The Effect of the Soil Compaction on the Contents of Alfalfa Root Reserve Nutrients in Relation to the Stand Density and the Amount of Root Biomass

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Abstract: The reserve root nutrients influence the overwintering, regrowth, yield, and persistence of alfalfa plants. The total amount of the root reserves is considered more important than their concentration. One of the factors which can affect the reserve content can be the soil compaction. The aim of this study is to clarify the effect of the soil compaction on the reserve root nutrients in relation to the stand density and the amount of the root biomass. In this experiment, the stand density ranged from 28 to 112 plants per m^2. The average soil bulk density in the uncompacted and compacted variants was found to be 1.38 and 1.52 g/cm^3, respectively. In spring and autumn periods, the root samples were taken from an area of 0.25 m^2 (the depth 150 mm) in four replications. The number of plants, the root weight, and the concentrations of starch, saccharose, fructose, and crude protein were assessed in each plot. The total amount of the root reserves was calculated from the determined concentrations and the weights of roots of each sample. A higher soil compaction reduced significantly the stand density, root weight, total amount of all nutrients as well as the starch and crude protein concentrations. The concentration of the soluble non-structural saccharides was identical to or increased over that in the compacted variant. The negative significant effect of a higher soil compaction on the root weight and, consequently, on the total amount of all reserve root nutrients was explained by the changes in the stand density. When the root weight effect was excluded, the compacted variant provided a significantly lower density and crude protein amount and concentration. The significant effect of density on the reserve nutrients was explained by changes in the root weight.

Keywords: alfalfa; soil density; root; reserve nutrient

According to the widely accepted knowledge (Velich 1975; Šantrůček & Svobodová 1988; Avice *et al.* 1997; Dhont *et al.* 2004), organic reserves in the under-ground storage organs are generally recognised as indicators of overwintering, regrowth, yield, and persistence potentials of alfalfa plants. Traditionally, root saccharides have been considered to be the primary organic reserve. Starch is regarded as the main root reserve structural saccharide (McKenzie *et al.* 1988; Míka *et al.* 1997). Out of the soluble non-structural saccharides present, saccharose and fructose contents

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were assessed by Hrušková (1983) and Kalista *et al.* (2006). The contents of saccharose, raffinose, and stachyose were evaluated by Castonguay *et al.* (1998). Nowadays, not only the root saccharides are regarded as the storage nutrients. Avice *et al.* (1997) confirmed the important role of the storage root protein as a key organic nutrient for alfalfa shoot regrowth.

Velich (1975) regarded the harvest frequency as the main factor influencing the reserve nutrient accumulation. The recent results also confirm this thesis (Dhont *et al.* 2004; Kalista *et al.* 2006). The fall harvest did not consistently affect the starch or the total non-structural carbohydrate concentrations in alfalfa roots (Dhont *et al.* 2002). As noted by Velich (1975), the amount of the root reserves is more important then their concentration. It is in accordance with the results presented by Dhont *et al.* (2004) who state that the amounts of the root carbohydrate reserves were significantly reduced by the fall harvest, and that they were even more closely related to the alfalfa regrowth potential than their concentrations.

According to Šantrůček and Svobodová (1988), other factors which can influence the reserve root nutrient accumulation are the term of sowing, morphology of the root system, and the level of the soil compaction. In their experiment, the soil density of 1.33 g/cm^3 reduced significantly the concentration of the root saccharides. Hrušková *et al.* (1989) described a negative effect of the soil compaction in combination with different terms of harrowing on the soluble non-structural saccharides concentrations. Previous authors evaluated the impact of different soil densities only on the root saccharides concentrations. According to the recent knowledge, the concentration as well as the total amount of nutrients is necessary to evaluate at different soil compaction. In addition, the plant density and the amount of root biomass play an important role in the reserve nutrient accumulation, and thus should be included. The aim of this study is clarify the effect of the soil compaction on the reserve root nutrients in relation to the stand density and the amount of root biomass.

