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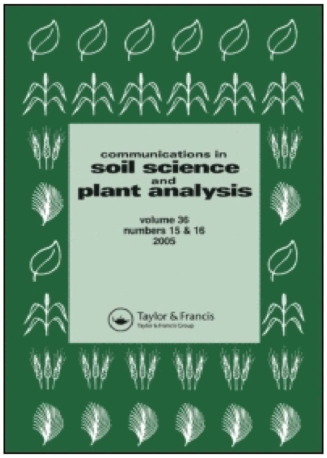

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Residue Decomposition and Fate of Nitrogen-15 in a Wheat Crop under Different Previous Crops and Tillage Systems

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Residue Decomposition and Fate of Nitrogen-15 in a Wheat Crop under Different Previous Crops and Tillage Systems

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Abstract: Nitrogen (N) management may be improved by a thorough understanding of the nutrient dynamics during previous-crop residue decomposition and its impact on fertilizer N fate in the soil–plant system. An experiment was conducted in the Argentine Pampas to evaluate the effect of maize and soybean as previouscrops and plow-till and no-till methods on N dynamics and ^{15}N-labeled fertilizer uptake during a wheat growing season. Maize and soybean residues released N under both tillage treatments, but N release was faster from soybean residues and when residues were buried by tillage. Net immobilization of N on decomposing residues was not detected. A regression model that accounted for 92% of remaining N variability included time, previous crop, and tillage treatment as independent variables. The rapid residue decomposition with N release was attributed to the high temperatures of the agroecosystem. The recovery of ^{15}N-labeled fertilizer in the wheat crop, soil organic matter, and decomposing residues was not statistically different between previous crop treatments or tillage systems. Crop uptake of fertilizer N averaged 52% across treatments. Forty percent of fertilizer N was removed in grains. Immobilization of labeled N on soil organic matter was substantial, averaging 34% of the ^{15}N-labeled fertilizer retained, but was very small on decomposing residues, averaging 0.2–3.0%. Fertilizer N not accounted for at harvest in the soil–plant system was 12% and was ascribed to losses. Previous crop or tillage system had no impact on wheat yield, but when soybean was the previous crop, N content of grain and straw + roots

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increased. Discussion is presented on the potential availability of N retained in wheat straw, roots, and soil organic matter for future crops.

Keywords: N fertilization, ^{15}N recovery, residue decomposition, tillage systems, wheat

INTRODUCTION

During decomposition, plant residues may act as a source or sink for nitrogen (N) (Mary et al. 1996). Decomposition is usually faster as the nitrogen (N) concentration of residues increase and the carbon (C)/N ratio decreases (Jensen et al. 2005). Nitrogen in residues follows a different trend than carbon or residue mass. Net N immobilization by residues usually occurs for N concentration lower than 1.5–2.0% (Seneviratne 2000; Trinsoutrot et al. 2000) or when the C/N ratio is greater than 20–30 (Jensen et al. 2005; Seneviratne 2000), and net N mineralization occurs at values greater and less than these thresholds, respectively. Therefore, different crop residues may impact N dynamics, generating different N credits for the present crops (Mayer et al. 2003). Legume residues usually generate a higher N credit for succeeding crops compared to nonlegumes, as a result of the greater N concentration in the former (Gentry et al. 2001).

Tillage system may affect soil N dynamics because buried residues decompose faster than when they are left on the soil surface as a consequence of their higher water contents (Christensen 1986). Under no-till, slower N release occurs from residues (Burgess, Mehuys, and Madramootoo 2002; Lachnicht et al. 2004) or it is also possible a higher net N immobilization (Schomberg, Steiner, and Unger 1994) than in tilled systems.

Changes in agricultural management involving different crop sequences and tillage systems may cause N deficiencies and produce changes in the economically and environmentally optimum fertilizer rates for grain production. Fertilizer N rates should be suitable to assure good crop yields without causing N losses. The ^{15}N techniques are robust tools that allow identification of sources and sinks of N within the soil–plant system, including crop N recovery and N losses (Follett 2001). Residual fertilizer remaining in soil N pools that could be available for succeeding crops may also be determined (Kumar and Goh 2002).

