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DEVELOPMENT OF ROOT MORPHOLOGY TRAITS OF THE CZECH LUCERNE VARIETIES IN CHERNOZEM OVER A THREE YEAR PERIOD

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Abstract

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The root system of plants is generally in relation to important agronomic and ecological characteristics. The aim of this study was to investigate differences in root morphology development of Czech lucerne varieties under chernozem soil conditions. In spring 2007, a field experiment with ten Czech lucerne varieties was established with a regular space of 125 mm between the rows. During the 2008–2010 period, the plants were sampled every autumn after the last cut in five blocks per each variety; the size of the sampling area was 50 × 50 cm and average depth of sampling was 0.25 m. All varieties provided similar trend in root morphology development but some differences could be detected in the rate of this development. From all evaluated root traits, these differences were connected mainly with tap-root diameter, intensity of root branching and lateral root number. Advisable varieties should provide higher density of plant together with higher root diameter and branching which is resulted to higher root weight per m^2 and consequently to higher stand productivity. The root-branched plants achieved a significantly higher tap-root diameter of 10.7 mm in comparison with unbranched-root plants with 7.1 mm. Except of plant age, the stand density and tap-root diameter could be considered as a parameter to drive lucerne root morphology development. Within a year, the increase of tap-root diameter was connected with increase of root branching at root-branched plants whilst decrease of plant density caused the beginning of the process of root branching at tap-rooted plants. The range of root traits influenced themselves so their joint presentation is advisable. It must be remembered that soil conditions are a factor which strongly modified the root morphology traits; therefore, these results must be completed with other experiments under various soil conditions. The knowledge of root morphology traits could contribute to the assessment of lucerne varieties specific features.

forage, alfalfa, *Medicago*, tap-root, lateral root

The root system of plants is generally regarded as a very important factor, which is in relation to its considerable agronomical and ecological characteristics. Lucerne plants generally have a unique very deep root system which reaches to a depth of several metres (FRAME *et al.*, 1997). The difference between the root weight in the arable layer and the root system size measured as electric capacity was described by HAKL *et al.* (2010) when *Medicago varia* Martyn produced the highest amount of root biomass in the arable layer but had a significantly lower root size than *Medicago sativa* L. under experimental soil conditions. At lucerne, the most frequently observed root morphology traits are the tap-root diameter and lateral root number, alternatively also the lateral root diameter and position and fibrous root mass. The depth of lucerne root sampling was usually focused on the arable layer and varied from 22 cm (LAMB *et al.*, 2000[a]) to 25 cm (JOHNSON *et al.*, 1998).

It is believed that in perennial lucerne, the traits associated with the persistence and productivity are influenced by root morphology (JOHNSON *et al.*, 1998). Several researchers have reported a correlation between the lucerne root morphology and yield (e.g. McINTOSH and MILLER, 1980). LAMB *et al.* (2000[b]) confirmed that the selection for fibrous and lateral roots within the lucerne germplasm increased herbage yield and HAKL *et al.* (2011) have shown that the productivity of lucerne stands basically corresponded with the root weights. JOHNSON *et al.* (1998) described the relation of root morphology traits to fall dormancy and geographic origin among the plant entries. The tap-root and lateral root diameter were positively correlated. Lateral root number and position and fibrous root mass were negatively correlated with fall dormancy. According to HAKL *et al.* (2011), the older plants with larger tap-root diameter have probably a higher persistency which was indicated by an extremely slow decrease in the stand density in the last three years of a seven year experiment. In the case of red clover (*Trifolium pratense* L.), HEJDUK and KNOT (2010) described considerable differences in the persistence among varieties, which are associated with different adaptability and disease resistance. These described differences among the varieties could be also related to different root morphology but this was not investigated in their study.

It is possible to assume that the lucerne root morphology is associated with important agronomic traits. The role of lucerne varieties in relation to their root morphology was investigated very rarely and the focus was on the lucerne plant entries in relation to fall dormancy and geographic origin (JOHNSON *et al.*, 1998). Their research suggests that the variation observed in root morphological traits in all the evaluated lucerne entries indicated that selection for specific root modifications could be effective. For the Czech lucerne varieties, these results are also very rare. HAKL *et al.* (2007) presented differences in root morphology between the Jarka variety and selected Czech candivars but long-term comparisons of higher number of varieties are needed to acquire information about our varieties in these traits. The present study reports results of an experiment which investigated the changes in the root morphology traits of ten Czech lucerne varieties under chernozem soil conditions over a three year period. In spite of the majority of previous research under special density arrangement, this experiment is focused on root development under common stand density in real field conditions. The aim of this paper was therefore to answer the following question: are there any differences in development of root morphology traits of the Czech lucerne varieties under chernozem soil conditions? Detected differences in the root development could be associated with important properties of individual varieties.

