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ORIGINAL ARTICLE

Decomposition and release of nutrients from leaves and pruned stems in vineyard

Decomposição e liberação de nutrientes de folhas e ramos de vinhedo

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ABSTRACT: The aim of this study was to evaluate the decomposition and release of nutrients and carbon from leaves and pruned stems deposited in the rows and in the spacing between rows of vineyards, throughout the vegetative and productive cycle of the grapevines in a vineyard in Santana do Livramento, Southern Brazil, from May to November 2009. Senescent leaves and new stems that were pruned and enriched with ^{15}N were collected, analyzed chemically and biochemically, and placed in litter bags, which were deposited in the vine rows and in the spacing between them. After 0, 30, 60, 90, 120, 150, 180, and 210 days of the deposition of the litter bags, these residues were collected, dry matter was determined, and the residues were analyzed for total contents of N, ^{15}N, P, K, and C. The rate of decomposition and release of C and nutrients from the leaves and pruned stems deposited on the soil surface was not affected by the place of deposition, row or spacing between rows, of the grapevines. The rate of decomposition and release of C and nutrients from the leaves deposited in the row and in between rows of the vineyard was greater than that of the pruned stems throughout the period evaluated.

RESUMO: *O objetivo deste trabalho foi avaliar a decomposição e liberação de carbono e nutrientes de folhas e ramos do ano depositados nas linhas e entrelinhas de vinhedos da região da Campanha Gaúcha, ao longo do ciclo vegetativo e produtivo de videiras. O estudo foi conduzido em um vinhedo em Santana do Livramento (RS) no período de maio a novembro de 2009. Folhas senescentes e ramos do ano podados enriquecidos com ^{15}N foram coletados, submetidos às análises químicas e bioquímicas e acondicionados em litter bags, posteriormente depositados na linha e entrelinha das videiras. Em 0, 30, 60, 90, 120, 150, 180 e 210 dias após a deposição dos litter bags os resíduos foram coletados e preparados, sua matéria seca foi determinada e eles foram submetidos à análise dos teores totais de C, N, ^{15}N, P e K. A taxa de decomposição e liberação de C e nutrientes das folhas e ramos do ano depositados sobre a superfície do solo não foi afetada pela posição de deposição, linha e entrelinha, de plantio das videiras. A taxa de decomposição e liberação de C e nutrientes das folhas depositadas na linha e entrelinha do vinhedo foi maior que a dos ramos do ano em todo o período avaliado.*

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1 Introduction

The vineyards of the Pampa Biome of Rio Grande do Sul (RS), Brazil, near the border with Uruguay, are generally established on flat or slightly wavy land and on soils with sandy surface texture that are acidic and of low natural fertility. Between the vine rows, spontaneous or sown species of soil cover plants are maintained to dissipate the kinetic energy of raindrops, minimize nutrient transfer by surface runoff or percolation, and promote nutrient cycling.

In the grapevine plant rows, the cover plants are desiccated, mainly to avoid competition for water and nutrients with the grapevines, or even to ease crop operations, such as manual grape harvest. Thus, in the grapevine plant rows, as opposed to between the rows, modifications are expected in factors such as soil temperature and evaporation and, consequently, modifications in water availability to plants, which may also reduce microbial activity in the soil (Gama-Rodrigues et al., 2007; Gömöryová et al., 2013; Kakumanu & Williams, 2014). The combination of these factors may delay decomposition and release of nutrients and carbon (C) from the litter derived from winter pruning and deposited on the soil surface. This litter may thus remain for a longer time on the soil surface in the plant row, which is desirable, because this may reduce water erosion and slow release of nutrients, increasing synchronism with uptake on the part of the grapevines.

During decomposition of the litter derived from winter pruning of grapevines, C is used as a source of energy by the microbial population, with part being released in the form of CO_2 to the atmosphere and the rest incorporated in soil organic matter. Part of the nutrients contained in the litter, such as nitrogen (N), which may be diagnosed using isotopes of 15N; phosphorus (P); and potassium (K) are released to the soil, increasing their availability, and they may be taken up by the grapevine during its cycle. Researchers have attributed the lack of response of the grapevine to fertilization to this fact. However, decomposition of plant litter and, consequently, the release of the aforementioned nutrients, are dependent on soil and climatic factors, such as temperature, moisture, pH values, and oxygen and nutrient contents (Campbell et al., 2016). In addition, the chemical composition of the litter is also an important factor for its decomposition, especially in relation to the cellulose and lignin contents, and the values of ratios such as C/N, lignin/N, and lignin/P (Giacomini et al., 2003; Carvalho et al., 2009; Matos et al., 2011; Marcelo et al., 2012; Bonanomi et al., 2013; Ferreira et al., 2014; Martins et al., 2014).

In general, residues that have greater values of C/N ratio, lignin, and cellulose, such as pruned shoots, are decomposed and release nutrients to the soil in a slower and more gradual way compared to residues with lower values of C/N ratio, lignin, and cellulose, such as senescent leaves, for which decomposition and nutrient release is faster and more intense (Redin et al., 2014). The latter may release most of the nutrients from the litter in the first few days after deposition. The aim of this study was to evaluate the decomposition and release of nutrients and carbon from leaves and pruned stems deposited in the row and between the rows of vineyards, throughout the vegetative and productive cycle of grapevines.

