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Winter cover crops as green manure in a temperate region: the effect on nitrogen budget and yield of silage maize

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Abstract. Winter cover crops may provide different environmental benefits in agricultural systems. The aim of this study was to determine the effect of cover crops used as green manure on the soil nitrogen (N) budget and yield of silage maize (*Zea mays* L.). A field experiment was conducted between 2011 and 2013 at three locations in Vojvodina Province, Serbia. It compared common vetch (*Vicia sativa* L.), triticale (× *Triticosecale* Wittm. ex A. Camus), their mixture grown as cover crops, N fertilisation at two doses (N1 and N2), and an unfertilised fallow as a control. Cover crops were sown in autumn 2011 and 2012 and were ploughed in during May of the year after which silage maize was sown. Results show that the ability of cover crops to provide benefit for a subsequent crop is highly related to weather conditions, mainly precipitation. The two years of the study experienced completely different weather conditions, showing two aspects of how cover crops can affect subsequent crop yield and amount of N left in the soil. In 2012, the N budget was higher in all three cover crops at all locations than N1 and the control because of unfavourable weather conditions for mineralisation of organic matter. However, the cover crops had a negative effect on silage maize yield. In 2013 (an average year), the N budget was significantly higher after cover crops, and was followed by a higher yield of silage maize. Based on the 2-year average, the highest value of apparent N remaining in the soil was recorded in the mixture treatment (288.13 kg N ha^{-1}); treatments with vetch and triticale had approximately equal values (272.17 and 272.71 kg N ha^{-1}). The N fertilisation treatments and the control had significantly lower average values of residual N.

Additional keywords: ARNS, legumes, silage corn.

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Introduction

The concept of conventional agriculture, which aims to achieve high yield and quality with maximum profit, requires intensification of all aspects of production, thus causing deterioration of the land, which is the primary resource of agricultural production (Tilman *et al*. 2002; Uphoff 2002; Smith *et al*. 2007). This system of cultivation has been used on the fertile land in Vojvodina Province, Serbia, and has resulted in decreasing organic matter content, damaged soil structure, and changes in the biological properties of the land (Ličina *et al*. 2011). In addition, the livestock production in Serbia is at low level and organic fertilisers are insufficiently used, indicating the need to introduce changes in the farming systems (Ćupina *et al*. 2011). A comparison of results of research carried out in 1993 with a land analysis performed in 2000 in Vojvodina showed that the decline in humus content averaged 0.38% (Hadžić *et al*. 2004). More recent data indicate that ~2.7% of the land has very low humus content, with 26% of the samples containing 1.5–3% humus (SEPA 2009; Ćupina *et al*. 2013).

For crop production, soil fertility requires special attention. Besides the natural content of nutrients present in the soil, plants can be provided with necessary nutrients by chemical means, i.e. application of mineral fertilisers (White and Brown 2010), or by implementing biological measures such as introducing organic fertilisers and growing cover crops (Yeganehpoor *et al*. 2015). Cover crops, which are crops grown between cash crops (Teasdale *et al*. 2007; Kruidhof *et al*. 2008), have several positive effects. For example, they reduce fertilisation costs (Sainju *et al*. 2005; Snapp *et al*. 2005; Ćupina *et al*. 2011); improve soil properties (Sarrantonio and Gallandt 2003); control weeds (Hatcher and Melander 2003), diseases (Manici *et al*. 2004) and pests (Peachey *et al*. 2002); and reduce nutrient leaching (mainly nitrogen, N) (Miller *et al*. 1994). These effects depend primarily on the selection of a plant species or its mixture, bearing in mind that appropriate selection of cover crops is determined by agro-ecological conditions, as well as the purpose of the crops. Selection of cover crops depends on whether the characteristics of the plants and their growth will fulfil existing needs (Guldan and Martin 2003). However, the effect of cover crops depends on the climate of a region (Clark 2007), and they can have negative effects on the subsequent crop, especially in conditions of insufficient rainfall (Nielsen *et al*. 2015).

Apart from application of mineral fertilisers, the soil can be provided with N by cultivation of legumes, owing to their symbiosis with bacteria of the genus *Rhizobium* (Wortman *et al*. 2012). If leguminous cover crops are used as green manure, the N input is significantly increased (Dabney *et al*. 2010; Tosti *et al*. 2012). Ploughing-in of legumes also allows part of the organic matter to enter the soil. In order to increase the content of organic matter in this way, priority should be given to species of the family Poaceae, because their higher carbon (C) : N ratio enables slower decomposition of plant material and better synthesis of humic substances (Diekow *et al*. 2005; Ugrenović and Filipović 2017). In addition, these species efficiently absorb nutrients and prevent their leaching into deeper soil layers (Sainju and Singh 2001; Dinnes *et al*. 2002). According to Cupina *et al*. (2016), the best option for the environmental conditions of Vojvodina is a mixture of legumes and small grains, because of the problem of deficit of N and organic matter in the soil. In such a mixture, N release is slower, which reduces the possibility of leaching and thus loss of N for the subsequent crop, while decomposition of the plant material is more favourable because of a higher number and greater activity of microorganisms (Fageria *et al*. 2005).

