EFFECT OF DIFFERENT N NUTRIENT CONTENTS ON BIOMASS OF GREEN MANURE AS SECOND CROP, UNDER UNFAVORABLE CLIMATE CONDITIONS IN HUNGARY

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Abstract. The growth and nutrient composition of three plant species produced as second crop for green manure purposes (phacelia – *Phacelia tanacetifolia* Benth., mustard – *Sinapis alba* L. and oilseed radish – *Raphanus sativus* L. *var. oleiformis* Pers.) were studied between 2007 and 2011 at the Crop Production and Biomass Utilisation Demonstration Centre (Növénytermesztési és Biomassza-hasznosítási Bemutató Központ) of Szent István University under unfavourable site conditions on Luvic Kastanozems soil (WRB 2014), subject to two different levels of fertiliser supply (0 kg/ha N; 50 kg/ha N).
The application of 50 kg/ha nitrogen active ingredient multiplied the biomass of each of the three plant species – as an average of the five years of the study to 2.86, 3.07 times and 2.51 times the amount produced without treatment, in the case of phacelia, mustard and oilseed radish, respectively. The rates of the increase of the dry matter content were somewhat lower than those of the green mass increase because the nitrogen improved supply also resulted in an increase in the water content of the green manure plants. One kilogram per hectare added nitrogen increased the green mass and the dry matter content by 412.5 kg and by 37.9 kg as an average of the five years of the study in the case of phacelia, while in the case of mustard the green mass and the dry matter content increased by 431.4 kg and 59.1 kg, respectively. In the case of oilseed radish the corresponding figures were 386.7 kg and 34.1 kg, respectively. Without added nitrogen however, the generally acceptable 10 t/ha biomass could not always be harvested from the given site of relatively unfavourable conditions.
The amount of NPK absorbed per hectare also increased in response to the added nitrogen – to 2.60/2.36/2.13 times the in the case of phacelia over 2007-2011, 2.81/2.29/2.29 times in the case of mustard and 2.72/2.09/1.95 times in the case of oilseed radish. Each kilogram of added nitrogen enabled the uptake of an added amount of 1.6 kg, 2.3 kg and 1.8 kg of additional nitrogen in the case of phacelia, mustard and oilseed radish, respectively, as an average of the period between 2007 and 2011. The nitrogen applied made a significant contribution to the uptake of phosphorous and potassium as well. Each kilogram of added nitrogen increased the uptake of P_2O_5 by 0.5 kg. 0.5 kg and 0.6 kg in the case of phacelia, mustard and oilseed radish, respectively and it boosted the uptake of K_2O by 1.8 kg, 2.1 kg and 1.4 kg in the case of phacelia, mustard and oilseed radish, respectively.
It may be concluded from the above results that when a second crop is grown for use as green manure at the given cropping site the application of nitrogen is always recommended, to the extent possible, but if the straw is left on the soil surface after cereals, it is definitely strongly recommended.
Keywords: *application of green manure, green manure crops, phacelia, mustard, oilseed radish, N nutrient content*

Introduction

Green manure plants are fresh green, non-woody plants, rich in water, sugar, starches, protein and nitrogen, worked into the soil (Kahnt, 1981). In analysing the effects of green manure plants on the next crop Kahnt (1981) identified a total of 14 factors of relevance. Owing to the large number of factors the effectiveness of the use of

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green manure can only be assessed on the basis of precise information of the given site's parameters.

Mustard (*Sinapis alba* L.) and oilseed radish (*Raphanus sativus* L. *var. oleiformis* Pers.) (both belonging to the *Brassicaceae* family) are particularly suitable for these purposes. They play a major role in soil protection (Brown and Morra, 1995; Grossman, 1993; Boydston and Hang, 1995) and in controlling soil-borne pathogens (Papavizas, 1966; Papavizas and Lewis, 1971; Ramirez and Villapudua Munnecke, 1988; Muelchen et al., 1990; Mayton et al., 1996; Croft et al., 1993; Deng et al., 1993), including nematodes (Mojtahedi et al., 1991, 1993), and soil-borne insects that are harmful to crops (Brown et al., 1991).