I: *List of evaluated Czech lucerne varieties and their basic description*

variety	registration	type	N fixation	n.P	n.RBP
Jarka	1995	P		427	162
Jitka	1995	SP		389	152
Kamila	2006	P		319	158
Magda	1986	P		342	134
Morava	1990	P		413	160
Niva	1995	SP	N	350	169
Oslava	2003	SP	N	397	152
Pálava	1967	P		437	182
Vlasta	1995	P		423	162
Zuzana	1990	SP	N	410	152

P = population, SP = synthetic population, N = improve N_2 fixation

n.P = number of all evaluated plants within three year period

n.RBP = number of evaluated root-branched plants within three year period

MATERIALS AND METHODS

In spring 2007, a field experiment with ten lucerne varieties was established near Opava in the Czech Republic (270 m a.s.l., 49°57´ N, 17°51´ E). In respect to aim of the work, all ten Czech lucerne varieties registered up to 2007 were included. The basic information about varieties is summarized in Table I. The detailed description of varieties was presented by FADRNÝ *et al.* (2006). The soil was deep loamy haplic chernozem with permeable subsoil. The soil conditions were homogenous in the field of the experiment area. The long-term mean annual temperature is 8.1 °C and the sum of precipitation 640 mm. The experiment was established with a regular space of 125 mm between the rows and the seeding rate of 15 kg per hectare. The long plot design was used where plot size of each variety was 8 × 190 m with total area 0.154 hectare. This plot was subdivided into five blocks with size 8 × 38 m. In 2008–2010, the plots were harvested four times a year (mower KUHN with conditioner, cutter CLAAS) mostly during the bloom stage. The yield of fresh matter was assessed in the whole plot per each variety only in 2008 and 2009. The dry matter yield was calculated from dry matter content in the samples.

During the 2008–2010 period, one sample of plants per each block was randomly taken from the middle part of block after the last cut. The size of the sampling area was 50 × 50 cm and depth of sampling was 0.25 m. The number of plants in the samples was determined and the plant density calculated per m^2 (D, plant.m^{-2}). The tap-root diameter under the crown (TD, mm), position of lateral roots closest to the crown (LRP, mm), lateral roots number per plant (LRN, pcs.$plant^{-1}$), and average lateral root diameter per plant (LRD, mm) were measured for each individual plant. The percentage ratio of root-branched plants (RBP, %) and intensity of root branching (IRB, pcs.$plant^{-1}$) were calculated. After the measurements, the root

II: *Description and statistics of evaluated variables (SD = standard deviation, n = number of samples)*

variables	description	mean	SD	min	max	n
D	stand density (plant/m²)	104	41	40	212	150
IRB	intensity of root branching (pcs of LRN per plant)	1.23	2.19	0	19	3 907
LRD	lateral root diameter (mm) per root-branched plant	1.41	0.74	1	10	1 583
LRN	lateral root number (pcs) per root-branched plant	3.04	2.52	1	19	1 583
LRP	lateral root position (mm) per root-branched plant	39.1	44.8	2	295	1 583
RBP	ratio of root-branched plants (%)	46	20	4	93	150
RW	dry matter root weight under crown to depth of sampling (g/m²)	181	46	87	314	150
TD	tap-root diameter under crown (mm)	8.56	3.60	2	26	3 907
TWR	dry matter tap-root weight ratio (%)	95.4	3.3	79.4	99.8	150

samples were mechanically separated into tap-roots and lateral roots, washed, and oven-dried at 60 °C. The tap-root weight ratio (TRW, %) and root weight (RW) were assessed and RW was calculated per m². Abbreviations of the variables, their descriptions and ranges are summarized in Table II.

Due to described design of experiment without true replicates, the direct comparison among varieties was not possible. From this reason, the differences in development of root traits within each variety were statistically evaluated by a one-way ANOVA. The variable IRB without normal distribution was processed by Kruskal-Walis test. The simple linear regression: root parameter (y) = a + b*time (x) was used to detect the relations of evaluated traits over years across varieties and within each variety. The regression coefficient was used as a value of average change per year for variables with significant linear decrease or increase. The correlation and partial correlation analyses were used to detect the relations of evaluated traits. All statistical procedures were performed using Statistica 9.0 (STATSOFT, Tulsa, OK, USA).

