INVESTIGATION OF THE EFFECTS OF GREEN MANURING ON SOIL CONDITION AND THE FOLLOWING CROP

Ph.D. theses of

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1. SCIENTIFIC BACKGROUND AND AIMS OF THE PH.D. WORK

Our soils are not delivered sufficient amount of manure long ago. The organic matter deficiency can lead to the deterioration of soil structure and the exhaustion of its fertility. Sustainable crop production can be conducted only on soils with well conserved soil structure and with available nutrient supply. The yield fluctuations due to more and more frequent weather extremities can be reduced only this way, and the raw material of food, feed and industry needed for the national economy be ensured.

The presence of higher amount of livestock manure is not expected in the near future due to the low number of livestock. The level of fertilizer utilization is also lower than needed. Some of the biomass power plants being built intend to use wheat straw and maize stem as raw materials that decreases further the amount of organic matter and nutrient elements left on the field. If present tendency continues, in some decades the safe crop production is endangered. Due to the abovementioned, the application of other type of methods for increasing organic matter content is needed. First- and second crop green manuring affords possibilities for that.

The importance of firstcrop green manuring has decreased as compulsory set-aside is suspended in the European Union, but as a possibility should not be forgotten. The possibilities offered by the secondcrop are not utilized unfortunately. According to Agricultural Economics Research Institute data, on less than 1 percent (14.568 ha) of the sowing area after early harvested precrops was sown with green manure plants in 2008, though the potential area is over 1.5 million ha.

According to Good Agricultural Practice, on at least 20 percent of the sowing area of the crop sequence pulses or green forage must be sown (at least once in every 5 year, including secondcrop). The secondcrop papilionaceous and non-papilionaceous green manure crops suit the requirements, and by emphasizing environmentally sound approach and along with closer supervision, a significant increase of their sowing area is expectable. Though green manuring has traditions in Hungary and several Hungarian researchers carried out regarding investigations previously, in the past decades only a few scientific contributions have been published unfortunately. On the contrary, in West Europe, USA and several parts of Asia, both research and practical utilization are widespread nowadays. As former national experimental results regard mainly to sandy soils of Nyírség and Duna-Tisza köze regions, and international experiences are not adaptable in all cases to national circumstances, the possibilities of green manuring need wider investigations (including more soil types and regions). The impacts due to climate change should also be taken into consideration.

In my investigations the effect of first- and secondcrop green manure plants on soil condition and aftercrop has been studied. In my research the determination of soil penetration resistance, soil humidity, biomass, NPK content and yield parameters of the aftercrop have been included. I also studied the less known cultivation purposes of green manure plants – for e.g. possible methods in weed control – and critical points of cultivation and application possibilities, too. One of the aims of my PhD work was to find the plant species with the most favourable effect both as first- and secondcrop, under unfavourable habitat circumstances by considering the year effect.

During my research the effect of green manure plants on the following parameters have been investigated:

1. Effect on soil condition:
   - changes in soil penetration resistance and soil humidity between soils covered with green manure plants, and uncovered control (black fallow in firstcrop, and stripped stubble in secondcrop),
2. Changes of plant canopy and phenology during vegetation:
   - development rate and weed suppression ability of certain green manure plants,
   - length of shoots and roots of different green manure plants.
3. Produced green and dry biomass of green manure plants and amount of NPK per hectare, affected by the year effect.
4. Following crop effect, yield quantity and quality of following crops.
5. Impact of nitrogen fertilization on the development of secondcrop green manure plants.

2. MATERIALS AND METHODS

2.1. Research background

2.1.1. The locations of research

My investigations have been carried out in 2 locations: in Mélykút and Gödöllő Szárítópuszta.

The experiment in Mélykút (46° 11’ 59’’ N; 19° 22’ 56’’ E; elevation: 128 m) was set up on Calcic Chernozem soil, homogenous and flat area. The important parameters of the experimental field are summarized in *Table 1*. The average annual mean temperature of the area is 10.7 °C, and yearly precipitation is 620 mm.

Table 1. Important pedological data of Mélykút experiment

genetic soil level	depth (cm)	pH (H_2O)	P_A*	humus (%)	$CaCO_3$ (%)	total N mg/kg	AL-P_2O_5 mg/kg	AL-K_2O mg/kg
Ap	0-30	7.72	37	1.63	12.23	503.5	634.5	498.4
A	30-60	8.34	44	1.16	15.26	435.9	553.8	386.2
B	60-80	8.07	43	1.03	18.65	585.2	589.8	372.1
C1	80-100	8.94	40	0.41	18.78	202.4	525.7	423.4
C2	100-120	8.98	35	0.37	23.36	242.3	494.4.	286.9
C3	120-150	9.06	35	0.20	20.04	147.5	474.2	297.2

* P_A= Arany-type plasticity index

In Gödöllő (47° 34’ 33’’ N; 19° 22’ 45’’ E; elevation: 230 m) on Luvic Calcic Phaeozem soil, the experimental plots were located on a slight north-west sloping area, prone to erosion. The important parameters of the experimental field are summarized in *Table 2*. The average annual mean temperature of the area is 9.4 °C, and yearly precipitation is 590 mm.

Table 2. Important pedological data of Gödöllő experiment

genetic soil level	depth (cm)	pH (H_2O)	P_A	humus (%)	$CaCO_3$ (%)	Σ salt (%)	total N mg/kg	AL-P_2O_5 mg/kg	AL-K_2O mg/kg
Ap	0-25	6.76	30	1.32	0.00	0.044	16.8	371.1	184.0
B	40-60	7.08	40	1.04	0.00	0.052	11.9	33.0	112.0
BC	60-70	7.66	61	0.88	0.00	0.060	2.0	123.0	127.1
C	70-100	8.10	60	0.54	5.57	0.075	16.8	107.5	110.8

* P_A= Arany-type plasticity index

2.1.2. Cultivation technology data of the experiments

The pre- and following crops, as well as sowing- and incorporation times of the experiments are included in *Table 3*. The investigated plant species are indicated in *Table 4*.