The soil disinfecting effects are caused by root excretions and, after their incorporation in the soil, the compounds released during their decomposition, even in small concentrations (Bialy et al., 1990; Lazzeri et al., 1993; Williams et al., 1993). Consequently, they inhibit the germination of weed seeds, along with the initial growth of the seedlings (Gardner et al., 1990; Bradow, 1991; Vaughn and Boydston, 1997).

Such positive effects have been observed in relation to phacelia (*Phacelia tanacetifolia* Benth.) as well (Dhima et al., 2009).

Phacelia and mustard are even suitable for the remediation of soils contaminated with heavy metals (Kim et al., 2010; Foucault et al., 2013).

Green manure plants absorb nitrogen from the soil, preventing its leaching out of the soil (Martinez and Guiraud, 1990; Jackson et al., 1993). The C:N ratio in the soil after the incorporation of the green manure plant depends on when it is worked into the soil, the type, moisture content and temperature of the soil (Cadisch and Giller, 1997). These are some of the parameters on which it depends whether the impact on the next crop is positive (Derpsch et al., 1986; Catt et al., 1992; Thorup-Kristensen, 1993; Kara and Penezoglu, 2000; Zhang and Fang, 2007; Collins, 2007), neutral (Allison et al., 1998a, 1998b; Richards et al., 1996), or negative (Allison and Armstrong, 1992; Clark et al., 1997a, 1997b; Vaughan and Evanylo, 1998).

The most important characteristics of a good green manure plant include rapid growth, a large amount of biomass and inexpensive sowing seeds. The aim of our research was to examine the performance of three green manure plants possessing each of the above characteristics, under the given unfavourable cropping site conditions. We sought for answers also to whether successful application of green manure is possible even without added nitrogen, in view of the expected pentosan effect or whether the application of nitrogen is an indispensable prerequisite. The amount by which a unit of added nitrogen increased the amount of the green mass and the dry matter was also examined, along with the increase in the per-hectare NPK uptake.

Material and methods

The trials were set up in the town of Gödöllő, in the Crop Production and Biomass Utilisation Demonstration Centre of Szent István University (47° 34' 43'' N; 19° 22' 39'' E; 229 m above sea level). The experiment site is in a low hilly area, on a gentle north-western slope. The area is rather heterogeneous, comprising spots of varying degrees of erosion and sedimentation.

The annual mean temperature is 9.4 ºC, the annual average amount of precipitation is 590 mm. The average rainfall during the months of August to October that is the most important period for the second crop in a given year is 150 mm.

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Crop-years 2007 and 2008 were of average pattern from the aspect of the second crop in those years, with 169.4 mm and 130.8 mm rainfall between August and October, respectively. 2009 and 2011 however, were dry years, with merely 32.0 mm and 30.0 mm rainfall during the growing season of the green manure plants grown as second crop. 2010 on the other hand, was a rather wet year with 198.6 mm rain during the months of August to October.

The site is located in the micro-region called Gödöllő Hilly Region. The hilly region is characterised by eroded carbonate soils that are typical of hilly regions, elevated to varying extents and broken up in a checker pattern. In the area around the town of Gödöllő upper Pannonian freshwater limestone and chalky clay (marl) are to be found on the surface at various spots among the loess, sand and slope clay settled on the upper Pannonian sandy clay and river sediment. The area elevated during the Pleistocene and a heavily fragmented hilly region with rather steep slopes developed where soil erosion and deflation have resulted in the redeposition of large amounts of materials. The soil in the experiment site is a rust-brown forest soil developed, for the most part, on sand (luvic calcic phaeozem) according to the Hungarian genetic soil classification system. The rust-brown forest soil subtype that has evolved on Tertiary sand and marl belongs to the Ramann's brown forest soil type. As a result of the degradation processes a slightly humic variant of a fertile layer of a medium depth has developed (Stefanovits, 1999a, 1999b; Füleky, 1999; Máté, 2005). The area is exposed to erosion and the soil is sensitive to compaction.