The most common cover crops in temperate regions of Europe are winter cover crops (De Baets *et al*. 2011; Ćupina *et al*. 2013). The species most often used as cover crops in this region are legumes such as field pea (*Pisum sativum* L.) and vetches (*Vicia* spp.) (Mikić and Mihailović 2014; Mikić *et al*. 2015); cereals such as oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.) and triticale (× *Triticosecale* Wittm. ex A. Camus) (Ćupina *et al*. 2013); and brassicas such as rapeseed (*Brassica napus* L.) and kale (*B. oleracea* L.) (Jeromela *et al*. 2017). Their importance is reflected, among other things, in the fact that by using cover crops, the land is covered by vegetation for as long as possible during the year, so that the soil is protected from erosion (Sapkota *et al*. 2012), weed infestation and other forms of degradation. In addition, biological diversity can be achieved by switching from monoculture to crop rotation systems that include cover crops (Teasdale *et al*. 2007). Introducing cover crops in commercial production practice could significantly contribute to increasing the sustainability of existing agricultural production systems (Salmerón *et al*. 2011). The importance of their introduction in cropping systems is also recognised by the European Commission; within its framework for land protection in the European Union, it assigned a special role to biomass production in preservation of soil functions (Jones *et al*. 2012).

The objective of this study was to investigate the effect of winter cover crops grown as green manure, compared with the application of mineral N, on the content and budget of N in the soil, as well as the yield of silage maize (*Zea mays* L.) in agro-ecological conditions of Vojvodina.

Materials and methods

Experimental site

A field experiment was conducted between 2011 and 2013 at three locations: Rimski Šančevi (45°19 N, 19°50 E; 80 m a.m.s.l.), Sombor (45°44 N, 19°08 E; 84 m a.m.s.l.), Senta (45°54 N, 20°05 E; 77 m a.m.s.l.). At all three sites, the trial was setup in rainfed conditions on Chernozem, medium deep form and calcareous, gleyed soil. Soil characteristics are presented in Table 1.

Weather conditions

The autumn of 2011 was extremely dry and unfavourable for planting winter crops (Fig. 1). Because of the dry soil, triticale, common vetch (*Vicia sativa* L.) and winter forage mixture had slow initial growth, failing to enter the winter period in the appropriate stages of development. The drought continued in spring 2012. In May 2012, precipitation was approximately the same as, or slightly higher than, the average; however, during summer, drought was present again at all localities, affecting the growth and development of the main crop. In terms of air temperature, the period 2011–12 was characterised by mild winters and extremely warm summers. The temperatures in March, April and May were above or around average, whereas the temperature was higher than the long-term average in June 2012 by 2.5–2.9°C (depending on the site), in July by 2.7–3.3°C, and in August by 2.4–3.0°C. The autumn of 2012 was favourable for planting and emergence of winter crops. High amounts of rainfall in late autumn 2012 and winter 2013 compensated for the severe lack of soil moisture and allowed for the spring season of 2013 to begin with good stocks of winter moisture. Monthly precipitation in the hydrological year 2012–13 was above the long-term average from October to March. Temperatures in the period October–November 2012–13 were higher than average at all three sites.

Experimental design, treatments and crop management

The experiment was conducted as a randomised block design with three replicates. Two sole cover crops (common vetch cv. Neoplanta and triticale cv. Odisej) and their mixture, two treatments with mineral fertilisation (N1 and N2), and an unfertilised control were included in the experiment.

Table 1. Chemical characteristics of the soils

Locality	Year	pH H_2O	pH KCl	$CaCO_3$ (%)	Humus (%)	P_2O_5 (mg 100 g^{-1} soil)	K_2O (mg 100 g^{-1} soil)
Rimski Šančevi	2011	7.77	8.56	8.01	2.07	34.74	26.96
	2012	7.60	8.61	5.48	2.49	46.04	24.13
Sombor	2011	7.60	7.36	6.80	3.08	22.50	22.05
	2012	7.50	7.25	7.40	3.12	21.80	21.10
Senta	2011	7.29	8.18	13.81	3.95	18.31	26.20
	2012	7.31	8.26	12.41	3.48	19.57	24.32

