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Nitrogen Transfer from Cover Crop Residues to Onion Grown under Minimum Tillage in Southern Brazil

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ABSTRACT: Nitrogen derived from cover crop residues may contribute to the nutrition of onion grown under minimum tillage (MT) and cultivated in rotation. The aim of this study was to evaluate the N transferred from different cover crop residues to the onion crop cultivated under MT in southern Brazil. In June 2014, oilseed radish, black oat, and oilseed radish + black oat residues labeled with ^{15}N were deposited on the soil surface before transplanting onions. During the growth season and at harvest, young expanded onion leaves, complete plants, and samples from different soil layers were collected and analyzed for recovery of ^{15}N-labeled residue. Oilseed radish decomposed faster than other residues and 4 % of residue N was recovered in leaves and bulbs at harvest, but in general, N in plant organs was derived from sources other than the cover crop residues. In addition, leaf N was in the proper range for all treatments and was adequately mobilized to the bases for bulbing. The N derived from decomposing residues contributed little to onion development and the use of these plants should be chosen based on their advantages for physical and biological soil quality.

Keywords: *Allium cepa* L., plant ^{15}N recovery, residue N, plant N partition, soil ^{15}N.

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INTRODUCTION

Cover crops offer many benefits for farmers seeking to reduce their reliance on external inputs (Haramoto and Gallandt, 2004). In Brazil, onion (*Allium cepa* L.) is grown predominantly under conventional tillage with soil disturbance, and soil, water, and nutrient losses from runoff may occur (Loss et al., 2015). The use of minimum tillage (MT) has been encouraged as an alternative practice to conventional tillage. In the MT system, onion is planted under residues of cover crops such as black oats (*Avena strigosa* Schreb) and oilseed radish (*Raphanus sativus* L.) grown during the fall and winter, alone or intercropped (Souza et al., 2013).

These residues protect the soil against the impact of raindrops, reduce runoff, suppress weed growth, and increase soil water storage and nutrient release (Haramoto and Gallandt, 2004; Mbuthia et al., 2015). The residues decompose during onion growth at different rates, according to their biochemical properties, the environmental conditions, and soil practices. During residue decomposition, residue N is mineralized and returns to the soil in the mineral form, rising the availability of N forms such as nitrate (NO_3^--N) and ammonium (NH_4^+-N) in the soil, which can be easily taken up by the crop throughout its cycle (Craine et al., 2015). It is expected that most N forms derived from the decomposition of residues in the soil are recovered by onion, thus promoting plant N nutrition and reducing the levels of mineral N accumulated in the soil, consequently decreasing the potential for N losses through leaching (Haramoto and Gallandt, 2004).

The biodegradation rate of plant material is affected by soil temperature, moisture, pH, oxygen and nutrient content, and the amount of plant residue and its chemical composition (Silva et al., 2016), e.g., the cellulose, lignin, and hemicellulose contents and the C/N, lignin/N, and lignin/P ratios (Carranca et al., 2009). In general, residues from plants like black oats, with high lignin content and high C/N, lignin/N, and lignin/P ratios are decomposed more slowly and release N more gradually (Mohanty et al., 2013) than residues from plants like oilseed radish, with lower lignin and higher cellulose contents and lower C/N, lignin/N, and lignin/P ratios (Cicek et al., 2015). Therefore, maintaining an adequate amount and type of plant residue on the soil surface is recommended (Martins et al., 2014). However, supplying N from cover crops, alone or intercropped, deposited on the soil surface has different patterns of release during decomposition of the residue due to different C/N ratios and lignin and cellulose content.

Nutrient partitioning between plant organs is an important issue that directly influences horticultural crop production (Rezaei et al., 2013) and it is highly influenced by environmental conditions and management practices. During the onion growth cycle (approximately 115 days), plant N is mobilized from leaves to bulbs, which are organs with intense cell division and rapid increase in dry matter production (Caruso et al., 2014).

Studies on the potential contribution of cover crop residues to onion N nutrition and growth are lacking (Haramoto and Gallandt, 2004). Thus, our hypothesis is that N derived from cover crop residues may contribute to the nutrition of onion grown under MT. The objective of the current study was to determine N transfer from cover crop residues to onion cultivated under MT in southern Brazil.

