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Effects of two plant arrangements in corn (Zea mays L.) and soybean (Glycine max L. Merrill) intercropping on soil nitrogen and phosphorus status and growth of component crops at an Argentinean Argiudoll

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Abstract: Intercropping systems can provide many benefits through increased efficiency of land and light use. The objectives of this study were to assess the main effects on a soil and plant growth of two arrangements of corn - soybean intercropping. In a 1-year experiment at 2011, the following treatments were randomly assigned in a CRD to 16 plots located on a vertic Argiudoll from Argentina: sole corn (Zea mays L.), sole soybean (Glycine max L.), corn-soybean 1:1 intercropping and corn-soybean 1:2 intercropping. Nitrate levels were modified by treatments, but these treatments did not affect available P contents due to very high levels of this element during the whole cropping cycles. The practice of intercropping did not enhance water uptake by crops in relation to sole crops, as might be expected from complementary root systems and development timelines. Corn N status improved with intercropping probably due to an enhanced growth of plants and their roots, but soybean chlorophyll content was decreased by intercropping treatments. Yield and growth of corn were stimulated by intercropping systems, but this system depressed soybean growth, particularly at 1:1 corn-soybean ratio. Based on the remarkable dominance of corn crop observed at this arrangement, it can be concluded that a 1:2 corn-soybean ratio could be more beneficial in terms of more symmetric ecological interactions.

Keywords: Corn, Soybean, Intercropping, Soil, Yield

1. Introduction

Intercropping is defined as the simultaneous growth of two or more species, grown in the same area where they share the use of resources during all or part of their growing season [45]. This tool was designed and manipulated to optimize the use of space, time and physical resources both above and below ground, to maximize positive interactions (facilitation) and minimize the negative (competition) between the component crops [31, 58]. Thus, intercropping systems can provide many benefits through increased efficiency of land use, enhancing the capture and use of light, water and nutrients, controlling weeds, insects and diseases and increasing the length of production cycles [37, 38, 48, 17, 7]. Other benefits of intercropping may be the improved quality of the seed, an improvement of the crop canopy structure susceptible to lodging [32], more stable yields and resilience to environmental perturbations [44], a decrease in environmental damage related to N cycling and emissions [25, 46] and better control of water quality through minimizing the use of inorganic N fertilizers, replacing them by the use of legumes [8].

By applying concepts of partition between aerial and underground parts, it has been observed that components of intercropping compete for soil resources at a greater extent than by light [65]. However, the mechanisms of differences in competitive abilities of different crops are poorly related to soil environment where the plants develop. The inclusion of a completed soil characterization and variability of the main parameters could help to explain the advantages and disadvantages of intercropping systems.

Where the plants grow together, interspecific competition and facilitation between plants may occur [58, 66].

Facilitative interactions at intercropping are probably more important in nutrient-poor soils and agro-ecosystems with low inputs or application of external inputs [23] as is the extensive production of grains of the Pampean Region in Argentina. Intercropping is commonly performed combining a legume and non legume plants, usually a cereal, being able the legume to provide N for non-legume directly through mycorrhizal links [59], root exudates or decomposition of root nodules, or indirectly, as the legume fixes atmospheric N (N_2), reducing competition for soil nitrate to non-legume [58, 2]. It has been shown that mineralization of decaying roots of legumes can increase available N to associated crop [11, 13]. Intercropping between cereals and legumes can undergo a complex series of inter and intraspecific interactions guided by modifications and uses of light, water, nutrients and enzymes [22, 34. Many plants have the ability to modify the rhizosphere pH [42, 9] and improve the availability of nutrients such as P, K, Ca and Mg, which are in unavailable forms [58, 26]. The leguminous induce many reactions that modify the rizospheric soil pH and affect nutrient uptake [3, 55, 56]. Legumes can increase the quantities of basic cations, and in the process of internal power balance, release H^+ ions in the rhizosphere resulting in soil acidification [55, 56, 9]. Other legumes such as alfalfa (Medicago sativa L.), chickpea (Cicer arietinum L.), Lupin (Lupinus albus L.) and cowpea (Vigna unguiculata L. Walp.) may release considerable amounts of organic anions and decrease the rizospheric soil pH [21, 68, 35]. These conditions favor organic P hydrolysis and thereby improve P nutrition to plants and soil microorganisms. For example it was observed that chickpea plants increased P uptake in intercropping with sorghum by exuding anions of piscidic acid that complexed Fe^{3+} and subsequently released P from ferric phosphates $FePO_4$ [1]; the ability of chickpea to mobilize organic P was shown, at the observed increases in P concentration in shoots of intercropped wheat [33]. It has also been observed that intercropping bean (Vicia faba L.) facilitated P uptake for corn (Zea mays L.) [34, 66, 36]. There are other works that reference a stimulating effect of a legume on phosphorus uptake of another species, usually a grass [1, 23]. However there are no reports of the effects of corn and soybean (Glycine max L.) plants growing in neighboring rows on the levels of pH and the availability of P in soil.

