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Germination and vigour of narrow-leaved lupin seeds as the effect of irrigation of parent plants and cultivation in different soil tillage systems

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Abstract. The research was conducted on the basis of the field experiment which was carried out at the Złotniki Research Station in Poland (52°29' N, 16°49' E) in the years 2008, 2009 and 2010. Two effects were studied: the first factor comprised overhead irrigation (non-irrigated vs. overhead irrigated), and the second factor was soil tillage systems (conventional tillage, reduced tillage and no-tillage). The aim of this study was to determine the influence of experimental factors on the quality of harvested seeds of narrow-leaved lupin. Irrigation of the parent plant decreased the germination of harvested seeds and increased percentage of mouldy seeds. Dry weight of seedlings from seeds produced under the irrigation treatments was significantly lower. The reduced and no-tillage systems decreased the germination of seeds produced under irrigation conditions. There was no significant effect of soil tillage systems in the non-irrigated variant.

keywords: legume, reduced tillage, no-tillage, sowing value, water

INTRODUCTION

According to Małecka et al. (2012), tillage systems currently used in Poland may be divided into two broad categories: inversion tillage, known as conventional tillage, and non-inversion tillage, known more widely as conservation tillage with shallow cultivation or direct drilling. Conventional tillage practices are one of the many emerging environmental, agronomic and economic issues that are addressed in contemporary cropping systems (Jug et al., 2011), but the use of non-inversion tillage, particular reduced tillage is gradually increasing (Małecka et al., 2015). Narrow-leaved lupin species can be cultivated in simplified soil tillage systems without losses of seed yield (Faligowska, Szukała, 2015). The second factor that can improve legume productivity is irrigation (Alderfasi, Alghamdi, 2010; Borówczak, Szukała, 1992; Borówczak at al., 2006; Knott, 1999; Szukała, Mystek, 2006). However, this factor may reduce the quality of harvested seeds (Borówczak, Szukała, 1992; Faligowska, Szukała, 2012; Ghassemi-Golezani et al., 2012; Szukała, Mystek, 2006). Agricultural productivity mainly depends on quality of seeds planted (Mumtaz Khan at al., 2003).

The aim of this study was to determine the effect of irrigation and different soil tillage systems on seed quality of narrow-leaved lupin (*Lupinus angustifolius* L.).

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MATERIALS AND METHODS

The research was conducted as a field experiment in three consecutive years, 2008, 2009 and 2010 at the Złotniki Research Station (52°29' N, 16°49' E, Poland) of the Poznań University of Life Sciences. The experiment was laid out in a randomized complete block design with split plot arrangements with 4 replications. The main-plot factor consisted of irrigation variants: natural rainfall (non-irrigated), and natural rainfall plus irrigation (irrigated); the sub-plot factor was the adopted soil tillage system: conventional tillage, reduced tillage and no-tillage. The non-irrigated and irrigated plots were divided into subplots of 24 m^2 and 48 m^2, respectively, where the soil tillage systems were tested. There was a gap of 6 m in width between non-irrigated and irrigated parts of plots. The study was conducted as a stationary experiment and at the same location for each year on grey-brown podsolic soil (pH = 4.8 measured in 1 M KCl; 1.3% organic matter: 50–110 mg P kg^{-1}, 115–195 mg K kg^{-1}) in a 4-crop rotation. Narrow-leaved lupin cultivar 'Baron' (at a rate of 150–160 kg ha^{-1} depending on weight of 1000 seeds and germination ability) was sown in first decade of April for all tillage systems. Sowing depth for all tillage systems was 4 cm and the row distance was 18 cm. In all the tillage systems plots were drilled with a double disk drill (Great Plains, Solid Stand 10' equipped with a fluted coulter for residue cutting, a double disk for seed placement, and a press wheel, 3 m wide).

