Nutritional and Agronomical Performance of Five Rice Varieties Cultivated in Saline Soils Amended with Leonardite

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ABSTRACT

Salinity affects 800 million hectares of agricultural soils in the world and represents a serious concern for crop production. The soils of the San Jacinto de Yaguachi canton (Guayas province, Ecuador), where rice has traditionally been grown with low yield, are characterized as saline. This research aimed to evaluate the agronomical performance and yield of five commercial rice varieties (INIAP FL-Arenillas, SFL 011, INIAP 14, INIAP 11, and Fedearroz 60) grown in a saline soil amended with leonardite (150 kg/ha). A randomized complete block design was used in a split-plot arrangement with three repetitions; the leonardite amendments corresponded to the main plot, and the rice varieties to the sub-plots. At harvest time, in the amended plots, increments in plant height, number of tillers, panicle number and length, number of grains per panicle, grain weight, and yield were obtained. Nutrient uptake also increased in the amended plants, with the sole exception of phosphorus, which responded poorly to the treatment. Under these conditions, it is concluded that the use of the leonardite amendment can be an effective practice for obtaining significantly higher rice production in saline soils.

INTRODUCTION

Rice is an economically important cereal that feeds more than half of the world’s population. In Ecuador, during 2020, 312,876 ha of rice were sowed, most of them in the province of Guayas (INEC-ESPAC, 2021), with an average yield of 4.3 Mg/ha, except for Yaguachi and Naranjal cantons where only 5.04 and 6.0 t/ha were produced, attributed to salinity and soil degradation problems (MAG, 2020).

One of the most burdensome and widespread agricultural problems is the accumulation of salts on the soil surface (Das et al., 2015; Setter et al., 2016). Globally soil salinity is estimated to take up to 1.5 million ha of cropland out of production each year (FAO, 2021). The area of Yaguachi, in the Guayas River basin (Ecuador), has saline soils (Medina Litardo et al., 2022). This condition could be caused by the intrusion of saline water from the Babahoyo River, used for irrigation, and is aggravated by poor soil drainage.

Salinity tolerance is the ability of a plant to thrive in saline conditions, with no or minimal declines in growth or yield, a mechanism that is controlled by many genes or by the combination of several genes in the plant (Zhang & Shi, 2013; Ma et al., 2022). Some of the most harmful effects caused by salinity are related to the excessive absorption of Na⁺ and Cl⁻, the nutritional imbalance caused by the interference of saline ions with

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essential nutrients, and the osmotic effect, or by the combination of the previous effects (Ma et al., 2022). Salinity is one of the main abiotic stressors affecting crop growth, production, and quality; it hampers germination, growth, photosynthesis, transpiration, and stomatal conductance (Arif et al., 2020). During rice cultivation, it affects plants during the transplanting and flowering stage, increases the sterility of the ears, and decreases their weight leading to a decrease in yields. In terms of rice plant nutrition, salinization can inhibit nitrogen translocation to the aerial part of the crop, related to the negative relationship between salts and soil nitrogen (Murtaza et al., 2016).

To counteract the detrimental effect of salinity in soils, one method is the application of amendments. Leonardite is a natural organic material oxidized from lignite that contains substantial amounts of humic substances (Sakulthaew et al., 2021), which are generally used in agricultural production and are widely known for their agronomic potential (Akimbekov et al., 2020). When applied to soil, humic acids have increased aggregate stability and contributed positively to root development and productivity of various crops (Gutiérrez et al., 2015; Tavares et al., 2021), favoring vegetative growth and rice yield (Saha et al., 2013). These substances are used as fertilizers or as plant growth stimulants. On the other hand, the amendment has helped to decrease the salinity condition in coastal soils and increased their potential for agricultural use (Wang et al., 2020). The application of leonardite and humic acids to soils under salinity conditions has promoted improvements in the growth of pepper plants (Bacilio et al., 2016).

Since there is an increasing need to use saline soils in agriculture, one of the viable solutions is the use of humic substances. These are the main components of soil organic matter, with several functions in plant growth, and the subject of study in various areas of agriculture, such as soil chemistry, fertility, and plant physiology (Ouni et al., 2014).

For a rice variety to be of agricultural relevance, it is essential to test its productivity level in field tests. Therefore, this study aimed to evaluate the agronomical performance and yield of five commercial rice varieties planted in saline soil amended or not with leonardite in San Jacinto de Yaguachi, Ecuador.