When the fertilizer N is limited, intercropping improves efficiency of the non legume component [4] and increases overall efficiency [46]. Other studies also showed that mixtures of cereals and leguminous cause increases in grain yield compared to growing crops alone [61, 47], even with yield increases in the legume component, usually dominated [67]. However, the manipulation of proportions and spatial design of the species involved must be carefully evaluated by the characteristics of the species and the environmental offer, since it has been observed that competition for water, light or P by cereals may decrease, rather than stimulate, N fixation by legumes in intercropping systems [24, 27].

One of the main measures to evaluate biological productivity and efficiency in intercropping is the land equivalent ratio (LER), which considers the performance of a component of the mixture with respect to the the its yield achieved at sole crop [40, 15]; when the LER is greater than 1 facilitation is contributing to a greater extent than the phenomena of competition. Another measure of efficiency, is the equivalent ratio of area and time ATER, this includes in the LER the duration of the area occupied by intercropping in relation to monoculture, and redefines yield in terms of area and time (Hiesbsch and McCollum, 1987). Competition measures that are used are aggressivity A, which measures the interspecific competition in intercropping, and the competitive ratio CR which measures competence and allows comparisons at competitive ability [63,64]. Soybean has a critical period of yield definition at a different moment than that of wheat, corn and sunflower, so it seems an interesting species for the realization of such cropping strategies. Recently in the Argentina Pampas, [12] found advantages in the production of corn-soybean intercropping compared to their monocultures. It is hypothesized that the practice of intercropping corn-soybean lead to changes in the availability of key nutrients for these crops, N and P, and due to a more efficient use of resources is more biologically productive than the corresponding sole crops. The objectives of this study were to assess the main effects on soil of two arrangements of corn - soybean intercropping, determine the biological efficiency and productivity through measurements of achieved density, leaf area index and grain yield and efficiency indexes LER and ATER, and to get an approach to balance between interspecific competence and facilitation in the studied conditions by calculating aggressivity and competitive ratio at different spatial combinations.

2. Materials and Methods

2.1. General Design and Treatments

A 1-year experiment was performed under field conditions at a vertic Argiudoll soil located at Agronomy College of the Buenos Aires University. At the beginning of the test, soil (0-20 cm) had the following characteristics: 48.95 kg ha^{-1} $N\text{-}NO_3^-$, 33.5 mg kg^{-1} extractable P (Bray & Kurtz 1), 33 g kg^{-1} of oxidizable C (Walkley & Black), pH (1:2.5 soil:H_2O ratio) 7.04 and 0.92 dS m^{-1} EC. The site was divided into 16 plots of 1.50 m by 3.64 m that were the experimental units to which the following treatments were randomly assigned in a completely randomized design (CRD): T1 sole corn (Zea mays L.), T2 sole soybean (Glycine max L.), T3 1:1 intercropping (a row of corn with a row of soybean) and T4 1:2 intercropping (a row of corn and two rows of soybean between corn rows). Each treatment was replicated four times. In every case the distance between rows was 52 cm. Genotypes were chosen according to the crop cycle and to the genetic resistance to the herbicide glyphosate, so that both corn and soybean contain the RR gene.

The experiment began with the manual sowing of corn (DK747, Monsanto) at a density of 80000 seeds ha^{-1} in all treatments including corn at September 2011. At 35 days after corn planting soybean (DM3800, Don Mario Seeds) sowing was done at a density of 350,000 seeds ha^{-1}, and fertilized with 14 kg ha^{-1} P as monoammonium phosphate in the seed line. Corn was fertilized a month after sowing, with 50 kg ha^{-1} of N as a solution of KNO_3 applied to the soil surface, at of 13 cm from the corn row. The incidence of insects and diseases was assessed weekly, controlling with appropriate biocides when necessary. Soil samplings (0-20 cm) were made as the crops developed. These soil sampling were conducted in the following phenological stages: sowing of corn (12/10/2010), and soybean (22/11/2010), maize at flowering (11/01/2011), soybean at grain filling (22/02/2011), the corn harvest (14/03/2011) and soybean (22/05/2011), post-harvest (approximately 25 days after each harvest) and being completed with some additional samplings. The measured edaphic variables were Nitrates [50], extractable phosphorus [6], pH in water in soil: water relationship 1:2.5 [57], electrical conductivity EC, oxidizable C [60] and gravimetric soil water content.

