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Proceeding Paper

Monitorization through NDVI of a Rice (*Oryza sativa* L.) Culture Production in Ribatejo Region †

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Abstract: Remote sensed data already have an important role in crop management. In fact, NDVI (normalized difference vegetation index) has been use for staple crop management and monitorization since the 1980s, namely, in rice, wheat and maize. Accordingly, this study aimed to monitor, through precision agriculture, the development of a highly produced and consumed rice genotype in Portugal (Ariete variety), submitted to a selenium biofortification workflow. Rice biofortification was promoted during the production cycle, and assessed after two foliar applications with selenium (sprayed with 50 and 100 g Se·ha^{-1} of sodium selenite). In this context, NDVI showed a high and identical value between control and biofortified plants, which indicated that the culture displayed a higher vigor and was in a healthy state of development despite foliar applications. Analyzes were further carried out for monitor the mobilization of photoassimilates, showing that plants did not demonstrate any negative impact on net photosynthesis and there was even a slight rise in the treatments. Additionally, to characterize the soil of the paddy rice field, some parameters were also analyzed, namely, organic matter, humidity, pH and electrical conductivity, being found that the parameters ranged between from 1.085–1.575%, 12.05–17.45%, 5.70–6.20, respectively, whereas the average conductivity was 223.4 μS cm^{-1}. Concerning to soil color, and considering the parameters L, a* and b* of the CIELab scale, significantly higher values in samples without humidity and without humidity and organic matter were found. In spite of the differences found, it is concluded that biofortification process did not affect any physiological parameters (net photosynthesis–Pn, stomatal conductance to water vapor—gs, transpiration rates—E and instantaneous water use efficiency—iWUE) in rice plants.

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1. Introduction

In Portugal, rice (*Oryza sativa* L.) production is more significant in areas located near the estuaries of the rivers Tejo, Sado, and Mondego, where the edaphoclimatic factors are more suitable [1,2]. Considering the unique and favorable conditions for rice cultivation in Portugal and the concern for growing and sustainable production, smart farming technologies emerge as a tool to support this whole process. Normalized vegetation indices (NDVI) are relatively simple algorithms determined by high correlations with the biophysical characteristics of plants [2]. These data allow assessing crop vigor and growth dynamics or plant cover. Remote sensing in agriculture allows to estimate yields, evaluate the nutritional and hydric state of plants [3], detect pests and diseases [4] as well as delimit areas associated with higher weed emergence density so that it is possible to perform differentiated treatments. In addition, these platforms allow the monitoring of large areas such as paddy rice fields. Selenium (Se) is an essential element in the human diet but the presence in plants is scarce [5] and biofortification is considered one of the most outstanding example of agronomic intervention [6]. Studies pointed on Se rice biofortification have indicated that selenite is more effective than selenate [7]. Studies show that the assessment of leaf gas exchange parameters combined with remote sensing data provides important inputs in biofortification processes [8]. In fact, the bioavailability of Se in soil is directly related to its content in plants [9]. Plant micronutrient availability decreases as soil pH approaches 8 [10]. As such, plants adapt intolerance to alkaline or acid soil conditions, however, they would rather near neutral pH. It is near this pH that the activity of microorganisms is greatest [10]. The soils in Portugal generally have a low organic matter content [11], with a tendency for its progressive decrease, as a result of climatic conditions favorable to its decomposition [12]. Accordingly, considering the increasing importance of precision technologies, this work aimed to implement and monitor agronomic biofortification (by foliar pulverization of sodium selenite) while evaluating the plant vigor and photosynthetic metabolism.

2. Materials and Methods

2.1. Experimental Fields

The trial was conducted at the experimental station of Rice Technological Center (COTArroz-Portugal), located in the lezíria ribatejana (39°02′21.8″ N; 8°44′22.8″ W), to grow Ariete variety. Field was sown in a randomized blocks and a factorial arrangement (3 concentrations × 1 form of selenium × 1 variety × 4 replicates = 12 plots), each plot size with 8 m length × 1.2 m width = 9.6 m^2. During the crop growing season from 30 May to 2 November 2018, the agronomic biofortification comprised selenium foliar pulverization, at the end of booting and at anthesis. The pulverizations occurred at 23 August and 31 August, respectively. During this period, plants were sprayed with sodium selenite (Na_2SeO_3) using the following concentrations: 50 and 100 g $Se{\cdot}ha^{-1}$, and control plants were not sprayed at any time.

2.2. Monitoring the Vigor between Treatments–Normalized Difference Vegetation Index (NDVI)

The experimental field was flow over twice with an Unmanned Aerial Vehicle synchronized by global positioning system (GPS), followed the methods described by Coelho et al. [13]. The first flight was performed before the implementation of the crop, on 11 May, to obtained an orthophotomap. The second flight was during the biofortification itinerary, after the 2nd application of sodium selenite, to characterize the vegetation index (NDVI), at 12 September, on control and treated plants.