MATERIAL AND METHODS

The plot experiment was established in the field of the Research station of the Czech University of Life Sciences in Červený Újezd in the spring of 2001. The site characteristics are: 405 m above sea level (latitude: 50°04' N, altitude: 14°10' E), the prevailing soil type is clay loam orthic luvisol, the kind of soil is medium with neutral soil reaction. The detailed experimental measurements were conducted in 2004 (last vegetation year). The cultivar used was Jarka, sown in 125 mm rows. The actual stand density ranged from 28 to 112 plants per m^2.

The plot experiment was carried out in the split plot design and was divided into two variants with four replications each: (1) uncompacted after cut; (2) compacted by roller after cut. The soil bulk density was assessed in the autumn term with 100 cm^{-3} soil roll in four replications per plot. The plants were sampled in two important periods: in the spring (6. 4.) at the start of regrowth, and in the autumn (18. 10.) before overwintering. The root samples were taken from an area of 0.25 m^2 (the depth 150 mm) in each plot. The number of plants and the weight of the root biomass per m^2 were determined. The samples of roots were dried at 60°C and the concentrations of starch, fructose, and saccharose were determined. The content of the root reserves was calculated from the determined concentrations and weights of the roots of each sample. The results were statistically evaluated by analysis of variance (Tukey, * = 0.05). For the evaluation of the relations between the parameters measured, we used partial correlation analysis. All these methods were performed by Statistica 6.0.

RESULTS AND DISCUSSION

Šantrůček and Svobodová (1999) stated that the soil bulk density is on average 1.33 g/cm^3, with the maximum of 1.70 g/cm^3 in the second and later years of alfalfa vegetation. In our experiment, the average soil bulk density was found to be 1.38 and 1.52 g/cm^3 in the uncompacted and compacted variants, respectively. The ANOVA results revealing the effects of the variants on the parameters measured are shown in Table 1. The effects of various periods were included in this model but are not presented here, due to the lack of any interest in this context. Generally, the concentrations and total amounts of all storage nutrients are significantly lower in the spring period in comparison with the autumn period (Hakl 2006). The higher soil compaction reduced significantly the stand density, the root weight, and total amount of all nutrients. As regards the nutrient concentrations,

Table 1. Results of ANOVA analyses of soil compaction effect on parameters measured

Parameters	Component	Compacted	Uncompacted	*P*-value
Concentration (g/kg)	starch	136.91	151.33	0.0368
	saccharose	117.96	116.19	0.7104
	fructose	9.05	7.85	0.0117
	crude protein	117.17	129.68	0.0157
Amount (g/m^2)	starch	14.96	25.31	0.0062
	saccharose	14.25	20.52	0.0245
	fructose	1.00	1.31	0.0462
	crude protein	13.06	20.80	0.0008
Soil density (g/cm^3)		1.52	1.38	0.0000
Root weight (g/m^2)		112.85	164.40	0.0076
Stand density (pcs/m^2)		35	64	0.0000

starch and crude protein concentrations were significantly reduced but that of fructose was significantly higher in the compacted variant. The saccharose concentration was not influenced by the higher soil compaction. We confirmed the results of Šantrůček and Svobodová (1988) that a higher soil compaction reduced the starch concentration but we did not observe the same effect on the soluble saccharides. This could be explained by a lower level of the soil compaction in their experiment. The reduced weight of roots in the compacted variant is in accordance with the results presented by Dančík (1981) who reports a lower root growth in the compacted soil due to a lower soil aeration.

The relation between the parameters measured was evaluated by partial correlation analysis. The results are shown in Table 2. The first part of the table represents the partial correlation matrix between the soil compaction, root weight, stand density, and nutrient amounts and concentrations. The effect of the period is excluded as covariate. A higher soil compaction significantly negatively correlates with the root weight, stand density, and the amount of all nutrients which is in accordance with ANOVA results. As regards the reserves concentration, Velich (1975) states that the higher saccharide concentration in roots can be caused by factors reducing the over-ground biomass growth or root respiration. In our experiment, the higher soil compaction reducing the root weight showed an identical or higher concentration of the soluble non-structural saccharide. The concentrations of starch and crude protein were reduced in the compacted variant. Similarly, the root weight was significantly positively related to the starch and negatively to the fructose concentrations. Only the starch concentration was significantly positively correlated with the amount of all nutrients.

