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# Agronomic efficiency of fertilizers based on humus, rock powder, and minerals on soybean yield in Paraguay-PY

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## ABSTRACT

Soybean is the most commercially cultivated crop in Paraguay, and obtaining high yields requires the application of large amounts of fertilizers, raising the cost of production. Developing strategies for the efficient use of applied nutrients is necessary. Therefore, the study aimed to evaluate the agronomic efficiency of combinations of mineral fertilizers with organic matter and rock powder in the development, nutrition, and yield of soybean. The experiment was carried out in Hernandarias, Paraguay, in the 2016-2017 harvest. The different fertilizers influenced the absorption of Zn, Mg and K, and grain yield. Among the treatments, the highlight was the agronomic efficiency index obtained by the replacement of 30% of mineral fertilizer by humus, presenting grain yield of 3219, 67 kg ha$^{-1}$. However, it was equal to the mixing 30% of humus + rock powder with 70% of NPK formulation 04:40:10 with grain yield of 3206.50 kg ha$^{-1}$, and the mixing 20% of humus + rock powder with 80% of NPK formulation 04:40:10 with grain yield of 3165.17 kg ha$^{-1}$. Thus, it is recommended to use rock powder and humus in soybean production in Paraguay, especially in Latossolos (Oxisols) that have little organic matter and low CTC.

**Keywords:** *Glycine max*, organic matter, organomineral.

## Eficiência agronômica de fertilizantes à base de húmus, pó de rocha e minerais no rendimento de soja no Paraguai-PY

## RESUMO

A soja é a cultura mais cultivada comercialmente no Paraguai e a obtenção de altos rendimentos requer a aplicação de grandes quantidades de fertilizantes, elevando o custo de produção. É necessário o desenvolvimento de estratégias para o uso eficiente dos nutrientes aplicados. Diante disso, objetivou-se avaliar a eficiência agronômica das combinações de fertilizantes minerais com matéria orgânica e pó de rocha no desenvolvimento, nutrição e produção de soja. O experimento foi realizado em Hernandarias, Paraguai, na safra 2016-2017. Os diferentes fertilizantes afetaram a absorção de Zn, Mg e K e produtividade de grãos. Entre os tratamentos, o destaque foi para o índice de eficiência agronômica obtido com a substituição de 30% de adubo mineral por húmus, apresentando produtividade de 3219, 67 kg ha$^{-1}$, sendo estatisticamente igual ao tratamento com 50% de húmus + 50% pó de rocha, composto por 30% de fertilização e complementado com 70% de minerais NPK com produtividade de 3206,50 kg ha$^{-1}$, e a mistura 50% de húmus + 50% pó de rocha, compondo 20% da fertilização complementada com 80% de minerais NPK e produtividade de 3165,17 kg ha$^{-1}$. Assim, recomenda-se o uso de pó de rocha e húmus na produção de soja no Paraguai especialmente em latossolos que apresentem pouca matéria orgânica e baixa CTC.

**Palavras-chave**: *Glycine max*, matéria orgânica, organomineral.

## 1. Introduction

Soybean (*Glycine max* L. Merril) is a crop of great importance worldwide and uses the monoculture as a production model (Correia, 2019). South America stands out as one of the largest producers of this grain. Paraguay is among the most prominent countries, and soybean is the most cultivated crop in the country, with an area of 3.61 million hectares and production of 10 million tons (Oliveira and Hecht, 2016; FAS, 2020).

The intensive use of synthetic fertilizers is a striking feature of the soybean production process (Vennet et al., 2015), and generally presents low use efficiency (Frazão et al., 2014). Several factors contribute to this low efficiency, such as soil acidity, presence of iron (Fe), phosphorus (P) fixation, low level of organic matter (OM), nutrients leaching, among others (Sfredo, 2008).

From an economic point of view, fertilizers represent a large part of the production cost of this crop, which makes it necessary to use strategies to improve efficiency (Brasil, 2011). Demanding the investigation of alternative sources (still little explored), such as rock powder and organic fertilization (Ribeiro et al., 2010; Khaim et al., 2013).