**MATERIALS AND METHODS**

**Experimental Site**

The research was conducted in the San Jacinto de Yaguachi canton, Ecuador (latitude 02°05' south, longitude 79°41' west, and 15 meters above sea level (masl), with flat topography, during the dry season from August till December 2019. The average temperature varies from 25.1 to 27.8°C, relative humidity is 80%, annual precipitation is 1227.8 mm with wind speed of 0.8 m/s (INAMHI, 2017). In this area, the soil of the area is classified as Vertisol, gley, montmorillonitic (2:1), with 35% clay, plastic, and sticky, with 50% expansive type 2:1 (FAO, 2015).

**Experimental Design and Treatments**

Rice varieties INIAP-FL-Arenillas, SFL 011, INIAP 14, INIAP 11, and Fedearroz 60 were evaluated, distributed in the field under a randomized block design with a split-plot arrangement and three repetitions, where the large plots corresponded to the amendment and the small plots to the rice varieties, for a total of thirty experimental units. The factors consisted of the amendment leonardite (Humivita®), a commercial product with 33% oxidizable organic matter and 18% humic acids (18%), applied in a dosage of 150 kg/ha of the product and the control without application, and the rice varieties.

**Crop Management and Amendment Application**

Plot preparation consisted of two harrowing passes at a depth of 0.20 m, followed by flooding and two passes of the muddler. Leonardite was incorporated according to the treatments. Individual walls were built at the boundaries of each main plot to avoid drift effects or contamination of plots by the application of the amendment and to achieve individualized and orderly irrigation management. One month after the amendment’s application, the five rice varieties were manually transplanted.

Based on the information from the soil analysis (pH = 6.79; electrical conductivity = 7.44 dS/m; 4.06% organic matter; 56.82 cmol/kg cation exchange capacity (CEC); 7.30% exchangeable sodium percentage (ESP); 4.70 sodium adsorption ratio (SAR); 16.60 meq/l sodium; 3.69 meq/l phosphorus; 0.62 meq/l potassium; 12.20 meq/l calcium; and 12.70 meq/l magnesium) and rice crop requirements (Harvest Index (HI) for nitrogen 0.66; phosphorus 0.84; potassium 0.10; calcium 0.04;
magnesium 0.42; and sulfur 0.64 (INPOFOs, 2002) in kg/Mg per grain (22.2 nitrogen; 3.1 phosphorus; 26.2 potassium; 2.8 calcium; 2.4 magnesium; and 0.94 sulfur), NPK fertilization was applied as follows Nitrogen (390 kg/ha) was split into three applications using NH\(_4\)SO\(_4\) (160 kg/ha) at 15 days after transplanting dat); and urea (154 and 76 kg/ha) at 30 and 45 dat. Phosphorus (136 kg/ha) was applied during transplanting and potassium (58 kg/ha) at 30 dat.

Flood irrigation was started at 15 dat, maintaining a water level of approximately 10 cm in depth, until 15 days before harvest, which took place at 120 dat. During the experiment, routine weed and pest control were carried out according to management needs.

Transplanting was done in rows spaced 0.25 m apart with 0.20 m between plants, for a density of 200,000 plants/ha. Five seedlings per point were placed in 10 m\(^2\) plots. The evaluation was performed on twenty plants (1 m\(^2\)) per experimental unit.

Variables Evaluated at Harvest

**Plant Height (PH)**

Measured from ground level to the apex of the tallest panicle, excluding the edges, on five randomly selected plants.

**Number of Tillers and Panicles per m\(^2\) (NT/m\(^2\) and NP/m\(^2\))**

It was evaluated by placing within the useful area of each plot, a wooden grid of 1 m\(^2\) and then counting the number of tillers and panicles present.

**Panicle Length (PL)**

It was measured from the ciliary node to the tip of the most pronounced grain, in ten randomly collected panicles.

**Number of Grains per Panicle (NGP)**

It was obtained from the average number of grains of ten panicles taken at random.

**Thousand-Grain Weight (TGW)**

One thousand grains per plot were counted and their oven-dried weight was determined on a precision balance (Adam brand, model HCB 2202).