In the experimental fields stubble-stripping has been carried out immediately after harvest by shallow disking, pressed by a ring packer, which was followed by a stubble treatment with disc + ring packer in mid-August. The secondcrop was sown into treated stubble. Previous to main crop experiments, 30 cm deep autumn ploughing was applied that was followed by a seedbed preparation with cultivator in the beginning of April.

The main crop experiments in Gödöllő in 2005, and in Mélykút the secondcrop experiments in 2005 were conducted in 5x5 m Latin square design. In other cases in order to facilitate sowing and harvest works, strip design was applied. The strip was 3 m wide and 50 m long. All of the experiments had 3 replications, randomized design.

Under main crops, the stubble-stripping of precrops were followed by autumn ploughing and seedbed preparation in the spring. Under secondcrops, sowing took place after stubble-stripping and seedbed preparation in August. Under the main crop 100 kg/ha 10:28 PK fertilizer was spread in the autumn, which was followed by 50 kg/ha ammonium-nitrate in the spring prior to sowing. Prior to secondcrop 50 kg/ha ammonium-nitrate was spread, either.

Table 3. Pre- and following crops, sowing- and incorporation times of the experiments

experiment	precrop	sowing time	incorporation time	following crop
Mélykút 2005 secondcrop	millet	6 August	22 October	oat
Gödöllő 2005 main crop	winter wheat	11 April	7 July	winter wheat
Gödöllő 2005 secondcrop	winter wheat	13 August	27 October	spring barley
Gödöllő 2006 main crop	winter rape	12 April	7 July	maize
Gödöllő 2006 secondcrop	winter wheat	21 August	25 October	maize
Gödöllő 2007 main crop	winter wheat	17 April	28 June	**
Gödöllő 2007 secondcrop	winter barley	19 July* 16 August*	6 November	**
Gödöllő 2008 secondcrop	winter rape	22 August	5 November	**

* two different sowing times
** following crop effect was not investigated

Table 4. Investigated green manure crop (Mélykút, 2005; Gödöllő, 2005-2008)

Mélykút	Gödöllő						
2005	2005		2006		2007		2008
secondcrop	main crop	secondcrop	main crop	secondcrop	main crop	secondcrop	secondcrop
phacelia	phacelia	phacelia	phacelia	phacelia	phacelia	phacelia [2]	phacelia
mustard	mustard	mustard	mustard	mustard	mustard	phacelia [3]	mustard
oil radish	oil radish	oil radish	oil radish	oil radish	oil radish	mustard[2]	oil radish
phacelia + mustard + oil radish	phacelia + mustard + oil radish	phacelia + mustard + oil radish	mustard + oil radish	spring rape	spring rape	mustard[3]	buckwheat[4]
spring rape	spring rape		buckwheat	buckwheat	buckwheat	oil radish[2]	
buckwheat	buckwheat		spring vetch	spring vetch	spring vetch	oil radish[3]	
hairy vetch + triticale	spring vetch + oat		spring vetch + phacelia	white lupine[1]	white lupine		
crimson clover	crimson clover		spring vetch + oat		melilot		
melilot	melilot		white lupine				
			crimson clover				
			melilot				

[1] late, sparse emergence

[2] July sowing

[3] August sowing

[4] blighted by frost in mid-October before sample taking

2.2. Research methods

2.2.1. Soil penetration resistance measurement

Soil penetration resistance measurements have been carried out in all of the treatments regarding the evaluation of soil physical properties by the penetrometer designed by MOBITECH Bt. Szarvas. The penetrometer is suitable for in situ measurement of soil penetration resistance up to 50 cm depth. The measurements were carried out up to 50 cm depth (1 measurement in each 10 cm soil layer), 3-4 times in the vegetation period.

2.2.2. Soil humidity content measurement

The determination of soil humidity content was conducted simultaneously with soil penetration resistance measurement. The humidity content of soil samples were determined in drying chamber (at 105 ^{o}C till weight consistency) or by Field Scout TDR 300 soil humidity data recorder.

2.2.3. Plant phenology investigation

Weed monitoring and weed suppression ability investigation of certain plants was carried out 6 weeks after emergence by the application of Újvárosi-type weed monitoring method.

In order to measure the biomass weight of green manure plants, samples have been taken with the help of a 0.25 m^2 quadrat in 3 replications. The sampling was done up to rooting depth to measure root length and root mass.

The shoot and root mass was measured immediately after digging out and removing soil with water. The determination of dry matter and humidity content after pre-drying in an airy spot till air-dry state was conducted at 60 °C in drying chamber.

2.2.4. Investigation of the chemical composition of plants

The determination of NPK was carried out by digestion with concentrated sulphuric acid from 1 g of fine milled absolute dry sample, and by 30% hydrogen peroxide destroying with heating. After destroying, NPK content was determined from up to 100 cm^3 diluted samples. For nitrogen recovery the Parnass-Wagner apparatus has been used.

In order to determine phosphor content, vanadate-molibdate method was used. Spekol 221 spectrophotometer was used for measuring the extinction of yellow colour solution.

The determination of potassium was conducted by flame photometer (Jenway PFP 7) with the help of a dilution line, and using the solutions mentioned at phosphor determination.

2.2.5. Investigation of the following crop yields

The harvest of the following crops was done by a plot-harvester. The chemical composition investigations were carried out by Instalab 600 NIR (Near Infrared Reflectance Analyzer) appratus. The device determines the chemical composition of fine milled samples up to a thousandth accuracy on the basis of infrared light reflection, digestion and calibrated values.

2.2.6. Investigation of the effect of nitrogen fertilization

In 2007 at July and August sown phacelia, mustard and oil-radish, in 2008 at phacelia, mustard and oil radish the development, biomass and chemical composition of plants was recorded under no nitrogen fertilization and 50 kg/ha nitrogen active agent. In 2008 the NPK uptake availability of nitrogen fertilization was investigated, either.

