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Root System Production and Aboveground Biomass Production of Chosen Cover Crops

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***Abstract*—**The most planted cover crops in the Czech Republic are mustard (*Sinapis alba*) and phacelia (*Phacelia tanacetifolia* Benth.). A field trial was executed to evaluate root system size (RSS) in eight varieties of mustard and five varieties of phacelia on two locations, in three BBCH phases and in two years. The relationship between RSS and aboveground biomass was inquired. The root system was assessed by measuring its electric capacity. Aboveground mass and root samples to be evaluated by means of a digital image analysis were recovered in the BBCH phase 70. The yield of aboveground biomass of mustard was always statistically significantly higher than that of phacelia. Mustard showed a statistically significant negative correlation between root length density (RLD) within 10 cm and aboveground biomass weight (r = -0.46*). Phacelia featured a statistically significant correlation between aboveground biomass production and nitrate nitrogen content in soil (r=0.782**).

***Keywords*—**Aboveground Biomass, Cover crop, Nitrogen content, Root system size

I. Introduction

THE main function of cover crops is a vegetation protection of soil during winter time and between two main crops [1]. Cover crops inhibit water and wind erosion, fix soil nitrogen, protect from weeds etc. Cover crops are divided into two groups based on the way they influence the nitrogen cycle in soil. Legumes and other fabaceous plants fix spare nitrogen by means of nodular bacteria. The other group of cover crops makes use of nitrogen ions to produce their biomass and thus drains away excess soil nitrogen [2]. In the Czech Republic mustard (*Sinapis alba* L.) and phacelia (*Phacelia tanacetifolia* Benth.) belong among the most commonly grown cover crops. Their popularity also lies in the price of seed, ease of cultivation and inability to winter in the climate of the Czech Republic. Thus it is not necessary to dispose of the vegetation chemically in the following year. The aim of this work was to determine inter-variety and inter-species differences in the production of underground and aboveground biomass and the ability to absorb soil nitrogen.

II. Materials and methods

A. Plant Material and Field Conditions

The trial was executed in the course of two years (2010 and 2011) and on two locations (Tresnovec, Troubsko) in Czech Republic (CZ). Tresnovec lies in a piedmont area. The place is characterized by inferior soil fertility, higher annual rainfall totals and lower average temperature.

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The soils are stagnosols with a plough layer of up to 30 cm. The location in Troubsko is represented by fertile soils in a warm and mostly dry agro-climatic area. The soils are mostly fluvisols. In all cases eight varieties of mustard (*Sinapis alba* L.) – Medicus, Seco, Semper, Severka, Sito, Sirte, Veronika, Zlata, and five varieties of phacelia (*Phacelia tanacetifolia* Benth.) – Lisette, Profa, Promoce, Protana, Větrovská, were grown in four repetitions. The vegetation was planted according to the standard seed producing technology. The seed was not chemically treated. During vegetation (elongation phase – BBCH 30, bloom – BBCH 60 and ripening – BBCH 70) root system size (RSS) was evaluated through its electric capacity [3]. The experiment was terminated in the ripening phase. In BBCH 70 aboveground biomass was recovered from each parcel and dry matter yield was assessed. The samples were used for a digital image analysis. Simultaneously soil sampling was carried out to determine the amount of soil nitrogen for each variety. Nitrogen content was determined by the Kjedahl method.

B. Root Size System Measurements

RSS measuring was executed with a VOLTCRAFT LCR 4080 device. For that purpose ten plants of each variety and repetition were used each time. 3120 plants altogether were measured in the course of growth. Another, destructive, method of root system measurement was the digital image analysis [4]. A sample of root system (BBCH 70) was recovered with a special proof rod of a 63 mm diameter. Sampling at point of a plant was up to 60 cm deep. Samples were divided into six parts by 10 cm and deep-frozen at -20 °C. When de-frosted each soil block was drenched through a body of sifters with a mesh diameter of 1.6 and 0.6 mm. Collected roots were hand-separated from other bio-material, dyed in a methylene blue solution and then scanned (Epson Perfection V700 Photo scanner device). Root system images were processed by a computer programme WinRHIZO Basic (Régent Instruments Inc., Quebec, Canada). Collected data on total root system length and surface were used to calculate RLD (Root Length Density), RSD (Root Surface Density, SRL (Specific Root Length) [5]. RLD and RSD represent root density in a soil capacity unit; SRL specifies root system length in its weight unit. All root system samples were dry-matter-weighed.