MATERIALS AND METHODS

Site description

The experiment was carried out in an onion (*Allium cepa* L., cv. Empasc 352 - "Bola Precoce") producing area cultivated under conventional tillage (plowing and harrowing) for 20 years, until 1996. The area was at the experimental station of the *Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina* in the municipality of Ituporanga, Alto Vale do Itajaí region, state of Santa Catarina (SC), in southern Brazil

(27° 24' 52" S, 49° 36' 9" W and altitude of 475 m). Since 1996, lime was applied on the area to raise the soil pH(H_2O) to 6.0 (CQFS-RS/SC, 2004) and MT was used for onion production. In 2009, onions grown under rotation with black oat (*Avena strigosa* Schreb), oilseed radish (*Raphanus sativus* L.), and rye (*Secale cereale* L.) was initiated.

The climate in the region is subtropical humid mesothermal (Cfa), according to the Köppen classification system (Kottek et al., 2006), with an average annual temperature of 17.6 °C and an average annual rainfall of 1,400 mm. The average values of air temperature and rainfall recorded during the experimental period were 17.1, 19.3, 21.4, 24.0, and 25.4 °C and 108, 233, 165, 132, and 213 mm for August, September, October, November, and December, respectively. The soil was classified as a *Cambissolo Húmico* (Souza et al, 2013) or Inceptisol (Soil Survey Staff, 2006). At the beginning of the experiment (April 2009), the chemical and physical properties in the 0.00-0.10 m layer were: total organic C 23.2 g dm^{-3} (Walkley-Black); pH(H_2O) 6.0; P 26.6 mg kg^{-1} and K 145.2 mg kg^{-1} (extracted by Mehlich-1); Al^{3+} 0.0 $cmol_c$ kg^{-1}, Ca^{2+} 7.2 $cmol_c$ kg^1, and Mg^{2+} 3.4 $cmol_c$ kg^{-1} (extracted by 1 mol L^{-1} KCl); $CEC_{pH7.0}$ 14.32 $cmol_c$ kg^{-1}; base saturation (V) 76 %; and Al saturation (m) 34 %.

The layout of the experiment was a randomized complete block design with three treatments and eight replicates. The treatments were as follows: black oat (BO), oilseed radish (OR), and OR + BO residues from plants that had been seeded at rates of 120, 20, and 10 + 60 kg seeds ha^{-1}, respectively (Monegat, 1991).

^{15}N-labelling procedure for cover crops

The OR and BO cover crops were grown in a *a Argissolo Vermelho Amarelo Distrófico* (Santos et al., 2013) or Typic Hapludalf soil (Soil Survey Staff, 2006), collected at the 0.00-0.20 m depth. After collection, the soil was air dried and passed through a 2 mm sieve. In June 2014, 15 kg of sieved soil was placed in 48 polypropylene trays (0.55 m length × 0.35 m width × 0.13 m height). The OR and BO cover crops were sown in a greenhouse until August 2014 in those trays at densities of 18 and 3 g m^{-2} of seeds, respectively, corresponding to 120 and 20 kg ha^{-1} of seeds (Monegat, 1991). Greenhouse conditions were controlled for internal air temperature at an average of 19 °C and for relative humidity at an average of 60 %.

Cover crops were grown with a photoperiod of approximately 12 h. Before sowing the cover crops, a solution containing 41 g N enriched with 4 atom % ^{15}N excess was carefully spread over the soil to label OR and BO plants with ^{15}N. Three applications were performed: the first application was conducted 10 days after OR and BO germination; the other two applications were performed throughout the time of plant growth. During the growing cycle, plants were supplied with a nutrient solution (Hoagland) free of N, and deionized water was added to the trays to maintain soil moisture content at around 70 % of field capacity. Weeds were removed manually to avoid uptake of ^{15}N.

Seventy days after plant emergence (August 17, 2014), OR and BO shoots were harvested near the soil surface (free of roots) to be used as cover crop residues for onion production. A sample of each crop species was oven dried at 65 °C until constant weight, ground, sieved at 0.5 mm, and chemically analyzed for several components (Table 1).