The Pampas region is a vast plain of around 50 Mha, which extends from 28° to 40° S in Argentina (Alvarez and Lavado 1998). Agriculture is performed in the subhumid and humid portions of the region on well-drained soils, mainly Mollisols, formed on loess-like materials under a temperate climate. More than 50% of the area is cropped with soybeans (*Glycine max*), maize (*Zea mays*), and wheat (*Triticum aestivum*) (Hall et al. 1992). The region is considered one of the most suitable areas for grain crop production in the world (Satorre and Slafer 1999). Since 1990, an exponential increase in no-till practices has occurred, with around 50% of agricultural lands now cropped under this practice (INDEC 2003). Fertilized areas have followed a similar trend, and in 2002 around 80% of the total wheat area received N fertilization (FAO 2004). Both maize and soybeans are common previous crops for wheat in the region. The effects of different combinations of previous crops and tillage systems on N dynamics during the wheat-growing season have not been studied, nor the possible impacts of such combinations on fertilizer uptake by wheat and fertilizer fate in the soil–plant system.

The objectives were to determine 1) the dynamics of the N release-immobilization processes of previous crop residues during the wheat growing cycle under contrasting tillage systems in the Pampas and 2) the fate of the ^{15}N-labeled fertilizer N applied to the crop.

MATERIALS AND METHODS

A field experiment was conducted at the Faculty of Agronomy of the University of Buenos Aires (34° 32′ S, 58° 28′ W) in Argentina. The climate is humid and temperate with a mean annual rainfall and temperature of 1000 mm and 18.8°C, respectively. Forty percent of the rainfall occurs during the fallow period before wheat and during the wheat growing season. The surface soil (0–30 cm) was a silty clay loam Typic Argiudoll with 375 g clay kg^{-1} soil, 519 g silt kg^{-1} soil, 1.25% organic carbon (C), 0.127% organic N, 11 mg kg^{-1} extractable phosphorus (P) (Bray 1), and a pH of 6.7. Soil bulk density averaged 1.26 g cm^{-3} in the 0- to 30-cm depth and 1.35 g cm^{-3} in the 30- to 60-cm depth. In May 1998, the experiment started on a grassland site. Twelve experimental plots (5 × 10 m each) were installed in a randomized complete block design with three replicates per treatment; the factorial design was previous crop × tillage treatment. Previous crops were maize and soybeans; tillage consisted in plowing up to a 15-cm depth followed by disking, whereas in no-till, weeds were chemically controlled. In June 1999, 2 months after maize and soybean harvest, tillage operations were repeated in the tilled treatments, whereas herbicides were applied in the no-till treatments. All plots were sown with spring wheat in August 1999 and subsequently fertilized with 30 kg P ha^{-1} as triple superphosphate. During wheat tillering, plots were fertilized with 110 kg N ha^{-1} as unlabelled urea, top-dressed by hand. Microplots of 1.2 × 1.2 m were installed within each main plot and fertilized by spraying uniformly with a solution of ammonium sulfate enriched at 1.462 at.% ^{15}N abundance.

Four soil samples were collected from each plot at wheat sowing and harvest and composed. Soil samples were taken from the 0- to 30-cm layer with a 46-mm-diameter soil sampler and from the 30- to 60-cm layer with a 17-mm diameter sampler. Fresh soil samples were thoroughly mixed, and ammonium + nitrate N was determined by steam distillation (Mulvaney

1996). The remaining residue biomass was sampled at 1, 63, 105, 140, and 187 days from plowing time in the main plots and only in the last date in microplots. Surface residues were collected from four 625-cm^2 square frames in each plot. Four soil columns were taken from each plot to a 30-cm depth. Soil samples were washed through a 500-μm sieve, and buried residues plus wheat roots larger than 500 μm were retained and ovendried at 60°C. Residues were manually separated from roots, and both components were weighed. At wheat maturity, aboveground plant biomass was harvested from four 0.5-m-long lines in each plot and microplot. Using the equation proposed by Jackson et al. (1996) for annual crops, wheat root biomass up to a 60-cm depth was estimated from 0- to 30-cm depth data obtained by washing. Nitrogen content of residues, wheat materials, and soil (0- to 30-cm) was determined by wet digestion (Bremmer and Mulvaney 1982). Nitrogen released by residues during a time period was calculated as the difference between initial and final residue N content. Nitrogen-15 at.% was determined by optical emission spectrometry (IAEA 1976) at the National Commission of Atomic Energy of Argentina. Soil results were transformed into a per-hectare basis using bulk density.

