Polish J. of Environ. Stud. Vol. 16, No. 5 (2007), 705-713

Original Research

Effect of Sowing Rate of Italian Ryegrass Drilled into Pea Stubble on Removal of Soil Mineral Nitrogen and Autumn Nitrogen Accumulation by Herbage Yield

B. Kramberger[1]*, A. Gselman[1], S. Kapun[2], M. Kaligaric[3]

[1]University of Maribor, Faculty of Agriculture, Vrbanska 30, 2000 Maribor, Slovenia
[2]Institute of Agriculture, Štefana Kovaèa 40, 9000 Murska Sobota, Slovenia
[3]University of Maribor, Department of Biology, Koroška cesta 160, 2000 Maribor, Slovenia

Received: January 16, 2007
Accepted: May 15, 2007

Abstract

The experiment was carried out in Slovenia in 2002-03 and 2004-05. The experimental design was a randomized completed block, with four replicates. In the summer after pea harvesting, 10, 20 and 30 kg of Italian ryegrass ha^{-1} were drilled into minimally cultivated pea stubble, in which, on average, 12.5 pea grains m^{-2} were left among crop residues. The ryegrass/pea mixtures in our experiments took up the soil mineral nitrogen the most efficiently and accumulated the highest amount of nitrogen in the autumn herbage yield, at a seeding rate of 30 kg drilled Italian ryegrass. The differences among treatments regarding 0–60 cm soil NO_3-N and NH_4-N contents were highest at the first cut and decreased until March of the next year. In order to achieve efficient early and high N uptake of mineralized nitrogen, it is not recommended to lower the sowing rates of Italian ryegrass for drilling into pea stubble to reduce the high cost of catch crop seeds.

Keywords: catch crop, Italian ryegrass, nitrogen uptake, pea stubble, soil nitrogen

Introduction

The increasing concern about environmental protection and the challenge of environmentally sound utilization of natural resources force farmers to take care of optimal utilization of crop residues, among which the residues of field pea (*Pisum sativum* L.) can play an important role.

After ploughdown of crop residues, their organic matter is subjected to mineralization. During this process, nutrients are released. In legumes, N mineralization takes place intensively shortly after ploughdown [1]. In peas, a large amount of biologically fixed N [2-4] is of great importance. The total amount of nitrogen left in harvest residues on the field can exceed 100 kg ha^{-1}. Due to early harvesting and low C/N ratio in harvest residues, intensive N mineralization during early stages of the decomposition of pea residues may occur [4]. If mineralized N is not taken up by the succeeding crop, N can be leached to lower soil layers.

Crops harvested in summer are traditionally [23] followed by catch crops. They can be used for forage, or are grown as catch crops for taking up nitrogen during the autumn and mild winter periods, aiming to contribute nitrogen to the succeeding main crop. One of the catch

*Corresponding author; e-mail: branko.kramberger@uni-mb.si

crops utilizing the retained soil N and at the same time preventing its leaching [5, 6] is Italian ryegrass (*Lolium multiflorum* Lam.), which, owing to its high forage value [7], is also very useful as a forage crop.

After grain pea harvesting, plant residues also contain grains dispersed and left in the field for different reasons (different cultivars, late harvesting, harvesting machines etc.). These grains can also be utilized as seeds for a catch crop to be grown in the late summer months and in the autumn.

The high costs of a catch crop for forage production can be reduced by the introduction of minimal tillage and by simultaneous sowing of the catch crop seeds [8], and by lowering the sowing rates of drilled catch crops, owing to the utilization of the remaining seeds in the pea stubble [9]. Consequently, our experiment aimed at investigating the effects of low sowing rates of drilled Italian ryegrass into pea stubble on the autumn herbage yield of mixtures (ryegrass/pea), on the amount of N taken up by herbage yield, and on soil NH_4-N and NO_3-N content during autumn and winter.

Material and Methods

Soil, Site and Experimental Design

Field experiments were conducted from July 2002 to March 2003 and from July 2004 to March 2005 at Martjanci near Murska Sobota, Slovenia (46° 41’ N, 16° 12’ E, 192 m a. s. l.). The yearly mean air temperature of the area is 10.2°C, the mean monthly minimum is in January (-0.4°C), and the average monthly maximum is in July (20.5 °C). The average annual rainfall in the area is ~ 800 mm. The average precipitation is relatively equally distributed over the whole year [10]. The average monthly air temperatures and amounts of monthly precipitation during the experiment are presented in Table 1. The sum

Table 1. Average monthly air temperature (°C at 2 m) and monthly amounts of precipitation (mm) during the experiments [25].

