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Research Article

Effects of Nutrient Replacement on Yields in the Corn-Wheat/Soybean Sequence

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Abstract

In Argentina, the process of agriculturalization, started in the corn kernel area in the mid-1970s, with excessive tillage, inadequate weed control and little nutrient replacement, which negatively impacts the trend in yields. In the mid-1980s, conservation work began to spread, which consisted of significantly reducing the number of tasks from the harvest of the previous crop to the implantation of the next. This was the previous step to the diffusion of direct sowing (SD) that, by leaving all the crop residues on the surface, reduces losses due to soil and water erosion, also improving its infiltration. In addition, the appearance of new herbicides allows better weed control. Everything results in higher crop yields compared to those implanted with soil removal, mainly attributable to more efficient use of rainwater and at the expense of soil nutrients, given that the balances (contribution through fertilization - extraction of nutrients by grain harvest) are negative. Thus, arises the need for information regarding nutrient replacement in continuous agriculture under SD. Given the above, there is a need for information regarding nutrient replacement in continuous agriculture under SD. INTA, the Association of producers in direct sowing (AAPRESID), the NUTRIENT Company and the International Institute of Plant Nutrition (IPNI), beginning in the 1999 - 2000 cycle and for 18 years two experiences, one in a batch with a long agricultural history without nearby layers and another where the agricultural history of the lot was brief but the layer was close to the roots. The investigation took place in the rural area of the INTA Corral de Bustos Extension Agency in the Marcos Juárez department, Córdoba province.

The objective of the experiences was to evaluate the physical and chemical characteristics of the soil and the yield of the crops before different fertilization treatments that included the replacement of nutrients when using the Maize-Wheat/Soybean sequence implanted in SD. The purpose was to find fertilization alternatives that improve soil quality and crop yield. In the present work the results referring to the crop yield are presented. In corn the best yields were achieved when replacement fertilization was used. In wheat, this only happened in the place with the greatest agricultural history. With this treatment in the site with the longest agricultural history and without nearby layers, 88% and 89% of the potential dryland yields in the study region were reached for wheat and corn, respectively. At the site with the lowest agricultural history and near groundwater, said potential was exceeded by 10 and 17% for wheat and corn, respectively, which showed the greater importance of increasing the fertilization doses in this type of environment. In soybeans, the best yields were achieved when fertilized with sulfur (S) or with S combined with other nutrients.

The results showed that, if fertilization were stopped, in lots with many years of continuous agriculture, wheat and corn yields would decrease by 50% and soybean yields by approximately 27%.

In the analyzed period, there was no significant incidence due to the application of micronutrients in the average yields obtained. However, there was a performance bonus when micronutrients were applied in some of the last cycles evaluated, suggesting that possibly from now on they become more important in the definition of yields.

Replenishment treatments, in the site with the longest agricultural history and without nearby water levels, with respect to the dose used by the average producer in the area, improved the efficiency of water use in wheat and corn by 11.4%, while for soybean cultivation, this improvement was 28% when comparing replacement treatments with the Control treatment without fertilization.

According to the comparative analysis of yields of the experiment with respect to the average yields of the producers of the Marcos Juárez department or that of producers with soils without water limitations, wheat mainly and also maize appear as the crops where the most effect would have to increase the dose of fertilization, in order to reduce the gap with respect to the potential yield possible to achieve.

Keywords: *Nutrient Replacement; Corn-Wheat/Soybean Sequence; Direct Sowing (SD); Association of Producers in Direct Sowing (AAPRESID); International Institute of Plant Nutrition (IPNI)*

Introduction

In the mid-1980s, the process of agriculturalization with excessive tillage and lack of adequate cultivation sequences made visible the deterioration of the soils, the increase in the erosive process and the greater weeding, negatively impacting the yield trend of the crops. Aware of this problem, in 1986 [1], INTA implemented the conservation agriculture project (PAC) which aimed to disseminate technology already proven in the experimental stations, with respect to reducing the number of tasks and implanting crops with the greatest quantity of stubble on the surface, make better weed control and diagnose the need for fertilization of the lots, all aimed at slowing down the deterioration of the soil and making more efficient use of rainwater, in order to stabilize and improve the crop yield. In the framework of the aforementioned project, an adaptive experimentation experience in the rural area of Camilo Aldao began in 1986, together with the Extension Agency of the INTA Corral de Bustos. In it, the maize-wheat/soybean-soybean sequence in direct sowing (SD) was compared for 16 years versus those implanted crops in combined tillage (LC): maize and soybean 1° in vertical tillage, wheat in minimum tillage and soybean of 2nd in SD. The results showed that the cultures in continuous SD presented on average the same or better yields than those implanted in LC and both treatments showed a favorable gap when compared with the yields obtained in the same period with those of the typical corn area. Regarding the chemical properties, the pH was maintained at values from the beginning of the experience and the organic matter declined considering the first 30 cm of soil. This deterioration and the estimated negative balance of nutrients indicated that their contribution via fertilization was insufficient for the productions obtained, which were possible due to efficient water management and at the expense of chemical deterioration of the soil.