2 Material and Methods

Leaves and pruned stems enriched with ^{15}N were used for the study. The grapevines were of the cv. Cabernet Sauvignon, grafted on SO4 rootstock, in the municipality of Santana do Livramento, Southern Brazil (Latitude 30°48'31"S and Longitude 55°22'33"W), planted in 1978 at a distance of 3.0 m between rows and 0.74 m within the row. The training system was a spur pruned cordon, featuring a single permanent cordon with seasonal growth (shoots) kept upwards. They were fertilized with urea at the rate of 21.42 kg N ha^{-1} (15 g N $plant^{-1}$), enriched with 3.00 at. % ^{15}N excess. The grapevines were surrounded with nylon screens to collect abscised leaves. In June 2008, the pruned stems of the grapevines were collected. The leaves and the shoots were dried in a forced air laboratory oven up to 65ºC, until constant weight. A leaf and pruned shoot subsample was analyzed for total C, N, P, and K concentrations and ^{15}N excess. The leaf litter had the following characteristics: total C = 54.7%, total N = 2.9%, total P = 0.3%, total K = 0.1%, at. %^{15}N excess = 2.93, C/N ratio = 18.3, C/P ratio = 182.4. The pruned shoot litter had the following characteristics: total C = 57.9%, total N = 0.72%, total P = 0.2%, total K = 0.07%, at. % ^{15}N excess = 0.66, C/N ratio = 80.4, C/P ratio = 289.5.

In April 2009, the experiment was established in the same vineyard of the cv. Cabernet Sauvigon grafted on SO4 rootstock, located in the municipality of Santana do Livramento (RS), but in grapevines not labeled with ^{15}N. The climate of this area is Cfa, with mean temperature of 18.4°C (Köppen-Geiger). January is the hottest month and July the coldest, reaching 24.9°C and 12.5°C, respectively, with mean rainfall of 1467 mm $year^{-1}$. Rainfall and air temperature recorded during the study are shown in Table 1.

Table 1. Data on mean rainfall and air temperature during the period of the experiment.

Tabela 1. Dados sobre precipitação média e temperatura do ar durante o período do experimento.

Month/2009	Rainfall (mm)	Air temperature (°C)
May	123.6	15.2
June	22.4	9.5
July	66.1	9.0
August	45.3	14.2
September	269.4	13.3
October	135.9	16.9
November	540.8	20.8

The soil was a Sandy Typic Hapludalf (Soil Survey Staff, 2006) and the soil characteristics are shown in Table 2.

Vegetation between the grapevine rows was composed of *Lolium perenne*, *Trifolium repens*, and *Paspalun notatum*. The shoots of these plants were periodically cut at approximately 10 cm height, and the residue deposited on the soil surface. A 1.20-m-wide strip, centered on the vine rows, was kept weed free by periodic application of non-residual herbicides. During the experiments, the area of the decomposition study was manually weeded, and no fertilizers or herbicides were applied.

One-mm mesh nylon netting was cut and sewn to create square 20 x 20 cm litter bags, which were filled with the

^{15}N-labeled biomass of leaves and stems. The equivalent of 30 g of dry matter (DM) of leaves and shoots was inserted into each bag. This amount corresponded to 750 g m^{-2} DM. On April 16, 2009, a total of 80 litter bags, 40 with leaves and 40 with stems, were placed on the weed-free soil surface of the plant row, which coincided with the projection of the grapevine canopy, and 80 litter bags in the center of the between-row area, in a completely randomized block experimental design with 5 replications.

Table 2. Main physical and chemical characteristics of the soil of the experimental site at the 0-20 cm depth.

Tabela 2. Principais características físicas e químicas do solo do experimento na profundidade de 0-20 cm.

	0-20 cm
Clay, g kg^{-1}(†)	162
Silt, g kg^{-1}(†)	558
Sand, g kg^{-1}(†)	280
Organic matter, g kg^{-1}(§)	30
pH in H_2O(§)	6.0
Total N, %(§)	0.21
Exchangeable Mg, cmol$_c$ dm^{-3}(¶)	3.8
Exchangeable Ca, cmol$_c$ dm^{-3}(¶)	7.5
P availability, mg dm^{-3}(¤)	81
Exchangeable K, mg dm^{-3}(4)	87

(†) Pipette method (Embrapa, 1997); (§) Determined according to Tedesco et al., (1995); (¶) extracted by 1 mol L^{-1} KCl (Tedesco et al., 1995); (¤)extracted by Mehlich 1 (Tedesco et al., 1995).

Litter bags were collected on April 16 (day 0), May 16 (day 30), June 16 (day 60), July 16 (day 90), August 16 (day 120), September 16 (day 150), October 16 (day 180), and November 16 (day 210). At each sampling time, 5 randomly chosen litter bags of both litter materials were collected from the row and from between the rows. The content of each collected litter bag was carefully cleaned of soil, oven dried at 65ºC, weighed, and ground.

