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ASSOCIATION BETWEEN SOIL ORGANIC MATTER AND WHEAT YIELD IN HUMID PAMPA OF ARGENTINA

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ABSTRACT

The Rolling and Flat Pampas are vast plains located in Argentina. Wheat is one of the most economically important crops of these regions. Two extensive studies have been preformed to evaluate the effects of nitrogen fertilization on wheat yield at field scale. We pooled these published data to establish relationships between wheat yield and soil and climate variables under a wide range of soils and management conditions. Total soil carbon was the variable more associated with yield ($r^2 = 0.25$). The increase in grain production expected between soils with low and high carbon levels rounded 2,200 kg ha^{-1}. A multivariate model which included carbon in the light fraction, potential mineralizaable nitrogen, available mineral nitrogen, and rainfall was obtained, explaining 50% of wheat yield variability. These results highlight the importance of organic matter on grain production in the Humid Pampas. This effect can be due to the role of organic soil components as source of nutrients for crops.

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INTRODUCTION

The Rolling and Flat Pampas are vast plains which represent about 20 Mha, located between 32–36°S and 58–63°W in Argentina (Fig. 1). Wheat is one of the most economically important crops of these regions, and these regions have contributed to more than half of Argentine wheat production. The climate is humid temperate, with Mollisols as predominant soils (1). Rainfall and temperature are the most important climatic factors determining crop production in the Pampas (1). Otherwise, crop yields are known to be influenced by soil properties. Organic matter has been found as a good index of crop production in the arid portion of the region, possibly because of its beneficial effects on soil water holding capacity and as a source of nutrients (2). The labile component of soil organic matter plays an important role in the short-term nutrient turnover (3). This organic pool may be estimated by densimetric techniques (4) that isolated

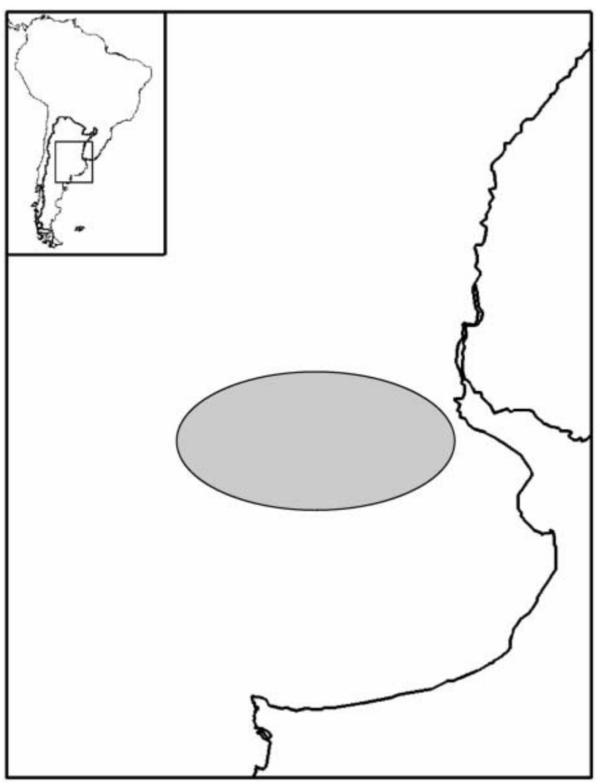


Figure 1. Map of whole Pampean Region with the study area darkened.

the carbon and nitrogen present in the soil light fraction. Labile fraction is depleted more than total organic matter with cultivation and, consequently, the capability of soils to mineralize nitrogen also decreased (5). There are few studies that related organic matter components or soil nitrogen mineralization potential with crop yields at field scale.

In the Rolling and Flat Pampas, two extensive studies have been performed by Barberis et al. to describe the effects of nitrogen fertilization on wheat yield (6,7). Rainfall, mineral nitrogen level, extractable phosphorus, organic carbon, carbon in the light fraction, and potentially mineralizable nitrogen related to wheat yield have been determined in the experiments. We pooled these datasets to establish relationships between wheat yield and soil properties under a wide range of environmental conditions and managements.