The N fraction derived from fertilizer (*Ndff*) in soil and plant material was estimated by the following equation:

$$Ndff = \frac{(a - b)}{(c - b)} \tag{1}$$

where a = at.% ^{15}N abundance of soil or plant component in the ^{15}N-labeled microplot, b = at.% ^{15}N abundance of soil in the unlabeled main plot, and c = at.% ^{15}N abundance of the ^{15}N-labeled fertilizer.

By subtracting the at.% ^{15}N abundance of soil or plant component in the unlabeled plot (b) from the at.% ^{15}N abundance of soil, plant, and fertilizer samples (a and c) instead of the at.% ^{15}N natural abundance of the atmosphere (0.366), Eq. (1) allowed the correction for isotopic discrimination during soil biological processes (Delwiche and Steyn 1970). This process leads to an enrichment of soil ^{15}N pools relative to the atmosphere (Amundson et al. 2003). The ^{15}N natural abundance of soil N in this experiment averaged 0.373 ± 0.003 at.%.

The remaining nitrogen (RM) in decomposing residues was fitted to the common first order negative exponential model (Andren and Paustian 1987) by least square techniques:

$$RM = 100\, e^{-kt} \tag{2}$$

where k = decomposition rate constant (day^{-1}) and t = time (days).

Decomposition rate constants of the models were compared by t-tests ($P < 0.05$) (Mead, Curnov, and Hasted 1993). Simple and multiple regression techniques were used to analyze the N contents in residues over time. Linear (x_1), curvilinear (x_1^2), and interaction terms (x_1x_2) were tested in multiple regression models (Colwell 1994). Only nonauto-correlated variables, as judged by the variance inflation factors (VIF) values (Neter, Wasserman, and Kutner 1990), were included in the multiple regression models, which were selected by the stepwise method ($P < 0.05$). Independent variables tested were time, cumulative air temperature (warmer than 0°C), residue mass, N concentration in residues, fraction of residues incorporated into the soil, and previous crop and tillage system. Previous crop and tillage systems were were tested in models as dummy variables. Models showing the highest R^2 were selected, and the significance of regressions tested by the F test ($P < 0.01$). Wheat yield and ^{15}N-fertilizer fate results were analyzed with analysis of variance (ANOVA) ($P < 0.05$); when statistical differences were detected least significant difference method (LSD) tests were performed for means comparisons.

RESULTS

During residue decomposition, air temperature rose and soil water content decreased as seasons changed from winter to spring (Figure 1A). In this period, average air temperature was 15.1°C and total rainfall was 420 mm. A significant correlation was observed between cumulative air temperature and time (Figure 1B). Initial residue mass and N concentrations differed between previous crops. Average dry matters of maize and soybean residues were 13,300 and 9,600 kg ha^{-1}, respectively. Initial N concentration averaged 0.60 and 1.30% and total N content was 125 and 80 kg ha^{-1} for soybeans and maize, respectively. Under plow-till, 90–95% of residues were buried, whereas under no-till, buried material averaged 36% of total residues.

Nitrogen content remaining in crop residues decreased during the experiment in all the treatments (Figure 2), indicating no net N

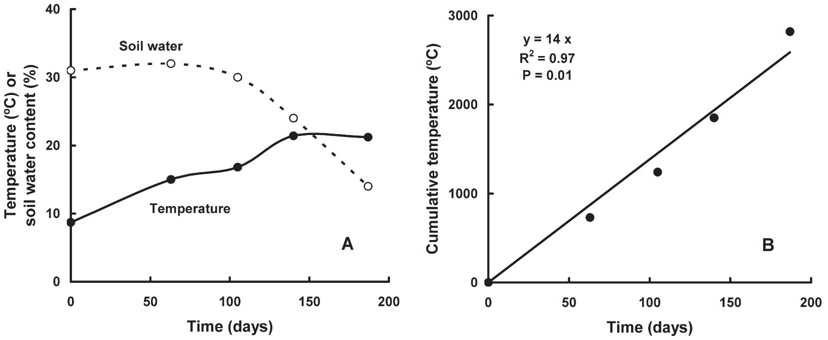

Figure 1. A) Temperature and soil water content evolution during the experiment. B) Relationship between cumulative temperature and time since initiation of decomposition evaluation.