Residue deposition on the soil surface

For this study, the stable ^{15}N isotope was used as a tracer to monitor the amount of N derived from residues and recovered by onion (Brunetto et al., 2014; Inácio et al., 2015). On August 18, 2014, cover crop residues (shoots) enriched with ^{15}N were added to the soil at the experimental site. Microplots of 0.5 m^2 (1.0 × 0.5 m) were randomly distributed in the field and fresh residues (containing about 3.8 % ^{15}N atom excess, table 1) were applied to a weed-free soil surface with total fresh matter of 0.805 kg of OR, 0.880 kg of BO, or 1.416 kg of OR + 0.200 kg of BO. These values corresponded

to 16,100; 17,600; and 28,320 + 4,000 kg ha^{-1}, respectively, of fresh weight, which is equivalent to 2,900; 4,400; and 5,100 + 1,000 kg ha^{-1} of dry matter (DM) for OR, BO, and OR + BO, respectively (Table 1).

The amount of residues added to the soil were equivalent to those produced in the field. In each microplot, a 2 mm nylon mesh was fixed to the soil to cover the residues in order to avoid their dispersion by wind, rainfall, or animals. Onions were sown in the microplots in two 1 m length rows, for a total of 20 plants per microplot. Throughout the period of onion growth, weeds were manually removed to avoid uptake of residue N.

Plant sampling

On each date at 28, 44, 66, and 83 days after residue addition, the youngest fully expanded onion leaf was collected from 10 plants per microplot (Kurtz et al., 2013). On November 10, 2014 (83 days after residue addition), three complete onion plants were harvested and separated into leaves and bulbs. The plant material was oven dried at 65 °C, ground, and sieved (<0.5 mm) and the DM was determined per plant.

Soil sampling

Soil samples were collected in the center of each microplot, in the 0.00-0.05, 0.05-0.10, 0.10-0.15, and 0.15-0.20 m layers. The soil was air dried and passed through a 2 mm sieve to be analyzed for total residual N (g kg^{-1}) and % ^{15}N enrichment.

Table 1. Chemical composition of oilseed radish (OR), black oat (BO), and oilseed radish + black oat (OR + BO) residues

	OR	BO	OR + BO
Total organic C (g dm^{-3})	374.9 ± 4.37[(1)]	453.1 ± 0.94	387.8 ± 2.48
Atom % ^{15}N excess (%)	3.8508 ± 0.02	3.7613 ± 0.03	3.8415 ± 0.01
Total N (g kg^{-1})	31.50 ± 0.51	36.70 ± 0.12	32.35 ± 0.34
Total P (g kg^{-1})	28.92 ± 1.12	13.95 ± 0.16	26.46 ± 0.96
Total K (g kg^{-1})	15.95 ± 0.57	14.30 ± 1.27	15.70 ± 0.28
Total Ca (g kg^{-1})	14.88 ± 0.16	3.00 ± 0.08	12.93 ± 0.13
Total Mg (g kg^{-1})	8.25 ± 0.18	2.31 ± 0.06	7.27 ± 0.14
Cellulose (g kg^{-1})	233.60 ± 10.85	198.70 ± 13.82	227.87 ± 9.73
Lignin (g kg^{-1})	61.50 ± 11.29	85.80 ± 15.77	65.48 ± 7.99
Non-structural biomass (g kg^{-1})	704.90 ± 3.37	715.50 ± 14.13	706.64 ± 4.09
C/N	11.90 ± 0.81	12.34 ± 0.17	11.98 ± 0.65
Lignin/N	1.95 ± 0.38	2.34 ± 0.43	2.02 ± 0.27
Lignin/P	12.96 ± 1.19	32.48 ± 0.73	14.65 ± 0.93
Cellulose/Lignin	3.80 ± 0.94	2.31 ± 0.60	3.48 ± 0.74
		Added amount	
Dry matter (kg ha^{-1})	2,900	4,400	6,100
Total organic carbon (kg ha^{-1})	1,087	1,994	2,365
Total N (kg ha^{-1})	91.35	161.48	197.33
Total P (kg ha^{-1})	83.87	61.38	161.41
Total K (kg ha^{-1})	46.25	62.92	95.77
Total Ca (kg ha^{-1})	43.15	13.20	78.87
Total Mg (kg ha^{-1})	23.92	10.16	44.35

[(1)] Mean ± standard error (n=3). C/N: carbon/nitrogen ratio. Total organic C: method proposed by Tedesco et al. (1995); atom % ^{15}N excess: mass spectrophotometry; total N: dry combustion; total P, K, Ca, and Mg: digestion with H_2O_2 and concentrated H_2SO_4; cellulose, lignin and non-structural biomass: method proposed by Aber and Martin (1999).

