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NITROGEN RELEASE DYNAMICS AND CARBON SEQUESTRATION BY LEGUME AND NON-LEGUME COVER CROPS UNDER PURE AND MIXED PLANTING CONDITIONS

SHAYESTEH SADRA, GHOLAMREZA MOHAMMADI*, FARZAD MONDANI

Razi University, Kermanshah, Iran

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Synchronizing crop residue decomposing and releasing nitrogen with subsequent cash crop needs provides benefits for ecosystems, but it is difficult to carry out. This study aimed to investigate the trend of decomposition of vetch (*Vicia sativa*), rye (*Secale cereal*e) and mixed (rye + vetch) cover crop residues as well as nitrogen release after incorporating them into the soil during 12 weeks of the potato growth season by using the mesh bag method. Vetch residues decomposed very quickly in the spring and their nitrogen is released due to their higher nitrogen content and consequently a lower Carbon/Nitrogen (C/N) ratio. However, rye residues decomposed at a slower rate compared to mixed treatment, and their nitrogen content was immobilized mainly due to a higher C/N ratio. A better understanding of cover crops residues decomposition dynamics leads to maximizing the cover crop effects and higher nutrient uptake by subsequent main crops. The results of this study showed that the input level of nitrogen fertiliser can be reduced by implementing management strategies in farming potatoes and using cover crops, which will reduce the harmful environmental effects and increase the economic benefit for farmers.

Key words: C/N ratio, cover crop, nitrogen release, rye, Vetch

Pollution of groundwater by nitrate is a result of intensive agricultural operations and non-planted farming soils during the fallow season. Planting cover crops between two main crops is considered an effective solution to reduce nitrate leaching from the soil (Constantin *et al.* 2011). More ever cover crops can release nitrogen stored in their tissues for the next crop after incorporating them into the soil (Justes *et al*. 2012). This service is highly dependent on the C/N ratio of cover crops (Justes *et al*. 2009).

Non-legume cover crops can effectively reduce nitrate leaching (Thorup-Kristensen *et al*. 2003) and uptake more than 70% of soil mineral nitrogen during the fallow period (Justes *et al*. 2012). High biomass is produced in a cold climate by non-legume cover crops such as rye, which leads to significant storage of soil mineral nitrogen (Shipley *et al*. 1992). In addition, rye cover crop reduces nutrient leaching due to their dense root system. Singh *et al*. (2018) reported that farming systems with rye can decline nitrogen leaching up to 81% in comparison with other cropping systems without rye. Due to the high C/N ratio in the rye, the decomposition rate of plant residue and nitrogen release is lower compared with legume cover crops (Sievers & Cook 2018), and even the insolubility of nitrogen occurs during the decomposition period (Kuo & Sainju 1998). In contrast, the lower the C/N ratio in legume cover crops can be led to faster residue decomposition, mineralization, process, and consequently more ni-

Shayesteh Sadra, Gholamreza Mohammadi (*Corresponding author), Farzad Mondani, Department of Plant Production and Genetic Engineering, Faculty of Agriculture and Natural Resources, Razi University, Kermanshah, Iran. E-mail: gr_mohammadi@razi.ac.ir.

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trogen release into the soil as compared to non-legume cover crops such as rye (Tonitto *et al*. 2006).

Some of the nitrogen stored in legume tissues comes from the biological fixation of the atmospheric N_2 (Peoples *et al*. 1995). On the other hand, legumes can act as a catch crop and uptake about 60% of the soil nitrogen compared to non-cultivated soils (Wortman 2016). However, the mixed cropping of legume and non-legume cover crops can have the benefits of both plants together and have fewer negative effects than mono-cropping. For example, the mixed cropping of vetch and rye produced higher biomass (Hayden *et al*. 2012), more mineral nitrogen storage (Tosti *et al*. 2010), more weed suppression (Hayden *et al*. 2014), and higher nitrogen content (Parr *et al*. 2011) in comparison with mono-cropping of vetch or rye.

According to Rosecrance *et al*. (2000), a moderate C/N ratio in a mixed vetch-rye cover crop treatment may be a reason for better decomposition rate and consequently high synchrony between nitrogen release from the cover crop tissues and cash crop demand for nitrogen (N). Some studies have shown that vetch-rye mixed cropping resulted in an equivalent accumulation of biomass and nitrogen when compared with their mono-cropping, and nitrogen released for the next crop is almost similar to that for vetch mono-crop (Sainju *et al*. 2005) in this system fixed nitrogen by legumes is transferred directly to the grasses via hyphae system or indirectly due to the decomposition of legume residues (Jensen 1996).

This study was carried out to investigate the dynamic of nitrogen release from the incorporated cover crop tissues, including vetch, rye, and their mixture during the growing season of subsequent potatoes and the ability of these cover crops to fix air carbon.

MATERIAL AND METHODS

Experimental site

The study was carried out during the 2018 − 2019 and 2019 − 2020 growing seasons at the Agricultural Research Farm of the Faculty of Agriculture & Natural Resources, Razi University, Kermanshah, Iran (47° 9′ E & 34° 21′ N and 1319 m above sea level) with a cold and temperate climate, an annual mean rainfall of 450 mm and an annual mean temperature of 22°C. Weather data during the experimental years and the soil traits of the experimental field are shown in Figure1 and Table 1, respectively.

Soil texture was determined by the method proposed by Gee and Bauder (1986), soil active pH and electrical conductivity (EC) were measured by the method described by McLean (1982). The acid neutralization method (Jackson & Barak 2005) applied to determine Calcium Oxide (CaO). Total nitrogen was measured via digestion or destruction by sulfuric acid, namely the Kjeldahl method (Bremner 1970). Available Phosphorus (P) (Olsen *et al*. 1954) and available Potassium (K) (De Sousa 1961) were determined by Spectrophotometer and Flame Photometer, respectively.