Month	Average monthly air temperature	Monthly precipitation
March 2002	7.2	20.2
April 2002	9.8	91.3
May 2002	17.5	74.1
June 2002	20.6	85.2
July 2002	21.5	121.2
August 2002	19.9	84.8
September 2002	14.4	45.7
October 2002	10.6	88.3
November 2002	8.4	31.0
December 2002	0.4	65.7
January 2003	-3.5	31.8
February 2003	-3.0	18.3
Average March 2002 – February 2003	10.3	∑ March 2002 – February 2003 757.6
March 2004	4.3	77.3
April 2004	10.7	65.6
May 2004	13.5	67.8
June 2004	18.0	154.6
July 2004	19.8	36.3
August 2004	20.0	97.8
September 2004	14.4	61.5
October 2004	11.8	98.6
November 2004	4.6	38.7
December 2004	1.0	43.1
January 2005	-0.9	9.0
February 2005	-1.6	52.7
Average March 2004 – February 2005	9.6	∑ March 2004 – February 2005 803.0

of temperatures above 0°C was calculated as the sum of mean daily temperatures of the air during the experimental period.

Experiment 1

The soil of the field in which the experimental work in the years 2002-03 was done, was district brown soil, with a pH_{H20} of 6.20 at a soil depth of 0-20 cm. P_2O_5 content of the soil was 19 mg and K_2O content 20.1 mg per 100 g of dry soil (ammonium lactate extraction). After field pea (*Pisum sativum* L. cv. 'Sponsor') for grain production harvested by combine, 12.5 (s.e.m. = 14.7) pea grains m^{-2} were retained as a part of the crop residue in the pea stubble. Immediately after pea harvesting (on 3 July 2002), Italian ryegrass (*Lolium multiflorum* Lam, cv 'Lipo') was drilled into the pea stubble at three different sowing rates (Treatment A = 10 kg ha^{-1}, Treatment B = 20 kg ha^{-1}, and Treatment C = 30 kg ha^{-1}). Sowing rates were chosen according to the sowing rate (20 kg ha^{-1}) that had already been recommended for drilling [9]. The plots were 10 by 30 m. The experimental design was a randomized complete block, with four replicates. Drilling was done simultaneously with minimal tillage, which was performed with a special machine. Rotovating mixed the upper 5 cm soil layer, the pea residue, and the drilled Italian ryegrass. Italian ryegrass/pea mixtures were grown without applying any fertilizer or manure, or using any herbicides. One week before pea harvesting, the soil contained 45.4 kg NH_4 + NO_3-$N_{(0-60\ cm)}$ ha^{-1}, and three weeks after drilling, when the Italian ryegrass was at the very early tillering stage of growth, the soil contained 59.1 kg NH_4 + NO_3-$N_{(0-60\ cm)}$ ha^{-1} (Table 2). The measurement of soil mineral N content three weeks after drilling was made according to the findings that legume N can be quickly mineralized, perhaps even before the succeeding crop has a high demand for it [11].

The first cut was performed on 5 September 2002. At this time the Italian ryegrass was in late tillering, whereas in peas pods green grains were filling. After the first cut, it was mostly the Italian ryegrass alone that continued to grow. The second cut was on 11 November 2002. Herbage yield was obtained by cutting catch crops to a stubble height of 5 cm and weighing the yields from $1m^2$ subplots (nine replicates from each plot). Soil samples for mineral $N_{(0-30cm;\ 30-60cm)}$ (N_{min}) were taken from the plots in September at harvesting, in November 2002, and in March 2003.

Experiment 2

Owing to very unfavourable growing conditions, it was impossible to continue (i.e. repeat) the field experiment in the period from July 2003 to March 2004. Consequently, a continuation of this experiment as Experiment 2 was conducted from July 2004 to March 2005. This experiment was located in the same village, but on another field with a pH_{H20} of 6.90 at a soil depth of 0–20 cm. The P_2O_5 content of the soil was 24.4 mg and K_2O content 29.0 mg per 100 g of dry soil (ammonium lactate extraction). The different years and soil types in the second experiment provide the rationale using the term 'different environments' (see the chapter Results and Discussion). The average air temperatures in the year 2004 were much lower than in the year 2002 (Table 1). Therefore, pre-crop field pea (cv' Sponsor), grown (as for Experiment 1) in rotation after maize, was harvested not earlier than the beginning of August, and the Italian ryegrass (Treatments A, B and C) was drilled into pea stubble not earlier than 13 August 2004. The experimental design, plot size and drilling were the same as described in the previous paragraph. Before the pea harvesting the soil contained 51.7 kg NH_4 + NO_3-$N_{(0-60\ cm)}$ ha^{-1}, and at the end of August, when the Italian ryegrass was in very early tillering, the soil contained 62.5 kg NH_4 + NO_3-$N_{(0-60\ cm)}$ ha^{-1} (Table 2). Because of heavy thunderstorms at the end of July there were more pea grains among the crop residue than in the year 2002. Therefore, the pea plant population was thinned by hand to 12.5 plants m^{-2}. Owing to the late sowing date and colder weather than in 2002 (Table 1), only one cut (on 15 October) was performed in 2004, when the ryegrass was in late