**Grain Yield (Y)**

The grain weight of the useful area, adjusted to 14% moisture, was determined using the following formula:

\[
Yield (kg/ha) = \left( \frac{100 - Fh}{100 - 14} \right) \times Fw \times \frac{10000}{Upa} \tag{1}
\]

Where: Fh = Field humidity, Fw = Field weight, Upa = Useful plot area (10 m\(^2\))

**Nutrient Uptake**

To determine the amounts of nutrients N, P, K, Ca, Mg, S, and Cl absorbed per hectare, the nutrient content of the grain and the nutrient content of the seed after harvest were added together. For this, the element concentration and dry matter production were used.

**Statistical Analysis**

All results were subjected to Tukey’s 5% probability and analysis of variance using the statistical program Infostat version 2018.

**RESULTS AND DISCUSSION**

**Effect of Leonardite Amendment Application**

No significant interaction was detected between amendment application and rice varieties in any of the vegetative growth and production variables (Table 1), and only in the case of Ca and S in the nutritional variables (Table 2).

**Effect of Amendment Application on Vegetative Growth Attributes**

**Plant Height (PH)**

The lack of interaction between the amendment dosage and the varieties indicates that leonardite did not affect the relative growth response among the different plant materials. The PH of those that received leonardite was always greater than that of control plants, indicating that growth increased consistently with the application of the amendment (Table 3). This also means that PH was a good indicator of plant growth in response to the amendment. On average, leonardite application increased the PH by 7.0 cm (40.70 cm vs. 33.70 cm), which represented an increase of 20.77%. Similarly, Al-bourky et al. (2021) observed that the use of humic acids significantly promoted PH when evaluating different rice varieties, and Moe et al. (2017, 2020) found that the application of organic amendments favored height in rice plants.

At maturity, PH varied among the different varieties, and regardless of amendment application, variety SFL 011 had the greatest height (105.8 cm), statistically exceeding the other four varieties, which ranged from 98.6 (INIAP-14) to 92.0 cm (INIAP-11). Lack of growth and development could be attributed to the stress caused in the plant because of salinity (Arif et al., 2020). It has been reported that humic
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acids provided by leonardite can directly present desirable effects on plant growth, increase shoot, and root development, and allow better nutrient uptake (Ayón et al., 2017).

Table 1. Probability (p) of the effect of amendment application and rice varieties on vegetative growth and yield variables in San Jacinto de Yaguachi canton, Guayas province, Ecuador

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>PH</th>
<th>NT/m²</th>
<th>NP/m²</th>
<th>PL</th>
<th>NGP</th>
<th>TGW</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amendment (E)</td>
<td>1</td>
<td>0.0091</td>
<td>0.0479</td>
<td>0.0453</td>
<td>0.0398</td>
<td>0.0106</td>
<td>0.0177</td>
<td>0.0113</td>
</tr>
<tr>
<td>Variety (V)</td>
<td>4</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0167</td>
<td>0.0143</td>
<td>0.0869 ns</td>
<td>0.4645 ns</td>
</tr>
<tr>
<td>Interaction E*V</td>
<td>4</td>
<td>0.3182 ns</td>
<td>0.9890 ns</td>
<td>0.8609 ns</td>
<td>0.7247 ns</td>
<td>0.2587 ns</td>
<td>0.7193 ns</td>
<td>0.8929 ns</td>
</tr>
</tbody>
</table>

Remarks: Probabilities (p) greater than 0.05 are not significant (ns) according to the analysis of variance. DF: degrees of freedom; PH: plant height; NT/m²: number of tillers per square meter; NP/m²: number of panicles per square meter; PL: panicle length; NGP: number of grains per panicle; TGW: thousand-grain weight; Y: yield

Table 2. Probability (p) of the effect of amendment application and rice varieties on nutrition variables in San Jacinto de Yaguachi canton, Guayas province, Ecuador

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amendment (E)</td>
<td>1</td>
<td>0.0358</td>
<td>0.6349 ns</td>
<td>0.0491</td>
<td>0.4148 ns</td>
<td>0.0484</td>
<td>0.1058 ns</td>
<td>0.0486</td>
</tr>
<tr>
<td>Variety (V)</td>
<td>4</td>
<td>0.2269 ns</td>
<td>0.3836 ns</td>
<td>0.1094 ns</td>
<td>0.1150 ns</td>
<td>0.1960 ns</td>
<td>0.0050</td>
<td>0.0010</td>
</tr>
<tr>
<td>Interaction E*V</td>
<td>4</td>
<td>0.2751 ns</td>
<td>0.5477 ns</td>
<td>0.3178 ns</td>
<td>0.0212</td>
<td>0.2506 ns</td>
<td>0.0016</td>
<td>0.1181 ns</td>
</tr>
</tbody>
</table>

