THE ROOT MORPHOLOGY OF NEW CZECH LUCERNE CANDIVARS*

J. Hakl, J. Šantrůček, J. Kalista, D. Kocourková

Czech University of Life Sciences, Faculty of Agrobiology, Food and Natural Resources, Prague, Czech Republic

The aim of this paper was to compare root morphology of three new Czech lucerne candivars with the standard variety Jarka under different levels of soil compaction. Three candivars with different ratio of American pasture lucerne varieties in their origin were used. Plot experiment was established in split plot design with four replications: variant 1 and 2 with average soil bulk density 1.39 $g.cm^{-3}$ and 1.51 $g.cm^{-3}$, respectively. These parameters were measured: tap-root diameter under crown (TD), lateral root number (LRN), lateral root diameter (LRD) and lateral root position (LRP) of plants sampled in spring and autumn period. The TD value was in positive correlation with LRN and LRD and all these were negatively correlated with the stand density. Only candivar XLII proved significantly lower TD in comparison with the standard variety Jarka, but this trait was not connected with more branched root or higher persistence. Significantly lower LRN was observed for all candivars; low reached values indicate the inclusion of all candivars within *sativa* limits. The higher soil compaction significantly reduced LRP, LRN, and number of plants per m^2. On the basis of these results, we can conclude that all evaluated candivars are without substantive differences in root morphology parameters compared to the standard variety Jarka. From the point of view of root morphology, evaluated candivars do not extend attributes of lucerne varieties in the Czech Republic.

lucerne; root morphology; candivar; soil compaction

INTRODUCTION

Cultivated lucerne (M. *sativa* subsp. *sativa*) is one of the most important forage crops in the world in terms of total area, economic value and energy efficiency (McCoy, Echt, 1992). Sickle lucerne (*Medicago sativa* subsp. *falcata* L.) is grown only in marginal areas, frequently in the grass legume mixture. The tetraploid form of M. *falcata* can be crossed with tetraploid M. *sativa* (Dukić, Erić, 1995). The most important characteristics contributed by M. *falcata* germplasm for breeding of M. *sativa* are winterhardiness, drought resistance, disease resistance, and creeping roots or rhizomes (Michaud et al., 1988). From the point of view species traits, Klesnil et al. (1965) characterized this lucerne as a species with yellow flowers, prostrate habitus and sickle pods. One of the most important traits is shallow and fibrous root system. The hybrid forms of lucerne (hybrids M. *sativa* x M. *falcata*, with different ratio of M. *falcata*) have shallower and more branched root system in comparison with M. *sativa* (Dukić, Erić, 1995).

Generally, morphological characteristics of lucerne are significantly correlated with yields and quality of dry matter (Katić et al, 2003). According to many authors, the lucerne root morphology is a very important agronomic trait. For example, Johnson et al. (1998) concluded that the root system morphology is in the relation with plant persistency and Lamb et al. (2000) presented that productivity of lucerne was influenced by root morphology. Bliss (2003) reported the positive effect of shallower and more branched root system for tolerance to worse soil conditions and better growing flexibility in various environments including legume grass mixture as well as a higher persistence in these stands. According to Kalista et al. (2006), the persistence of lucerne stands is also affected by autumn cut management. Root morphology traits in lucerne are heritable, but are strongly influenced by dormancy and geographic origin (Lamb et al., 1999). Šantrůček (1988) concluded that reasons for more branched lucerne root system are, except for genotype, the term of stand establishment, stand density, and soil compaction.

There are 14 lucerne varieties listed in the Czech Republic – 9 domestic and 5 of foreign origin (National list&plant variety right database, 2005). It seems that all these varieties have a long, main tap-root that grows deep to the soil. Nowadays, we tested new experimental candivars of lucerne with higher ratio of M. *falcata* at the Department of Forage Crops and Grassland Management. These candivars come from the breeding station in Želešice in South Moravia. The aim of this paper is to compare root morphology of three candivars with the standard variety Jarka under different levels of soil compaction. If the new experimental candivars have root morphology with traits near to M. *falcata*, we will be able to consider their higher persistency and potential using in worse soil conditions as well as in legume grass mixture or pasture. Lucerne varieties with these traits would extend a list of Czech lucerne varieties.