C. Stastistical Analysis

Collected data were statistically processed ANOVA and post hoc LSD test by a programme Statistica, version 9 (StatSoft Inc., Tulsa, OK). Correlation coefficients were calculated according to [6] who indicated the most appropriate correlation coefficient as rrest (rr).

This coefficient was derived from the data after variety and location effects were removed.

III. Results and Discussion

Collected data were compared by variety means for each crop (varietal data not shown). TABLE I shows average values of monitored characteristics in mustard and phacelia, results of the LSD post hoc test.

In all samples of mustard a significantly higher electric capacity was measured than that in phacelia. However, this entry is for reference only as electric capacity cannot be compared in different plant species. Specific root system length (SRL) was always greater in phacelia over mustard except for the year 2010 in Tresnovec (Table I). The difference was statistically significant in 2011. This can lead to the conclusion that phacelia produces finer root system. The trial in Troubsko showed an average dry matter yield of 11.05 t/ha^{-1} in mustard and 4.17 t/ha^{-1} in phacelia. In Tresnovec 4.17 t/ha^{-1} and 3.07 t/ha^{-1} (Table I). Phacelia aboveground biomass always featured a significantly lower weight than that of mustard. Brant et al. [7] reached similar results. Their average dry aboveground biomass yield in a fertile area in Czech is 1.382 t/ha^{-1} in mustard and 0.826 t/ha^{-1} in phacelia. The yield in a less fertile area in Czech was 0.412 t/ha^{-1} in mustard and 0.361 t/ha^{-1} in phacelia (both species were grown as subsequent crops after the main crop).

TABLE I
AVERAGE VALUES OF MONITORED CHARACTERISTICS AND SUBSEQUENT TESTING (FISHER LSD TEST)

crop	RSS(nF)	SRL	RLD	Ab. biomass kg/m^{-2}	N-NO_3	N-NH_4	N-an
Tresnovec 2010							
Mustard	0.722b	175.991a	6.710b	0.450b	0.6a	4.1a	5.8a
Phacelia	0.290a	91.112a	4.321a	0.238a	1.12a	3.12a	5.2a
Troubsko 2010							
Mustard	0.930b	30.567a	3.985a	1.178b	38.14b	2.813a	49.55b
Phacelia	0.663a	58.903a	3.391a	0.213a	30.26a	3.320a	41.02a
Tresnovec 2011							
Mustard	0.722b	81.510a	16.633a	1.019b	6.23a	4.39a	13.20a
Phacelia	0.554a	219.054b	19.367a	0.376a	8.42a	3.60a	14.84a
Troubsko 2011							
Mustard	0.771b	39.935a	6.512a	1.031b	13.24a	2.19a	18.06a
Phacelia	0.663a	81.718b	7.828a	0.620a	13.94a	2.30a	18.77a

Values in each column differ significantly (p=0.05) if marked by different letters.
Ab. Biomass – Aboveground biomass

Reference [8] indicates the root/shoot biomass ration in mustard and phacelia within 0.07 to 0.36. This ratio depends a lot on soil characteristics, sowing date, air temperature and rainfall totals [9]. In our trial phacelia featured in average a higher R/S ratio (0.45) than mustard (0.32) whereas the year impacted the ratio more than the production area type. At the same time root biomass weight to total plant weight ratio was from 7.2% to 43.5% (22.9% in average) in mustard and from 15.6% to 44.2% (30% in average) in phacelia. That is significantly less than in grasses which feature 60 – 90 % underground biomass to total biomass [10].

