Floristic composition of weeds and the efficacy of PRE herbicides in a black locust (*Robinia pseudoacacia* L.) nursery

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Abstract

Field trials were conducted in 2010 and 2011 to evaluate floristic composition of weeds and the efficacy of pre herbicides in black locust (*Robinia pseudoacacia* L.) nurseries. The weed population in both years was consisted mainly of annual spring and summer weeds, and some perennial weeds. The weediness in both years was relatively high. Weed density in the untreated control plots was 106.5 plants per m^2 in 2010 and 87.4 plants per m^2 in 2011. The most dominant weeds were *Chenopodium album, Polygonum aviculare* and *Amaranthus retroflexus* in 2010 and *Polygonum aviculare, Tribolus terestris* and *Cynodon dactilon* in 2011. By taxonomic aspect, the weed flora was distributed in 11 families. 15 weed species were dicotyledons and 2 weed species were monocotyledons. Terophytes were the dominant life form weed category in black locust nurseries. Efficacy of herbicides 28 days after treatment (DAT) ranged from 91.0% (pendimethalin) to 95.3% (linuron) in 2010, and 74.5% (linuron) to 88.0% (pendimethalin) in 2011, respectively. Efficacy of herbicides 56 DAT ranged from 93.6% (pendimethalin) to 98.3% (linuron) in 2010, and from 74.8% (linuron) to 83.1% (pendimethalin) in 2011, respectively. Prevailing weed control by herbicides was not consistent over the years. However, efficacy of herbicides in control of prevailing weeds 28 and 56 DAT ranged from 88% to 100% in 2010 and 7% to 86% in 2011, respectively. Lower herbicide efficacy in 2011 was most likely due to high precipitation occurred immediately after herbicide application and domination of perennial weeds, particularly *Cynodon dactilon*.

Keywords

Black locust; Weed population; Life forms; Ecological indices; Herbicides

Contents

1 Introduction

In The Republic of Macedonia, *Robinia psedoacacia* L. (black locust) is an allochtonous species, well adapted and widely spread on almost all territory, in a range of altitude between 50-1300 m a.s.l. Its plasticity in the term of ecophysiological and morphological adaptation and capability of easy vegetative regeneration, allow this species to spread spontaneously. Due to these characteristics, black locust is used mostly for ameliorative purposes, especially for the stabilization of erosive areas, for afforestation of barren lands, reclamation of waste land etc. (Trendafilov et al. 2009). It is also an important tree species for establishing short-rotation biomass energy plantations, for production of biomass as a renewable resource for bioenergy etc. (Rédei et al. 2002; Mantovani et al. 2014).

Annual production of black locust seedlings in Macedonia is about 2-3 million one-year-old barren root seedlings, which represent 85% of all broadleaves species produced. The production area of the nurseries is quite small (0.5-5 hectares) therefore all nursery operations, with the exception of mechanical soil preparation, as seedbeds preparation, sowing, covering, cultivation and weeding are carried out manually.

The black locust seeds, which are prior sowing hydro-thermically treated (Stamenkov and Kolevska 2000), are usually sawn from mid-April to mid-May, depending on the weather conditions and the altitude. The seeds germinate relatively quickly, i.e. in favorable conditions within 7 - 10 days. In the first one or two months the seedlings are quite small and they insufficiently cover the soil, and due to relatively wide spacing between rows and intensive irrigation, particularly during the summer, weeds are a major production problem for black locust growers. Weeds compete with black locust for light, moisture and nutrients and can drastically reduce its quality and yield.

A number of weed controlling methods are available in black locust production, but their affordability predominantly depends on lack of herbicide application knowledge and understanding of authorities.

Manual labor in nurseries, especially weeding, is very expensive and time consuming (Weiland et al. 2011). The reduction of this expense with improved weed control methodologies and understanding weed control would have a significant impact on nursery production (Case et al. 2005). In Macedonia, hand weeding in forest nurseries represents c/a 41% of the total production costs (Anonymous 2010).

Chemical control is the most reliable method for controlling weeds in black locust and other forest plant nurseries. The importance of their control has been emphasized by various authors (Abrahamson 1985; Schroeder et al. 1995; Glavaš 2009; South and Carey 2005; Timmons 2005; Willoughby et al. 2007; Weiland et al. 2011; Vasić et al. 2012; Treštić et al. 2013).