The key soil parameters of the experimental plot are set out in *Tables 1-2*. According to the standards laid down in the MÉM-NAK (the Crop Protection and Agricultural Chemistry Centre of the Ministry of Agriculture and Food) (MÉM, 1979) the soil contains a low level of N, a very high level of P_2O_5 and a good supply of K_2O.

Table 1. *The soil profile of the experimental site*

Ap layer (0-25 cm)	Brown (10YR 3/3), fresh, loose, slightly structured soil comprising predominantly small crumbs, densely interwoven with root residues, with a high proportion of sand but no chalk. Rich in earthworm channels. The transition into the layer below is sharp, a straight line in the soil profile.
A_2 layer (25-40 cm)	Brown (10YR 3/3), humid, slightly compacted, moderately structured, comprising small crumbs, interwoven with root residues, with some earthworm channels, containing no chalk. The transition into the accumulation (subsoil) layer is gradual, showing a wavy line.
B layer (40-60 cm)	Red-brown (2.5YR 3/6), humid, compacted, of a granular structure, less densely interwoven with roots, loam. The transition into the layer below is gradual, showing a wavy line.
BC layer (60-70 cm)	Mixed colour (10YR 3/3 and 10YR 7/4), fresh, slightly compacted, a clay of no particular structure. The transition into the layer below is gradual, showing a baggy pattern.
C layer (70-100 cm)	Light yellowish brown (10YR 7/4), dry, tightly packed, with no structure, a silted clay.

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Table 2. *Important pedological data of experiment*

Genetic soil level	pH (H_2O)	Arany-type plasticity index	humus (%)	$CaCO_3$ (%)	total salt (%)	total N mg kg^{-1}	AL-P_2O_5 mg kg^{-1}	AL-K_2O mg kg^{-1}
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

The green manure experiments with the second crops were conducted in 2007-2011. The seeds of the plants grown as second crops in the experiments were sown after harvesting the previously grown winter wheat, where harvest was immediately followed by stubble stripping. In each year the second crop was sown right after stubble treatment, on 15 August split-plot experimental design. One plot size was 10 x 100 meters. Three plant species (phacelia – *Phacelia tanacetifolia* Benth., mustard – *Sinapis alba* L, oilseed radish – *Raphanus sativus* L. *var. oleiformis* Pers.) were grown and two different doses of nutrients (0 kg/ha N; 50 kg/ha N) were applied in three iterations. Ammonium-nitrate was used as fertiliser, incorporated in the soil as part of stubble treatment. The seeds of the green manure plants were drilled in accordance with the sowing seed norms found in technical literature (Antal, 2000) (*Table 3*).

Table 3. *The seeds requirement of green manure plants*

plants	germinal number ha^{-1}	seeds requirement (kg ha^{-1})
phacelia	5.000.000	10
mustard	2.000.000	15
oilseed radish	2.500.000	25

The biomass so produced was measured and samples for the analysis of chemical composition of the biomass were taken in early November before freezing of the vegetation.

The NPK content was established from 1 g finely ground absolute dry sample with sulphuric acid digestion and 30 % hydrogen-peroxide thermal decomposition. After decomposition the N, P and K content was established from samples diluted up to 100 cm^3. The nitrogen content was measured using a Parnass-Wagner water steam distiller apparatus.

The phosphorous content was measured using the vanadate-molybdate technique. The extinction of the yellow-colour solution was measured with a spectrophotometer (Spekol 221).

The potassium content was measured in the solutions used for the establishment of the phosphorous content as well, with a series of dilutions with a flame photometer (Jenway PFP 7).

The statistical evaluation was based on ANOVA test, one- and a two-factor variance analysis and post hoc tests.

