cold weather). After hardening, seedling transplanting took place on 18 and 22 May in the experimental field of the Agricultural University of Athens (site 1) and the field in Domokos (site 2), respectively. Seedlings were transplanted by hand in rows 90 cm apart. Transplants were planted every 30 cm and the weeds were controlled 40 days after transplanting by hand.

Samplings, measurements, and methods

Legumes

Biomass samples were taken at the end of April. To define biomass the plants from a 1 m^2 area were measured, taken twice from 2 randomly selected spots of each plot. The %N from biomass was measured with the Kjeldahl method (Bremner, 1960). The total N was determined by multiplying dry weight (kg ha^{-1}) by N%.

Tobacco: Dry weight of leaves and height

The samplings were taken 86 days after the transplanting date of tobacco (DAT). To define biomass the plants from 1 m^2 were measured, taken from 2 different places of each plot. The dry weight of leaves was determined after drying for 96 h at 70 °C. Plant height was determined by measuring the height of 10 plants per plot.

Weeds

The number and dry weight of the dominant weeds were assessed (**Athens**: a) **annual weeds**: Redroot pigweed: *Amaranthus retroflexus* L., Jimsonweed: *Datura stramonium* L., Black nightshade: *Solanum nigrum* L., Puncturevine: *Tribulus terrestris* L., Yellow foxtail: *Setaria glauca* (L.) P.Beauv, b) **perennial weeds**: Field bindweed: *Convolvulus arvensis* L. and Purple nutsedge: *Cyperus rotundus* L. **Domokos**: a) **annual weeds:** Redroot pigweed, Jimsonweed, Black nightshade, Venice mallow: *Hibiscus trionum* L., Common purslane: *Portulaca oleracea* L., Barnyardgrass: *Echinochloa crus-galli* L. b) **perennial weed**: Field bindweed). Weeds were measured twice

(35 and 81 DAT) during the cultivation period. A 1 m × 1 m quadrat was used, 3 times per plot. All weeds were collected from the measured area and weighed in order to determine the dry matter.

Weed Population Analysis

The species diversity of weed groups was characterized using Shannon-Weiner's index (Booth et al. 2003):

$$H = -\sum(Pi)(\ln Pi),$$

where Pi is the fraction of the weed density belonging to the i^{th} species in a given group. A diversity index intends to measure the biodiversity of an ecosystem. The advantage of this index is that it takes into account the number of species (species richness) and the evenness of the species. The species evenness is the relative abundance or proportion of individuals among the species. The index is 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 index the software Species Diversity and Richness III (PISCES Conservation Ltd., IRC House, Pennington, Lymington, SO41 8GN, UK) was used.

Statistical analysis

For statistical analysis of variance and mean comparisons the software Statistica (Statsoft, Inc., Tulsa, OK, USA) was used. The data were subjected to statistical analysis according to the split plot design. Differences among the means were compared using the least significant difference (LSD) test. All comparisons were made at the 5% level of significance.

Results

Legumes-Tobacco

The dry weight of vetch plants was 449 kg ha^{-1} for site 1 and 436 kg ha^{-1} for site 2. The biomass of red clover crop was 268 kg ha^{-1} for site 1 and 390 kg ha^{-1} for site 2. The amount of N that was accumulated by vetch plants was 188 kg ha^{-1} and 191 kg ha^{-1} for site 1 and 2, respectively. The amount of N that was accumulated by red clover plants fluctuated from 149 kg ha^{-1} for site 1 to 158 kg ha^{-1} for site 2.

Green manures increased tobacco height (Table 1). At site 1, there were significant differences between

Table 1. Influence of irrigation system (Drip irrigation: D, Sprinkler irrigation: S) and green manure (control, vetch, red clover) on dry weight of leaves (kg ha^{-1}) and stem height (cm) of tobacco crop (86 days after transplanting).

