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AGROTECHNICAL INDICATORS FOR *Trigonella foenum-gracum* L. PRODUCTION IN THE ENVIRONMENTAL CONDITIONS OF NORTHEASTERN EUROPE

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ABSTRACT

The aim of this paper was to study the impact of key agrotechnical factors: seed inoculation *Rhizobium meliloti*, sowing date, row spacing, weed control, and pathogen control, on productiveness of fenugreek seeds in the environmental conditions of the north-eastern Europe. The results indicate that the average seed yield of fenugreek from 54 test technology variants was 759 kg ha^{-1}, within a 9% variation range. The primary decision-supporting criteria for classification of a given technology of growing fenugreek for seeds as a high-yielding one under the environmental conditions of north-eastern Europe are: the earliest possible sowing date or the one delayed by no more than 10 days relative to the former, as well as the inter-row spacing of 15 cm; the second most important criteria include technological variants with chemical weed control and full antifungal protection. Among the yield-protecting treatments tested, weed control of fenugreek plantations as an agrotechnical factor was responsible for the highest variation of seed yields. Irrespective of a weeding technique (mechanical, chemical), the sowing of seeds at the earliest possible date or delayed by 10 days did not cause a significant decline in seed yield, although the sowing date postponed by 20 days might reduce the seed yield by 3-10% when mechanical weed control techniques are applied, and by 3-13% on fields treated with a herbicide.

Keywords: fenugreek, plant protection, *Rhizobium*, row spacing, sowing, yielding

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.) is an annual, medicinal, leguminous crop. It is grown across the continents, under diverse soil and climatic conditions. Recently, there has been a growing interest in the production of fenugreek, especially in North American countries and in Europe (Basu et al., 2008; Hussein et al., 2011; Kinji and Rahdari, 2012; Soori and Mohammadi-Nejad, 2012). One of the most widely appreciated features of this crop is its ability to improve soil fertility by fixing atmospheric nitrogen, owing to which less nitrogen fertilization is required under subsequent crops (Basu et al., 2004; Khan et al., 2014; Kolodziej and Zejdan 2000). In order to reinforce this property, soil under leguminous crops is inoculated with appropriate *Rhizobium* bacteria so as to ensure the proper course of nodulation. Inoculation is recognized to be an agrotechnical factor which stimulates the plant growth and reduces production costs by decreasing the demand for expensive artificial nitrogen fertilizers (Ndakidemi et al., 2007). In another study, Naimuddin et al. (2014) reported that germination was accelerated by seed inoculation with *Rhizobium*. Seed yield was significantly higher in treatments with manure application and *Rhizobium* inoculation than in the control variant. In cultivation of the common fenugreek, inoculation with *Rhizobium meliloti* is particularly important when the plant is grown under unfavourable conditions, e.g. excessive salinity of soil (Abd-Alla and Omar, 1998), or else when seed quality traits are being modified (Wierzbowska and Żuk-Gołaszewska, 2014).

The date of sowing and row spacing are two important agronomic factors, both having a direct impact on the level of yield. In general, earlier sowing dates are preferred because of their anticipated beneficial effects on the seed germination, plant growth and development, duration of the growing season and finally the yielding

(Matelic and Jevdjovic, 2007; Pandita and Randhawa, 1994; Sheoran et al., 2000). Besides, an optimal sowing date paves the way for a more efficient use of time, light, temperature, precipitation and other environmental factors (Maletic and Jevdjovic, 2007).

The recommendations on row spacing in fenugreek cultivation are not univocal. The following row spacing has been tested in research: 15, 20, 25, and 30 cm (El Awad and El Fahal 2006); 18 cm (Basu et al., 2008); 25 cm (Sadeghadeh-Ahari et al., 2009) 30, 40, 50, and 60 cm (Khan et al., 2005), or else a 20-60-20 cm belt system was tested (Kołodziej and Zejdan, 2000).

The agrotechnical factors which determine plant growth and yielding involve plant protection against weeds and pathogen control. After sowing, fenugreek seeds emerge quickly but plants grow relatively slowly in comparison with many other legumes, as a result of which fenugreek plants do not compete effectively with the spring weeds. Therefore, mechanical and/or chemical weed control is crucial. However, to this day, no agrotechnical approaches have been worked out for weed control on fenugreek fields in the north-eastern Europe. Also, there is insufficient knowledge on an adequate agrotechnical approach to pathogen control through seed treatment and during the growth of fenugreek crop as well as its effect on yield. Fenugreek seedlings are infected by *Pythium* species and other root rot pathogens such as *Rhizoctonia* and *Fusarium*. The two most common fungal diseases affecting fenugreek in further stages of plant development are *Cercospora* leaf spot and powdery mildew (AAFRD, 1998). In Australia, yield of fenugreek was badly stricken by blight disease caused by *Cercospora traversiana* and wilt caused by *Fusarium oxsysporum* and *Rhizoctonia*, concomitant with collar rot, leaf spot and pod spot diseases (Petropoulos, 2002).

In Poland, and elsewhere in the north-eastern part of the Europe, fenugreek is a relatively new crop, which is why adequate agricultural practices and well as knowledge about environmental interference and commercial potential are only now being gradually developed. The aim of this study is to determine the effect of five agrotechnical factors, e.g. (A) seed inoculation with bacteria *Rhizobium meliloti*, (B) sowing date, (C) row spacing, (D) weed control, and (E) pathogen control on yield components and seed yield of fenugreek.

MATERIALS AND METHODS

Experiments and measurements

The field experiments were conducted in 2008-2009, at the University of Warmia and Mazury Research Station in Tomaszkowo (53°43’ N, 20°24’ E). In each field experiment there were tested five agrotechnical factors:

A. application of a bacterial inoculum composed of *Rhizobium meliloti* (0: no, 1: yes) - fenugreek seeds were Nitragina- treated before sowing

B. date of seed sowing (0: the earliest possible date, 1: delayed by 10 days, 2: delayed by 20 days) and three factors on three levels)

C. row spacing (0: 15 cm, 1: 30 cm, 2: 45 cm)

D. weed control (0: mechanical, 1: chemical)

E. protection from pathogens (0: seeds not dressed, chemical plant protection, 1: seed dressing without chemical plant protection, 2: seed dressing and chemical plant protection).

The field scheme of a fractional, factorial experiment in a completely randomized design, encompassing ½ of the complete pool of 108 combinations (54 plots) was generated according to the Connor and Zelen’s classification (McLean and Anderson, 1984) with Statistica® software. The experiment was set up on typical brown soil, which belonged to the soil gradation IVa and overlay light loam. The soil had slightly acid reaction and a moderate content of phosphorus and potassium, while being poor in magnesium. The content of nitrogen in 2008 and 2009 was 1.13 and 0.98 g kg^{-1} of soil, respectively (Table 1).