2.3. Statistical methods

The statistical evaluation was done by Microsoft Excel program. One-way analysis of variance and regression analysis were used for data evaluation.

3. RESULTS

3.1. Results of soil penetration resistance and soil humidity

The effect of important green manure plants on soil penetration resistance in the average of main- and secondcrop experiments in Gödöllő is shown in *Figure 1.* In 0-10 cm layer, except spring vetch + oat, and in 20-30 cm layer except buckwheat, all of the treatments were proved to be more compacted significantly, than control. The difference between soil penetration resistance of plots covered with green manure plants and the control was proved to be higher in deeper layers, than of those close to soil surface. By taking the whole 50 cm layer as a basis, the soil was 12.4-30.2% more compacted under green manure plants, than in case of control. The value and the difference of soil penetration resistance were higher in deeper layers than close to soil surface, even compared to control *(Table 5.)*.

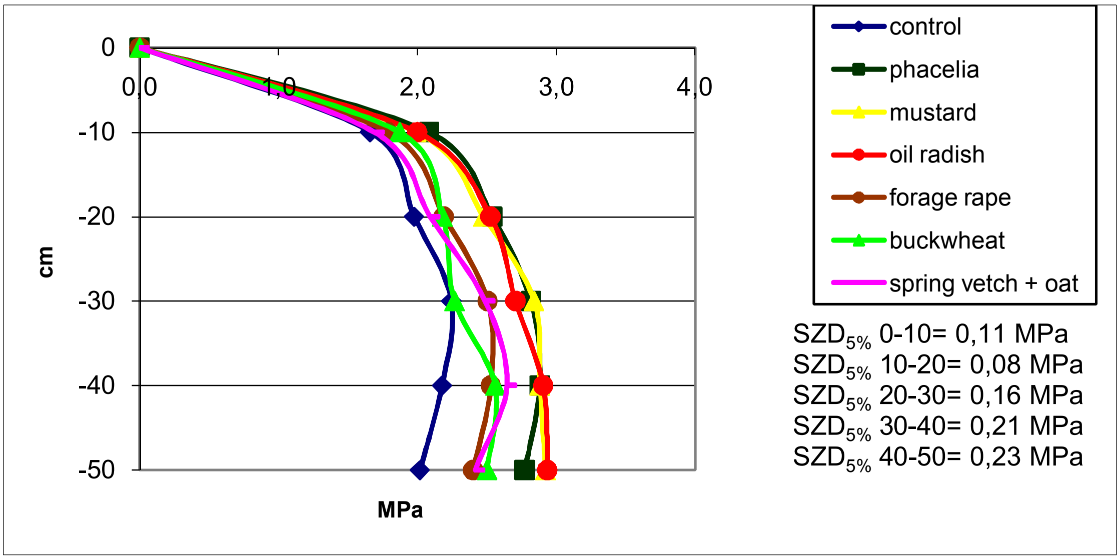

Figure 1. Effect of green manure plants on soil penetration resistance (MPa) in the average of 7 experiments (Gödöllő, 2005-2008)

Table 5. Average soil penetration resistance value of green manure plants (MPa) in the average of 7 experiments (Gödöllő, 2005-2008)

soil penetration resistance (MPa)	control	phacelia	mustard	oil radish	spring rape	buck-wheat	spring vetch + oat
0 – 10 cm	1.7	2.1	2.0	2.0	1.8	1.9	1.7
in % of control	100.0%	125.5%	120.0%	120.5%	107.5%	112.8%	101.8%
10 – 20 cm	2.0	2.5	2.5	2.5	2.2	2.2	2.1
in % of control	100.0%	128.4%	125.3%	127.8%	110.8%	110.3%	105.8%
20 – 30 cm	2.2	2.8	2.8	2.7	2.5	2.3	2.5
in % of control	100.0%	125.5%	126.6%	120.5%	111.6%	101.0%	110.8%

Table 5. continuation

30 – 40 cm	2.2	2.9	2.9	2.9	2.5	2.6	2.6
in % of control	100.0%	132.4%	132.4%	133.4%	116.1%	117.6%	121.5%
40 – 50 cm	2.0	2.8	2.9	2.9	2.4	2.5	2.4
in % of control	100.0%	137.4%	144.9%	145.4%	119.0%	123.9%	119.7%
0-50 cm átlag	2.0	2.6	2.6	2.6	2.3	2.3	2.3
in % of control	100.0%	129.9%	130.2%	129.7%	113.2%	112.9%	112.4%

The effect of important green manure plants on soil humidity in the average of main- and secondcrop experiments in Gödöllő is shown in *Figure 2.* In the average of 7 experiments regarding the layer of 0-30 cm, the soil under phacelia, mustard and oil radish was proved to be significantly dryer compared to control. Between spring rape, buckwheat and spring vetch + oat, no significant difference could be proved statistically. In the 30-60 cm layer, the soil of phacelia, mustard, oil radish and spring vetch + oat was proved to be significantly dryer compared to control. No significant difference was found between spring rape, buckwheat and control. In the average of experiments, regarding the whole 0-60 cm layer phacelia was proved to be 10.7%, mustard 12.5 %, oil radish 14.9%, and spring rape 10% dryer compared to control *(Table 6.)*