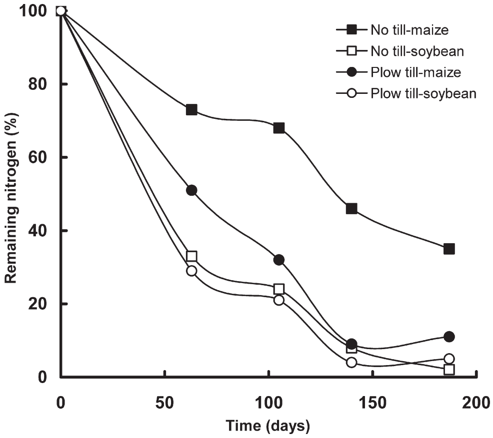

Figure 2. Evolution of remaining nitrogen in decomposing maize and soybean under plow-till and no-till treatments.

immobilization. Nitrogen release was faster from soybean residues than from maize residues and also under plow-till maize compared to no-till maize plots. The dynamics of N content in residues over time could be predicted fairly well by a negative exponential model (Table 1). Decomposition rate constants were significantly greater for soybean residues than for maize residues. Comparing tillage treatments, significant differences were only detected for maize residues, which decomposed faster under plow-till than under no-till. As decomposition advanced, N concentration increased in maize residues but was stable in soybean residues (Figure 3A). Consequently, a significant linear correlation was observed between N content and biomass in soybean residues (Figure 3B). In contrast, biomass decreased at a faster rate than N content in maize residues, and a significant curvilinear function was fitted. A very simple multiple regression model accurately predicted the N content remaining in residues for all treatments (Figure 4). Nitrogen content in crop residues decreased over time and was faster when the previous crop was soybean or the tillage system was plow-till. An alternative, more sophisticated

Table 1. Decomposition rate constants of the negative exponential model fitted to remaining nitrogen data and corresponding determination coefficients

Treatment	k (day^{-1})	R^2
No-till maize	−0.0050	0.957
No-till soybean	−0.0164	0.991
Plow-till maize	−0.0121	0.978
Plow-till soybean	−0.0181	0.990

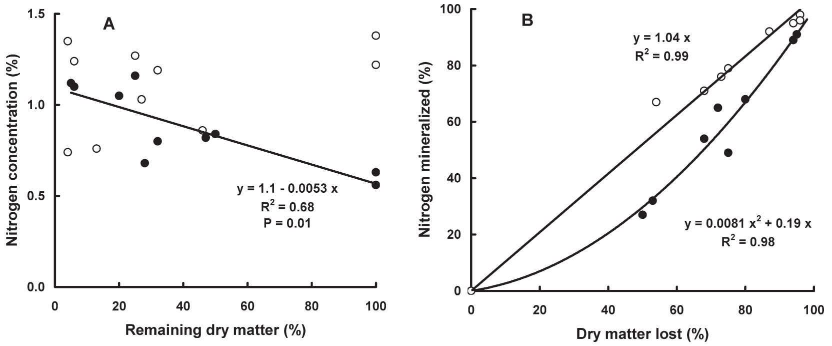

Figure 3. A) Relationship between nitrogen concentration of decomposing residues and residual dry matter of crop residues. B) Relationship between nitrogen mineralized from residues and cumulative dry matter lost. Full circles: maize; empty circles: soybean.

model could be fitted using time, initial N concentration of residues, and fraction of residue incorporated as independent variables, which accounted for 93% of the remaining N variability (results not presented). Immobilization of ^{15}N-labeled fertilizer on decomposing residue was very small. Around 3% of the ^{15}N-labelled fertilizer was recovered in maize residues under no-till treatment at the end of the experiment and only 0.20–0.30% in the other treatments.