MATERIAL AND METHODS

The plot experiment with evaluated candivars was established in the field of the Research station of the Czech

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University of Life Sciences in Červený Újezd in spring 2001. The mean annual temperature is 7.7 °C, the long-term annual sum of precipitation is 493 mm. The detailed experimental measurement of root morphology was conducted in 2004 (last vegetation year). According to L a m b et al. (2000), densely seeded plants needed more time to show maximum expression of root traits and scored lower for LRN and had smaller TD than spaced plants. Based on this thesis, we assumed that the most expressive differences in root morphology should be determined by open stands in last year in comparison with dense stands in previous years.

There were used following candivars with origin in American pasture lucerne varieties: ŽE XLI (strain of variety Preserve), ŽE XLII (strain mixture of varieties Preserve, Spreador, Drummor) and ŽE XLV (strain mixture of varieties Drummor, Niva, N 2 II, KAP, Zuzana). Variety Jarka was used as a control. Plot experiment was in split plot design and divided into two variants with four replications: **1**. no treatment after cut (average soil bulk density 1.39 $g.cm^{-3}$) **2**. roller after cut (average soil bulk density 1.51 $g.cm^{-3}$). The plants were sampled in spring and in autumn from area 0.25 m^2 (a depth 150 mm) in each plot. The number of plants per m^2 was determined. The following parameters were measured by individual plants: tap-root diameter under crown (TD), lateral root number (LRN), lateral root diameter (LRD) and lateral root position (LRP – a depth of first branch). These morphological parameters were statistically evaluated by multivariate analysis of variance (ANOVA) or analysis of covariance (ANCOVA) with interaction (Tukey, $\alpha = 0.05$). For evaluation of relations among measured parameters we used PCA analysis. All these methods were performed by Statistica 6.0. For separating of evaluated variables effects a variation partitioning by redundancy analysis (RDA) in Canoco was used. The RDA analysis is a linear ordination method based on PCA (L e p s , S m i l a u e r, 2003).

RESULTS AND DISCUSSION

The values of measured parameters by candivar, variant and period are in Table 1. The results of PCA show that TD value was positively correlated with LRN and LRD and all these were negatively correlated with the stand density. These parameters were displayed on first axis, which explained 53.86% of measured parameters variability. This ascertainment corresponds to results of J o h n s o n et al. (1998) about positive relationship between TD and LRN as well as of Š a n t r ů č e k (1988) about impact of stand density on branching of lucerne roots. The LRP value was not affected by other parameters and was connected with soil compaction.

The statistical results of ANOVA and ANCOVA by candivar, period, variant and their interaction for evaluated parameters are shown in Table 2. On the basis of PCA results, we used analysis of covariance for TD, LRN, and LRD evaluation due to significant relations of these parameters with stand density and tap-root diameter. Š a n t r ů č e k (1988) described significantly lower TD of the variety Rambler (M. *varia*) in comparison with the variety Palava (M. *sativa*). In our experiment, the candivar ŽE XLII provided the lowest values of TD in comparison with the other candivars and the control variety, but this trait was not connected with more branched root or higher persistence. According to our expectation, the effect of stand density on TD value was highly significant. There were some differences in LRD value among candivars and the variety Jarka, but these differences were not significant after ANCOVA. It can be explained by changes in TD values. We can conclude that stand density was strongly correlated with root morphology of lucerne candivars. These results correspond to L a m b et al. (2000). In their experiment, all root traits were affected by plant spacing but, no germplasm X plant spacing interactions were found. In our experiment, it seems that the most important morphological trait was TD which significantly influenced other traits. Its elimination (covariate) gave no significant differences among candivars and variants.