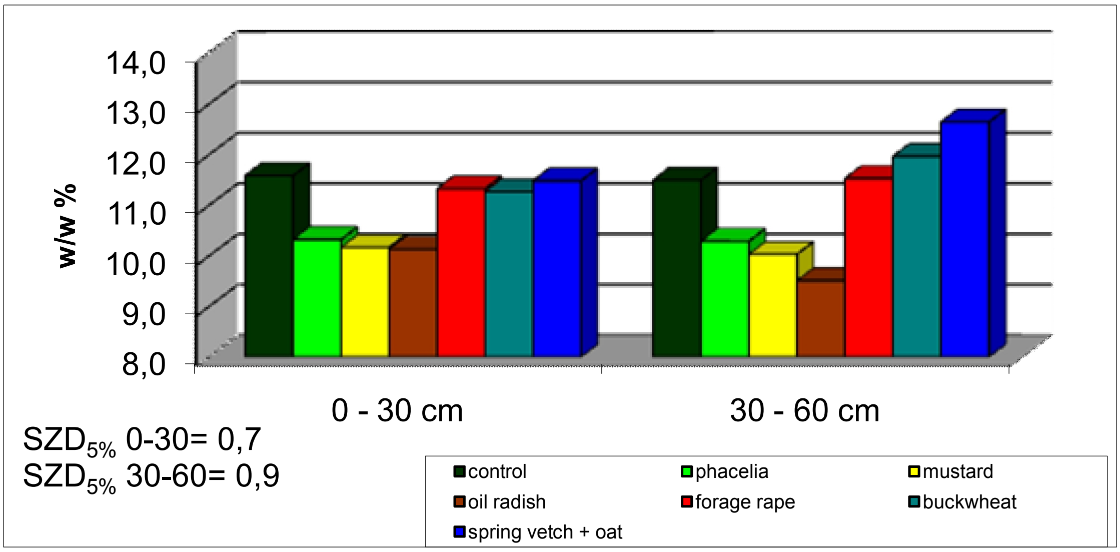

Figure 2. Effect of green manure plants on soil humidity (w/w %) in the average of 7 experiments (Gödöllő, 2005-2008)

Table 6. Average soil humidity value (w/w %) of green manure plants in the average of 7 experiments (Gödöllő, 2005-2008)

soil humidity (w/w %)	control	phacelia	mustard	oil radish	spring rape	buck-wheat	spring vetch + oat
0 – 30 cm	11.6	10.3	10.2	10.1	11.3	11.3	11.5
in % of control	100.0%	89.1%	87.8%	87.5%	97.8%	97.3%	99.1%
30 – 60 cm	11.5	10.3	10.0	9.5	11.5	12.0	12.6
in % of control	100.0%	89.5%	87.2%	82.7%	100.3%	104.1%	110.0%
0-60 cm average	8.0	7.2	7.0	6.8	7.9	8.1	8.4
in % of control	100.0%	89.3%	87.5%	85.2%	99.0%	100.5%	104.3%

The soil penetration resistance value is closely dependent on the year effect and local habitat circumstances. Therefore soil penetration resistance values of the plots covered with green manure plants varied within wide limits in different experiments. But mostly, green manure plants resulted in significantly more compacted soil condition at the time of incorporation compared to control. Soil humidity is strongly dependent on the year and habitat, either. Although not in all experiments have significant differences been detected, but if yes, mostly the plots covered with green manure plants were proved to be drier.

Especially in drier years – under certain habitat circumstances – in case of green manure plants, more unfavourable, more compacted and drier soil condition was detected at the time of incorporation compared to uncovered control, but this difference was no longer experienced after a few months.

3.2.2. Biomass and NPK content investigation

The green-, and dry mass, N, P_2O_5 and K_2O values of green manure plants are shown in the Appendix *52-59.* of the PhD thesis. Depending on the year effect, significant difference was shown in the biomass and the quantity of digested nutrients, either. However, even in 2007, in the weakest main crop experiment, all of the plants have produced the literaturally determined min. 10 t/ha green mass. The summarized data of the 8 experiments are shown in *Table 7.*

Table 7. Green mass, dry mass (t/ha), uptaken NPK (kg/ha) of green manure plants in the average of 8 experiments (Mélykút, 2005, Gödöllő, 2005-2008)

plant	green mass (t/ha)	dry mass (t/ha)	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
phacelia	41.7 (11.9-65.9)*	6.5 (2.2-14.1)	156.2 (30-346)	84.4 (15-174)	233.7 (43-375)
mustard	39.4 (11.9-86.0)	7.2 (2.2-11.5)	208.3 (30-361)	79.1 (15-128)	215.0 (43-308)
oil radish	61.9 (24.0-150.6)	7.9 (4.2-15.6)	214.9 (60-325)	104.7 (34-168)	292.6 (83-509)
phacelia + mustard + oil radish	48.5 (33.4-50.7)	7.5 (3.4-12.0)	173.9 (97-319)	82.2 (46-139)	217.1 (157-292)
spring rape	40.4 (25.7-69.7)	6.3 (3.5-9.7)	172.1 (65-297)	58.8 (27-103)	180.3 (85-305)
buckwheat	19.8 (10.6-31.7)	4.6 (2.1-7.5)	96.3 (49-149)	50.9 (22-95)	99.5 (48-175)
spring vetch + oat	32.7 (11.8-54.5)	8.9 (3.1-14.4)	299.8 (51-727)	81.4 (22-151)	239.8 (57-463)
lupine	25.8 (17.8-33.9)	6.7 (3.0-10.4)	255.1 (105-406)	48.2 (19-77)	130.5 (65-196)
crimson clover	20.5 (12.9-31.3)	3.5 (2.6-6.5)	104.0 (63-189)	32.6 (25-59)	95.7 (70-176)
melilot	25.3 (13.2-36.7)	4.8 (2.2-6.7)	183.8 (83-335)	46.4 (16-75)	113.8 (47-176)

* minimum and maximum values are indicated in bracket

In the average of experiments highest green mass (61.9 t/ha) was reached by oil radish. The phacelia, mustard and spring rape produced almost equal, high amount of green biomass (41.7 t/ha; 39.4 t/ha; 40.4 t/ha). The green mass of phacelia-mustard-oil radish mixture (48.5 t/ha) was lower than pure sowing oil radish, and suits the average of the ingredients only. The spring vetch + oat mixture has produced 32.7 t/ha green mass in the average of experiments. The green mass production of leguminous plants was 20-25 t/ha on the average. According to average yield, the biomass production of buckwheat was proved to be the lowest (19.8 t/ha).