MATERIALS AND METHODS

The Rolling Pampa is an extensive plain with rolling relief with Typic and Vertic Argiudolls as predominant soils. Mean annual precipitation varies from 1000 mm in the east to 900 mm in the west. In the Flat Pampa, Typic and Entic Hapludolls, and Haplustolls are the dominant soils widespread in a flat landscape. Mean annual precipitation decreases from 900 mm in the east to a minimum of 700 mm in the west. Soil pH is slightly acid in all these soils. Mean annual temperature ranges from 16 to 17°C in both areas (8).

Twenty-two field experiments were conducted in the Rolling Pampa and 19 in the Flat Pampa, from 1978 to 1982 in order to quantify wheat responses to nitrogen fertilization. A detailed description of the experiments and the methods employed had been published elsewhere (6,7). Briefly, in each experiment a control and different fertilization treatments (35, 50, 75, and 100 kg N ha^{-1} as urea), were applied in 3 plots with a randomized design. Individual plots had an area of 1–2 ha. By pooling these data 160 different situations were obtained considering year, site and fertilization treatment interactions. The experiments were managed under moldboard plow tillage, and comprised different previous crops (mainly corn and soybean), periods of land cropping (2 to 40 years) and fallow duration (14 to 129 days). A composited soil sample of 15 subsamples was taken by plot from the upper 20 cm of the profile at wheat presowing. Organic carbon was determined by the Walkley and Black method (9) and using an estimated bulk density of 1.3, carbon content on an area basis was calculated. The organic carbon in the soil light fraction was isolated using a bromoform: ethanol mixture (density $= 2\,g\,mL^{-1}$) (10). Sieved soil samples (<500 μm) were agitated with the separation liquid by hand by one minute and then centrifuged at 1000 g. The supernatant was filtered through fibber glass under suction. Potentially mineralizable nitrogen was determined by the technique proposed by

Stanford and Smith (11), from the nitrogen mineralized in four weeks incubations. Nitrate nitrogen at seeding was determined by colorimetry (12) and available mineral nitrogen calculated as the sum of nitrate nitrogen and fertilizer rate. Extractable phosphorus was measured by Bray and Kurtz 1 (13). Rainfall was monitored in each experiment. The crop was harvested mechanically.

The associations between yield, rainfall, and soil properties were analyzed using simple linear regressions and the stepwise method for constructing multiple regressions. Only variables not autocorrelated were included in the models. The significance of the regressions was analyzed by the F test.

RESULTS

Pooling the data, broad ranges of rainfall and soil properties were obtained (Table 1). Organic carbon content was the soil variable more correlated with wheat yields (Fig. 2). A difference of 2,200 kg grain ha^{-1} may be expected between soils with low and high organic matter content. Rainfall during the period from the beginning of the fallow to the end of the growing cycle (maturity), carbon in the soil light fraction and potential mineralizable nitrogen were also significantly correlated with yield. Other soil properties like available nitrogen and phosphorus were not associated with yield. Relationships were of curvilinear form and no more than 25% of the yield variability could be explained by simple regressions. The carbon in the soil light fraction represented around 20% (9–38%) of the total soil organic carbon, whereas potentially mineralizable nitrogen comprised on an average 9% (4–4%) of the total organic nitrogen.

Transformation of variables for linearization was performed by logarithmization and using the stepwise method a multiple regression model was obtained that explained 47% of the variability in grain production (Fig. 3). The model included as explaining variables carbon in the light fraction, potential mineralizable nitrogen, available mineral nitrogen, and rainfall. Total soil organic carbon was excluded by the program because there was autocorrelation with carbon in the light fraction ($r^2 = 0.38$) and potential mineralizable nitrogen ($r^2 = 0.19$). The model tended to overestimate grain production in the lower range, and to underestimate it at high yields.