The positive effects of soil organic matter have long been recognized. It is especially beneficial for the retention and availability of nutrients, through the complexation and protection of mineral nutrients by organic acids (Ulsenheimer et al., 2016; Costa et al., 2018). Likewise, the use of rock powder sources has shown satisfactory results. Bakken et al. (2000) highlight that the use of rock powder has shown technical feasibility in agricultural cultivation. Further studies are needed due to the low availability of information in the literature (Oliveira et al., 2006; Fernandes et al., 2013).

Research shows that the replacement of part of chemical fertilizers with manure-based or inorganic fertilizers has the potential to improve production without compromising crop yield, contributing to the physical-chemical and biological properties of soil (Gezahegn et al., 2017). For high yield, the crop nutritional requirements must be considered, supplying the demand through an adequate supply of fertilizers, in doses and sources, appropriately (Reetz Júnior, 2017). The combination, whenever possible of chemical fertilizers with alternative sources and/or protection technologies aiming at higher efficiency and yield indexes, must be considered (Reeve and Drost, 2012). Given the above, the study aimed to evaluate the agronomic efficiency of mixtures of humus and rock powder, with mineral fertilizers and their effect on the development and yield of soybean.

## 2. Material and Methods

The experiment was carried out in the agricultural research station of the Agronomico S.A. company, in Hernandarias, Paraguay, in a Latossolo (Oxisol) (López et al., 1995). The chemical and particle size characterization of soil is shown in Table 1.

The climate of the region is classified as Cfa-type (warm and temperate) (Köppen and Geiger, 1928). Temperature and precipitation data (during the experiment) are shown in Figure 1.

Sowing (cultivar Monsoy 6410 IPRO) was carried out on November 1st, 2016, with an estimated plant population of 300.000 plants $ha^{-1}$. The seeds were treated with Cropstar, 3.0 ml $kg^{-1}$ (Imidacloprid 15% + Thiodicarb 45%); Acronis, 1.25 ml $kg^{-1}$ (Pyraclostrobin 50 g $L^{-1}$ + Thiophanate-methyl 450 g $L^{-1}$); and GrapNod, 2.0 ml $kg^{-1}$ (*Bradyrhizobium japonicum*).

A randomized block design with eight treatments and six replications was used. The plots had 5.0 m wide (nine soybean rows) and 10 m long, totaling an area of 50 $m^2$ per plot. The treatments were: T1 - control without fertilizer; T2 - Mixing 10% of humus + rock powder with 90% of NPK formulation 04:40:10; T3 - Mixing 20% of humus + rock powder with 80% of NPK formulation 04:40:10; T4 - Mixing 30% of humus + rock powder with 70% of NPK formulation 04:40:10; T5 - Mixing 40% of humus + rock powder with 60% of NPK formulation 04:40:10; T6 - Mixing 50% of humus + rock powder with 50% of NPK formulation 04:40:10; T7 - 100% of NPK formulation 04:30:10; and T8 - Mixing 30% of humus with 70% of NPK formulation 04:30:10. Rock powder and humus were mixed in the proportion (1:1). The results of the chemical properties of rock powder and the mixture of rock powder + humus (1:1) are shown in Table 2.

**Table 1.** Physical-chemical properties of the soil in the experimental area.

| pH $CaCl_2$ | Argila | M.O | $Ca^{2+}$ | $Mg^{2+}$ | $K^+$ | $Al^{3+}$ | H+Al | CTC | CTCe |
|---|---|---|---|---|---|---|---|---|---|
| | % | g/kg | | -------------------------- cmolc/dm³ ------------------------ | | | | | |
| 4,40 | 52,12 | 27,50 | 2,78 | 1,29 | 0,23 | 0,95 | 6,10 | 5,24 | 10,40 |
| V | m | P¹ | P rem | $SO_4^{2-}$ | B | Cu | Fe | Mn | Zn |
| ------- % ------- | | mg/dm³ | mg/L | | -------------------- mg/dm³ ------------------------- | | | | |
| 41,06 | 19,49 | 25,08 | 19,17 | 19,99 | 0,48 | 4,64 | 34,54 | 95,49 | 3,29 |