Treatments and field practices

The study was carried out based on a randomized complete block design with three replications. Cover crop treatments consisted of control (no cover crop), rye *(Secale cereale)*, vetch *(Vicia sativa),* and mixed (rye + vetch). The soil was prepared before planting. Cover crops were planted on 1 and 4 November in the first and the second year, respectively. Planting densities were 150 and 80 kg/ha for rye and vetch, respectively, as well as mixed cropping (rye + vetch) was considered as a 50 + 50 ratio. In both years, cover crops emerged 13 − 18 days after planting (3 − 5 days after the first precipitations). Plots were not irrigated and no chemical fertilisers and pesticides were used during the growing seasons.

Cover crops were incorporated into the soil using a moldboard plow on 6 and 7 April 2019 and 2020, respectively. Quantities and qualities of the incorporated cover crops depended on the type of the cover crops and the year, and the data are presented in Table 3.

Before incorporation cover crop biomass was determined using a 0.5 × 0.5 quadrat randomly located in each plot. Samples were dried using an oven at 70°C for 72 hours. Organic carbon contents of the soil and cover crops were determined by the Walkley-Black method described by Nelson and Sommers (1983) and nitrogen was measured via the Kjeldahl method (Bremner 1970).

The trend of nitrogen decomposition and release from the cover crop tissues incorporated into the soil were evaluated by Stute and Posner (1995) methods. Before incorporation, the shoot and root of each cover crop treatment were sampled, chopped into 3 − 5 cm pieces, and placed in mesh plastic bags then were buried in the soil at a depth of 30cm. The weight and nitrogen content of the buried samples were measured at a two-week interval until 12 weeks after burring them into the soil. Obtained data were used to investigate the process of nitrogen release from cover crop residues, release synchrony with potato, and crop residue decomposition process. Soil samples of each plot were collected from a depth of 0 − 30 cm 5 months after incorporating them into the soil, carbon sequestration was calculated using the following equation:

$$CS = 10{,}000 \times BD \times \%OC \times e$$

Where: CS is carbon sequestration [kg/ha], BD is soil bulk density [g/cm^3], %OC is soil organic carbon content and e is the depth of sampling [m].

Potato tubers of cultivar Santa (an early maturing cultivar) were planted manually at a distance of 75 cm between the rows and 23 cm distance between plants in the same row on 21 and 22 April in the first (2019) and the second year (2020), respectively. So the synchrony between the maximum potato

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Soil characteristics of the experimental field

EC [ds/m]	Active pH	CaO [%]	Organic carbon [%]	Total N [mg/kg]	Available P [mg/kg]	Available K [mg/kg]	Clay [%]	Silt [%]	Sand [%]
0.98	8	9	0.28	590	6.2	230	8	9	83

EC − electrical conductivity.

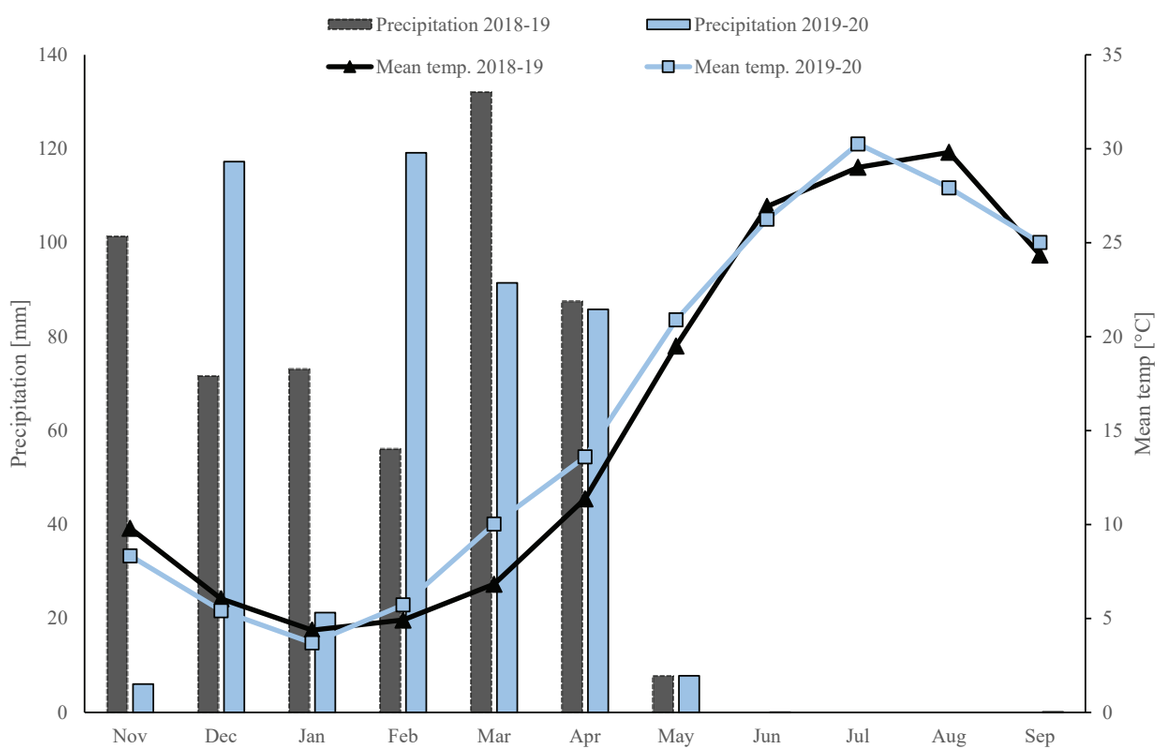


Figure1. Monthly precipitation and mean temperature data during the first and the second year of the study.

requirement and maximum nitrogen release from cover crop residues during the potato growth stages was measured.