Table 1. Chemical properties of the arable layer of soil under the experimental field.

Year of study	pH	N total	Content of available macronutrients		
			P	K	Mg
	in 1M KCl	g kg^{-1}soil	mg kg^{-1}soil		
2008	6.13	1.13	59.4	200.0	30.0
2009	5.81	0. 98	65.7	140.0	61.9

Each plot covered 10.8 m^2. Seeds were sown to the depth of 2-3 cm and in the amount of 20 kg ha^{-1} of germinating seeds. The mineral fertilization consisted of 30 kg N ha^{-1} (urea), 30.5 kg P ha^{-1} (46% granulated triple superphosphate) and 83 kg K ha^{-1}(60% potassium salt).The seeds (including the ones treated with *Rhizobium meliloti* (factor A) were sown (factor B) on 16 April 2008 and 14 April 2009 (first date), on 26 April 2008 and 24 April 2009 (second date), and on 6 May 2008 and 4 May 2009 (third date). Mechanical weed control (factor D) consisted of double manual weeding, whereas chemical plant protection involved the application of the herbicide Reglone 200 SL according to the producer’s recommendations. The plant protection against pathogens (factor E) in variants with seed dressing included an application of Dithane–M 45; in the variants with antifungal plant protection, the preparation Penncozeb 80 WP was applied.

The degree of weed infestation on fenugreek plantations was assessed three times: 1st assessment was after plant emergence (3-4 weeks after sowing) but before mechanical weeding (T1), 2nd assessment – 14 days after the mechanical or chemical weeding treatment (T2), and 3rd assessment – before harvest (T3). During the research, the species composition and number of weeds were determined with the frame method on an area of 1 m^2 of each plot. In order to estimate the relative abundances of different species and equitability, the Simpson's indices of diversity D and evenness E_d were calculated from the formulas: $D = \frac{1}{\sum_{i=1}^{S} p_i^2}$, and ED $E_D = D\frac{1}{S}$, where p is the proportion of species i in relation to the total number of species, and S is the maximum diversity which equals to the number of species (Simpson 1949). The assessment of plant infestation by weeds on a 0-5° scale given by Hinfner and Papp (1964) was done 14 days after the weeding treatments. The Percent Disease Index (*PDI*) was calculated according to the McKinney's formula (1923): $PDI = \frac{\sum(a \times b)}{n \times x} \times 100$, where: $a \times b$ – the total sum of the products of affected organs (a) by the determined degree of infection (b); n – number of examined plants; x – the maximum score on the scale.

The harvest was carried out at the full maturation stage - 14, 22 and 26 August 2008 and 26 August and 08 September (second and third date) 2009. Immediately prior to the harvest, ten plants per plot were randomly selected for determination of yield components and seed yield per plant. The following were measured: plant height (cm), number of branches, number of pods, number of seeds per pod, number of seeds per plant, one thousand seed weight, and weight of seeds per plant. After the harvest, seeds were weighed and seed yield was determined.

Statistical analyses

Data from the experiments on plant yield components and yield per hectare were analyzed with the use of factorial ANOVA. Non-significant higher order interactions composed the experimental error. Significant two-factor interactions were visualized in graphs. Interrelationships between plant yield components were studied according to the Wright's path analysis (Wright 1934). All analyses were performed at the significance level $P<0.05$.

The classification tree method was applied to evaluate the rank of agrotechnical factors and to discriminate between the tested technologies. A classification tree was built on the basis of a learning set, which was composed of the lower and upper quartile, which corresponded to the low (L) and high (H) yield, respectively (Breiman et al., 1984). The trees were created according to the C&RT method (Classification and Regression Trees). For each agrotechnical factor, possible intervals were tested in order to find the one in which the highest improvement of the goodness of fit (according to the Gini measure) was achieved. The size of trees was determined based on the V-th cross validation.

The course of climatic conditions during the research

The meteorological data were recorded at the Meteorological Station in Tomaszkowo, which stands 200-400 m away from the experimental field. Generally, the plant growing season from April to August in 2008 and September in 2009 was dry and warm, as evidenced by the high temperatures and low precipitations recorded then (Table 2). The average temperatures during the two seasons were 14.8 and 15.1°C, being above the average temperature from a multiannual period (1961-2000) by 7% and 9%, respectively. The sum of precipitation during those seasons was 273.8 mm yr^{-1} in 2008 and 240.9 mm yr^{-1} in 2009, while the multiannual total was 367.2 mm yr^{-1}.

Table 2. Mean air temperature and total precipitation during the years of the experiment.

Year	April	May	June	July	August	September	Whole season
Average temperature, °C							
2008	7.7	12.3	16.9	18.4	18.4	15.1	14.8
2009	9.4	12.8	14.9	21.1	18.2	14.2	15.1
Multiannual period (1961-2000)	6.9	12.7	15.9	17.7	17.2	12.5	13.8
Total precipitation, mm							
2008	31.4	27.0	32.7	57.7	102.1	22.9	273.8
2009	4.8	52.9	136.9	48.3	19.3	25.7	287.9
Multiannual period (1961-2000)	36.1	51.9	79.3	73.8	67.1	59.0	367.2

In 2008, the average daily air temperature in April and from June to September was about 1°C higher than the multiannual (1961-2000) average temperature. In May only the average temperature was approximately the same as during the multiannual period. The total rainfall in April, May, June and July corresponded to 87, 52, 41 and 78%, respectively, of the multiannual precipitation sum. In contrast, the last two months of the plant growth, August and September, were extremely different: the sum of precipitation in August exceed the multiannual average by 52%, whereas in September the total rainfall was lower than the multiannual average by as much as 71%.

The weather conditions during the 2009 fenugreek growing season were more changeable than in 2008. The average daily temperatures were 1.3ºC higher than the multiannual means, although June was by 1ºC cooler.

Particularly big differences in temperatures were noted in April and July, when the daily average temperatures exceeded the multiannual ones by 2.5 and 3.4ºC, respectively. The total of precipitations in 2009 was 12.3% lower than the mean precipitation sum in 1961-2000. April was extremely dry, with the rainfall of about 4.8 mm; in May, the rainfall was on the level of average precipitation from the multiannual period. In turn, July was a wet month, with the sum of rainfall reaching 136.9 mm, almost 50% higher than the sum from the 40-year period. The other months were characterized by a distinct shortage of rains.