The highest average dry mass production per hectare was achieved by spring vetch + oat mixture. Although its biomass production was lower than of cruciferous plants, due to higher dry matter content of the oat, this mixture has produced the highest amount of dry mass per hectare. The oil radish, mustard and phacelia-mustard-oil radish mixture produced over 7 t/ha dry matter in the average of experiments. The dry matter mass of phacelia, spring rape and white lupine over 6 t/ha, melilot and buckwheat nearly 5 t/ha on the average is significant. The lowest average dry matter mass (3.5 t/ha) was achieved by crimson clover.

According to the average of the experiments, spring vetch + oat mixture contained highest amount of nitrogen per hectare (299.8 kg/ha) as did white lupine (255.1 kg/ha). The mustard and oil radish have digested more than 200 kg/ha N in the average of the experiment. The phacelia-mustard-oil radish mixture, spring rape and melilot have left behind nearly equal, 172-183 kg/ha N after incorporation. The buckwheat with low N content, and crimson clover contained 100 kg/ha N on the average. The low N content and low amount of biomass of crimson clover is due to unfavourable habitat circumstances.

The highest amount of phosphor (104.7 kg/ha) was digested by oil radish on the average of the experiments. The phacelia, mustard, phacelia-mustard-oil radish mixture and spring vetch + oat both contained around 80 kg/ha P_2O_5. After spring rape incorporation, the phosphor availability of the following crop has been increased by 58.8 kg/ha P_2O_5 on the average. The amount of phosphor digested by buckwheat, white lupine and melilot was nearly identical, 50.9; 48.2 and 46.4 kg/ha. As in the case of N, also crimson clover had lowest P_2O_5 content per hectare, which can be due to its lowest dry matter mass per hectare. In the case of average amount of digested potassium per hectare, the tendency tipical of phosphor was observed. The highest amount of potassium was digested by oil radish, 292.6 kg/ha on the average. The phacelia, mustard, phacelia-mustard-oil radish mixture and spring vetch + oat delivered more than 200 kg/ha potassium. The K_2O content of spring rape was 180.3 kg/ha on the average of the experiment. 130.5 and 113.8 kg/ha potassium has been left behind after incorporating white lupine and melilot. The lowest amount of potassium (99.5 and 95.7 kg/ha) has been digested by buckwheat and crimson clover on the average.

3.2.3. Correlations of dry matter mass and the year effect

According to references, especially in secondcropping, the success of green manuring is mainly dependent on the amount of precipitation in the vegetation period. As among climatic factors precipitation is the most limiting factor regarding crop production, the relationships between dry matter mass of green manure plants per hectare and precipitation in the vegetation period and heat sum have been investigated in main and secondcrop, either. The closest relationship was found for hidrotermic coefficient.

In almost every development stages of the plants has an optimal heat- and water supply relation number. In case of optimal rate of heat and precipitation, the production of plant depends on the hidrotermic index parabolically. Determination follows:

$$HTC = P * 10 / T^{o}$$

P – precipitation amount of growing season (mm)

T^{o} – total heat sum (°C)

The relationships between dry matter mass and hidrotermic coefficient of main and secondcrop phacelia, mustard and oil radish are shown in *Figure 3* and *4*. As main crop, very close relationship was observed. In case of secondcropping of all three plants, close relationship was found as R^2 value was over 0.8.

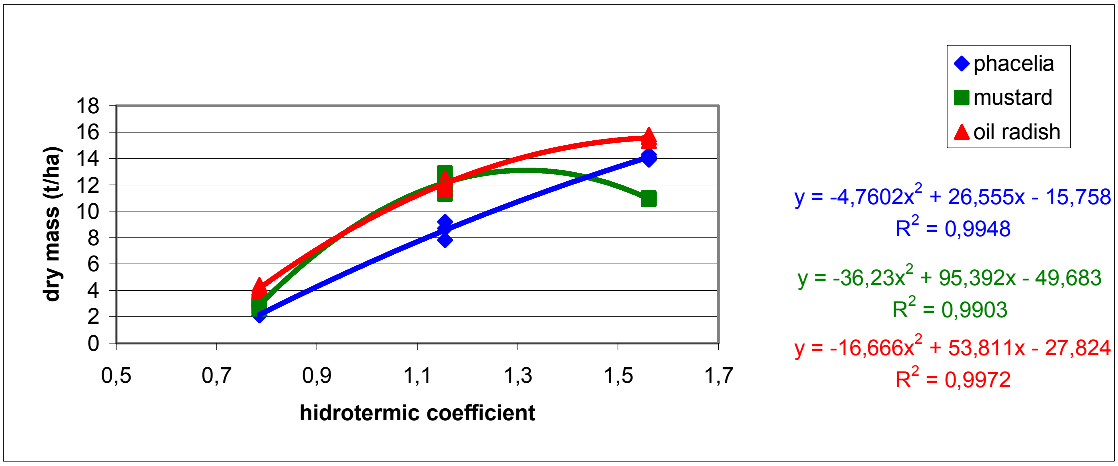

Figure 3. Relationships of hidrotermic coefficient and dry matter mass of main crop (Gödöllő, 2005-2007)

