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Effect of winter cover crops on the dynamics of soil mineral nitrogen and yield and quality of Sudan grass [*Sorghum bicolor* (L.) Moench]

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Abstract

The experiment was carried out in the Vojvodina province, Serbia between 2004-05 and 2005-06. The objectives of this study were to assess the effect of cover crops grown as green manure on the dynamics of NO_3-N in the soil and on the yield and quality of Sudan grass. Three sole cover crops and one mixture were included in the experiment, namely wheat (*Triticum aestivum* L.), field pea (*Pisum sativum* L.), mixture of field pea and wheat and oilseed rape (*Brassica napus* L.), as well as mineral fertilization treatments, namely 40 kg N ha^{-1} (N_1) and 80 kg N ha^{-1} (N_2) and an unfertilized control. Cover crops and N treatment significantly affected the soil NO_3-N content. In the treatments with field pea and its mixture with wheat, the contents of symbiotically fixed N were 140.97 and 53.9 kg N ha^{-1}, respectively. The highest nitrogen contribution was in the field pea (165.26 kg N ha^{-1}), while the control and N_1 had negative N balances (- 59.48 kg N ha^{-1} and -25.40 kg N ha^{-1}, respectively). The yields of Sudan grass following the addition of N_2 and field pea cover crop were higher than the control, while they were on the same level as the control after cover crops of oilseed rape and the mixture of wheat-field pea. Wheat produced the lowest yield of Sudan grass, due to nitrogen deficiency after ploughing-in. The N_2 treatment had the highest crude protein content at the first cut and the lowest at the second cut.

Key words: cover crop; quality; soil mineral nitrogen; Sudan grass; yield.
Abbreviations: ARNS – apparent N remaining in the soil, BDMY – biomass dry matter yield, DM – dry matter, FP – field pea, FP/W – mixture of field pea and wheat, Nf – amount of N applied through NH_4NO_3, Ni – mineral N content in the soil at the time of Sudan grass sowing, Nmin(legume) – amount of mineral N in soil under the legume, Nmin(non-fixing control) – amount of mineral N in soil under the non-legume, Npot – amount of mineral N which will be released by the mineralization of organic matter in the soil during vegetative growth, Nsymb – amount of symbiotically fixed N, Ntg – total need for nitrogen, Nyield(legume) – amount of N accumulated by legume, Nyield(non-fixing control) – amount of N accumulated by the non-legume, OSR – oilseed rape, W – wheat.

Introduction

The use of cover crops is one measure that has been taken in agricultural production in order to increase environmental protection and to encourage sustainable use of natural resources. Cover crops offer many benefits to sustainable agriculture (Dabney et al., 2001). The integration of cover crops into cropping systems brings costs and benefits, both internal and external to the farm (Snapp et al., 2005). In annual cropping systems, cover crops are often included to maximize benefits such as biomass and nitrogen production. The main benefits of winter cover crops can be gained by careful selection of appropriate plant species (Guldan and Martin, 2003). Thus, fitting a cover crop into the sequence of a crop rotation must be taken into consideration. Fast-growing, drought-tolerant cover crops that require minimal management are preferred. Cover crops with fast germination and good seedling vigour are usually chosen because of their ability to compete with weeds (Olorunmaiye, 2010). Also, species with the potential to reduce pest populations should be chosen, while those that harbour harmful diseases or pests of the cash crops should be avoided (Dabney et al., 2001; Ilnicki and Enache, 1992). Species from the family of grasses (*Poaceae*) and crucifers (*Brasicaceae*) are commonly used as winter cover crops. They are efficient in the uptake of residual nutrients from the soil (Kuo and Jellum, 2002). If soil pests are a major yield limiting factor in cash crop production, then the use of brassica cover crops should be considered. Cereal cover crops produce the largest amount of biomass and should be considered when the goal is to rapidly build soil organic matter. Legume-cereal mixtures show great potential over a wide range of niches (Snapp et al., 2005). According to Sainju et al. (2001) bi-culture legume-cereal cover cropping may enhance above and below ground biomass yield and C and N content. The increase in C and N supply to the soil has the potential to improve soil quality and crop productivity compared with monoculture cover crop species. For ecological reasons, legumes (*Fabaceae*) are gaining increasing importance (Brandsaeter and Netland, 2000). Legume cover crops can be easily included in a crop rotation and, in contrast to grasses and crucifers, contribute additional N to the nutrient cycle by symbiosis (Evans and Taylor, 1987). Most of the symbiotic N is used for legume growth (Peoples et al., 1995) and is therefore accumulated in organic matter. Some of this N can be used later as animal feed in the form of protein in herbage (Kramberger et al., 2007) while the rest of the accumulated N can be taken up by subsequent crops after ploughing-in and mineralisation of the organic matter (Voughan et al., 2000; Andraski and Bundy, 2005). After mineralisation of ploughed - in cover crops,