	Irrigation System			
Green manure	Site 1 (Athens)		Site 2 (Domokos)	
Dry weight	D	S	D	S
Vetch	2940	1980	3720	2940
Red clover	2460	1800	3520	2520
Control	1400	910	2470	1940
$LSD_{irrigation}$	*107.4*		*729.9*	
$LSD_{green\text{-}manure}$	*193.3*		*407.9*	
Stem height	D	S	D	S
Vetch	117	95	154	146
Red clover	109	90	149	141
Control	80	66	135	117
$LSD_{irrigation}$	*6.00*		*2.83*	
$LSD_{green\text{-}manure}$	*2.73*		*5.41*	

The LSD (P = 0.05) for green manure and irrigation treatments are also shown.

the red clover and vetch fertilization. Furthermore, at site 2, there were no significant differences between the red clover and vetch fertilization. The highest stem height of tobacco plants was found in the drip irrigation system. Moreover, the lowest dry height of tobacco leaves was found in the control plots. Drip irrigation increased the dry weight of leaves. There were significant differences between the drip and sprinkler irrigation system regarding the dry weight of tobacco leaves.

Weed flora

Irrigation system

At site 1, the highest population density (number of weeds) was recorded for the species *Amaranthus retroflexus*, *Setaria glauca*, and *Tribulus terrestris*. At site 2, the highest population density was recorded for the species *Echinochloa crus-galli*, *Portulaca oleracea*, and *Solanum nigrum*. The highest total number and dry weight of weeds (Tables 2 and 3) at both sites were observed in the sprinkler irrigation system. At the first measurement no significant differences were found between drip and sprinkler irrigation for *Datura stramonium*, *Cyperus rotundus* (site 1), *Amaranthus retroflexus*, *Datura stramonum*, and *Convolvulus arvensis* (site 2). At the second measurement no significant differences were found between drip and sprinkler irrigation for *Datura stramonium*, *Solanum nigrum* (site 1), *Amaranthus retroflexus*, *Hibiscus trionum*, and *Portulaca oleracea* (site 2). Final, the highest values of Shannon-Weiner's index (Figure 2), at the first sample date, were obtained in the sprinkler irrigation system. In contrast, at the second measurement the highest values of Shannon-Weiner's index were measured in the drip irrigation system.

Green manures

The number of weeds had no significant differences between vetch, red clover, and control plots (Tables 2 and 3) at site 1 (Athens). Furthermore,

Table 2. Influence of irrigation system (Drip irrigation: D, Sprinkler irrigation: S) and green manure (control, vetch, red clover) on population density (no m^{-2}) of weeds, in organic tobacco crop (35 days after transplanting).

Site1 (Athens)	Vetch		Red clover		Control		LSD_{irr}	LSD_{gr}
	D	S	D	S	D	S		
Amaranthus retroflexus	35.50	56.50	20.00	49.00	26.00	52.00	11.02	7.38
Datura stramonium	0.50	1.00	1.50	1.50	0.75	1.50	1.00	2.67
Setaria glauca	8.00	33.50	13.00	25.00	9,00	23.50	13.76	11.77
Solanum nigrum	3.00	6.75	1.75	7.00	0.50	6.00	2.09	7.14
Tribulus terrestris	3.50	7.50	2.50	9.00	4.00	5.00	1.55	6.24
Convolvulus arvensis	0.50	6.50	1.50	5.50	1.00	4.25	2.95	2.23
Cyperus rotundus	0.50	0.00	0.00	0.50	1.00	0.00	0.61	0.72
Total	*51.50*	*111.75*	*40.25*	*97.50*	*42.25*	*92.25*	*43.63*	*9.23*
Site 2 (Domokos)	Vetch		Red clover		Control		LSD_{irr}	LSD_{gr}
	D	S	D	S	D	S		
Amaranthus retroflexus	0.50	1.00	0.75	0.25	0.25	0.25	0.43	0.85
Datura stramonium	0.75	1.50	0.75	2.00	1.00	0.75	1.90	1.97
Echinochloa crus-galli	9.25	27.75	3.25	8.00	7.50	19.50	4.54	2.75
Hibiscus trionum	1.25	5.75	1.75	5.75	1.50	6.50	3.21	3.15
Portulaca oleraea	1.00	5.00	1.00	2.75	0.50	3.25	1.42	2.90
Solanum nigrum	10.50	20.25	4.25	9.75	7.00	21.00	4.33	9.35
Convolvulus arvensis	0.00	0.00	0.00	0.00	0.00	0.00	-	-
Total	*23.25*	*61.25*	*11.75*	*28.50*	*17.75*	*51.25*	*9.31*	*11.43*

The LSD (P = 0.05) for green manure and irrigation treatments are also shown.