RESULTS AND DISCUSSION

Plants sown on an optimal day are more likely to achieve a proper phenological development. Delayed sowing, on the other hand, shortens the duration of a plant growing season and consecutive phases in a plant development. Sheoran et al. (2000) demonstrated that when sowing was delayed by 14 days, the fenugreek genotypes they analyzed began the inflorescence phase earlier and matured sooner. Besides, delayed sowing diminished the plant's requirements for warm temperatures, which is extremely important when plants which demand higher temperatures must be adapted to growing in more severe climates. The common fenugreek is sensitive to periodical shortages of moisture, in particular immediately after sowing, which in Poland is typically carried out in April (Żuk-Gołaszewska et al., 2015). This is confirmed by Akhalkatsi and Losch (2005) in their study on *Trigonella coerulea* L., which showed that water shortage during the seed germination limits the plant emergence and development. The cited authors demonstrated that in comparison with the control conditions and a variant which included plant watering twice daily, plants grown under water deficit conditions were significantly shorter (90±9.5 cm) and produced significantly fewer seeds (633.3±117.4 seeds). Moreover, fenugreek plants growing at water deficit generated significantly lower mass of seeds compared to the control plants, which had the highest seed yield, such as 7.7 g per plant. Meanwhile, compared to the control, the size and quality of seeds yielded by plants growing in soil with a higher moisture content did not demonstrate any significant differences.

Seed weight per plant

The mean values of the measured traits, yield components and seed yields from fenugreek plants are set in Table 3 together with the assessment of the significance of differences between years and agrotechnical factors. The main sources of variability of the traits were the years, dates of sowing and weed control. The weather conditions during the two years of the experiment caused differences in the height of plants, number of branches and number of seeds per pod. Compared to the mean values of these traits in 2008, the weather conditions in 2009 enabled the plants to grow higher, produce fewer branches and have more seeds per pod. In 2009, after a spell of dry weather immediately after seed sowing and then a period of moderate temperatures, June brought heavy rains, which may have caused a very intensive growth of vegetative parts of plants and their height. On the other hand, in 2008, heavy rains fell during the phase of pod filling, as a result of which no significant differences were observed in the 1,000 seeds weight or seed yield per plant between the two years, despite the smaller number of seeds per pot in that season. In the experiment conducted by Basu et al. (2008), fenugreek plants yielded higher in years with higher precipitation during the growing season (May to September) in 2004 (286 mm) compared to 2005 (102.8 mm).

Table 3. The effects of years and agrotechnical factors on average values of yield components of fenugreek plants.

Factors/levels		Plant height (cm)		No of branches		No of pods per plant		No of seeds in pod		1000 seed weight (g)		Seed yield plant $^{-1}$ (g)	
Total mean		30.1		4.60		12.26		6.75		14.7		1.20	
Year	2008	27.9	a	5.11	a	12.76	a	6.34	b	15.0	a	1.19	a
	2009	32.3	b	4.08	b	11.75	a	7.16	a	14.4	a	1.22	a
Seed inoculation	0	29.9	a	4.42	a	11.98	a	6.61	a	14.6	a	1.16	a
(A)	1	30.3	a	4.77	a	12.53	a	6.89	a	14.8	a	1.25	a
Sowing date (B)	0	32.0	a	5.45	a	13.74	a	7.37	a	14.2	a	1.43	a
	1	29.2	b	4.07	b	10.86	b	6.51	b	14.9	a	1.04	b
	2	29.1	b	4.27	b	12.16	a	6.38	b	15.0	a	1.14	b
Row spacing (C)	0	28.6	b	4.60	a	12.55	a	6.76	a	14.2	a	1.19	a
	1	30.6	ab	4.58	a	12.05	a	6.45	a	14.8	a	1.14	a
	2	31.2	a	4.60	a	12.17	a	7.05	a	15.1	a	1.28	a
Weed control (D)	0	30.5	a	4.92	a	13.06	a	6.86	a	15.0	a	1.31	a
	1	29.8	a	4.27	b	11.45	b	6.64	a	14.4	a	1.10	b
Fungicide	0	29.4	a	4.53	a	12.03	a	6.68	a	14.5	a	1.15	a
protection	1	30.7	a	4.70	a	12.14	a	6.90	a	14.8	a	1.24	a
(E)	2	30.2	a	4.57	a	12.59	a	6.67	a	14.8	a	1.22	a

a, b – means for years and agrotechnical factors denoted with the same letter do not differ significantly acc. to the Tukey's T test.

Fenugreek is sensitive to application of various factors which compose a given technology, including seed inoculation, the date of sowing, row spacing, weed control, disease management and the way of harvest (Gendy, 2013, El Awad and El Fahal, 2006, Tuncturk and et al., 2011, Petropoulos, 2002).

As proven by a Desperrier et al. (1995), fenugreek can fix 48% of its total N_2 during the vegetation season. In our study, the seed inoculation of fenugreek did not differentiate yields of the common fenugreek. The not significant effect of *Rhizobium* inoculation on yield may be affected by environmental conditions during the study seasons. High temperatures and water deficit in 2008 and a relatively cooler season at the excessive rainfall in 2009 limited the N_2-fixing process. Zahran (1999) pointed out that symbiotic rhizobial activity is not expected to express its full capacity for nitrogen fixation if environmental factors impose limitations on the vigor of the host legume. In a study on fenugreek, Gendy (2013) showed that *Rhizobium* inoculation resulted in the highest values of the number of leaves per plant, plant dry weight and number of nodules per plant compared with the uninoculated control. In turn, Poi et al. (1991) reported that *Rhizobium* inoculation of fenugreek led to an increase in the plant biomass and a higher seed production.

The sowing date differentiated all seed yield components except the 1,000 seed weight. Overall, delayed sowing resulted in fenugreek plants growing shorter, with fewer branches, pods and seeds in pods, which eventually meant smaller yields. In generally, better values of the measured traits were achieved when weeds were controlled mechanically. In these treatments, plants produced a relatively larger number of branches and pods per plant, as well as generating higher yields than on plots with the chemical protection of plants against weeds. The spacing between rows of plants affected only the height of plants, which grew taller at a larger distance between rows. The other agrotechnical factors we analyzed, such as the inoculation of seeds with the bacterium *Rhizobium meliloti* or the protection of seeding material and plants from pathogens, did not cause significant variation in the mean values of the traits. Figure 1 illustrates significant interactions between the years of cultivation and agrotechnical factors concerning the plant height, number of branches, number of pods per plant and 1,000 seeds weight. These traits achieved different values on the consecutive dates of sowing, depending on the climatic and soil conditions in each of the years.