[1]Mehlich extractor. O.M.: Organic matter; $Ca^{2+}$: Calcium; $Mg^{2+}$: Magnesium; $K^+$: Potassium; $Al^{3+}$: Aluminum. CEC: Cation exchange capacity; ECTC: Effective cation exchange capacity; V: Base saturation; m: Aluminum saturation; P: Phosphorus; P rem: Remaining phosphorus; $SO_4^{2-}$: Sulfur; B: Boron; Cu: Copper; Fe: Iron; Mn: manganese; Zn: Zinc. $Ca^{2+}$, $Ma^{2+}$, Cu, Fe, Mn, and Zn measured by atomic absorption spectrometer; B: measured by the volumetric method of D-mannitol (D-sorbitol); K+: measured by flame photometry; S-$SO_4^{2-}$: measured by the colorimetric method of barium chloranilate.

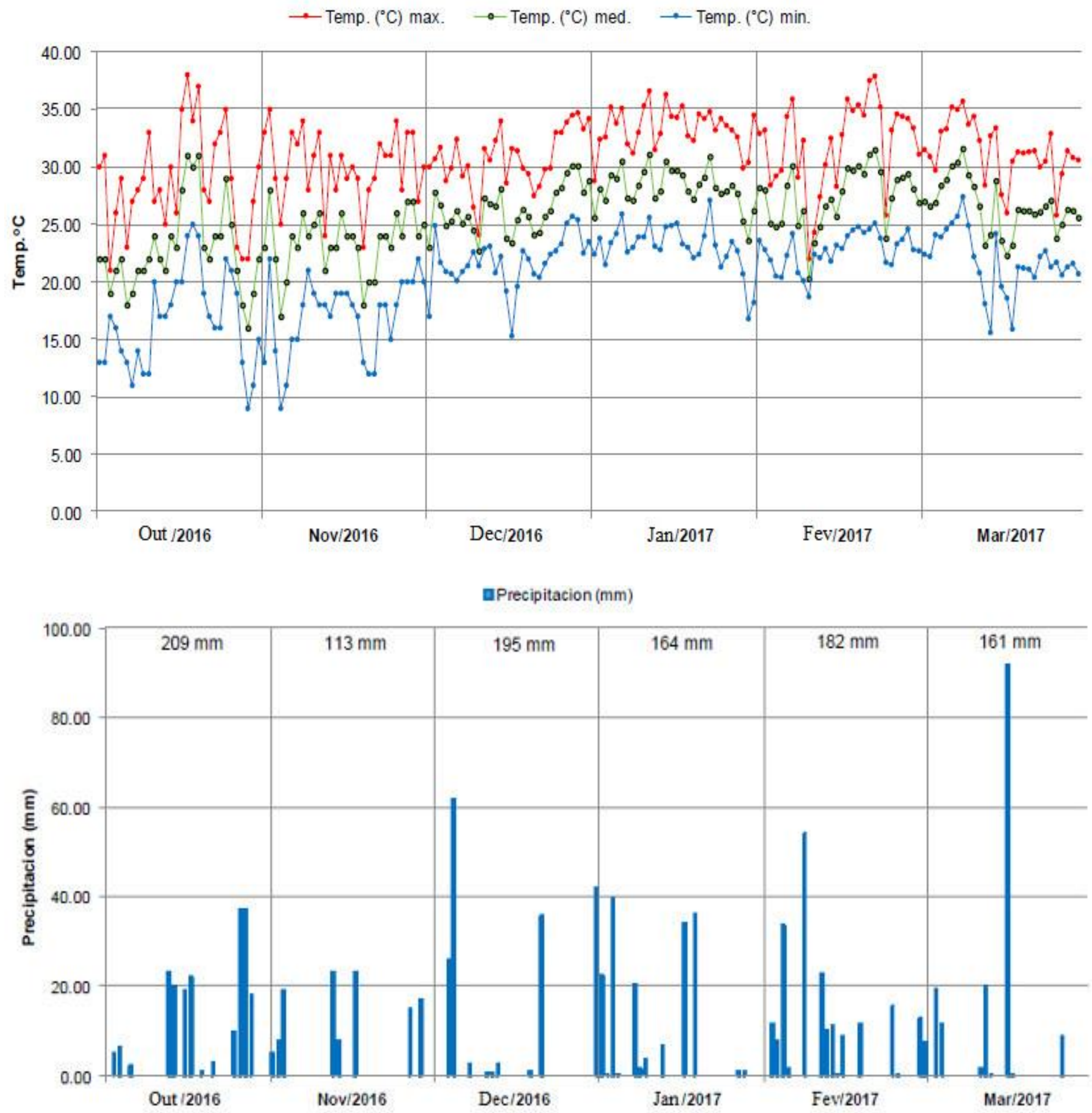


**Figure 1.** Maximum, average, and minimum temperature (ºC) (1st image) and accumulated daily precipitation (mm) (2nd image) in the agricultural research station, from January 1st, 2016 to March 30th, 2017.

**Table 2.** Chemical properties of rock powder and the mixture of humus with rock powder (1:1).

| | | | **Rock powder** | | | |
|---|---|---|---|---|---|---|
| N | $P_2O_5$ | $K_2O$ | $Ca^{2+}$ | $Mg^{2+}$ | $Fe^{2+}$ | Mn |
| | ------------------- | ------------------- | % | ------------------- | ------------------- | |
| 0,04 | 0,57 | 0,03 | 3,07 | 3,49 | 5,89 | 0,08 |
| $SO_4^{2-}$ | B | Cu | Zn | Co | Mo | Se |
| ------ % ------ | | ----------------- | ----------------- | mg $kg^{-1}$ | ----------------- | |
| 0,06 | 0,40 | 30,00 | 90,00 | 34,00 | 4,20 | 0,50 |

| | | | **Mixture of humus + rock powder (1:1)** | | | | |
|---|---|---|---|---|---|---|---|
| O.C[1] | N | $P_2O_5$ | $K_2O$ | $Ca^{2+}$ | $Mg^{2+}$ | $Fe^{2+}$ | |
| | ------------------- | ------------------- | % | ------------------- | ------------------- | | |
| 6,58 | 0,32 | 0,42 | 0,10 | 4,99 | 3,81 | 4,10 | |