The total contents of C, P, and K were analyzed (Tedesco et al., 1995) in the different collection time periods in the litter removed from the litter bags. Total N and 15N abundance were measured with an elemental analyzer (EA 1110, Carlo Erba instruments) coupled to an isotopic ratio mass spectrometer (Delta Plus, Finnigan-Matt, Germany).

The 15N excess was calculated by subtracting standard 15N abundance from 15N abundance determined in the samples. Atmospheric 15N abundance (0.3663 atom % 15N) was considered as the standard for determination of 15N excess in the litter material.

Decomposition of the litter material and nutrient release were estimated by the variation in the initial weight of the material and C, N, P, and K content in the litter, in relation to the weight and content remaining in the litter bags in each collection period. The results for the remaining percentage of each variable were fitted to the exponential mathematical model used by Boer et al., (2007), X= Xoexp(-kt), in which X = the weight or nutrient content remaining after a period of time t, in days; Xo = the initial weight or nutrient content; and k = the decomposition constant. The half-life (t½ = 0.693/k) was calculated from the value of k (Paul & Clark, 1989); half-life expresses the period of time necessary for half of the residues to decompose and for half of the nutrients contained in the residues to be released.

3 Results and Discussion

The quantity of DM, C, and K, and the excess of 15N (atom % 15N) were similar in all the collections made for the leaves and pruned stems deposited in the plant row and between the plant rows of the vines (Table 3). Based on these results, it may be inferred that, possibly, the soil of the grapevine plant row and the soil between the rows had similar climate and soil conditions, such as temperature, moisture, oxygen, pH, and nutrient availability (Campbell et al., 2016), which are determining factors for microbial activity, which, in turn, is responsible for decomposition and release of nutrients from crop residues (Kakumanu & Williams, 2014).

Table 3. Mass (g litter bag^{-1}) and ^{15}N excess (atom %^{15}N), C, N, P, and K (g kg^{-1}) accumulated in leaves and shoots (1 year old) of grapevines in decomposition in the row and between rows (average ± standard errors).

Tabela 3. Massa (g saco de decomposição^{-1}) e excesso de 15N (átomo% 15N), C, N, P e K (g kg^{-1}) acumulados nas folhas e ramos (1 ano de idade) das videiras em decomposição na linha e entre linhas (média ± erros padrão).

Litter	Position	Time (days)							
		0	30	60	90	120	150	180	210
		Mass (g litter bag^{-1})							
Leaves	In the row	30 ± 0.00	25.36 ± 0.25	22.69 ± 0.42	21.09 ± 0.85	18.13 ± 3.31	15.96 ± 0.17	15.96 ± 1.75	13.54 ± 1.57
	Betw. rows	30 ± 0.00	24.15 ± 0.19	22.05 ± 0.36	19.99 ± 0.05	19.75 ± 0.60	17.40 ± 1.02	17.01 ± 1.09	12.79 ± 0.45

Table 3. Continuation...

Tabela 3. Continuação...