Data were analysed by using MSTATC software and the means were compared using the *LSD* test at the 0.05 level of probability. The homogeneity of variance test was performed on the data obtained from the study before the composite analysis.

RESULTS AND DISCUSSION

Cover crop C content, N content, C/N ratio, and biomass

Analysis of variance showed that both biomass and carbon content of the cover crops were significantly different between the years of the experiment ($p \leq 0.01$). However, the nitrogen content and C/N ratio were not significantly influenced by this factor (Table 2).

The conditions of germination and establishment of cover plants in the first year were better than in the second year. In general, cover crops showed higher biomass and carbon (C) contents in the first year of the experiment probably due to essentially higher precipitation during November (101 mm) when compared with the second year (6 mm). Moreover, the precipitation amount during March when cover crops produced a high biomass value was more in the first than in the second year (Figure 1).

Thorup-Kristensen *et al*. (2003) suggested that biomass accumulation and nitrogen uptake in cover crops depend on climatic conditions. Unger and Vigil (1998) reported that water available during the planting phase, rainfall and low temperatures during the growing phase are major factors determining the growth of cover crops in semi-arid regions. This is in accordance with Gabriel and Quemada (2011) who reported annual variation in terms of biomass and nitrogen content of cover crops.

In our study, the highest biomass was produced from rye, and the lowest one was observed in vetch, treatments (Table 3). Rye is more adapted to cold and dry conditions than vetch. As it can grow much faster before the occurrence of low temperatures and cover the soil surface. Our results are consistent with the finding of Ramirez-Garcia *et al*. (2015).

Gabriel *et al*. (2016) found that in the first year of the establishment, there was no significant difference between the biomass produced by vetch and barley cover crops, however, in the second-year vetch produced 550 kg/ha more biomass than barley. Mancinelli *et al*. (2019) by examining two cover crops (vetch and rye) found no significant difference between the biomass produced by them.

The highest biomass was produced by rye, which was 33% more than that produced by vetch (Table 3). According to Gabriel *et al*. (2016), the nitrogen content of the vetch cover crop was significantly higher than barley. In another study, Mancinelli *et al*. (2019) found the bigger nitrogen content of vetch when compared with rye cover crop.

The higher nitrogen content of vetch can be explained by its ability to fix atmospheric nitrogen while rye completely depends on soil nitrogen which is limited in many conditions. Schomberg *et al*. (2005) observed that a large part of the nitrogen content in chickpea cover crop residues is related to atmospheric N_2 fixation, while the nitrogen in rye biomass and brassica was due to mineralization of

Table 2

Analysis of variance for the cover crop traits

Source	Mean square			CV [%]
	Year	Cover crop	Year × Cover crop	
C content	18,378.9^{++}	168,623.3^{++}	108.79$^{n.s}$	11.78
N content	152.7$^{n.s}$	1,356.5^{++}	7.53$^{n.s}$	11.14
C/N ratio	0.7$^{n.s}$	239.3^{++}	0.08$^{n.s}$	8.66
Biomass	115,040.0^{+}	609,394.0^{++}	700.05$^{n.s}$	8.82

$^{n.s}$ Non-significant, $^{+}$ and $^{++}$ significant at the 0.05 and 0.01 level of probability, respectively.
C/N – carbon to nitrogen; CV – coeficient of variation.

soil organic nitrogen or mineralized nitrogen from the previous crop. Vetch has the highest nitrogen content in its tissues as a legume due to its ability to fix atmospheric nitrogen (Anugroho *et al*. 2009). Conversely, in grasses such as rye, the amount of nitrogen in their tissues depends on their ability to absorb nitrogen from the soil (Valkama *et al*. 2015).

In both years, the highest C/N ratio was recorded in the rye treatment, and the lowest value was measured in vetch plots (Table 2). Organic carbon content was not significantly different between the rye and the mixture treatments, and the lowest one was observed in vetch in both years of the experiment.

Weidhuner *et al.* (2019) concluded that the concentration of nitrogen in the biomass of vetch was higher than in rye, which led to a decrease in the C/N ratio of this cover crop. Similar results were obtained by Jahanzad *et al.* (2016) who reported the highest C/N and lowest nitrogen content in the rye cover crop. In their study, rye also produced the lowest biomass compared to chickpea and forage radish. Seman-Varner *et al*. (2019) also showed a higher C/N ratio for rye cover crops as compared with vetch.

Nitrogen release from cover crop residues

The pattern of nitrogen release from the residues of vetch, rye, and mixed (rye+vetch) treatments was almost the same in both experimental years (Figure 2).