Although such studies have been carried out worldwide, there is a lack of studies for the evaluation of herbicide efficacy in black locust nursery production in The Republic of Macedonia.

Taking into consideration the necessity of chemical weed control for stable black locust seedling production, the objective of this study was to estimate floristic composition of weed vegetation and herbicide efficacy in a black locust nursery.

2 Materials and Methods

The investigation was realized in the nursery of the PE "Macedonian Forests", subsidiary "Karadžica" in Dračevo during 2010 and 2011, on fluvisol sandy loam with 10.50% coarse, 63.10% fine sand, 26.40% clay+silt, 3.1% organic matter and pH 7.0. The nursery is located at N41°56.140, E21°30.745, altitude of 250 a.s.l., inclination of 4-5^0, north-west exposition.

The experiment method was set at randomized complete block design with four replications, on a total area of 600 m^2, the size of the elementary plot was 15 m^2 (3 x 5m).

The seedbed was prepared by moldboard plowing in the autumn, followed by two passes with a field cultivator in the spring. Before sowing in the spring, fertilizer was incorporated at rates indicated by soil tests. One day prior to sowing, the black locust seed was hydro-thermally treated in boiling water for 10 seconds, than cooled in cold water and left soaked for 24 hours in water with 10 g Benomil 50 WP per 10 kg of seeds. Germination rate of the seeds was 65.5%.

Black locust seeds were seeded in well-prepared seedbeds at a sowing rate of 25 g m^{-1} seeds on May 5th, 2010 and May 14th, 2011, respectively. The interrow spacing was 25 cm and sowing depth was about 2 cm.

During both investigation years, survey of weed population in the black locust nursery was done. The research activities were conducted in herbicide untreated black locust control plots. Detailed weed population analysis was made on 1 m^2 plots, in 4 replicates placed evenly on every marked area, before weed control efficacy was estimated for the first time (28 days after treatment-DAT). The collected plant material was identified by using appropriate literature i.e. keys for identification (Kojić 1981; Domac 1984; Klapp and Opitz von Boberfeld 1990). Floristic analysis of the weed species includes: analysis of life forms and analysis of ecological indices. Life forms were determined according to Kovačević (1976) and Oberdorfer (2001). Ecological indices according Ellenberg for each species were recorded following Kojić and Janjić (1994).

Herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 400 L ha^{-1} aqueous solution at 220 kPa. PRE herbicide treatments were applied one day after sowing, on May 6th, 2010 and May 15th, 2011, respectively. PRE herbicide treatments were: Imazethapyr (Pivot 100-E, 100 g a.i. L^{-1}, BASF Agro B.V., Arnhem, NL, Switzerland) at 1.0 L ha^{-1}, pendimethalin (Stomp Aqua, 455 g a.i. L^{-1}, BASF Agro BV, Arnhem, NL, Switzerland) at 5.0 L ha^{-1}, s-metolachlor (Dual Gold, 960 g a.i. L^{-1}, BASF Agro B.V., Arnhem, NL, Switzerland) at 1.0 L ha^{-1}, linuron, (Linurex 50 SC, 500 g a.i. L^{-1}, Makteshim-agan (UK) limited, Thatcham, Berkshire, UK) at 2.0 L ha^{-1}. Untreated control was included in the studies, as well. Weed control was estimated visually 28 and 56 days after treatment (DAT) using a scale of 0 to 100%, where 0% = no weed control and 100% = complete weed control (Frans et al. 1986).

Total monthly rainfalls are shown in Table 1. Generally, 2010 was drier than 2011. Precipitations in May 2010 were very low (20 mm). However, June, and even July were unusually wet months. In August and September precipitation occurred during 3 days in the middle of August, and during the first 2 and the last 4 days of September. Opposite to this, spring of 2011 was humid. Precipitation occurred during May were a little bit above the 30 years average for the Skopje locality; precipitation occurred in the first and at the middle of the second decade of May. Particularly high precipitation occurred immediately after herbicide application (28 L m^{-2}). In June, precipitation occurred mainly in the second decade of the month (40 L m^{-2}). Summer months in 2011, particularly July and September, were very humid, 61% above the 30 years average for the Skopje locality (80 L m^{-2}).