RESULTS

Throughout the three years of the experiment, the lucerne stand survived without any substantial damage by pests or water logging of soil. The dominant weed species was the dandelion (*Taraxacum* sp.) with increasing dominance throughout the years. The total cover of all weed species in the stand did not exceed 30% in the final years of the experiment. Due to natural decrease of stand density and fixed sample area of 0.25 m², the number of evaluated plants decreased from 1807 (437) plants in 2008 to 1283 (629) plants in 2009 and to 817 (515) plants in 2010. The values in brackets represent number of root-branched plants.

The yield assessment in this design had only supplementary value, and therefore it is not presented per each variety. The average year stand productivity reached 12.05 and 13.48 tonnes dry matter per hectare in 2008 and 2009, respectively.

Changes over the years

The changes in root morphology over three years across all varieties are presented in Table III. The TD, IRB, RBP, and LRN values significantly increased over this period. The stand density and LRP values decreased in the same period whilst the RW reached significantly the highest value in the middle of year 2009. For TRW, the lowest value was observed in the last year but there was a significant difference only in comparison with the year 2009. For LRD, the changes between the years were not significant. The significant linear trend was observed for all variables but accepted r^2 over 0.40 was recorded only for D, TD, IRB, RBP, LRN and RW. The regression coefficient as a value of average change per year is shown in the last row in Table III. It must be remembered that effect of year consisted of plant age effect connected with actual weather in the experiment soil conditions.

III: *Development of evaluated root parameters over a period of time (given years). Significant (α = 0.05) linear regression: root parameter (y) = a + b*time is given by r² (coefficient of determination) and b (regression coefficient)*

year	D (p./m²)	TD (mm)	IRB (pcs)	RBP (%)	LRP (mm)	LRN (pcs)	LRD (mm)	RW (g/m²)	TWR (%)
2008	145 [a]	6.4 [a]	0.54 [a]	24 [a]	42 [a]	2.22 [a]	1.35	157 [a]	95.7 [ab]
2009	102 [b]	9.4 [b]	1.43 [b]	49 [b]	42 [a]	2.94 [b]	1.44	216 [b]	96.1 [a]
2010	65 [c]	12.2 [c]	2.45 [c]	63 [c]	32 [b]	3.87 [c]	1.44	171 [a]	94.4 [b]
p	< 0.00	< 0.00	< 0.00*	< 0.00	< 0.00	< 0.00	0.13	< 0.00	0.03
r²	0.62	0.87	0.60	0.55	0.08	0.45	0.03	0.41	0.03
b	−40	2.9	0.97	19	−5	0.90	0.05	19	−0.7

n = 150; One-way ANOVA, different letters document statistical differences among years for Tukey HSD, α = 0.05; * = Kruskal-Wallis test, differences at α = 0.05; for the description of variables see Table II

Variety effect

The development of the root morphology traits within varieties is presented in Tables IV and V. The significant increase of tap-root diameter over years was recorded at all varieties. The average increase varied from 2.8 to 3.4 mm per year except of Niva variety where this increase was only 2.1 mm. Generally, the root-branched plants achieved an average value 10.8 mm which was significantly higher in comparison with unbranched-root plants with 7.1 mm.

The increase of root branching intensity over years was recorded for all varieties but there were differences in significance between them. For Jitka, Magda, Morava, Vlasta and Zuzana, this value significantly increased between all years whilst no-significant differences were observed between two last year for Jarka, Oslava, Pálava and Niva. Across

IV: *Development of root parameters over a period of time for evaluated varieties; significant (α = 0.05) linear regression: root parameter (y) = a + b*time is given by r^2 (coefficient of determination) and b (regression coefficient); The regression and coefficient of variation (CV) is uniformly calculated on sample level (n = 5)*