Remarks: Probabilities (p) greater than 0.05 are not significant (ns) according to the analysis of variance; DF: degrees of freedom

Table 3. Vegetative growth variables as a function of rice variety and leonardite amendment applied to the soil in the San Jacinto de Yaguachi canton, Guayas province, Ecuador

<table>
<thead>
<tr>
<th>Factor A (leonardite)</th>
<th>Factor B (Varieties)</th>
<th>PH (cm)</th>
<th>NT/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>No (control)</td>
<td></td>
<td>93.5±5.78 b</td>
<td>369±68.99 b</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td>100.5±6.38 a</td>
<td>419±69.16 a</td>
</tr>
<tr>
<td>INIAP FL-Arenillas</td>
<td></td>
<td>95.6±3.77 bc</td>
<td>331±51.18 b</td>
</tr>
<tr>
<td>SFL 011</td>
<td></td>
<td>105.8±6.16 a</td>
<td>351±18.93 b</td>
</tr>
<tr>
<td>INIAP 14</td>
<td></td>
<td>98.6±6.95 b</td>
<td>467±61.87 a</td>
</tr>
<tr>
<td>INIAP 11</td>
<td></td>
<td>92.0±5.22 c</td>
<td>464±56.14 a</td>
</tr>
<tr>
<td>Fedearroz 60</td>
<td></td>
<td>93.0±2.43 bc</td>
<td>357±41.49 b</td>
</tr>
</tbody>
</table>

CV (%) 3.71 11.27

Remarks: CV: coefficient of variation; Values within each column followed by different letters are significantly different from each other according to Tukey’s test (p ≤0.05); PH: plant height; NT/m²: number of tillers per square meter
Number of Tillers per Surface Area
The treatment with leonardite favored the average number of tillers per square meter among the different varieties from 369 to 419 (Table 3), an increase of 13.55%. Varieties INIAP 11 and INIAP 14 exceeded 464 tillers/m² and were statistically different from the others, which showed a maximum of 357 tillers/m².

The results showed that the variable number of tillers/m² presented significant differences with the application of leonardite depending on the rice variety (Table 3). According to Ayón et al. (2017), the humic acids obtained from leonardite can directly present positive effects on the growth of the plant, increasing its development, in the shoots, and roots, allowing better absorption of N, K, Ca, Mg, and P.

Effect of Amendment Application on Yield Attributes

Number of Panicles per Surface
Significant differences were found with the use of the amendment. The application of leonardite caused an increase of 57 panicles/m² from those of the control, which corresponds to an increment of 15.75% (Table 4). The performance of the rice varieties was statistically different from each other. It was found that INIAP 11 and INIAP 14 produced more than 450 panicles/m² and were superior to the rest of the varieties, which had less than 360 panicles/m².

Wang et al. (2017) and Zhou et al. (2017) showed that the number of rice panicles increased proportionally to the increase of nitrogen levels, while Al-bourky et al. (2021) noted significant differences between humic acid treatment levels and rice growth traits increments.

Panicle Length
Rice varieties showed significantly different panicle lengths, with INIAP FL-Arenillas expressing the highest value (27.5 cm) (Table 4), compared to INIAP 11 and INIAP 14, and statistically like SFL 011 and Fedearroz 60. Plants with leonardite amendment showed an increment of 10.7% in panicle length when compared to the control.

Regarding PL, this characteristic showed significant differences between leonardite application and non-application. Studies by Moe et al. (2017, 2020) indicated that the application of compost induced a large increase in rice PL.

Number of Grains per Panicle
Significant differences were found in the NGP, where the addition of leonardite caused an increase of 10.6 grains per panicle, corresponding to an 8.47% increase (Table 4). Among the varieties, Fedearroz 60 achieved the highest number of grains, which was higher than INIAP 14 and SFL 011, and statistically similar to INIAP 11 and INIAP FL-Arenillas. Leonardite addition seemed to favor the NGP, depending on the rice variety; the combined use of organic amendments and chemical fertilizers has resulted in an important increment (Iqbal et al., 2020).