According to our expectation, the amount of all nutrients is significantly positively correlated with the root weight and stand density which are positively correlated with each other. Partial correlation with separated effects of the root weight and the stand density is shown in the second part of Table 2. After excluding the stand density effect, the soil compaction had no significant effect on the parameters measured. The root weight was still related to the amount of all nutrients as well as to the starch concentration. It is possible to conclude that the negative effect of the soil compaction on the root weight and the reserve nutrient amount can be explained only by the changes in the stand density. If the density was uniform, the root weight was significantly correlated with the amount of all nutrients. After excluding the root weight effect, the soil compaction has a negative effect on the stand density and crude protein amount and concentration. It is possible to expound that a higher soil compaction provided a lower stand density in the case of identical root weights. The significant effect of density on the reserve nutrients was eliminated by excluding the root weight effect. On excluding both parameters was confirmed no

Table 2. Partial correlation matrix with including covariates between factors evaluated; correlations significant at $P < 0.05$ are in bold

	C	*RW*	Density	*c* CP	*c* St	*c* Fr	*c* Sa	*t* CP	*t* St	*t* Fr	*t* Sa
C	1.00										
RW	**–0.47**	1.00									
Density	**–0.67**	**0.74**	1.00								
c CP	**–0.44**	0.23	0.32	1.00							
c St	–0.36	**0.58**	**0.38**	0.35	1.00						
c Fr	**0.45**	**–0.39**	–0.32	**–0.74**	–0.25	1.00					
c Sa	0.08	0.16	0.21	–0.23	–0.10	0.21	1.00				
t CP	**–0.55**	**0.98**	**0.76**	**0.39**	**0.63**	**–0.46**	0.14	1.00			
t St	**–0.41**	**0.88**	**0.55**	0.32	**0.71**	**–0.41**	–0.06	**0.88**	1.00		
t Fr	**–0.37**	**0.91**	**0.73**	0.04	**0.39**	–0.14	0.31	**0.86**	**0.66**	1.00	
t Sa	**–0.39**	**0.96**	**0.66**	0.23	**0.59**	–0.36	0.23	**0.94**	**0.90**	**0.86**	1.00
Covariate	period										
	C	*RW*		C	density		C				
Density	–	–		**–0.54**	1.00		–				
RW	0.04	1.00		–	–		–				
c CP	–0.32	–0.00		**–0.39**	0.23		–0.32				
c St	–0.15	**0.47**		–0.12	–0.07		–0.19				
c Fr	0.34	–0.24		0.33	–0.05		0.36				
c Sa	0.30	0.01		0.18	0.13		0.30				
t CP	–0.08	**0.95**		**–0.46**	0.30		–0.37				
t St	–0.07	**0.84**		–0.01	–0.29		–0.20				
t Fr	0.23	**0.81**		0.16	0.22		0.34				
t Sa	0.08	**0.94**		0.25	0.29		0.12				
Covariate	period density			period RW			period density RW				

C = compaction; *RW* = root weight; *c* = concentration (g/kg); *t* = total (g/m^2); CP = crude protein; St = starch; Fr = fructose; Sa = saccharose

significant effect of a higher soil compaction on all the parameters evaluated.

CONCLUSION

With limited data on lower actual stand density, it is possible to conclude that the higher soil compaction significantly reduced the stand density, root weight, total amount of all evaluated nutrients as well as the starch and crude protein concentrations. On the other hand, the concentration of the soluble non-structural saccharides was identical or increased in the compacted variant with the reduced root weight. The negative significant effect of the higher soil compaction on the root weight and reserve root nutrient was explained by the changes in the stand density. When the root weight was identical, the compacted variant provided a significantly lower density and crude protein amount and concentration. The significant effect of density on the reserve nutrients was explained by the changes in the root weight.

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