In 2008, lower values were recorded as the sowing date was delayed. In turn, in 2009, the traits were lower on later sowing dates except the 1,000 seeds weight, which followed a reverse trend. The significant *years* x *row spacing* interaction in the determination of the plant height obtained similar values in 2008 irrespective of the spacing between rows, and significantly higher values in 2009 when the distance between rows was bigger. Contrary effects in the two years of study were generated by the plant protection from weeds (*years* x *weed control*). The assessment of the number of branches and number of pods per plant demonstrated a stronger effect of the mechanical than chemical weeding treatment in 2008, whereas in 2009 both techniques had a similar effect. Relatively few significant interaction effects were noted between the agrotechnical factors. They only appeared for the interactions *sowing date* x *weed control* in the evaluation of the plant height, and *inoculation* x *weed control* in the number of pods per plant. As the sowing date was delayed, the height of plants in the variant with mechanical weeding decreased, while the ones given chemical weed control grew to a similar height. In turn, the *inoculation* x *weed control* interaction was significant owing to the fact that the number of pods per plant was similar regardless of the way in which plants were protected from weeds. However, when inoculation was applied, the number of pods per plant in the variant with mechanical weed control was higher than in the variant with chemical weeding.

The phenotype correlation coefficients between seed yield components per plant and the Wright's path coefficients are presented in Table 4. All the analyzed yield components, except the number of seeds per pod in 2008 and the weight of 1,000 seeds in 2009, were correlated with the seed yield per plant. Moreover, the traits were interrelated each other. The only exception was associated with the weight of 1,000 seeds which was correlated with plant height, the number of branches and pods only in 2009.

The analysis of path coefficients demonstrated that the significant correlation between the seed yield versus the plant height and number of branches was mainly attributable to the high direct effect of the number of pods per plant. Significantly positive direct effects of the number of pods, number of seeds per pod and 1,000 seeds weight exceeded analogous values of coefficients of the phenotype correlation with yield, which means that these effects are masked by negative indirect effects of the other traits. The high indirect effect and high direct effects of the number of pods per plant suggest that this characteristic is the major component of seed yield from a plant. This, in turn, implies that a higher number of pods per plant can play a role in seed yield per plant prognosis, and that this trait should be taken into consideration when making evaluation of agrotechnical factors involved in cultivation of fenugreek for high seed yields.

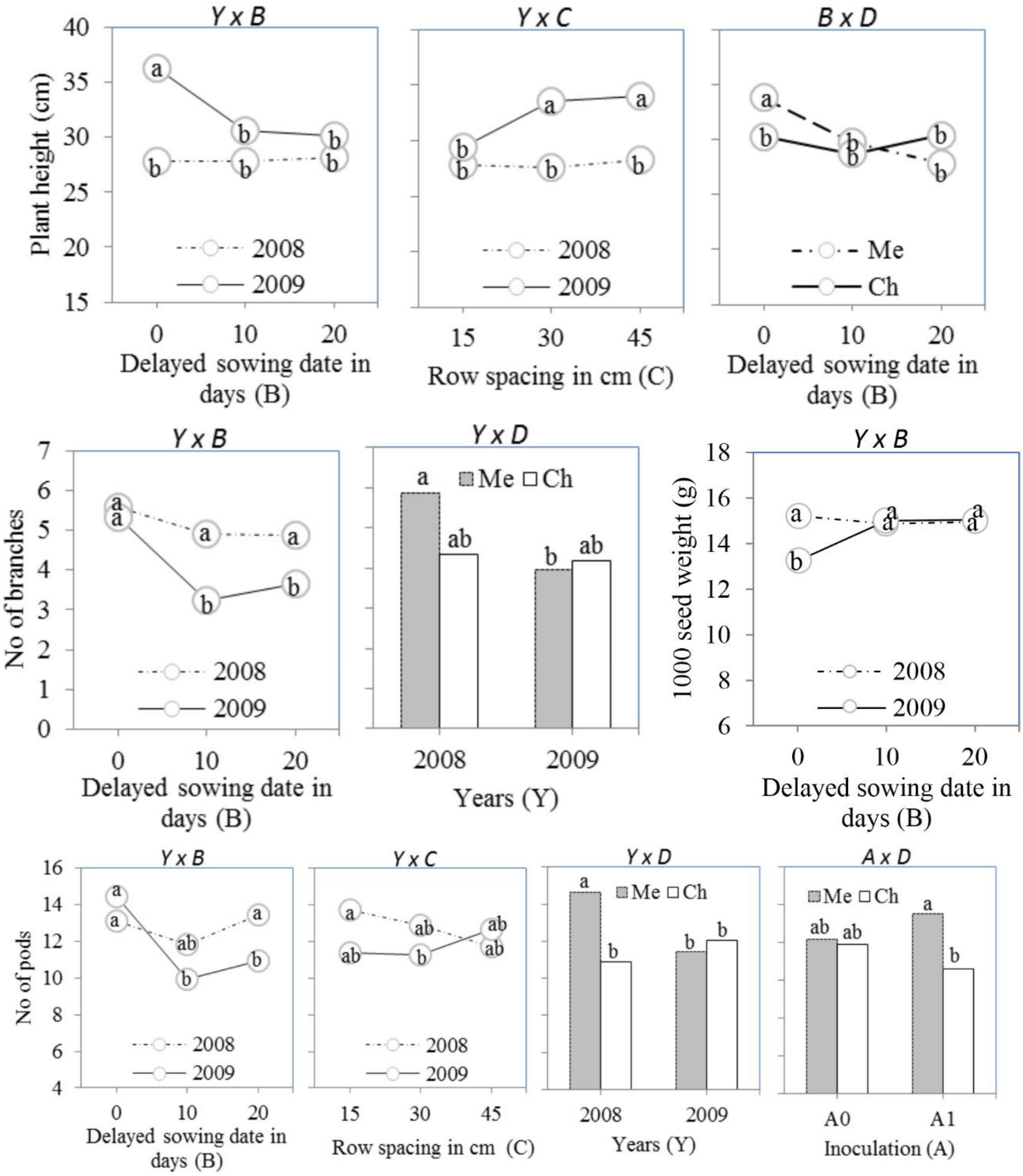

Figure 1. Significant two-factor interaction effects between years and agricultural factors for yield components of fenugreek plants (from upper left: plant height, No of branches, thousand seed weight, No of pods per plant,). Abrev.: Y – years, A – inoculation, B – sowing date, C – row spacing, D – weed control (Me – mechanical, Ch – chemical), E – pathogen control. (The letters in the diagrams were assigned according to the results of the significance evaluation between the mean T-Tukey's test at P<0.05; same letters indicate means which did not differ statistically significantly).

Table 4. Matrices of simple correlation and path coefficients between yield components of fenugreek in the study years.