Litter	Position	Time (days)							
		0	30	60	90	120	150	180	210
Shoots	In the row	30 ± 0.00	27.23 ± 0.10	26.74 ± 0.20	26.02 ± 0.22	25.01 ± 0.15	23.37 ± 0.16	23.27 ± 0.89	22.51 ± 0.24
	Betw. rows	30 ± 0.00	27.26 ± 0.14	26.33 ± 0.39	25.95 ± 0.13	25.67 ± 0.14	23.92 ± 1.57	22.69 ± 0.43	21.58 ± 1.12
					C (g kg^{-1})				
Leaves	In the row	547.11 ± 4.03	590.81 ± 7.20	554.78 ± 39.63	578.80 ± 81.11	575.80 ± 16.00	481.06 ± 34.51	470.05 ± 11.34	522.09 ± 81.21
	Betw. rows	547.11 ± 4.03	581.80 ± 8.12	547.76 ± 42.04	554.78 ± 33.05	569.79 ± 10.00	503.08 ± 93.76	523.20 ± 54.18	533.10 ± 31.25
Shoots	In the row	579.14 ± 32,18	619.84 ± 41.23	627.84 ± 30.00	634.84 ± 34.54	544.11 ± 11.12	590.15 ± 83.32	590.10 ± 37.98	567.61 ± 64.65
	Betw. rows	579.14 ± 32.18	619.47 ± 31.87	642.86 ± 34.23	587.48 ± 21.28	547.12 ± 40,49	592.15 ± 28.87	587.15 ± 45,28	549.76 ± 18.21
					^{15}N excess (atom %^{15}N)				
Leaves	In the row	0.047 ± 0.04	0.046 ± 0.003	0.043 ± 0.003	0.039 ± 0.005	0.036 ± 0.004	0.032 ± 0.01	0.035 ± 0.003	0.040 ± 0.001
	Betw. rows	0.047 ± 0.04	0.052 ± 0.003	0.040 ± 0.001	0.035 ± 0.01	0.044 ± 0.004	0.040 ± 0.005	0.043 ± 0.001	0.042 ± 0.008
Shoots	In the row	0.039 ± 0.02	0.037 ± 0.003	0.037 ± 0.006	0.035 ± 0.004	0.039 ± 0.001	0.030 ± 0.002	0.041 ± 0.005	0.033 ± 0.001
	Betw. rows	0.039 ± 0.02	0.040 ± 0.003	0.045 ± 0.004	0.037 ± 0.006	0.037 ± 0.004	0.037 ± 0.003	0.038 ± 0.004	0.041 ± 0.002
					N (g kg^{-1})				
Leaves	In the row	29.80 ± 0.50	30.14 ± 1.99	30.80 ± 0.55	33.68 ± 2.76	31.41 ± 0.05	28.43 ± 2.48	26.85 ± 0.91	36.24 ± 0.46
	Betw. rows	29.80 ± 0.50	28.93 ± 0.55	31.79 ± 4.08	32.13 ± 0.45	33.56 ± 4.52	26.61 ± 0.44	28,76 ± 2.81	31.69 ± 1.10
Shoots	In the row	7.20 ± 0.49	6.90 ± 1.10	7.73 ± 0.05	8.44 ± 0.11	8.39 ± 0.22	7.39 ± 0.11	7.62 ± 0.49	8.12 ± 0.38
	Betw. rows	7.20 ± 0.49	6.74 ± 0.11	7.34 ± 0.90	7.07 ± 0.44	6.51 ± 0.44	7.39 ± 0.33	7.62 ± 0.11	8.00 ± 0.27
					P (g kg^{-1})				
Leaves	In the row	3.02 ± 0.15	2.47 ± 0.03	2.48 ± 0.12	2.71 ± 0.29	3.03 ± 0.27	2.84 ± 0.18	2.78 ± 0.09	2.47 ± 0.12
	Betw. rows	3.02 ± 0.15	2.41 ± 0.13	2.74 ± 0.12	2.65 ± 0.03	2.94 ± 0.17	2.20 ± 0.59	2.93 ± 0.24	2.70 ± 0.04
Shoots	In the row	2.04 ± 0.09	2.08 ± 0.17	1.72 ± 0.22	1.79 ± 0.33	1.82 ± 0.43	1.65 ± 0.09	1.58 ± 0.23	1.52 ± 0.42
	Betw. rows	2.04 ± 0.09	1.89 ± 0.12	1.69 ± 0.17	1.96 ± 0.19	1.92 ± 0.12	1.68 ± 0.21	1.67 ± 0.18	1.68 ± 0.19
					K (g kg^{-1})				
Leaves	In the row	1.10 ± 0.08	0.75 ± 0.05	0.63 ± 0.05	0.55 ± 0.06	0.58 ± 0.03	0.35 ± 0.05	0.23 ± 0.05	0.10 ± 0.05
	Betw. rows	1.10 ± 0.08	0.63 ± 0.03	0.60 ± 0.10	0.50 ± 0.04	0.55 ± 0.06	0.18 ± 0.03	0.45 ± 0.04	0.10 ± 0.05
Shoots	In the row	0.65 ± 0.07	0.63 ± 0.06	0.45 ± 0.04	0.55 ± 0.03	0.55 ± 0.08	0.33 ± 0.04	0.28 ± 0.05	0.10 ± 0.04
	Betw. rows	0.65 ± 0.07	0.58 ± 0.04	0.48 ± 0.07	0.50 ± 0.07	0.45 ± 0.09	0.30 ± 0.03	0.33 ± 0.07	0.18 ± 0.08

The DM remaining in the leaves and pruned stems deposited in the plant row and between the plant rows decreased over time (Table 3, Figure 1A, Figure 2A).

For the leaves, the DM remaining at 30 days after deposition (DAD) in the plant row and between the rows was approximately 85% and 80%, respectively (Figure 1A), whereas at 210 DAD, it was approximately 45% and 43% in the plant row and between the rows, respectively. In relation to the pruned stems, the DM remaining at 30 DAD in the plant row and between the rows was approximately 91% for both, whereas at 210 DAD, the DM in the plant row was near 75% and between the rows 72% (Figure 2A). The half-life (t1/2) of the DM remaining in the leaves and the pruned stems deposited in the row and between the rows was 231 (Table 4) and 693 days (Table 5), respectively.