Irrigation treatments were applied when consumption of 30% of the readily available soil moisture was obtained in the 0.30 m root zone during flowering, pods and seeds ripening (May, June, July). The soil moisture content was measured by the gravimetric method. The number of irrigation applications was four in 2008, one in 2009, and three in 2010, to give a total of 160 mm, 40 mm and 120 mm, respectively. Water was taken from a small reservoir near the experimental site. Irrigation was performed using a water pump with outlet pipes and a rotary sprinkler. Aluminum pipes of 110 mm in diameter were used and the diameters of the nozzles were 20 mm. The main pipes with the rotary sprinkler were placed in the middle of irrigated parts of plots, there was one rotary sprinkler for irrigated part of main plots

The tillage systems have been applied continuously since 1997 (Table 1). Fertilisation was uniform for all the tillage systems for each experimental year (80 kg P ha^{-1}, 100 kg K ha^{-1}). Before sowing, the seeds were dressed with a fungicide containing thiram and carboxin (350 ml per 100 kg of seeds in 700 ml water). Weeds were controlled with a herbicide at the rate of 1.5 L ha^{-1} (linuron). Ten days before harvest depending on stage of irrigated plants, the lupin was desiccated by diquat (1.5 L ha^{-1}). Lupin was harvested annually in early August from the plot of 11.5 m^2 (7.6 × 1.5) using a 1.5 m wide Wintersteiger Classic Plot Combine. The standard germination test was followed (ISTA, 2006) on 100 randomly selected seeds from each replication using the between-paper method at 20 ± 1ºC. Seeds were placed equidistantly apart from each other on moist germination paper. The paper was rolled up and placed in a thermostat. Germination percentage was estimated after 5 days (first count) and then after 10 days (final count): the number of normal seedlings, abnormally germinated seed and mouldy seed were counted. The seeds were visually assessed and the results were presented as percentages.

In the electrical conductivity test (ISTA, 2006), 50 randomly selected and weighed seeds from each replication were soaked in 250 cm^3 deionized water in beakers and kept in a thermostat at 20 ± 1ºC for 24 hours. After stirring of the liquid the electrical conductivity of the solute with the seeds was measured (without removing the seeds from the beakers) with an Elmetron CC-551 microcomputer conductometer. The results were recorded in µS cm^{-1} g^{-1}.

During the seedling length (Dąbrowska et al., 2000) test, a roll of moistened germination paper with 25 seeds was placed in a thermostat at 20 ± 1ºC. After 10 days, when the test was complete, the length (cm) of normally sprouted seedlings was measured. The value was calculated as the sum of the length of all sprouted seedlings, which was divided by 25.

Mean seedling dry weight (Dąbrowska et al., 2000). In order to measure dry weight the normal seedlings from each roll were dried at 80 ± 1ºC for 24 hours, they were weighed and their dry mass was divided by the number of normal seedlings from the roll. The results were recorded in mg.

All the data were processed using the analysis of variance (ANOVA) with the SAS package.

The means of treatment were compared by means of Tukey's Multiple Range test and honestly significant difference (HSD) was declared at P<0.01 and P<0.05. The data were analyzed as a split-plot randomized complete block design with four replications.

The relationship between seed characteristics was determined with the correlation coefficient.

The mean air temperatures during the vegetation season of lupin were higher than the 55-year mean, except in June 2009 and May 2010 (Table 2). In general, all the three years were warmer than the long-term mean. Total precipitation during the growing season was greater in 2009 (368.1 mm) and 2010 (433.0 mm) than the 55-year mean (265.8 mm). The precipitation in 2008 was only 230.6 mm. The best weather conditions for the development of lupins were in 2009, when during production of flowers and pods (June-July), while the precipitation were higher than in the other two years.

Table 1. Tillage systems.

