CORN-SOYBEAN INTERCROPPING: TEMPORAL AND SPATIAL VARIATION OF SOIL PROPERTIES

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SUMMARY

The dynamics of nutrient availability and other soil properties can be strongly altered by agricultural practices like intercropping. A test was made on an agricultural soil with the following treatments: i) sole cropped soybean, II) sole cropped maize and III) intercropped corn-soybean in a 1:2 ratio. Surface soil samplings were made in two moments: the first one (F1) was made with corn at V5 and soybean just emerged; the second one (F2) with corn crop at R1 and soybean crop at V7-R1, both at two distances of the furrows: 5 and 19 cm. Oxidizable C contents were always maximum at the treatments including corn cropping. At both dates, extractable P was maximum at sole corn and minimum at sole soybean crop, which can be attributed to a strong uptake by the leguminous plant. In the first measurement date, at 5 cm of the corresponding furrow, nitrate availability was significantly greater at the soybean treatments with respect to treatments including corn, whereas in the second date, nitrate availability was minimum at sole soybean, which seems to be due to differences in crops development. Finally, the practice of intercropping, within the frame of this test, did not prove to be a viable alternative to limit the existence of high nitrate levels.

Key Words. Crops, Carbon, Phosphorous, Nitrates, Calcium, Potassium.

INTERSIEMBRA MAÍZ-SOJA: VARIACIÓN ESPACIAL Y TEMPORAL DE PROPIEDADES DEL SUELO

RESUMEN

La dinámica de los nutrientes y otras propiedades del suelo pueden ser alteradas fuertemente por prácticas agrícolas como la intersiembra. Se propusieron los siguientes objetivos: i) comparar sistemas de intersiembra soja-maíz con respecto a los monocultivos en cuanto a la cantidad de carbono del suelo ii) evaluar la disponibilidad de los principales nutrientes en estos sistemas. Se realizó un ensayo en un suelo Hapludol típico de la Pampa Arenosa con los siguientes tratamientos: i) soja pura, ii) maíz puro y iii) soja y maíz intersembrados en una relación 2:1, todos manejados en secano. Se realizaron muestreos de suelo en dos momentos: el primero (F1) se realizó con el maíz en V5 y la soja recién emergida; el segundo (F2) con el cultivo de maíz en R1 y el cultivo de soja en V7-R1, a dos distancias de los surcos: 5 y 19 cm. En todos los casos los contenidos de C oxidable fueron máximos bajo los tratamientos que incluían al cultivo de maíz. El nivel de P extractable fue menor en el cultivo de soja avanzado (F2) que en el monocultivo de maíz, lo que fue notable a 5 cm del surco, debido probablemente a una fuerte absorción por parte de la leguminosa. En la primera fecha de medición, a 5 cm del surco correspondiente, la disponibilidad de nitratos fue significativamente mayor en el tratamiento de soja con respecto a los tratamientos que incluían al maíz, mientras que en la segunda fecha de medición, la disponibilidad de nitratos fue mínima en dicho tratamiento, lo que parece deberse a diferencias en el desarrollo de los cultivos. Por último, la práctica de intersiembra dentro del marco de este ensayo no probó ser una alternativa viable para limitar la existencia de elevados niveles de nitratos.

Palabras clave. Cultivos, Carbono, Fósforo, Nitratos.

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INTRODUCTION

In intercropping systems, two or more species are grown simultaneously in the same place so that the overlapping period is long enough to include the vegetative stages. Intercropping is an old and widespread practice in low input systems at the tropics (Willey & Rao, 1980), although in areas of higher production level these systems have not been taken into account for the complexity of their interactions, because agrochemicals are hard to handle (Hauggard-Nielsen *et al.*, 2009a) and because of other drawbacks regarding technological application. Intercropping plays a critical role in temperate, tropical and subtropical regions due to its effective use of resources (Van der Meer, 1989). It is generally considered that the intercropping of different species uses more efficiently light, water and nutrients than sole crops. The reason for this argument is that different species require different resources in time and space, complementing their use (Zheng *et al.*, 2003). The resources use by crops changes over time (Ghaley *et al.*, 2005), so that interactions between species are not fixed but dynamic, and can be useful for designing production systems with limited external inputs. It was also found that intercropping systems can be economically sustainable (Gunes *et al.*, 2007), although this consideration depends on the economic frame for each situation. Other benefits of intercropping may be an improved quality of seed, an improvement in the crop canopy structure susceptible to lodging, an ease of harvest for the species involved (Hummel *et al.*, 2009), more stable yields and resilience to environmental perturbations (Neumann *et al.*, 2007) and a decrease in environmental damage regarding N cycle and its emissions (Hauggaard-Nielsen *et al.*, 2003).