Table 2. Soil NH_4-N and NO_3-N contents (kg ha^{-1}) before and three weeks after drilling.

Soil layer	Before drilling		Three weeks after drilling	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N
Experiment 1				
0 – 30cm	17.2	4.1	21.6	6.0
30 – 60 cm	19.5	4.6	28.2	3.3
0 – 60 cm	36.7	8.7	49.8	9.3
Experiment 2				
0 – 30 cm	20.5	1.9	27.0	1.3
30 – 60 cm	26.3	3.0	30.1	4.1
0 – 60 cm	46.8	4.9	57.1	5.4

tillering and the peas pods were swelling. Soil samples for $N_{min\ (0\text{-}30cn;\ 30\text{–}60cm)}$ determination were taken from the plots in October at the time of harvesting, in November 2004 and in March 2005.

Analyses

Soil samples were frozen immediately. Later, soil samples were analyzed for NH_4-N and NO_3-N (N_{min}) by colorimetric methods analysis after extraction with 2 M KCl [24].

Dry matter yield was obtained by drying samples at 70°C for 24 h in a forced-draught oven, and weighed. In the subsamples, organic matter content was determined after ashing at 500°C. The herbage was analyzed for N content by Kjeldahl methods. 'In vitro' organic matter digestibility was determined using the two-stage technique of Tilley and Terry [26]. Net energy for lactation (NEL) was calculated using equation [7]:

NEL (MJ) = 0.6 x (1 + 0.004 x (q – 57)) x metabolize energy (ME) (MJ).

Analyses of variance were carried out on yield, its components, nitrogen uptake by plants and $N_{min\ (0\text{-}30,\ 30\text{-}60,\ 0\text{-}60\ cm)}$, separately for each experiment. An F-ratio with $P \leq 0.05$ was regarded as statistically significant.

Results and Discussion

Soil Mineral Nitrogen

In both experiments different sowing rates (treatments) of Italian ryegrass drilled into the pea stubble significantly affected NO_3-N and NH_4-N contents in the 0–60 cm soil layer at the first cut after summer drilling (Table 3). Generally, the lowest contents were obtained by Treatment C and, on account of the lowest sowing rate, the highest soil N contents were obtained as predicted by Treatment A. Because of N uptake by catch crops, the values of NO_3-N content in November were generally lower than at first cut, and the lowest were in March of the next year. On the contrary, in both experiments the values of NH_4-N content in November and in March were slightly higher than at the first cut (Table 3), which could be the result of N mineralization to NH_4 only, while on account of low temperatures, mineralization was not continuing to NO_3, as is the process explained by Killhan [27].

In Experiment 1 (Table 3), where intensive uptake of soil N was effected during the vigorous growth of the catch crop, differences among treatments in NO_3-N content were highest at the first cut (23.6 kg ha^{-1} at the Treatment A; 8.1 kg ha^{-1} at the Treatment C) and diminishing until March of the next year when differences were no longer significant. In Treatment A of the second experiment the soil NO_3-N content remained high in November and even in March of the next year, when soil NO_3 content differed significantly between Treatments A (43.1 kg ha^{-1}) and B and C (32.9 kg ha-1), which means that N uptake by Treatment A during the late autumn did not increase to the level of N uptake of Treatments B and C.

What is notable are the differences in soil N content between experiments, where values of NO_3-N content and consequently of total mineral N are much higher in Experiment 2, while values of NH_4-N content are higher in Experiment 1. Higher values of NH_4-N content in Experiment 1 could be explained by lower soil pH value [12], while differences in NO_3-N content could be caused by different environments and consequently by very different growth of catch crops, which resulted in different uptake of soil N (Table 4). In Experiment 2, the NO_3-N content (61.0 kg ha^{-1}) and total mineral N content (64.8 kg ha^{-1}) at first cut in Treatment A were even higher than three weeks after drilling (57.1 kg ha^{-1}; 62.5 kg ha^{-1}). This means that N mineralization was higher than soil N removal by the ryegrass/pea mixture of this treatment.