Other plant measurements were made: plant stand in both crops at R1 [49, 14], plant height in two stages (corn at R1 and R3 and soybean at R1 and R5), leaf area index (LAI) of corn crop at R2, soybean soil coverage at R1 (by measuring radiation attenuation at different crop heights), leaf greenness index (corn at R2 and R5 and soybean at R1 and R5), and soybean stem diameter at 8 cm height at R1. The greenness index was measured with the Minolta SPAD 502 chlorophyll meter at the main ear leaf in corn and at the fourth trifoliate leaf in soybean. Harvest was done manually by determining the main components of yield, weight and number of grains. Yields were expressed on dry weight basis to allow comparison between treatments. The crop duration was 147 days for maize and 182 days for soybean, coexisting 113 days.

2.2. Calculations and Statistical Analysis

The land equivalent ratio, LER [40], was calculated as the following expression:

$$LER=\left(\frac{Yij}{Yii}\right)+\left(\frac{Yji}{Yjj}\right) \quad (1)$$

Where: Yii and Yjj are i and j crops yields in monoculture and Yij and Yji are j and i crops yield in association with i and j. LER values less than one indicate that the association is less efficient than monocultures of the component species of the association, and at LER values greater than the unit the association of species is more efficient than monocultures.

The area time equivalent ratio ATER [30] was calculated as follows:

$$ATER=\frac{(Li*Ti+Lj*Tj)}{T} beingLi:\left(\frac{Yij}{Yii}\right) andLj:\left(\frac{Yji}{Yjj}\right) \quad (2)$$

being Li and Lj the relative yields of component species in the same terms as in the LER, Ti and Tj the durations of crops of the species i and j respectively, and T the total duration of the association in days.

Competition in intercropping was evaluated by means of the competitive ratio CR [64] and aggressiveness A [63]. The competitive ratio is expressed as:

$$CR=\frac{\left(\frac{Yij}{Yii}\right)}{\left(\frac{Yji}{Yjj}\right)}*\left(\frac{Sj}{Si}\right) \quad (3)$$

Where Si and Sj are the relative space occupied by crops i and j. Aggressiveness was calculated as follows:

$$A = [(Yij/Yii)*Si]- [(Yji/Yjj)*Sj] \quad (4)$$

A positive value of aggressivity corresponds to the dominant specie and a negative value of the same magnitude to the dominated one; aggressivity is zero if both crops are equally competitive, higher values of aggressivity indicate a greater dominance, enabling this index comparisons between cultivars and treatments [63].

The data were analyzed using the SAS software package [51]. Previously, the assumptions of normality through the Shapiro-Wilk test [53], homogeneity of variances and independence of observations were checked. Simple regression analysis between the response variables (yield and growth parameters) and soil variables were performed using the PROC REG procedure of SAS. The yield and plant growth variables and soil properties were evaluated with conventional analysis of variance, with means separation performed by Duncan test when the F-statistic was significant between treatments.

3. Results

3.1. Evolution of Soil Parameters

Initially at the first three dates of sampling periods to determine nitrate levels were highest in the sole soybean and lowest in the case of corn-soybean 1:2 intercropping (Fig. 1a). At the fourth measurement date, all treatments had low values, although the 1:2 intercropping treatment showed significantly lower levels nitrate ($p = 0.03$) than monocultures. After the corn harvest, trends were reversed: nitrate values were always minimal in the sole soybean (Fig. 1), including in postharvest, while the peak values occurred in the sole corn. At harvest of corn, 1:2 intercropping treatment also had lower values of this anion that 1:1 intercropping treatment, whereas after this point these treatments had similar nitrate levels.

Extractable phosphorus values were initially low and increased during crops cycles (Fig. 2). There were no statistical differences (p> 0.05) among treatments on any of the measurement days.

The soil pH values remained fairly constant during the crops cycles (data not shown). The values of oxidizable C initially decreased and then remained more or less stable during the crops cycles (data not shown). Neither were detected statistical differences (p> 0.05) in soil pH or in the oxidizable C among treatments at any of the moments evaluated. EC values slightly increased during the crops cycles (Fig. 3). Until corn harvest EC values were similar between treatments (p> 0.05). At crops harvest, the EC values were significantly highest (p <0.05) in the sole corn and lowest in the sole soybean. At the last measurement date, at post-harvest, EC values were again similar among treatments.

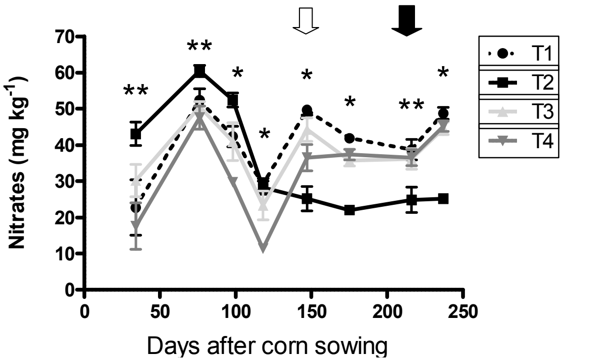

*Figure 1. Evolution of soil (0-20 cm) nitrates during crops cycles. The white arrow indicates corn harvest and the black one soybean harvest. Each point is the mean of 4 replicates, and small bars are the SEM. * and ** represent significant differences at α=0.01 and α=0.05, respectively.*