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Results and discussion

The biomass of the green manure plants was heavily affected by the amount of precipitation (*Table 4*). The crop-year effect was particularly pronounced in the case of the plots where no fertiliser had been applied. Phacelia without fertiliser produced only 4.8 t/ha green mass in 2009, in contrast to the 20.3 t/ha produced in 2011. Phacelia did not produce the minimum 10 t/ha green mass (Késmárki and Petróczki, 2003) without added nitrogen in 2008 and 2009. Nitrogen top dressing increased the green mass to 1.91-3.95 times – 2.85 times, as an average of five years – the amount produced without added nitrogen. Phacelia was hard hit by the drought of 2009, yet the application of nitrogen improved the plants' stress tolerance substantially, along with the efficiency of its utilisation of what little water there was, resulting ultimately in a 16.7 t/h green mass. The shortage of air in the soil, caused by the heavy rains in 2010 had a negative impact on the growth of the plants as well. This is considered to be the reason for the larger green mass produced in 2011. Similar results were also observed by Blazewick-Wozniak and Wach (2012).

In the case of mustard, the green mass produced without added nitrogen was below 10 t/ha only in 2008 and 2010 (7.3 t/ha and 7.7 t/ha, respectively). The application of 50 kg/ha nitrogen active ingredient boosted the amount of biomass produced to 3.07 times the amount produced without added nitrogen (that is, to 33.1 t/ha), as an average of the 5 years of the experiment. The poor yield recorded in 2008 was caused by the drought, while in 2010 it was a result of the pentosan effect caused by the excessive rains.

Oilseed radish produced 9.8-22.5 t/ha biomass without and 27.6-43.4 t/ha with added fertiliser. Added nitrogen boosted the green mass produce to 1.93-3.33 times the amount produced without the application of fertiliser.

As an average of the five years of the experiment each of the three green manure plants produced similar amounts of biomass. Studies conducted by Stivers-Young (1998) however, showed that mustard and oilseed radish are capable of producing larger amounts of biomass than phacelia.

In terms of dry mass produced per hectare of land similar trends were observed to those found in regard to green mass, however, the increase in dry mass after the application of nitrogen fell short of the increase in green mass by 75.6 % in the case of phacelia, 52.2 % in the case of mustard and 54.3 % in the case of oilseed radish, as an average of five years (*Table 5*). The reason for this was that the application of nitrogen resulted in an increase in the plants' water content as well. Phacelia, though the plants were not as tall as the mustard plants, produced as much or even more dry mass than the latter. Similar results were observed by Asagi and Ueno (2009) as well.

The nitrogen content per hectare increased after the application of nitrogen fertiliser to 2.6 times the amount found without added nitrogen in phacelia as an average of five years, from 57.3 kg/ha to 136/1 kg/ha. The 50 kg/ha nitrogen fertiliser enabled the uptake of an additional 28.8 kg/ha of nitrogen (*Table 6*). Although Asagi and Ueno (2009) found that phacelia was capable of fixing as much nitrogen as mustard, our results showed that this is significantly affected by the so-called crop-year effect. Each of phacelia, mustard and oilseed radish was, however, capable of fixing N even at low temperatures (Stivers-Young, 1998).

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Table 4. *The green mass of green manure plants (t ha^{-1}) (Gödöllő, 2007-2011)*

treatments		2007	2008	2009	2010	2011	mean	$LSD_{5\%}$
phacelia	no fertilisation	18.4±2.9Ac	9,7±1.5Ab	4,8±0.7Aa	12,8±3.4Abc	20,3±1.3Ac	13,2	4.0
	with 50 kg N ha^{-1} fertiliser	35.2±2.3Bb	38,5±4.8Bbc	16,7±2.5Ba	37,3±2.6Bbc	41,5±1.4Bc	33,8	5.3
	change in biomass (%)	191%	395%	345%	292 %	204%	286%	
	$LSD_{5\%}$	5.9	8.0	4.1	6.8	3.1		
mustard	no fertilisation	12.9±2.8Ab	7,3±2.5Aa	16,6±3.8Ab	7,7±2.4Aa	13,3±1.1Ab	11,6	4.8
	with 50 kg N ha^{-1} fertiliser	26.3±1.0Ba	31,7±3.8Ba	48,2±5.7Bb	29,4±2.7Ba	30,0±0.9Ba	33,1	6.1
	change in biomass (%)	204%	433%	291%	383%	225%	307%	
	$LSD_{5\%}$	4.7	7.3	11.0	5.7	2.3		
oilseed radish	no fertilisation	13.9±1.0Ab	9,8±0.5Aa	10,3±2.4Aa	13,6±1.6Ab	22,5±1.2Ac	14,0	2.7
	with 50 kg N ha^{-1} fertiliser	30.4±0.2Bab	27,6±2.5Ba	34,4±7.5Bb	31,0±1.3Bab	43,4±0.9Bc	33,3	6.5
	change in biomass (%)	219%	282%	333%	228%	193%	251%	
	$LSD_{5\%}$	1.6	4.1	12.6	3.2	2.4		