Traits	Plant height	No of branches	No of pods per plant	No of seeds per pod	Weight of 1000 seeds	Seed yield plant^{-1}
	***X*₁**	***X*₂**	***X*₃**	***X*₄**	***X*₅**	***Y***
Matrix of simple correlation coefficients (data for 2008: above diagonal, 2009: under diagonal)						
X_1	1	0.4525*	0.5464*	-0.3815*	0.1620	0.3591*
X_2	0.7480*	1	0.7978*	-0.2835*	0.0638	0.5142*
X_3	0.6842*	0.7735*	1	-0.5148*	0.1804	0.6221*
X_4	0.3579*	0.3563*	0.3143*	1	0.0086	0.1808
X_5	-0.2738*	-0.4985*	-0.4193*	-0.2579	1	0.6277*
Y	0.6395*	0.6340*	0.7734*	0.7967*	-0.2081	1
$r_{tab.}(0.05) = 0.268$ (n=54)						
Matrix of path coefficients (direct effects on diagonal)						
2008						
X_1	0.0802	-0.0361	0.4873	-0.2457	0.0735	
X_2	0.0363	-0.0798	0.7115*	-0.1826	0.0289	
X_4	-0.0306	0.0226	-0.4591	0.6439*	0.0039	
X_5	0.0130	-0.0051	0.1608	0.0055	0.4534*	
P_e: random factor = 0.2377						
2009						
X_1	0.0314	-0.0047	0.4477	0.2303	-0.0650	
X_2	0.0235	-0.0063	0.5061	0.2292	-0.1184	
X_3	0.0215	-0.0049	0.6543*	0.2022	-0.0996	
X_4	0.0112	-0.0023	0.2057	0.6433*	-0.0613	
X_5	-0.0086	0.0032	-0.2744	-0.1659	0.2375*	
P_e: random factor = 0.1321						

* significant at P<0.05

Seed yield

Table 5 sets average fenugreek seed yields from both years of the experiment, and in relation to the tested agrotechnical factors. The yield variation under the soil and climate conditions during the experiment was significant, with the higher yields obtained under more favourable conditions in 2009. The principal effects of the analyzed agrotechnical factors were not significant and the yields oscillated around the average yield from all cultivation variants, on a level of 759 kg ha^{-1}. Admitting the 8% error tolerance, it can be concluded that the variation of yields from different sowing dates, with a decreasing yield on later dates, was significant weeding control. Practically, for the future development of fenugreek cultivation technologies it may be anticipated that seed yield will be the results of interaction effects between years and agrotechnical factors applied. Out of the analyzed agrotechnical conditions, a contrary response was demonstrated by fenugreek plants cultivated in the different weed control variants in the two years. When weeds were controlled mechanically, similar yields were harvested in both years. However, with the herbicide, the yield in 2009 reached 826 kg ha^{-1}, which was 19% more than in 2008. Another significant interaction appeared between the date of sowing and weed control technique. Irrespective of how weeds were controlled, sowing fenugreek on the earliest date or 10 days later did not result in a significant yield decrease. However, when the sowing date was postponed by 20 days, the yield was reduced by 3-10% in the mechanical weeding variant and by 3-13% when the herbicide was applied. Considering the relations between average yields from the first two sowing dates, it is possible to point to a certain tendency for yields which vary depending on the weeding method. Mechanical weed control may prove more effective on plants sown later, whereas an application of herbicide might be a better choice when fenugreek is sown as early as possible. It should be noted that some other interactions, such as *inoculation* x *date of sowing* (P<0.0593) and *date of sowing* x *row spacing* (P<0.0789) can be seen as significant if a higher error tolerance margin is assumed. The former interaction arose from the fact that the date of sowing was not significant on plots cropped with inoculated seeds. In contrast, the plots with non-inoculated seeds were found to yield significantly lower when the sowing date was delayed by 20 days.

Table 5. Seed yield of fenugreek in kg ha^{-1}.

Factor/ level		Year	Inoculation A		Sowing date B			Row spacing C			Weeding D		Fungicide protection E		
			0	1	0	1	2	0	1	2	0	1	0	1	2
2008		723_{b}	712	735	726	749	696	739	709	723	752_{bc}	694_{c}	697	731	742
2009		795_{a}	802	789	840	793	753	823	768	796	765_{ab}	826_{a}	803	814	769
A	0				790	790	690	768	728	774	752	760	769	775	727
	1				776	752	758	793	749	744	762	761	732	770	784
B	0							794	809	745	745_{ab}	821_{a}	718	822	809
	1							834	714	766	803_{ab}	739_{ab}	794	768	751
	2							714	692	767	729_{b}	720_{b}	739	727	707
C	0										797	765	782	800	761
	1										736	741	737	741	737
	2										743	775	732	776	769
D	0												736	767	774
	1												765	777	738
Mean		759	757	762	783	771	724	781	738	759	759	760	750	772	756

a, b – means for years and agrotechnical factors denoted with the same letter do not differ significantly according to the Tukey's T test.

On the other hand, the yield response to row spacing was varied. The highest yields were obtained at the row spacing of 15 cm for plants sown 10 days after the earliest sowing date, and at 30 cm when plants were seeded on the earliest possible date. When the sowing date was postponed by 20 days, the largest tested row spacing, i.e. 45 cm, proved to be the best for seed yields. In literature, the response of fenugreek plants to row spacing is also reported to vary. Experiments by Khan and et al. (2005), El Awad and El Fahal, (2006) suggested that the distance between rows of plants did not affect the yield structure components. On the other hand, Kumawat et al. (1998) claimed that seed yield of fenugreek was higher at 30 cm spacing. In another study, the highest fenugreek seed yield was achieved by plants sown at row spacing of 30 and 60 cm (Sharma 2000). Pandita and Randhawa (1994) reported that inter-row spacings significantly affected the plant height in fenugreek. With an increase in the distance between rows from 10 to 30 cm, the plant height was significantly decreased. In the study by Tuncturk and et al., (2011), the highest seed yield (777-785 kg ha^{-1}) was obtained from 30-cm row spacing variants in two following experimental years. Bhat (1988) showed that closer row spacings of 20 and 30 cm gave significantly higher yields than the 40 cm row spacing. Considering the gradation of yields from the lowest to the highest ones in the two experimental years, the 54 cultivation technologies were grouped into the ones providing low yield (L – the lower quartile) and high yield (H – the upper quartile), after which an analysis of classification trees was done (Figure 2). The input decision criterion in fenugreek cultivation was the date of sowing: the earliest possible date (B0) and delayed by 10 days (B1), which classified technologies with high yields, and delayed by 20 days (B2), which classified technologies with low yields. Another discriminating factor between high and low yield technologies was the inter-row spacing. Technologies with high yields were distinguished by the 15-cm row spacing (C0), and some of the high yield technologies were classified to the group of low-yield ones (26 technologies), which at the subsequent division stage were grouped into technologies with high yields in variants with mechanical weeding (D0), date of sowing delayed by 10 days (B1), the earliest possible sowing date (B0) and variants with pathogen control composed of seed dressing (E1) and full fungicidal protection (E2). The above relationships are verified by the rank list of the importance of factors, with the date of sowing considered to be the input classification criterion for low and high yield technologies (100%), followed by the row spacing factor (84%). The discriminating contribution of the other agrotechnical factors ranged around 30%.