Thousand Grains Weight
Significant differences were detected in this variable, with the incorporation of leonardite, which caused an increase of 3.4 g in the weight of one thousand seeds, corresponding to a 13.70% increase (Table 4). There were no significant differences between varieties although the weight varied between 25.7 and 27.4 g per thousand seeds significantly with the addition of leonardite. The application of organic compost alone or combined with artificial fertilizer has resulted in a significant increase in seed weight (Hoque et al., 2018; Ismael et al., 2021).

Yield
Significant differences were observed for the application of leonardite which increased rice yield by 1579.3 kg/ha, corresponding to an increase of 22.99% (Table 4). Meanwhile, no significant differences were observed between varieties (Factor B), and their mean values ranged between 7322.9 and 8506.2 kg/ha.
Table 4. Reproductive growth variables as a function of rice variety and leonardite amendment applied to the soil in the San Jacinto de Yaguachi canton, Guayas province, Ecuador

<table>
<thead>
<tr>
<th>Factor A (leonardite)</th>
<th>Factor B Varieties</th>
<th>NP/m²</th>
<th>PL (cm)</th>
<th>NGP</th>
<th>TGW (g)</th>
<th>Y (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No (control)</td>
<td>362±68.99 b</td>
<td>24.3±2.21 b</td>
<td>125.1±13.33 b</td>
<td>24.9±1.60 b</td>
<td>6868.7±789.28 b</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>419±69.16 a</td>
<td>26.9±1.58 a</td>
<td>135.7±13.77 a</td>
<td>28.3±1.02 a</td>
<td>8448.0±1367.9 a</td>
</tr>
<tr>
<td>INIAP</td>
<td>FL-Arenillas</td>
<td>325±51.18 b</td>
<td>27.5±1.76 a</td>
<td>126.9±6.70 ab</td>
<td>26.8±2.12 a</td>
<td>7322.9±671.14 a</td>
</tr>
<tr>
<td></td>
<td>SFL 01</td>
<td>352±18.93 b</td>
<td>25.6±2.13 ab</td>
<td>123.3±9.99 b</td>
<td>27.4±2.29 a</td>
<td>7407.6±1864.1 a</td>
</tr>
<tr>
<td></td>
<td>INIAP 14</td>
<td>460±61.87 a</td>
<td>24.0±2.38 b</td>
<td>124.4±4.44 b</td>
<td>25.7±2.56 a</td>
<td>8506.2±1290.0 a</td>
</tr>
<tr>
<td></td>
<td>INIAP 11</td>
<td>451±56.14 a</td>
<td>24.5±2.23 b</td>
<td>130.7±23.86 ab</td>
<td>26.3±2.38 a</td>
<td>7675.8±1673.7 a</td>
</tr>
<tr>
<td></td>
<td>Fedearroz 60</td>
<td>353±41.49 b</td>
<td>26.3±1.75 ab</td>
<td>146.6±5.58 a</td>
<td>26.7±1.70 a</td>
<td>7378.9±1079.9 a</td>
</tr>
</tbody>
</table>

CV (%)  
10.59  6.52  8.54  3.71  16.24

Remarks: CV: coefficient of variation; Values within each column followed by different letters are significantly different from each other according to Tukey’s test (p ≤0.05); NP/m²: number of panicles per square meter; PL: panicle length; NGP: number of grains per panicle; TGW: thousand-grain weight; Y: yield; *: measured at 14% grain moisture

Table 5. Nutrient uptake by rice plants (kg/ha) as a function of the variety and leonardite amendment in San Jacinto de Yaguachi canton, Guayas province, Ecuador