Given the above, there is a need for information regarding nutrient replacement in continuous agriculture under SD. INTA, AAPRESID, ASP and IPNI jointly begin in the 1999 - 2000 cycle and for 18 years two experiences with different fertilization options for the corn-wheat/soybean sequence in the area of the INTA Extension Agency Corral de Bustos in the Marcos Juárez department, Córdoba province.

Objective of the Study

The objective of the experiences was to evaluate the physical and chemical characteristics of the soil and the yield of the crops before different fertilization options that included the replacement of nutrients when using the M-T/S sequence implanted in SD. The purpose of it was to find fertilization alternatives that improve soil quality and crop yield. In the present work the results referring to the performance variable are presented.

Materials and Methods

Since the 1999 - 2000 cycle, in the area of the Corral de Bustos Extension Agency, EEA INTA Marcos Juárez, two experiences were conducted with different fertilization alternatives in the corn-wheat/soybean sequence with all the crops implanted under SD. The lots where the experiences were carried out are located in the establishments "Don Osvaldo" (DO), (33° 11' 20,09'' Lat. S - 61° 58′ 49,34′′ Long. O) and "Los Chañaritos" (LCH), 33° 17′ 3,43′′ Lat. S - 64° 7′ 9,08′′ Long. O) in the rural areas of Camilo Aldao and Corral de Bustos, Córdoba province, respectively. The climate is temperate with an annual average temperature of 16.5°C, humid sub-humid with an annual average of 830 mm, excess water in spring and summer drought; the first attenuates the second, and the soils are typical Argiudoles from the Hansen series (INTA, 1985). At the beginning of the experience, DO had a 31-year agricultural history of continuous agriculture with only two pastures in the last 100 years, 2.4% OM and 8 $mg.kg^{-1}$ of extractable P (Pe) up to 18 cm in depth. The pH of the soil was 6.1 and 6.2 of 0 - 5 cm and 5 - 18 cm depth, respectively. On the other hand, LCH had 12 years of continuous agriculture (CA), 3.12% OM and 15 $mg.kg^{-1}$ of Pe. The pH of the soil was 6.2 and 6.25 of 0 - 5 cm and 5 - 18 cm depth, respectively. It is necessary to clarify that LCH, in addition to the best initial soil condition of the site, presented shallow water layers, from where the roots of the crops could have been supplied with water in dry periods. On the other hand, at the DO site, the layers were deeper than the roots. The experiments were carried out in the field in contiguous strips and each treatment had an area of 6300m^2 in DO and 3600m^2 in LCH. The treatments that were evaluated were the following: 1) unfertilized control (T); 2) sulfur (S); 3) nitrogen (N); 4) nitrogen + phosphorus (NP); 5) nitrogen + phosphorus + sulfur (NPS) (for these treatments, the dose used by the average producer in the area was used, which on average was 80 $kg.ha^{-1}$ of N, 17 $kg.ha^{-1}$ of P and 15 $kg.ha^{-1}$ of S, for corn, and 80 $kg.ha^{-1}$ of N, 21 $kg.ha^{-1}$ of P and 14 $kg.ha^{-1}$ of S, for wheat/soybean) 6) nitrogen + phosphorus + replacement sulfur (NPSr) (the nitrogen, phosphorus and sulfur that the grains take with the harvest are replaced) and 7) NPSr + micronutrients (NPSrm) (equal to treatment 6, plus replacement of zinc and boron). The determination of the replacement dose was made based on an objective yield defined for each crop and the requirements per ton of grain of each one, using the value referenced by the International Institute of Plant Nutrition [2]. 60% of soybean N was considered to come from biological fixation, as evaluated by Salvagiotti., *et al* [3]. To determine crop yields, the entire plot was harvested. The study covered the period 1999-2016/7 and the comparison between sites was invalidated, given that when corn is implanted in one of them, wheat/soybean is implanted in the other and vice versa. Crop water use efficiency was determined from averages of yields and rainfall during the crop cycle between 1999 and 2013.

For the analysis of the results, Mixed Linear Models were used, considering the years as random effects and the treatments as fixed. The means were compared with the Fisher's LSD test (5%).