Plant and soil analyses

Cover crops and onion plants taken at 83 days after residue addition were analyzed for total N (g kg^{-1}) and atom % ^{15}N enrichment by dry combustion and mass spectrometry (Delta V Advantage, Thermo Fisher Scientific, Bremen, Germany), respectively.

Cover crop residues were also subjected to digestion with H_2O_2 and concentrated H_2SO_4 for P determination by spectrometry, using a spectrophotometer (UV-1600, Pró-Análise, Porto Alegre, Brazil); for K determination by flame photometry, using a flame photometer (DM-62, Digimed, São Paulo, Brazil); for Ca and Mg contents determined by atomic absorption spectrophotometry (A Analyst 200, Perkin Elmer, Waltham, USA); and for C content by the method proposed by Tedesco et al. (1995). Contents of cellulose, lignin, and non-structural biomass in plant residues were also estimated according to the procedures described by Aber and Martin (1999).

The atom % ^{15}N excess in onion, plant residues, and soil samples was calculated according to equation 1:

$$Atom\ N excess\ in\ sample\ (\%) = atom\ \%\ ^{15}N in\ sample - 0.3663\% \quad \text{Eq. 1}$$

where 0.3663 % is the % ^{15}N natural air abundance.

Onion and soil N derived from residue (% Ndfr) was calculated using equations 2 and 3:

$$Nitrogen\ derived\ from\ residue\ (\%\ Ndfr) = \frac{atom\ N excess\ in\ sample}{atom\ N excess\ in\ residue} \times 100 \quad \text{Eq. 2}$$

$$Nitrogen\ derived\ from\ residue\ (Ndfr,\ mg) = total\ N\ in\ sample\ (mg) \times \frac{\%\ atom\ N excess\ in\ sample}{\%\ atom\ N excess\ in\ residue} \quad \text{Eq. 3}$$

Onion and soil N derived from sources other than crop residues (% Ndfs) was calculated using equation 4:

$$Nitrogen\ derived\ from\ ther\ sources\ (\%Ndfs) = 100 - Nitrogen\ derived\ from\ residue\ (\%Ndfr) \quad \text{Eq. 4}$$

Statistical analysis

Data were analyzed for normality and homogeneity using the Shapiro-Wilk test and then subjected to analysis of variance. Data were subjected to means separation using the Tukey test at the 5 % probability level, using the Sisvar® 5.4 software. The standard error of the mean was also estimated.

RESULTS

Influence of cover crop residues on onion dry matter yield

No differences were observed for total leaf and bulb production under the different types and amounts of cover crop residues, averaging 5.1 and 7.9 g dry weight, respectively (Table 2). This indicates that the amount of N released from residues was not particularly different from each cover crop.

N concentration in onion leaves during the growth cycle

The highest total N content in onion leaves was observed for the OR treatment, particularly in leaves taken at 28 and 44 days after residue addition onto the soil as compared to leaves collected at 63 and 83 days (Table 3). In onions grown under the OR + BO combination, the highest N content was observed in leaves collected at 44 days after residue addition (Table 3). The % Ndfr in onion leaves was also highest under the OR treatment, particularly at the 28, 44, and 63 day sampling period (Table 3). In plants grown under the BO and

Table 2. Dry matter yield (DMY), total N, atom ^{15}N excess, N derived from residue (Ndfr), and N derived from other sources (Ndfs) in leaves, bulbs, and leaves + bulbs of onion plants collected at harvest time (83 days after residue addition), in response to soil treatment with oilseed radish (OR), black oat (BO), and oilseed radish + black oat (OR + BO) residues

Treatment	DMY	Total N		Atom^{15} N excess	Ndfr		Ndfs	
	g per organ	g kg^{-1}	mg g^{-1} per organ DW	%	%	mg g^{-1} per organ DW	%	mg g^{-1} per organ DW
				Leaves				
OR	5.02 a[(1)]	23.3 b	116.84 ab	0.1347 a	3.58 a	4.12 a	96.42 b	112.71 b
BO	5.93 a	26.4 a	155.72 a	0.0389 b	1.01 b	1.66 b	98.99 a	154.06 a
OR + BO	4.43 a	24.8 a	109.35 b	0.0185 b	0.48 c	0.51 c	99.52 a	108.84 b
CV (%)[(2)]	14.20	8.94	4.79	19.74	15.77	21.18	0.17	4.82
				Bulbs				
OR	9.00 a	16.2 a	145.03 a	0.1335 a	3.55 a	5.25 a	96.45 b	139.61 a
BO	7.93 a	16.4 a	127.43 a	0.0379 b	0.99 b	1.25 b	99.01 a	126.18 a
OR + BO	6.79 a	17.7 a	114.15 a	0.0184 c	0.48 c	0.53 b	99.51 b	113.61 a
CV (%)	17.13	26.81	5.83	20.49	20.52	26.00	0.17	5.84
				Leaves + Bulbs				
OR	14.02 a	-	261.87 a	-	-	9.37 a	-	252.32 a
BO	13.86 a	-	283.15 a	-	-	2.91 b	-	280.24 a
OR + BO	11.22 a	-	223.50 a	-	-	1.04 c	-	222.45 a
CV (%)	10.48	-	4.09	-	-	23.47	-	11.16