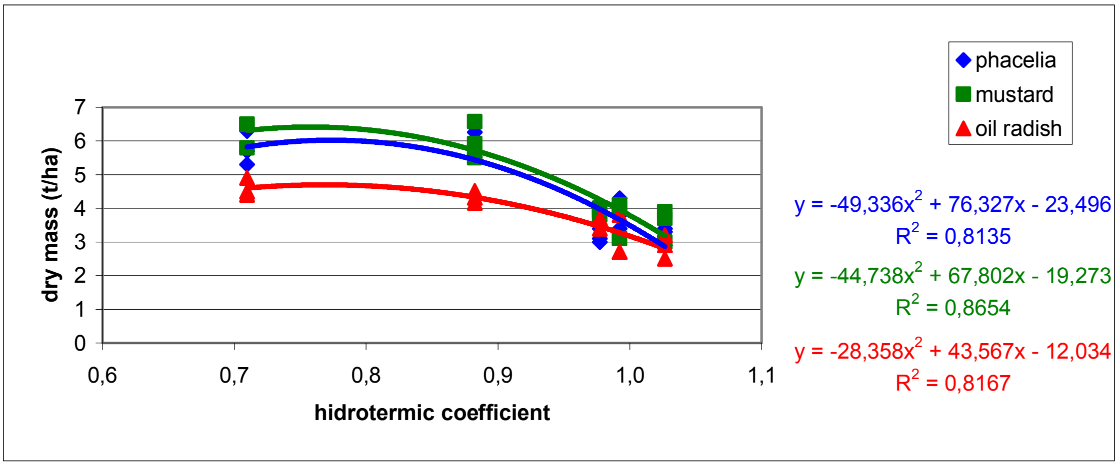

Figure 4. Relationships of hidrotermic coefficient and dry matter mass of secondcrop (Gödöllő, 2005-2008)

3.2.4. Investigation of following crop effect

The investigations of following crop effect have been conducted in 5 experiments *(Table 8.)*. No significant difference was found regarding yields in any of the plots. Regarding yield quality, significant difference was found between treatments for protein content of oat following crop in Mélykút. In Gödöllő, no significant difference was found in any of the experiments.

Table 8. Following crops and yields of following crops in green manure experiments (Mélykút, 2006; Gödöllő, 2006, 2007)

experiment	following crop		
	crop	yield	quality of yield
Mélykút 2005 secondcrop	oat	NS*	SZD5% = 0.2 %
Gödöllő 2005 main crop	winter wheat	NS	NS
Gödöllő 2005 secondcrop	spring barley	NS	NS
Gödöllő 2006 main crop	maize	NS	NS
Gödöllő 2006 secondcrop	maize	NS	NS

NS* - not significant

The protein content of oat following secondcrop green manure experiment in Mélykút was significantly higher after all green manure treatments compared to control, though differences were lower than 1 %. The highest protein content was observed after leguminous precrops.

3.2.5. Correlations of fertilization and the biomass

The plots withot fertilization produced much lower amount of plant mass both in 2007 and 2008. Without additional nitrogen, in all of the treatments weak, yellow, retarded development plants could be observed due to very strong pentosan effect. Significant differences have been found between nutrient applications regarding biomass *(Figure 5., Table 9-10.).*

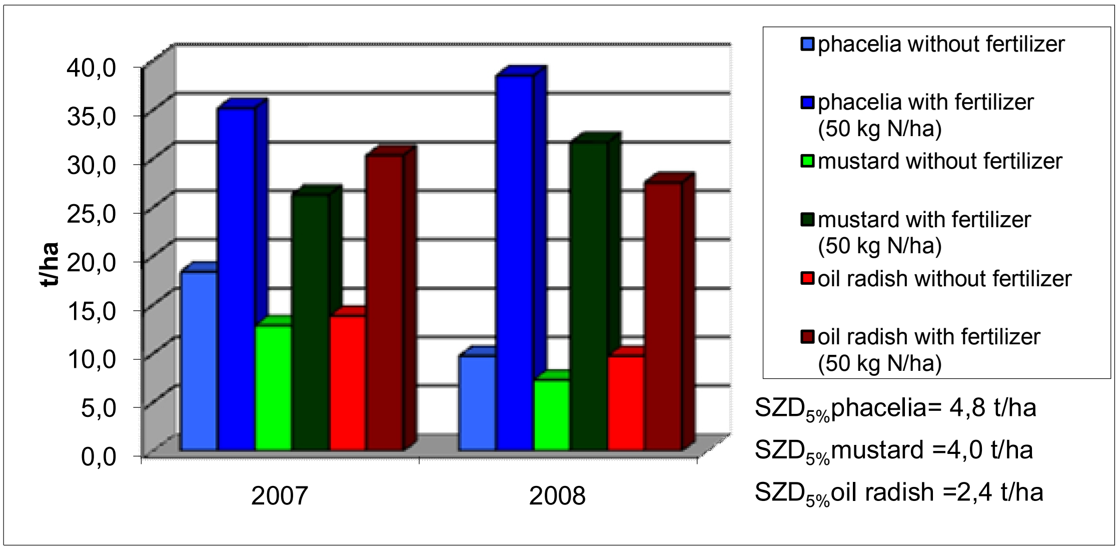

Figure 5. Effect of different nutrient rates on the green mass of green manure plants (t/ha) (Gödöllő, 2007-2008)

Table 9. Change in biomass after 50 kg/ha N, compared to no fertilization (%) (Gödöllő, 2007-2008)

plant	2007		2008		average	
	green mass	dry mass	green mass	dry mass	green mass	dry mass
phacelia	191%	141%	395%	242%	293%	192%
mustard	204%	165%	433%	310%	319%	237%
oil radish	219%	141%	282%	212%	251%	177%

Table 10. Specific biomass increasing effect of 1 kg additional N (kg/ha) (Gödöllő, 2007-2008)

plant	2007		2008		átlag	
	green mass increase	dry mass increase	green mass increase	dry mass increase	green mass increase	dry mass increase
phacelia	336.1	26.2	575.8	37.4	455.9	31.8
mustard	268.5	38.9	487.3	48.1	377.9	43.5
oil radish	329.8	23.1	356.1	30.2	342.9	26.6

In both years nearly equal amount of biomass (25-35 t/ha) has been produced of all the three plants after nitrogen application, but without nitrogen fertilizer heterogenous plant stand was found. In 2007 green mass has slightly exceeded, but in 2008 has not reached the expected 10 t/ha yield. In 2007, at all plants, the low amount of nitrogen application have increased green mass by 1.9-2.2, in 2008 at phacelia 4.0, at mustard 4.3, at oil-radish 2.8 times. The increase of yield in the average of two years was at phacelia and mustard 2.9 and 3.2 times, at oil-radish 2.5 times. In 2007, regarding dry matter mass 1.4-1.7 times increase has been observed for all the three plants. In 2008 the dry matter mass of phacelia was increased up to 2.4 times, mustard 3.1 times, while oil radish up to 2.1 times due to nitrogen application. In the average of two years the increase of yield of phacelia was 1.9 times, mustard 2.4 times, while at oil radish 1.8 times.