Finally, a comparison was made of the averages of the NPSr yields (1999 - 2015) with those obtained on average in the Marcos Juárez Department (Ms. Jz. Department), based on data from MINAGRI "Ghida Daza, INTA Marcos Juárez, com. Per.", And with those obtained on average by producers with soil of capacity of use I and II without limitations and with 50% of the surface with nearby layers, which use the sequence corn-wheat/soybean-soybean in SD based on information of groups CREA Monte Buey-Inriville, Province of Cordoba "Peretti and Cottura, INTA Marcos Juárez-CREA, com. pers" [4].

Results and Discussion

Figure 1-3 show the crop yields in each cycle evaluated. In the LCH site with a lower previous agricultural history, the crops expressed a higher yield potential due to a better soil condition and also to the proximity of the layer that could have reduced the water deficit in years with less rainfall. For the cultivation of wheat in DO (Figure 1A), there was response to NPS used individually and a performance enhancement when these nutrients were applied jointly.

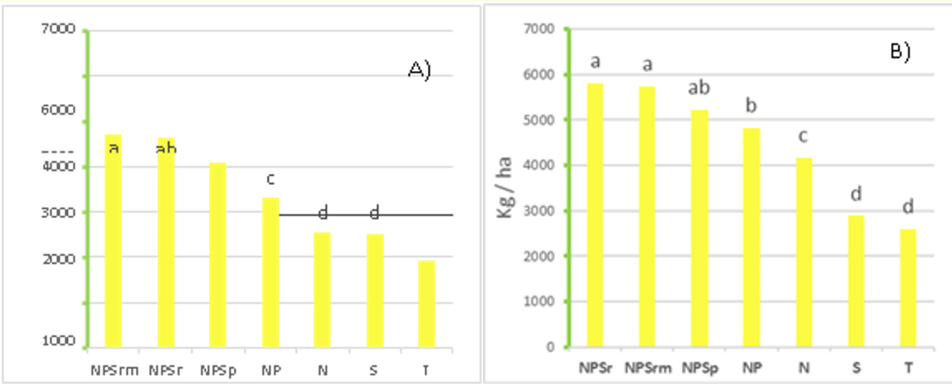

Figure 1: *Average yield of the wheat crop A): Don Osvaldo and B): Los Chañaritos, period 1999/2000-2016/2017. T: Unfert ilized Control; S: Sulfur; N: Nitrogen; NP: N + phosphorus; NPS: N + P + S producer dose; NPSr: N + P + S replacement dose; NPSrm: Ditto NPSr + micronutrient replacement.*

Treatments S and N had a 30% and 30.3% yield increase, respectively, in relation to T. Treatment NP had 31% more performance than N, showing the response to P. When the three nutrients were used together, the performance was enhanced, surpassing that of NP by 23%. NPS replacement fertilization did not improve the yield of the NPS dose used by the producer, except when, in addition, micronutrients were added to the replacement dose, surpassing NPSrm by 15.2% to NPS. In any case, we cannot say that there was a response to the application of micronutrients since NPSr and NPSrm had a very similar performance without significant differences between them.

In CH (Figure 1B), there was a response to N and P, but not to S. An increase of 60% and 15.8% in yields was obtained when comparing N with T and NP with N, respectively. The dose of S applied individually did not exceed the control and the dose of NPS did not exceed that of NP. There was also no higher performance when the replacement dose alone or in combination with micronutrients was used. The previous history of the lot with the lowest year of agriculture, the highest amount of organic matter and the availability of nutrients could explain this lower response to fertilization.

For the cultivation of corn in DO, figure 2A, there was a response to the application of sulfur and nitrogen: treatments S and N had a yield increase of 41% and 43.7%, respectively, in relation to T. A Despite the fact that the batch studied had low P content in its initial characterization, when N was compared with NP, no major difference was observed due to the addition of P, but synergism occurred when the three nutrients were used together: the NPS treatment 29.2% superior to NP. This marks the importance of fertilizing with all the nutrients that are diagnosed as deficient. With the replacement treatments, NPSr and NPSrm, the best yields were obtained, exceeding by 15 and 12%, respectively, NPS. There was no response to the application of micronutrients, achieving with NPSr a performance similar to NPSrm.