<table>
<thead>
<tr>
<th>Factor A (leonardite)</th>
<th>Factor B (variety)</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Mg</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No (control)</td>
<td>136.58±39.30 b</td>
<td>30.17±22.40 a</td>
<td>87.58±50.21 b</td>
<td>37.69±7.90 b</td>
<td>269.81±50.42 b</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>160.91±49.27 a</td>
<td>23.61±3.00 a</td>
<td>110.65±60.79 a</td>
<td>54.59±12.41 a</td>
<td>330.70±57.38 a</td>
</tr>
<tr>
<td>INIAP</td>
<td>FL-Arenillas</td>
<td>147.93±72.1 a</td>
<td>20.25±4.96 a</td>
<td>103.23±70.32 a</td>
<td>44.73±12.87 a</td>
<td>237.98±60.12 b</td>
</tr>
<tr>
<td></td>
<td>SFL 01</td>
<td>151.72±45.52 a</td>
<td>25.55±11.98 a</td>
<td>117.94±75.72 a</td>
<td>51.57±20.03 a</td>
<td>334.26±74.97 a</td>
</tr>
<tr>
<td></td>
<td>INIAP 14</td>
<td>158.55±35.58 a</td>
<td>26.19±12.28 a</td>
<td>93.07±41.55 a</td>
<td>43.22±11.65 a</td>
<td>316.89±52.67 a</td>
</tr>
<tr>
<td></td>
<td>INIAP 11</td>
<td>155.93±33.10 a</td>
<td>29.12±22.19 a</td>
<td>88.19±44.69 a</td>
<td>43.42±9.89 a</td>
<td>315.62±45.76 a</td>
</tr>
<tr>
<td></td>
<td>Fedearroz 60</td>
<td>129.58±41.81 a</td>
<td>33.37±23.92 a</td>
<td>93.14±55.32 a</td>
<td>48.74±10.29 a</td>
<td>296.53±24.29 a</td>
</tr>
</tbody>
</table>

CV (%)  
15.0  41.6  19.6  15.8  10.81

Remarks: CV: coefficient of variation; Values within each column followed by different letters are significantly different from each other according to Tukey’s test (p ≤0.05); N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Cl = chlorine
In a study evaluating the effect of humic acids on yield in different rice varieties, there was an increase in the number of panicles, the number of grains per panicle, and plant yield (Al-bourky et al., 2021). The positive effect of humic substances on saline soils could be, in part, attributed to a direct action on the plant along with an indirect action on microorganism metabolism, nutrient uptake dynamics, and soil physical conditions (Ouni et al., 2014). Likewise, the stimulating effect of nitrogen contained in humic acids can help in the reduction of biotic and abiotic stresses in rice (Geary et al., 2015).

The addition of organic amendments has significantly improved grain yield in various genotypes and helped tiller growth and spikelet formation, which resulted in better crop yields (Wang et al., 2017; Zhou et al., 2017; Haque et al., 2021). The increase in the yield of rice is essentially attributed to the increase in the number of panicles and the number of grains per panicle.

Saha et al. (2013) reported that growth variables such as plant height, panicle length, the number of grains per panicle, and grain weight of rice increased with the addition of humic acid-based substances. In contrast, Al-bourky et al. (2021) noted that the addition of humic acids did not affect grain weight.

The mechanism of action of humic substances remains partially unknown, although it is known that they could increase the concentration of cytokinin in sprouts, and indole-3-acetic and jasmonic acids in roots. Since they lead to short-term increases in root abscisic acid or root plasma membrane H-ATPase activity, two crucial effects on plant physiology, it has been proposed that the beneficial effects of humic acids may be due to plant adaptation to mild transient stress caused by the application of this substance (De Hita et al., 2020).

Since the application of the amendment achieved the highest percentage increases in yield (22.99%), plant height (20.77%), and the number of panicles per surface area (15.75%), it can be suggested that yield is strongly influenced by plant height and number of panicles. Using organic fertilizers has significantly helped the vegetative growth of plants. However, as already mentioned, increments of plant height should be considered up to a certain limit because of the accompanying lodging problem. Consequently, the number of panicles could be used as a key morphological indicator, which allows pointing out that, to achieve a high grain yield, the most important aspect to consider in rice growth is the number of panicles per unit area.

**Effect of Amendment Application on Nutrient Uptake**

Regarding nutrient uptake, significant differences were only found for Leonardite application, but not among varieties (Table 5). In the case of N, the uptake was considerably higher (160.91 kg/ha) than in untreated plants (136.58 kg/ha). Conversely, P uptake was not affected by the application of the amendment and showed similar values to the control plants.