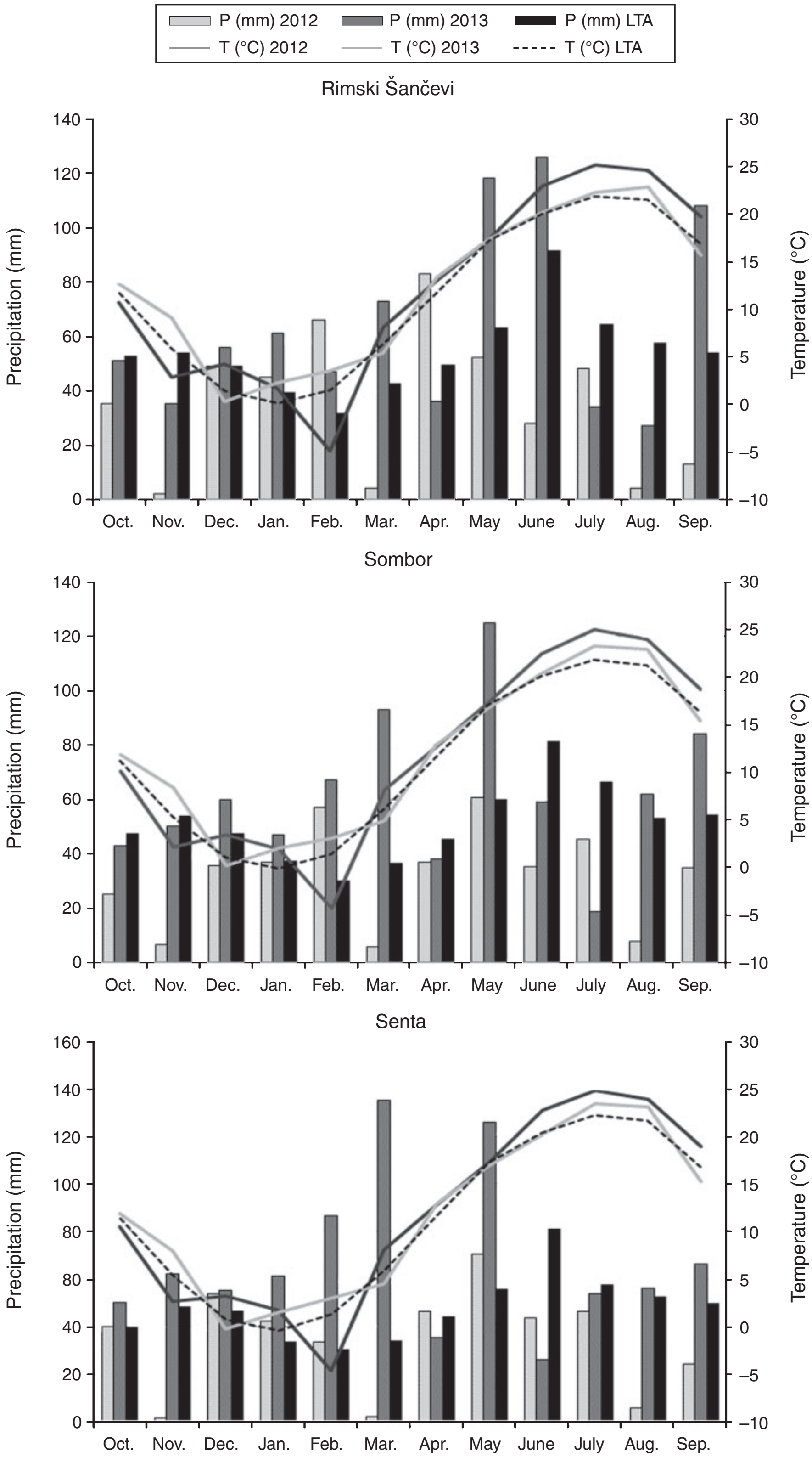

Fig. 1. Long-term average (LTA) and total monthly precipitation (P) and average monthly air temperature (T) for hydrological years (2011–13). Bars and left *y*-axis represent temperature data; lines and the right *y*-axis represent precipitation data. Monthly precipitation and temperature data were collected from on-site weather stations.

The control was performed with ploughing during autumn followed by bare fallow (without cover crop during winter) and silage maize seeding in spring with no N added during fertilisation. On the premise that the total need of silage maize for N is ≤180 kg N ha^{-1} (Latković *et al*. 2011, 2012), total amounts of N applied through fertilisation in treatments N1 and N2 (kg N ha^{-1}) were calculated by the following equations:

$$N1 = (120\,kg\,N\,ha^{-1} - Ni - Npot) \quad (1)$$

$$N2 = (160\,kg\,N\,ha^{-1} - Ni - Npot) \quad (2)$$

where Ni is mineral N content in the soil at the time of sowing silage maize (Table 2), and Npot is amount of mineral N that will be released by the mineralisation of organic matter in the soil during vegetative growth (estimated value 40 kg N ha^{-1}; Bogdanović 1981). Total amounts on N applied as ammonium nitrate in treatments N1 and N2 are shown in Table 1.

Plot size was 5 m by 5 m. Winter cover crops were planted in accordance with local agro-ecological conditions in the first half of October 2011 and 2012, at the usual seeding rates (Table 2). No weed control was used in cover crop management. The winter cover crops were ploughed in during mid-May 2012 and 2013 (Table 2). After the cover crops were ploughed in, silage maize (cv. AS 31) was planted at a row distance of 22 cm and a seeding rate of 65 000 plants ha^{-1}. Nitrogen was applied with the ploughing-in.

All data regarding timing of specific agronomic operations are presented in Table 2.