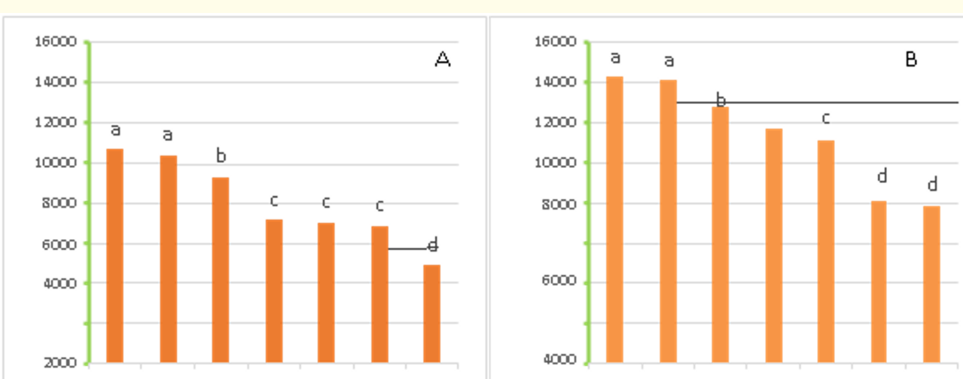

Figure 2: *Average yield of the corn crop A): Don Osvaldo and B): Los Chañaritos, period 1999/2000-2016/2017. T: Unfertilized Control; S: Sulfur; N: Nitrogen; NP: N + phosphorus; NPS: N + P + S producer dose; NPSr: N + P + S replacement dose; NPSrm: Ditto NPSr + micronutrient replacement.*

For corn in LCH, figure 2B, when comparing treatments S and T, no response to the application of sulfur was observed, perhaps due to the higher initial content of OM in this batch. Yes, a response could be verified by the application of N, with which it was possible to overcome the unfertilized control by 38.1%; response to P, treatment NP increased yield 5.3% with respect to N; while S became important when NP was added to the treatment, since NPS improved performance by 10.9% compared to NP. The best yields were obtained with the NPSr and NPSrm treatments, which exceeded the NPS treatment by 10.4% and 11.9%, respectively. The increase in yields due to the application of micronutrients was not significant. The boron and zinc values, above the critical level at the end of the experience, could explain the lack of response to these nutrients.

In DO soybean, figure 3A, the only response observed is by the application of sulfur, obtaining a yield of 36.3% when comparing S with T. There are no differences in treatments that include sulfur among the nutrients applied.

A marked limitation of available sulfur was manifested in the system, wheat used little, available sulfur, inducing a greater deficiency of this nutrient, which was accentuated when it was only fertilized with nitrogen.

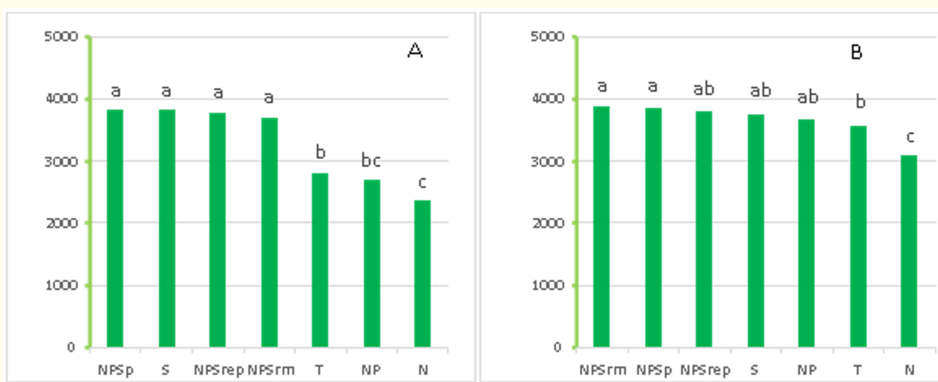

Figure 3: *Average yield of soybean cultivation A): Don Osvaldo and B): Los Chañaritos, period 1999/2000-2016/2017. T: Unfertilized Control; S: Sulfur; N: Nitrogen; NP: N + phosphorus; NPS: N + P + S producer dose; NPSr: N + P + S replacement dose; NPSrm: Ditto NPSr + micronutrient replacement.*

In LCH, figure 3B, the differences in yield between fertilized treatments compared to the unfertilized control are not significant except when the control is compared with the NPSrm or NPSp treatments, although there are no differences between these and NPSr, S or NP. The answer is not very clear. Everything indicates that, being a lot with fewer years of agriculture, richer in OM and with a greater possibility of offering available sulfur, this nutrient for cultivation is not yet deficient. A performance depression was observed when only N fertilized, which could suppose the negative effect on the biological fixation of this nutrient when it is not applied together with sulfur or phosphorus or phosphorus + sulfur.

In both sites, the lack of response to the application of micronutrients in soybeans, NPSr versus NPSrm, could be explained because their values in the soil; at the end of the experience, 0.6 $mg.kg^{-1}$ for boron (Reussi Calvo, Integrated Unit Balcarce EEA INTA-FCA UNMP, personal communication) [5] and 1 $mg.kg^{-1}$ for zinc (Barbieri were above those considered critical. *et al*. 2015) [6].