After 1 kg of additional nitrogen phacelia has produced 455.9 kg green mass in the average of two years, which equals 31.8 kg dry matter. The green mass increase of mustard was 377.9 kg in the average of two years that has meant 43.5 kg dry matter. At oil radish, green mass increase was 342.9 kg in the average of two years, which contained 23.6 kg dry matter.

Similar tendency was shown regarding the amount of digested NPK per hectare *(Figure 6., Table 11-12.)*.

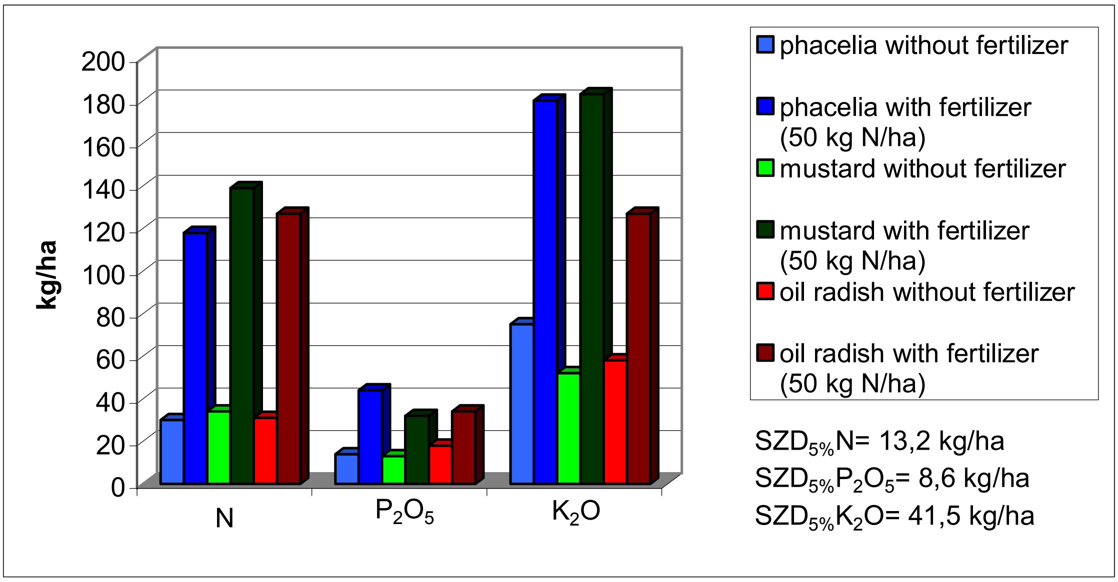

Figure 6. Effect of different nutrient levels on the uptake of NPK amount of green manure plants (kg/ha) (Gödöllő, 2008)

Table 11. Change in NPK amount after 50 kg/ha N application, compared to unfertilized plot (%) (Gödöllő, 2008)

plant	N	P_2O_5	K_2O
phacelia	393%	314%	240%
mustard	409%	246%	352%
oil radish	410%	189%	219%

Table 12. Specific NPK content increasing effect of 1 kg additional N (kg/ha) (Gödöllő, 2008)

plant	N	P_2O_5	K_2O
phacelia	1.8	0.6	2.1
mustard	2.1	0.4	2.6
oil radish	1.9	0.3	1.4

As a consequence of nitrogen fertilization the amount of uptaken nitrogen per hectare has increased by 3.9-4.1 times. The phosphor and potassium uptake has also been facilitated by nitrogen. The phosphor availability per hectare has been increased by 3.1 times in the case of phacelia, 2.5 times in mustard, 1.9 times in oil radish. The potassium content per hectare has increased by 2.4 times in phacelia, 3.5 times in mustard, 2.2 times in oil radish.

1.8 kg nitrogen, 0.6 kg phosphor and 2.1 kg potassium have been digested as an effect of 1 kg additional nitrogen application. In mustard the surplus was measured as 2.1 kg nitrogen, 0.4 kg phosphor and 2.6 kg potassium. Regarding oil radish, each additional kilogram of nitrogen has resulted in 1.9 kg nitrogen, 0.3 kg phosphor and 1.4 kg potassium surplus.

The application of low nitrogen rate (50 kg/ha) has resulted in steady green mass and significant amount of uptaken NPK regarding all the three investigated plants, but without additional nitrogen application under such weak habitat circumstances the sufficient amount of biomass was not available.

4. NEW SCIENTIFIC RESULTS

1. The effect of green manure plants on soil condition is unfavourable particularly in dryer years. Due to 12.4-30.2 % higher soil penetration resistance, the tillage of plant covered plots is more difficult compared to unsown control.

2. The more compacted soil condition detected at the time of incorporation of green manure plants ends 3 months after incorporation, and moreover, due to digestion a more favourable – 1.6-18.1 % lower soil penetration resistance, 1.0-9.3 % higher soil humidity was proved – compared to unsown control.

3. Under unfavourable habitat circumstances, one-time green manuring has no yield increasing effect despite the high amount (30-60 t/ha) of green biomass, positive effect can only be achieved after multiple application.

4. The similar climatic parameters have different outcomes on main- and secondcrop green manure plants. The dry matter weight shows close correlation with heat- and water supply relation number, and bioclimatic index, as well as with hidrotermic coefficient.