Table 1. Basic chemical characteristics of the soil

Depth (cm)	pH KCl	pH H_2O	$CaCO_3$ (%)	Humus (%)	N total (%)	Al-P_2O_5 mg $100g^{-1}$	Al-K_2O mg $100g^{-1}$
0-30	7.41	7.90	5.61	2.97	0.196	17.99	21.00
30-60	7.50	7.95	7.52	2.05	0.185	13.45	18.23

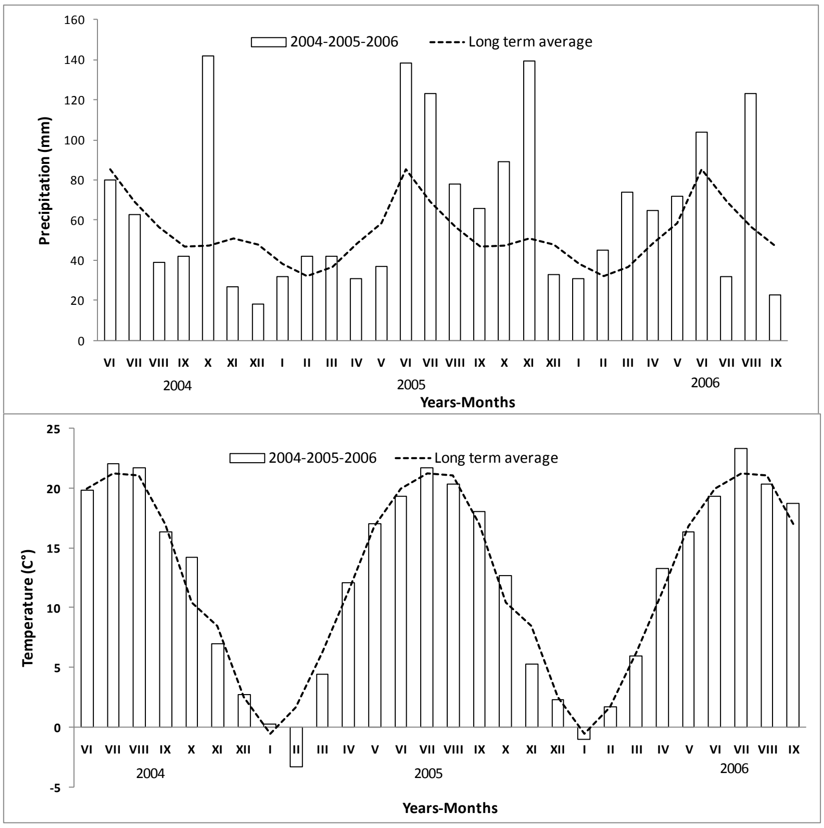

Fig 1. Total monthly precipitation and monthly air temperature for hydrological years (2004–2006)