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Table 5. *The dry mass of green manure plants (t ha^{-1}) (Gödöllő, 2007-2011)*

treatments		2007	2008	2009	2010	2011	mean	$LSD_{5\%}$
phacelia	no fertilisation	3.2±0.6Ac	1.3±0.1Aab	0.9±0.2Aa	2.9±0.8Ac	1.8±0.1Ab	2.0	0.8
	with 50 kg N ha^{-1} fertiliser	4.5±0.3Bd	3.2±0.3Bb	2.3±0.1Ba	5.8±0.4Be	3.8±0.1Bc	3.9	0.5
	change in biomass (%)	141%	242%	267%	200%	205%	211%	
	$LSD_{5\%}$	1.0	0.5	0.3	1.4	0.3		
mustard	no fertilisation	3.0±0.7Ac	1.1±0.3Aa	2.1±0.4Ab	2.3±0.7Ab	1.8±0.05Aab	2.1	0.9
	with 50 kg N ha^{-1} fertiliser	4.9±0.2Bb	3.6±0.5Ba	6.7±1.0Bc	6.0±0.5Bc	3.9±0.1Ba	5.0	1.0
	change in biomass (%)	165%	310%	323%	266%	202%	255%	
	$LSD_{5\%}$	1.1	0.9	1.8	1.4	0.2		
oilseed radish	no fertilisation	2.8±0.2Ab	1.3±0.1Aa	1.6±0.2Aa	3.1±0.4Ab	1.6±0.1Aa	2.1	0.4
	with 50 kg N ha^{-1} fertiliser	4.0±0.03Bb	2.8±0.3Ba	4.8±1.0Bc	4.3±0.2Bbc	3.1±0.1Ba	3.8	0.8
	change in biomass (%)	141%	212%	293%	140%	193%	196%	
	$LSD_{5\%}$	0.4	0.6	1.6	0.6	0.2		

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Table 6. *Effect of different nutrient levels on the uptake of N amount of green manure plants (kg ha^{-1}) (Gödöllő, 2007-2011)*

treatments		2007	2008	2009	2010	2011	mean	$LsD_{5\%}$
phacelia	no fertilisation	73.7±13.8Ac*	30.1±4.7Aa	31.7±5.4Aa	103.4±21.7Ad	47.8±3.1Ab	57.3	21.9
	with 50 kg N ha^{-1} fertiliser	164.4±11.4Bc	118.2±12.0Bb	86.1±10.7Ba	214.1±29.7Bd	97.9±3.8Bab	136.1	29.2
	change in nutrient content (%)	223%	393%	271%	207%	205%	260%	
	$LSD_{5\%}$	28.7	20.7	19.2	59.0	7.9		
mustard	no fertilisation	88.1±17.5Ab	33.6±8.7Aa	85.2±18.9Ab	96.6±22.4Ab	47.7±2.7Aa	70.2	28.7
	with 50 kg N ha^{-1} fertiliser	188.0±6.7Bb	138.8±21.0Ba	283.2±42.4Bc	220.3±9.8Bb	103.0±3.1Ba	186.7	39.8
	change in nutrient content (%)	213%	413%	333%	228%	216%	281%	
	$LSD_{5\%}$	30.0	36.5	74.4	39.2	6.6		
oilseed radish	no fertilisation	64.1±12.6Ab	31.1±6.8Aa	57.4±9.4Ab	103.3±6.5Ac	51.5±3.9Ab	61.5	15.3
	with 50 kg N ha^{-1} fertiliser	174.9±9.0Bb	127.0±13.7Ba	172.0±33.1Bb	180.7±5.8Bb	102.7±2.2Ba	151.5	30.5
	change in nutrient content (%)	273%	409%	299%	175%	199%	271%	
	$LSD_{5\%}$	24.9	24.4	55.2	13.9	7.2		