[(1)] For each plant organ, means followed by the same lowercase in the column do not differ among treatments ($p>0.05$) by the Tukey test. [(2)] CV: coefficient of variation.

OR + BO residue additions, the % Ndfr in leaves did not vary over the sampling period. In contrast, the % Ndfs in leaves of onions grown with the OR treatment was higher at day 83, but there was no significant difference from leaves collected at day 63 (Table 3). Overall, the % Ndfs in onion leaves was higher in the BO and OR + BO treatments than in the OR treatment, and it did not vary during the period of onion growth.

N partition in onion organs at harvest

Nitrogen accumulated in onion leaves at harvest (83 days after residue addition) was significantly higher under the BO treatment (156 mg g^{-1} leaf DW) than the other treatments (Table 2). The N concentration in leaves collected at harvest for the BO and OR + BO treatments was higher than the total N in the youngest fully expanded leaves collected at day 83 (Table 3). This seems to indicate that leaf sampling in onion plants must be very judicious. Unlike leaves, total N in the bulbs did not vary with the residue treatment (Table 2), but the highest Ndfr was observed in bulbs cultivated under the OR treatment, whereas the highest value of % Ndfs was found in bulbs produced under the BO treatment.

N distribution in the soil

The highest total N content and % Ndfr in the soil was observed in the uppermost layer (0.00-0.05 m) for all treatments. These values decreased along the soil profile, without any variation at lower depths (Table 4).

DISCUSSION

Residue N recovered by onion plant organs

The % Ndfr in onion leaves taken at the first sampling date (28 days after residue addition) under the addition of OR residue was higher than in leaves collected later and higher than in leaves of plants grown under the BO and OR + BO treatments. Apparently, this

Table 3. Total N, atom ^{15}N excess, N derived from residues (Ndfr), and N derived from other sources (Ndfs) in the youngest fully expanded onion leaves collected at 28, 44, 63, and 83 days after addition of oilseed radish (OR), black oat (BO), and intercropped oilseed radish + black oat (OR + BO) residues

	Days after residue addition	OR	BO	OR + BO
Total N (g kg^{-1} DW)	28	38.2 aA(1)	33.8 abB	32.3 bB
	44	38.3 aA	34.5 aA	38.5 aA
	63	28.3 bA	27.9 cA	29.2 bA
	83	28.6 bA	29.8 bcA	28.6 bA
Atom ^{15}N excess (%)	28	0.2076 aA	0.0636 aB	0.0290 aB
	44	0.2273 aA	0.0690 aB	0.0253 aB
	63	0.1636 abA	0.0473 aB	0.0183 aB
	83	0.1066 bA	0.0536 aAB	0.0160 aB
Ndfr (%)	28	5.52 aA	1.66 aB	0.75 aB
	44	6.04 aA	1.79 aB	0.66 aB
	63	4.35 abA	1.22 aB	0.48 aB
	83	2.83 bA	1.39 aB	0.42 aB
Ndfs (%)	28	94.48 bB	98.35 aA	99.25 aA
	44	93.96 bB	98.21 aA	99.34 aA
	63	95.65 abB	98.78 aA	99.52 aA
	83	97.17 aB	98.61 aB	99.58 aA

DW: dry weight. (1) For each variable and column, means followed by the same lowercase letter do not differ according to sampling period ($p>0.05$) by the Tukey test; for each sampling period, means with the same uppercase letter in the line do not differ ($p>0.05$) by the Tukey test.