accumulated N is available for subsequent crops in the field crop rotation. When a legume cover crop is incorporated into the soil, a substantial amount of nitrogen is usually mineralised within a few weeks. Nitrogen continues to mineralise in ensuing weeks as the organic matter decomposes (Snapp et al., 2005). Recently, emphasis has been placed on the uptake of soil mineral N which could otherwise be leached as NO_3 into deeper soil layers and ground water (Shipley et al., 1992; Logsdon et al., 2002), lost during nitrification as NO and N_2O, or denitrified as N_2 (Jenkinson, 2001). The contribution of symbiotically fixed N by winter legume cover crops to the nitrogen cycle in field rotation can exceed one hundred kilos N per hectare (Mueller and Thorup-Kristensen, 2001; Gselman and Kramberger, 2008) with beneficial effects on the succeeding crop in the rotation (Sainju and Singh, 2001; Hanly and Gregg, 2004). The succeeding crop recovery of N was estimated from 10-36% of total N in legume residues (Ranells and Wagger, 1996; Peoples et al., 2004; Tonitto et al., 2006). Most non-legume cover crops do not fix nitrogen, but they can affect soil nitrogen availability. Small grains can absorb large quantities of nitrogen from the soil, thereby reducing the potential for nitrate leaching. Because of the high carbon-to-nitrogen (C/N) ratio of grasses, their residues decompose slowly, and soil nitrogen availability may be substantially decreased following their incorporation into the soil. Several species in the *Brassicaceae* family also readily take up nitrogen. Due to lower C/N ratios, however, these species decompose and release their absorbed nitrogen into the soil more rapidly than grasses (Dean and Weil, 2009). As an annual summer grass, Sudan grass (*Sorghum bicolor* (L.) Moench) serves as a low input forage crop. Compared with maize (*Zea mays* L.), Sudan grass has a requirement for higher temperatures, but significantly lower requirement for water (Torrecillas et al., 2011). This is important for the production of these crops under the ecological conditions of the Vojvodina province where they are grown under rain-fed conditions (Ćupina et al., 2007). The practice of cover cropping in the Vojvodina province has gained importance in view of the decline of animal production and the related reduced availability of organic fertilizers. Fertile soils such as chernozem have suffered a significant reduction in humus content, in some cases as much as 50%, which justifies the introduction of cover cropping in commercial production. The main objective of this study was to assess the effects of different cover crops grown as green manure on the dynamics of NO_3-N in the soil, before and after ploughing-in of the cover crops, and the soil of Sudan grass grown as a sole crop. The additional goal was to assess the effect of the cover crops on the yield and quality of Sudan grass.

Table 2. Cover crops species and agronomic management

Code	Common name Latin name	Cultivar	Sowing rate (kg ha^{-1})
W	Wheat (*Triticum aestivum* L.)	Pobeda	250
FP	Field pea (*Pisum sativum* L.)	NS-Pionir	150
FP/W	Mixture of field pea and wheat	-	120 + 30
OSR	Oilseed rape (*Brassica napus* L.)	NS-Bikovo	8

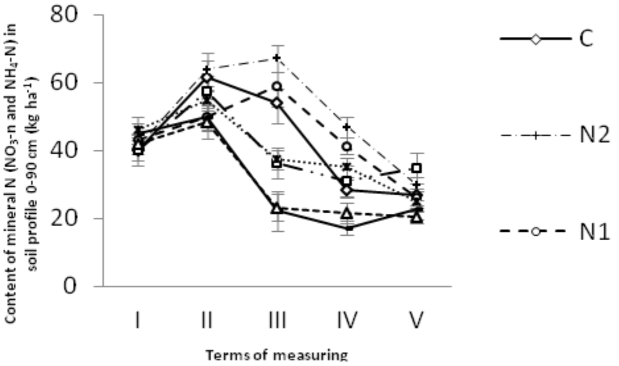

Fig 2. Dynamic of mineral nitrogen (NO_3-N and NH_4-N) in the soil during the trial period (average of 2005 and 2006). Bars represent standard error of means.