		individual plants (n – see table 1)					samples (n=5)			
variety	**year**	**TD (mm)**	**IRB (pcs)**	**LRP (mm)**	**LRN (pcs)**	**LRD (mm)**	**D (P./m^2)**	**RBP (%)**	**RW (g/m^2)**	**TWR (%)**
	2008	6.4^{a}	0.35^{a}	58	1.79^{a}	1.65	161^{a}	18^{a}	169^{a}	93.5
	2009	10.2^{b}	1.41^{b}	50	2.78^{ab}	1.52	101^{b}	51^{b}	249^{b}	95.3
	2010	12.2^{c}	2.01^{b}	33	3.46^{b}	1.39	80^{b}	59^{b}	117^{a}	94.4
Jarka	p	< 0.00	< 0.00*	0.057	< 0.00	0.24	< 0.00	< 0.00	0.04	0.83
	r^2	0.87	0.70	0.48	0.63	-	0.65	0.66	0.54	-
	b	2.9	0.86	–11	0.82	-	–40	21	21	-
	CV	27	73	45	36	14	37	45	39	5
	2008	6.8^{a}	0.54^{a}	26	2.25^{a}	1.16	134^{a}	24^{a}	149^{a}	94.0
	2009	9.0^{b}	1.20^{b}	36	2.95^{a}	1.21	110^{a}	41^{a}	213^{b}	97.9
	2010	12.5^{c}	3.15^{c}	27	4.73^{b}	1.29	67^{b}	68^{b}	158^{a}	96.0
Jitka	p	< 0.00	< 0.00*	0.42	< 0.00	0.31	< 0.00	< 0.00	0.01	0.14
	r^2	0.94	0.77	-	0.63	-	0.79	0.65	0.45	-
	b	2.9	1.33	-	1.36	-	–34	22	21	-
	CV	26	77	36	21	17	31	51	23	3
	2008	7.0^{a}	0.93^{a}	45^{a}	2.55^{a}	1.26^{a}	97^{a}	37^{a}	122^{a}	94.9
	2009	9.6^{b}	1.58^{a}	37^{ab}	2.96^{a}	1.31^{a}	102^{a}	54^{b}	210^{b}	95.3
	2010	13.2^{c}	2.77^{b}	26^{b}	4.28^{b}	1.77^{a}	57^{b}	64^{b}	208^{b}	96.3
Kamila	p	< 0.00	< 0.00*	0.048	< 0.00	0.04	< 0.00	< 0.00	< 0.00	0.83
	r^2	0.90	0.55	0.40	0.52	0.28	0.43	0.35	0.37	-
	b	3.0	0.90	–10	0.93	0.22	–20	13	23	-
	CV	27	59	26	25	15	30	28	27	4
	2008	6.3^{a}	0.36^{a}	44	1.89^{a}	1.25	119^{a}	18^{a}	125^{a}	95.3
	2009	9.8^{b}	1.50^{b}	36	3.29^{b}	1.67	98^{a}	46^{b}	243^{b}	96.6
	2010	12.4^{c}	2.84^{c}	35	3.98^{b}	1.65	56^{b}	72^{c}	150^{a}	94.2
Magda	p	< 0.00	< 0.00*	0.65	< 0.00	0.26	< 0.00	< 0.00	< 0.00	0.24
	r^2	0.79	0.87	-	0.55	-	0.69	0.94	-	-
	b	3.0	1.28	-	1.03	-	–32	27	-	-
	CV	30	72	42	37	15	35	52	25	2
	2008	5.9^{a}	0.49^{a}	47^{a}	2.39^{a}	1.21^{a}	160^{a}	21^{a}	155^{a}	96.5
	2009	9.3^{b}	1.34^{b}	51^{ab}	2.84^{a}	1.58^{b}	107^{b}	47^{b}	237^{b}	95.6
	2010	12.7^{c}	2.93^{c}	28^{b}	4.14^{b}	1.44^{ab}	63^{b}	72^{c}	190^{ab}	94.9
Morava	p	< 0.00	< 0.00*	0.03	0.07	< 0.00	< 0.00	< 0.00	< 0.00	0.65
	r^2	0.96	0.74	-	0.49	-	0.87	0.57	0.31	-
	b	3.4	1.24	-	0.95	-	–48	26	15	-
	CV	31	84	38	37	26	40	52	23	3

One-way ANOVA, different letters document statistical differences among years for Tukey HSD, α = 0.05; * = Kruskal-Wallis test, differences at α=0.05; for the description of variables see Table II