In figure 4 to 9 it is possible to appreciate the relative performance of the NPS, NPSr and NPSrm treatments with respect to the T treatment, for each year and culture in both experiences, and to identify the years in which the NPSr and NPSrm treatments did not differ from the NPS treatment.

In the DO site, for the grass crops, the yield of the replacement treatments exceeded that of the NPS treatment, except in two years in corn and one in wheat, in which, due to low rainfall, the yields were equalized (Figure 4 and 5); and even in 2008 wheat, replacement yield fell below NPS since there was no rainfall from May to September, the total of them in the crop cycle being 35% less than the historical ones, so the yield maximum of the crop was below 2000 kg.ha^{-1} (Figure 5).

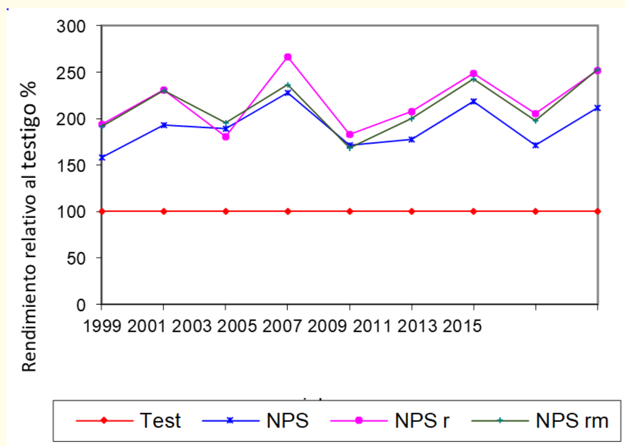

Figure 4: *DO corn evolution of relative yields.*

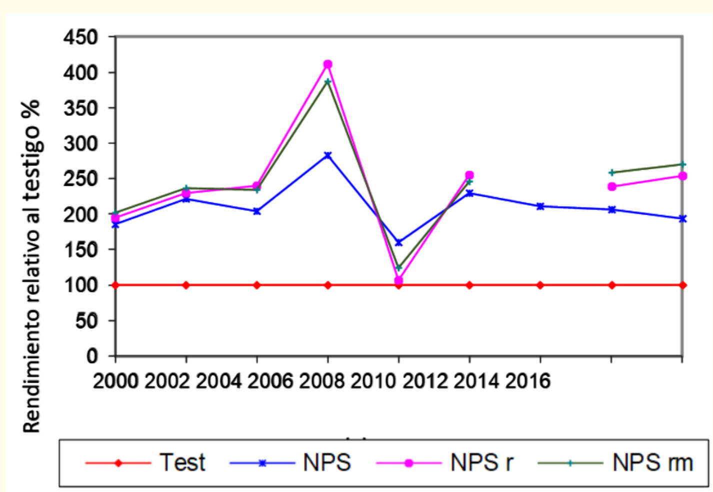

Figure 5: *Wheat DO evolution of relative yields.*

It is necessary to clarify that in the 2012 cycle due to marketing problems, the producer decided not to implant wheat and implanted barley, and the replacement treatments could not be harvested due to the total upset they suffered (Figure 5).

In soybean cultivation, only a response to the application of S was reflected, without major differences between the treatments fertilized with this nutrient, whose yields in 2010 fell below the control because rainfall during the soybean cycle was 58% of the historical average, so that the control treatment, having a predecessor with a lower yield, may have benefited from a greater initial water reserve (Figure 6).