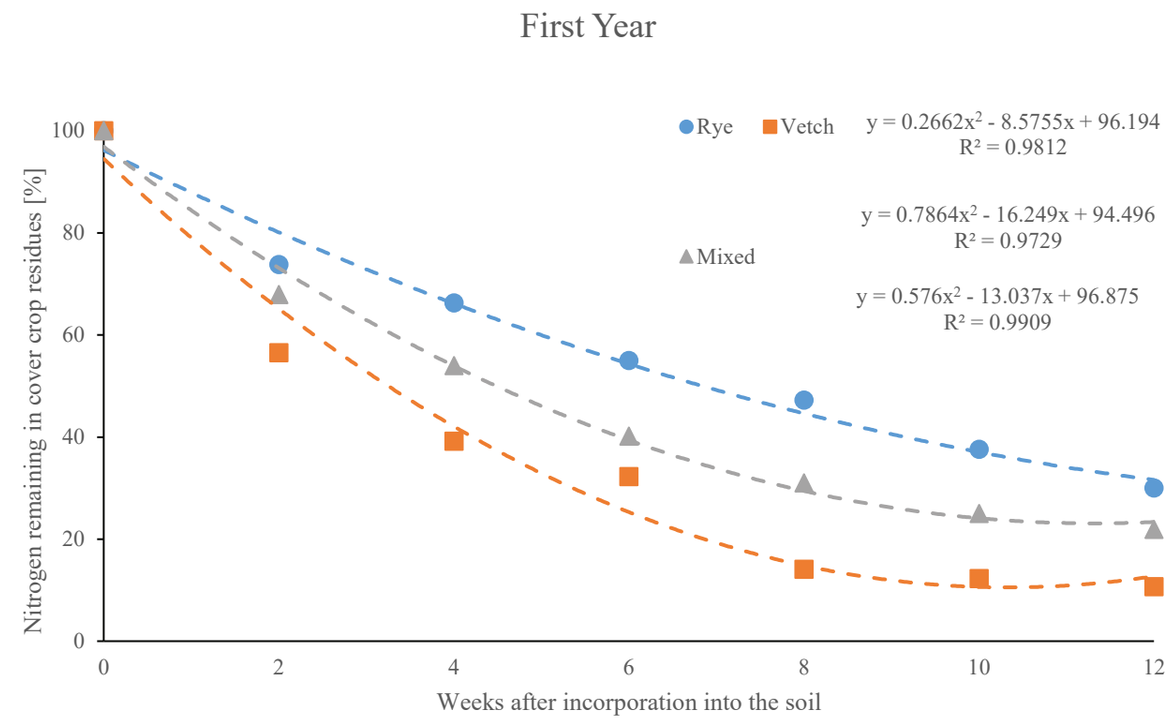
In both years' vetch and mixed treatments showed the highest N release rate until 8 weeks after incorporating them into the soil followed by a lag phase up to 12 weeks later (Figure 2). In the case of rye, nitrogen release showed a slower and more consistent pattern during the period after incorporation it into the soil (Figure 2). Generally, in both years' vetch showed a higher rate of N release throughout the incorporation followed by mixed and rye treatments (Figure 2). For vetch cover crops, more than 80% of N content was released until 8 weeks after incorporation while the value for rye was about 50% in the same period (Figure 2). However, the mixed treatment showed an intermediate rate of N release in both years (Figure 2).

T a b l e 3

Mean comparison of some traits of the cover crops under study

		Cover crop	C content [kg/ha]	N content [kg/ha]	C/N ratio	Biomass DW [kg/ha]
First year (2019)		Rye	930.0^{a}	44.47^{c}	21.18^{a}	2,417^{a}
		Vetch	670.8^{b}	76.37^{a}	8.83^{c}	1,820^{b}
		Mixed (Rye+Vetch)	992.8^{a}	61.50^{b}	16.40^{b}	2,337^{a}
		LSD Value	217.20	14.47	2.83	426
Second year (2020)		Rye	857.30^{a}	39.90^{b}	21.87^{a}	2,232^{a}
		Vetch	615.1^{b}	67.95^{a}	9.12^{c}	1,670^{b}
		Mixed (Rye+Vetch)	929.4^{a}	57.00^{a}	16.67^{b}	2,192^{a}
		LSD Value	227.3	14.75	3.30	416
Combined analysis	Year	2019	864.50^{a}	60.77^{a}	15.47^{a}	2,191^{a}
		2020	800.60^{b}	54.95^{a}	15.88^{a}	2,031^{b}
	Cover crops	Rye	893^{a}	42.18^{c}	21.52^{a}	2,324^{a}
		Vetch	642^{b}	72.16^{a}	8.97^{c}	1,745^{b}
		Mixed (Rye+Vetch)	961^{a}	59.25^{b}	16.53^{b}	2,265^{a}
		LSD Value	184	12.13	2.55	350

Figures with the same letters in each column have no significant difference at the 0.05 level of probability (*LSD* test).
C/N − carbon to nitrogen; DW − dry weight; *LSD* − least significant difference.