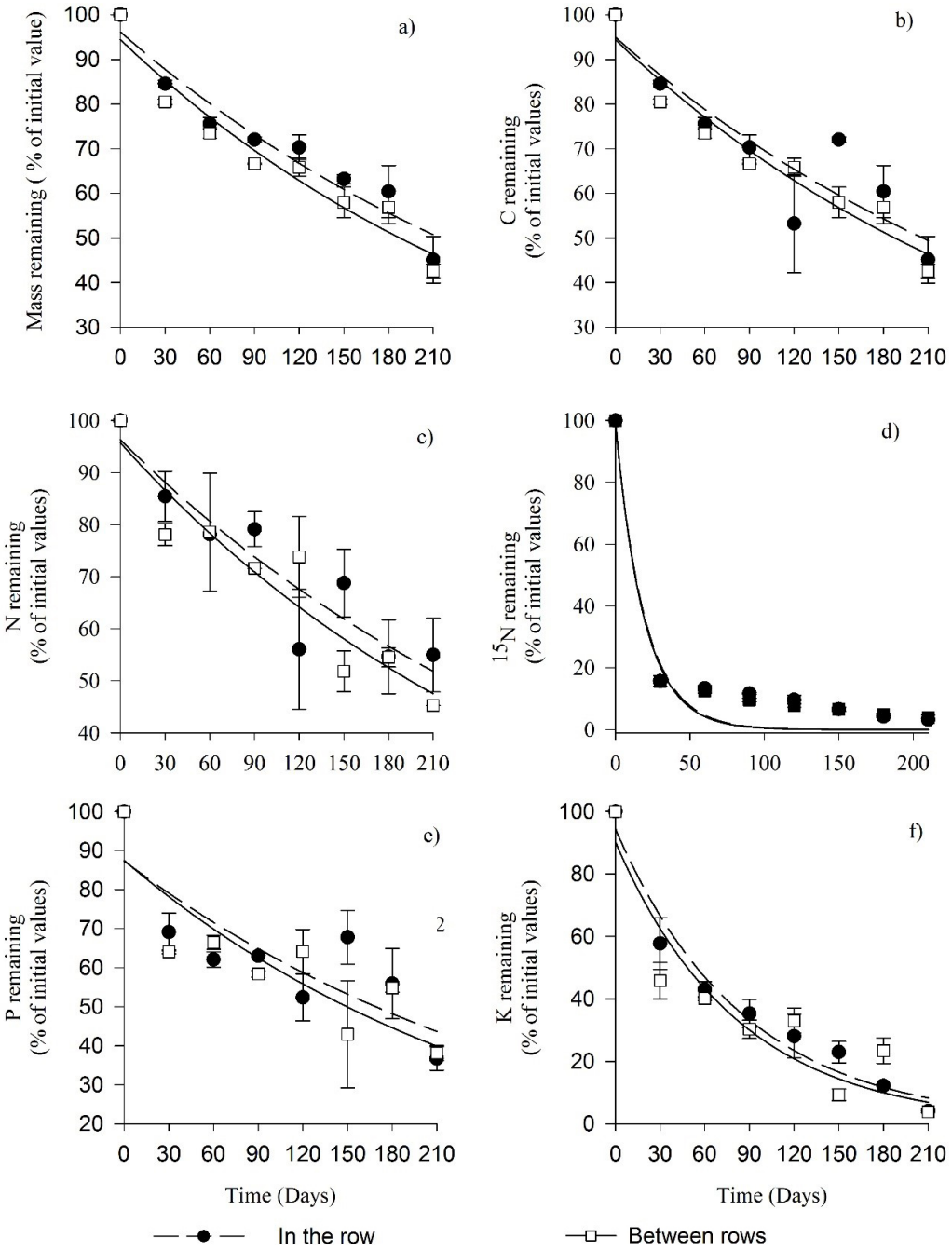

Figure 1. Amounts remaining of mass (A), C (B), N (C), ^{15}N (D), P (E), and K (F) in leaves from grapevines in decomposition in the row (•) and between rows (□); values expressed as % of initial values. The percentage of mass and nutrients remaining was calculated as the ratio of the amount of mass or nutrients (total g) in the decomposing litter on the sampling dates, and the amount of mass or nutrients (total g) in the plant material at the beginning of the experiment. Vertical bars represent standard errors.

Figura 1. Quantidades de massa seca remanescente A), C (B), N (C), ^{15}N (D), P (E), and K (F) em folhas (1 ano de idade) de videira em decomposição na linha (•) e entre linhas (□); valores expressos em % dos valores iniciais. A percentagem de massa e nutrientes remanescentes foi calculada como a razão da quantidade de massa ou nutrientes (total g) coletado em sacos de decomposição.

