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Investigation of the Biomass and Nutrient Content of Green Manuring Plants as Second Crops in Hungary

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Abstract

The growth, and the development and trends of the nutrient content parameters of three different plant species (*Phacelia tanacecifolia, Sinapis alba, Raphanus sativus*) grown as secondary crops for green manure, as a function of two different fertiliser doses (0 kg/ha N; 50 kg/ha N), was studied under unfavourable site conditions at the Crop Production and Biomass Utilisation Demonstration Centre of the Szent István University, Gödöllő, Hungary. The application of the small, 50 kg/ha dose of nitrogen increased the biomass yield in each case, to 2.78-3.11 times that of the control field. The dry matter content of the produce increased only by 2.11-2.66 times, as the water content of the green manure plants also increased as a result of the nitrogen supplement. The increased amount of nitrogen boosted the availability of all of the other macro elements for the plants. In view of the present findings it can be recommend the application of some nitrogen fertiliser in the given site before growing some crop for use as green manure in all cases but where the straw after cereals is left on the soil surface nitrogen should be applied to alleviate the pentosan effect and to increase the uptake of macro elements.

Keywords: biomass, green manuring, mustard, oil radish, phacelia

Abbreviations: *Phacelia tanacecifolia* (I.), *Sinapis alba* (II.), *Raphanus sativus* (III.), no fertilization (NF), with fertilization (WF), change in nutrient content (CNC)

Introduction

Climate and soil conditions have a profound impact on the goals of the production of green manure crops/ catch crops. In West European countries with higher annual precipitation the key objective is to prevent the leaching of nutrients, while in the no-tillage systems applied in the USA the primary aim is to improve the structure of the soil. In Hungary however, besides the protection of the soil structure, increasing the soil's nutrient content is also a crucial objective as soils in this country have been inadequately supplied with nutrient for quite a number of years.

Problems in addition to the shortage of farmyard manure resulting from the decrease in livestock and the decline in fertiliser application are caused by the fact, that some of the biomass power plants that are being constructed are planned to be fuelled with wheat straw and maize stalks further reducing thereby the amount of organic materials and nutrients left on the fields after harvest (Birkás, 2010).

Catch crops play an important role in crop rotation in many countries, particularly in West Europe and in North America (Hall and Hartwig, 1989; Henderson, 1989; Larson *et al*., 1998; Rasmusen and Andersen, 1994). Crops take up the nutrients (primarily nitrogen) leached out of the soil and retain them for the next crop (Allison *et al*., 1998a, 1998b; Breland, 1995; Thorup-Kristensen *et al*., 2003). Moreover, they improve the soil's condition, alleviate soil compaction along with damage caused by erosion or deflation (Muller *et al*., 1989; Smith *et al*., 1987; Unger and Vigil, 1998). They contribute to the forming of soil aggregates, improve the soil's water intake and water retaining capacity and enhance the soil's stability (Andraski and Bundy, 2005; Burket *et al*., 1997; Stivers-Young, 1998).

Other benefits afforded by catch crops include the significant nematode controlling effects of the catch crop species belonging to the *Brassicaceae* and *Hydrophyllacea* families. Their nematode controlling effects will be observed whether they are produced as main crops or as green manure crops (Johnson *et al*., 1967; Lewis and Papavizas, 1971; Mojtahedi *et al*., 1991, 1993). By combining a suitable crop rotation scheme with the application of green manure, the number of nematodes can be significantly reduced, even to levels below the threshold over which they can cause economic damage (Chikaoka *et al*., 1982; Dickson and Hewlett, 1989; Duddington and Duthoit, 1960; Duddington *et al*., 1961; Kahnt, 1983). Inderjit (2004) demonstrated that growing *Phacelia tanacecifolia*, *Sinapis alba* or *Raphanus sativus* for green manure is an effective solution against the most dangerous pest of sugar beets, that is *Heterodera schachtii*. Moreover, green manure plants also provide a good habitat for useful organizations (Axelsen and Kristensen, 2000).

By studying different schemes of manure/fertiliser application Bolton *et al*. (1985) found that the application of green manure increased the counts of bacteria utilizing the soil's organic and inorganic nitrogen content by 2-3 times, while boosting the effectiveness of a number of enzymes as well.