Table 1. Total monthly rainfall from May to October in 2010 and 2011 at the experimental location.

Month	**Precipitation (L m^{-2})**	
	Skopje locality	
	2010	**2011**
May	20	49
June	51	58
July	48	54
August	10	22
September	23	75

The data was tested for homogeneity of variance and normality of distribution (Ramsey and Schafer 1997) and were log-transformed as needed to obtain roughly equal variances and better symmetry before ANOVA were performed. Data was transformed back to their original scale for presentation. Means were separated by using LSD test at 5% of probability.

3 Results and Discussion

The weed population in the black locust nursery consisted mainly of annual spring and summer weeds, and some perennial weeds. A total of 17 weed species were registered and determined in the black locust nursery in the both years (Table 2). The weediness was relatively high. In 2010 the weed population consisted of 11 weed species, and the total number of weeds was 106.5 plants per m^2. The most prevailing among the 11 weed species were *Chenopodium album* (33.8 plants per m^2), *Polygonum aviculare* (23.5 plants per m^2) and *Amaranthus retroflexus* (19.5 plants per m^2). In 2011 the weediness was lower in comparison to the previous year. Total number of weeds was 87.4 plants per m^2. The most prevailing among the 12 weed species were *Polygonum aviculare* (18.0 plants per m^2), *Tribolus terestris* (16.8 plants per m^2), and *Cynodon dactilon* L. (10.5 plants per m^2) (Table 2).

Taxonomic analysis of weed population in the black locust nursery (Table 3) shows that all 17 registered and determined weed species belong to the division *Angiospermae* (*Magnoliophyta*). 15 weed species are dicotyledons (class *Magnoliatae*) and 2 weed species are monocotyledons (class *Liliatae*). The weed flora is distributed in 11 families. The biggest number of weed species belong to the family *Asteraceae* (5), followed by *Amaranthaceae* and *Poaceae* (2).

In the life form spectrum of weed population in the black locust nursery (Table 4) the most dominant were terophytes, which were present with 13 species (76.5%). Participation of other life form categories is significantly lower.

Ecological indices for the weed population in the black locust nursery (Table 5) show that most of the species (13 and 16, respectively) have optimal growth in warm habitats (T) under full daylight (L). About half of them (8 weed species) are mesophytes which are adapted to moderately moist soils (F). The biggest part of these weed species (11) develop optimally in habitats with medium to high supply of mineral matter (N) on slightly acid to neutral soil pH.

Table 2. Floristic composition, weed density (plants per m^{-2}) and ecological indices of species in black locust nursery. Life forms: T - terophytes; H - hemicryptophytes: G - geophytes. Ellenberg's agro-ecological indicators: T - temperature; L - light; F - moisture; R - chemical reaction of soil or water; N - soil fertility.

Family	**Weeds species**	**Life form**	**Years**		**Ellenberg's agro-ecological indices of species**				
			2010	**2011**	**T**	**L**	**F**	**R**	**N**
			plants per m^2						
Chenopodiaceae	*Chenopodium album* L.	T	33.8	9.5	3	4	2	3	4
Polygonaceae	*Polygonum aviculare* L.	T	23.5	18.0	3	4	3	3	4
Amaranthaceae	*Amaranthus retroflexus* L.	T	19.5	7.8	4	4	2	3	4
Zigophyllaceae	*Tribolus terrestris* L.	T	10.5	16.8	4	4	2	3	4
Solanaceae	*Solanum nigrum* L.	T	6.0	-	4	4	3	4	3
Amaranthaceae	*Amarantus blitoides* Wats.	T	2.8	-	5	4	2	3	4
Asteraceae	*Xanthium spinosum* L.	T	2.5	-	5	4	1	3	4
Portulacaceae	*Portulaca oleracea* L.	T	1.8	3.3	4	4	3	3	4
Asteraceae	*Datura stramonium* L.	T	1.5	-	4	4	3	3	4
Asteraceae	*Xanthium strumarium* L.	T	1.3	7.3	5	4	3	3	5
Asteraceae	*Sonchus asper* (L.) Hill	T	1.3	-	4	4	3	4	4
Ranunculaceae	*Ranunculus arvensis* L.	T	-	5.3	3	4	3	3	3
Boraginaceae	*Heliotropium europeum* L.	T	-	1.8	5	4	2	4	4
Asteraceae	*Chondrila juncea* L.	H	-	1.8	5	3	5	1	1
Poaceae	*Cynodon dactilon* L.	G	-	10.5	3	4	3	3	4
Poaceae	*Sorgum halepense* (L.)Pers.	G	-	4.0	5	4	1	2	3
Convolvulaceae	*Convolvulus arvensis* L.	G	-	1.3	4	4	2	4	3
	Total weed species	17	11	12					
	Total weeds (plants per m^2)		106.5	87.4					