Results and discussion

Nitrate content in the soil

Cover crops and N treatment significantly affected the soil Nmin content. At the first two sampling dates, soil nitrate content was higher in the non-cropped treatments i.e. in the control (bare fallow) and the mineral fertilization treatments (Fig. 2). This can be explained by the fact that, when sampled, these treatments had no plants that could uptake N from the soil. The lowest soil Nmin content was in winter wheat and its mixture with field pea as a consequence of intensive N uptake by the plants. At the second sampling date, the soil Nmin content in the treatments with cover crops was lower in relation to the initial status because of Nmin uptake by the cover crops themselves. In the treatments in which cover crops had not been grown prior to the second sampling date, Nmin content was increased due to mineralization of organic matter (Fig. 2). The differences in Nmin content among these treatments may be attributed to the natural heterogeneity of the analysed soils. After the first cut of Sudan grass, the Nmin content was lower in all treatments than those after the cover crop had been ploughed-in, due to significant removal of N by the Sudan grass yield (Table 3). The treatment with winter field pea had a higher Nmin content at the time of first cut than the control treatment although the former had the highest yield of Sudan grass as well as the highest N removal. The higher Nmin content in the treatment with field pea compared with the control was a result of intensive mineralization after the ploughing-in of the legume crop (Chavez et al., 2004; Boldrini et al., 2006). The lowest Nmin content at the time of first cut were found in those treatments with winter wheat and crop mixture, in which nitrogen immobilization and decrease occurred after organic matter introduction, affecting the Sudan grass yield at the end of the growing season (Fig. 2). At the time of the last soil sampling date (after the second cut), the highest Nmin content was found in the treatment with winter field pea, with all treatments except those with field pea and crop mixture having a lower Nmin content than previously. The lowest soil Nmin content was recorded in the treatments with winter wheat, crop mixture and the crucifer, which also had the lowest yields of Sudan grass. Significant correlation (r = 0.86**) was established between soil Nmin content at the end of the growing season (after the second cutting) and the total yield of Sudan grass. The correlation between soil NO_3-N content at the time of ploughing-in and the first cut on one side and yield on another were not statistically significant.

Cover crops yield and N accumulation

Based on the two year average, the legume cover crop (FP) achieved the highest dry matter (DM) and N yield (Fig. 3). This is consistent with results obtained by Mihailović et al. (2007). However, Snapp et al. (2005) reported that cereal cover crops produce the largest amount of biomass and should be considered when the goal is to rapidly build soil organic matter. At the same time, legume cover crops are the most reliable means of enhancing cash crop yields compared with fallow or other cover crop species. Nevertheless, DM yields and nitrogen accumulation in above ground biomass of FP/W were much higher than those in treatments W and OSR (Fig. 3). Nitrogen content in non-legume crops was very low, as expected (76 kg N ha$_{-1}$ for OSR and 125 kg N ha$_{-1}$ for W). Since cover crops were not fertilized with N low amounts of nitrogen in the soil available for non-legume cover crops resulted in low concentration of N in plants, especially in oilseed rape (Table 3). Symbiotically fixed N in the treatments FP and FP/W was 140.97 and 53.9 kg N ha$_{-1}$, respectively (Table 3). These results are in line with Rochester and Peoples (2005) and Kramberger et al. (2009).

Sudan grass nitrogen budget

The highest Sudan grass nitrogen budget was recorded in treatments N2 (132.52 kg N ha$_{-1}$) and FP (123.9 kg N ha$_{-1}$), while the lowest value was recorded in treatments W (106.6 kg N ha$_{-1}$) and FP/W (108.10 kg N ha$_{-1}$). In the control treatment the nitrogen uptake was at the same level as in other treatments except for FP and N2 in which the uptake was significantly higher. It could be concluded that treatments had no effect on soil nitrogen balance. Comparing ARNS values, nitrogen balance was positive in most treatments, confirming the fact that the cover crop nitrogen uptake is partly available for the following crop because of mineralisation, while higher N amounts remain in an organic form mineralising later (Peoples et al., 2004; Tonitto et al., 2006). In both control and N1 treatments, ARNS values were negative, confirming the utilisation of soil mineral nitrogen resources by Sudan grass plants. With the introduction of field pea as a cover crop in Sudan grass production, the soil nitrogen content increased by 165.3 kg N ha$_{-1}$. The achieved yield was at the same level as in the conventional production when 80 kg N ha$_{-1}$ (N2) was applied (Table 4). On the other hand, in treatments W and FP/W where ARNS values were also positive (Table 4), a significantly lower yield was recorded in comparison with the treatment N2 (Table 4). After the ploughing-in wheat and crop mixture, the nitrogen content was lower while the C/N ratio was higher than in field pea (Table 3), resulting in slower mineralisation (Pansu and Thuries , 2003) and producing imbalance in the