Another advantage of green manure plants is that the species producing large amounts of biomass, such as *Phacelia tanacecifolia*, are also good for use as fodder (Djordjevic, 2005). In analyzing the effects of green manure plants on the next crop Kahnt (1983) identified as many as 14 factors. Due to the large number of relevant factors the effectiveness of the application of green manure can be assessed only on the basis of accurate knowledge of the parameters of the site concerned.

The most important characteristics of a good green manure plant species include rapid growth, large biomass production and cheap sowing seeds. The objective of the research was to study three green manure plants featuring each of the above attributes, under unfavourable site conditions. Answers were sought also to the question of whether successful green manure application is possible without supplementary nitrogen application in view of the likely pentosan effect or nitrogen supplementation is indispensable. Another aspect of the study was the extent to which the delivered nitrogen increases the specific green mass and the specific dry mass output as well as the NPK uptake per hectare.

Materials and methods

The experiments were set up at the Crop Production and Biomass Utilisation Demonstration Centre of the Szent István University, Gödöllő, Hungary (NL 47°34'43"; EL 19°22'39"; 229 m above sea level). The site is on a slight east-west slope in a hilly area of heterogeneous features, characterised by different degrees of erosion and sedimentation in different places. The annual mean temperature is 9.4°C and the annual precipitation is 590 mm. The average precipitation in the crucial period for secondary crops, from August to October, is 150 mm (Tab. 1).

Tab. 1. Monthly amount of precipitation (P) and monthly average air temperature (t) from August to October (Gödöllő, 2007-2009)

Month	2007		2008		2009	
	P (mm)	t (°C)	P (mm)	t (°C)	P (mm)	t (°C)
VIII.	54.0	22.9	28.6	21.9	21.6	22.8
IX.	54.6	14.1	82.0	15.5	27.4	19.0
X.	55.2	10.5	20.2	11.8	50.2	10.6
Total	163.8	-	130.8	-	99.2	-

From the aspect of the secondary crop, in terms of the precipitation during the growing season (between August and October), 2007 was a rainy year, 2008 was a year of average precipitation while 2009 was a dry year (163.8 mm, 130.8 mm and 99.2 mm, respectively).

The site is located in the micro-region of low hills called "Gödöllői-dombság". The soil of the experimental plots is, according to the WRB soil classification; luvic calcic phaeozem. As a consequence of the degradation processes a variant of a shallow fertile layer and low humus content has developed in the site. The area is exposed to erosion and the soil is sensitive to compaction.

The key parameters of the experimental site are summed up in (Tab. 2). The soil is low in nitrogen, with excellent P_2O_5 supply and a good K_2O supply.

The experiments with green manure plants grown as secondary crops were carried out between 2007 and 2009. The previous crop was winter wheat in every case, and the harvest was immediately followed by stubble stripping. The seeds of the secondary crop were sown in each year right after stubble treatment, on 15 August. Three different plant species (phacelia-*Phacelia tanacecifolia* Benth., white mustard-*Sinapis alba* L. and oil radish-*Raphanus sativus* L. *convar. oleiferus* (Mill.) Metzger) were grown, two different fertiliser doses were applied and the experiment was designed in three replications, in strips. Ammonium nitrate fertiliser was applied, incorporated in the course of stubble treatment. The seeds of the green manure plants were sown in accordance with the sowing seed norms prescribed in technical literature (Antal, 2000) (Tab. 3).