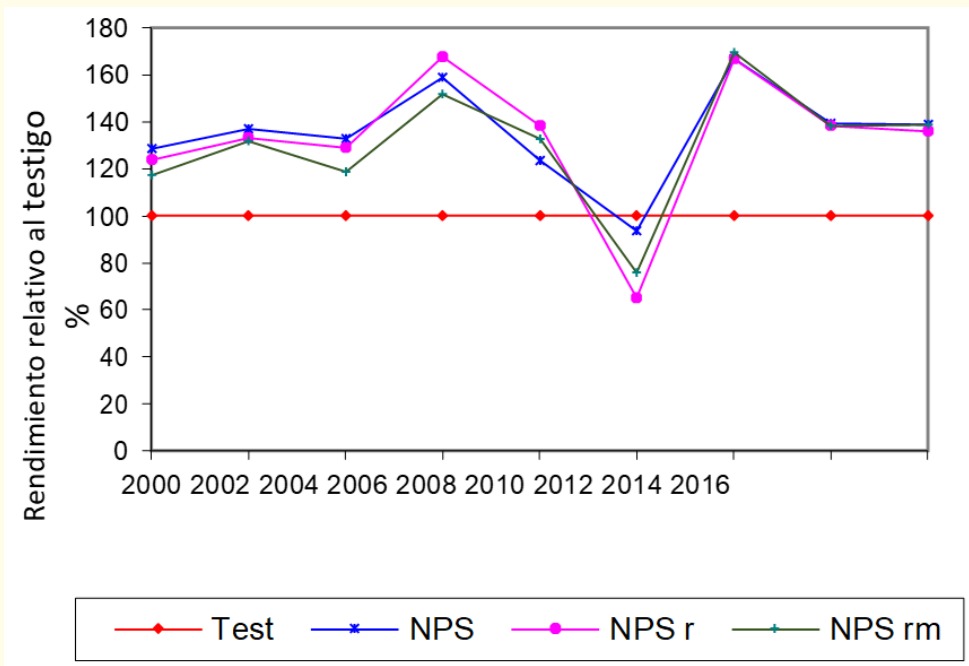

Figure 6: *Soy DO evolution of relative yields*

In the LCH site (Figure 7-9) for grass crops, the performance of replacement treatments exceeded that of NPS, except in some years in which due to water deficit (two years in corn, deficit in critical period, and two in wheat; deficit in critical period and grain filling) and excess rainfall (one year in corn), yields were equal and even in 2015, in wheat, they fell below that achieved by NPS as they were most affected by stem rust (Figure 7 and 8). For soybean cultivation, it was observed that there were no major differences between replacement treatments and NPS. All treatments were increasingly differentiated from T in the course of the experience, which would be explained by the deficit of S that is accentuated with the passage of time in the treatment without fertilization with this nutrient. In 2015, soybeans were not harvested since, due to the rise in the water table, the experiment was under water for a large part of the cycle and the crop was lost (Figure 9).