As shown in Table 3, the NO_3-N content in the 0–30 cm soil layer was generally lower than in the 30–60 cm layer at first cut. But until March of the next year the content of NO_3-N in the 30–60 cm soil layer generally decreased below the values for the upper layer. The results can be explained by intensive nitrogen absorption by Italian ryegrass and by field pea. Italian ryegrass/pea mixtures in the first cut and Italian ryegrass after the first cut were effectively taking up released nitrogen. Therefore, despite mineralization, the content of NO_3 in the 0–30 cm soil layer did not increase over the values observed three weeks after drilling. The exception was Treatment A in Experiment 2, where the very low sowing rate of drilled Italian ryegrass (10 kg ha^{-1}) was too low to produce enough effective catch crops for sufficiently early effective N absorption. Effective NO_3 absorption from the top soil layer could result in the prevention of downward NO_3 movement and a lowering of NO_3-N content in the 30–60 cm soil layer. This explanation is in agreement with Thorup-Kristensen [13], who stressed that early N uptake from the upper soil layers reduces the downward movement of NO_3. In their experiments Italian ryegrass reduced NO_3 content in the 1–1.5 m soil layer by approximately 50%, even though it would have had very few roots in this soil layer.

Herbage Yield and Nitrogen Uptake

Owing to very favourable growing conditions in the year 2002, the previous crop, field pea for grain production, which yielded 3250 kg of dry grain and 3780 kg of straw ha^{-1}, was harvested at the beginning of July. The favourable growing conditions also continued through the summer and autumn. More than 340 mm of precipitation was equally distributed over the period from the beginning of July to the end of October, and the sum of temperatures above 0°C in this period exceeded 2000°C. Consequently, in Experiment 1 the sum of temperatures above 0°C from the date of drilling (3 July) to the date of the first cut (5

Table 3. Effect of sowing rates of drilled Italian ryegrass into minimally cultivated pea stubble on the soil NH_4-N and NO_3-N contents (kg ha^{-1}) in soil layers 0-30 cm, 30–60 cm and 0–60 cm.

N_{min} in soil layer			Treatment		
			A	B	C
Experiment 1					
1st cut	NO_3-N	0 – 30 cm	10.8[a]	8.5[b]	4.0[c]
		30 – 60 cm	12.8[a]	8.9[b]	4.1[c]
		0 – 60 cm	23.6[a]	17.4[b]	8.1[c]
	NH_4-N	0 – 30 cm	8.8[a]	9.9[a]	4.8[b]
		30 – 60 cm	6.1[a]	6.4[a]	4.0[b]
		0 – 60 cm	14.9[a]	16.3[a]	8.8[b]
November	NO_3-N	0 – 30 cm	10.8[a]	6.8[b]	7.9[b]
		30 – 60 cm	7.8	5.4	8.6
		0 – 60 cm	18.6[a]	12.2[b]	16.5[ab]
	NH_4-N	0 – 30 cm	13.3[a]	11.5[a]	7.9[b]
		30 – 60 cm	6.6	7.4	5.5
		0 – 60 cm	19.9[a]	18.9[a]	13.4[b]
March	NO_3-N	0 – 30 cm	8.3	8.3	9.0
		30 – 60 cm	6.6	5.5	6.2
		0 – 60 cm	14.9	13.7	15.2
	NH_4-N	0 – 30 cm	8.6	9.7	10.4
		30 – 60 cm	7.5[a]	7.4[a]	5.5[b]
		0 – 60 cm	16.1	17.1	15.9
Experiment 2					
1st cut	NO_3-N	0 – 30 cm	27.4	23.6	23.5
		30 – 60 cm	33.6	28.8	26.3
		0 – 60 cm	61.0[a]	52.4[b]	49.8[b]
	NH_4-N	0 – 30 cm	1.3	0.9	1.3
		30 – 60 cm	2.5[a]	2.7[a]	1.8[b]
		0 – 60 cm	3.8	3.6	3.1
November	NO_3-N	0 – 30 cm	26.7[a]	16.4[b]	20.6[ab]
		30 – 60 cm	28.3[a]	20.3[b]	16.8[b]
		0 – 60 cm	55.0[a]	36.7[b]	37.4[b]
	NH_4-N	0 – 30 cm	3.3[ab]	4.5[a]	2.5[b]
		30 – 60 cm	3.7	4.0	4.1
		0 – 60 cm	7.0	8.5	6.6
March	NO_3-N	0 – 30 cm	23.5[a]	17.8[b]	17.1[b]
		30 – 60 cm	19.6	15.1	15.8
		0 – 60 cm	43.1[a]	32.9[b]	32.9[b]
	NH_4-N	0 – 30 cm	4.5	4.5	5.0
		30 – 60 cm	3.3	2.8	3.8
		0 – 60 cm	7.8	7.3	8.8

Means followed by different letters in the same row are significantly different ($P \leq 0.05$, Tukey HSD test).