2.3. Leaf Gas Exchange Measurements

Leaf gas exchange parameters were determined in control and treated plants after the 2nd application of sodium selenite using 5 randomized leaves per treatment, on 12 September, according the methods described elsewhere [14]. Leaf rates of net photosynthesis (Pn), stomatal conductance to water vapor (gs) and transpiration (E) and were obtained under photosynthetic steady-state conditions after ca. 2 h of illumination, followed the methods described [13]. A portable open-system infrared gas analyzer was used and photosynthetic photon flux density (PPFD) of ca. 1000 µmol m^{-2} s^{-1}. Leaf instantaneous water-use efficiency (iWUE = Pn/E) representing the units of assimilated CO_2 per unit of water lost through transpiration.

2.4. Soil and Colorimetry Analysis

The quantification of organic matter and humidity considered 16 samples collected along the paddy rice field at 11 May, followed the methodology described by [8]. Soil samples were removed from muffle at 100 °C. Soil electrical conductivity and pH were measured, followed [15]. Determination of the colorimetric parameters using a fixed wavelenght, followed the methodology [16]. The colorimeter parameters of the soil samples followed the methodology described by [8]. The soil samples were analyzed without humidity and without humidity and organic matter.

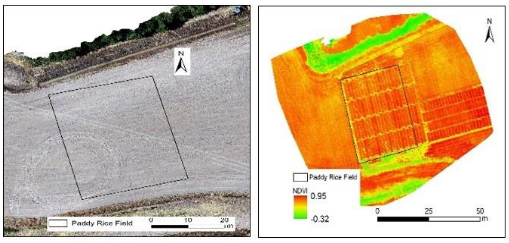
2.5. Statistical Analysis

Statistical analysis was carried out using a One-Way ANOVA ($p \leq 0.05$) to assess differences among treatments. Based on the results, a Tukey's for mean comparison was performed, considering a 95% confidence level.

3. Results

3.1. Monitor the State of the Culture

In paddy rice field the application of sodium selenite did not show a negative impact on the level of plant vigor (Figure 1a). In the normalized vegetation index values, there were no significant differences (Figure 1b) regarding control.



Treatments (g Se.ha^{-1})	NDVI
Control	0.799a ± 0.060
50	0.803a ± 0.050
100	0.802a ± 0.055

(a) (b)

Figure 1. Orthophotomap and normalized vegetation index (NDVI) obtained from images of UAV's (n = 12) of Oryza sativa (Ariete variety) after the 2nd application of 50 and 100 g Se·ha^{-1} sodium selenite (**a**). Mean values of NDVI ± standard deviation (**b**). Information collected at 12 September 2018. Letter a indicate the absence of significant differences among treatments ($p \leq 0.05$).

3.2. Physiological Monitoring during Biofortification

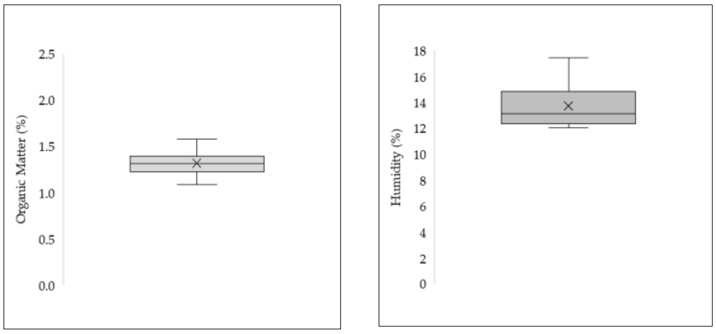
The plants did not show a negative impact on Pn after pulverization with Na_2SeO_3, regardless of the dose (50 or 100g Se·ha^{-1}), however shows a marginal increase in P_n (Table 1). The sprayed plants showed higher gs and E, particularly with increasing dose, regarding to the control. As a consequence of the increase in gs and E, iWUE values decreased from 4.15 to 2.44 CO_2 mol^{-1} H_2O.

Table 1. Leaf gas exchange parameters – net photosynthesis (Pn), stomatal conductance to water vapor (gs), transpiration (E) rates and instantaneous water use efficiency (iWUE = Pn/E) in leaves of *Oryza sativa*, variety Ariete. Average values ± standard errors (n = 4–6). Letters a, b and c indicate significant differences between treatments ($p \leq 0.05$).

Treatments (g Se·ha^{-1})	**Pn (µmol CO_2 m^{-2}·s^{-1})**	**gs (mmol H_2O m^{-2}·s^{-1})**	**E (mmol H_2O m^{-2}·s^{-1})**	**iWUE (mmol CO_2 mol^{-1}·H_2O)**
Control	15.8a ± 0.24	182c ± 5.9	3.81c± 0.06	4.15a ± 0.01
50	16.7a ± 0.21	281b ± 1.4	5.13b ± 0.02	3.25b ± 0.03
100	16.2a ± 0.24	369a ± 23	6.66a ± 0.24	2.44c ± 0.05

3.3. Characterization of the Paddy Rice Field

In the paddy rice field some soil chemical properties were analyzed (Figure 2). Regarding, the organic matter content, the values obtained ranged from 1.085–1.575% (Figure 2a). The minimum humidity value registered was 12.05% whereas the maximum value was 17.45% (Figure 2b). The pH ranged from 5.7 to 6.2, whereas the average electrical conductivity was 223.4 µS cm^{-1} (varied from 144.6 to 428.0 µS cm^{-1}).