Results of soil nitrogen amount monitoring at the end of vegetation do not show an explicit crop impact. Three times was nitrate nitrogen balance in soil with mustard lower than with phacelia at the end of the trial (a statistically insignificant difference).

In 2010 a contradictory result was observed in Troubsko (Table I). Phacelia featured a statistically significantly lower soil nitrate nitrogen balance at the end of the experiment. These results do not correspond to [11] who identified minimal loss of nitrogen in mustard.

Plant biology was the decisive factor influencing aboveground biomass production. Root system characteristics was not influenced by species significantly. The statistically significantly greatest SRL was identified in phacelia (2011) and in mustard (2010) in Tresnovec (TABLE II). The statistically greatest RLD was observed in both crops in Tresnovec. Minimal values of RLD (3.391 mustard, 3.987 phacelia) were reached in Troubsko (TABLE II). The above mentioned might lead to the conclusion that root system size RLD, SRL is mostly influenced by specific soil characteristics on a given locality.

TABLE II
FOLLOW-UP TESTING OF A MULTI-FACTOR ANALYSIS OF S SELECTED FACTORS VARIANCE (FISHER LSD TEST)

Crop	**Locality**	**Year**	**SRL**
mustard	Troubsko	2010	30.657a
mustard	Troubsko	2011	39.935a
phacelia	Troubsko	2010	58.903a
mustard	Tresnovec	2011	81.510a
phacelia	Troubsko	2011	81.718a
phacelia	Tresnovec	2010	91.112a
mustard	Tresnovec	2010	175.991b
phacelia	Tresnovec	2011	219.054b
Crop	**Locality**	**Year**	**Aboveground biomass**
phacelia	Troubsko	2010	0.213a
phacelia	Tresnovec	2010	0.238a
phacelia	Tresnovec	2011	0.376b
mustard	Tresnovec	2010	0.450b
phacelia	Troubsko	2011	0.620d
mustard	Tresnovec	2011	1.019c
mustard	Troubsko	2011	1.031c
mustard	Troubsko	2010	1.178f
Crop	**Locality**	**Year**	**RLD**
phacelia	Troubsko	2010	3.391a
mustard	Troubsko	2010	3.985ab
phacelia	Tresnovec	2010	4.321ab
mustard	Troubsko	2011	6.512abc
mustard	Tresnovec	2010	6.710bc
phacelia	Troubsko	2011	7.827c
mustard	Tresnovec	2011	16.633d
phacelia	Tresnovec	2011	19.367d

Values in right column differ significantly (p=0.05) if marked with different letters