Table 3. Effects of cover crop on the ploughed-in biomass dry matter yield (BDMY), content and the amount of in biomass accumulated N, C/N ratio and symbiotically fixed N

Parameter	Cover crops			
	W	FP	FP/W	OSR
N content (%)	1.79	3.24	2.57	1.10
C/N ratio	28	16	21	33
Symbiotically fixed N (kg ha^{-1})	-	140.97	53.93	-

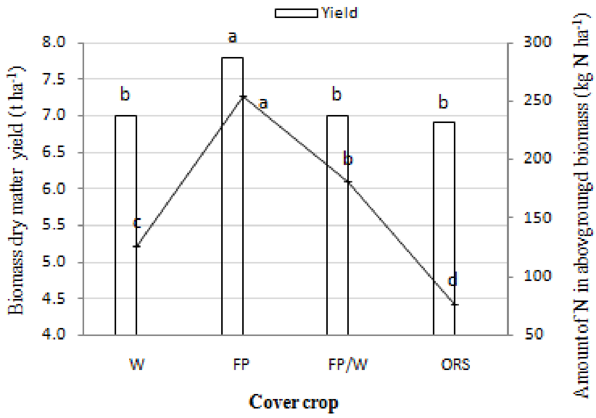

Fig 3. Cover crops DM yield (t ha^{-1}) and nitrogen accumulation in above ground biomass of cover crops (kg N ha^{-1}) (average 2005-2006)

requirements of the succeeding crop (Pang and Letey, 2000). During the longer part of the growing season, as measured by the total N content of Sudan grass, the mineral soil nitrogen content in these two treatments was significantly lower than in other treatments (Table 4).