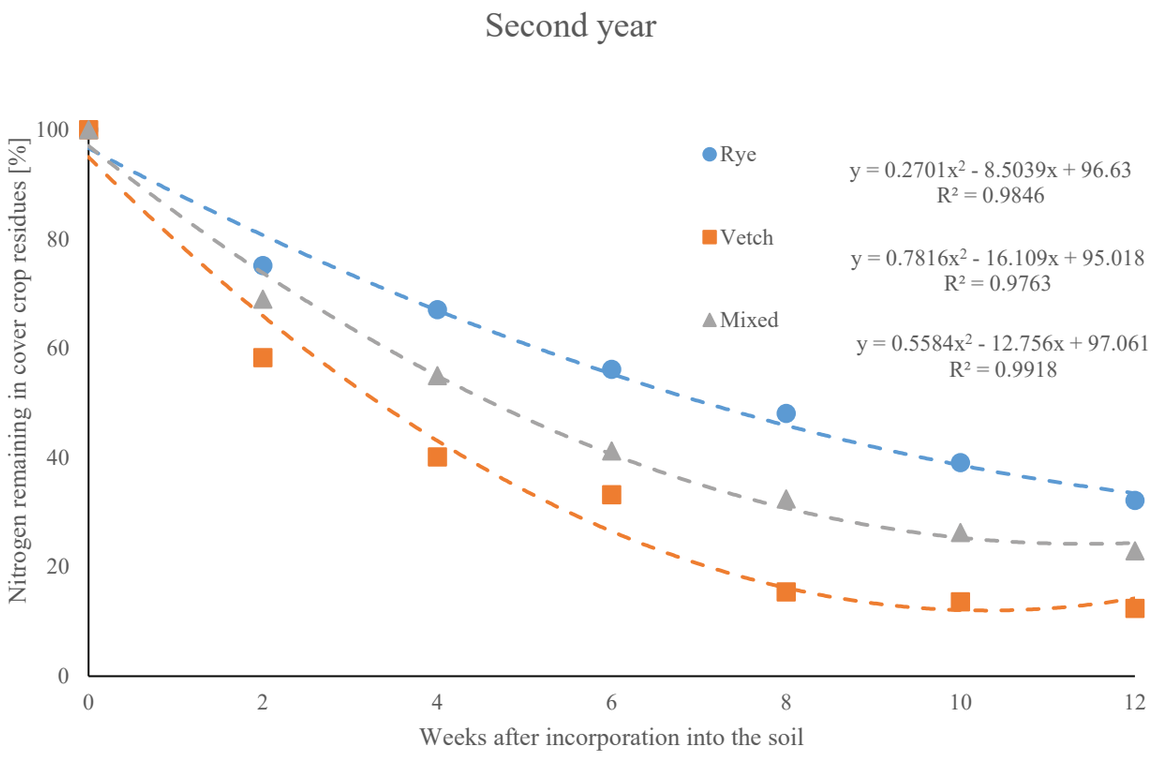


Figure 2. Nitrogen remained in the cover crop residues over weeks after incorporation into the soil.

According to Sarrantonio and Scott (1998), large amounts of nitrogen were released during a 2 − 5 week period after the incorporation of cover crops into the soil in the spring, and after that decomposition rate and N releases notably reduced during the growth season. Nevins *et al*. (2020) reported that the decomposition rate of vetch residue incorporated into the soil was higher than rye and their mixtures. Abera *et al*. (2014) studied the decomposition rate of several legume cover crops in Africa and found that 89% of the nitrogen in chickpea and bean residues was released within 150 days of incorporating them into the soil.

Singh *et al*. (2020) observed that nitrogen release from vetch cover crop was higher than rye as vetch showed maximum nitrogen release in the second and the third week after incorporation into the soil during the first and the second experiment, respectively. But the release of nitrogen from rye residues was significantly slower than vetch residue, and even led to the N immobilization until 6 to 10 weeks in 2017 and 5 weeks in 2018 after incorporating it into the soil.

Our study confirmed that vetch cover crops with a lower C/N ratio have a higher nitrogen release after incorporation into the soil, while rye with a higher C/N ratio showed a lower N release which can be an indicator of nitrogen immobilization.

Sievers and Cook (2018) suggested that lignin concentration and C/N ratio are effective factors in decomposition processes and the lower C/N ratio of Vetch in comparison with rye is the main reason for the higher vetch residue decomposition rate. Jahanzad *et al*. (2016) attributed the lower residue decomposition and nitrogen release rate in the rye to the high C/N and lignin ratio in comparison with chickpeas and forage radishes.

A high level of carbon incorporated into soils by rye cover crop can result in nitrogen immobilization and a decrease in the soil available nitrogen (Roth *et al*. 2018).

The results showed that N was released at a higher rate for the mixed treatment (vetch + rye) when compared with rye. The mixture of legume and non-legume cover crops avoids the immobilization of nitrogen by non-legume cover crops and consequently leads to faster nitrogen mineralization. Brennan and Boyd (2012) found that mixed planting of legume cover crops with cereals can prevent nitrogen loss compared to their monoculture. Alonso-Ayuso *et al*. (2014) found that nitrogen immobilization can be reduced by using cover crops having lower C/N ratios, mixed planting of cover crops, and suitable time incorporating them into the soil.

Synchrony between potato need for nitrogen and nitrogen release from the cover crop residues

Using nitrogen fertiliser in farming potatoes during our study was performed in three stages emergence (14 days after planting), tuber initiation (45 days after planting), and tuber bulking (60 days after planting). The emergence, tuber initiation and bulking stages coincided with 4, 8 and 10 weeks after returning residues to the soil, respectively. According to Figure 3, the higher nitrogen release from the cover crop residues occurred two weeks after incorporating them into the soil. At this time, vetch showed a higher N release rate than rye and mixture, and the trend continued until 4 weeks after the incorporation. After that, mixed and rye treatments showed a higher nitrogen release rate compared to vetch. According to these estimates, it can be concluded that the level of nitrogen fertiliser input can be reduced with some management practices. By eliminating nitrogen fertilisation at the emergence stage and providing the plant nutrition needs by cover crops, or by changing the potato farming date, better synchrony can be made between releasing nitrogen for cover crops and the maximum potato requirement.

According to Radicetti *et al*. (2016), vetch can add a large amount of mineral nitrogen to the soil in a short time when it is incorporated into the soil, which is usually not synchronized with the maximum nitrogen uptake by subsequent vegetables such as peppers. The vegetables grow slowly at the beginning of the growing season and a large amount of nitrogen is lost reach of plants.

Jahanzad *et al*. (2017) by studying the synchrony between potato need and nitrogen release from forage radish, chickpea and rye cover crops concluded that at the time of maximum potato need for nitrogen, forage radish, chickpea and rye released 52, 70 and 40% of N from their residue, respectively. Murungu *et al.* (2011) measured the amount of nitrogen and mineral phosphorus released from legume and ce-

real cover crops and found that legume cover crop supply more nitrogen for the next cash crop in comparison with cereals. Ibewiro *et al*. (2000) suggested that the C/N ratio and decomposition rate could be used as indicators for nitrogen release from cover crop tissues and its synchronization cash crop needs.