V: *Development of evaluated root parameters over a period of time for evaluated varieties; significant (α = 0.05) linear regression: root parameter (y) = a + b*time is given by r^2 (coefficient of determination) and b (regression coefficient); The regression and coefficient of variation (CV) is uniformly calculated on sample level (n = 5)*

		individual plants (n – see table 1)					**samples (n=5)**			
variety	**year**	**TD (mm)**	**IRB (pcs)**	**LRP (mm)**	**LRN (pcs)**	**LRD (mm)**	**D (P./m^2)**	**RBP (%)**	**RW (g/m^2)**	**TWR (%)**
Niva	2008	6.6^{a}	0.93^{a}	36	2.33	1.36	128^{a}	40	148^{a}	97.6^{a}
	2009	8.9^{b}	1.15^{ab}	40	2.23	1.23	94^{b}	51	197^{b}	97.7^{a}
	2010	10.6^{c}	1.78^{b}	45	2.90	1.33	58^{c}	62	173^{ab}	91.9^{b}
	p	< 0.00	< 0.00*	0.52	0.16	0.38	< 0.00	0.058	0.04	< 0.00
	r^2	0.84	0.28	-	0.31	-	0.82	-	0.77	-
	b	2.1	0.48	-	0.41	-	–35	-	29	-
	CV	21	60	37	45	11	35	30	19	3
Oslava	2008	6.0^{a}	0.43^{a}	51	1.86^{a}	1.38	161^{a}	27	180	98.1
	2009	9.3^{b}	1.66^{b}	44	3.01^{ab}	1.40	91^{b}	53	188	95.9
	2010	11.7^{c}	2.16^{b}	35	4.11^{b}	1.33	66^{b}	54	178	94.3
	p	< 0.00	< 0.00*	0.32	< 0.00	0.80	0.01	0.053	0.88	0.38
	r^2	0.90	0.56	-	0.61	-	0.53	0.30	0.59	0.51
	b	2.9	0.89	-	1.25	-	–48	13	26	–2.8
	CV	31	84	38	37	26	40	46	17	3
Pálava	2008	6.1^{a}	0.57^{a}	40	2.42^{a}	1.43	180^{a}	22^{a}	173	97.0
	2009	9.0^{b}	1.82^{b}	42	3.29^{b}	1.51	98^{b}	56^{b}	188	95.0
	2010	11.8^{c}	2.03^{b}	43	2.96^{ab}	1.30	71^{c}	70^{b}	188	96.5
	p	< 0.00	< 0.00*	0.93	0.03	0.24	< 0.00	< 0.00	0.76	0.49
	r^2	0.93	0.67	-	-	-	0.71	0.76	-	-
	b	3.1	0.77	-	-	-	–54	24	-	-
	CV	29	54	30	33	15	47	46	19	3
Vlasta	2008	6.3^{a}	0.59^{a}	35	2.56^{a}	1.35	161^{a}	23^{a}	172	96.9
	2009	9.2^{b}	1.26^{b}	47	2.74^{a}	1.46	113^{b}	48^{b}	234	94.7
	2010	12.0^{c}	2.73^{c}	29	4.33^{b}	1.41	65^{c}	62^{b}	173	94.4
	p	< 0.00	< 0.00*	0.07	0.01	0.65	< 0.00	< 0.00	0.06	0.12
	r^2	0.90	0.63	-	0.51	-	0.80	0.66	0.52	-
	b	2.8	1.02	-	0.96	-	–48	20	21	-
	CV	27	71	59	44	12	40	46	25	2
Zuzana	2008	6.6^{a}	0.44^{a}	42	1.92^{a}	1.43	145^{a}	23^{a}	174	93.5
	2009	9.3^{b}	1.41^{b}	39	3.30^{b}	1.48	110^{b}	46^{b}	201	96.9
	2010	12.5^{c}	2.21^{c}	24	3.86^{b}	1.51	71^{b}	58^{b}	174	91.2
	p	< 0.00	< 0.00*	0.08	< 0.00	0.86	< 0.00	< 0.00	0.59	0.08
	r^2	0.91	0.48	0.41	0.43	-	0.68	0.70	0.64	-
	b	2.9	0.91	–9	1.03	-	–37	17	22	-
	CV	28	86	35	44	14	35	42	25	4

One-way ANOVA, different letters document statistical differences among years for Tukey HSD, α = 0.05; * = Kruskal-Wallis test, differences at α = 0.05; for the description of variables see Table II

varieties, an average increase was represented by 0.97 branch on tap-root per year. Varieties with the highest increase were Jitka (1.33), Magda (1.28) and Morava (1.24), the lowest value was recorded for Niva variety (0.48). Examples of observed intensity of root branching is showed in Fig. 1.