The biomass measurements and the sampling required for the green manure nutrient content tests were carried out in early November. The NPK content was measured in 1 gram of ground absolute dry sample by means of digestion by undiluted sulphuric acid and by way of decomposition by heat in a 30% hydrogen-peroxide solution. After decomposition the N, P and K content was established from samples diluted to 100 cm^3. The nitrogen content was measured with a Parnass-Wagner water steam distiller apparatus. The phosphorus content was measured with the aid of the vanadate-molybdate procedure. A spectrophotometer (Spekol 221) was used for measuring the extinction of the yellow-coloured solution. The potassium

Tab. 2. Key pedological data of experiment

Genetic soil level	pH (H_2O)	Liquid limit	Humus (%)	$CaCO_3$ (%)	Σ salt (%)	Total N (mg/kg)	AL-P_2O_5 (mg/kg)	AL-K_2O (mg/kg)
A (0-40 cm)	6.76	30	1.32	0.00	0.044	16.8	371.1	184.0
B (40-60 cm)	7.08	40	1.04	0.00	0.052	11.9	33.0	112.0
BC (60-70 cm)	7.66	61	0.88	0.00	0.060	2.0	123.0	127.1
C (70-100 cm)	8.10	60	0.54	5.57	0.075	16.8	107.5	110.8

Tab. 3. The seeds requirement of green manure plants (Antal, 2000)

Plants	Germ number (seed/ha)	Seed requirement (kg/ha)
Phacelia tanacecifolia (I.)	5 000 000	10
Sinapis alba (II.)	2 000 000	15
Raphanus sativus (III.)	2 500 000	25

content was measured from the solutions and dilution series referred to in the description of the establishment of the phosphorus content, with flame photometer (Jenway PFP 7).

The statistical evaluation was carried out with the EXCEL program, through one- and two-factor variance analysis.

Results and discussion

The amount of precipitation had a significant impact on the biomass production of the green manure plants (Tab. 4). The impact of the growing season's conditions was particularly heavy on the parcels without fertiliser application. *P. tanacecifolia* produced a green mass of only 4.8 t/ha in 2009 without fertiliser, in contrast to the 18.4 t/ha in the rainy year of 2007. *P. tanacecifolia* could not produce the minimum expected 10 t/ha green mass (Buckles *et al*., 1998) in 2008 and 2009 without N supplementation. As a result of N top-dressing the green mass increased by 1.91-3.95 times, with a 3.11 times increase as an average of the three years concerned. The drought in 2009 had a severely adverse impact on *P. tanacecifolia* but the N supplement resulted in a substantial improvement in the plant's stress tolerance and in its water utilisation, as a result of which it produced a green mass of 16.7 t/ha (Tab. 4).

In the case of *S. alba* the green mass without N was below 10 t/ha (that is, 7.3 t/ha) in 2008, while the 50 kg/ha N content increased the green mass of this plant to 31.7 t/ha. The three year average of the green mass increment was 3.09 times, with a 35.4 t/ha average green mass produce.

In the case of *R. sativus* it was found more balanced yield levels, the different growing seasons had smaller impacts on this crop. Without fertiliser and with fertiliser the green mass varied between 9.8 and 13.9 t/ha and between 26.6 and 34.4 t/ha, respectively. The small N dose increased the green mass production by 2.19-13.9 times.

The absolute dry mass per hectare figures reflected the trends described with regard to the green mass, however, as a result of the application of N fertiliser the growth in the dry mass yield fell short of the increase in the green mass by 94% in the case of *P. tanacecifolia,* by 43% in the case of *S. alba* and by 118% in the case of *R. sativus*. This is explained by the fact that the water content of the green manure plants also increased as a result of the N supplement.

The nitrogen content per-hectare was measured in 2008 and 2009 (Tab. 5), in *P. tanacecifolia* the N-content per hectare increased by 3.32 times, from 30.9 kg/ha to 102.1 kg/ha as an average of the two years. The 50 kg/ha N fertiliser enabled the uptake of an additional 71.2 kg/ha nitrogen. With the supplementary nitrogen supply the per-hectare nitrogen content of *P. tanacecifolia* matched the amount found in the experiment of Thorup-Kristensen (2001).

In the case of *S. alba* the nitrogen uptake per hectare increased by 3.73 times as an average during the two years of experiments. The 50 kg N fertiliser enabled the uptake of an additional 151.6 kg of nitrogen per hectare. Nitrogen transport is very fast in *S. alba* (Corbesier *et al*., 2001), therefore it can very quickly take up the soil's available nitrogen content. Like the amount of biomass produced by this species however (Brant *et al.*, 2009), the amount of the nitrogen uptake is also heavily affected by the growing season effect.