A – 10 kg of drilled Italian ryegrass; B – 20 kg of drilled Italian ryegrass; C – 30 kg of drilled Italian ryegrass into minimally cultivated pea stubble.

September) was 1280°C and from the date of the first cut to the date of the second cut (11 November) was 730°C. As a result of favourable growing conditions, yields from all treatments in Experiment 1 exceeded 2.5 t herbage DM ha^{-1} in the first cut and 1.1 t ha^{-1} in the second cut. Differences in amounts of herbage DM yield between Treatments A and B were not significant (Table 4), but herbage DM yields of Treatment C were significantly higher (3.29 t ha^{-1} in the first cut and 1.49 t ha^{-1} in the second cut) than that of Treatments A and B. In Experiment 1, pea seeds left on the field after pea harvesting contributed 40% of the herbage DM yield of the first cut (Table 4). Differences among the Treatments in pea content in botanical composition were not significant, but the Treatments differed significantly in the content of ryegrass and other plants (weeds), where the higher seeding rate of drilled Italian ryegrass (30 kg ha^{-1}) resulted in a higher proportion of ryegrass in the yield and a lower proportion of weeds. After the first cut, only Italian ryegrass continued to grow and was the only composition of the second cut yield. Yields from the first cut were high enough to be used for forage. Despite the different botanical compositions of the Treatments, we did not find statistically significant differences ($P \leq 0.05$) among them in net energy for lactation, in 'in vitro' organic matter digestibility or in crude protein content (Table 4). Nitrogen uptake by herbage yield differed significantly among the Treatments and was highest in Treatment C (128.4 kg ha^{-1} = sum of the first cut and the second cut).

In Experiment 2 the average air temperatures during the spring and early summer of the year 2004 were much lower than in the year 2002 (Table 1). The previous crop of Experiment 2, pea for grain, which yielded 2350 kg of dry grain and 3800 kg of straw ha^{-1}, was harvested in August. Owing to the later drilling of Italian ryegrass into minimally cultivated pea stubble than in the year 2002, and also because of the colder autumn, only one cut of the catch crop was obtained in Experiment 2. The sum of temperatures above 0°C from the date of drilling (13 August) to the date of harvesting (15 October) was only 950°C. This was lower than the sum of temperatures for the first cut in the year 2002, which resulted in an earlier cut, if we take into account the growth stage of the catch crop at harvesting. Consequently, the highest forage dry matter yield obtained by Treatment C was only 1.62 t DM ha^{-1}, and differed significantly from Treatments A (1.39 t DM ha^{-1}) and B (1.34 t DM ha^{-1}). Proportions of pea in the botanical composition were between 0.40 and 0.47 and proportions of ryegrass were between 0.45 and 0.53. However, differences in botanical composition among the Treatments were not significant, as they were not significant among them in the components of forage quality, which was generally higher than in Experiment 1 (Table 4), especially if we take into account crude protein content. Owing to the low herbage DM yields, nitrogen uptake by herbage yield was only between 49.0 (Treatment B) and 55.2 kg N ha^{-1} (Treatment C).

Discussion

Differences among Treatments A, B and C in soil NO_3-N and NH_4-N and the diminishing of differences in

Table 4. Effect of sowing rates of drilled Italian ryegrass into minimally cultivated pea stubble on nitrogen uptake by herbage, herbage dry matter yield, and on botanical composition and forage quality of the yield of first cut of Italian ryegrass/pea mixtures.