The value of lateral root position decreased over time but this decrease was no-significant for most varieties. These significant changes were recorded only for Kamila and Morava and almost significant for Jarka, Vlasta and Zuzana. In this case, the average decrease achieved approximately 10 mm per year. The significant changes of lateral root number over years were recorded at all varieties except for Niva variety. For Pálava variety, the linear trend over years was not significant. The average increase was calculated as 0.90 branch on tap-root of root-branched plant per year. The varieties with the highest increase were Jitka (1.36) and Oslava (1.25) whilst the lowest value was observed in the Niva variety (0.41). For lateral root diameter, there was generally no-significant effect of time at most varieties except for Kamila and Morava where higher values were observed in comparison with the first year 2008. The significant linear increase was recorded only for Kamila variety and value achieved 0.22 mm per year.

The average decrease of stand density was 40 plants per year but this trend was not always linear and depended on number of plants in the first year 2008. Varieties with highest stand density over 160 plants per m^2 in 2008 provided the highest decrease over 47 plants per year (Morava, Oslava, Pálava, Vlasta). For Kamila variety, the lowest stand density (97) was observed in 2008. In this year, this density highly varied from 76 to 124 which was probably connected with higher heterogenity of stand at this variety. Kamila provided the lowest average decrease 20 plants per year, but between the last years, this decrease was also about 40 plants per year.

For ratio of root-branched plants, the significant or almost significant increase over years was observed for all evaluated varieties. In the first harvest year 2008, the average value 24% was recorded, but approximately 40% was observed for the Niva and Kamila variety. The average increase of RBP was 19 abs. % per year. The varieties with the highest increase were Magda (27), Morava (26), and Pálava (24), the lowest values were recorded for Oslava (13) and Kamila (13). For Niva variety, the linear trend over years was not significant.

The root weight per m^2 reached the significantly highest value in year 2009 at most of varieties. In spite of it, the root weight per one plant significantly increased from 1.13 in 2008 to 2.14 in 2009 and to 2.74 g in 2010. The linear trend of root weight per m^2 over years was recorded for all varieties except for Magda and Pálava. The varieties with no-significant changes of this value between the years were Oslava, Vlasta, and Pálava. The highest value in the last year was observed for Kamila, Morava, and Pálava. The changes of tap-root weight ratio over years were not significant at all varieties except for Niva variety when the significantly lowest value was observed in the last year 2010. The linear decrease in this trait was observed for the Oslava variety. The intra-variety variability of all root traits was similar between the varieties.

Relations between root traits

The age of plants (year) was significantly positively correlated with all evaluated morphological traits as shown in Table III. Correlations and partial correlations between the evaluated traits to stand density and tap-root diameter are shown in Table VI. Over years, the TD could be considered as the most important trait because it was significantly correlated with all evaluated parameters. Stand density was negatively correlated with all traits connected with root branching. Within years (years as a covariate), the TD is still significantly positively related to the traits of root branching intensity as IRB, RBP, LRN, and LRD. The negative correlations were observed with LRP. The stand density within the year was correlated significantly negatively with TD and intensity of branching only in the sample level (IRB, RBP). The relation to intensity of branching at root-branched plants such as LRN or LRD was not significant. Similarly, the same relation between stand density and root traits was observed under standardized TD within years. Root weight per m^2 was positively correlated with TD and stand density in almost all cases.

DISCUSSION

Lucerne root morphology development over time was studied by UPCHURCH and LOVVORN (1951) or SUZUKI (1991) and they all reported that the tap-root diameter and lateral roots number increased with age in lucerne, in contrast to decrease of stand density. The identical trends in the development of root morphology traits were observed within Czech lucerne varieties in chernozem over three year period. It was obvious that age of plants is in relation to all evaluated root parameters. The increase of stand productivity in 2009 in comparison with 2008 was in relation to observed increase of root weight. It is in accordance with HAKL *et al.* (2011) that the stand productivity basically corresponded with the root weight with regard to the weather conditions in a particular year. A decrease in the stand density and the following lucerne plant development over the years is also associated with the changes in the forage quality (DOLEŽAL and SKLÁDANKA, 2008).

In this experiment, the effect of year consisted of effect of plant age connected with actual weather in the chernozem soil conditions. SUZUKI (1991) established lucerne stand each year over ten year period. It was presented that root development pattern changed from vertical extension in the seeding year to lateral development of branched roots in post-seeding years. No other effect of year was reported for development of root parameters in contrast to effect of age. Therefore, it is possible to presume that the effect of post-seeding year on root morphology is probably immaterial in comparison with the age effect.

Stand density and tap-root diameter

Except of plant age, the stand density and tap-root diameter could be considered as a parameter to drive lucerne root morphology development in the field condition. These two traits were in significantly negative correlation. According to LAMB *et al.* (2000), all lucerne root traits were affected by plant spacing. Dense seeded plants needed more time to show a maximum expression of root traits and scored lower tap-root diameters than spaced plants. A slower development of root morphology traits in chernozem under high stand density over a seven year period was also described by HAKL *et al.* (2011).