In the case of *R. sativus* the amount of active ingredient taken up by the plants increased by an average of 3.54

Tab. 4. The green and dry mass of green manuring plants (t/ha) (Gödöllő, 2007-2009)

Treatments		Green mass					Dry mass				
		2007	2008	2009	Average	$LSD_{5\%}$	2007	2008	2009	Average	$LSD_{5\%}$
I.	NF	18.4	9.7	4.8	11.0	2.2	3.2	1.3	0.9	1.8	0.2
	WF	35.2	38.5	16.7	30.2		4.5	3.2	2.3	3.3	
	CNC	191	395	345	311		141	242	267	217	
	$LSD_{5\%}$	2.9					0.3				
II.	NF	12.9	7.3	16.6	12.3	1.2	3.0	1.1	2.1	2.1	0.3
	WF	26.3	31.7	48.2	35.4		4.9	3.6	6.7	5.1	
	CNC	204	433	291	309		165	310	323	266	
	$LSD_{5\%}$	3.8					0.6				
III.	NF	13.9	9.8	10.3	11.3	1.9	2.8	1.3	1.6	1.9	0.3
	WF	30.4	27.6	34.4	30.8		4.0	2.8	4.8	3.9	
	CNC	219	282	333	278		141	212	293	215	
	$LSD_{5\%}$	3.4					0.4				

Tab. 5. Effects of different nutrient levels on the uptake of N, P_2O_5 and K_2O amount of green manure plants (kg/ha) (Gödöllő, 2008-2009)

Treatments		N				P_2O_5				K_2O			
		2008	2009	AVG	$LSD_{5\%}$	2008	2009	AVG	$LSD_{5\%}$	2008	2009	AVG	$LSD_{5\%}$
I.	NF	30.1	31.7	30.9	16.4	13.9	8.7	11.3		75.2	34.0	54.6	23.6
	WF	118.2	86.1	102.1		43.5	23.2	33.4	5.5	179.5	97.8	138.7	
	CNC	393	271	332		313	265	289		239	287	263	
	$LSD_{5\%}$		13.0				6.2				23.9		
II.	NF	33.6	85.2	59.4	43.7	12.7	22.7	17.7	11.8	52.3	91.6	72.0	37.5
	WF	138.8	283.2	211.0		32.3	61.8	47.0		183.2	218.4	200.8	
	CNC	413	333	373		254	272	263		350	238	294	
	$LSD_{5\%}$		25.4				10.6				24.6		
III.	NF	31.1	57.4	44.3	26.4	18.3	17.3	17.8		58.0	62.1	60.0	40.8
	WF	127.0	172.0	149.5		34.1	58.4	46.2	9.6	126.8	175.6	151.2	
	CNC	409	299	354		186	338	262		219	283	251	
	$LSD_{5\%}$		17.5				9.1				13.5		

Tab. 6. Specific biomass increasing effect of 1 kg additional N (kg/ha)

Plants	Biomass	2007	2008	2009	Average	$LSD_{5\%}$
I.	Green mass	336.1	575.8	238.0	455.9	167.3
	Dry mass	26.2	37.4	28.0	31.8	NS
II.	Green mass	268.5	487.3	632.0	377.9	90.1
	Dry mass	38.9	48.1	92.0	43.5	20.6
III.	Green mass	329.8	356.1	482.0	342.9	NS
	Dry mass	23.1	30.2	64.0	26.6	20.7

Tab. 7. Specific NPK content increasing effect of 1 kg additional N (kg/ha)

Plants	NPK	2008	2009	Average	$LSD_{5\%}$
I.	N	1.8	1.1	1.4	NS
	P_2O_5	0.6	0.3	0.4	0,2
	K_2O	2.1	1.3	1.7	NS
II.	N	2.1	4.0	3.0	NS
	P_2O_5	0.4	0.8	0.6	NS
	K_2O	2.6	2.5	2.6	NS
III.	N	1.9	2.3	2.1	NS
	P_2O_5	0.3	0.8	0.6	0.4
	K_2O	1.4	2.3	1.8	NS

times in the two years concerned, i.e. the 50 kg/ha applied nitrogen resulted in the uptake of an additional 105.2 kg nitrogen per hectare. With the nitrogen supplement it was also found results similar to those measured in the Thorup-Kristensen (2001) experiment in regard to the per-hectare nitrogen content of *R. sativus*.