Table 4. Total N, atom ^{15}N excess, and N derived from residue (Ndfr) in different layers of soil treated with cover crop residues and cultivated with onion [Treatments: oilseed radish (OR), black oats (BO), and oilseed radish + black oats (OR + BO)]

	Layer	OR	BO	OR + BO	CV
	m				%
Total N (g kg^{-1})	0.00-0.05	2.6 aA(1)	2.6 aA	2.9 aA	14.07
	0.05-0.10	1.8 bA	2.4 abA	2.3 abA	16.94
	0.10-0.15	1.5 bA	1.1 bcA	1.4 bA	4.33
	0.15-0.20	1.4 bA	1.3 cA	1.3 bA	7.84
CV (%)		12.34	19.39	22.40	
Atom ^{15}N excess (%)	0.00-0.05	0.0186 aA	0.0129 aA	0.0106 aA	22.18
	0.05-0.10	0.0086 bA	0.0085 bA	0.0042 bA	17.95
	0.10-0.15	0.0058 bA	0.0047 bAB	0.0039 bB	13.95
	0.15-0.20	0.0044 bA	0.0046 bA	0.0035 bA	10.97
CV (%)		23.14	23.46	18.73	
Ndfr (%)	0.00-0.05	0.49 aA	0.33 aA	0.27 aA	22.08
	0.05-0.10	0.22 bA	0.22 bA	0.11 bA	17.96
	0.10-0.15	0.15 bA	0.12 bAB	0.10 bB	13.47
	0.15-0.20	0.11 bAB	0.12 bA	0.09 bB	10.87
CV (%)		23.01	23.46	18.73	

CV: coefficient of variation. (1) for each variable, means followed by the same lowercase letter in the column do not differ among soil depths ($p>0.05$) by the Tukey test; for each soil layer, means with the same uppercase letter in the line do not differ among treatments ($p>0.05$) by the Tukey test.

result may be explained by a more rapid decomposition of OR tissue on the soil surface than decomposition of BO tissue since OR contained a slightly lower concentration of lignin, and higher cellulose content and cellulose/lignin ratio (Table 1). Residues with lower lignin content provide less mechanical protection of the cell wall, thus favoring microbial degradation of organic materials (Sánchez, 2009). Kurtz et al. (2012) observed that onion took up larger quantities of mineral N around 60 days after transplanting. Carranca et al. (2009) observed that after a short period of N immobilization, lupine residue with a lignin/N ratio of 26, much higher than the residues in this study, was mineralized within 60 days. These results may explain the higher residue N recovered in leaves collected after the period of 28 days.

However, over the period of onion growth until harvest, the Ndfs was the main N source recovered in onion plant organs (>96 % Ndfs); a maximum of 3.58 % of N was recovered in leaves and bulbs derived from the OR residue (Table 2). This shows very low recovery of cover crop residue N by onion plants. Some explanations for this fact may include: (i) the plant has low N-use efficiency due to its shallow root system, as observed by Carranca (2005) for spinach with a similar growth cycle (18 % N-use efficiency); (ii) mineral ^{15}N was lost by leaching, especially in the form of NO_3^--N, accompanying the downward movement of water in the soil profile; and (iii) the simultaneous mineralization of soil organic matter may have diluted the ^{15}N released from residues (Brunetto et al., 2014).

Since N content in the bulbs was not affected by the type and amount of residues applied on the soil surface, a similar rate of N translocated from leaves to bulbs in the form of amino acids during the maturation process must have occurred (Caruso et al., 2014; Mirete, 2015). However, onion bulb dry weight (8 g) was lower than the reference values (Mirete, 2015), i.e., 10 and 22 g was obtained with addition of 0 and 128 kg ha^{-1} of mineral N, respectively. Bulb biomass depends not only on N nutrition but also on plant genotype. Mirete (2015) reported leaf biomass of 4.6 g DW after a period of growth similar to the present study and in response to the maximum N rate of 128 kg ha^{-1}. That leaf dry weight was similar to the result of this study (5.1 g DW), which resulted from an average residue N addition of 150 kg ha^{-1}, not so different from the mineral N rate reported above. Therefore, N taken up from other sources than cover crop residues was sufficient to obtain reasonable bulb production, and N was adequately mobilized from leaves to the bases for bulbing.

Residue N recovery in the soil

The highest concentrations of total N and Ndfr in soil were observed in the uppermost layer (0.00-0.05 m) for all treatments. This may have occurred due to residue deposition on the soil surface, without incorporation (Brunetto et al., 2014). However, residue N was measured up to the 0.20 m depth, especially under the OR residue, showing that some N movement in the soil has occurred (Ismaili et al., 2015). The ^{15}N in the soil profile may also have resulted from N compounds exuded from onion roots (Peoples et al., 2015) and by the senescence and decomposition of these roots (Sun et al., 2013).