DISCUSSION

Genetic and cultural management improvements rise wheat yields about 19 kg $ha^{-1} y^{-1}$ in the Pampean Region (14). This means an increase of 300 kg ha^{-1} since the experiments were performed up to day. In spite of this mean increment, grain yield nowadays rounded 2,200 kg ha^{-1}, considerably

Table 1. Main Characteristics of Climate and Soil of the Experimental Sites

	Organic C ($t\,ha^{-1}$)	Soil Light Fraction C ($t\,ha^{-1}$)	Mineral Available N ($kg\,ha^{-1}$)	PMN ($mg\,N\,kg^{-1}$ Soil)	Extractable P ($kg\,ha^{-1}$)	Rainfall (mm)
Mean	45	8.87	86	147	48.5	325
Minimum	17.4	3.64	12	81.4	14.3	114
Maximum	79.8	25.2	216	234	94.9	612

Organic C: organic carbon in the 0–20 cm layer. Soil light fraction C: carbon in the soil light fraction (density $\leq 2\,g\,mL^{-1}$) in the 0–20 cm layer. Mineral available N: NO_3-N in the 0–60 cm depth + N fertilizer rate. Extractable P: extractable phosphorus in the 0–20 cm layer. PMN: potentially mineralizable nitrogen in the 0–20 cm layer. Rainfall: rainfall during the fallow period and the wheat cycle.

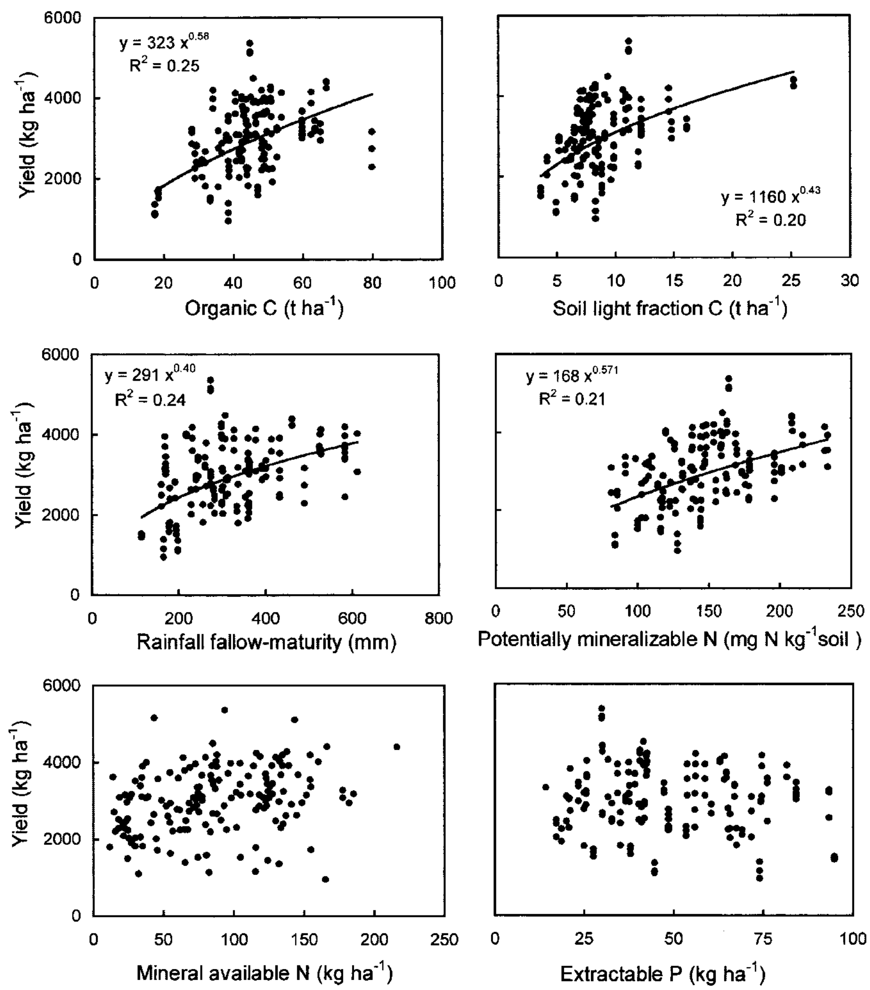
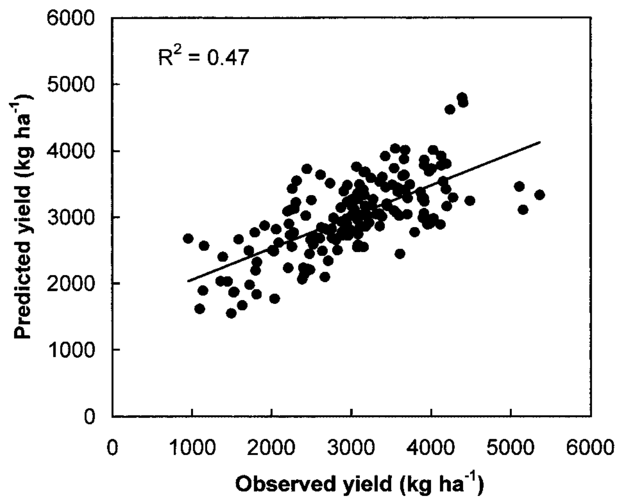