Measurements and analytical determination

Soil pH was determined in a suspension of soil and H_2O by pH meter (MA 3657; METREL, Horjul, Slovenia). The $CaCO_3$ content was determined volumetrically by Scheibler calcimeter and total N and carbon content determined by CHNS analyser (Vario EL; Elementar Analysensysteme, Hanau, Germany). Humus content was determined by oxidising organic matter with potassium dichromate(VI) (Simakov and Tsyplenkov 1969). Plant-available phosphorus (P) and potassium (K) in the soil were extracted with a solution of 0.1 M ammonium lactate and 0.4 M acetic acid (pH 3.75), at a soil to solution ratio of 1 : 20 (w/v). The concentration of P was measured by spectrophotometry, while the concentration of K was measured by flame photometry (Enger *et al*. 1960). Mineral N in the soil was extracted by using 2 M KCl (1 : 4, soil : 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, 30–60, 60–90 and 90–120 cm was monitored by the method of Wehrmann and Scharpf (1979). The content of soil mineral N (N_{min}) was measured twice in the course of the growing season in each trial year and each site: first, directly after ploughing-in of cover crop (end of May); and second, after harvest of silage maize (September–October) (Table 2).

The aboveground dry matter yield biomass (t ha^{-1}) and N content (%) of cover crops was evaluated before ploughing-in during the spring, by cutting the crop to a stubble height of 5 cm. The yield (t ha^{-1}) and N content (%) of silage maize was measured by randomly choosing 15 plants from each plot. The dry matter yield was obtained by drying samples (2 kg each) to a constant mass at 70°C. The yield of silage maize was analysed for N content by using the Kjeldahl method.

Because several factors influence the N cycle, there are different approaches to calculating the N budget. The approach used in this paper is the calculation of apparent N remaining in the soil (ARNS) following the maize crop. ARNS is expressed as the N budget using the modified formula (Eqn 3) of Kramberger *et al*. (2009):

Table 2. Agronomy practices and timing of field operations at three locations for each year of study during the season 2011–12 and 2012–13
N_i, Content of mineral N in soil layer 0–90 cm at the time of sowing of silage maize; N1, fertiliser-applied N up to 120 kg N ha^{-1}; N2, fertiliser-applied N up to 160 kg N ha^{-1}

	Rimski Šančevi		Sombor		Senta	
	Cover crop seeding rates					
	(kg ha^{-1})	(viable seeds m^{-2})	(kg ha^{-1})	(viable seeds m^{-2})	(kg ha^{-1})	(viable seeds m^{-2})
Common vetch	120		120		120	
Triticale	220	500	220	500	220	500
Mixture	90 + 30		90 + 30		90 + 30	
	Date of field operation					
	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13
Cover crop sowing	26.x.11	22.x.12	27.x.11	24.x.12	24.x.11	14.x.12
Cover crops ploughing-in	29.v.12	16.v.13	23.v.12	30.v.13	26.v.12	25.v.13
Silage maize sowing	30.v.12	20.v.13	26.v.12	02.v.13	28.v.12	30.v.13
Silage maize harvest	11.v.12	02.v.13	13.v.12	05.v.13	12.v.12	16.v.13
Soil sampling for N_{min}:						
First sampling	30.v.12	17.v.13	27.v.12	30.v.13	27.v.12	30.v.13
Second sampling	12.ix.12	08.ix.13	15.ix.12	06.ix.13	14.ix.12	18.ix.13
	Soil mineral N and applied amounts of N at fertilisation treatments					
N_i (kg ha^{-1})	130	72	131	78	142	92
Fertilisation rates:						
N1 (kg N ha^{-1})	–	48	–	42	–	28
N2 (kg N ha^{-1})	30	88	29	82	18	68

$$\text{ARNS}\ (\text{kg N ha}^{-1}) = (N_{cc} + N_{min} + N_f + N_{pot}) - N_{yield} \quad (3)$$

where N_{cc} is N in the cover crop, N_{min} is soil mineral N at silage maize sowing, N_f is N added with fertilisation, N_{pot} is N mineralisation potential of soils, and N_{yield} is N taken up in aboveground silage maize yield.

The amount of N created from soil organic matter mineralisation (N_{pot}) was measured in the control plot without fertilisation and calculated by following formula:

$$N_{pot}\ (\text{kg N ha}^{-1}) = (\text{N in soil at the end of silage maize vegetation} + N_{yield}) - N_{min} \quad (4)$$

The water content of the soil profile was calculated by summation of water content of each depth (Gardner *et al.* 2000) (Table 3).

Differences between the treatments for all mean values were tested by ANOVA and the relationships between variables by regression and correlation, by using statistical software STATISTICA version 13.0 (Statistica, Tulsa, OK, USA). Means were separated by Duncan's multiple range test and statistical significance was evaluated at $P \leq 0.05$.