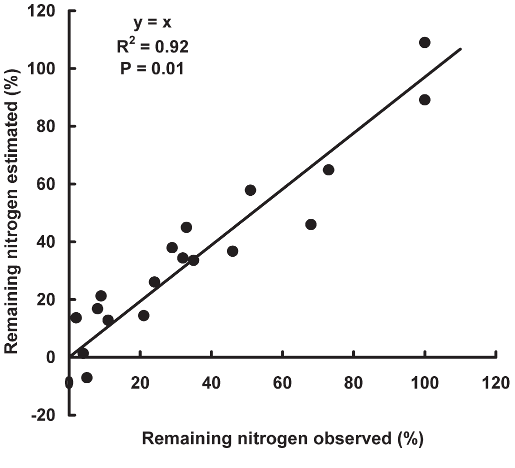

Figure 4. Relationship between remaining nitrogen in residues observed and estimated by the following regression model: Remaining N (%) = 109 – 0.85 T + 0.0024 T^2 – 20 PC – 0.11 T × TS where T = time (days), PC = previous crop (maize 0, soybean 1), and TS = tillage system (no-till 0, plow-till 1).

Wheat yield and biomass production was similar between previous crops and tillage treatments, averaging 5200 kg grain DM ha^{-1}. Nitrogen concentration in wheat grain and straw + roots was greater when soybean was the previous crop compared to maize (2.3 vs. 2.0% N in grain and 0.54 vs. 0.47% in straw + roots for previous crops soybean and maize, respectively). Tillage systems had no impact on wheat N concentration. ^{15}N-labeled fertilizer recovery in above- and belowground biomass averaged 53% without significant differences between treatments. Less than 1% of fertilizer was present in the soil as inorganic forms (ammonium or nitrates), and 34% was immobilized in soil organic matter (Figure 5). Twelve percent of ^{15}N-labeled fertilizer was not recovered in the soil–plant system at harvest to 60 cm deep, without differences between previous crops or tillage systems. Residual ^{15}N-labeled fertilizer in soil at wheat harvest averaged 48% across treatments.

DISCUSSION

Crop residue decomposition and N release were more rapid in this experiment than in other studies conducted in similar, temperate environments (Cogle et al. 1987; Kalburtji and Mamolos 2000). Six months after the beginning of residue decomposition, almost all N in residues of buried and surface soybean and N from buried maize residues was released. Temperature is the most important factor regulating microbial mineralization processes in the Pampas region (Alvarez and Alvarez 2001). Cumulative temperature during

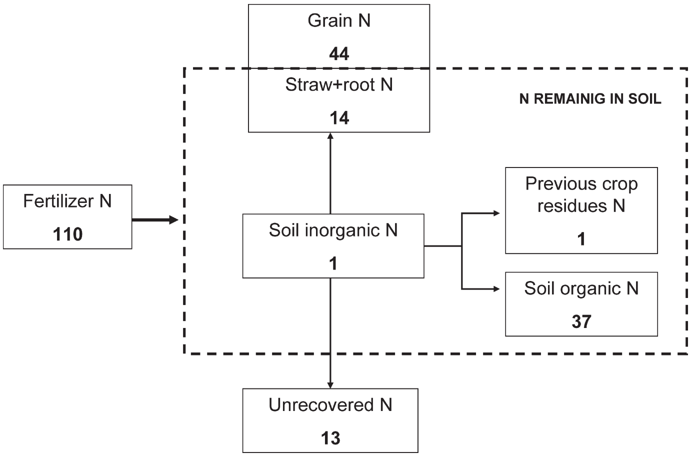

Figure 5. Fate of labeled fertilizer nitrogen at wheat harvest time. Values are expressed in kg N ha^{-1}.

the experimental period was 2880°C. This high value explained the fast residue decomposition observed.

Initial N concentration of residues impacted decomposition rate and N release, mainly when residues were left on the soil surface, but only small effects were detected when they were buried. During the 0- to 100-day period after the beginning of residue decomposition, soybean residues tended to decompose faster than maize residues, but differences diminished later. Even though maize residue decomposition was slower than soybean residue decomposition, all treatments resulted in net N mineralization to the soil. With a N concentration as low as 0.6%, maize residues released N.