Weed infestation

There were 33 species of weeds identified during the cultivation of fenugreek (Table 6). The dominant weeds were *Echinochloa crus-galli* (L.) Beauv. (44%), *Capsella bursa-pastoris* (L.) Medik.(19%), *Anthemis arvensis* L. (Ant) (7%) and *Veronica persica* Poir. (6%). Nineteen weed species occurred only sporadically, and their per cent share was about 3%. Khan et. al., (2014) claimed that the most common weeds on fenugreek fields, in diversified global ecology, were *Orobanche crenata* Forskk, *Orobanche ramosa* L. and *Orobanche foetida* Poir.; *Chenopodium album* L. and *Chenopodium murale* L., *Fumaria parviflora* Lam., *Melilotus indica* (L.) All., *Melilotus alba* Medik., *Vicia sativa* L., *Anagallis arvensis* L., *Cyperus rotundus* L., *Gnaphalium indicum* L., *Cuscutacam pestris* Yuncker and *Parthenium hysterophorus* L. Weeds reduced yield by 69% during whole cropping season. Among the analyzed agrotechnical factors, the date of sowing (B) and weed control techniques (D) caused changes in weed communities. The structure and abundance of weeds were determined on three dates (T1, T2, T3). Table 7 and Figure 3 illustrate changes in the structure and abundance of weeds depending on the sowing date and weed control method. The number of weeds on the second and third assessment dates nearly doubled compared to the first assessment.

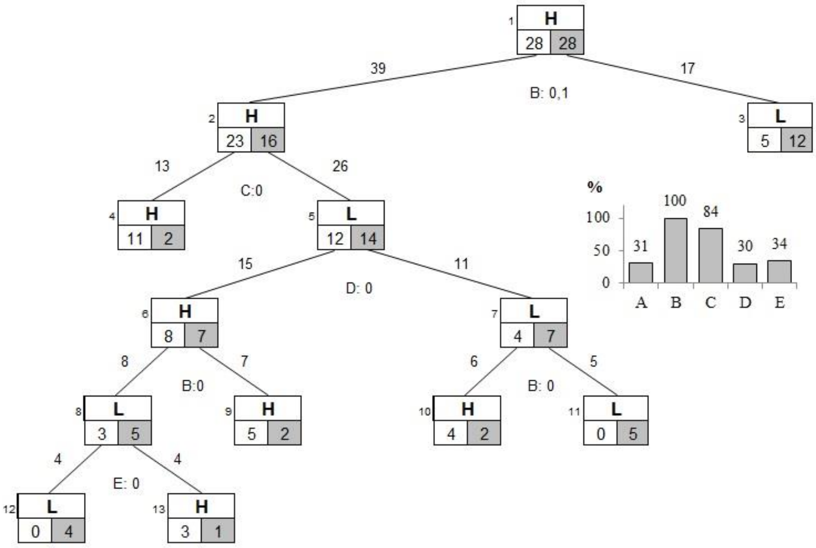

Figure 2. A classification tree for low (L) and high (H) fenugreek yield technologies, and importance of agrotechnical factors (%) (number of erroneously classified cases 12 out of 54).

Table 6. Specification of weeds present in cultivation of fenugreek and frequency of their occurrence.

Intervals	Total No of weeds per interval	No of species	Species (acronym)
>500	874	1	*Echinochloa crus-galli* (L.) Beauv. (Ech)
200-500	387	1	*Capsella bursa-pastoris* (L.) Medik. (Cap)
100-200	274	2	*Anthemis arvensis* L. (Ant); *Veronica persica* Poir. (Ver)
50-100	189	3	*Poa annua* L. (Poa); *Chenopodium album* L. (Che); *Stellaria media* (L.)Vill. (Ste)
10-50	212	7	*Vicia angustifolia* L. (Vic); *Viola arvensis* Murr. (Vio); *Thlaspi arvense* L. (Thl); *Spergula arvensis* L. (Spe); *Taraxacum officinale* F. H. Wigg. (Tar); *Plantago maior* L. (Pla); *Trifolium repens* L. (Trir)
5-10	37	5	*Equisetum arvense* L. (Equ); *Geranium pusillum* Burm. F. ex L. (Ger); *Amaranthus retroflexus* L. (Ama); *Sonchus arvensis* L. (Son); *Chamomilla suaveolens* (Pursh) Rydb. (Cha)
1-5	31	14	*Lamium amplexicaule* L. (Lam); *Polygonum aviculare* L. (Pola); *Lycopsis arvensis* L. (Lyc); *Cirsium arvense* (L.) Scop. (Cir); *Galinsoga parviflora* Cav. (Galp); *Agropyron repens* (L.) P. Beauv. (Agr); *Convolvulus arvensis* L. (Con); *Barbarea vulgaris* R.Br. (Bar); *Galium aparine* L. (Gala); *Lolium perenne* L. (Lol); *Polygonum convolvulus* L. (Polc); *Polygonum convolvulus* L. (Poll); *Sinapis arvensis* L. (Sin); *Tripleurospermum inodorum* L. (Trii)
Total	2004	33	

Table 7. Number of weeds on assessment dates depending on sowing date and weed control.

Term of estimation	Sowing date			Weed control		Tot al
	B0 the earliest	B1 delayed by 10 days	B2 delayed by 20 days	D0 mechanical control	D1 chemical control	
T1	216	129	90	282	153	435
T2	229	433	119	145	636	781
T3	315	206	267	341	447	788