Nutrient dynamics and other soil properties can be strongly altered by agricultural practices such as intercropping. The challenge from a nutritional and environmental point of view would be framed in a better understanding of the soils functioning and the soil-plant system so as to take advantage of soil applied fertilizers in these intercropping systems, preventing accumulations or losses leading not only to unsuitable cost-benefit equations, but to real environmental problems. It is suggested that intercropping of species inefficient in capturing certain nutrient with species that efficiently use that nutrient could increase the nutrition of the inefficient one (Li *et al.*, 2003a). This could be of great interest for relatively immobile nutrients such as phosphorus. Most studies have addressed the intercropping of grass with a legume crop, because they form sustainable production systems (Zhang & Li, 2003), although the efficiency of these systems compared with its sole crops is not yet fully understood (Ghosh *et al.*, 2009). Legume plants release to soil large amounts of enzymes such as alkaline and acid phosphatases and phytases, allowing the mobilization and utilization of organic phosphorus (Gunes *et al.*, 2007). There are several studies that reference a stimulating effect of a legume on phosphorus uptake of another species, usually a grass (Cu *et al.*, 2005; Gunes *et al.*, 2007).

It is also known that cereals can get part of the nitrogen they need from intercropped legume crops (Hauggaard-Nielsen et al. 2009a; Jensen, 1996); there have been improvements of 20-40% in the use of nitrogen sources in grass-legume intercropping with respect to their sole crops (Hauggaard-Nielsen *et al.*, 2009a and b). Cereals can strongly compete for nitrogen in the rhizosphere of legumes-grass intercropping, leading to nitrogen depletion in the soil in contact with the legume roots, stimulating biological nitrogen fixation (BNF) by symbiotic rhizobiacea bacteria (Hauggaard-Nielsen *et al.*, 2001b, 2009a; Li *et al.*, 2003b; Ghaley *et al.*, 2005). Therefore, when intercropping a legume with a grass the first has a higher competitive ability in nitrogen-deficient sites and the second in sites with greater availability of that element (Ghaley *et al.*, 2005). Recently, Sawyer *et al.* (2010) found no differences in nitrate availability through soil profile between a corn monocrop and a cornclover (*Trifolium ambiguum* M. Bieb.) intercropping, during and after the growing season, and Hauggaard-Nielsen *et al.* (2009b) found that the biotic and abiotic stress conditions in conjunction with local longterm crop sequence history influenced more strongly the amounts of mineral N and N utilization than the effects of short-term cultivation. However, there are no more reports than these ones in terms of soil nitrate concentrations at intercropping systems.

The absorption of other nutrients than nitrogen and phosphorus can also be modified in intercropping systems. Potassium concentration decreases were observed in wheat (*Triticum aestivum* L.) and lentil plants (*Lens culinaris* L.) when these crops were intercropped with each other or with chickpea plants (Cicer arietinum L.), with respect to their monocultures (Gunes *et al.,* 2007). Hauggard-Nielsen *et al.* (2009a) found a better use (20% higher) of P, K and S in pea / barley intercrops than in their respective sole crops, but the concentration of elements such as Ca, Mg and K in soils subjected to intercropping were not measured. Song *et al*. (2007) showed that the pH values of the rhizosphere soil of wheat was not significantly altered by intercropping with beans or maize. Knowledge of chemical and biochemical properties of rhizosphere and off-rhizosphere soil that are actually modified by intercropping is scarce, and it is possible that the effect of intercropping on soil properties varies according to the distance among the coexisting crops.