| Mn | $SO_4^{2-}$ | B | Cu | Zn | Co | Mo | Se |
| --------- | % | --------- | | ------------- | mg $kg^{-1}$ | ------------- | |
| 0,05 | 0,30 | 0,20 | 30,00 | 100,00 | 17,00 | 2,10 | 0,25 |

[1]O.C.: organic carbon. Analysis methodology, according to Brasil (2014).

The fertilizers were applied in the sowing furrow, and the fertilization was complemented with the superficial application of 100 kg $ha^{-1}$ of KCl, before sowing (Cubilla et al., 2012). The variables analyzed were plant stand, plant height, number of nodes, number of pods per plant, number of grains per pod, 1000-grain weight, and grain yield (ISTA, 1996). At the R3 stage, leaf analysis was carried out to check macro and micronutrient content (Farias et al., 2007). The five central rows of the plot were harvested for the evaluation of grain yield. The plants were threshed in a thresher, and the grain yield was corrected for the humidity of 13%.

The relative agronomic efficiency (RAE) index was calculated (Goedert et al., 1986) to compare the treatments relative to the grain yield. The mineral fertilizer was used as a reference, according to the following equation:

$$\text{RAE} = \frac{\text{GYo} - \text{GYc}}{\text{GYm} - \text{GYc}} \text{ x } 100$$

where:

GYo - grain yield obtained with the tested fertilizer, at dose n.

GYm - grain yield obtained with the mineral fertilizer.

GYc - grain yield of the control treatment.

The results were subjected to analysis of variance, and the means were submitted to t-test at 5% probability. The analysis was performed with the R software (R Core Team, 2013). The grain yield data for treatments from 2 to 7 were subsequently separated and submitted to regression analysis to estimate the effect of the proportions of the mixtures of humus and rock powder and mineral fertilizer.