Figure 2. Relationships between wheat yield with rainfall and soil properties. Organic C: organic carbon in the 0–20 cm layer. Soil light fraction C: carbon in the soil light fraction (density $\leq 2\ g\ mL^{-1}$) in the 0–20 cm layer. Mineral available N: NO_3-N in the 0–60 cm depth+N fertilizer rate. Extractable P: extractable phosphorus in the 0–20 cm layer. Potentially mineralizable N: potentially mineralizable nitrogen in the 0–20 cm layer.

lower than those observed in the experiments of Barberis et al. (6,7). In these field trials mean yield was 2,700 kg ha^{-1}, with some cases higher than 5,000 kg ha^{-1}. This figure is high, even for today (15). Consequently, yield data may still be considered representative of pampean agrosystems productivity.



OY= -8430 + 737 ln LFC + 800 ln PMN + 295 ln MAN + 813 ln RFM

Figure 3. Relationship between observed yield and predicted yield with the multiple regression model. OY: observed yield, LFC: light fraction C ($t\,ha^{-1}$), PMN: potentially mineralizable nitrogen ($mg\ N\,kg^{-1}$ soil), MAN: mineral available nitrogen ($kg\ N\,ha^{-1}$) and RFM: rainfall fallow-maturity (mm).

Organic matter is usually considered a main factor controlling soil quality (16). Stenberg (17) under climatic controlled conditions, obtained high single associations between rye grass yield and the logarithm of organic nitrogen ($r^2 = 0.50$), organic carbon ($r^2 = 0.30$) and denitrification potential ($r^2 = 0.27$), among many physical, chemical and biological tested variables. In our study, grain yield presented higher single relationship with total carbon than with the labile organic fractions. In spite of this, labile organic fractions joined with rainfall and nitrogen availability were the best combination of variables for explaining yield. Carbon in the light fraction and potentially mineralizable nitrogen, which quantifies the labile organic fractions, allowed to evaluate the impact of the quality of organic matter on nutrient dynamics. Many studies indicated weak correlation between carbon in the light fraction and nitrogen mineralization, according to a high C:N ratio of this fraction (18,19). In this study, the relationship between these variables was not statically significant and both could integrate the multivariate model.

In the Semiarid area of the Argentine Pampa located at the west edge of the studied area, where coarse soils predominate, in years with high precipitation during the wheat cycle, grain yield is associated with chemical soil properties, as total organic nitrogen and phosphorus availability. Meanwhile, in years with apparent water deficit stress, yield correlated with total carbon and water retention (2). These relationships were obtained in a three-year study with data from 134 fields, where some climate and soil characteristics were determined. Fields were selected by a similar cultural history: fallow period (5 months), previous crop (sunflower), tillage system (disking), fertilizer use (none) and medium maturity class varieties. The effect of organic matter on yield was attributed to its ability to act as a source of nitrogen for crops and to increase soil water holding capacity. Although the selection of experimental sites allowed to obtain a homogeneous set of situations, no more than half of the wheat yield variation could be explained. In the Humid Pampa, precipitation during wheat cycle is higher than in the Semiarid Pampas Region and consequently soil characteristics associate with nutrient supply had an important impact on wheat yield. The results obtained highlight the importance of the soil organic matter pools on wheat yields in this humid region. These results also suggest that practices which induce the loss of the labile organic fractions might result in a markedly decline wheat yield.

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