TS	Cultivation measures
CT	Post-harvest cultivation: disk harrow (2.5 m wide) to a depth of 8 cm and fertilization Basic land preparation: ploughing to a depth of 30 cm Pre-plant tillage: cultivator followed by harrowing and rolling (to a depth of 8 cm)
RT	Post-harvest cultivation: application of glyphosate herbicide (3 L ha^{-1}) and fertilization Basic land preparation: stubble cultivator (2.5 m wide) Pre-plant tillage: cultivator followed by harrowing and rolling (to a depth of 8 cm)
NT	Post-harvest cultivation: application of glyphosate herbicide (3 L ha^{-1}) and fertilization Basic land preparation: - Pre-plant tillage: application of glyphosate herbicide (3 L ha^{-1}) and sowing directly into the stubble of the previous crop

TS: tillage system; CT: conventional tillage; RT: reduced tillage; NT: no-tillage.

Table 2. Mean daily air temperatures and total precipitation in the vegetation periods in 2008–2010 and 1951–2006 (from the Agrometeorological Observatory in Złotniki).

Years	Vegetation period					Mean of total
	April	May	June	July	August	
			Mean temperatures [◦C]			
2008	10.0	16.2	20.6	22.2	19.7	17.74
2009	14.2	15.1	16.7	21.7	21.4	17.82
2010	10.5	12.0	19.2	23.0	19.6	16.86
1951–2006	8.5	14.2	17.4	19.1	18.4	15.52
			Total precipitation [mm]			Sum of total
2008	77.5	9.5	8.4	46.6	88.6	230.6
2009	16.0	92.3	129.1	104.6	26.1	368.1
2010	38.5	134.6	26.6	100.9	132.4	433.0
1951–2006	31.3	48.0	57.8	74.5	54.2	265.8

RESULTS

In the study, both factors of the field experiment had a significant effect on germination of collected seeds (Table 3). Overall, in comparison to the non-irrigated variant, irrigation decreased seed germination percentage and increased the percentage of mouldy seed and abnormally germinated seed. Significant interactions were also found between the experimental factors. Under irrigation treatments, both reduced and no-tillage cultivation decreased the germination percentage after 5 days and after 10 days, while at the same time they caused an increase in the percentage of mouldy seed compared to conventional tillage. The lowest germination percentage and the highest percentage of mouldy seed were recorded under no-tillage conditions. The soil tillage systems did not influence seed germination at the non-irrigated variant. On average, compared to conventional tillage, reduced tillage and no-tillage decreased the germination percentage and increased the percentage of mouldy seed.

The seed vigour measurements (Table 4) showed no significant interactions between the experimental factors and no effect of soil tillage systems. The analysis of variance showed a significant difference of mean seedling dry weight between the non-irrigated variant and irrigation treatments. Irrigation decreased dry mass of seedlings by

Table 3. The effect of irrigation variants and soil tillage systems on seed germination [%].

Specification	Irrigation variants (IV)	Tillage systems (TS)			Average
		CT	RT	NT	
Germination after 5 days	NI	93	93	92	93
	I	91	86	82	86
Average		92	89	87	
Germination after 10 days	NI	95	95	94	95
	I	93	88	87	89
Average		94	92	90	
Mouldy seed	NI	3	3	3	3
	I	2	7	9	6
Average		3	5	6	
Abnormally germinated seed	NI	2	2	4	2
	I	4	5	5	5
Average		3	3	4	

HSD values	Germination after 5 days	Germination after 10 days	Mouldy seed	Abnormally germinated seed
IV	2.5**	2.3**	1.8**	0.9**
TS	2.2**	1.9**	1.8**	NS
IV×TS	3.1**	2.6**	2.6**	NS

NS: not significant; *$p < 0.05$ and **$p < 0.01$. Irrigation variants: NI, non-irrigated; I, irrigated. Tillage systems: CT, conventional tillage; RT, reduced tillage; NT, no-tillage.

Table 4. The effect of irrigation variants and soil tillage systems on seed vigour.