Table 3. Soil water content (mm) in soil layer 0–120 cm at the time of silage maize sowing in two research years (2012 and 2013) for three sites

Within columns, means followed by the same letter are not significantly different ($P > 0.05$)

	2012			2013		
	Rimski Šančevi	Sombor	Senta	Rimski Šančevi	Sombor	Senta
Vetch	194.0b	209.4b	238.4b	264.7a	239.5bc	251.4b
Triticale	201.1b	168.5c	209.8c	216.3b	242.9b	224.6c
Vetch–triticale	211.2b	179.0c	226.2bc	211.5b	228.4c	220.6c
N1	288.3a	240.4a	280.3a	287.8a	288.9a	281.3a
N2	281.0a	249.7a	284.1a	268.8a	289.7a	285.5a
Control	301.7a	239.8a	291.4a	272.1a	298.3a	278.0a

Results

Nitrogen budget after silage maize

In 2012, the highest value of ARNS at Rimski Šančevi was determined in the N2 treatment (287.00 kg N ha^{-1}), whereas in treatments with winter cover crops, the values ranged from 232.81 kg N ha^{-1} with triticale to 265.82 kg N ha^{-1} with vetch. The highest value of ARNS at Sombor was determined in the treatments with vetch (275.58 kg N ha^{-1}), and the lowest value was in the control (194.89 kg N ha^{-1}). On average, the highest values were registered at the third locality (Senta), with an average of 382.68 kg N ha^{-1}, which was significantly higher than the averages at other sites. Concerning the average treatment values, the highest value was registered in N2 (324.25 kg N ha^{-1}), followed by the mixture (304.66 kg N ha^{-1}), whereas the lowest value was registered in the control (241.16 kg N ha^{-1}).

The amounts of residual N in the soil after maize cutting in 2013 were different from those in 2012 at all localities. Taking into account the favourable weather conditions in the second year of the study and the more intensive mineralisation of N, the release of N was also more intensive, so the values of ARNS were lower. The trends of cover crops in 2013 differed from those in 2012, and in certain treatments, it was possible to identify significant deviations of the values obtained (Table 4). These results can be associated with a higher yield of dry matter of cover crops in the analysed treatments. It was noted that ARNS values for treatments with winter cover crops were positive and significantly higher than the treatments with N and the control. The highest ARNS value at the first site was found in the treatment with triticale (395.48 kg N ha^{-1}), and the highest value at the second site was in the treatment with the crop mixture (396.16 kg N ha^{-1}). At the second site, the N1 treatment had a negative ARNS value (–58.40 kg N ha^{-1}). At Senta in 2013, the N2 treatment had the highest ARNS value (189.33 kg N ha^{-1}); among the cover crops, the vetch treatment had the highest ARNS (163.36 kg N ha^{-1}).

Table 4. Effect of cover crop and nitrogen rate on apparent nitrogen remaining in the soil (ARNS, kg N ha^{-1}) at three locations during 2011–12 and 2012–13

Within locality and year, treatment means followed by the same lower case letter are not significantly different; within treatment and year, locality means followed by the same upper case letter are not significantly different ($P > 0.05$)

Locality	Treatment						
	Vetch	Triticale	Vetch–triticale	N1	N2	Control	Average
			2011–12				
Rimski Šančevi	265.82aB	232.81bB	265.59aB	216.96bcB	287.00aB	192.43cB	243.44B
Sombor	279.36aB	248.50abB	245.58abB	224.66abB	265.02aB	194.89bB	243.00B
Senta	364.90abA	376.93abA	402.81abA	394.58abA	420.72aA	336.15bA	382.68A
Average	303.36AB	286.08B	304.66AB	278.73B	324.25A	241.16C	289.71
			2012–13				
Rimski Šančevi	283.99bA	395.48aA	320.18abB	74.92cB	108.46cA	93.44cA	212.75A
Sombor	275.58bA	256.28bB	396.16aA	–58.40eA	156.81cA	31.12dA	176.26 B
Senta	163.36aA	126.28aC	98.46aC	101.07aA	189.33aA	91.45aA	128.33C
Average	240.98A	259.35A	271.60A	39.20C	151.53B	92.45C	175.85
			Average 2011–13				
Rimski Šančevi	274.91aA	314.14aA	292.88aA	145.94cB	197.73bB	142.94cB	228.09B
Sombor	277.47bA	252.39bB	320.87aA	83.13dC	210.91cB	113.01dB	209.63C
Senta	264.13abA	251.60ab	250.63abB	247.83abA	305.02aA	213.80bA	255.50A
Average	272.17A	272.71A	288.13A	158.97C	237.89B	156.58C	231.07

On the basis of the average values for both study years (Table 4), the highest ARNS value was recorded in the treatment with the crop mixture (288.13 kg N ha^{-1}), whereas the treatments with vetch and triticale had about the same values (272.17 and 272.71 kg N ha^{-1}). The fertilisation treatments and the control had significantly lower average values of residual N, especially prominent in the N1 treatment (158.97 kg N ha^{-1}) and the control (156.58 kg N ha^{-1}).

Silage maize yield

By analysing the 2-year average, it was noted that the obtained yield was higher in the fertilised treatments and the control than in the treatments with ploughing-in of cover crops. Silage maize yield varied significantly between different localities in both study years. In 2012, the highest silage maize yield at Rimski Šančevi was registered in the control (19.60 t ha^{-1}), and the lowest yield in the treatment with common vetch ploughed in (8.80 t ha^{-1}); all of the treatments with winter cover crops had statistically lower silage maize yield than the fertilisation treatments and the control (Fig. 2). During the first study year, all treatments with winter cover crops at Sombor had statistically lower yields than the fertilisation treatments. The lowest yield was obtained when the preceding crop was triticale (0.46 t ha^{-1}), and the highest yield was obtained in N1 treatment (16.46 t ha^{-1}). Silage maize yield at Senta in 2012 ranged from 4.90 t ha^{-1} when triticale was the preceding crop to 21.09 t ha^{-1} in the N1 treatment (Fig. 2).