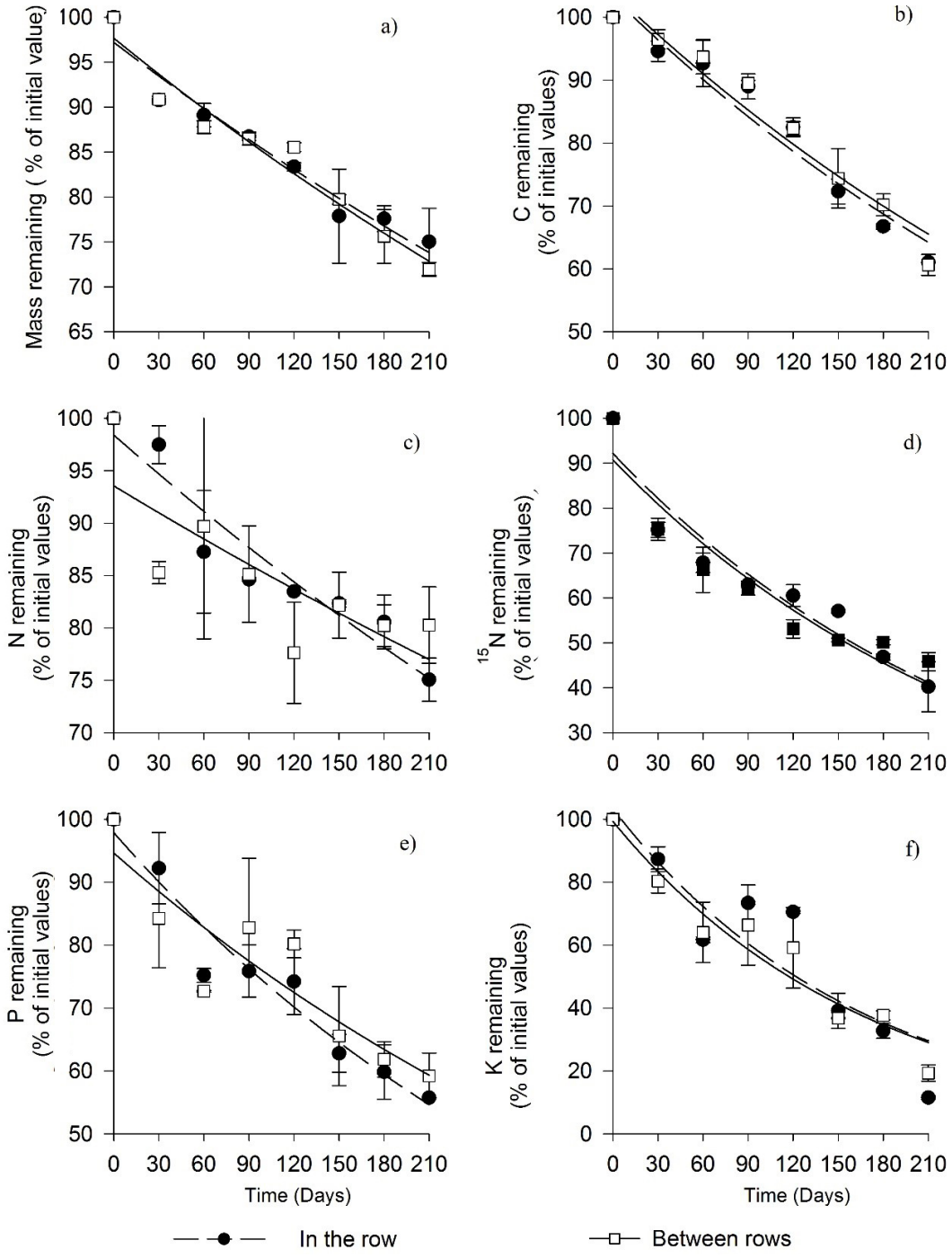

Figure 2. Amounts remaining of mass (A), C (B), N (C), ^{15}N (D), P (E), and K (F) in pruned stems (1 year old) from grapevines in decomposition in the row (•) and between rows (□); values expressed as % of initial values. The percentage of mass and nutrients remaining was calculated as the ratio of the amount of mass or nutrients (total g) in the decomposing litter on the sampling dates, and the amount of mass or nutrients (total g) in the plant material at the beginning of the experimment. Vertical bars represent standard errors.

Figure 2. Quantidades de massa seca remanescente A), C (B), N (C), ^{15}N (D), P (E), and K (F) em ramos podados (1 ano de idade) de videira em decomposição na linha (•) e entre linhas (□); valores expressos em % dos valores iniciais. A percentagem de massa e nutrientes remanescentes foi calculada como a razão da quantidade de massa ou nutrientes (total g) coletado em sacos de decomposição.

The residues of the leaves and of the pruned stems deposited in the plant row and between the rows were decomposed over the period of the collections made during senescence of the grapevine leaves up to change in color of the berries. Decomposition occurred because of microbial activity and removal of the soluble compounds by rainwater (Li & Ye, 2014).

The greater percentages of residual DM and t1/2 in the pruned stems at 210 DAD in relation to the leaves may be explained,

in part, by the C/N ratio, which was 80 for the pruned stems and 18 for the leaves.

Residues with a C/N ratio greater than 20 are less colonized by the microbial population because there is less N content available for constitution of tissue, which reduces mineralization of components of the residue, and this is then reflected in greater residual DM (Silva et al., 2008). In addition, the pruned grapevine shoots normally have greater lignin contents and greater values of the lignin/N and lignin/P ratio, but lower values of the cellulose/lignin ratio, in relation to leaves (Nikolaidou et al., 2010). Thus, residues with high lignin values, which may, for example, result in greater values of the lignin/N ratio, have slower decomposition over time because the lignin tends to mechanically protect the cellulose of the cell wall against degradation (Gonzalo et al., 2016).

The C remaining in the leaves and pruned stems deposited in the plant row and between rows reduced over time (Table 3, Figure 1B, Figure 2B). For leaves at 30 DAD, residual C was approximately 85% and 80% in the row and between rows, respectively, whereas at 210 DAD, residual C was near 45% in the row and 43% between rows (Figure 1B). For the pruned stems, residual C at 30 DAD was approximately 95% and 97% in the row and between rows, respectively, and at 210 DAD, it was near 61% in the row and between rows (Figure 2B). The half-life (t1/2) of the C remaining in the leaves and pruned stems deposited in the row and between rows was 231 (Table 4) and 346 days (Table 5), respectively.