Table 3. Influence of irrigation system (Drip irrigation: D, Sprinkler irrigation: S) and green manure (control, vetch, red clover) on population density (no m^{-2}) of weeds, in organic tobacco crop (81 days after transplanting).

Site1 (Athens)	Vetch		Red clover		Control		LSD_{irr}	LSD_{gr}
	D	S	D	S	D	S		
Amaranthus retroflexus	3.50	5.50	2.50	4.50	2.50	6.00	2.15	3.53
Datura stramonium	0.50	0.50	1.00	0.50	0.00	0.50	1.88	0.97
Setaria glauca	2.50	12.00	3.50	10.00	2.00	15.50	3.81	6.07
Solanum nigrum	0.50	0.00	3.00	2.00	2.00	0.00	2.35	2.42
Tribulus terrestris	0.50	2.00	1.00	3.25	2.50	4.00	2.75	2.70
Convolvulus arvensis	1.00	5.00	3.50	7.50	1.00	5.00	2.67	5.42
Cyperus rotundus	0.50	5.00	1.00	8.50	0.50	4.50	4.41	2.97
Total	*9.00*	*30.00*	*15.50*	*36.25*	*10.50*	*35.50*	*13.61*	*6.24*
Site 2 (Domokos)	**Vetch**		**Red clover**		**Control**		**LSD_{irr}**	**LSD_{gr}**
	D	S	D	S	D	S		
Amaranthus retroflexus	0.75	0.50	1.00	0.50	1.25	2.00	3.38	1.68
Datura stramonium	1.25	8.00	1.00	6.00	2.50	3.25	2.71	5.50
Echinochloa crus-galli	1.50	5.75	2.75	8.25	5.00	12.50	5.11	5.57
Hibiscus trionum	2.75	4.50	4.75	4.00	4.00	4.00	5.52	3.67
Portulaca oleracea	3.50	28.00	6.75	14.25	5.00	16.75	8.18	5.74
Solanum nigrum	6.50	19.25	9.00	16.00	8.75	17.75	9.25	8.47
Convolvulus arvensis	0.75	0.75	0.75	1.25	1.25	0.75	1.14	1.33
Total	*17.00*	*66.75*	*26.00*	*50.25*	*27.75*	*57.00*	*28.03*	*17.47*

The LSD (P = 0.05) for green manure and irrigation treatments are also shown.

at the first measurement the lowest dry weight of weeds (*Amaranthus retroflexus*) was found in the control plots. At the second measurement the lowest dry weight of weeds (*Setaria glauca*, *Tribulus terrestris*) was recorded in vetch plots. At site 2, during the first assessment there were no significant differences between vetch, red clover, and control plots regarding the number of *Amaranthus retroflexus, Datura stramonium, Hibiscus trionum, Portulaca oleracea*, and *Convolvulus arvensis*. In addition, the lowest numbers of *Echinochloa crus-galli* and *Solanum nigrum* were found in red clover plots. The lowest dry weight of weeds was found in red clover plots (Table 4). At the second measurement the number of weeds demonstrated no significant differences between vetch and red clover plots. Moreover, the lowest dry weight of weeds (*Echinochloa crus-galli*, *Portulaca oleracea*, *Hibiscus trionum*) was observed in vetch plots (Table 5). The lowest values of Shannon-Weiner's index (Figure 2) were observed in vetch plots. At the second assessment, the highest values of Shannon-Weiner's index were found in control and red clover plots, for site 2 and site 1, respectively. Finally, in weed measurements, an irrigation × green manure interaction was not found.