CONCLUSIONS

In onion leaves and bulbs, N was derived especially from sources other than the cover crop residues deposited on the soil surface at the time of transplanting.

Nitrogen derived from cover crop residues contributed little to the development of this crop with a short growth cycle, but oilseed radish decomposed faster than other residues and 4 % of residue N was recovered in onion leaves + bulbs.

The N from cover crops has little impact upon the N taken up by onions, and that the use of these plants should be chosen based on the advantages they provide to physical and biological soil quality.

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REFERENCES

Aber JD, Martin M. 1999. Leaf Chemistry, 1992-1993 (ACCP). [Leaf Chemistry, 1992-1993 (Accelerated Canopy Chemistry Program)]. Data set. Available at: http://www.daac.ornl.gov. https://doi.org/10.3334/ORNLDAAC/421

Brunetto G, Ceretta CA, Melo GWB, Kaminski J, Trentin G, Girotto E, Ferreira PAA, Miotto A, Trivelin PCO. Contribution of nitrogen from agricultural residues of rye to '*Niagara Rosada*' grape nutrition. Sci Hortic. 2014;169:66-70. https://doi.org/10.1016/j.scienta.2014.02.019

Carranca C. Crop management and postharvest quality of spinach for fresh consumption and processing. In: Dris R, editor. Vegetables: Growing environmental and mineral nutrition. Helsinki: WFL Publisher; 2005. p.260-70.

Carranca C, Rocha I, Varennes A, Oliveira A, Pampulha ME, Torres MO. Effect of tillage and temperature on nitrogen mineralization and microbial activity and microbial numbers of lupine amended soil. Agrochimica. 2009;LIII:183-95.

Caruso G, Conti S, Villari G, Borrelli C, Melchionna G, Minutolo M, Russo G, Amalfitano C. Effects of transplanting time and plant density on yield, quality and antioxidant content of onion (*Allium cepa* L.) in southern Italy. Sci Hortic. 2014;166:111-20. https://doi.org/10.1016/j.scienta.2013.12.019

Cicek H, Martens JRT, Bamford KC, Entz MH. Late-season catch crops reduce nitrate leaching risk after grazed green manures but release N slower than wheat demand. Agric Ecosyst Environ. 2015;202:31-41. https://doi.org/10.1016/j.agee.2014.12.007

Comissão de Química e Fertilidade do Solo - CQFS-RS/SC. Manual de adubação e calagem para os estados do Rio Grande do Sul e Santa Catarina. 10a ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo; 2004.

Craine JM, Brookshire ENJ, Cramer MD, Hasselquist NJ, Koba K, Marin-Spiotta E, Wang L. Ecological interpretations of nitrogen isotope ratios of terrestrial plants and soils. Plant Soil. 2015;396:1-26. https://doi.org/10.1007/s11104-015-2542-1

Haramoto ER, Gallandt ER. Brassica cover cropping for weed management: a review. Renew Agric Food Syst. 2004;19:187-98. https://doi.org/10.1079/RAFS200490

Inácio CT, Urquiaga S, Chalk PM, Mata MGF, Souza PO. Identifying N fertilizer regime and vegetable production system in tropical Brazil using ^{15}N natural abundance. J Sci Food Agric. 2015;95:3025-32. https://doi.org/10.1002/jsfa.7177

Ismaili K, Ismaili M, Ibijbijen J. The use of ^{13}C and ^{15}N based isotopic techniques for assessing soil C and N changes under conservation agriculture. Eur J Agron. 2015;64:1-7. https://doi.org/10.1016/j.eja.2014.12.005

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World Map of the Köppen-Geiger climate classification updated. Meteorol Zeitsch. 2006;15:259-63. https://doi.org/10.1127/0941-2948/2006/0130

Kurtz C, Ernani PR, Coimbra JLM, Petry E. Rendimento e conservação da cebola alterados pela dose e parcelamento do nitrogênio em cobertura. Rev Bras Cienc Solo. 2012;36:865-75. https://doi.org/10.1590/S0100-06832012000300017