The C content decreased in the leaves and pruned stems deposited in the plant row and between rows over the period of collection because of leaching of soluble organic C from the litter, which may rapidly be assimilated by the microbial population, actually speeding decomposition of the residues. The C content also decreased because of degradation of recalcitrant organic compounds, which have different degrees of degradation (Campbell et al., 2016). The greater percentages of residual C and t1/2 at 210 DAD in the pruned stems in relation to the leaves may be associated with a greater C/N ratio (80). But they are also probably associated with the lower contents of cellulose and greater contents of lignin in the plant tissue, which lead to slower decomposition, through formation of a phenolic polymer of condensed aromatic rings that substantially contributes to the formation of more recalcitrant C compounds in the cell wall (Heim & Schmidt, 2007), which are more difficult for the microbial population to degrade (Paul et al., 2015).

The N and 15N remaining in the leaves and pruned stems deposited in the plant row and between rows decreased over time (Table 3, Figure 1C, Figure 2C). The N remaining in the leaves at 30 DAD was 85% and 78% in the row and between rows, whereas at 210 DAD, these percentages were 55% and 45% in the row and between rows, respectively (Figure 1C). For 15N, the content remaining in the leaves deposited in the plant row and between rows at 30 DAD was 15%, and at 210 DAD it was 3% (Figure 1D). The t1/2 of the N and of the 15N remaining in the leaves deposited in the row and between rows was 231 and 14 days, respectively (Table 4).

Table 4. Parameters of the models ($X= Xo^{exp(-kt)}$) fitted to the residual values of mass, carbon (C), nitrogen (N), ^{15}N excess, phosphorus (P), and potassium (K), half-life ($t^{½}$), and the value of the coefficient of determination (R^2) in residue of leaves in decomposition in a vineyard soil.

Tabela 4. Parâmetros dos modelos ($X= Xo^{exp(-kt)}$) ajustados aos valores residuais de massa, carbono (C), nitrogenio (N), excesso de 15N, fósforo (P) e potássio (K), tempo de meia-vida ($t^{½}$), e o valor do coeficiente de determinação (R2) no resíduo de folhas em decomposição em solo de vinhedo.

Litter	Parameters of the decomposition equation			
	Xo(†)	k(§)	t½(¶)	R^2
	%	g g^{-1}	(days)	
		Mass		
In the row	96.17	0.003*	231	0.90*
Betw. rows	94.43	0.003*	231	0.92*
		C		
In the row	95.00	0.003*	231	0.75*
Betw. rows	94.43	0.003*	231	0.92*
		N		
In the row	96.30	0.003*	231	0.75*
Betw. rows	95.71	0.003*	231	0.82*
		^{15}N excess		
In the row	99.29	0.05*	13.86	0.95*
Betw. rows	99.43	0.05*	13.86	0.96*
		P		
In the row	87.25	0.003*	231	0.63*
Betw. rows	87.45	0.004*	173	0.69*
		K		
In the row	94.41	0.01*	69.3	0.94*
Betw. rows	90.19	0.01*	69.3	0.84*

(†) Initial proportion of material; (§) Decomposition constant; (¶) Half-life; * Significant at 5% probability.

The N remaining in the pruned stems in the plant row and between rows at 30 DAD was 97% and 85%, and at 210 DAD, it was 75% and 80%, respectively (Figure 2C). The t1/2 of the N remaining in the pruned stems deposited in the row and between rows was 693 days (Table 5). For 15N, the content remaining in the pruned stems deposited in the row and between rows was 75% at 30 DAD, and at 210 DAD, it was 40% and 45% in the row and between rows, respectively (Figure 2D). The t1/2 of the 15N remaining in the pruned stems deposited in the row and between rows was 173 and 139 days, respectively (Table 5).

With the decrease in the percentage of residual N in the leaves and pruned stems, as well as of the 15N derived from nitrogen fertilization, an increase in the mineral N content in the soil of the plant row and between the rows is expected. At 210 DAD of the leaves in the plant row and between the rows, which coincided with the change in color of the berries, approximately half of the N contained in the plant tissue was released to the soil, and part may have been taken up by the vine roots since the N was made available over the period of important phenological stages, such as budding and, especially, flowering, at which time there was greater formation of fine and white roots, which are responsible for water and nutrient uptake (Ferreira et al., 2014).

Table 5. Parameters of the models ($X= Xo^{exp(-kt)}$) fitted to the residual values of mass, carbon (C), nitrogen (N), ^{15}N excess, phosphorus (P), and potassium (K), half-life ($t^{½}$), and the value of the coefficient of determination (R^2) in residue of pruned stems in decomposition in a vineyard soil.

Tabela 5. Parâmetros dos ($X= Xo^{exp(-kt)}$) ajustados aos valores residuais de massa, carbono (C), azoto (N), excesso de 15N, fósforo (P) e potássio (K), meia-vida ($t½$), e o valor do coeficiente de determinação (R2) no resíduo dos ramos em decomposição em solo de vinhedo.