By applying concepts of partition between aerial and belowground biomass, it was observed that components of intercrops compete for soil resources more strongly than for light (Willey& Reddy, 1981). The inclusion of a complete soil characterization and the variability of its key parameters could help to explain the advantages and disadvantages in the production of intercropping systems. In the central region of the humid pampas the current option includes two modes for intercropping: corn-soybean (*Glycine max* L.) and sunflower (*Helianthus annus* L.)-soybean. Soybean crop has the critical stage of yield determination at very different moments than wheat, corn and sunflower, which makes it an interesting species for conducting this type of cropping. Soybean and corn are the two most important summer crops at the Argentinean Pampas, the following objectives were established: i) to compare soybean corn intercropping systems with their respective sole crops from an environmental point of view in terms of soil quality-related parameters, including the amount of soil organic matter, ii) to assess the availability of major nutrients in these systems. It is hypothesized that the practice of intercropping corn with soybean affects relevant soil properties as compared to their sole crops.

MATERIALS & METHODS

Experimental design and sampling

The trial was conducted on 2007-2008 at the department of Carlos Casares, at a Typic Hapludoll soil of loamy texture (415.5 g kg^{-1}, 394.5 g kg^{-1} and 190 g kg^{-1} of sand, silt and clay, respectively). The experimental design was completely randomized, with three replicates and treatments were: i) sole soybean, ii) sole corn and iii) Intercropping of corn and soybean in a 2:1 ratio (two rows of soybean and 1 row of corn). Corn crop (hybrid material DK 747 MGRR, Monsanto) was sown at sole and intercropped situations on September 26th, 2007, and soybean material (DM 4870 Don Mario & Associates), sole and intercropped, on October 10th of the same year. In all systems the distance between rows was 37.5 cm, and the density of plants m^{-2} was the recommended by the seed suppliers, to isolate possible effects of distance between rows. No fertilization was applied in both crops, since we aimed to detect effects of crops on soil nutrients availability. Soil samples were taken at a depth of 0-20 cm in two dates: the first (F1) was made when the corn was in five fully expanded leaves (V5, scale Ritchie & Hanway 1982) and the soybean crop recently emerged (Vc, Fehr &Caviness scale 1977), the second (F2) was performed at the silking of corn (R1) and soybean crop at V7-R1 (early flowering). Time elapsed between both stages was sixty-five days. The samples were taken at 5 and 19 cm from the soybean furrow at i treatment and at 5 and 19 cm from the corn furrow at ii and iii treatments, since it was intended to assess whether there were differences in the effects on soil properties at different sites of the soil-crop system, supposing stronger effects of the corn crop.

Samples handling and chemical determinations

Prior to chemical analysis, the samples were air dried, ground and sieved (2-mm mesh size). pH was measured in soil-water relationship 1:2.5 (Thomas, 1996) and electrical conductivity (EC) at a saturated soil sample. Oxidizable organic C (OC) was analyzed by the modified dichromate oxidation method (Nelson and Sommers 1982), which involved the oxidation of soil organic carbon with 1.5 Ml 0.06N potassium dichromate and 3 Ml of concentrated H_2SO_4. The residual dichromate was titrated with 0.03N Mohr´s Salt. Nitrate-N was determined by extracting a fresh 20g sample from each soil core with 100 ml 0.25% $CuSO_4$+0.01MBO_3H_3 solution; the soil solution was filtered and N-NO_3^- content determined colorimetrically by the hydrazine-reduction method (Carole and Scarigelli 1971).

Total nitrogen was determined by the widespread Kjheldahl method (Bremner & Mulvaney, 1982). Extractable P was removed with Bray & Kurtz 1 extractant and colorimetrically determined by the molybdate-complexation method (Kuo, 1996). Cation contents (Ca, Mg, Na and K) were extracted with 1N pH7Ammonium Acetate and determined with flame photometry or atomic absorption (Thomas, 1982).

Statistical analysis

Statistical Analysis System SAS package was used for data analysis by the (SAS Inc. Institute, 1995). Previously, assumptions of normality, through Shapiro-Wilk test (Shapiro-Wilk, 1965) and variance homogeneity were tested. Conventional ANOVA were performed through PROC GLM proccedure to detect treatment effects on measured soil variables, with means separation by Duncan test when F-statistic was significant.