VI: *Correlation and partial correlation matrix with including covariates between variables evaluated (n = 150; correlations significant at α = 0.05 are in bold)*

	TD	D	TD	D	TD	D	TD	D
D	**–0.78**		**–0.19**			-	-	
IRB	**0.79**	**–0.70**	**0.30**	**–0.23**		**–0.19**	**0.26**	
RBP	**0.73**	**–0.70**	**0.17**	**–0.27**		**–0.25**	0.12	
LRP	**–0.32**	**0.21**	**–0.17**	–0.02		–0.06	**–0.18**	
LRN	**0.69**	**–0.60**	**0.25**	–0.16		–0.12	**0.23**	
LRD	**0.25**	–0.10	**0.26**	0.00		0.06	**0.26**	
RW	**0.19**	0.09	**0.20**	**0.31**		**0.36**	**0.28**	
TWR	**–0.18**	0.13	–0.07	–0.04		–0.06	–0.08	
covariate	-		time (given years)		time, TD		time, D	

For the description of variables see Table II

1: *Variability of intensity of root branching in autumn 2009 – upper line represents the unbranched-roots and low intensity of root branching, lower line represents high intensity of root branching*

In the same age of plant, the average increase of TD was only 1.9 mm per year. They also described that the effect of density on root morphology was not stable across a given year in relation to the actual stand density. HAKL *et al.* (2007) reported that the effect of stand density explained about 15% of measured root morphology traits variability in the fourth year of experiment. As was noted by SUZUKI (1991), age of plants has a similar effect to that of the plant density.

Generally, it is possible to assume that stand density showed significantly negative relations to TD and LRN values according to previous results (UPCHURCH and LOVVORN, 1951; LAMB *et al.*, 2000; HAKL *et al.*, 2007). The same relations were observed in results of correlation analysis (Table VI) but there were some differences in partial analyses. After excluding the time and/or TD effect, the decrease of stand density was significantly correlated only with RBP and IRB whilst correlation with LRN was no-significant. It seems that the decline of stand density did not increase the LRN at root-branched plants but caused the beginning of root branching at tap-rooted plants which resulted in higher RBP and IRB.

In contrast, the TD was significantly related to all root traits within a year except of TRW. If the time and density were uniformed, the TD was significantly correlated only with parameters connected with intensity of branching at root-branched plants such as LRN and LRD. It is possible to assume that increase of TD was connected with increase of root branching at root-branched plants whilst decrease of plant density caused the beginning of root branching at tap-rooted plants.

Variety effect

The contribution to the used entries towards explaining the variability of root morphology was very small in comparison with the age of the plants or stand densities in accordance with the results presented by HAKL *et al.* (2011). All Czech lucerne varieties provide similar habitus and earliness as they are a progeny of three national landraces (Hodonínka, Přerovská, Kaštická) so any high differences in root morphology could not be expected. In spite of it, some differences in development were recorded in this experiment. There is not a previous research among Czech or foreign lucerne varieties in the root morphology under field conditions; consequently the direct comparison with previous results is not possible.

In the case of irregularly-spaced plants in the varieties evaluation, an assessment of density in the samples should be recommended because the differences in root morphology among the varieties could be caused by the differences in the densities of individual varieties (HAKL *et al.*, 2011). According our opinion, the research should not be focused only on observed value of root traits but also on rate of increase or decrease over years.

The most different root development over years was observed for Niva variety in comparison with other varieties. It seems that this variety provided very slow root development from the second year of vegetation which was indicated by the lowest increase for TD, IRB and LRN. It could not be directly connected with breeding for higher nitrogen fixation at this variety because the similar effect was not observed for other varieties with improved nitrogen fixation. The similar low values and increase of IRB and LRN were also recorded for Pálava variety but one of the highest values of RBP was recorded in this case. In contrast to Niva and Pálava, the varieties with the highest increase and values of IRB and LRN were Jitka, Magda, and Morava. It must be remembered that the IRB variable is a function of RBP and LRN when these variables explained 95% of IRB variability. The increase of IRB was given by increase of RBP and/or also LRN with their possible compensation ability. For Magda and Morava, the increase of IRB was connected mainly with increase of RBP whilst it was related to increase of LRN for Jitka variety. ŠANTRŮČEK and SVOBODOVÁ (1988) commented that the ratio of root-branched plants was also influenced by the time of the year of the stand establishment and soil compaction.