(**a**) (**b**)

Figure 2. Average soil parameters ± standard deviation (n = 16) of organic matter (**a**) and humidity (**b**) of the paddy rice field.

The analysis of the colorimetric parameters showed significant differences on the CIELab scale (L, a* and b*) (Table 2). Regarding the a* and b* parameters, both samples revealed red and yellow colors, respectively. The data obtained in the samples without humidity and organic matter are significantly highest compared with the samples without humidity.

Table 2. Colorimeter parameters of the paddy rice field soil without humidity (A) and without humidity and organic matter (B) ± standard deviation (n = 4). Letters a and b indicate significant differences among treatments ($p \leq 0.05$).

Soil	**L**	**a***	**b***
A	40.8b ± 0.39	1.59b ± 0.06	7.70b ± 0.11
B	55.2a ± 0.52	5.37a ± 0.20	14.8a ± 0.08

4. Discussion

Several studies have related NDVI values with crop yields of rice, wheat, and maize [17]. The use of spectral imaging has been widely used in precision spraying control, weed, and pest identification in crops [18]. Studies conducted, in paddy rice fields, using a rapid acquisition of NDVI values and mapping data study the nitrogen use efficiency of rice [19]. In this study, the NDVI values of the selenium treated plants showed no significant changes compared to the control (Figure 1). NDVI values can range from −1 to 1, and thus higher values indicate healthy crop plants [20]. Since all treatments showed values of approximately 0.8 (including the control) this suggests that the application of sodium selenite did not negatively impact crop vigor. In this case, selenite pulverization enters the plant through the cuticle or via stomata [21]. Based on this, it was necessary to complement leaf gas exchange parameters data. In this analysis, the plants showed no negative impact on Pn and a slight increase, compared to the control (Table 1). Additionally, the increase in the dose of selenium applied increased the values of gs and E, regarding the control. Comparing the NDVI data with leaf gas ex-change parameters, it is possible to verify that selenium stimulates net photosynthesis [22]. Considering that soil conditions have direct implications on the cultivation of rice plants, soil analyses showed that the paddy rice field was to be suitable for crops management at the pH and conductivity level. According to the literature, soils with a pH around neutral are suitable for rice production [23]. Our findings fall within this pH range (5.70–6.20). The electrical conductivity obtained was less than 600 µS cm^{-1}, which is in accordance with the recommended value for the conductivity of soils where crops are to be grown [11]. The electrical conductivity depends, among other properties, on soil humidity [24]. The rate of decomposition of organic matter is a result of high temperature and precipitation which promotes the release of nutrients to the soil [10]. The increase in precipitation promotes the infiltration of water into the soil, which will increase the organic matter content below the surface soil level, which justifies the values obtained at 30 cm deep. Studies show that higher rates of organic matter decomposition are obtained in irrigated soils, such as in rice cultivation, in hot regions [10]. Organic matter influences soil characteristics, in particular its color, due to the formation of organic mineral complexes [25]. The sum of the colors of the mineral matrix and the organic matter result in the soil color [25]. Therefore, it is necessary to study the effect of organic matter on mineral pigments. Using the CIELab system a connection between soil color and organic matter content (pigment substances) is established numerically [26]. Furthermore, organic matter showed (Figure 2) an impact in the colorimeter parameters on the CIELab scale (L, a* and b*) (Table 2). The b* value tends towards yellow, a lighter color, which allows the conclusion that the soil has less humus [25]. The organic carbon content affects the parameters L*, a*, and b* of the soils [25]. This approach may justify the significant changes in the samples after burning (without humidity and organic matter).

Soil characterization analyses were favorable for the implementation of the paddy rice field in the Ribatejo region. The results obtained by remote sensing complemented with net photosynthesis analysis suggest that the doses of 50 and 100 g Se·ha^{-1} can be applied in the Ariete variety without compromising the NDVI values.

5. Conclusions

Foliar application of the 50 and 100 g Se·ha^{-1} of sodium selenite in Ariete variety did not affect the NDVI values of the plants, which was verified in the absence of any negative impact. The vigor of rice plants showed high values, compared to the control. Net photosynthesis showed a slight rise in the treatments however plants did not demonstrate any negative impact. Regarding to soil characterization, organic matter, humidity, pH and electrical conductivity were considered. The colorimetric indices revealed significant differences when comparing soil samples without humidity with samples without humidity and organic matter. Despite the differences found, it is concluded that biofortification process did not affect any physiological parameters studied in the rice plants.

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