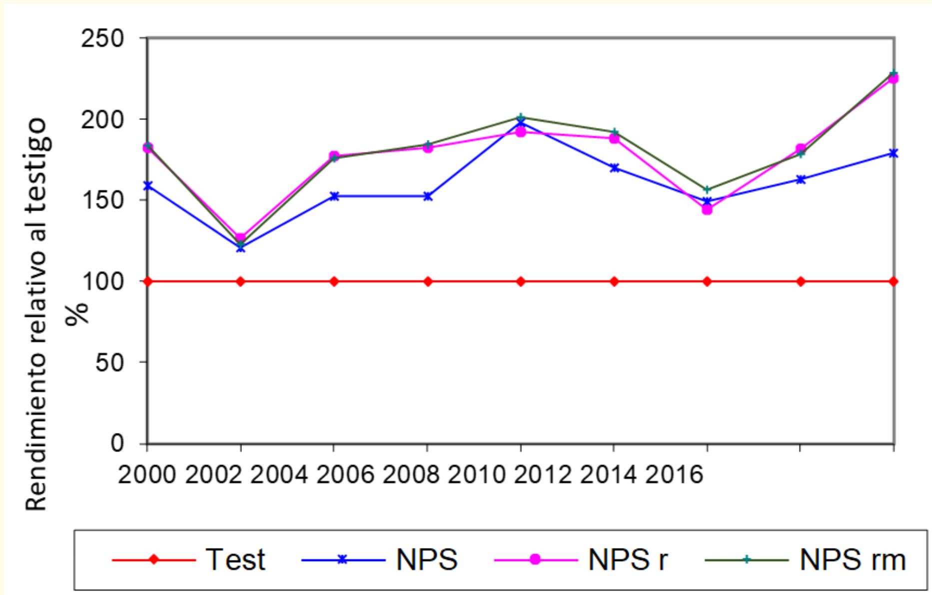

Figure 7: *Maiz LCH Evolution of relative yields*

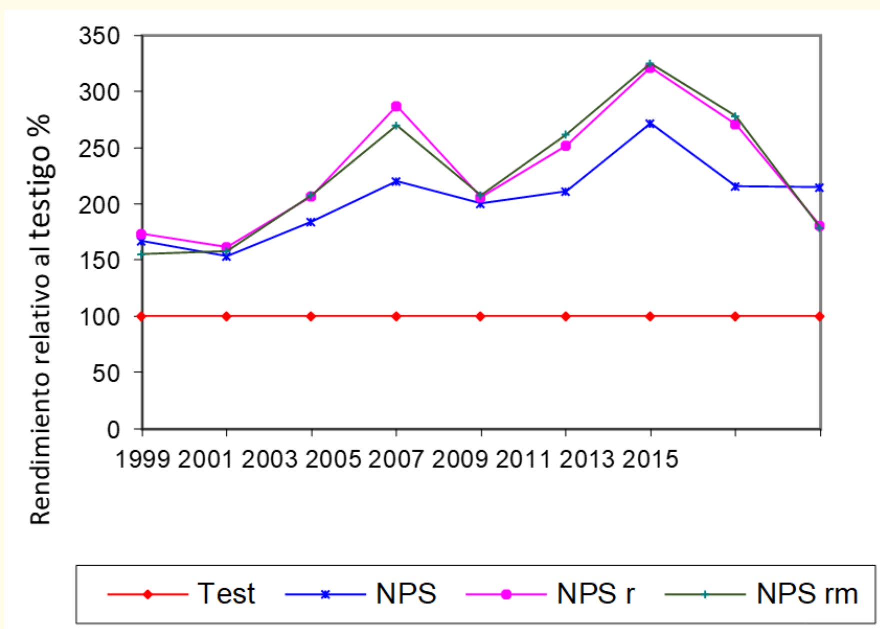

Figure 8: *LCH wheat evolution of relative yields.*

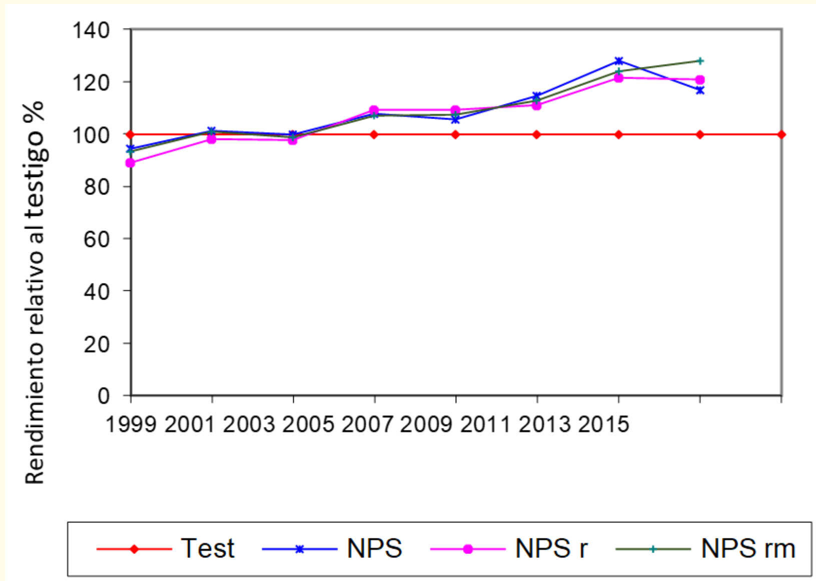

Figure 9: *LCH soybean evolution of relative yields.*

In summary, in most of the years better yields were obtained in grass crops when the NPSr and NPSrm doses were used. In the years when this did not occur, in almost all situations, the water deficit, mainly in critical periods of crops, would explain this different behavior. Weather forecasts could help define when replacement doses would need to be reduced and when to use them to decrease yield gaps. Considering the potential yields of rainfed, in the study region, 12000, 5300 and 4400 $kg.ha^{-1}$ for corn, wheat and soybeans, respectively [7], at the DO site, without nearby layers, 77% and 88% were obtained in wheat; 87% and 86% in soybeans and 77% and 89% in corn for the NPS and NPSr doses, respectively, of the referred potential. At the LCH site, with nearby nappa, the NPS treatment achieved 99%, 88%, and 107% of the dry potential for wheat, soybeans and corn, respectively. Nutrient replacement achieved 87% of the potential in soybeans, while in wheat and corn the potential was exceeded by 10 and 17% respectively, indicating the greater importance of increasing fertilization doses in environments where the napa of somehow ensures the provision of water for these crops.

Effect on water use efficiency

Table 1 presents the estimation of the water use efficiency of each crop for contrasting DO treatments, based on the average yields and rainfall during the crop cycle from 1999 to 2013.

Treatment	T	NPS	NPSr	NPSrm
Culture	kg of grain. mm^{-1} of available water			
MAIZ	9,6	17,5	19,7	19,3
TRIGO	8,2	17,6	19,8	19,8
SOJA	6,2	8,3	8,0	7,9

Table 1: *Efficiency of water use at the Don Osvaldo site, period 1999 - 2013.*
T: Witness unfertilized; NPS: N + P + S producer dose; NPSr: N + P + S replacement dose;
NPSrm: Ditto NPSr; + replacement of micronutrients.