## 3. Results and Discussion

### 3.1. *Growth and performance traits*

The variables related to plant growth and performance are shown in Table 3. Treatment T7 had a higher number of nodes than treatments T2 and T8. There was no statistical difference between the treatments related to the variables plant stand, plant height, number of pods per plant, number of grains per pod, and 1000-grain weight (Table 3). This fact can be explained because these traits are related to the genetic component of the cultivar, with less influence from factors such as fertilization. Other variables are related to seed vigor, as in the case of the plant stand (Schuch et al., 2012). As pointed out by Leite et al. (2015), plant growth traits, such as height and number of pods per plant, are related to genotype and heritability.

The T1 and T6 treatments showed grain yield lower than the standard fertilization, with mineral fertilizer (T7). The other treatments showed similar grain yield results. These results indicate that the mixture of humus and rock powder replacing up to 30% of the mineral fertilizer composition provided the same result as the fertilization with 100% of mineral fertilizer. Mamia et al. (2018), when using earthworm compost to replace 25% of the recommended dose of mineral fertilizer, obtained similar results, with gains in soybean yield in response to the increase in the percentage of humus.

Based on the results of polynomial regression analysis referring to the grain yield according to fertilizer doses (Figure 2), a significant effect was observed ($p \leq 0.05$). According to the model obtained, the 30% mixture results in a soybean grain yield of 3169.2 kg $ha^{-1}$. The determination coefficient obtained was high (0.96). Thus, the quadratic equation is adequate to predict the increase in grain yield according to the increase in humus doses.

Based on the regression equation, the estimated combination to obtain the maximum grain yield (corresponding to 3,180.24 kg $ha^{-1}$) was 25% of the humus + rock powder mixture, with 75% of mineral fertilizer. On the other hand, Costa et al. (2018), when evaluating the agronomic performance of conventional soybean grown with organomineral and mineral fertilizers, observed an increase in grain yield in response to the increase in the dose of organomineral fertilizer. The initial rise and subsequent decline in grain yield can be explained by the Mitscherlich's Law of Diminishing Returns (Mitscherlich, 1909), in which quantities above the ideal can promote a decrease in yield.

**Table 3.** Plant stand (Std), plant height (Plh), number of pods per plant (Pd), number of grains per pod (Gr/pd), and 1000-grain weight (1000W) according to the treatments based on mixtures of humus, rock powder, and mineral fertilizer.

| Treatments* | Std Plant/m | Plh cm | Plant knots un/pl | Pd un | Gr/pd un | 1000W g | Prod. kg $ha^{-1}$ | IEA % |
|---|---|---|---|---|---|---|---|---|
| T1 – Control | 14,42a | 111,00a | 17,00ab | 45,57a | 2,05a | 111,11a | 2904,17b | 0 |
| T2 – 10% HR | 14,00a | 112,50a | 16,58b | 45,16a | 2,15a | 112,22a | 3065,50ab | 54,12b |
| T3 – 20% HR | 14,17a | 109,67a | 18,14ab | 43,92a | 1,86a | 112,12a | 3165,17a | 87,29ab |
| T4 – 30% HR | 13,08a | 107,67a | 18,90ab | 43,49a | 2,05a | 113,33a | 3206,50a | 101,11a |
| T5 – 40% HR | 13,92 a | 114,33ª | 17,60ab | 44,01a | 2,14a | 110,25a | 3042,67ab | 46,32b |
| T6– 50% HR | 13,50a | 108,83a | 16,93ab | 44,09a | 1,99a | 106,67a | 2912,50b | 2,79c |
| T7 – 100% M | 14,08a | 111,67a | 17,99a | 44,39a | 2,27a | 116,67a | 3203,17a | 100a |
| T8 – 30% Hc | 14,42a | 107,67a | 16,49b | 44,52a | 2,20a | 114,44a | 3219,67a | 102,95a |
| Mean | 13,95 | 110,42 | 17,45 | 44,39 | 2,09 | 112,22 | 3089,92 | 70,66 |
| DMS (5%) | 1,54 | 8,51 | 2,37 | 4,21 | 0,44 | 10,48 | 218,23 | 14,02 |

*Means followed by the same letter, in the column, do not differ statistically from each other by the t-test at 5% probability.