5. The low rate – 50 kg/ha nitrogen application – significantly promotes the development of secondcrop green manure plants, as increases green mass by 1.9-4.0 times. 1 kg of additional nitrogen results in significant increase in specific biomass weight and NPK content. Without additional nitrogen application under weak habitat circumstances the sufficient amount of biomass is not available.

5. CONSEQUENCES AND RECOMMENDATIONS

The investigations connected with my PhD thesis have been carried out in 2005 in Mélykút on Mezőség soil (Calcic Chernozem), and in Gödöllő-Szárítópuszta Experimental and Study Farm of Szent István University Institute of Crop Production, under weak habitat circumstances on Luvic Calcic Phaeozem soil between 2005-2008. The statements, consequences and recommendations have been drawn on the basis of my investigations.

The penetration resistance of soils of plant covered plots was proved to be significantly higher compared to unsown control. The soil was 12.4-30.2% more compacted under green manure plants compared to control, by taking into consideration the whole 50 cm layer. The soil penetration resistance value and its difference compared to control were higher in deeper layers than close to soil surface. The effect had inceased occurrence in drier seasons. Significant differences have either been found between plant species, but less, compared to control. 2-3 months after incorporation the higher soil penetration resistance was no longer experienced, the positive effect of green manuring expressly prevailed and soil condition became more favourable. The most compacted soil condition was measured (in percentage of control) at the incorporation of plants with strong and rich root systems, but 3 months after incorporation the soil condition became most favourable following those plants.

In case of significant difference regarding soil moisture, the plant stand was measured drier due to higher water consumption compared to control. 2-3 months after incorporation the previously mentioned unfavourable soil condition could no longer be detected, and a more humid soil condition was established after green manure plants. All of the plant species have been proved suitable for green manuring in the investigated production site concerning soil penetration resistance and soil moisture values. As the favourable effect occurs on soil only several months after incorporation, only spring sown crop is advised after secondcrop green manure plants. In this way the digestion of nutrients takes place and the unfavourable effect of instant sowing after incorporation, which is also mentioned in references, can be avoided.

Regarding weed suppression ability, the tendencies mentioned in references prevailed. The cruciferous plants had excellent weed suppression ability, and the competition ability of phacelia, vetch and buckwheat have also been proved appropriate. The melilot and crimson clover could not suppress weeds successfully at the beginning of vegetation due to slower initial development. The crimson clover developed rather weakly under unfavourable habitat circumstances in Gödöllő, though desired green mass 10 t/ha was reached. In crimson clover, the average weed canopy was 21.7 %, but in several experiments exceeded 30 %. Regarding weed suppression ability, except crimson clover, all of the investigated plant species have been proved suitable for green manuring under given production site circumstances.

As long as ensuring nutrient source for bees or other beneficial organisms beside green manuring is also an objective, the production of phacelia and mustard is recommended.

The average root mass was between 5-15 % depending on plant species and year effect, in percentage of total biomass. The only exception was melilot, where root system exceeded 43.7 % of total biomass. Among investigated plant species melilot and oil radish have produced high amount of mass (7.9 t/ha; 5.9 t/ha) with deep rooting system (17.5 cm; 22.2 cm).

The difference in the amount of digested nutrients and biomass was significant either, depending on the year effect. The highest amount of average green mass (61.9 t/ha) was reached by oil radish. The phacelia, mustard and spring rape have produced equally high amount (40 t/ha) of biomass. The nitrogen content per hectare was proved to be highest in pulses, cruciferous plants and phacelia. The digested nitrogen was 150-200 kg per hectare on the average. Regarding phosphor and potassium, the cruciferous plants, phacelia and spring vetch have digested the highest amount of nutrients. The average nutrient content was 60-80 kg/ha for phosphor and 150-200 kg/ha for potassium. Between average dry matter mass and NPK content, medium correlation was found. By considering the amount of biomass per hectare and chemical composition parameters, cruciferous plants, phacelia and spring vetch were proved to be the most favourable green manure plants under given production site circumstances.

During following crop effect investigation in Mélykút, no significant difference was found regarding the amount of yield of oat as following crop. But on the contrary, in the quality of yield, in protein content significant, but lower than 1 % differences were proved between certain treatments. In Gödöllő, no significant differences have been shown regarding the amount and quality of yield in any of the following crops, so I concluded that the instant yield increasing effect of one-time green manuring can not be proved. As a result of green manuring, positive soil chemical and physical processes start certainly, so by repeated applications the improvement of soil condition can be facilitated. On the other hand, by simultaneous investigation of several factors it can be determined that one-time application is advantageous, either.

The low nitrogen rate (50 kg/ha) promoted significantly the increase of biomass and chemical composition parameters in all of the plants in the investigated years, while without nitrogen the plant stand has suffered from pentosan effect. After nitrogen application the nitrogen content per hectare has increased by 4 times in all the 3 plants. The nitrogen active agent promoted phosphor and potassium uptake, either. The phosphor availability per hectare increased by 3 times in phacelia, 2.5 times in mustard, and 2 times in oil radish. The potassium content per hectare has increased by 2 times in phacelia and oil radish, and 3.5 times in mustard.

The application of low nitrogen rate (50 kg/ha) has resulted in steady green mass and significant amount of uptaken NPK regarding all the three investigated plants, but without additional nitrogen application under such weak habitat circumstances the sufficient amount of biomass was not available. On the basis of results, if possible, in all cases, but in case of leaving cereal straw on soil surface, nitrogen application is definitely recommended.

By comparing heat- and water supply relation-, hidrotermic- and bioclimatic index and yield, a close correlation can be determined between the investigated parameters. Accordingly, in view of certain climatic parameters the expected result can be modeled well both in main and secondcrop. In main crop the soonest possible sowing time is advisable, while in secondcropping the later, August sowing time results in higher yields.

On the basis of the results, except crimson clover – though minimum criterias mentioned in references have been fulfilled even by that plant – all of the investigated plants were proved to be suitable for green manuring, but depending on the cultivation purpose, different plant species were found most appropriate.

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