Sowing rate	First cut yield								Second cut yield	
	Botanical composition			DMY	CP	IVOMD	NEL	N uptake	DMY	N uptake
	Ryegrass	Pea	Other plants							
Experiment 1										
A	0.39^{b}	0.42	0.19^{a}	2.60^{b}	186	0.68	5.1	77.4^{b}	1.18^{b}	26.8^{b}
B	0.55^{a}	0.41	0.04^{b}	2.83^{b}	175	0.71	5.4	79.2^{b}	1.30^{b}	30.6^{ab}
C	0.56^{a}	0.38	0.06^{b}	3.29^{a}	167	0.73	5.4	87.9^{a}	1.49^{a}	40.5^{a}
Experiment 2										
A	0.50	0.46	0.04	1.39^{b}	226	0.73	5.3	50.2^{ab}	-	-
B	0.45	0.47	0.08	1.34^{b}	229	0.74	5.2	49.0^{b}	-	-
C	0.53	0.40	0.07	1.62^{a}	213	0.74	5.4	55.2^{a}	-	-

Means followed by different letters in the same column for the same treatment in the experiment are significantly different ($P \leq 0.05$, Tukey HSD test).

DMY – dry matter yield (t ha^{-1}); CP – crude protein content (g kg^{-1}DM); IVOMD – 'in vitro' organic matter digestibility; NEL – net energy for lactation (MJ kg^{-1} DM): N uptake – nitrogen uptake by herbage yield (kg ha^{-1}).

A – 10 kg of drilled Italian ryegrass; B – 20 kg of drilled Italian ryegrass; C – 30 kg of drilled Italian ryegrass into minimally cultivated pea stubble.

soil mineral N content among Treatments from the 1st cut to March show that the mineralized N in the soil cannot be taken up fast enough and in high enough amounts by drilling low sowing rates of Italian ryegrass into the pea stubble. The number of tillers of Italian ryegrass at early growth stages and the number of pea plants were too low to uptake all available N in the soil. However, at later growth stages, with the formation of many new tillers of Italian ryegrass, the catch crop is dense enough to uptake more mineralized N. The differences among treatments with low and high sowing rates therefore diminished through late autumn and early spring. Undoubtedly, the catch crop accumulates the mineralized N released from the crop residues after harvesting, which has been reported by many researchers [2, 4, 13]. Therefore we did not include the treatment without catch crop in the experiment.

Our experiment was based on utilizing pea grains left on the field after harvesting for a catch forage crop mixture of Italian ryegrass/pea. Such a mixture can be successfully obtained only by drilling Italian ryegrass into minimally cultivated pea stubble. This is why different tillage systems and comparisons to no tillage were not studied in the experiment. Some researchers [14, 15] did not find strong influences of tillage on mineral soil N, but others proved that different tillage systems [16, 17] and the time of tillage can have strong effects on soil nitrogen mineralization [18] and soil moisture content in a dry summer [19]. On the other hand, Herzog and Konrad [16], showed that tillage effects on N_{min} and NO_3 concentrations in the soil are hardly detectable if the tillage is combined with the catch crop, owing to the uptake of mineralized N. However, N uptake is affected by different tillage systems [20].

Since Italian ryegrass develops the majority of its roots in the upper layers of the soil, it is at first sight not appropriate for N uptake from lower soil layers. More appropriate are considered to be plants with rapid lengthening of roots and deeper root systems, e.g. cruciferous crops [13] such as winter rapeseed (*Brassica napus*), fodder radish (*Raphanus sativus*) and white mustard (*Sinapis alba*). However, in our experiments and in the experiments carried out by Thorup-Kristensen [13], the Italian ryegrass nevertheless reduced the N content in the lower soil layers. The reason for this lies in its fast growth after sowing and early N uptake from upper soil layers, which reduce the downward movement of NO_3 and thereby reduce the NO_3 concentrations below its rooting depth. The sowing rate of Italian ryegrass in Thorup-Kristensen's experiment was 20 kg ha. On the basis of the results of our experiment, it can be concluded that the Italian ryegrass sown at the sowing rate of 30 kg ha^{-1}, at early growth stages takes up even more N and prevents its downward movement to an even larger extent. This is in agreement with Thorup-Kristensen's [13] report stating that when catch crops are grown to prevent N leaching losses, it is important that they are able to decrease the soil NO_3-N pool to very low levels. However, if compared to cruciferous crops, the Italian ryegrass, in addition to having a high forage value, in the climatic conditions of Central Europe can be a more appropriate catch crop because of its good wintering (taking up N from soil in mild winter periods). From the organic farming point of view, it also has an advantage over cruciferous crops because no application of insecticides is required for its production, which, however, it is often necessary to use against *Phyllotreta* sp. for cruciferous crops sown in late summer in some areas of Central Europe.