*Capital letter: post hoc test between treatments
Small letter: post hoc test between years

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As an average of the five years of the experiment the amount of absorbed nitrogen per hectare increased to 2.81 % the amount fixed without added nitrogen. The application of 50 kg/ha nitrogen enabled the utilisation of an additional 66.5 kg nitrogen active ingredient. Of the plants used in the experiment mustard contained the largest amount of nitrogen. Its efficiency in fixing nitrogen had been observed by Baggs et al. (2000) as well. The growth of mustard sown among short-day plants remained vegetative, producing a substantial mass of foliage, and it is the very leaves of the plant that can store the largest quantities of nitrogen (Chaves et al., 2004).

In the case of oilseed radish the active ingredient uptake increased by 2.7 times as an average over five years, i.e. the delivery of 50 kg/ha nitrogen enabled the uptake of an additional 40.0 kg/ha. Like mustard, oilseed radish also produced a large mass of foliage, and of all plant organs leaves contain the largest quantities of nitrogen (Rogasik et al., 1992; Muller et al., 1988).

The per-hectare P_2O_5 contents are illustrated by the figures presented in *Table 7*. The P_2O_5 content of phacelia increased to 2.36, that of mustard grew to 2.29 times and that of oilseed radish increased to 2.09 times the amounts measured on plots without fertiliser, as an average of the five years of the experiment. The application of nitrogen fertiliser enabled, as an average of five years, the uptake of an additional 26.6 kg of P_2O_5 in the case of phacelia, while the increase in the case of mustard and oilseed radish amounted to 27.0 kg and 30.4 kg, respectively. The increase in the per-hectare amount of P_2O_5 absorbed by plants is explained by Liebig's minimum law.

The per-hectare K_2O contents are illustrated by the figures presented in *Table 8*. The K_2O content of phacelia increased to 2.13, that of mustard grew to 2.29 times and that of oilseed radish increased to 1.95 times the amounts measured on plots without fertiliser, as an average of the five years of the experiment. The application of nitrogen fertiliser enabled, as an average of five years, the uptake of an additional 88.1 kg of P_2O_5 in the case of phacelia, while the increase in the case of mustard and oilseed radish amounted to 102.9 kg and 69.2 kg, respectively.

Significant differences between the biomass increase caused by the application of one unit (1 kg) of nitrogen active ingredient and the crop-year effect could be detected in all cases (*Table 9*). The adding of one unit of nitrogen resulted in a significant increase in the biomass produced. One kg of nitrogen active ingredient increased the green mass by 412.5 kg and the dry mass by 37.9 kg as an average of the five years of the experiment. In the case of mustard the green mass grew by 431.4 kg, the dry mass increased by 59.1 kg, while in the case of oilseed radish the corresponding figures were 386.7 kg and 34.1 kg.

The crop-year effect did not always have a statistically proven impact on the per-hectare NPK uptake increase caused by the application of a unit of fertiliser active ingredient (*Table 10*). The quantity of nutrients absorbed increased regardless of the amount and distribution of precipitation. One kilogram of nitrogen active ingredient enabled, the uptake of an additional 1.6 kg of nitrogen in the case of phacelia, 2.3 kg in the case of mustard and 1.8 kg in the case of oilseed radish, as an average of the period between 2007 and 2011. This is of particular importance in view of the fact that the soil of the experiment site has a low nitrogen content. The added nitrogen increased the availability of P_2O_5 as well, as each kg of added nitrogen resulted in a 0.5 kg. 0.5 kg and 0.6 kg of additional P_2O_5 uptake in phacelia, mustard and oilseed radish, respectively. Each kg of added active ingredient resulted in an 1.8 kg, 2.1 kg and 1.4 kg additional K_2O uptake in phacelia, mustard and oilseed radish, respectively.