RESULTS

Carbon contents differed between treatments at both dates, and at both distances (Fig. 1). In all cases oxidizable C contents were greatest ($p<0.05$) at treatments including corn. Differences in oxidizable C

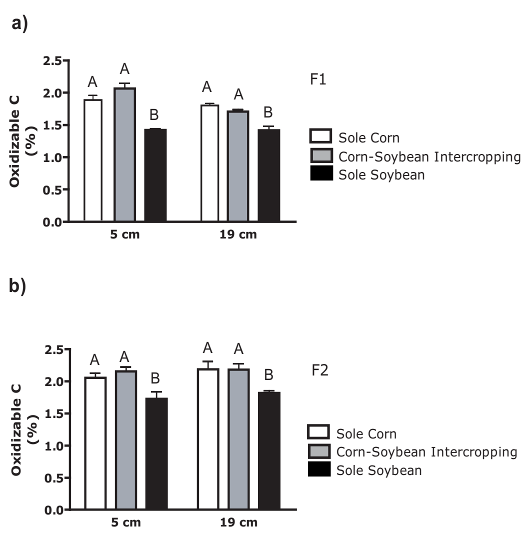

FIGURE 1. **Soil oxidizable C Content for different treatments and at two distances in the first (a) and second sampling date (b). Large bars correspond to the mean of 3 replicates, while small bars represent the mean standard error (MSE). Different letters indicate the presence of statistically significant differences (α = 0.05) between treatments.**

were more clear when soil was sampled at 5 cm than at a greater distance from the furrows. There were no statistical differences in any case between sole corn and intercropping treatments.

Extractable phosphorus (B&K 1) differed statistically ($p = 0.008$) between treatments only at the second measurement date and when sampled at 5 cm from the furrows (Fig. 2b). On both measurement dates, extractable P was greatest at the sole corn and minimum in the sole soybean crop, although this effect was statistically detected only in the second sampling at 5 cm from the furrow.

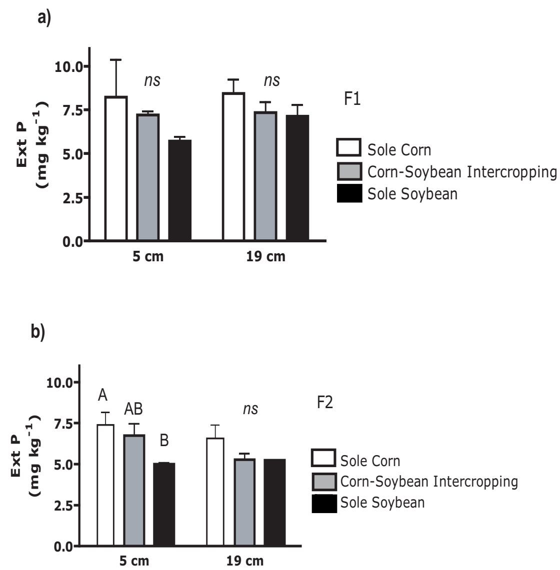

FIGURE 2. **Soil extractable P for different treatments and at two distances in the first (a) and second sampling (b) soil. Large bars correspond to the mean of 3 replicates, while small bars represent the mean standard error (MSE). Different letters indicate the presence of statistically significant differences (α = 0.05) between treatments, ns indicates the absence of such differences.**

The availability of nitrate varied over time, and differences between treatments also suffered a temporal variation. At F1, when sampled at 5 cm from the row, nitrate content was significantly higher ($p = 0.01$) at sole soybean with respect to treatments that included corn (Fig. 3a). At the F2, and at 5 cm from the furrow, the trend was the opposite of what happened in the F1 (Fig. 3b), with minimum nitrate availability at the sole soy-bean treatment ($p = 0.01$). Nitrate content at 19 cm from the furrows did not significantly differ between treatments in any date.