Generally, L a m b et al. (1999) published that realized heritabilities from lucerne germplasm sources ranged from 11 to 43% for lateral root number. In contrast with our expectation, the significantly highest LRN value was observed for the variety Jarka in comparison with all candivars (Table 1). The variability of LRN by candivars and the variety Jarka is shown in Fig. 1. J o h n s o n et al. (1998) compared 1067 lucerne plant entries and described the highest LRN by *falcata* and x *varia* entries. The average LRN class in their experiment was from 8 to 11 LRN. In comparison with their results, our obtained values of LRN were very low, so we can suppose that our candivars are within sativa limits in this trait. The significantly higher LRN value was observed for uncompacted variant and in spring.

The values of TD and LRD were significantly influenced by sampling period as well. These changes could be caused by a decrease of stand density and following plant development. Š a n t r ů č e k (1988) described significant effect of soil compaction on lucerne root morphology. In our experiment, the variant 2 with higher soil compaction had a significantly lower count of plant per m^2, lower LRN and lower LRP in comparison with variant 1. On the other hand, variant 2 reached higher TD value than variant 1. However, it was caused only by lower density because ANCOVA provided no significant results. Conversely, Š a n t r ů č e k (1988) presented significantly lower TD values under higher soil compaction in the second and third vegetation year but no significant differences in count of plant per m^2 were described among compacted and uncompacted variants in his experiment. It seems that higher soil compaction caused the shallower branching and in case of lower number of plants per m^2, consequently a higher TD values by open stand. The variety Jarka and XLII provided significantly higher plants number per m^2 in comparison with XLI and XLV. There were no significant differences between variants for XLV and between periods for Jarka. It seems that Jarka showed higher stand persistence evaluated by number of plants because of no

Table 1. Average values of measured traits including covariates: taproot (TD) and lateral root diameter (LRD), lateral root number (LRN), lateral root position (LRP) and number of plants per m^{-2}

Factor		TD (mm)	LRP (mm)	LRN ($pcs.plant^{-1}$)	LRD (mm)	density ($pcs.m^{-2}$)
Candivar	ŽE XLI	12.26	13.83	1.19	2.76	61
	ŽE XLII	10.93	13.45	1.12	3.01	75
	ŽE XLV	13.07	12.25	0.98	3.03	62
Variety	Jarka	12.55	15.77	1.48	3.28	76
Variant	uncompacted	12.06	15.72	1.35	3.08	77
	compacted	12.33	11.93	1.02	2.95	59
Period	spring	10.97	13.73	1.41	3.28	83
	autumn	13.43	13.91	0.97	2.76	54

Table 2. Results of ANOVA or ANCOVA of taproot (TD) and lateral root diameter (LRD), lateral root number (LRN) and lateral root position (LRP) and number of plants per m^{-2}

	Factor	Df	*F*-ratio	*P*	Tukey
TD	plants per m^{-2} (covariate)	1	12.58	0.0004	
(ANCOVA)	candivar	3	11.31	0.0000	XLII < all**, XLI < XLV
	period	1	58.96	0.0000	spring < autumn**
	variant	1	0.85	0.3567	
	candivar*period	3	2.84	0.0369	XLII < all** in autumn
	candivar*variant	3	0.90	0.4412	
	period*variant	1	1.65	0.1988	
LRP	candivar	3	1.46	0.2238	
(ANOVA)	period	1	0.02	0.8816	
	variant	1	9.35	0.0022	unC > C**
	candivar*period	3	1.68	0.1688	
	candivar*variant	3	1.73	0.1600	
	period*variant	1	0.18	0.6679	
LRN	TD (covariate)	1	204.98	0.0000	
(ANCOVA)	candivar	3	5.82	0.0006	Jarka > all**, XLI > XLV*, XLII**
	period	1	21.17	0.0000	spring > autumn**
	variant	1	13.43	0.0002	unC > C**
	candivar*period	3	0.61	0.6098	
	candivar*variant	3	0.36	0.7827	
	period*variant	1	0.70	0.4043	
LRD	TD (covariate)	1	245.61	0.0000	
(ANCOVA)	candivar	3	1.42	0.2365	
	period	1	7.53	0.0061	spring < autumn**
	variant	1	0.47	0.4925	
	candivar*period	3	1.07	0.3600	
	candivar*variant	3	3.29	0.0201	XLI unC > C*
	period*variant	1	1.05	0.3052	
Plants per m^2	candivar	3	25.48	0.0000	Jarka, XLII > XLI**, XLV**
(ANOVA)	period	1	352.59	0.0000	spring > autumn**
	variant	1	145.37	0.0000	unC > C**
	candivar*period	3	37.89	0.0000	XLI, XLII, XLV spring > autumn**
	candivar*variant	3	37.71	0.0000	Jarka, XLI, XLII unC > C**
	period*variant	1	7.14	0.0075	unC > C** at spring and autumn