Sudan grass forage yield and quality

Under average agro-ecological conditions and appropriate management practices, Sudan grass may yield over 15 t ha$_{-1}$ of dry matter. However, the yield capacity varies depending on management practices and growing conditions, primarily depending on the total and distribution of rainfall (Ćupina et al., 2007). The average lower yield in this trial can be attributed to the sowing date, since the Sudan grass was sown as a so-called second crop, one month later than regular sowing. As a consequence of the amount of rainfall and its distribution (Fig. 1), higher average forage DM yields were obtained in the first year (8.87 t ha$_{-1}$) than in the second (8.37 t ha$_{-1}$) of the trial (Table 5). The yield for all treatments was significantly higher during the first cut than in the second (5.06 t ha$_{-1}$ and 3.35 t ha$_{-1}$, respectively). Accumulated N is available to the succeeding crop after mineralization of N in the organic matter of cover crops (Vos and van der Putten, 2001). However, the beneficial effects of the N contribution of the cover crop will only be realised if N becomes available during the period of high N demand by the succeeding crop (Ranells and Wagger, 1996). The dynamics of net N mineralization or N immobilisation depends on the C/N ratio, cellulose and lignin concentrations and neutral detergent fibre concentration in organic matter (Jensen et al., 2005). Based on the two-year average, the highest Sudan grass yield was obtained following N2 treatment (9.62 t ha-1) and field pea (9.32 t ha$_{-1}$) (Table 5). This is in accordance with results of Timothy et al. (2004) and Sainju et al. (2001). Snapp et al. (2005) reported that legume cover crops are the most reliable means of enhancing cash crop yields compared with fallow or other cover crop species. Fernando et al. (2005) claim that legume winter cover crops increased corn yield as a cash crop by 37 % when no nitrogen (N) fertilizer was applied and this benefit decreased with the application of N fertilizer. This is in line with results in which field pea cover crop increased Sudan grass yields by 5.91 %. In both years, the treatments with wheat produced the lowest yield of Sudan grass (7.68 t ha-1), which might be due to nitrogen deficiency after the ploughing-in wheat having a higher C/N ratio than the reduced Sudan grass yield. Smith and Sharpley (1990) found that the incorporation of non-legume cover crops led to a depression of N availability and thus affected the yield of subsequent crops. Non-leguminous cover crops, which typically have low N content show little or no beneficial effects on the succeeding crops and in some cases the effects are even negative (Kuo and Jellum, 2002). The Sudan grass DM yield was higher on the control (8.80 t ha$_{-1}$), than in the treatments with cover crops except for the field pea. Since bare fallow had no plants that could take up NO_3-N, mineralization was higher and thus a higher N contribution to the Sudan grass DM yield. As for intercropping (FP/W), the proportion of wheat in sowing was 20%, because of its high ability to tiller, and the proportion was much higher in the growing season i.e. technological maturity, when cover crops were ploughed-in. This affected N mineralization and the Sudan grass DM yield. Raimbault et al. (1990), Choi and Daimon (2008) reported that other reasons for possible negative effects of cover crops on the succeeding crops in field rotation are soil moisture depletion by cover crops in spring, while Munawar et al. (1990) mentioned allelopathy. According to Fernando et al. (2005) agricultural practices involving cover crops, such as species, fertilization, kill date, and tillage significantly affect subsequent crop yields. On the other hand, Andraski and Bundy (2005) found that beneficial cover crop effects were primarily the result of a rotation effect rather than direct N contributions from the cover crop. Cherr et al. (2006) claim that the cover crops used may be substituted only for a relatively small portion of synthetic N rates. From this point of view the economic aspect of crop production should be taken into consideration. The highest CP contents were obtained in the N2 treatment during the first cut (9.68%) and the lowest (7.55 %) during the second cut in the same treatment. The significant difference between the treatments with N application - in the first and second cuts - can be explained by the fact that, in the first cut, the fertilizer N was directly available to plants while the N from ploughed-in plant material was gradually mineralized becoming available to plants in considerably lower amounts. During plant growth and development at the second cut, it was evident that the mineral nitrogen level in the soil solution was reduced compared with the status at the beginning of the season; this meant that the protein content in plants was considerably reduced at the second cut as a direct consequence of reduced mineral nitrogen content in the soil. CP in W and FP were higher in the first cut than in the second one. The lowest CP content in Sudan grass was recorded following OSR (8.00%) in the first cut, which can be attributed to the concentration of nitrogen in OSR at technological maturity when ploughed-in. Comparing the CP contents in two cuts, the average CP content was significantly higher in the first than in the second cut (8.97% and 8.32%, respectively). The management decision concerning the use of cover crops should be based on the balance between farm profitability and environmental sustainability (Kramberger et

Table 4. Nitrogen content in above ground Sudan grass yield (N yield), and apparent N remaining in the soil (ARNS) after Sudan grass harvesting as affected by cover crop and fertilization treatments (average 2005-2006)

Treatments/ Cover crops	N yield (kg N ha^{-1})	ARNS (kg N ha^{-1})
W	106.65b	41.55c
FP	123.91a	165.26a
FP/W	108.10b	94.03b
OSR	112.61ab	0.37e
C	113.48ab	-59.48g
N1	110.27ab	-25.40f
N2	132.52a	29.0c

al., 2009). The effect of cover crops on the Sudan grass yield and quality varied from positive (FP and FP/W) to negative (W). N mineralization should be regulated in accordance with the N demands of the subsequent crop. In animal production areas, cover crops can be an important source of quality forage or can be used for mulching. In such cases and in rotation with Sudan grass, cover crops should fulfil the following requirements: low-cost production, yield and quality, N uptake during periods critical for leaching and no negative effects on subsequent crops**.**

Materials and methods

Experimental site

A field experiment was conducted under rain-fed conditions between 2004 and 2006 at the Experimental Field of the Institute of Field and Vegetable Crops at Rimski Šančevi, Serbia (45° 20' N and 19° 51' E and 84 m asl). The soil in which the field experiment was set up was a medium deep, calcareous, gleyed chernozem. Soil characteristics are presented in Table 1.