For K uptake, significant differences were detected with the application of Leonardite, which stimulated uptake of 110.05 kg/ha in contrast to only 87.57 kg/ha in the control plants (26.34% increase). In this same variable, there were no differences in absorption among the varieties evaluated (Table 5). Taking into consideration the values of uptake (Table 5) and harvest index (INPOFOS, 2002), the nutrient extraction by plants in the amended plots was 106.2, 19.8, and 11.0 kg/ha for N, P, and K, respectively.

Higher Mg uptake was observed in plants amended with Leonardite compared to control plants (54.59 kg/ha vs. 37.69 kg/ha, corresponding to an increase of 44.84%). All varieties had similar levels of magnesium uptake, with no statistical differences among them (Table 5).

CI uptake was higher in the amended plants when compared to the control plants (330.70 vs. 269.81 kg/ha), which represented a 22.57% increase. Among the varieties, the response was similar except for INIAP FL-Arenillas, which showed a significantly lower chlorine uptake value than the rest of the materials (Table 5).

Concerning nutrient uptake, significant differences were only found for Leonardite application, but not between varieties (Table 5). The application of humic acids improved rice nutrient uptake, especially nitrogen, in plants grown under saline conditions (Suntari et al., 2015). Likewise, plant nutrition can confer resistance or tolerance in reducing pest and disease infestation (Sun et al., 2020).

In this study, the N uptake was considerably higher in treated plants (Table 5). It is likely that the humic amendment provided significant amounts of nitrogen to the plant and showed its potential to increase soil N availability and usage efficiency as reported by Bao et al. (2018).

Concerning nutrient uptake, significant differences were only found for Leonardite application, but not between varieties (Table 5). The application of humic acids improved rice nutrient uptake, especially nitrogen, in plants grown under saline conditions (Suntari et al., 2015). Likewise, plant nutrition can confer resistance or tolerance in reducing pest and disease infestation (Sun et al., 2020).

In this study, the N uptake was considerably higher in treated plants (Table 5). It is likely that the humic amendment provided significant amounts of nitrogen to the plant and showed its potential to increase soil N availability and usage efficiency as reported by Bao et al. (2018).
On the other hand, P uptake was not affected by the application of the amendment, and no statistical differences were observed with the values of the control plants. This lack of response seems to be attributed to the high variability of phosphorus values (Table 5), which presented a high coefficient of variation (41.6%).

For K uptake, significant differences were detected with the application of leonardite, which stimulated uptake of 110.05 kg/ha in contrast to only 87.57 kg/ha in the control plants (26.34% increase). Also, there were no differences in P absorption among the varieties evaluated with the amendment application (Table 5).

Given that N and K uptake values are within ranges similar to or not lower than those of other rice varieties with comparable yields, it could be presumed that inhibition of photosynthesis, which is one of the main physiological effects of deficiencies of these nutrients during rice growth according to Hou et al. (2018), was not evident in our trial.

Taking into consideration the values of uptake (Table 5) and harvest index (INPOFOS, 2002), the nutrient extraction by the plant in the amended plots was 106.2, 19.8, and 11.0 kg/ha for N, P, and K, respectively.

Regarding the interactions that occurred in the nutritional variables (Table 2), it was found that, in the case of Ca, the highest absorption occurred in the variety SFL 011 that received the application of the amendment (105.53 kg/ha), thus surpassing all the varieties without application, except for the variety Fedearroz 60, with which it shared statistical similarity (Table 6).

The amendment tended to increase Ca uptake in all varieties except Fedearroz 60 which showed no response. In the case of S, the highest absorption occurred in the combination of the INIAP 11 variety with amendment (33.50 kg/ha), which surpassed the rest of the combinations, except for Fedearroz 60 with the amendment.

**CONCLUSION**

The application of leonardite (150 kg/ha) increased the yield of rice varieties grown in saline soil (electrical conductivity of 7.44 dS/m). The varieties INIAP FL- Arenillas, SFL011, INIAP 14, INIAP 11, and Fedearroz 60, grown in that soil with the application of leonardite, showed superior performance compared to the same varieties under control conditions in the variables of plant height, tillers per plant, length, and panicles per plant, grains per panicle and grain weight. The application of leonardite to saline soils along with proper fertilization practice not only increased rice growth and yield but also improved mineral nutrient uptake. The above indicates that the use of the amendment would be very effective in obtaining significantly higher rice yields in soils with similar salinity characteristics.
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REFERENCES