Soil mineral N affects crop residue N dynamics. When soils have low mineral N levels, residues tend to release N (Kalburtji and Mamolos 2000). In this experiment, mineral N content of the soil was low during the initial phase of decomposition (ca. 6 mg N kg^{-1} soil), and this condition may produce N release from maize residues. After an initial phase of rapid decomposition of buried maize residues in comparison to surface residues, decomposition rates became similar between tillage systems. Similar results have been reported previously for wheat materials in other agroecosystems (Cogle et al. 1987). In previous studies, decomposition of maize residues under no-till treatment in the Pampas region have been reported to be slower than when they are incorporated into soil by tillage. This has been attributed to drier conditions in crop residues left on the soil surface (Sánchez 1988).

Previous crops had no impact on wheat yield but affected N content in wheat biomass. Nitrogen uptake was around 40 kg ha^{-1} higher when soybean preceded wheat in comparison to maize. This may be attributed to a greater N release from soybean residues, due to a combination of an initial higher N content of soybean residues and a faster decomposition rate. The recovery of N from decomposing residues by succeeding crops is very variable. Using ^{15}N-labeled plant materials, low residual N recoveries of 1–4% (Glasener et al. 2002; Mubarak et al. 2003) to recoveries of 38–50% (Bergensen et al. 1992; Hood et al. 2000) have been reported, depending on residue composition and environmental conditions. In our experiment, N release from soybean residues averaged 120 kg N ha^{-1}. Assuming that 50% of the nitrogen from residues is incorporated into microbial biomass during decomposition (Parton et al. 1993), a net release to the mineral N soil pool of 60 kg N ha^{-1} was produced. Buried maize residues released 72 kg N ha^{-1} and surface maize residues 52 kg N ha^{-1}. These values are equivalent to estimated net releases to the mineral pool of 36 and 26 kg N ha^{-1}, respectively. Consequently, estimated net release of N from soybean residues was around 24–36 kg N ha^{-1} higher than from maize residues. Most of the greater wheat N uptake when soybean was the previous crop in relation to maize may be attributed to N released from decomposing residues.

Maize and soybean residues immobilized a very low quantity of fertilizer N during the wheat growing cycle. Previous crop or tillage system had no impact on fertilizer N recovery by wheat or retained in the soil–plant system. In contrast, other studies have reported a significant effect of crop residues on ^{15}N-labeled fertilizer recovery in soils. By comparing management practices where residues are left on the soil surface or removed, many authors have observed greater ^{15}N-labeled fertilizer recoveries in soils with residues (Bird et al. 2001; Ismail, Hofman, and Ichir 2003; Mubarak et al. 2003). This circumstance may be attributed to N immobilization on residues. In our experiment, different crop residues caused only minor differences in ^{15}N-labeled fertilizer immobilization, showing an insignificant effect on fertilizer uptake by wheat.

Tillage systems have been shown to affect fertilizer use by crops. Malhi Nyborg, and Solberg (1996) observed a lower fertilizer N recovery when crops were managed under no-till than tilled systems, as the result of a greater N immobilization under no-till treatment. However, this did not occur in our experiment.

Soil organic matter was an important sink for fertilizer N in our experiment. Similar results have been reported in other environments (Bundy and Andraski 2005; Ichir, Ismail, and Hofman 2003; Stevens, Hoeft, and Mulvaney 2005). Part of the immobilized N has been found in microbial biomass and organic extractable forms of N, but the major fraction is present in stable organic components (Bird et al. 2001; Blankenau, Kuhlmann, and Olfs 2000). Although this immobilized N could be a potential source for future crops, its availability for subsequent crops has been observed to be very low (Bundy and Andraski 2005; Ichir, Ismail, and Hofman 2003; Mubarak et al. 2003; Stevens, Hoeft, and Mulvaney 2005). This is a consequence of a low remineralization rate of immobilized N (Ichir, Ismail, and Hofman 2003) or, in other cases, of intense N losses from the agroecosystem (Bird et al. 2001; Bundy and Andraski 2005). Previous crop and tillage systems had no impact on N recovery in a Pampean agroecosystem during a first-year wheat crop, but future studies are needed to study the long-term dynamics of N under these management practices.

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