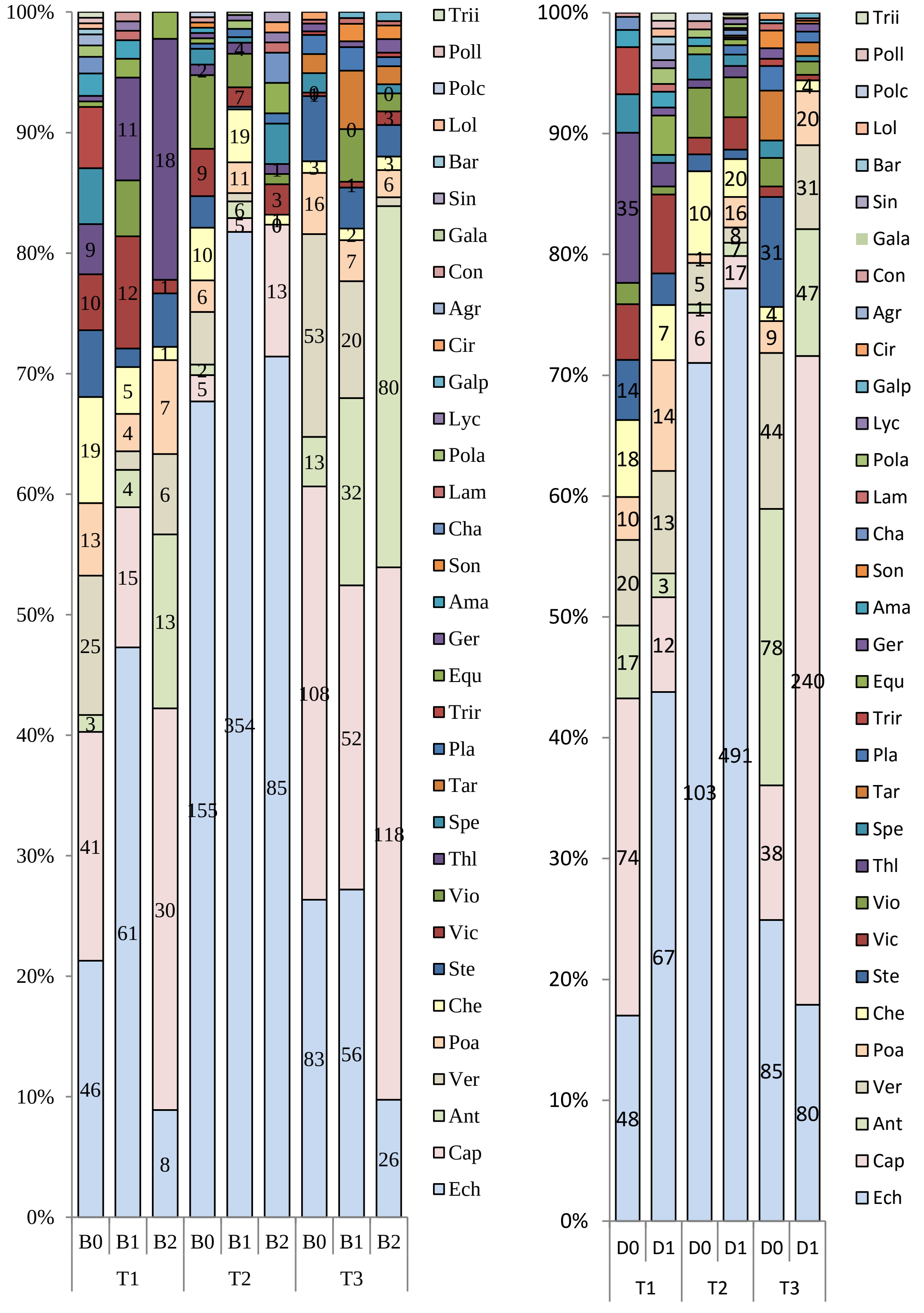

Figure 3. Per cent structure of weeds depending on date of sowing fenugreek seeds (B0 and weed control method (D) on weed estimation dates (T1, T2, T3) (numbers within bars – number of identified weeds within a specific species)

On the first assessment date, the number of weeds was highly varied, mainly in respect of the dominant weeds *Echinochloa crus-galli* (L.) Beauv. and *Capsella bursa-pastoris* (L.) Medik. The counts of these weeds were similar on plot sown on the earliest possible date, while *Echinochloa crus-galli* (L.) Beauv. dominated among weeds on but the fenugreek plots seeded 10 days later, and *Capsella bursa-pastoris* (L.) Medik. was most abundant on plots sown at 20 day delay, where other weeds were also found in large numbers, e.g. *Anthemis arvensis* L. and *Thlaspi arvense* L. The second weed assessment date demonstrated the dominance of *Echinochloa crus-galli*

(L.) Beauv., irrespective of the sowing date, but the results achieved on the third assessment date showed that *Capsella bursa-pastoris* (L.) Medik. and *Anthemis arvensis* L. tended to dominate as the later sowing dates. Under mechanical weed cotnrol, on the first assessment date, the structure of weeds was relatively well-balanced, with a 43% total share of *Echinochloa crus-galli* (L.) Beauv.(17%) and *Capsella bursa-pastoris* (L.) Medik (24%); on the third date of weed infestation measurements, apart from the three species mentioned above, there were larger numbers of *Capsella bursa-pastoris* (L.) Medik., *Anthemis arvensis* L and *Stellaria media* (L.)Vill. (81%). When the herbicide had been applied, results from the first and second assessment were dominated by the species *Echinochloa crus-galli* (L.) Beauv.(42% and 76%), but on the last assessment date the prevalent species was *Capsella bursa-pastoris* (L.) Medik (54). The Simpson’s indices of diversity and evenness for significant interactions between assessment dates, sowing dates and weeding methods, presented in Figure 4, support the results described above. The Simpson’s index of diversity was 2.45, which confirms the dominance of 2-3 species of weeds. On the other hand, the average Simpson’s index of evenness was 0.66, indicating a large deviation from ideal species evenness, which assumes the value 1. In the evaluation of the interactions *assessment date x sowing date* and *assessment date x weed control*, the highest species diversity appeared on the first date of assessment performed on plots where the sowing date was the earliest (4.7) and weeds were controlled mechanically (3.8). In general, as the sowing date was delayed, the values of this index continued to decline and were lower when weeds were controlled with herbicide. On the second date of weed infestation measurements, all the variants of sowing dates and weed control methods were dominated by 1-2 weeds, which was additionally verified by low values of the Simpson’s index of evenness. The interpretation of the *date of sowing x weed control* interaction draws attention to the fact that weeds were better balanced on plots given mechanical weed treatments and sown on the earliest sowing date or 10 days later; another notable fact is that the disproportion between these values relative to the sowing date postponed by 20 days was more distinct.