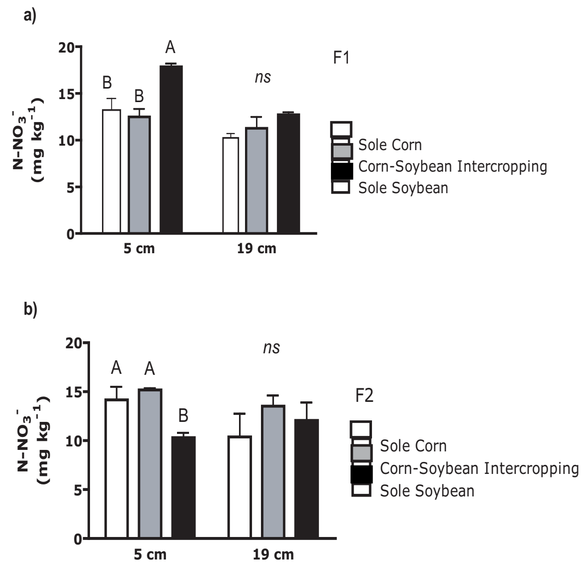

FIGURE 3. **Soil $N\text{-}NO_3^-$ for different treatments and at two distances in the first (a) and second sampling (b) soil. Large bars correspond to the mean of 3 replicates, while small bars represent the mean standard error (MSE). Different letters indicate the presence of statistically significant differences ($\alpha = 0.05$) between treatments, ns indicates the absence of such differences.**

Soil Ca content was highest at F1 in the sole soybean (Fig. 4a). This effect was more noticeable when sampled at 5 cm from the corn or soybean furrows, where the differences between treatments were statistically significant ($p = 0.01$). At F2 this pattern was repeated when sampled at 5 cm from the furrows, with significant differences ($p = 0.04$) showing this content a light tendency to be lower at the intercropping treatment.

Soil K contents sampled were greatest at sole soybean when sampled at 5 cm from the furrows (Fig. 5); this difference was more noticeable at the F2 date (Fig. 5b), where differences among treatments were statistically significant ($p = 0.02$). On the other hand, and similarly to what happened with Ca contents, K contents did not differ significantly between treatments when sampled at 19 cm at both dates.

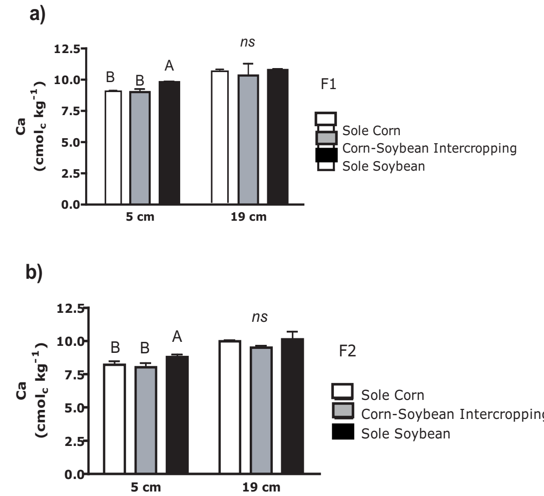

FIGURE 4. **Soil exchangeable Ca for different treatments and at two distances in the first (a) and second sampling (b) soil. Large bars correspond to the mean of 3 replicates, while small bars represent the mean standard error (MSE). Different letters indicate the presence of statistically significant differences ($\alpha = 0.05$) between treatments, ns indicates the absence of such differences.**

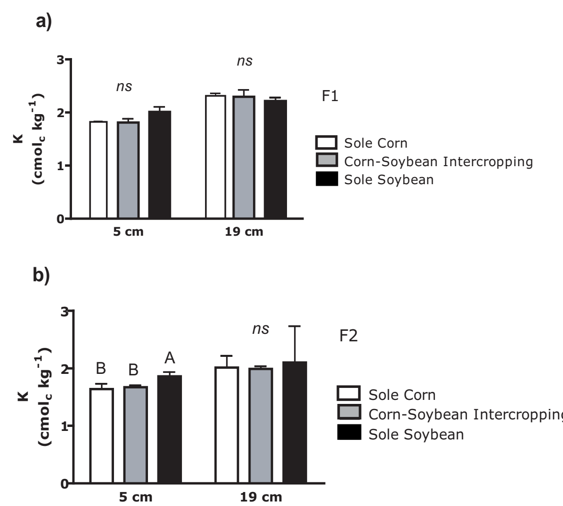

FIGURE 5. **Soil exchangeable K for different treatments and at two distances in the first (a) and second sampling (b) soil. Large bars correspond to the mean of 3 replicates, while small bars represent the mean standard error (MSE). Different letters indicate the presence of statistically significant differences ($\alpha = 0.05$) between treatments, ns indicates the absence of such differences.**

The rest of the measured variables did not differ significantly between treatments in any of the sampling dates or distances.