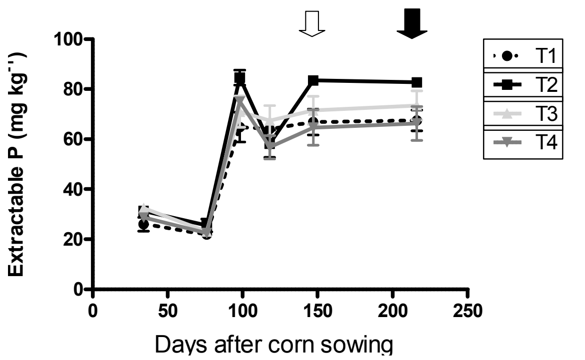

Figure 2. Evolution of soil (0-20 cm) extractable P during crops cycles. The white arrow indicates corn harvest and the black one soybean harvest. Each point is the mean of 4 replicates, and small bars are the SEM.

Moisture levels fluctuated with the time in response to plant uptake and the prevailing weather conditions (Figure 4). After soybean sowing, 34 days after corn planting, moisture contents at the first measurements were the highest in the sole soybean and the lowest in the sole corn. After 118 days since corn sowing, with this crop at phenological stage R3 and soybean at R5, moisture levels of the different treatments were equalized and remained similar until the harvest of soybean (Fig. 4). After harvesting the legume, soil water content in the sole soybean was significantly lower (p = 0.05) than at the other treatments.

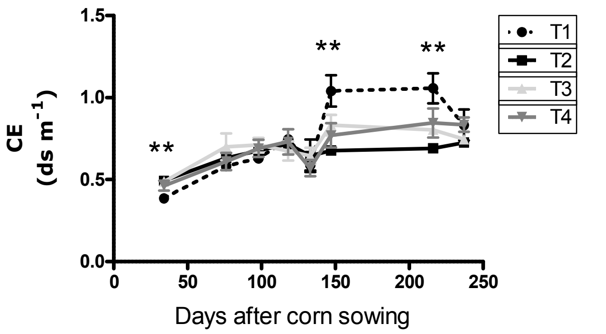

Figure 3. Evolution of soil (0-20 cm) Electrical Conductivity EC during crops cycles. The white arrow indicates corn harvest and the black one soybean harvest. Each point is the mean of 4 replicates, and small bars are the SEM.

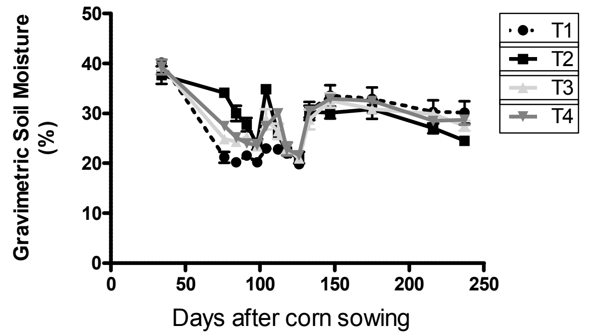

Figure 4. Evolution of soil (0-20 cm) gravimetric moisture during crops cycles. The white arrow indicates corn harvest and the black one soybean harvest. Each point is the mean of 4 replicates, and small bars are the SEM.

3.2. Crops Response

No statistically significant differences in the plant densities of corn (p = 0.27) or soybean (p = 0.54) were found in early reproductive stages among treatments. The height of corn at R1 was significantly (p = 0.001) greater under intercropping treatments than in sole crop (Fig. 5a), while soybean at R1 under monoculture conditions presented slightly greater heights than when intercropped with corn (Fig. 5b), although differences were not statistically significant. (p = 0.54). The height of corn crop at R3 was significantly higher (p = 0.008) under 1:1 intercropping (T3) than in monoculture (Figure 6a), while the 1:2 intercropping treatment (T4) values of corn height were intermediate. Soybeans at R5 showed a significantly (p<0,0001) greater height in sole crop conditions than when intercropped with corn; 1:1 intercropping led to the lower height of the legume at this moment (Fig. 6b).

Soybean at R1 stage presented in monoculture conditions a mean stem diameter significantly greater than in the case of soybean intercropped with corn; 1:1 intercropping led to the smaller diameter stem of the crop at this moment (Fig.

7).