Table 3. Taxonomic analysis of weed species in the black locust nursery.

Division	**Class**	**Species**		**Family**	**Species**	
		No	**%**		**No.**	**%**
Angiospermae (Magnoliophyta)	Magnoliatae (Dicotyledons)	15	88.2	*Amaranthaceae*	2	11.8
				Asteraceae	5	29.4
				Boraginaceae	1	5.9
				Chenopodiaceae	1	5.9
				Zigophyllaceae	1	5.9
				Polygonaceae	1	5.9
				Portulacaceae	1	5.9
				Ranunculaceae	1	5.9
				Convolvulaceae	1	5.9
				Solanaceae	1	5.9
	Liliatae (Monocotyledons)	2	11.8	*Poaceae*	2	11.8

Table 4. Life form of weed species in the black locust nursery.

Life form	**Number of species**	**%**
Terophytes	13	76.5
Hemicryptophytes	1	5.9
Geophytes	3	17.6
Chamaephytes	-	0.0

Table 5. Ecological indices for weed species in black locust nursery. Ellenberg's agro-ecological indicators: T - temperature; L - light; F - moisture; R - chemical reaction of soil or water; N - soil fertility.

Ecol. value	**Ecological index of species**									
	T		**L**		**F**		**R**		**N**	
	No. of species	**%**	**No. of species**	**%**	**No. of species**	**%**	**No. of species**	**%**	**No of species**	**%**
1	-	-	-	-	2	11.8	1	5.9	1	5.9
2	-	-	-	-	6	35.3	1	5.9	-	-
3	4	23.5	1	5.9	8	47.0	11	64.7	4	23.5
4	7	41.2	16	94.1	-	-	4	23.5	11	64.7
5	6	35.3	-	-	1	5.9	-	-	1	5.9
Average	4.1		3.9		2.2		3.1		3.6	

Weed control and herbicide efficacy: Criterion for herbicide efficacy was taken as the percentage of weeds that are controlled by any particular treatment in comparison with untreated control. Data regarding herbicide efficacy presented in Table 6 show that all investigated herbicides had a significant ($P < 0.05$) effect on weed density per m^{-2}. In both years maximum weeds were recorded in untreated control plots (96.5 and 77.4, respectively). Minimum weeds 28 DAT in 2010 were counted in plots treated with linuron (5.0) followed by S-metolachlor (6.5), while in 2011, minimum weeds were observed in plots treated with pendimethalin (10.5) followed by S-metolachlor (12.0) and Imazethapyr (13.8). Minimum weeds 56 DAT in 2010 were counted again in plots treated with linuron (1.8) followed by S-metolachlor (2.0). Similarly, in 2011, minimum weeds were observed in plots treated with pendimethalin (14.8) followed by S-metolachlor (15.3) and Imazethapyr (17.5). Reduction of the weed density was in positive correlation with herbicide efficacy. Efficacy of herbicides 28 DAT was ranged from 91.0% (pendimethalin) to 95.3% (linuron) in 2010, and 74.5% (linuron) to 88.0% (pendimethalin) in 2011, respectively. Efficacy of herbicides 56 DAT was ranged from 93.6% (pendimethalin) to 98.3% (linuron) in 2010, and 74.8% (linuron) to 83.1% (pendimethalin) in 2011, respectively. Lower herbicide efficacy in 2011 was most likely due to high precipitation occurred immediately after herbicide application and domination of perennial weeds, particularly *Cynodon dactilon*.