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Table 7. *Effect of different nutrient levels on the uptake of P_2O_5 amount of green manure plants (kg ha^{-1}) (Gödöllő, 2007-2011)*

treatments		2007	2008	2009	2010	2011	mean	$LSD_{5\%}$
phacelia	no fertilisation	39.2±16.3Abc*	13.9±2.9Aab	8.7±2.4Aa	26.0±6.2Ab	29.0±1.8Abc	23.4	14.6
	with 50 kg N ha^{-1} fertiliser	61.0±4.1Bc	43.5±3.9Bb	23.2±3.7Ba	64.8±7.7Bc	57.4±2.2Bc	50.0	8.5
	change in nutrient content (%)	156%	313%	265%	198%	198%	236%	
	$LSD_{5\%}$	26.9	7.8	7.2	15.8	4.6		
mustard	no fertilisation	27.3±4.7Abc	12.7±2.8Aa	22.7±7.1Ab	30.9±3.6Ac	25.5±3.0Abc	23.4	8.2
	with 50 kg N ha^{-1} fertiliser	46.2±1.5Bb	32.3±4.3Ba	61.8±9.3Bc	62.7±9.4Bc	49.0±1.5Bb	50.4	11.4
	change in nutrient content (%)	169%	254%	272%	203%	192%	229%	
	$LSD_{5\%}$	7.9	8.2	18.7	16.1	5.4		
oilseed radish	no fertilisation	38.8±2.8Ab	18.3±1.8Aa	17.3±0.5Aa	35.1±3.3Ab	50.5±9.3Ac	32.0	8.5
	with 50 kg N ha^{-1} fertiliser	51.9±4.7Bb	34.1±5.5Ba	58.4±12.1Bb	65.1±9.1Bb	102.7±2.2Bc	62.4	13.8
	change in nutrient content (%)	134%	186%	338%	185%	203%	209%	
	$LSD_{5\%}$	8.8	9.3	19.4	15.6	15.3		

* Capital letter: post hoc test between treatments
Small letter: post hoc test between years

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Table 8. *Effect of different nutrient levels on the uptake of K_2O amount of green manure plants (kg ha^{-1}) (Gödöllő, 2007-2011)*

treatments		2007	2008	2009	2010	2011	mean	$LSD_{5\%}$
phacelia	no fertilisation	190.8±9.9Ad*	75.2±4.9Ab	34.0±3.7Aa	111.3±17.0Ac	92.3±10.5Abc	100.7	18.8
	with 50 kg N ha^{-1} fertiliser	251.7±15.6Bcd	179.5±17.6Bb	97.8±23.6Ba	219.4±24.1Bc	195.8±7.7Bbc	188.8	34.1
	change in nutrient content (%)	132%	239%	287%	197%	212%	213%	
	$LSD_{5\%}$	29.7	29.3	38.3	47.3	20.8		
mustard	no fertilisation	156.4±24.7Ac	52.3±18.6Aa	91.6±23.4Ab	98.7±19.2Ab	73.1±6.6Aab	94.4	35.6
	with 50 kg N ha^{-1} fertiliser	253.8±23.4Bcd	183.2±33.2Bab	218.4±27.0Bb	169.3±16.0Ba	161.7±4.8Ba	197.3	42.0
	change in nutrient content (%)	162%	350%	238%	172%	221%	229%	
	$LSD_{5\%}$	54.6	61.0	57.3	40.0	13.2		
oilseed radish	no fertilisation	121.8±6.6Ad	58.0±2.7Aa	62.1±6.4Aa	111.1±3.4Ac	81.0±4.4Ab	86.8	9.1
	with 50 kg N ha^{-1} fertiliser	178.9±13.8Bb	126.8±27.2Ba	175.6±42.1Bab	132.4±17.9Bab	166.4±19.7Bab	156.0	47.5
	change in nutrient content (%)	147%	219%	283%	119%	205%	195%	
	$LSD_{5\%}$	24.5	43.9	68.2	29.4	32.4		