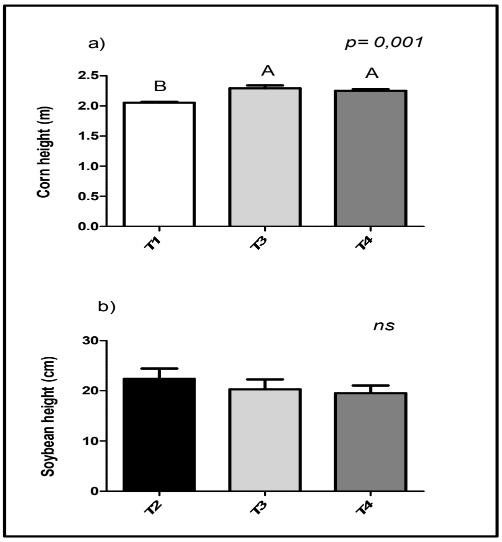

Figure 5. *Height of corn (a) and of soybean (b) at R1 for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05).*

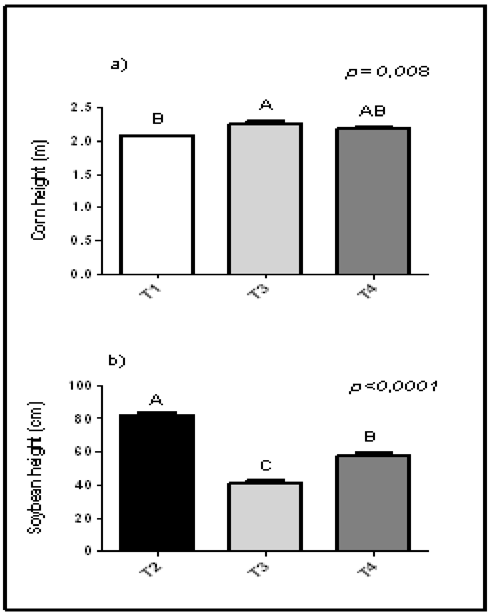

Figure 6. *Height of corn at R3 (a) and of soybean at R5 (b) for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05).*

The leaf area of corn at R2 was significantly higher (p = 0.001) under intercropping treatments than in its respective sole crop (Fig. 8a). Soybean at initial reproductive stages, R1, showed a significantly higher coverage under monoculture conditions than soybean intercropped with corn at 1:1 ratio; 1:2 corn-soybean intercropping led to intermediate levels of legume coverage (Fig. 8b).

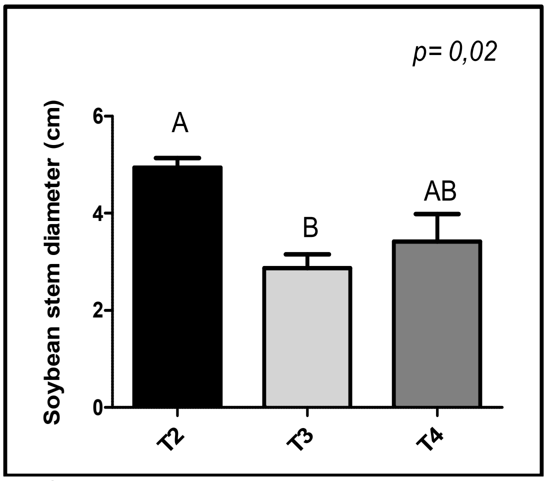

Figure 7. *Soybean stem diameter at 8 cm height at R1 for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05).*

The greenness of corn was significantly higher under intercropping treatments than in the monocrop at R2 (p= 0.001, Fig. 9a) and at R5 stages (p <0.0001; Fig. 9b) Soybean at R1 under monoculture conditions showed a significantly higher greenness index than in the case of intercropping with corn (Fig. 10a). By contrast, no statistically significant differences between treatments were found in the greenness index of soybean crop leaves at R5 phenological stage(Fig. 10b).

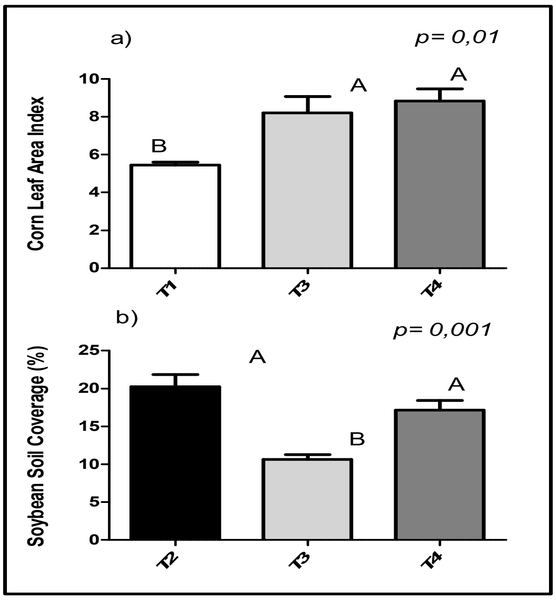

Figure 8. *Corn Leaf Area Index LAI at R2 stage (a) and soybean soil coverage at R1 stage (b) for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05).*