Discussion

Advanced drip irrigation systems have great differences compared to the sprinkler and furrow irrigation systems: reduced water use (Cetin and Bilgel 2002; Bilalis et al. 2009) and high yields (Tiwari et al. 2003; Malash et al. 2005). The yield of tobacco irrigated with the drip irrigation system was higher than that irrigated with sprinklers.

Our results have clearly demonstrated that irrigation management can play a great role in weed control in summer row crops such as tobacco. The

Table 4. Influence of irrigation system (Drip irrigation: D, Sprinkler irrigation: S) and green manure (control, vetch, red clover) on dry matter of weeds (g m^{-2}), in organic tobacco crop (35 days after transplanting).

Site1 (Athens)	Vetch		Red clover		Control		LSD_{irr}	LSD_{gr}
	D	S	D	S	D	S		
Amaranthus retroflexus	10.62	25.78	9.47	23.95	4.37	12.79	3.80	4.69
Datura stramonium	0.11	0.67	0.22	0.09	0.23	0.14	0.82	0.69
Setaria glauca	0.41	1.86	1.06	1.70	0.69	1.62	0.72	1.45
Solanum nigrum	0.18	0.89	0.38	0.79	0.15	0.85	0.32	0.75
Tribulus terrestris	2.83	3.43	2.24	1.95	1.85	1.46	4.32	3.30
Convolvulus arvensis	0.12	2.07	0.67	1.65	0.27	1.66	0.99	0.80
Cyperus rotundus	0.33	0.00	0.00	0.12	0.20	0.00	0.32	0.28
Total	*14.59*	*34.69*	*14.03*	*30.24*	*7.75*	*18.51*	*6.99*	*5.10*
Site 2 (Domokos)	**Vetch**		**Red clover**		**Control**		**LSD_{irr}**	**LSD_{gr}**
	D	S	D	S	D	S		
Amaranthus retroflexus	0.04	0.02	0.01	0.01	0.02	0.01	0.03	0.03
Datura stramonium	0.07	0.08	0.03	0.06	0.06	0.06	0.07	0.10
Echinochloa crus-galli	0.66	2.24	0.13	0.35	0.48	1.86	0.16	1.29
Hibiscus trionum	0.11	0.25	0.04	0.22	0.13	0.54	0.20	0.21
Portulaca oleraea	0.10	0.34	0.17	0.12	0.04	0.24	0.32	0.18
Solanum nigrum	0.20	0.94	0.12	0.40	0.31	0.93	0.33	0.38
Convolvulus arvensis	0.00	0.00	0.00	0.00	0.00	0.00	-	-
Total	*1.18*	*3.87*	*0.50*	*1.16*	*1.03*	*3.63*	*0.59*	*0.61*

The LSD (P = 0.05) for green manure and irrigation treatments are also shown.

highest number and dry weight of weeds were observed in the sprinkler irrigation system. In the drip system, water is only delivered to the root zone of each tobacco plant, whereas in the sprinkler system, the entire field receives a uniform amount of water, resulting in more weeds throughout the field. Moreover, the lowest values of Shannon-Weiner's index (Figure 2) at the second assessment were observed in the sprinkler irrigation system. The lower values of this index in sprinkler irrigation may be attributed to the prevalence of some weed species in this treatment. The density of *Setaria glauca*, *Convolvulus arvensis, Cyperus rotundus* (site 1), *Echinochloa crus-galli*, *Portulaca oleracea*, and *Solanum nigrum* (site 2) was much greater than the density of other species.