In a study, legumes and cereals were compared to evaluate their nitrogen fixation and releasing abilities and was found that legumes with a lower C/N ratio increased dry matter produced and nitrogen uptake by subsequent cash crops as compared with cereals (Ibewiro *et al*. 2000). The quality of cover crop residues such as the C/N ratio and their chemical composition besides the quantity of nitrogen have the greatest effects on the nitrogen cycle in relation to the synchrony between corn nitrogen uptake and the rate of cover crop residue decomposition (Dabney *et al*. 2001; Crews & Peoples 2005).

Legume cover crops such as milkvetch, clover and purple vetch can play important roles in fixing atmospheric nitrogen, reducing nitrate leaching and increasing soil nitrogen availability for the cash crop that reduces relying on synthetic nitrogen fertiliser and the risk of environmental pollution (Zhu *et al*. 2014). In contrast, the ability of non-legume cover crops is lower to release nitrogen in synchrony with the cash crop need (Thilakarathna *et al*. 2015).

Decomposition of cover crop residues

The trend of dry matter reduction in the rye, vetch and mixed (rye + vetch) cover crops in both years of the experiment is shown in Figure 4. In both years, a sharp decrease occurred in dry matter of the cover crops during two weeks after incorporating them into the soil. On average, vetch showed a higher decomposition rate compared to rye and mixed treatments. Residue decomposition rates in the first sampling date (two weeks after cover crop incorporation) were 32 and 33% for vetch, 21 and 22% of rye, and 24 and 25% for the mixed treatment in the first and the second year of the experiment, respectively (Figure 4).

The higher decomposition rate in the first and the second sampling is due to ease decomposition of carbohydrates, proteins, and components resulting from a low C/N ratio. While the lower rate of decomposition in the subsequent sampling during the growing season is due to higher levels of recalcitrant materials such as lignin in cover crop tissues. Vetch has soft tissues with low C/N which led to a maxi-

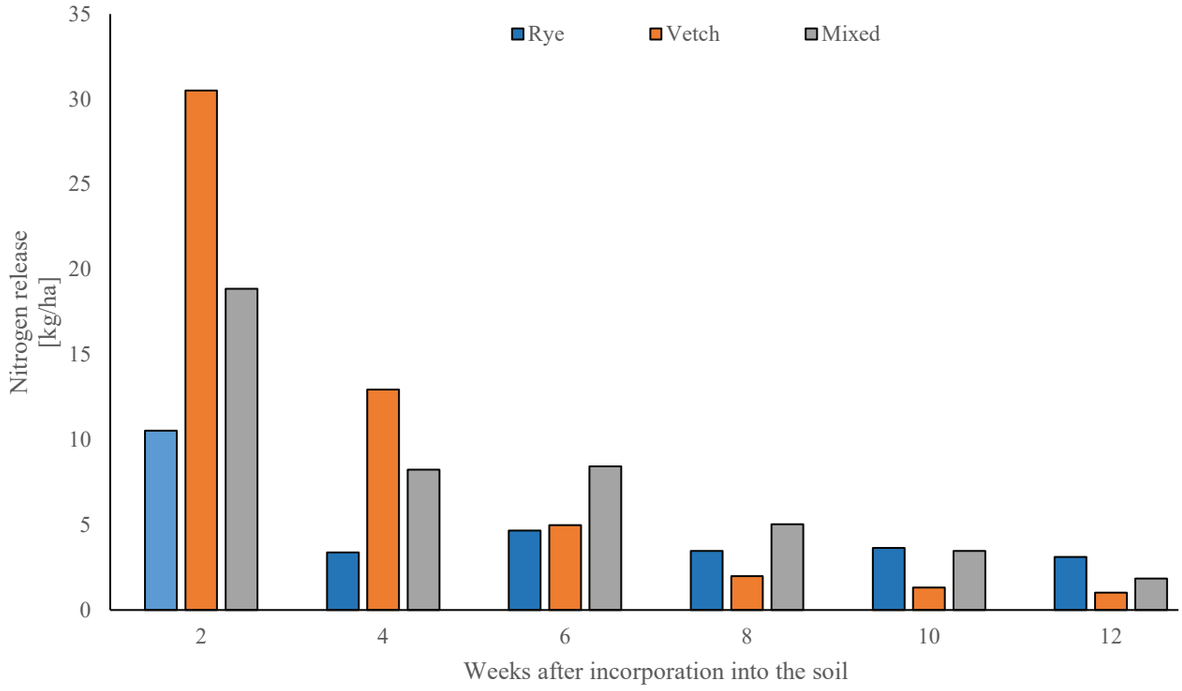


Figure 3. Nitrogen is release from the cover crop residues over weeks after incorporation into the soil.

mum decomposition rate over time compared with other treatments so that non-decomposed residue remained for vetch, mixed crop and rye at the last sampling date were 16% and 15%, 26%, and 25% and 35% and 34% in the first and the second year, respectively (Figure 4). According to the current results, it seems that there is a positive relationship between the amount of nitrogen in plant tissue with the decomposition rate of residue and nutrient release such as nitrogen from it. Frankenberger and Abdelmagid (1985) reported that there is a high correlation between the nitrogen content of plant biomass with nitrogen release and decomposition. A study by Singh *et al*. (2020) showed that vetch decomposed much faster than rye during the first weeks after incorporating it into the soil. Paul and Clark (1989) state that the presence of slowly degradable components such as lignin, cellulose, and hemicellulose in crop residues can significantly reduce the decomposition rate over time.