Nevertheless, high N uptake in our experiment cannot be ascribed only to Italian ryegrass as the catch crop, since our results are obtained by mixtures of drilled Italian ryegrass and self reseeded peas. As reported by Ilgen and Stamp [21], the main root length of pea sown as a catch crop can be as long as the main root lengths of mustard and radish or even longer with a high nitrogen supply. From this point of view, it seems that such Italian ryegrass/pea mixtures could be very effective in soil N uptake after grain pea harvesting.

In the case of the relatively early sowing date of drilled Italian ryegrass (beginning of July), the first cut of the Italian ryegrass/pea mixture in optimal growth conditions should be performed as early as the beginning of September. This is the only way to achieve maximal exploitation of the self-reseeded pea plants and the growth potential of drilled Italian ryegrass for economically efficient utilization of forage yield [22]. On stockless organic farms, catch crop yield cannot be utilized as forage. In such cases, the catch crop can be intended only for dry matter production and for taking up N during the autumn and mild winter periods, in order to prevent N leaching. If cut in September, the herbage yield should be composted or mulched. In the latter case the yield would remain in the field. It is a question of to what extent the Italian ryegrass would be able to take up the further mineralized N from the remaining pea residue and mineralized N from additional decomposing organic matter from the mulched catch crop. If only autumn or spring ploughdown is performed, it can be estimated that a different dynamic of dry matter and N accumulation would be achieved. This would almost certainly result in different NH_4-N and NO_3-N contents in the soil. In order to avoid N leaching, it is undoubtedly better that at least part of the catch crop yield is removed from the field and, if at all possible, used for forage.

Our experiments were executed in three extremely different meteorological years. In the first year (Experiment 1) growing conditions were very favourable for catch crop production. In the second year drought accompanied by high temperatures destroyed pea as a main crop and consequently we could not continue the experimental work. And finally, owing to lower air temperatures than in the previous years, in the third year the pre-crop was harvested not earlier than in the middle of August (Experiment 2). Late catch crop sowing and low temperatures during the autumn as well resulted in low catch crop herbage yields and low mineralized soil N uptake by plants. On the other hand, the later sowing date and lower temperatures are obviously the main reason, that simple calculation of net mineralization (N taken up by herbage + soil N_{min} at the end of experiments – soil N_{min} at the beginning of experiments) shows much lower soil N mineralization in Experiment 2 than in Experiment 1. However, data on net N mineralization are not presented in the tables, because two items of important data for the net N mineralization calculation were not measured (i.e. N concentration in roots of cover crops and N leaching).

In this part of Europe unpredictable and very changeable weather during the summer months causes troubles in planning catch crop production. Consequently, farmers must continuously adapt catch crop management to actual conditions. Our experiments have proved that with a sufficiently high sowing rate of drilled Italian ryegrass into pea stubble and minimal tillage it is possible to utilize pea grains dispersed as residue after harvesting for a very productive catch crop forage mixture (Italian ryegrass/pea), which also efficiently takes up large amounts of mineralized N from the soil. However, results are more significant for favourable growing conditions. For practical catch crop management and for environmentally sound farming, further research is necessary in the field of optimising catch crop production after pea for grain as main production, which left a large amount of organic N in the field. Research should also include other catch crops for forage (not only Italian ryegrass), combined with different tillage systems.