unC – uncompacted, C – compacted variant, * – differences significant on 0.05 probability value, ** – 0.01 probability value

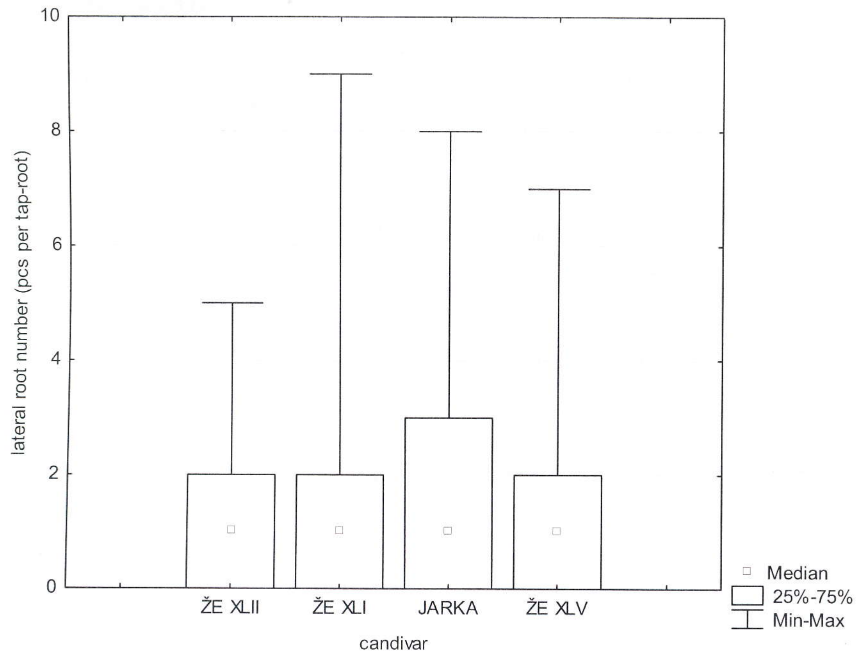

Fig. 1. Box and whisker plots for LRN measured by candivars and variety Jarka

Table 3. Results of RDA analysis (explanatory variables of all canonical axes, unrestricted permutations, number of permutations 499)

Factor	Covariables	% of explained variability	*F*-test	*P*-value
All	–	41.6	8.100	0.0020
Variety	–	6.3	1.462	0.1520
Period	–	28.1	27.375	0.0020
Compaction	–	4.6	3.281	0.0360
Density	–	15.4	12.538	0.0020
Variety	compaction, period, density	5.8	2.272	0.0180
Period	variety, compaction, density	15.7	18.340	0.0020
Compaction	variety, period, density	3.4	3.954	0.0080
Density	compaction, period, variety	2.6	3.054	0.0340

significant changes between periods in comparison with all candivars.

For separating of factor effects on measured parameters, we used the variation partitioning performed by RDA analysis (Table 3). The results without covariables represent effect of each factor without influence of other factors; including covariables represent effect of each factor after including other. On the basis of this analysis, we can conclude that the most important factors, which influenced root morphology of lucerne, are the period and stand density. The influence of these cannot be exactly separated due to overlap of their effects (approximately 12%). The candivars and soil compaction explained substantially lesser part of variability but were still significant with included covariables. The whole model explained 41.6% of measured parameters variability.