Specification	Irrigation variants (IV)	Tillage systems (TS)			Average
		CT	RT	NT	
Electrical conductivity test	NI	14.5	17.0	16.1	15.8
[µS cm^{-1} g^{-1}]	I	16.9	17.8	19.8	18.2
Average		15.7	17.4	18.0	
Seedling length [cm]	NI	9.13	8.70	8.96	8.93
	I	9.15	8.32	9.39	8.95
Average		9.14	8.51	9.17	
Mean seedling dry weight [mg]	NI	24.7	24.7	26.4	25.2
	I	23.2	20.9	21.6	21.9
Average		23.9	22.8	24.0	

HSD values	Electrical conductivity test	Seedling length	Mean seedling dry weight
IV	NS	NS	2.28**
TS	NS	NS	NS
IV×TS	NS	NS	NS

NS: non-significant; *P < 0.05 and **P < 0.01. Irrigation variants: NI, non-irrigated; I, irrigated. Tillage systems: CT, conventional tillage; RT, reduced tillage; NT, no-tillage.

Table 5. Correlation coefficients between laboratory measures in irrigation variants.

IV	r	Mean seedling dry weight	Abnormally germinated seed	Mouldy seed	Germination after 5 days	Germination after 10 days
NI	Mean seedling dry weight	1	-0.28	-0.51*	0.59*	0.46
	Abnormally germinated seed		1	0.63*	-0.78**	-0.87**
	Mouldy seed			1	-0.94**	-0.93**
	Germination after 5 days				1	0.96***
	Germination after 10 days					1
I	Mean seedling dry weight	1	0.39	-0.73*	0.70*	0.70*
	Abnormally germinated seed		1	-0.51*	0.31	0.29
	Mouldy seed			1	-0.95***	-0.97***
	Germination after 5 days				1	0.97***
	Germination after 10 days					1

IV: irrigation variants; NI: non-irrigated; I: irrigated.
* P<0.05, ** P<0.01, *** P<0.001

Table 6. Correlation coefficients between laboratory measures in tillage systems.

TS	r	Mean seedling dry weight	Abnormally germinated seed	Mouldy seed	Germination after 5 days	Germination after 10 days
CT	Mean seedling dry weight	1	-0.13	-0.60*	0.56*	0.52*
	Abnormally germinated seed		1	0.14	-0.62*	-0.63*
	Mouldy seed			1	-0.77**	-0.83**
	Germination after 5 days				1	0.95***
	Germination after 10 days					1
RT	Mean seedling dry weight	1	0.00	-0.74*	0.81**	0.75**
	Abnormally germinated seed		1	-0.20	-0.13	-0.15
	Mouldy seed			1	-0.92**	-0.94**
	Germination after 5 days				1	0.98***
	Germination after 10 days					1
NT	Mean seedling dry weight	1	-0.02	-0.57*	-0.63*	0.57*
	Abnormally germinated seed		1	-0.14	-0.06	-0.16
	Mouldy seed			1	0.93***	-0.96***
	Germination after 5 days				1	0.98***
	Germination after 10 days					1

TS: tillage system; CT: conventional tillage; RT: reduced tillage; NT: no-tillage.
* P<0.05, ** P<0.01, *** P<0.001

3.3 mg. The electrical conductivity test and seedling length did not show any significant differences between the irrigation variants.

The parameters were correlated to a varied extent (Tables 5 and 6). The strongest relationships at the irrigation variants and soil tillage systems (where the correlation coefficients were greater than 0.75) were found between: the germination percentage after 5 days and germination percentage after 10 days. The high percentage of mouldy seed resulted in reduced germination after 5 and 10 days, because of the strong, but negative relationships between these parameters.