Greater efficiency in replacement treatments for grass crops can be observed from the best yields obtained with the same availability of water during the cycle. For soybeans, the difference was only between the fertilized treatments and the unfertilized control, since the only response to fertilization is by the application of sulfur. Note the better efficiency of grass crops compared to legumes, especially when fertilized.

Comparative performance analysis

Table 2 shows for the DO site and table 3 for the LCH site, the yield averages (1999 - 2015) of corn, wheat and soybeans obtained in the NPSr treatment compared to the average of each crop obtained in the same period in the Dto. Ms. Jz. and in table 4, the yield of corn, wheat and soybeans of the average NPSr treatment of the DO and LCH sites is presented, compared to the averages obtained by producers with class I and II soil without limitations and with 50% of the surface with nearby layers. In the DO experience, 17%, 49% and 11% more corn, wheat and soybeans were obtained, respectively, then the average of the Dto. Ms. Jz. (Table 2). When the comparison is made with the data from the LCH site, these differences were expanded for corn and wheat (48%, 90%, 18% respectively) (Table 3). It is also valid to clarify that the average of the Dto. Ms. Jz. it includes first and second-rate soybeans, while in the experiments it was always second-rate soybeans. The comparison with the averages obtained by the producers with class I and II soils without limitations and with 50% of the surface with nearby layers, shows that the NPSr treatment has a yield increase of 20%, 33% and 18% for corn, wheat and soybean, respectively (Table 4). This suggests that there is an important part of the yield gap that could be reduced by improving fertilization management [8-15].

Site	Performance (kg/ha)		
	MAIZ	TRIGO	SOJA
NPSr Don Osvaldo	10662	4495	3838
Dto. Ms. Jz.	9102	3020	3468
Relationship NPSr/Dto. Ms. Jz.	117	149	111

Table 2: *Comparative analysis of average performance NPSr Don Osvaldo vs. Department of Marcos Juárez (Dto. Ms. Jz.), period 1999/2000-2015/16. NPSr: N + P + S replacement dose.*

Site	Performance (kg/ha)		
	MAIZ	TRIGO	SOJA
LOS CHAÑARITOS NPSr	14068	5805	3813
Dto. Ms. Jz.	9489	3063	3241
Relationship NPSr/Dto. Ms. Jz.	148	190	1,18

Table 3: *Comparative analysis of average NPSr performance at the Los Chañaritos site vs. Department of Marcos Juárez (Dto. Ms. Jz.), period 1999/2000 - 2015/16. NPSr: N + P + S replacement dose.*

Site	Performance (kg/ha)		
	MAIZ	TRIGO	SOJA
Average DON OSVALDO-LOS CHAÑARITOS NPSr	12365	5150	3825
Producers Soils CI-C2 Unlimited, 50% with nearby layers. Dto. Ms. Jz.	10289	3884	3235
Relationship NPSr/Ms. Jz.	120	133	1,18

Table 4: *Comparative analysis of average yield NPSr average of the Don Osvaldo-Los Chañaritos sites vs. producers Marcos Juárez Department (Dto. Ms. Jz.) without limitations, period 1999/2000 - 2015/16. NPSr: N + P + S replacement dose.*

Conclusion

In corn, the best yields were achieved when replacement fertilization was used. In wheat, this only happened in the place with the greatest agricultural history. With this treatment in the site with the longest agricultural history and without nearby layers, 88% and 89% of the potential dryland yields in the study region were reached for wheat and corn, respectively. At the site with the lowest agricultural history and near groundwater, said potential was exceeded by 10 and 17% for wheat and corn, respectively, which showed the greater importance of increasing the fertilization doses in this type of environment. In soybeans, the best yields were achieved when fertilized with S or with S combined with other nutrients.

The results showed that, if fertilization were stopped, in lots with many years of continuous agriculture, wheat and corn yields would decrease by 50% and soybean yields by approximately 27%.

In the analyzed period, there was no significant incidence due to the application of micronutrients in the average yields obtained. However, there was a performance bonus when micronutrients were applied in some of the last cycles evaluated, suggesting that possibly from now on they become more important in the definition of yields.

Replenishment treatments, in the site with the longest agricultural history and without nearby water levels, compared to NPS, improved the efficiency of water use in wheat and corn by 11.4%, while for soybean cultivation this improvement was 28% when compared to T treatment.

According to the comparative analysis of yield with respect to the average of the Marcos Juárez department or that of producers with unlimited soils, that of wheat mainly and also that of corn appear as the crops where the most effect would have to increase the dose of fertilization, in order to decrease the achievement gap possible to achieve.

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