DISCUSSION

Among the crops tested, corn led to the highest levels of oxidizable C in soil. Soil C is a key element in the sustainability of agroecosystems and may be considered the most direct indicator of soil quality (Giuffré *et al.*, 2006). As we sampled during the crop cycle and only one year, it is likely that these differences in total C were due to differences in young or particulate organic matter, which corresponds to slightly decomposed plant debris (Cambardella & Elliott, 1992) derived from falling leaves and decaying roots during the crop cycle. The difference between the levels of organic carbon may be due to the fact that at both dates the biomass generated by corn crop was significantly higher than that generated by the soybean crop, specially in the first sampling when the legume was recently emerged; it is possible at F1, that despite the small amount of aerial biomass that is liklely to fall and incorporate to the soil, the predominant effect of increased root biomass in corn crop justifies these results. The corn crop, in addition to generating a much larger amount of biomass than soybean, has a C/N ratio higher than that of the legume, so that the carbon in the biomass of corn is decomposed at a lower rate, a fact that becomes more important at the second sampling date. It can be concluded that by including a high biomass cereal such as corn in intercropping systems, these may lead to high soil C accumulations, higher than sole soybean systems. Unfortunately there are no other reports of effects of intercropping on the C contents to compare the obtained data.

The level of P in soil solution depends on its outputs, mainly due to plant uptake and on its replenishment mechanisms from the organic and inorganic fractions, whose importance varies greatly among soils. Although it is known that legumes such as soybean can mobilize insoluble organic phosphorus (Gunes *et al.*, 2007), soybean is a highly P demanding crop , for its energy metabolism and for a proper functioning of the biological N fixation (BNF), so it is likely that the decrease in extractable P at advanced stages (F2) in systems including soybean can be attributed to a strong uptake by plants. As can be seen by comparing the concentration of extractable P between the treatments of sole corn and corn-soybean intercropping, and considering that in the latter case the sampling was performed at 5 cm from the corn row, intercropping with soybean did not appear to affect with relevance the availability of P for intercropped corn. On the contrary, Ghosh *et al.* (2009) recently suggested that soybean crop in advanced stages with a developed root system can increase the availability of P for both crops when intercropped; the difference between these works may be because in our trial there was no fertilization at all, whereas at that carried out by Ghosh *et al.* (2009) different strategies of organic and inorganic fertilization were practiced. It has been also suggested that P uptake by different species living together could lead to over-extraction phenomena or «mining» of soil nutrients in intercropping systems, of high nutritional demand (Adu-Gyamfi *et al.*, 2007). Based in our results, sole soybean crop seems to be the one conducting to lower soluble P contents, since the values of extractable P in intercropping systems were intermediate between those of sole crops, but more mid and long-term studies would be needed to consider the consistence of this effect. There are no previous reports of the effect of intercropping practices on the levels of soil available P.

In contrast to the findings of Hauggaard-Nielsen *et al.* (2009b) and Sawyer *et al.* (2010), imposed treatments exerted strong influences on soil nitrate levels, mainly when sampling at 5 cm from the furrows. The difference in nitrate levels between treatments among the sampled moments seems to be due to differences in crop development. In the first sampling date, the soybean crop was just emerging, with a very limited nutrient uptake, so that the mineralization of organic matter seemed to be the dominant factor in the balance of soluble N, while the corn crop was at this point growing and with high requirements for water and nutrients. The soybean crop, despite having the capacity to sustain biological N fixation process in its roots, and due to the proteinaceous nature of its seeds, is highly demanding of soil N, and can intensively uptake mineral N when the crop grows and covers the inter-furrow space (Gutierrez Boem &

Scheiner, 2005) competing with intercropped cereals (Ghosh *et al.,* 2009), which could explain the lower levels of mineral N in the second sampling at the sole soybean than in treatments including corn. Song *et al.* (2007) found higher levels of mineral nitrogen close to the roots of wheat or corn plants when they were intercropped with bean crops, this effect did not occur in our study probably because, unlike what has been done by these researchers, crops were not fertilized with N, so the predominant process was the competition for N and not an interspecific facilitation phenomena, as observed in other cases of coexistence of cereals and legumes (Harris *et al.,* 2008; Ghosh *et al.,* 2009). The management of the proportions and design of the intercropped species should be carefully evaluated by the main features of species and the environmental supply, given that competition for water, light or P by cereal species may decrease in some cases, rather than stimulate, N fixation by legumes in intercropping systems (Hauggard-Nielsen *et al.,* 2001 a,b , 2009a).