*Capital letter: post hoc test between treatments
Small letter: post hoc test between years

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Table 9. *Specific biomass increasing effect of 1 kg additional N (kg ha^{-1})*

plants	biomass	2007	2008	2009	2010	2011	mean	$LSD_{5\%}$
phacelia	green mass	336.1±69.0ab	575.8±114.0d	237.5±57.3a	490.3±90.4c	423.0±37.2bc	412.5	111.9
	dry mass	26.2±12.2a	37.4±4.4a	29.1±4.8a	58.2±18.2b	38.5±3.8a	37.9	14.8
mustard	green mass	268.5±36.8a	487.3±56.9d	633.3±38.8e	434.2±12.6c	333.6±25.1b	431.4	53.1
	dry mass	38.9±9.4a	48.1±7.6a	93.0±13.1c	74.9±4.2b	40.7±2.9a	59.1	11.9
oilseed radish	green mass	329.8±20.9a	356.1±60.2ab	480.8±102.6c	349.0±6.8ab	417.7±7.9b	386.7	77.5
	dry mass	23.1±4.2a	30.2±9.6a	63.0±14.6b	24.8±3.7a	29.5±0.5a	34.1	11.7

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Table 10. *Specific NPK content increasing effect of 1 kg additional N (kg ha^{-1})*

plants	NPK	2007	2008	2009	2010	2011	mean	$LSD_{5\%}$
	N	1.8±0.3	1.8±0.3	1.1±0.3	2.2±1.0	1.0±0.1	1.6	ns
phacelia	P_2O_5	0.4±0.2a	0.6±0.1a	0.3±0.1a	0.8±0.2a	0.6±0.03a	0.5	0.8
	K_2O	1.2±0.4a	2.1±0.4b	1.3±0.5a	2.2±0.8b	2.1±0.2b	1.8	0.5
	N	2.0±0.3b	2.1±0.4b	4.0±1.2d	2.5±0.4c	1.1±0.1a	2.3	0.2
mustard	P_2O_5	0.4±0.1	0.4±0.1	0.8±0.3	0.6±0.2	0.5±0.1	0.5	ns
	K_2O	1.9±0.8b	2.6±0.5c	2.5±0.9c	1.4±0.1a	1.8±0.1b	2.1	0.2
	N	2.2±0.2	1.9±04	2.3±0.6	1.5±0.2	1.0±0.1	1.8	ns
oilseed radish	P_2O_5	0.3±0.1	0.3±01	0.8±0.2	0.6±0.1	1.0±0.1	0.6	ns
	K_2O	1.1±0.4ab	1.4±0.6b	2.3±1.0c	0.4±0.4a	1.7±0.3bc	1.4	0.8

Conclusions

Each of the three plant species involved in the experiment was suitable for use as green manure under the given unfavourable site conditions, fulfilling their roles in terms of soil protection and organic matter conserving. In regard to the per-hectare biomass and chemical composition, particularly in view of the uptake of nitrogen, the cruciferous mustard and oilseed radish were found to perform better than phacelia.

The 50 kg/ha nitrogen active ingredient made a significant contribution to the increase in the total amount of biomass produced and improvement in its chemical composition, while without added nitrogen the crop was badly affected by what is known as pentosan effect. The application of nitrogen fertiliser multiplied the per-hectare nitrogen content in each of the three plant species. The added nitrogen also greatly facilitated the uptake of phosphorous and potassium.

After the delivery of 50 kg/ha nitrogen each of the three plant species produced a stable green mass with substantial amounts NPK absorbed, but without added nitrogen the poorly endowed site could not always produce the amount that would have been considered as adequate. It is concluded from the results of the experiment that when growing second crops for green manure at the given site nitrogen should always be applied but when the straw is left on the field to be incorporated into the soil after the harvest of cereal crops, the application of nitrogen is indispensable.

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ELECTRONIC APPENDIX

This article has an electronic appendix with basic data.

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