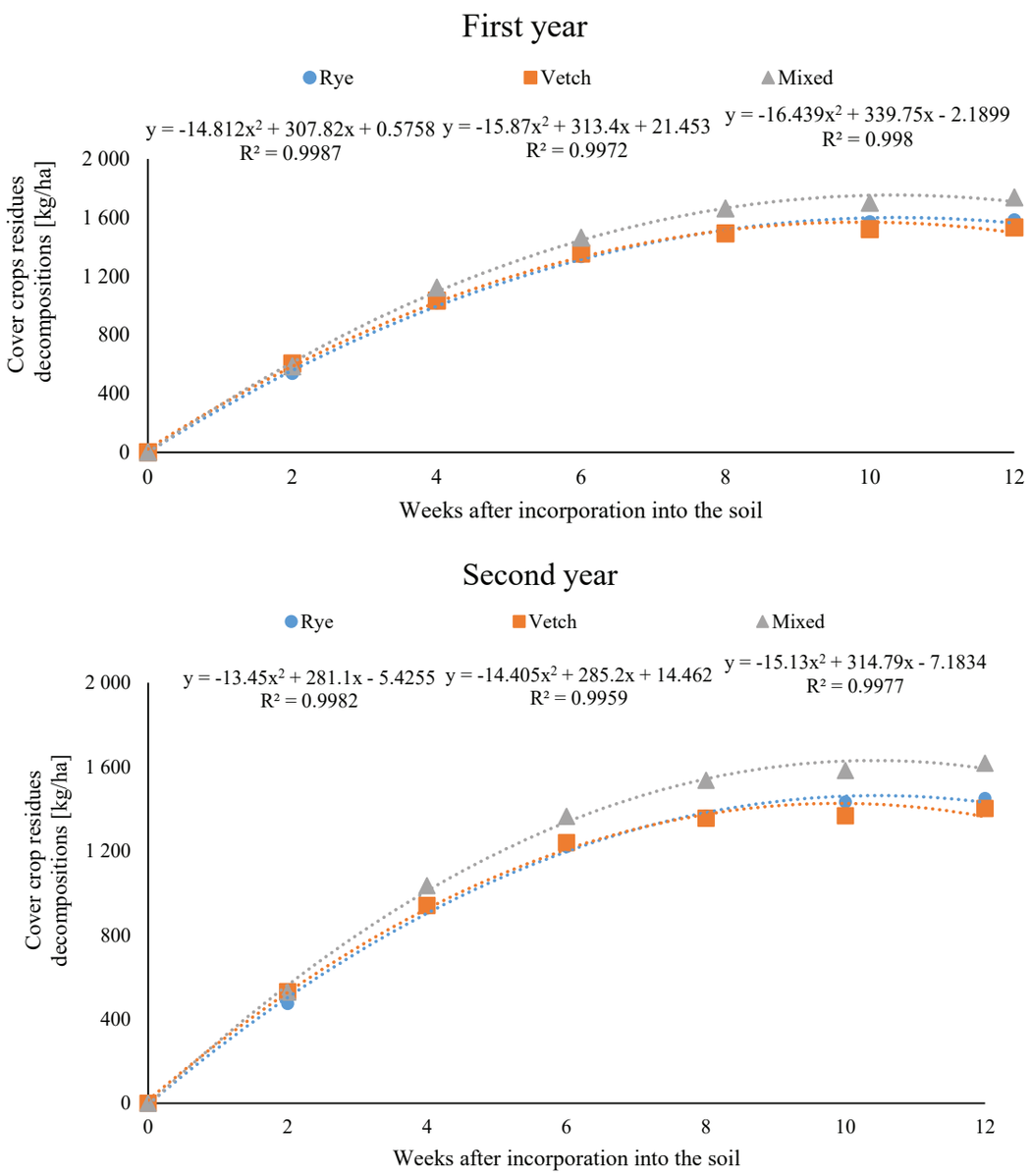


Figure 4. The trend of cover crop decomposition over weeks after incorporation into the soil.

The decomposition and mineralization of crop residues depend on some properties such as nitrogen and carbon contents, residue particle size, and the amount of residue incorporated into the soil. Main soil properties such as soil texture, soil pH, aerobic conditions as well as soil and residue nutrient contents play important roles in the residue decomposition process (Parr & Papendick 1978).

Ruffo and Bollero (2003) reported that the C/N ratio is an important factor influencing residue decomposition rate as a lower C/N ratio causes faster decomposition. Sievers and Cook (2018) related vetch´s higher decomposition rate to a lower C/N ratio when compared with rye. Jahanzad *et al*. (2016) concluded that the decomposition rate of rye residues was slower than chickpea and forage radish cover crops so that at 6 weeks after incorporation, both chickpeas and forage radish lost 50% of their residue weight, while the value recorded for rye was only 30%. Singh *et al*. (2020) showed that vetch had a higher decomposition rate compared to rye and concluded that vetch residue can release its nutrients in a few days after incorporation into the soil, which is highly dependent on environmental conditions, C/N ratio, and residue quality. Cookson *et al*. (1998) by comparing legumes and cereals found that the decomposition rate of legume residues was then that of cereals 90 days after incorporating them into the soil.

Carbon fixation

For both years, the ability of the cover crop treatments to fix carbon was significantly different. The highest carbon fixation was observed in the mixed treatment with the amount of 3,249 and 2,837 kg/ha and the lowest ones were observed for vetch by 1153 and 1029 kg/ha in the first and the second year, respectively (Figure 5). Higher C fixation in the mixed and rye treatments can be attributed to the more biomass production and carbon concentration in their residues.