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TABLE III

CORRECTED ANALYSIS OF CORRELATION OF SELECTED MONITORED FEATURES – MUSTARD

dF	Factor	RSS-average x N-NO_3	dF	Factor	Ab. biomass x N-an
31	Total	0.800**	31	Total	0.647**
7	Varieties	-0.026	7	Varieties	-0.568
3	Locality	0.840	3	Locality	0.722
21	Rest	0.229	21	Rest	-0.125
dF	Factor	RSS-average x N-NH_4	dF	Factor	Ab. biomass x N-NO_3
31	Total	-0.433*	31	Total	0.659**
7	Varieties	-0.219	7	Varieties	-0.575
3	Locality	-0.584	3	Locality	0.732
21	Rest	-0.069	21	Rest	-0.087
dF	Factor	RSS-average x N-an	dF	Factor	Ab. biomass x N-NH4
31	Total	0.786**	31	Total	-0.371*
7	Varieties	-0.093	7	Varieties	-0.124
3	Locality	0.830	3	Locality	-0.514
21	Rest	0.107	21	Rest	-0.075
dF	Factor	RSS-average x RLD	dF	Factor	Ab. biomass x RSS-average
31	Total	-0.574**	31	Total	0.883**
7	Varieties	0.483	7	Varieties	-0.036
3	Locality	-0.158	3	Locality	0.984
21	Rest	-0.133	21	Rest	0.278
dF	Factor	RSS-average x RSD	dF	Factor	Ab. biomass x RLD
31	Total	-0.687**	31	Total	-0.526**
7	Varieties	-0.510	7	Varieties	-0.185
3	Locality	-0.971	3	Locality	-0.665
21	Rest	0.126	21	Rest	-0.055
dF	Factor	SRL x Ab. biomass	dF	Factor	RLD x SRL
31	Total	-0.632**	31	Total	0.524**
7	Varieties	0.317	7	Varieties	0.381
3	Locality	-0.971	3	Locality	0.812
21	Rest	-0.114	21	Rest	-0.030
dF	Factor	SRL x N-an	dF	Factor	RLD x N-an
31	Total	-0.517**	31	Total	-0.602**
7	Varieties	-0.202	7	Varieties	0.173
3	Locality	-0.721	3	Locality	-0.728
21	Rest	-0.085	21	Rest	-0.226
dF	Factor	SRL x N-NO_3	dF	Factor	RLD x N-NO_3
31	Total	-0.521**	31	Total	-0.636**
7	Varieties	-0.024	7	Varieties	0.455
3	Locality	-0.747	3	Locality	-0.777
21	Rest	0.064	21	Rest	-0.255
dF	Factor	SRL x N-NH_4	dF	Factor	RLD x N-NH_4
31	Total	0.200	31	Total	0.507**
7	Varieties	-0.446	7	Varieties	-0.779
3	Locality	0.703	3	Locality	0.963
21	Rest	-0.330	21	Rest	0.012

** statistically significant correlation, **statistically highly significant correlation*

A corrected analysis of correlation between monitored features in each crop was executed (Table III and Table IV). A corrected correlation (rr) negates location and variety impact [6].

Significant correlations were disclosed between monitored characteristics in mustard. A significant correlation (total) both between RSS and N-an (r=0.786**), N-NO_3 (r=0.800**), N-NH_4 (r=0.433*) as well as between aboveground biomass and N-an (r=0.647**), N-NO_3 (r=0.659**), N-NH_4 (r=0.371*).

After applying a corrected analysis the above mentioned correlations (rr rest) are no longer significant (TABLE III). That is caused by the essence of monitored features. RSS cannot be compared between localities and years. As well as the soil nitrogen amount, this depends a lot on locality and the course of weather in a given year too.

After correction a significant negative correlation (r=-0.46*) was identified between aboveground biomass weight and RLD within 10 cm of depth.

There is a possible influence of the strategy of investment in morphological structures which ensure better access to only limitedly accessible growth factor [12]. Mustard produced more aboveground biomass at the expense of the root system in fertile soil.

A highly significant negative correlation (r=-0.632**) was observed between SRL and aboveground biomass. The correlation coefficient between SRL and RLD (0-20 cm deep) was highly significant (r=0.524**) (TABLE III). It is possible to presume a positive relation between root system density and root system fineness. A statistically highly significant relation between RLD and SRL was identified in phacelia (non-corrected r=0.864**, corrected rr=0.405). A non-corrected correlation coefficient between aboveground biomass weight and residual N-an and NNO_3 was not significant (Table IV).

After the correction of trial effects the correlation coefficient was highly significant (rr=0.782**; rr=0.711**). It is possible to presume that the above mentioned relation is a consequence of another factor.

This factor could be the specific root system length. In three cases phacelia featured greater SRL than mustard (TABLE I). Drenching taken samples, a visibly better substrate structure and soil particles disintegration on sifters was observed. It is thus possible that better root system with finer roots (with help of root excretion) could influence the soil nitrogen cycle.