DISCUSSION

Narrow-leaved lupin is one of the lupin species important in Poland and Russia (Dracup, Kirby, 1996). As feed for animals it may be used as seeds and green forage, which may also be turned into silage (Faligowska et al., 2014). Moreover, forage legumes are widely used as a preceding crop to improve soil fertility and to increase the yield of subsequent crops in rotation (Gül et al., 2008). One of the major factors that restrict the yields of legumes is shortage of rainfall, especially in the so-called critical period at blooming and pod setting (Jasińska, Kotecki, 1993). The irrigation generally improves the yielding of legumes (Alderfasi, Alghamdi, 2010; Borówczak, Szukała, 1992; Borówczak et al., 2006; Knott, 1999; Szukała, Mystek, 2006), but can also reduce the quality of harvested seed (Borówczak, Szukała, 1992; Faligowska, Szukała, 2012; Ghassemi-Golezani et al., 2012; Szukała, Mystek, 2006).

In the non-irrigation variant, there was a strong negative relationship of the correlation coefficients between germination and both mouldy seed and abnormally germinated seed, while in the irrigation treatments the correlation coefficients showed that the main reason for reduced germination percentage was connected only with the increase of percentage of mouldy seed. In the field, the overhead irrigation moistened the plants, developing pods and seeds, promoting greater infestation of irrigated seeds by fungi and moulds. We observed significant differences for laboratory germination percentages between soil tillage systems in irrigation conditions. The increased percentage of mouldy seed was caused by both: by irrigation and by the higher weed infestation that we observed on the field under reduced and no-tillage tillage systems. The simplified soil tillage systems usually cause the increase of weed infestation (Auskalniene, Auskalnis, 2009; Gill, Arshad, 1995; Rusu et al., 2006). In this situation the plants and seeds also had greater problems with drying, their moisture was higher and this led to increase in the infestation by fungi and moulds. Rusu et al., (2006) observed higher incidence of diseases in minimum tillage and increased amounts of weeds in all the minimum soil tillage systems compared to the plough cultivation. Under non-irrigation conditions the soil tillage systems did not differ for the germination of produced seed lots. All the experiment lots were above the 75% minimum germination required for sale in Poland.
The germination test is widely accepted and frequently used as an indicator of seed lot quality. However, under field/greenhouse conditions the germination test overestimates the performance of seeds, because it is performed under optimal conditions for each species. Furthermore, it is inadequate for discriminating between seed lots in terms of the speed and uniformity of seed germination (Copeland, McDonald, 2001). The vigour tests are used to indicate the relative emergence performance of seed lots more reliably than with a standard germination test (Matthews et al., 2009). Legumes with large, normally living cotyledons are good candidates for the electrical conductivity vigour test to indicate field emergence, because they still germinate in the laboratory even with considerable areas of dead tissue on their cotyledons provided that the critical areas of the embryo remain alive (ISTA, 2003). In this experiment the electrical conductivity test did not show any influence of irrigation and soil tillage systems on vigour of harvested seeds, but we could observe some tendency: on average a greater leakage of exudates was found for seeds produced under irrigation conditions and also under reduced and no-tillage systems, moreover irrigation significantly decreased dry mass of seedlings. In an experiment of Ghassemi-Golezani et al. (2014), seeds of mung bean produced under the lowest dose of watering (70 mm) had the largest seedlings. Ghassemi-Golezani et al. (2012) studied seed vigour and field performance of lentil under different irrigation treatments and found that seedling dry weight and emergence percentage were increased with increasing seed vigour. Increased irrigation treatments and a reduced seed vigour led to significant reductions in ground cover, mainly due to poor stand establishment. Ghassemi-Golezani and Hosseinzadeh-Mahootchy (2009) indicated no significant cultivar × irrigation interaction, as the differences in seed vigour among the faba bean cultivars were similar under all irrigation treatments. The authors concluded that although water stress may reduce seed weight and yield of the crop (Ghassemi-Golezani et al., 1997), it had no significant effect on seed vigour.

CONCLUSIONS

1. Irrigation of parent plant leads to decreased germination of harvested seed due to increase of percentage of mouldy seed.
2. Under irrigation condition the conventional tillage did not influence on sowing value of seeds but simplified cultivation of narrow-leaved lupin may result in decreased germination of produced seeds. Under natural rainfall conditions the reduced and no-tillage systems did not influence on the quality of seed.

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