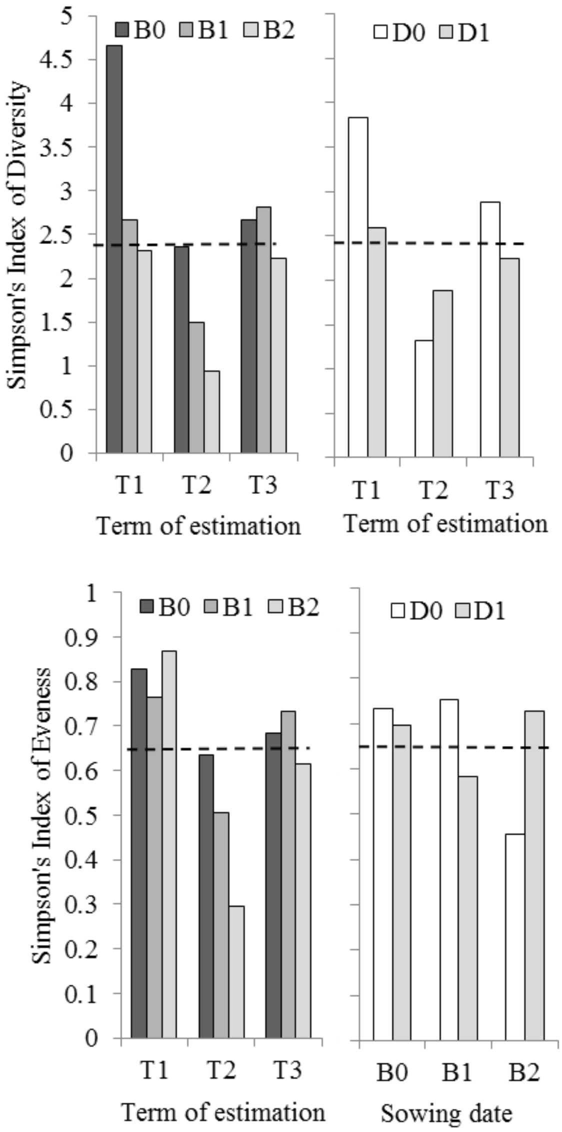

Figure 4. Significant interaction effects between agrotechnical factors and the date on which weed presence was estimated in the assessment of ecological indices of weed presence in fenugreek cultivation (the dash line shows mean indices).

Pathogenic infection

Table 8 contains estimated degrees of fungal infection of fenugreek plants. In 2008, small spots on leaves caused by *Botrytis cinerea* and *Alternaria alternata* were observed. In 2009, large spots on leaves were noticed and the presence of numerous fungi was determined, such as *Botrytis cinerea*, *Alternaria alternata*, *Humicola grisea*, *Altarnata tennissima*, *Fusarium avenaceum*, *Peacylomyces*, *Mucorkieralis*. Dhruj et.al., (2000), and Zimmer (1984) stated that the major diseases affecting fenugreek are *Cercospora* leaf spot and powdery mildew caused by *Leveillulataurica* i *Erysiphepolygoni*. In Australia, yield of fenugreek was seriously affected by blight disease caused by *Cercospora traversiana* and wilt caused by *Fusarium oxsysporum* and *Rhizoctonia*

Diseases observed to be associated with fenugreek are collar rot, leaf spot and pod spot diseases (Petropoulos, 2002). Fogg et al. (2000) reported bacterial leaf spot in fenugreek caused by *Pseudomonas syringae* pv. syringae in New Jersey, USA. It has also been suggested that the bacterium *Xanthomonas alfalfa* can infect fenugreek (Petropoulos, 2002), leading to loss in productivity. The results of our assessment of the fungal infection degree among fenugreek plants demonstrate significant variation of the infection index in the two years of the experiment and the following interactions *sowing date x antifungal protection* as well as *weed control x antifungal protection*. The fenugreek plants grown in 2009 were more severely infected by fungal diseases (34%) than the plants cultivated in 2008 (14%). A probable cause was the abundant rainfall at the annual average temperature in

June. However, in another study, reported by Achraya et al. (2006), fenugreek plants were not observed to have been infected by diseases, which may be associated with a small area cropped with this plant. Powdery mildew occurs on fenugreek, but is not considered a serious problem. Cercospora leaf spot can cause grave defoliation and can also affect stems and pods. It has not been observed on fenugreek in Saskatchewan and may not become a concern because it is favoured by warm, humid conditions.

Table 8. The Percent Disease Index of fenugreek plant infestation in years of study and in relation to agrotechnical factors (raw percentages in the table and in the case of significant factors or interactions the homogenous groups of means were assessed on the basis of Tukey's T test applied to the Bliss' transformed data).

Factor/ level	Year	Inoculation A		Sowing date B			Row spacing C			Weeding D		Fungicide protection E		
		0	1	0	1	2	0	1	2	0	1	0	1	2
2008	10.4_b	12.0	10.7	10.9	9.6	9.2	10.2	11.9	10.4	10.4	10.8	10.9	9.5	21.3
2009	34.0_a	38.0	35.9	32.8	33.2	31.3	34.0	36.7	34.3	33.7	34.0	34.8	33.2	9.5
A 0				20.2	18.8	19.1	18.9	18.7	20.5	17.4	20.4	19.8	21.6	16.7
1				26.4	24.9	23.7	21.5	25.5	28.1	24.8	25.4	25.0	24.1	26.0
B 0							19.3	23.8	26.8	24.1	22.6	26.2_a	22.8_{ab}	21.1_{ab}
1							20.4	23.1	22.2	22.1	21.7	23.7_{ab}	22.4_{ab}	19.6_{ab}
2							20.9	19.3	23.8	20.9	21.8	17.4_b	23.3_{ab}	23.3_{ab}
C 0										19.9	20.6	20.9	21.3	18.5
1										21.4	22.8	19.3	24.6	22.4
2										25.7	22.8	27.1	22.7	23.1
D 0												21.4_{ab}	20.8_{ab}	24.8_a
1												23.4_{ab}	24.9_{ab}	17.8_b
Mean	27	25_b	29_a	28	27	26	25_b	27_{ab}	28_a	27	27	27	27	26

a, b – means for years and agrotechnical factors denoted with the same letter do not differ significantly according to the Tukey's T test.

Under the conditions of the earliest possible sowing date and sowing delayed by 10 days, the antifungal protection variants produced comparable results, although when seed dressing and fungicide sprays were performed, a tendency for lesser plant infection was observed than in the variant including fungicide sprays alone (E0). In turn, when the sowing date was delayed by 20 days, fungicide spraying was most effective, thus indicating relatively weaker effectiveness of seed dressing than plant sprays with fungicide at that sowing date. Under mechanical weed control, the effects of antifungal protection variants were similar, whereas the combination of chemical weeding and full protection (seeds and plants) against fungi produced the best results in terms of a reduced degree of plant infection by pathogens.

CONCLUSIONS

Agrotechnical factors differently modify the formation of particular seed structure components depending on the soil and weather conditions in individual years. Our analysis of correlations between seed yield structure components demonstrated that the basic seed yield structure component in fenugreek is the number of pods, which suggests that this trait should be included in investigations dedicated to fenugreek cultivation technologies.

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