In a similar study with cotton Veeraputhiran and Kandasamy (2001) reported that drip irrigation significantly reduced the weed density and dry weight in comparison to furrow irrigation. Sabra (2000) found that the potato field irrigated by sprinkler irrigation was highly infested by weeds compared to drip or flood irrigation systems. Moreover, Smith et al. (1988) reported that buried drip irrigation gave over 80% reductions in weed density in comparison to superficial irrigation (furrow or sprinkler irrigation). The weed distribution under drip and sprinkler irrigation is related not only to the soil surface but also to competition from the crop for water and light. The highest dry weight of leaves and height of tobacco plants were evaluated in the drip irrigation system. Similar results were also obtained by Grattan et al. (1990). Moreover, density and number of perennial weeds (*Convolvulus arvensis* and *Cyperus rotundus*) was influenced by the irrigation method (Table 2). On the other hand, Grattan et al. (1990) found that growth of *Convolvulus arvensis* was not influenced by the irrigation method.

Table 5. Influence of irrigation system (Drip irrigation: D, Sprinkler irrigation: S) and green manure (control, vetch, red clover) on dry matter of weeds (g m^{-2}), in organic tobacco crop (81 days after transplanting).

Site1 (Athens)	Vetch		Red clover		Control		LSD_{irr}	LSD_{gr}
	D	S	D	S	D	S		
Amaranthus retroflexus	4.71	10.68	8.69	7.91	11.01	17.33	12.43	9.80
Datura stramonium	3.59	3.21	2.78	2.43	0.00	2.56	8.36	5.03
Setaria glauca	4.51	11.74	6.99	16.58	6.34	21.27	5.72	1.36
Solanum nigrum	1.20	0.00	2.40	3.90	2.04	0.00	3.08	3.87
Tribulus terrestris	1.60	10.61	2.24	8.71	14.38	18.50	3.41	5.60
Convolvulus arvensis	0.35	2.42	1.67	6.81	2.16	7.17	8.67	5.87
Cyperus rotundus	0.36	2.83	0.50	3.12	0.56	2.71	1.47	0.93
Total	*16.31*	*41.48*	*25.26*	*49.45*	*36.49*	*69.53*	*22.73*	*10.97*
Site 2 (Domokos)	**Vetch**		**Red clover**		**Control**		LSD_{irr}	LSD_{gr}
	D	S	D	S	D	S		
Amaranthus retroflexus	0.01	0.10	0.13	0.04	0.33	0.10	0.23	0.15
Datura stramonium	0.04	2.06	0.01	0.94	0.68	0.73	1.71	1.31
Echinochloa crus-galli	0.42	2.40	0.80	2.65	2.20	6.48	1.58	3.21
Hibiscus trionum	0.32	1.45	0.96	2.35	0.73	2.21	0.96	0.34
Portulaca oleraea	1.79	25.36	4.61	17.34	3.04	42.58	11.68	9.29
Solanum nigrum	0.60	1.92	0.65	2.04	0.97	1.70	1.20	1.51
Convolvulus arvensis	0.17	0.11	0.29	0.14	0.47	0.09	0.56	0.24
Total	*3.35*	*33.39*	*7.44*	*25.50*	*8.42*	*53.89*	*14.01*	*10.79*

The LSD (P = 0.05) for green manure and irrigation treatments are also shown.

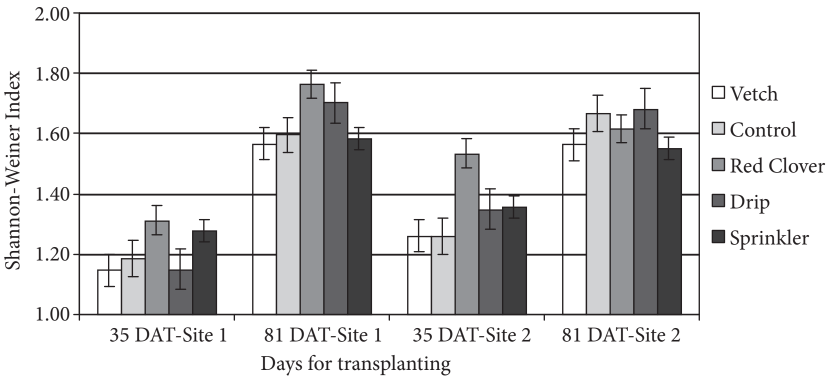

Figure 2. Shannon-Weiner index of weed populations (35 and 81 days after transplanting) under different green manure and irrigation treatments (mean values ± standard error).