At the time of silage maize sowing at the three locations, all cover crop treatments had soil-water content lower than, and statistically different from, fertilised treatments and the control. In 2012 at Rimski Šančevi, the lowest soil-water content was registered in the treatment with vetch (194.0 mm), whereas at Sombor and Senta, it was in the treatment with triticale (168.5 and 209.8 mm) (Table 3).

In the second year, yield was significantly higher at all sites. At Rimski Šančevi after ploughing-in of triticale, the maize yield was 24.40 t ha^{-1}, whereas with the N1 treatment, the yield was 36.80 t ha^{-1}. At Sombor, the yield in the N treatments and the control was also significantly higher in 2013, whereas at Senta, the yield from the N2 treatment (25.55 t ha^{-1}) and the cover crop mixture (24.21 t ha^{-1}) was approximately the same.

Soil-water content at the time of maize sowing was higher in the fertilised treatments and the control than the cover crop treatments in 2013. In the treatments with cover crops, at Rimski Šančevi and Senta, the highest soil water content was measured in the treatment with vetch (264.7 and 251.4 mm) whereas at Somborn it was in the treatment with triticale (242.9 mm) (Table 3).

Silage maize yield showed a high response to soil-water content and ARNS values. A significant positive correlation ($r = 0.73$) was found between soil moisture at the time of maize sowing and the yield of silage maize (Fig. 3). The negative linear correlation was established between ARNS and silage maize yield ($r = –0.64$) (Fig. 4).

Discussion

Nitrogen budget after silage maize

An important aspect of cover crops is that they can provide benefits that are not directly related to yield of the subsequent crop (Liebig *et al*. 2015). Those authors suggest that cover crops could help in conservation of N. Franzluebbers and Stuedemann (2015) emphasised that even low productivity of cover crops can be a valuable forage source in forage-limited situations. In 2012, the average ARNS values after the harvest of silage maize were higher in all three ploughed-in cover crops than in the N1 treatment and the control. This was due to various factors that influenced the N budget; however, the primary cause was unfavourable conditions for mineralisation of organic matter from the cover crops that were incorporated in the soil. On the one hand, soil moisture was very low and unfavourable; on the other, the temperatures were almost optimal for organic matter mineralisation (Kätterer *et al*. 1998). In such circumstances, there was no N leaching into the lower layers, so in the treatments with ploughing-in of cover crops, the layer at 0–30 cm had the highest N content. The highest average ARNS value was registered in the cover crop mixture, followed by the vetch, and the lowest value was registered in triticale, which is expected given the fact that small grains have a higher C : N ratio and release N more slowly, and are essential for increasing organic matter in the soil. This is in line with findings of Kramberger *et al*. (2009) and Tonitto *et al*. (2006), who reported that the N accumulated in the soil from winter cover crops becomes a part of the organic system, is mineralised, and is partially accessible to the subsequent crop. In 2012, there was relatively low silage maize yield on the cover crops treatment, so the N uptake was minimal, whereas in treatments without cover crops, forage yield was higher and so was the N uptake. These findings indicate that, depending on the growing conditions, in particular in severe drought, cover crops may have a negative impact on the subsequent crop, especially under dryland farming conditions (Liebig *et al*. 2015). The ARNS value in the N2 treatment was also high, there being no leaching to the deeper layers because of a larger amount of applied N that plants did not use and a lack of rainfall. Weather conditions in 2013 were favourable for plant development; therefore, the cover crops had higher yields and higher N uptake, but also higher N input through the yield compared with 2012. With regard to the N budget in 2013, N uptake through silage maize yield was higher than in 2012, which caused lower and different ARNS values for treatments N1, N2 and the control compared with the other treatments. According to Meisinger *et al*. (2008), nitrate depletion in the root-zone is not uncommon at the end of a growing season. The factors causing nitrate depletion are high yields, weather conditions favourable for denitrification in wet years, and in some cases loss by leaching, as documented by Jokela and Randall (1997) and Di and Cameron (2002).

Silage maize yield

The variability of cover crop effects on yield and N uptake by the subsequent crop depends on the region, and not only on cover crop species and management (Gabriel *et al*. 2016). As such, positive effects may be absent, whereas an effect of decreased yield can be recorded owing to water or nutrient competition (Kramberger *et al*. 2009). Thus, the amount of soil water used by cover crops, which may reduce available soil moisture for the main crop, can be a key concern among farmers when growing cover crops (Wortman *et al*. 2012). In this study in a semi-arid system in the Vojvodina Province, the year, rather than the cover