Litter	Parameters of the decomposition equation			
	Xo(†)	k(§)	t½(¶)	R^2
	%	g g^{-1}	(dias)	
		Mass		
In the row	97.21	0.001*	693	0.87*
Betw. rows	97.67	0.001*	693	0.93*
		C		
In the row	103.18	0.002*	346,5	0.93*
Betw. rows	102.85	0.002*	346,5	0.92*
		N		
In the row	98.40	0.001*	693	0.83*
Betw. rows	93.56	0.001*	693	0.52*
		^{15}N excesso		
In the row	92.18	0.004*	173.25	0.91*
Betw. rows	90.73	0.005*	138.6	0.88*
		P		
In the row	97.87	0.002*	231	0.89*
Betw. rows	94.64	0.002*	346.5	0.67*
		K		
In the row	103.36	0.006*	115.5	0.83*
Betw. rows	99.31	0.006*	115.5	0.85*

(†) Initial proportion of material; (§) Decomposition constant; (¶) Half-life; * Significant at 5% probability.

The uptake of N derived from decomposition of organic residues on the soil surface, including leaves, may partially explain the low utilization of N derived from topdressed nitrogen fertilization in vineyards set up in sandy texture soils, such as the Ultisol of the present study and, consequently, the lack of increase in yield or even impact on the N content in the grapevine leaves or on the composition of the grape and of its must (Brunetto et al., 2011). It should be noted that the N15 contained in the leaves derived from topdressed nitrogen fertilization on the grapevines was released to the soil quickly, especially soon after depositing the leaves on the soil surface in the plant row and between rows, which coincided with the period of dormancy, which is a period of low demand of N by the grapevines (González-Rossia et al., 2008). This increases the potential for N transfer, for example, by leaching since the soil has a sandy texture and low organic matter content, and rainfall is frequent and of high intensity throughout the winter (Bechmann, 2014). However, transfer of N15 may be minimized if part of the N15 is taken up by the soil cover plants that cohabitate the vineyards, especially between the rows. In contrast, at 210 DAD of the pruned stems in the row and between rows, nearly 80% of the N remained, which indicates little contribution of the N derived from shoots in the increase of its mineral forms in the soil which, consequently, reduces availability to plants, including grapevines or soil cover plants. In addition, though this was not observed over the period of evaluation, lower availability of N over time may occur because of its immobilization, since the shoots have a high C/N ratio, which explains in part the t1/2 of 693 days (Nikolaidou et al., 2010).

The P remaining in the leaves and pruned stems deposited in the plant row and between rows decreased over time (Table 3, Figure 1E, Figure 2E). The P remaining in the leaves at 30 DAD was 69% and 64% in the row and between rows, and at 210 DAD, it was 34% and 36% in the row and between rows, respectively (Figure 1E). The half-life (t1/2) of the P remaining in the leaves deposited in the row was 231 days and between the rows, it was 173 days (Table 4). The P remaining in the pruned stems at 30 DAD was 92% and 84% in the row and between rows, respectively, and at 210 DAD, it was 55% and 59% for the row and between rows, respectively (Figure 2E). The half-life (t1/2) of the P remaining in the pruned leaves deposited in the row and between rows was 231 and 346 days, respectively (Table 5).

The fact that the percentages of residual P are similar at 210 DAD, in comparing the leaves and pruned stems deposited in the plant row and between rows, is probably because most of the P in the plant tissue is found in the vacuole of the cell in the form of inorganic P and monoesters, which are soluble in water (Salmi et al., 2006) and, for that reason, more easily released. The rest of the P present in the residues, such as diesters (nucleic acids, phospholipids, and phosphoproteins), is released by the action of the microbial population (Giacomini et al., 2003). The P released from the tissue can increase the labile fraction, which may be taken up by the grapevines or cover plant species that cohabitate the vineyards (Ferreira et al., 2014), or be incorporated in more stable fractions in the soil.

The K remaining in the leaves and pruned stems deposited in the plant row and between rows decreased over time (Table 3, Figure 1F, Figure 2F). The K remaining in the leaves at 30 DAD was near 58% and 46% in the row and between rows, respectively, and at 210 DAD, it was 4% in the row and between rows (Figure 1F). The half-life (t1/2) of the K remaining in the leaves deposited in the row and between rows was 69 days (Table 4). The K remaining in the pruned stems at 30 DAD was 87% and 80% in the row and between rows, respectively, and at 210 DAD, the residual percentage of K in the pruned stems deposited in the row was 12%, and between rows, 19% (Figure 2F). The half-life (t1/2) of the K remaining in the pruned stems deposited in the row and between rows was 115 days (Table 5). The small percentages of K remaining at 210 DAD possibly occurred because K is not associated with any structural component in the plant tissue (Boer et al., 2007) and, for that reason, it is found in soluble form in litter in decomposition (Ferreira et al., 2014).

4 Conclusions

The rate of decomposition and release of carbon and nutrients from the leaves and pruned stems deposited on the soil surface was not affected by the position of deposition, in the plant row or between rows of the grapevine.

The rate of decomposition and release of carbon and nutrients from the leaves deposited in the row and between rows of the vineyard was greater than that of the pruned stems throughout the period evaluated.

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