Weather conditions

The long term mean annual air temperature of the area is 11.2 °C, the mean monthly minimum is in January with -0.5 °C and the average monthly maximum is in July with 25.7 °C. The average annual rainfall in the area is 624 mm. The average monthly temperatures and amount of precipitation during the experiment are presented in Fig. 1. Weather conditions in the years of crop establishment differed significantly. The spring of 2006 was very suitable for crop growth and development, contrary to 2005. The summer months of both growing seasons (except July, 2006) had significant amounts of rainfall (Fig. 1).

Experimental design, treatments and crop management

The experiment was conducted as a randomized complete block design with four replicates. Three sole cover crops and one mixture were included in the experiment (Table 2), along with two mineral fertilization treatments, 40 kg N ha^{-1} (N_1) and 80 kg N ha^{-1} (N_2) and unfertilized control (C).The control treatment was ploughed in autumn followed by bare fallow (without cover crop). In the basic Sudan grass treatment, prior to sowing cover crops in 2004 and 2005, NPK fertilizer was applied to all plots based on soil supply and on the premise that the Sudan grass required a maximum of 150 kg N ha^{-1} (Ćupina et al., 2007). Using equation (1), the total amount of N required to meet Sudan grass needs N_2 (80 kg N ha^{-1}) was calculated.

$$N_f = (N_{tg} - N_i - N_{pot}) \quad (1)$$

where: Nf, amount of N applied as NH_4NO_3 (kg N ha^{-1}); Ntg, total requirement for nitrogen (150 kg N ha^{-1}); Ni, mineral N content in the soil when Sudan grass was sown (30 kg N ha^{-1}); Npot, amount of mineral N estimated to be released by the mineralization of organic matter in the soil during the growing period (40 kg N ha^{-1}) (Bogdanović, 1981). The first dose N_1 represented one half of N_2 (40 kg N ha^{-1}). Based on soil chemical properties, prior to sowing the cover crop, 50 kg P_2O_5 ha^{-1} as triple superphosphate and 100 kg K_2O as potassium sulphate were applied as basal dressings. Plot size was 2 m x 10 m. Winter cover crops were planted, in accordance with local agro-ecological conditions, in the first half of October of 2004 and 2005, at typically recommended seeding rates (Table 3).The previous crop was millet (*Panicum miliaceum* L.). No weed control was used in the cover crop management. The winter cover crops were ploughed-in mid-May 2005 and 2006. After the cover crops were ploughed-in, Sudan grass (cv. Srem) was planted using a seeding rate of 20 kg ha^{-1}. Nitrogen was applied together with ploughing-in. The amount of symbiotically fixed N was calculated using the formula (2) of Evans and Taylor (1987):

$$Nsymb = [N_{yield}(legume) - N_{yield}(non\text{-}fixing\ control)] + [N_{min}(legume) - N_{min}(non\text{-}fixing\ control)] \quad (2)$$