Barbera *et al*. (2012) showed a high correlation between soil carbon input and changes in soil organic carbon in their study. Several other studies have reported that soil carbon sequestration increased linearly with the addition of organic matter (Ghosh *et al*. 2012; Hua *et al*. 2014). Soil microbial activity and carbon sequestration are increased by any management practice that leads to an increase in organic inputs (such as crop biomass and manure) (Jarecki & Lal 2003). Chahal *et al*. (2020) found that the content of soil organic carbon increased from 11 to 22% in cover crop treatments compared to control (no cover crops) in their study, carbon sequestration

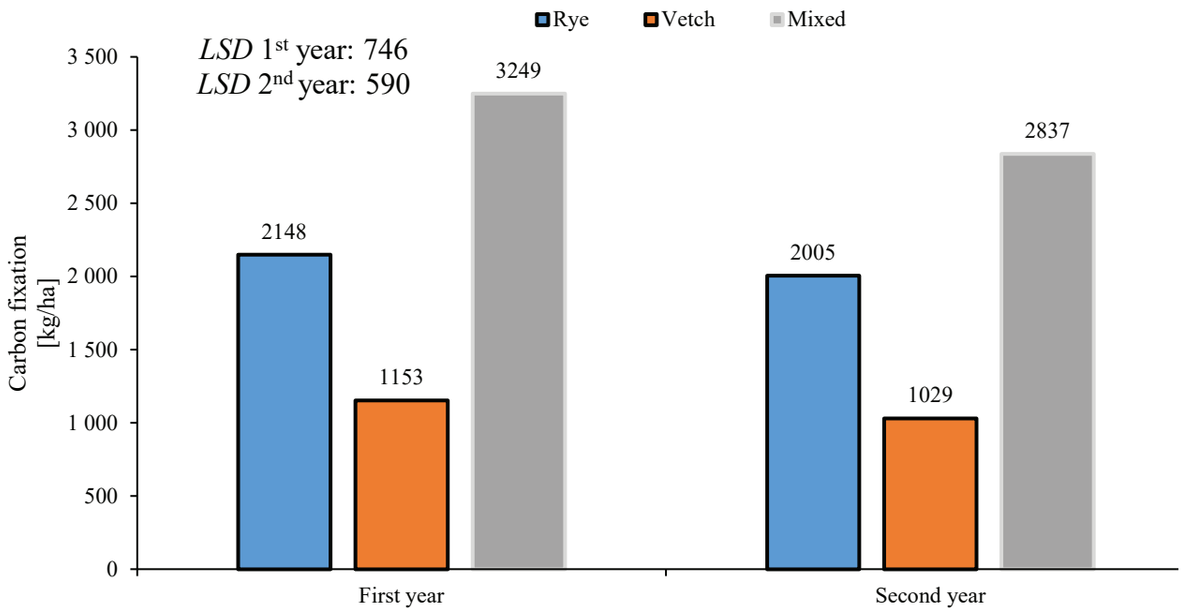


Figure 5. Carbon fixation influenced by cover crop treatments in two years of the experiment.
LSD − least significant difference.

values were between 10 − 20 tons per hectare in the plots under cover crop treatments.

Several studies have confirmed the positive effect of cover crops on soil organic carbon (Jiang *et al*. 2017; Büchi *et al*. 2018).

Jiang *et al*. (2017) concluded that the incorporation of 4,000 and 8,000 kg/ha of corn residues into the soil caused 0.48 and 1.02 t/ha carbon sequestration, respectively. Therefore, adding extra carbon to the soil through residues leads to more carbon sequestration in the soil. Liu *et al*. (2014) showed that about 16.3% of carbon returned to the soil can be sequestrated. the amount of carbon sequestrated resulting from organic carbon inputs (crop and animal residues) was between 6.3 to 31% (Wang *et al*. 2015) depending on carbon input quantity and quality.

Based on studies conducted by Tautges *et al*. (2019), it was found that the mixed cropping of legumes as cover crops before corn and tomatoes under conventional or conservation agriculture increased soil carbon content by 2.03 and 1.25 g/kg at 0 − 15 and 15 − 30 cm of soil depth, respectively. Although planting some legumes such as chickpeas and vetch in their study added less biomass and mineral carbon to the soil when compared with non-legumes but these legume cover crops increased carbon fixation in 0 − 30 cm depth. Soil microbial biomass was increased by legumes at a soil depth of 0 − 30 cm, and using the carbon fraction of cover crops by soil microbes is an important way to increase soil carbon content (Kallenbach *et al*. 2015). Lange *et al*. (2015) suggested that the microbial use efficiency of carbon added by cover crops into the soil can be enhanced by increasing nitrogen available due to use the legume cover crops and lead to an increase in soil organic carbon. Frasier *et al*. (2016) reported that vetch, rye, and mixed (vetch + rye) cover crops increased carbon at a soil depth of 6 − 12 cm soil by examining while this increase was higher in vetch treatment on the soil depth of 0 − 6 cm.

CONCLUSIONS

This study confirmed that there are notable differences between legume and non-legume cover crops in terms of the rate of decomposition of residues and nitrogen release. Vetch had a higher rate of residue decomposition and nitrogen release compared to rye and mixed treatments for four weeks after incorporation into the soil, but it decomposed at a slower rate after this time. Mixed treatment (rye + vetch) had a higher effect on carbon fixation compared to rye and vetch and may be more effective to slow carbon release from the cropping system. In general, vetch cover crops should be incorporated into the soil a short time before the planting of the subsequent spring crop in order to better use of the released nitrogen and avoid N loss due to the processes such as leaching and denitrification. In contrast, the subsequent spring crop can be planted with a longer interval after the incorporation of the mixed and especially rye cover crops into the soil because of a slower N release from their residues which is mainly related to the higher C/N ratios.

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