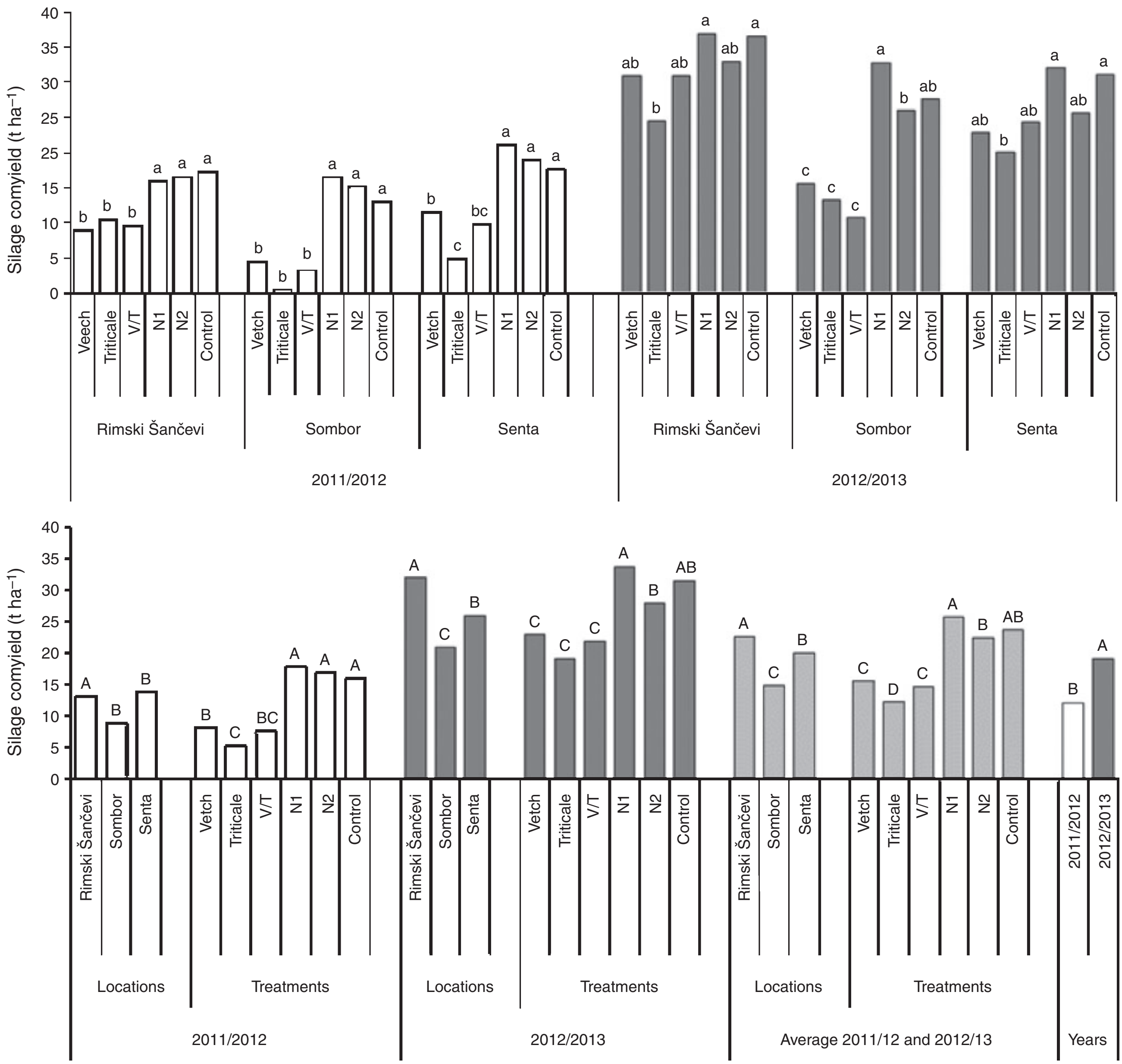

Fig. 2. Effect of cover crop and nitrogen fertilisation on silage maize yield at three localities in 2012 and 2013. Lower case letters are for comparison of treatments within locality and year; upper case letters are for comparison among localities or among treatments within years or averaged over years; bars with the same letter are not significantly different ($P > 0.05$).

crops, led the response of crop yield. The yield of silage maize in both research years depended not only on the type of cover crop, but also on the weather conditions, i.e. precipitation and available soil moisture. This was also reported by Unger and Vigil (1998), who pointed out that in rainfed, semi-arid environmental conditions, cover crops may be problematic because they can limit soil water for the next crop. Extremely low rainfall in 2012 at all three locations and temperatures higher than average were unfavourable for maize development in the subsequent sowing. These circumstances caused lower yields of silage maize in all treatments in 2012. Forage yield was extremely low in the treatments with ploughed-in cover crops, with winter cover crops using up the winter moisture stocks from the soil. An extreme case was recorded at Sombor, where, with a preceding crop of triticale, there was practically no yield formation. The impact of the winter cover crops determined in this research is consistent with the findings of Smith *et al.* (1987) on how winter cover crops affect soil moisture, i.e. how they reduce the moisture content in the soil (Utomo 1986). Results are also in compliance with Reese *et al.* (2014) concerning increased water stress on the subsequent crop and thus neutral or negative effects on crop yield.