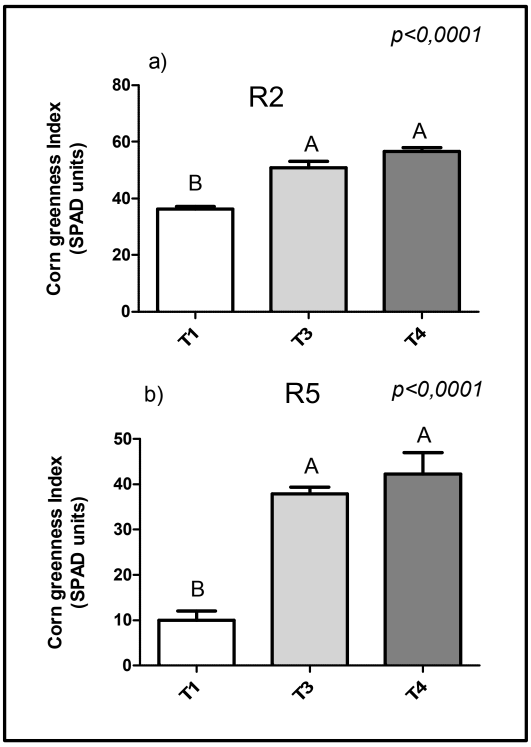

Figure 9. Greenness index of corn at R2 (a) and at R5 stage (b) for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05).

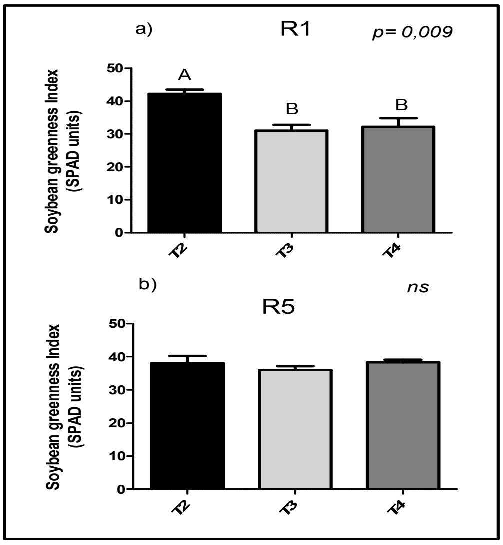

Figure 10. Greenness index of soybean at R1 (a) and at R5 stage (b) for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05).

Corn yield was significantly higher (p <0.001) under intercropping treatments than in the sole crop (Fig. 11a). The opposite occurred with soybean crop as the best performance took place when grown as sole crop (Figure 11b).

The partial LER of corn was similar between intercropping treatments with 1:1 and 1:2 corn:soybean relationships (Fig. 12a). However, the higher partial LER value of soybean crop was higher at the 1:2 ratio than in the 1:1 one, leading to a lower value of overall LER at the latter . The ATER was similar between involved intercropping treatments (Fig. 12b). The competitive ratio CR and the Coefficient of aggressivity A were highest in the 1:1 corn: soybean intercropping treatment (Figs. 13 a,b); the positive A coefficient indicates an aggressive competition from the dominant species, in this case corn, on soybean.

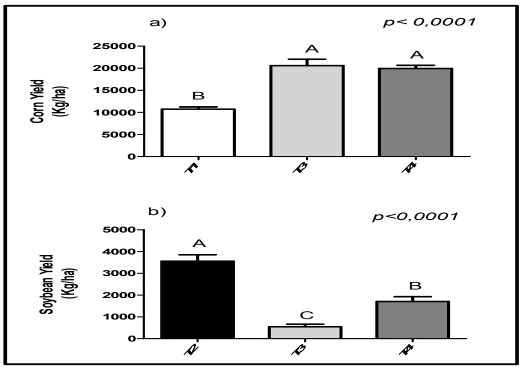

Figure 11. Corn (a) and soybean (b) yield for different treatments. Large bars represent the mean of four replicates while small bars represent SEM. Different letters indicate significant differences (p<0.05

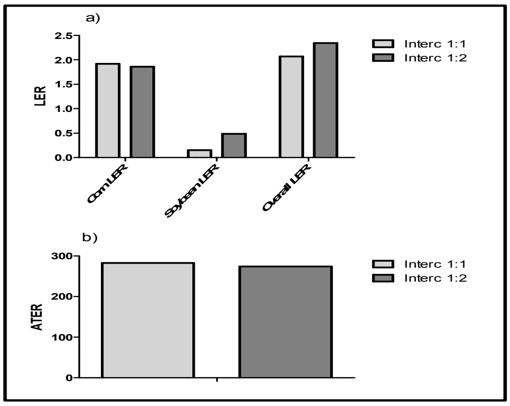

Figure 12. Land Equivalent Ratio LER (a) and equivalent ratio of area and time ATER (b) for intercropping treatments.