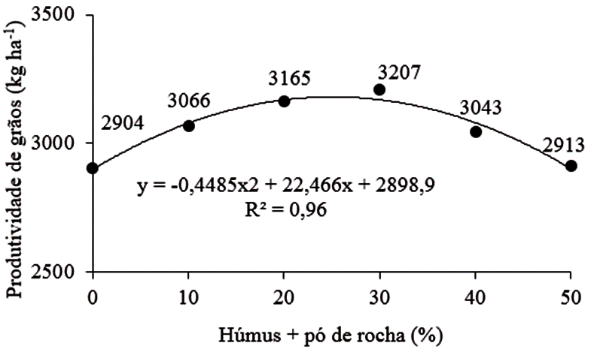


**Figure 2.** Soybean grain yield according to the mixture of humus + rock powder to replace part of the mineral fertilizer.

About the Relative Agronomic Efficiency (RAE) Index of soybean, when it received different mixtures of rock powder + humus with mineral fertilizer and humus + mineral fertilizer, it was found that this index decreased in the following order: T8 (102.95%) > T4 (101.11) > T7 (100%) > T3 (87.29) >T2 (54.09) > T5 (46.32) > T6 (2.79%). The RAE of the sources indicates that these fertilizers offer good prospects for use in soybean cultivation since the appropriate dose is used. In the case of the present study, the application of 30% humus + 70% mineral fertilizer had a high RAE (102.95%), and it was statistically superior to treatments T6, T5 and T2, and equal to the others. Among rock powder + humus mixtures, the use of 30% of the mixture with 70% mineral fertilizer presented the highest RAE (101.11%), and it was higher than the T6, T5, and T2 treatments and equal to the others. Thus, it can be inferred that the mixture of rock powder and humus with mineral fertilizer in an option that has high agronomic efficiency for the soybean yield. However, further studies on soil mineralization processes, the effect on the microbiota, the costs, and benefits of using these fertilizers are needed.

### 3.2. *Macro and micronutrient contents in leaves*

The macronutrient content in the leaf tissue is shown in Table 4. The treatments did not influence the P, S, and Ca contents. Although there are no significant differences for K content in leaves, the leaf concentration of this element was below the appropriate critical level for soybean (17 g $kg^{-1}$) (Cubilla et al., 2012) in all treatments, indicating that the plants suffered a deficiency of this nutrient for a period. The occurrence of K leaf deficiency does not present a clear justification, since the topdressing fertilization was carried out, the climatic conditions in the experimental period were normal, and the leaves did not show deficiency symptoms. A hypothesis for the low contents of K would be the relationship between the date of leaf sampling, carried out at the R3 stage (Farias et al., 2007) and the plant growth habit (cultivar with indeterminate growth habit). The sampling period may have caused a K drainage effect for the pods in the basal portion of the plant during the grain filling (Embrapa Soja, 2013). Regarding the contents of N, Mg, and S, although there are some differences between treatments, the three nutrients showed contents considered adequate for soybean production (Embrapa Soja, 2013).

Leaf concentrations of micronutrients are shown in Table 5. There were no significant differences in the Cu, Fe, and Mn contents between treatments. However, T6 treatmnet had a higher Boron content than T2 and T5 treatments. Also, T6 had higher Zinc content than T2 and T7 treatment. However, it is necessary to emphasize that all treatments provided B and Zn contents in leaves suitable for the crop (Embrapa Soja, 2013).

The contents of soil organic matter (Table 1) were within the range considered ideal (Malavolta, 1980), justifying the adequacy in the quantity of micronutrients in plants, due to the availability in the environment. Botero et al. (2010) and Oliveira et al. (2015) state that humic substances present in organic matter can originate stable complexes with nutrients in the soil. The natural degradation of organic matter makes it possible to release nutrients into the soil solution. However, there was no significant increase in micronutrient contents in the plant. This result can be justified by the fact that vegetables absorb nutrients in the quantities necessary for their development (Silva and Trevizam, 2015).