For other traits as LRP, LRD or TWR, the differences between varieties developments were not substantial. The TWR value varied from 91.2 to 98.1 and was slightly decreasing over years. It seems that TWR maintained the relatively high value over all three years under chernozem soil conditions.

The RW values were significantly varied between years at almost all varieties, except for Pálava, Oslava and Vlasta. These varieties provided almost constant value of RW during three-year-period. It could be interpret that negative effect of decrease of the stand density on root weight in the arable layer was compensated by increase of TD, IRB, and LRN which all is connected with the root weight of one plant. The higher value of root weight per m^2 is connected with higher stand yield (HAKL *et al.*, 2011) so the increase of RW could be considered as a positive trend. The lowest values of RW were observed for Jarka (117), Magda (150) and Jitka (158). For Kamila variety, the highest value of root weight (208) and also of TD was observed. According to PEDERSON *et al.* (1984), the progenies from high root weight selection had greater root diameter, root branching and shoot weights that progenies from low root weight selection. It is possible to conclude that advisable varieties should provide higher plant density (persistency) together with higher root diameter and branching (plant productivity) which is resulted to higher root weight per m^2 (stand productivity).

Plant persistency

The decrease of stand density over years was evident, logical and expected. As was presented by HAKL *et al.* (2011), older plants with larger

TD had probably a higher persistency which was indicated by an extremely slow decrease in the stand density in the last three years of seven year experiment. Association of branched roots with persistence have been also reported by JANSSEN (1929). Based on our results, the root-branched plants achieved a significantly higher value of TD in comparison with unbranched-root plants. The RBP was increased over years and absolute number of root branched plants reached the highest value in the middle year of 2009. Increasing RBP over years with simultaneous decrease of plant density can support the idea that root-branched plants could have a higher persistency and survived longer in the stand. However, this effect could be also connected with beginning of root branching at tap-rooted plants so the comparison with other field experiments is necessary. It must be remembered that all these results are corresponding with the optimal soil conditions for lucerne growth in this experiment. It has long been appreciated that the growth of root systems in soils is affected by a wide range of soil properties but, in turn, the properties of soils are modified by roots (GREGORY, 2006).

CONCLUSION

Plant age, stand density and tap-root diameter could be considered as a parameter to drive lucerne root morphology development. The root morphology can play an important role in plant productivity over years; however the stand density should be also taken into account. In the chernozem, the all evaluated Czech lucerne varieties provided similar development of root morphology traits but some differences could be detected in the rate of this development. Some of root traits influenced the other so their joint presentation is advisable. It must be remembered that soil condition is a very important factor in relation to root morphology traits; therefore, for the final conclusion about variety differences these results must be completed by other experiments under various soil conditions.

SUMMARY

The root system of plants is generally in relation to important agronomic and ecological characteristics. The aim of this study was to investigate the differences in root morphology development of Czech lucerne varieties under chernozem soil conditions. In spring 2007, a field experiment with ten Czech lucerne varieties was established with a regular space of 125 mm between the rows. During the 2008–2010 period, the plants were sampled every autumn after the last cut in five blocks per each variety; the depth of sampling was 0.25 m. The size of the sampling area was a 50 × 50 cm. In comparison with other varieties, Niva variety provided slower root development from the second year of vegetation which was indicated by the lowest increase of tap-root diameter, intensity of root branching and lateral root number. The similar slow development was observed for Pálava variety except for tap-root diameter. In contrast to it, the varieties with the highest increase of root branching were Jitka, Magda, and Morava. For other traits such as lateral root position or diameter, the differences between varieties developments were not substantial. For Zuzana variety, the highest value of root weight was observed in the last year. Advisable varieties should provide higher density together with higher tap root diameter and branching which resulted into higher root weight per m^2 in arable layer and consequently into higher stand productivity. The root-branched plants achieved a significantly higher tap-root diameter of 10.7 mm in comparison with unbranched-root plants with 7.1 mm. Except for plant age, the stand density and tap-root diameter could be considered as a parameter to drive lucerne root morphology development. These two traits were in significant negative correlation. The increase of TD was connected with increase of root branching at root-branched plants whilst decrease of plant density caused the beginning of the process of root branching at tap-rooted plants.

It must be remembered that soil condition is a very important factor in relation to root morphology traits; therefore, for the final conclusion about varieties, these results must be completed by other experiments under various soil conditions.

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