An alternative method of weed management is weed suppression from green manures, which are incorporated into the soil. Green manures could be used for the suppression of weeds in crops and consequently to minimize herbicide usage. Dhima et al. (2009) found that green manure of aromatic plants could be used for management of barnyadgrass and some broadleaf weeds in maize. In addition, Norsworthy et al. (2005) observed that Brassicaceae green manures (*Brassica juncea* L., *Sinapis alba* L.) could be used as weed suppressants in *Vigna unguiculata* L. Green manuring of sunflower (*Helianthus annus* L.) and dhaincha (*Sesbania aculeata* Pers) reduced plant population of *Phalaris minor* Retz. 42% and 15%, respectively, under field conditions (Om et al. 2002).

Legume green manures have been used for millennia as sources of N for succeeding crops, but they are also sources of phytotoxic compounds that may selectively influence the performance of crop and weed species (Liebman and Gallandt 2002). Ohno et al. (2000) have also reported that legume green manures (red clover) could be used for weed suppression. Moreover, Liebman and Gallandt (2002) indicated that substitution of red clover green manure for ammonium nitrate fertilizer can be compatible with bean production goals and can contribute to the management of wild mustard (*Brassica kaber* L.). At site 2, total weed density and biomass were significantly influenced by red clover green manure (Tables 2 and 4). Red clover significantly reduced the density and biomass of barnyardgrass (*Echinochloa crus-galli* (L.) P.Beauv.) but only at the first assessment after transplanting of tobacco (35 DAT).

Moreover, red clover reduced the density and biomass of *Solanum nigrum* but there were no statistically significant differences between green manure treatments. Xuan et al. (2005a) reported that alfalfa (*Medicago sativa* L.) and kava (*Piper methysticum* L.) strongly inhibited barnyard grass growth for up to 10 days (80%-100% weed control). After 20-25 days, the magnitude of inhibition was drastically reduced, but was still effective (50% weed control). In contrast, there were no significant differences between vetch, red clover, and the control for number of weeds at site 1. Thus, the phytotoxic potential of red clover plants at site 2 was higher than that at site 1. The weed suppression at site 2 may be attributed to the amount of red clover incorporated into the soil: 390 kg ha^{-1} and 270 kg ha^{-1}, at site 2 and site 1, respectively. Khanh et al. (2005) reported that alfalfa, incorporated at 1-2 t ha^{-1}, reduced weed biomass by about 70%. However, allelopathy in soil is a complicated phenomenon that is affected by soil condition, growth condition of the donor and receiver plants, and climatic conditions (Kobayashi 2004).

Moreover, the lowest dry weight of weeds and values of Shannon-Weiner's index (Figure 2) at the second assessment was observed in vetch plots. Thus, weed distribution under green manure treatments is related not only to the allelopathy potential of legumes but also to competition from the tobacco crop for water and light. As presented in Table 1, the biomass of leaves and the height of tobacco plants in vetch plots were always higher than those in control and red clover plots. Moreover, the lowest dry weight of weeds, at both measurements, was obtained at site 1. The lower weed biomass at site 1 may be attributed to the growth of tobacco. The biomass of tobacco crop at site 2 was always higher than that at site 1.

Our study indicated that the irrigation system can affect greatly the weed distribution in tobacco crop. The greatest number and dry weight of weeds was observed in sprinkler irrigation. Moreover, the number of weeds had no significant differences between vetch, red clover, and control plots at site 1. In contrast, at site 2 the lowest number of weeds was found in red clover plots. Red clover strongly inhibited the germination and growth of barnyardgrass (*Echinochloa crus-galli* (L.) P.Beauv.) but only at the first assessment after the transplanting of tobacco (35 DAT).

Regarding organic agriculture, both green manure and the irrigation system can affect tobacco growth. The choice of suitable green manure and irrigation system can also affect the weed density and biomass.

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