CONCLUSION

Evaluated by PCA, the LRN and LRD values were correlated with TD changes so we used it as covariate for other analyses. After this procedure, the candivar ŽE XLII reached the lowest values of TD in comparison with the other candivars and control variety but this trait was not connected with more branched root or higher persistence. The significant differences among germplasms were in LRN but low obtained values indicate the inclusion of all candivars into sativa group. Furthermore, it seems that new candivars reached a lower stand persistency in comparison with the variety Jarka. The higher soil compaction reduced significantly LRP, LRN, and number of plants per m^2, consequently higher TD values for plants from open stand. The effect of candivars and soil compaction on root morphology was significant but explained substantially lesser part of variability than stand density and sampling period. On the basis of these results, we can conclude that all evaluated candivars are without substantive differences in root morphology parameters in comparison with the standard variety Jarka; thus they are within *sativa* limits. From the point of view of root morphology, evaluated candivars do not extend attributes of lucerne varieties in the Czech Republic.

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Morfologie kořenového systému českých novošlechtění vojtěšky seté.

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Cílem práce bylo porovnat morfologii kořenového systému u novošlechtění vojtěšek se standardní odrůdou Jarka při různém utužení půdy. Byla použita tři experimentální novošlechtění s různým podílem amerických pastevních vojtěšek ve svých původech. Pokus byl založen ve schématu split plot ve čtyřech opakováních s variantou 1. objemová hmotnost půdy redukovaná 1,39 g.cm^{-3} a variantou 2. s hodnotou 1,51 g.cm^{-3}. Na základě údajů v literatuře byla podrobná měření provedena v posledním roce vegetace, neboť nejvýraznější rozdíly v morfologii kořenového systému lze očekávat u prořídlých porostů. Byly hodnoceny tyto parametry: průměr hlavního kořene pod kořenovým krčkem (TD), počet (LRN), průměr (LRD) a hloubka prvního větvení (LRP) laterálních kořenů u rostlin odebíraných na podzim a na jaře. Hodnota TD byla kladně korelována s LRN a LRD, tyto všechny pak byly v negativní korelaci s hustotou porostu. Z tohoto důvodu byla v následných statistických analýzách hodnota TD použita jako kovariáta při hodnocení LRN a LRD a hustota porostu jako kovariáta při hodnocení TD. V porovnání s kontrolou byl u novošlechtění XLII zjištěn průkazně nižší TD, ale tento parametr nebyl spojen s více rozvětveným kořenovým systémem ani s vyšší vytrvalostí. U všech novošlechtění byl zjištěn průkazně nižší LRN v porovnání s kontrolní odrůdou Jarka. Dosažené hodnoty byly ale velice nízké (1–1,4 větve na hlavní kořen) a nekorespondovaly s výsledky jiných autorů uváděných u vojtěšek typu *falcata* a x *varia* (8–11 větví). Z hlediska vytrvalosti porostů (hodnoceno počtem přežívajících rostlin. m^{-2} a změnami mezi obdobími) se Jarka ukazuje jako vytrvalejší než hodnocená novošlechtění. Vyšší utužení půdy průkazně snižovalo LRP, LRN a hustotu porostu, s následně vyšším TD u takto prořídlých porostů. Výsledky RDA analýzy ukazují, že nejvýznamnější vliv na morfologii kořenového systému vojtěšky mělo období odběru (28,1, resp. 15,7 %) a hustota porostu (15,4, resp. 2,6 %). Na základě zhodnocených výsledků lze říci, že z hlediska morfologie kořenového systému patří všechna hodnocená novošlechtění do skupiny vojtěšky seté a nepředstavují tedy z pohledu vlastností kořenového systému rozšíření sortimentu vojtěškových odrůd v České republice.

vojtěška; morfologie kořenů; novošlechtění; utužení půd

Contact Address:

Ing. Josef H a k l , Česká zemědělská univerzita v Praze, Fakulta agrobiologie, potravinových a přírodních zdrojů, katedra pícninářství a trávníkářství, Kamýcká 129, 165 21 Praha 6-Suchdol, Česká republika, tel.: 224 383 043, e-mail: hakl@af.czu.cz