Warmund et al. (1983) report that efficacy of herbicides Alachlor, Chloroxuron, DCPA, EPTC, Napropamide, Oxadiazon and Profluralin on germination and field survival of black locust varied from 5% (Chloroxuron) to 100% (Oxadiazon), however these results were inconclusive because of poor field germination (only 4%). Schroeder et al. (1995) for control of Canada thistle (*Cirsium arvense)* in seedbeds *with Caragana* sp. (fam. *Fabaceae*) carried out direct application of glyphosate (Roundup 36% Solution) avoiding contact with tree foliage, and as an alternative treatment was tested clopyralid (Central 36% EC) at a rate of 0.8 L ha^{-1} applied as an overall spray. Caragana and other legumes proved to be very sensitive to clopyralid.

Table 6. Effect of herbicidal treatments on weeds and herbicide efficacy in both years.

Treatments	Rate L ha^{-1}	28 DAT				56 DAT			
		Weed density per m^2		Herbicide efficacy (%)		Weed density per m^2		Herbicide efficacy (%)	
		2010	2011	2010	2011	2010	2011	2010	2011
Untreated control	-------	106.5^b	87.4^b	-------	-------	106.5^b	87.4^b	-------	-------
Imazethapyr	1.0	8.3^a	18.8^a	92.2	78.5	3.5^a	19.5^a	96.7	77.7
S-metolachlor	1.0	6.5^a	17.0^a	93.9	80.5	2.0^a	19.3^a	98.1	77.9
Linuron	2.0	5.0^a	22.3^a	95.3	74.5	1.8^a	22.0^a	98.3	74.8
Pendimethalin	5.0	9.8^a	15.5^a	91.0	88.0	6.8^a	14.8^a	93.6	83.1
LSD 0.05		*10.71*	*8.97*			*11.62*	*8.60*		

Prevailing weed control by herbicides was not consistent over the years. However, efficacy of herbicides in control of prevailing weeds 28 and 56 DAT was ranged from 88% to 100% in 2010 and 7% to 86% in 2011, respectively (Tables 7 and 8). All investigated herbicides showed lower herbicide efficacy in 2011 because of high precipitation which occurred immediately after PRE application and dominant *Cynodon dactilon*.

Imazethapyr at the recommended rate of 1 L ha^{-1} provided greater than 90% control of all species at both estimation period (28 and 56 DAT) in 2010 (Table 7), but in 2011 provided control levels of predominant weeds between 28 and 81%, 28 DAT, and 21 and 78%, 56 DAT, respectively (Table 8). A rate of 45 g a.i. ha^{-1} or greater, imazethapyr maintains consistent control of *Chenopodium album* and *Sinapis arvensis* when was applied PRE. *Setaria viridis* and *Amaranthus retroflexus* control was excellent at all PRE rates 56 days after treatment, and 75 a.i. ha^{-1} rate was required to maintain effective and consistent control of *Ambrosia artemisifolia* in pea (Sikkema et al. 2005). According to Vencil et al. (1990) imazethapyr at 36 to 69 a.i. ha^{-1} applied PPI, PRE, or POST in pea and snap beans controlled >80% of *Chenopodium album* throughout the growing season. Yenish and Eaton (2002) found that imazethapyr at 53 a.i. ha^{-1} provided 90% control of *Chenopodium album* in pea.

Table 7. Control of predominant weeds with soil-applied herbicides in 2010. CHEA L- *Chenopodium album*; POLAV - *Polygonum aviculare*; AMARE - *Amaranthus retroflexus.*

Treatments	Rate (L ha^{-1})	Weed control (%)					
		28 DAT			56 DAT		
		CHEAL	POLAV	AMARE	CHEAL	POLAV	AMARE
Untreated control	------	0^d	0^c	0^d	0^d	0^c	0^b
Imazethapyr	1.0	93^{bc}	90^{ab}	98^b	96^{bc}	93^{ab}	100^a
S-metolachlor	1.0	95^{ab}	90^{ab}	100^a	96^{bc}	91^b	100^a
Linuron	2.0	98^a	94^a	100^a	100^a	97^a	100^a
Pendimethalin	5.0	90^c	88^b	96^c	93^c	90^b	100^a
LSD 0.05		*3.59*	*4.71*	*1.93*	*3.58*	*5.53*	*0.87*