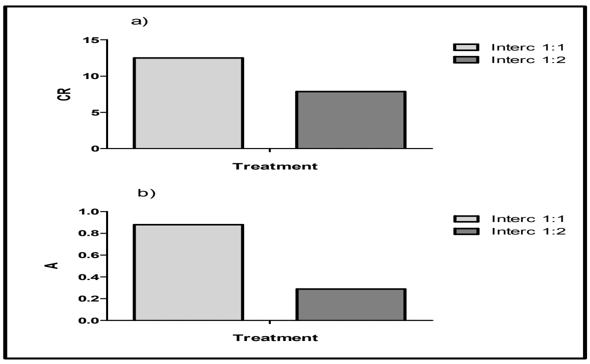

Figure 13. Competitive ratio CR (a), and Aggressiveness A (b) for intercropping treatments

4. Discussion

Nitrate contents varied over time, and so did differences between treatments, which can be attributed to several factors. The evolution of nitrate levels was modified by the imposed treatments, by the development of the crops involved, and by environmental conditions and soil productive history. The first peak of nitrates at the second measurement date occurred probably due to increased mineralization of soil organic matter, since this occurred at a moment of high temperatures, considering that the previous crop was a pasture not disturbed for several years; this peak was highest at sole soybean probably due to a greater amount of sun light reaching the soil. Subsequent increases in nitrate levels were caused by a decreased crops uptake after the end of their cycles. Initially, the high demand for soil N when corn was grown, in sole crop and intercropped, nitrate levels were depressed in relation to sole soybean. It is remarkable that during the first 4 measurement dates an apparently high uptake of nitrates caused that the lowest nitrate values corresponded to 1:2 corn-soybean intercropping. It is possible then to suggest that initially an arrangement of 1:2 corn-soybean intercropping could promote the complementarity in the uptake of soil nitrates, being this point relevant since high concentrations of nitrates in moments of high temperature and rainfall can stimulate environmental damaging processes as nitrate leaching to groundwater and the formation and emission of nitrous oxide, N_2O into the atmosphere, a strong greenhouse gas. Root patterns differ between cereals and legumes [2], leading to more efficient exploration of soil volume by the mixture cereal - legume. Other authors [46] also reported at cereal-legume intercropping systems, with respect to monocultures, a limiting action on possible environmental detrimental effects of nitrate surplus. At the end of the crop cycles soil nitrate contents were markedly influenced by the presence of corn: when this cereal was present, nitrates values were relatively high, probably because a lower total uptake than soybean crop. This increased N uptake by the legume can be explained by the proteinaceous nature of the soybean and therefore it is a highly demanding crop in N, and because the peak of N uptake of soybean generally takes place during a longer period and after the moment of greatest uptake by corn. In addition, soybean plants at intercropping with corn are of a size and development lower than when grown in monoculture, limiting N uptake and absorption by corn-soybean system. It can be concluded that when soybean grows in monoculture without limitations, such as a strong competition of a larger crop as corn, it efficiently depletes soil N, an effect that lasts even after soybean harvest.

In contrast to the findings in this paper, other authors found no strong effects of cropping system on mineral N contents of soil. Hauggaard-Nielsen et al. found that conditions of biotic and abiotic stress in conjunction with local long-term history of the crop sequence influenced more strongly the amounts of mineral N and N dynamics than the effects of short-term cultivation [28]. Recently, [52] found no differences in the availability of nitrate in the soil profile between a sole corn and intercropping of maize and clover, during and after the growing season. It is likely that differences in soil type, crop sequence and N fertilization explain these differences, but it is clear that each situation must be analyzed and it would be risky to extrapolate the test results to different conditions.

Extractable phosphorus levels were initially moderate and then increased dramatically over time; this effect was probably a result of strong mineralization of organic phosphorus, leading to high levels of inorganic P, represented by extractable P. Ghosh et al. concluded that soybean in advanced stages, with a developed root system, can increase the availability of native and fixed P for intercrops; however in our work imposed treatments did not affect available P contents due to very high levels of this element from the beginning during the whole crop cycles [20].

Soil pH was almost constant during the crop cycle, being unaffected by treatments, agreeing with [54], who showed that the pH of the rhizosphere soil of wheat was not significantly altered by intercropping with beans or corn. The higher productivity of intercropping and a longer duration of plant growth period, may cause a high amount of plant biomass which then should become soil organic matter in several stages of decomposition; nevertheless soil C was also unaffected by cropping treatments, probably because this effect should be noticeable after several years after installation of the practice. The EC was initially low and similar among treatments and increased slightly over time until harvest corn, and intensely from this moment, except at sole soybean. It may be thought then that, when corn is grown, especially in sole culture, from the crop harvest the absence of nutrient uptake, as seen in the soil nitrates dynamics, led to more concentrated soil solutions, supported in this case also by a decrease in the amount of rainfall. However, the EC values did not exceed 2 dS m^{-1}, which is the usually considered threshold for salinity damage to most crops.