As an average of the two years, the P_2O_5 content increased in *P. tanacecifolia, S. alba and R. sativus* by 2.89, 2.63 and 2.62 times, respectively. The application of nitrogen fertiliser resulted in the uptake of 22.1 kg, 29.3 kg and 28.4 kg of additional amounts of P_2O_5 in *P. tanacecifolia, S. alba* and *R. sativus* respectively, as an average over the two years of the experiments. The increase in the per-hectare P_2O_5 uptake is explained by Liebig's minimum law.

As an average of the two years, the K_2O content increased in *P. tanacecifolia, S. alba and R. sativus* by 2.63, 2.94 and 2.51 times, respectively. The application of nitrogen fertiliser resulted in the uptake of 84.1 kg, 128.8 kg and 91.2 kg of additional amounts of K_2O in *P. tanacecifolia, S. alba* and *R. sativus* respectively, as an average over the two years of the experiments.

It was not always possible to identify a significant difference between the biomass increase caused by a unit (1 kg) of nitrogen active ingredient and the growing season effect (Tab. 6). However, the biomass increasing impact of a unit of nitrogen was found to be significant. As an average of the three years one kilogram of nitrogen active ingredient resulted in a 455.9 kg increases in the green mass and by 31.8 kg increases in the dry mass content of *P. tanacecifolia*. In the case of *S. alba* and *R. sativus* the green mass increased by 377.9 kg and 342.9 kg while the dry mass grew by 43.5 kg and by 26.6 kg, respectively.

The growing season had no effect on the increase in the NPK content taken up per hectare caused by one unit of active ingredient, apart from the P_2O_5 content of *P. tanacecifolia* and *R. sativus,* (Tab. 7). The amount of the nutrient uptake increased regardless of the amount of precipitation. As an average over the 2008-2009 period one kilogram of nitrogen resulted in the uptake of 1.4 kg, 3.0 kg and 2.1 kg of additional nitrogen in *P. tanacecifolia*, *S. alba* and *R. sativus.* Accordingly, the intermediate catch crops did play a major role in the nitrogen transports (Allison *et al.,* 1998a, 1998b; Thorup-Kristensen *et al.*, 2003). This is an all the more important finding in view of the poor nitrogen supply of the site of the experiment.

The additional nitrogen application resulted in an increase in the availability of P_2O_5 as well, each kg of additional nitrogen resulted in the uptake of an additional 0.4 kg of P_2O_5 in *P. tanacecifolia* and 0.6 kg in *S. alba* and in *R. sativus*. The additional nitrogen contributed to increased K_2O uptake: by 1.7 kg in *P. tanacecifolia*, 2.6 kg in *S. alba* and by 1.8 kg in *R. sativus*.

Conclusions

Each of the plant species studied in the experiment was suitable for use as green manure under the given unfavourable site conditions, fulfilling their soil protecting and organic matter preserving functions. In terms of the biomass and nutrient content parameters, particularly in terms of the N uptake per-hectare however, the cruciferous *S. alba* and *R. sativus* were found to be more favourable than *P. tanacecifolia*. The application of small doses (50 kg/ha) of nitrogen resulted, in each of the years of the experiments, in substantial increases in the total biomass and the nutrient content parameters, while without the application of nitrogen the next crop suffered from pentosan effect. The delivery of nitrogen fertiliser multiplied the crop's nitrogen content in each of the three plants. The use of nitrogen fertiliser boosted the uptake of phosphorus and potassium as well.

In response to the delivery of the small dose of 50 kg/ha nitrogen each of the three plant species involved in the experiments produced a stable green mass yield and substantial amounts of NPK stored in the green mass but without the nitrogen supplement it was not always possible to produce adequate amounts of biomass in the low quality site. The results showed that in the production of green manure crops nitrogen should preferably be applied in the given site in general, but if the straw after harvesting cereal precrops is not removed from the field, nitrogen should be applied by all means.

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