S-metolachlor provided greater than 90% control of predominant weeds 28 DAT and 93% 56 DAT in 2010, respectively (Table 7). Similar results were reported by Procopio et al. (2001). S-metolachlor gave a good *Brachiaria plantaginea* control up to 35 days after emergence, when there was sufficient for a complete covering of the soil by the bean crop. S-metolachlor does not provide effective control of *Cynodon dactylon*, but controlled *Polygonum aviculare* and *Tribulus terestris* more than 83% 28 DAT, and 77% 56 DAT in 2011 (Table 8). Similarly, metolachlor in combination with imazethapyr and flumetsulam does not provide consistently effective control of morningglory species, but controlled *Chenopodium album* and *Ambrosia artemisiifolia* greather than 93% (Vangessel et al. 1998).

28 DAT linuron provided control of predominant weeds between 94% and 100%, and more than 97% 56 DAT in 2010, respectively (Table 7). In 2011, linuron provided more than 80% and 75% control of predominant annual broadleaf weeds 28 and 56 DAT, respectively. But, it showed poor control of *Cynodon dactylon* (Table 8). Linuron and a combination of linuron + hand hoeing were found to be the most effective for control of broadleaf weeds in winter lentil throughout the investigation period (Erman et al. 2004). Control of *Solanum sarrachoides, Chenopodium album* and *Amaranthus retroflexus* was 99-100 % with linuron, but the same herbicide did not control either *Senecio vulgaris* or *Erodium cicutarium* in seed carrots (Butler et al. 2003).

Pendimethalin provided control levels bigger than 88% at 28 and 56 DAT in 2010 (Table 7). Similar results were found by Taylor-Lovell et al. (2002). According to them, pendimethalin at 1120 g a.i. ha^{-1} resulted in less than 80% control of *Setaria faberi*, but controlled *Chenopodium album* and *Amaranthus retroflexus* at least 85% in soybean crop. In 2011, pendimethalin provided poor control of *Cynodon dactylon*, but controlled *Polygonum aviculare* and *Tribulus terrestris* more than 81% (28 DAT), and 75% (56 DAT), respectively (Table 8).

Table 8. Control of predominant weeds with soil-applied herbicides in 2011. POLAV - *Polygonum aviculare*; CYNDA - *Cynodon dactylon;* TRITE - *Tribulus terrestris.*

Treatments	**Rate ($L\ ha^{-1}$)**	**Weed control (%)**					
		28 DAT			**56 DAT**		
		POLAV	**CYNDA**	**TRITE**	**POLAV**	**CYNDA**	**TRITE**
Untreated control	------	0^{b}	0^{d}	0^{b}	0^{b}	0^{b}	0^{c}
Imazethapyr	1.0	79^{a}	28^{ab}	81^{a}	75^{a}	21^{a}	78^{ab}
S-metolachlor	1.0	83^{a}	22^{b}	86^{a}	77^{a}	20^{a}	81^{ab}
Linuron	2.0	80^{a}	9^{c}	85^{a}	75^{a}	7^{b}	82^{a}
Pendimethalin	5.0	81^{a}	31^{a}	86^{a}	80^{a}	23^{a}	75^{b}
LSD 0.05		*4.35*	*7.68*	*5.53*	*5.15*	*9.43*	*6.26*

Control of *C. dactylon* was less than 31% and 23% with any PRE treatment 28 and 56 DAT, respectively (Table 8). In general, preemergence herbicides do not control *C. dactylon*, because the principle means of its propagation is through the rhizomes and stolons (Holm et al. 1977; Kostov 2006).

4 Conclusions

Results of this work demonstrate that the efficacy of PRE herbicides imazethapyr, S-metolachlor, linuron and pendimethalin in black locust nurseries are strongly depended by the amount of precipitation and weed population. High precipitation after PRE application in 2011 contributed to the poor performance of these herbicides at both estimation periods.

Therefore, these herbicides reduced dominant *Chenopodium album*, *Polygonum aviculare*, and *Amaranthus retroflexus* in 2010, and partially *Polygonum aviculare* and *Tribulus terrestris* in 2011, but not *Cynodon dactylon* in the same year. This suggests that the application of PRE herbicides for residual weed control is unnecessary and does not improve weed control under precipitation occurring immediately after PRE application only. The precipitation amount should be considered when selecting the most appropriate PRE weed management strategy in black locust nurseries.

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