Intercropping of cereals and leguminous species can increase the total absorption of soil nitrate, leading to low levels of this anion in the soil profile under conditions of low and high nitrogen fertilization (Li *et al.,* 2001); this effect was not observed in our trial, and instead, the values of nitrates in the F2 at both distances were never minimal in the intercropping system, and were even higher than those found at 5 cm from sole soybean furrow. Only at F1 intercropping with corn could be considered to reduce the existence of large amounts of nitrates in the early stages of a soybean crop, although this trend was reversed after 65 days, when the soybean root system developed. It can be concluded then that, within the framework of this trial, intercropping would not be a viable option to limit the environmentally harmful processes that cause the existence of high levels of nitrates at the surface soil as the nitrous oxide (N_2O) formation, of strong greenhouse effect.

Calcium availability was highest when sampled at 5 cm from the furrow at the sole soybean treatment in both samplings, while there were no significant differences between treatments when sampled at 19 cm from the lines. Intercropping showed low levels of exchangeable Ca at 5 cm from the furrow and similar to the sole corn treatment, probably because in these systems, the sampling was done closer to the lines of corn than soybean. It seems logical that the difference between treatments is due again to the crop development, given that at both samplings corn crop had a significantly higher amount of biomass than soybean, especially at F1 in which soybean crop was recently emerged.

Patterns of availability of exchangeable Ca and K were similar, so the considerations for calcium is also in line with the results of the exchangeable K levels. In addition, corn crop requires to achieve a regular yield 210 kg ha^{-1} of K (Echeverría & Sainz Rozas, 2005), while soybean crop requires for a yield of 3 tons ha^{-1} 100 kg ha^{-1} of K; these differences in the extraction of this cation may help to explain the differences found between treatments. Although it has been observed that in intercropping systems spatial complementarity in root uptake may cause sharp decreases in the concentration of nutrients compared to its respective sole crops in soils (Andersen *et al.,* 2007) or in plant tissues (Gunes *et al.,* 2007), our work cannot confirm the presence of over-extraction of these cations in intercropping systems, but a strong influence of corn crop on the availability of these nutrients.

It is noteworthy that most of the effects of cropping systems were more noticeable when the variables were measured at 5 cm from the rows of corn and soybean. At 19 cm of these rows, the effects tend to fade and uniform. That is why future research on the subject should focus in the space closest to the sites of growth of the involved species. It is also clear that in intercropping systems there is a great complexity of interactions between plants, their environment and the rest of the biotic components involved. This implies that determining the success of intercropping systems cannot rely on a single feature of the system as could be crops yields, so a multidisciplinary approach that includes a view from the soil resources seems the best strategy to understand with, as much detail as possible, the positive and negative changes generated by intercropping systems.

CONCLUSIONS

The practice of intercropping showed intermediate values of the variables between corn and soybean crops, resembling more to the sole corn in the biological variables, C and nitrates, and in the availability of Ca and K. By contrast, soybean crop exerted a greater influence in the case of extractable P; the level of this nutrient was lower at advanced sole soybean than in sole corn, which was noticeable at 5 cm from the furrow, probably due to a strong uptake by the legume. Intercropping system, if it includes a high biomass cereal such as corn, may have high soil C accumulations, a key soil component in the sustainability of agroecosystems, greater than sole soybean crop. The dynamics of surface nitrate concentrations was highly dependent on the development and growth of the crops involved; in any case the practice of intercropping in the context of this trial did not prove an alternative for limiting the existence of high levels of nitrates and moderating the environmental consequences that could cause such high levels. Most of the effects of cropping systems were more noticeable when the variables were measured at 5 cm from the furrows of corn and soybeans, so that future research on the subject should focus in the space closest to the sites of growth of the species involved. The complexity of interactions between plants, their environment and the rest of the biotic components involved makes the need for more multidisciplinary studies in a longer term to explain in detail the effects of intercropping systems on the most relevant soil variables on plant growth.

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