**Table 4.** Macronutrient content in soybean leaves according to the treatments based on mixtures of humus, rock powder, and mineral fertilizer.

| Treatments* | N | P | K | Ca | Mg | S |
|---|---|---|---|---|---|---|
| | | ------------------------------ | g/kg | ---------------------------------- | | |
| T1– Control | 43,83 ab | 3,00 a | 15,00 b | 8,13 a | 4,28 ab | 2,47 a |
| T2 – 10% H | 44,11 ab | 2,98 a | 16,29 a | 7,95 a | 4,12 b | 2,35 a |
| T3 – 20% H | 43,64 ab | 2,99 a | 14,79 b | 8,06 a | 4,36 ab | 2,37 a |
| T4 – 30% H | 42,36 b | 2,95 a | 15,00 b | 8,34 a | 4,29 ab | 2,37 a |
| T5 – 40% H | 43,80 ab | 3,05 a | 14,29 b | 8,02 a | 4,74 a | 2,50 a |
| T6 – 50% H | 45,75 a | 3,00 a | 15,17 ab | 8,49 a | 4,43 ab | 2,46 a |
| T7 – 100% H | 44,34 ab | 3,02 a | 14,88 b | 8,18 a | 4,21 b | 2,45 a |
| T8 – 30% Hc | 44,02 ab | 3,03 a | 15,38 ab | 7,88 a | 4,08 b | 2,47 a |
| Mean | 43,98 | 3,00 | 15,10 | 8,13 | 4,31 | 2,43 |
| DMS (5%) | 3,12 | 0,13 | 1,23 | 0,83 | 0,51 | 0,20 |

*Means followed by the same letter, in the column, do not differ statistically from each other by the t-test at 5% probability.

**Table 5.** Micronutrient contents in soybean leaves according to the treatments based on mixtures of humus, rock powder, and mineral fertilizer.

| Treatments* | B | Cu | Fe | Mn | Zn |
|---|---|---|---|---|---|
| | ------------------------------------ mg/kg-------------------------------- | | | | |
| T1 – Control | 53,09 ab | 9,24 a | 87,45 a | 120,09 a | 39,57 ab |
| T2 – 10% H | 52,15 b | 10,09 a | 88,08 a | 117,74 a | 38,81 b |
| T3 – 20% H | 52,49 ab | 9,35 a | 84,41 a | 123,06 a | 39,93 ab |
| T4 – 30% H | 53,43 ab | 10,20 a | 90,95 a | 121,03 a | 41,33 ab |
| T5– 40% H | 54,04 ab | 9,84 a | 89,18 a | 136,75 a | 42,38 a |
| T6 – 50% H | 56,59 a | 10,43 a | 88,58 a | 124,08 a | 41,39 ab |
| T7 – 100% H | 52,99 ab | 9,29 a | 84,05 a | 120,28 a | 38,35 b |
| T8 – 30% Hc | 55,25 ab | 10,38 a | 88, 75 a | 115,92 a | 39,60 ab |
| Mean | 53,75 | 9,85 | 87,68 | 122,36 | 40,17 |
| DMS | 4,28 | 1,80 | 10,50 | 25,75 | 3,32 |

*Means followed by the same letter, in the column, do not differ statistically from each other by the t-test at 5% probability.

The transformation of organic matter and organic fertilizers in the soil when subjected to the action of the microfauna, liberates organic complexes that, in association with mineral fertilization, acts with a chelating effect on nutrients, avoiding losses by leaching and other processes, helping to fix these nutrients to the soil and facilitating its availability to plants (Garay et al., 2003). However, these compounds have a slow release of nutrients when compared to mineral fertilizers (Melamed et al., 2007), requiring further studies to assess this reaction in the soil.

Studies on the relationship between rock powder and humus in the agronomic and nutritional traits of a soybean are still incipient and initial. Thus, further research on the potential use of rock powder and humus, its viability, and the effect of nutrient release is necessary to consolidate the information in the present study.

## 4. Conclusions

According to RAE, the mixture of 30% of humus + rock powder with 70% of NPK formulation 04:40:10, the mixture of 30% humus with 70% NPK formulation 04:30:10, and the mineral fertilizer are the most suitable for soybean production in Latossolos (Oxisols), in Paraguay.

The mixture of humus and rock powder, replacing 30% of the mineral fertilizer composition, had the same result as the 100% mineral fertilizer. The maximum grain yield was estimated with the combination of 25% of humus + rock powder, with 75% of the NPK formulation 04:30:10.

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