References

1. SMITH S.J., SHARPLEY A.N. Soil Nitrogen Mineralization in the Presence of Surface and Incorporated Crop Residues. Agron. J. **82**, 112, **1990**.
2. JENSEN E. S. Nitrogen Accumulation and Residual Effects of nitrogen Catch Crops. Acta Agric. Scand**.** **41**, 333, **1991**.
3. KUMAR K., GOH K.M. Biological nitrogen fixation, accumulation of soil nitrogen and nitrogen balance for white clover (*Trifolium repens*, L.) and field pea (*Pisum sativum* L.) grown for seed. Field Crops Res. **68** (1), 49, **2000**.
4. MAIDL F.X., SUCKERT J., FUNK R., FISCHBECK G. Standorterhebungen zur Stickstoffdynamik nach Anbau von Körnerleguminosen. J. Agron. and Crop Sci. **167** (4)**,** 259, **1991**.
5. SVENSSON K.S., LEWAN E., CLARHOLM M. Effects of Ryegrass Catch Crop on Microbial Biomass and Mineral Nitrogen in an Arable Soil during Winter. Swedish J. agric. Res. **23**, 31, **1994**.
6. THOMSEN I.K., CHRISTENSEN B.T. Nitrogen conserving potential of successive ryegrass catch crops in continuous spring barley. Soil use manage. **15**, 195, **1999**.
7. DLG – Futterwerttabellen Wiederkäuer. Universität Hohenheim – Dokumentationsstelle. DLG Verlag, Frankfurt, **1999**.
8. KRAMBERGER B. Ozelenitev tal v kmetijstvu. Fakulteta za kmetijstvo UM, Maribor, pp 56-60, **2003**.
9. KAPUN S., ABRAHAČ PANIČ Z., JERIČ D., SLAVIČ A. Možnosti vkljuèevanja mešanice silirane rastline krmnega graha in mnogocvetne ljuljke v prehrano plemenskih svinj. In: Proceedings of the conference on nutrition of domestic animals (Ed Pen A.), Zadravec-Erjavec days'. ŽVZ Murska Sobota, pp 91-102, **1998**.
10. STATISTICAL YEARBOOK. Eds Kuhar de Domizio A., Novak A., Statistical Office of the Republic of Slovenia, Ljubljana**. 2002**.
11. CREAMER N.G., BALDWIN K.R. Summer Cover Crops. 2/99 – HIL-37, http://www.ces.ncsu.edu/depts/hort/hil/hil-37.html, **1999**.
12. KYVERYGA P.M., BLACKMER A.M., ELLSWORTH J.W., ISLA R. Soil pH Effects on Nitrification of Fall-Applied Anhydrous Ammonia. Soil Sci. Soc. Am. J. **68**, 545, **2004**.
13. THORUP-KRISTENSEN K. Are differences in root growth of nitrogen catch crops important for their ability to reduce soil nitrate-N content, and how can this be measured? Plant Soil. **230**, 185, **2001**.
14. SOON Y.K., ARSHAD M.A. Tillage and liming effects on crop and laible soil nitrogen in an acid soil. Soil Till. Res. **80** (1-2), 23, **2005**.
15. VAUGHAN J.D., HOYT G. D., WOLLUM A. G. Cover Crop Availability to Conventional and No-Till Corn: Soil Mineral Nitrogen, Corn Nitrogen Status, and Corn Yield. Commun. Soil Sci. Plant Anal. **31** (7-8), 1017, **2000**.
16. HERZOG H., KONRAD R. Nitrogen Movement in a Arable Sandy Soil and Ways of Reducing Nitrogen Losses – Preliminary Results. J. Agron. and Crop Sci. **169**, 135, **1992**.
17. SAINJU U.M., SINGH B.P., WHITEHEAD W.F. Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. Soil Till. Res. **63**, 167, **2002**.
18. STENBERG M., ARONSSON H., LINDEN B., RYDBERG T., GUSTAFSON A. Soil mineral nitrogen and nitrate leaching losses in soil tillage systems combined with a catch crop. Soil Till. Res. **50**, 115, **1999**.
19. SARRANTONIO M., SCOTT T.W. Tillage Effects on Availability of Nitrogen to Corn Following a Winter Green Manure Crop. Soil Sci. Soc. Am. J. **52**, 1881, **1988**.0
20. KUMAR K., GOH K.M. Management practices of antecedent leguminous and non-leguminous crop residues in relation to winter wheat yields, nitrogen uptake, soil nitrogen mineralization and simple nitrogen balance. Eur. J Agron. **16** (4), 295, **2002**.
21. ILGEN B., STAMP P. Nitrogen Effects on Seedling Roots of Crucifers and Legumes. J. Agron. and Crop Sci. **170**, 18, **1993**.
22. ROZMAN Č., PAŽEK K., JANŽEKOVIČ M. Feasibility analysis of three different catch crops for milking cow animal feed. Krmiva **68** (4), 167, **2006**.
23 VOS J., van der PUTTEN P.E.L. Field observations on nitrogen catch crops. I. Potential and actual growth and nitrogen accumulation in relation to sowing date and crop species. Plant Soil. **195**, 299, **1997**.
24. KEENEY D.R., NELSON D.W. Nitrogen – inorganic forms. In: Methods of Soil Analysis. (Eds Page, A.L., Miller R.H.,

Keeney D.R.), 2nd ed., American Society of Agronomy, Madison, pp 643-698, **1982**.
25. ENVIRONMENTAL AGENCY OF THE REPUBLIC OF SLOVENIA. Meseèni bilteni. http://www.arso.gov.si/o agenciji/knji~znica/publikacije/bilten.htm, **2006**.
26. TILLEY M., TERRY R. A two stage technique for the in vitro digestion of forage crops. J. Brit. Grass. **18**, 104, **1963**.
27. KILLHAM K. Soil Ecology. Cambridge University Press, Cambridge, pp 28-31, **1994**.