Moisture contents relied on a greater extent to the environmental conditions than on differential evapotranspiration of crops. The practice of intercropping did not enhance water uptake by crops in relation to sole crops, as might be expected from complementary root systems and development timelines, and could be a viable alternative when there are low moisture contents at corn sowing or when moisture profile after crops needs to be recovered earlier than at sole soybean.

Final plant density was similar between treatments, so the differences found in the crop growth and yields are due to different individual growth and not to a different number of plants. Intercropping treatments stimulated corn growth, which strongly inhibited the growth of intercropped soybean, especially at the 1:1 ratio, as can be seen in the decreases in height and coverage of the legume under these systems. Cereals generally have greater height and growth rate so that they often suppress the growth of intercropped legumes, which was found in soybean-sorghum intercrops [19,20] and more recently in the Argentinean Pampas at soybean-corn and soybean -sunflower intercroppings [12, 7]. In this study we found a high competitive ratio CR and aggressiveness of corn when it was intercropped with soybean on a 1:1 arrangement. The 1:2 ratio allowed a little looser soybean growth compared to 1:1 intercropping system, so that the growth of corn was a little less stimulated, showing lower heights than the corresponding to the 1:1 systemGhosh et al. found, however, that by intercropping sorghum (cycle and size similar to corn) and soybean, even at a higher proportion of the dominated component (1:3), due to differences in crops height, sorghum plants heavily shaded intercropped soybean plants, affecting their photosynthesis, their ability to growth, N uptake and final biomass, even though sowing of both species was made in the same day [20]. Regarding the leaf area of corn, there were no differences between intercropping arrangements, but these had higher LAI values than sole corn, highlighting once again the growth stimulation of intercropped corn.

Corn N status also improved with intercropping probably due to an enhanced growth of plants and their roots, however direct N transfer processes from legume to corn cannot be discharged; it is known that legume crops may release great amounts of N in the so called rizodeposits, which include root exudates, rootlets and decaying roots during crop cycle [29]. On the contrary, soybean chlorophyll concentration, an index of N status, was unaffected by intercropping treatments; this effect could be explained by a nutritional adjustment or C balance between growth of crop and fixing bacteria, since N biological fixation relies on C gain of host plant, i.e. small plants have low N fixation but same final N content than bigger plants.

Corn yields were 91% and 86% greater at 1.1 and 1:2 intercropping arrangements, respectively, than at sole corn. Soybean yields were 84% and 52% lower at 1.1 and 1:2 intercropping arrangements, respectively, than at sole soybean. At corn-soybean intercropping systems, [62] observed yield increases of 30% at corn and decreases of 27% at soybean yields at Indiana, USA, while [18] found that intercropping at Iowa, USA, led to corn yields 20-24% greater, and to soybean yields 10-15% lower than their respective sole crops. It can then be concluded that in our work corn crop exerted a highly dominating competition on intercropped soybean, probably due to a greater amount of days between corn and soybean sowing day.

Yield responses were related to crop biomass, height, diameter and LAI measurements, stimulating intercropping systems corn yield and depressing soybean growth, particularly at 1:1 corn-soybean ratio. Based on this remarkable dominance of corn crop observed at this arrangement, it can be concluded that a 1:2 corn-soybean ratio could be more beneficial in terms of more symmetric ecological interactions and with a more balanced final productivity. This idea is confirmed through calculation of LER, since the very low partial soybean LER at 1:1 design makes overall LER to be lowest at this arrangement, agreeing with other authors [41]. Díaz et al. found, also at argentinean Mollisols, greater global biomass productions at 2:2 corn-soybean intercropping systems than at 1:1 designs, due to the strong decresase of soybean growth at the latter [10]. Nevertheless, at both treatments overall LER was greater than 1, so it can be concluded that these systems are more efficient than sole crops at the environmental conditions of the test. It has also been reported in other studies that even though soybean yields are decreased by shadowing and soil resources competition by corn crop, the land use efficiency increases with respect to their sole crops [39, 43, 16].

5. Conclusion

Nitrate levels were changed by treatments, but these treatments did not affect available P contents due to very high levels of this element during the whole cropping cycles. The practice of intercropping did not enhance water uptake by crops in relation to sole crops, as might be expected from complementary root systems and development timelines. Corn N status improved with intercropping probably due to an enhanced growth of plants and their roots, but soybean chlorophyll content was decreased by intercropping treatments. Yield and growth of corn were stimulated by intercropping systems, but this system depressed soybean growth, particularly at 1:1 corn-soybean ratio. Based on the remarkable dominance of corn crop observed at this arrangement, it can be concluded that a 1:2 corn-soybean ratio could be more beneficial in terms of more symmetric ecological interactions.

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