With regard to the application of N, it is noteworthy that N1 and the control obtained higher silage maize yield than the treatment with a 2-fold dose (N2), which is a significant

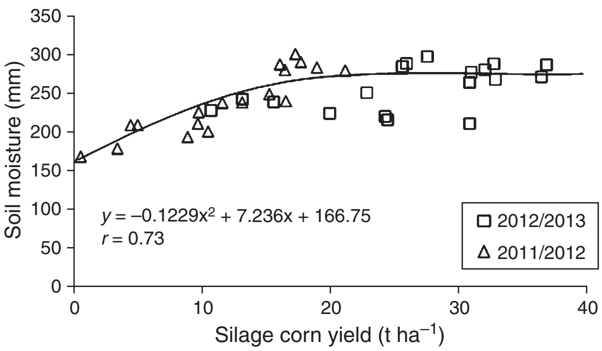

Fig. 3. Relationships between soil moisture and silage maize yield for all treatments and sites in 2011–12 and 2012–13.

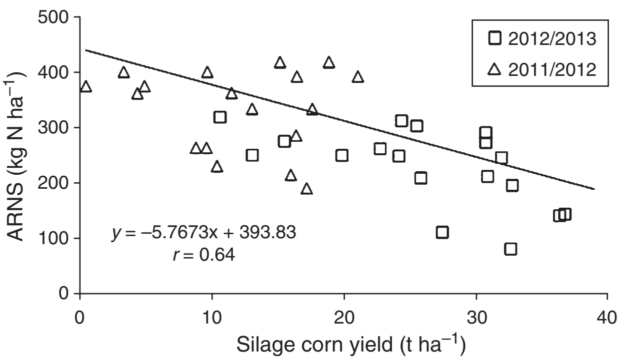

Fig. 4. Relationships between apparent nitrogen remaining in the soil (ARNS) and silage maize yield for all treatments and sites in 2011–12 and 2012–13.

conclusion from both economic and environmental aspects of production. The lowest yield of silage maize in both research years was obtained after triticale, due to the high consumption of soil water by the triticale as a preceding crop. On the other hand, the highest yield in both years was achieved when common vetch was a preceding crop, owing to its low water consumption. These results are consistent with the results of Ebelhar *et al*. (1984), Utomo (1986) and Herbek *et al*. (1987), who examined maize grain yield after winter cover crops. Similar results were reported by Salmerón *et al*. (2011), who found that the yield of silage maize was highest when the preceding crop was vetch. In the second year, the yield was significantly higher at all sites, because of favourable weather conditions, with the high rainfall in May and June compensating for the loss of water consumed by the cover crops. Remarkably high rainfall during these months was recorded at Rimski Šančevi, where the average yield of silage maize was significantly higher than at the other localities. In our study, the cover crops were harvested in spring, and thus there were no possibility of sufficient time for soil-water recharge, which directly reflected on maize development and the obtained yield. In the study performed by Lyon *et al*. (2007), cover crops were harvested in autumn and the response crops were planted the following spring, which resulted in greater soil-water content. However, in 2013 in the present study, the silage maize yield in the subsequent sowing was close to the average yield obtained in commercial production in a regular sowing term, which provides several benefits from the agronomic, and especially from the economic aspect.

The two years of our research with completely different weather conditions have shown two sides of how cover crops can affect subsequent crop yield and amount of N left in the soil. In extremely low precipitation years in semi-arid dryland cropping systems, inclusion of cover crops in the cropping system decreased soil-water availability to subsequent crop (Reese *et al*. 2014), thereby decreasing its yield with insufficient release of N during the main crop-growing season. By contrast, results suggest that in an average year (2013), winter cover crops in annual crop production systems in the Vojvodina Province can provide effects on the subsequent crop as well as N conservation. To ensure security of such production, especially in temperate climates, use of irrigation is recommended in silage maize production in the subsequent sowing. Otherwise, as Farahani *et al*. (1998) indicate, highly variable weather conditions with inadequate precipitation and short growing seasons can make crop production risky if cover crops are included. However, although inclusion of winter cover crops depends on environmental conditions, it is a useful practice in crop rotations (Ćupina *et al*. 2011). The usefulness and benefits of cover crops are important over the long term, bearing in mind that enhancement of soil quality, i.e. primarily organic matter content, requires time to build up and is essential for crop production. Findings from this study also suggest that in the given conditions, winter cover crops significantly increased soil coverage, indicating that they provide an ecosystem service for wind-erosion prevention. In addition, late-season production of cover crops also suits regional livestock producers. Thus, as Clark (2007) stated, the benefits of growing cover crops vary by location and season, but there are usually at least two or three with any cover crop. Costs associated with seeding and growing cover crops can be a limiting factor (Nielsen *et al*. 2015), but a wider view of the role of cover crops sees investments that respond to the present soil and environmental condition in intensive agricultural production.

The use of mixtures, especially legume–small grain proved a very effective strategy for the management of winter cover crops, because cereal and annual legume complement each other very well. The grass is capable of high growth rates during the cold season, and legume is very important in spring, when N becomes the limiting factor (Bedoussac *et al*. 2015).

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