Kurtz C, Ernani PR, Pauletti V, Menezes Junior FOG, Vieira Neto J. Produtividade e conservação de cebola afetadas pela adubação nitrogenada no sistema de plantio direto. Hortic Bras. 2013;31:559-67. https://doi.org/10.1590/S0102-05362013000400009

Loss A, Basso A, Oliveira BS, Koucher LP, Oliveira RA, Kurtz C, Lovato PE, Curmi P, Brunetto G, Comin JJ. Carbono orgânico total e agregação do solo em sistema de plantio direto agroecológico e convencional de cebola. Rev Bras Cienc Solo. 2015;39:1212-24. https://doi.org/10.1590/01000683rbcs20140718

Martins RP, Comin JJ, Gatiboni LC, Soares CRF, Couto RR, Brunetto G. Mineralização do nitrogênio de plantas de cobertura, solteiras e consorciadas, depositadas sobre um solo com histórico de cultivo de cebola. Rev Ceres. 2014;61:587-96. https://doi.org/10.1590/0034-737X201461040020

Mbuthia LW, Acosta-Martínez V, DeBruyn J, Schaeffer S, Tyler D, Odoi E, Mpheshea M, Walker F, Eash N. Long term tillage, cover crop, and fertilization effects on microbial community structure, activity: implications for soil quality. Soil Biol Biochem. 2015;89:24-34. https://doi.org/10.1016/j.soilbio.2015.06.016

Mirete D. Influence of mineral nitrogen and phosphorus fertilizer rates on growth, yield components and bulb yield of onion (*Allium cepa* var. *cepa)* at Kobo, Northern Ethiopia [dissertation]. Haramaya: Haramaya University; 2015.

Mohanty M, Sinha NK, Reddy KS, Chaudhary RS, Rao AS, Dalal RC, Menzies NW. How important is the quality of organic amendments in relation to mineral N availability in soils? Agric Res. 2013;2:99-110. https://doi.org/10.1007/s40003-013-0052-z

Monegat C. Plantas de cobertura do solo: características e manejo em pequenas propriedades. 2a ed. Chapecó: Edição do Autor; 1991.

Peoples MB, Chalk PM, Unkovich MJ, Boddey RM. Can differences in ^{15}N natural abundance be used to quantify the transfer of nitrogen from legumes to neighboring non-legume plant species? Soil Biol Biochem. 2015;87:97-109. https://doi.org/10.1016/j.soilbio.2015.04.010

Rezaei EE, Kafi M, Bannayan M. Nitrogen and cultivated bulb weight effects on radiation and nitrogen-use efficiency, carbon partitioning and production of Persian Shallot (*Allium altissimum* Regel.). J Crop Sci Biotechnol. 2013;16:237-44. https://doi.org/10.1007/s12892-013-0076-8

Sánchez C. Lignocellulosic residues: biodegradation and bioconversion by fungi. Biotechnol Adv. 2009;27:185-94. https://doi.org/10.1016/j.biotechadv.2008.11.001

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Oliveira JB, Coelho MR, Lumbreras JF, Cunha TJF. Sistema brasileiro de classificação de solos. 3a ed. Rio de Janeiro: Embrapa Solos; 2013.

Silva EC, Muraoka T, Franzini VI, Sakadevan K, Buzetti S, Arf O, Bendassolli JA, Soares FAL. Use of nitrogen from fertilizer and cover crops by upland rice in an Oxisol under no-tillage in the Cerrado. Pesq Agropec Bras. 2016;6:728-37. https://doi.org/10.1590/S0100-204X2016000600004

Soil Survey Staff. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. 10th ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2006.

Souza M, Comin JJ, Leguizamón ES, Kurtz C, Brunetto G, Müller Júnior V, Ventura B, Camargo AP. Matéria seca de plantas de cobertura, produção de cebola e atributos químicos do solo em sistema plantio direto agroecológico. Cienc Rural. 2013;43:21-7. https://doi.org/10.1590/S0103-84782012005000150

Tao S, Zijun M, lili D, Lingling H, Yuan S, Xiuwei W. Further evidence for slow decomposition of very fine roots using two methods: litterbags and intact cores. Plant Soil. 2013;366:633-46. https://doi.org/10.1007/s11104-012-1457-3

Tedesco MJ, Gianello C, Bissani CA, Bohnen H, Wolkweiss SJ. Análises de solo, plantas e outros materiais. 2a ed rev ampl. Porto Alegre: Universidade Federal do Rio Grande do Sul; 1995. (Boletim técnico, 5).