Better soil aeration supports organic nitrogen mineralization. A greater amount of nitrate or inorganic nitrogen could make the plant produce a greater amount of aboveground biomass. To confirm or disprove this hypothesis needs further research of the physiology of phacelia, mainly the production of root excretion and its influence on converting soil nitrogen.

TABLE IV
CORRECTED ANALYSIS OF CORRELATION OF SELECTED MONITORED FACTORS – PHACELIA

dF	Factor	RSS-average x RLD	dF	Factor	Ab. biomass x RSS-average
19	Total	0.091	19	Total	0.524*
4	Varieties	-0.523	4	Varieties	-0.678
3	Locality	0.098	3	Locality	0.572
12	Rest	0.091	12	Rest	-0.113
dF	Factor	RSS-average x $N\text{-}NO_3$	dF	Factor	Ab. biomass x $N\text{-}NO_3$
19	Total	0.693**	19	Total	-0.063
4	Varieties	-0.388	4	Varieties	0.932
3	Locality	0.719	3	Locality	-0.134
12	Rest	0.230	12	Rest	0.782**
dF	Factor	RSS-average x $N\text{-}NH_4$	dF	Factor	Ab. biomass x $N\text{-}NH_4$
19	Total	-0.220	19	Total	-0.455*
4	Varieties	-0.075	4	Varieties	0.636
3	Locality	-0.377	3	Locality	-0.750
12	Rest	0.488	12	Rest	-0.032
dF	Factor	RSS-average x N-an	dF	Factor	Ab. biomass x N-an
19	Total	0.655**	19	Total	-0.123
4	Varieties	-0.344	4	Varieties	0.885
3	Locality	0.679	3	Locality	-0.200
12	Rest	0.307	12	Rest	0.711**
dF	Factor	RSS-average x SRL	dF	Factor	Ab. biomass x SRL
19	Total	-0.124	19	Total	0.082
4	Varieties	0.500	4	Varieties	0.262
3	Locality	-0.136	3	Locality	0.104
12	Rest	-0.104	12	Rest	-0.07
dF	Factor	SRL x $N\text{-}NO_3$	dF	Factor	SRL x RLD
19	Total	-0.395	19	Total	0.864**
4	Varieties	0.590	4	Varieties	-0.126
3	Locality	-0.136	3	Locality	0.969
12	Rest	-0.104	12	Rest	0.405
dF	Factor	SRL x $N\text{-}NH_4$	dF	Factor	SRL x N-an
19	Total	0.308	19	Total	-0.361
4	Varieties	0.780	4	Varieties	0.641
3	Locality	0.543	3	Locality	-0.403
12	Rest	-0.203	12	Rest	-0.235

** Statistically significant correlation, **statistically highly significant correlation*

IV. CONCLUSION

The trial assessed inter-variety and inter-species differences in root system size of two cover crops – mustard and phacelia. At the same time aboveground biomass production and impact of these factors on soil nitrogen ions draw was investigated. Observation was executed on two localities in the course of two years.

In all cases mustard produced more biomass than phacelia. A statistically significant impact of root system size on aboveground biomass weight was not confirmed. A significant negative correlation between RLD in up to 10 cm depth and aboveground biomass production in mustard suggests competition among parts of the plant. In phacelia a highly significant positive correlation was disclosed between aboveground biomass and the amount of soil nitrate nitrogen. This phenomenon confirms that greater biomass production does not mean lesser amount of soil nitrate nitrogen. In three cases mustard varieties with larger root system (RSS) left lesser amount of nitrate nitrogen in soil at the end of the trial (the difference was not statistically significant).

The results of the trial indicate a recommendation to grow mustard in areas that are not pressed with an abundance of brassica oilseed crops (especially winter rapeseed). In a less fertile area mustard showed a faster biomass production, better soil cover and thus it was more competitive. Growing phacelia can be recommended in locations with fewer weeds or in more fertile areas where the growth gets integrated more quickly. Soil after phacelia was left in a better structured state.

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