Nsymb = amount of symbiotically fixed N (kg ha^{-1}); Nyield(legume) = amount of N accumulated by legume (kg ha^{-1}); Nyield(non-fixing control) = amount of N accumulated by the non-legume (kg ha^{-1}); Nmin(legume) = amount of mineral N in soil under the legume (kg ha^{-1}); Nmin (non-fixing control) = amount of mineral N in soil under the non-legume (kg ha^{-1}). Contrary to Thorup-Kristensen (2001) and Mueller and Thorup-Kristensen (2001), who used Italian ryegrass (*Lolium perenne* L.) as non-fixing control, in this research wheat (*Triticum aestivum* L.) was used as the non-fixing control for calculating Nsymb. The apparent N remaining in the soil (ARNS) is expressed as the N budget using the formula (3) of Kramberger et al. (2009):

$$ARNS\ (kg\ ha^{-1}) = (N\ in\ the\ cover\ crop + soil\ N_{min}\ at\ the\ Sudan\ grass\ sowing + N\ added\ with\ fertilization) - N\ taken\ up\ in\ above\ ground\ Sudan\ grass\ yield \quad (3)$$

Measurements and analytical determination

Soil pH was determined in a suspension of soil and H_2O, by *METREL*, MA 3657 pH meter. $CaCO_3$ content was determined volumetrically, by a Scheibler calcimeter. The total N and C contents were determined by CHNS analyser (ELEMENTAR, Vario EL, Elementar Analysensysteme GmbH, Hanau, Germany). Humus content was determined, by oxidizing organic matter with potassium bichromate (Simakov and Tsyplemkov, 1969). Available P and K contents were determined using the AL method (Enger et al., 1960). Mineral N in the soil was extracted with 2 M KCl

Table 5. Effect of cover crops on Sudan grass DM yield (t ha^{-1}) and crude protein content (%) (two-year average 2005-2006)

Treatment	Yield			Crude protein	
	First cut	Second cut	Total	First cut	Second cut
W	5.13 b	2.55 d	7.68 d	8.76 b	8.60 a
FP	5.64 ab	3.67 ab	9.32 a	8.51 b	8.12 ab
FP/W	4.83 b	3.39 b	8.23 c	8.52 b	7.91 bc
OSR	5.06 b	3.59 ab	8.66 b	8.00 b	8.41 ab
N1	5.09 b	2.99 c	8.08 c	8.66 b	8.40 ab
N2	5.77 a	3.85 a	9.62 a	9.68 a	7.55 c
C	5.37 ab	3.42 b	8.80 b	8.56 b	7.56 c
Average	5.06	3.35	8.63	8.67	8.08
2005	4.67 b	4.20 a	8.87 a	8.36 b	31.99 b
2006	5.87 a	2.49 b	8.37 b	8.98 a	34.43 a

Values followed by the same letter within columns are not significantly different ($P < 0.05$)

(1:4, soil to solution ratio, weight basis) and determined by steam distillation (Bremner, 1965). The content of mineral forms of N (NO_3-N and NH_4-N) in soil layers 0-30 cm, 30-60 cm and 60-90 cm was monitored by the method of Wehrmann and Scharpf (1979). The content of mineral N (Nmin) in the soil was measured five times in the course of the growing season in each trial year:

I - before cover crop sowing (first half of October);
II - beginning of the spring growing season of the cover crop (early March);
III - directly after ploughing-in of cover crop (end of May);
IV - after the first cutting of the Sudan grass (mid-August);
V - after the second cutting of the Sudan grass (mid-October).

The above ground dry matter yield of biomass or forage (t ha^{-1}) and nitrogen content (%) of cover crops were determined prior to ploughing-in during the spring, by cutting the crop to a stubble height of 5 cm. The yield (t ha^{-1}) and nitrogen content (%) of two cuttings of Sudan grass was obtained at the silage stage by randomly choosing 15 plants from each plot. Plants were cut to a stubble height of 10 cm, particularly important for Sudan grass regeneration. The dry matter yield was obtained by drying samples (2 kg each) to a constant mass at 70 °C. The N content of cover crops DM and Sudan grass forage was analysed by the Kjeldahl method. The Sudan grass yield and quality were presented and discussed as a two year average. The significance of differences between means was tested by analysis of variance and relationships between variables by regression and correlation analysis by Statistica 8.0 statistical software. A Fisher's LSD test was used to detect significant differences between the treatments for all mean values at $P = 0.05$.

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