Delineation of Site-specific Nutrient Management Zones to Optimize Rice Production using Proximal Soil Sensing and Multispectral Imaging

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Abstract.

Evaluating nutrient uptake and site-specific nutrient management zones in rice in Costa Rica from plant tissue and soil sampling is expensive because of the time and labor involved. In this project, a range of measurement techniques were implemented at different vintage points (soil, plant and UAVs) in order to generate and compare nutrient management information. More precisely, delineation of site-specific nutrient management zones were determined using 1) georeferenced soil/tissue sampling, 2) proximal soil sensing (soil pH, Electrical Conductivity ECa, and dual-wavelength optical measurements) and 3) multispectral (blue, green, red, red edge, near IR narrowband wavelengths) and thermal images (0.1 °C temperature resolution) generated from UAV platforms.

New nutrient management plans were designed and applied based on site-specific soil/plant deficiencies and nutrient uptake at commercial scale. Two treatments were implemented to evaluate the benefits of site-specific nutrient management, namely i) Business-as-usual (control) where the conventional fertilization was maintained (4.33 ha) and ii) Optimized fertilization using nutrient deficiency maps (soil and plant) and variable rate applications (4.56 ha). The zoning maps were used to apply macro and microelements according to soil deficiencies and crop needs.

Delineation maps have shown to be a useful approach to guide fertilization operations. The grain yield was 4.72 Mg/ha for the conventional fertilization and 5.62 Mg/ha for the optimized site-specific fertilization resulting in a production yield increase of 18.9%. The yield of the optimized fertilization was 42.6% higher than the Costa Rican average. A cost-benefit analysis was carried out indicating that the optimized site-specific fertilization resulted in gains of USD $188/ha per rice cycle compared to conventional fertilization practices.

This study indicates that this new multi-sensor and data fusion approach is a useful technique to improve yield, generate gains (after cost of data generation), and to optimize rice production.

Keywords. *Site-specific Nutrient Management, Optimized Fertilization, Proximal Soil Sensing, Hyperspectral Imaging, Precision Agriculture, Rice.*

Introduction

Precision agriculture (PA) is relatively new in Central America. This approach based on site-specific management provides a path to achieve agricultural sustainability since its objective is to maximize finite resources, maintain economic stability and increase productivity (Corwin and Lesch, 2010).

Although the term PA seem to appear more and more frequently in discussions and recent publications, Melo *et al.* (2014) stated that there was a lack of research on the application of PA in tropical soils. Specifically in Costa Rica, there is a lack of information regarding PA in academic research and commercial applications in the agro-industry.

In Costa Rica, rice is an essential staple food but only half of the rice consumed is being produced locally. This forces the country to depend heavily on rice imports (Tinoco and Acuña, 2009). In addition, the national average productivity of this crop (dry and clean grain) for the year 2014 was 3.94 Mg/ha. This value is very low compared to the production average of other rice producing countries like Argentina (6.50 Mg / ha) or Uruguay (8.05 Mg / ha) (FAOSTAT, 2017) for the same year.

For this reason, the research aimed to validate the use of precision farming techniques in the rice production system (Oryza sativa) under rainfed conditions in Guanacaste, Costa Rica, mapping physical and chemical soil parameters with grid sampling in order to determine applications of variable ranges and comparing concentrations of nutrients at leaf level, number of productive tillers, yield and net profit / ha.

Methodology

This study was carried out in two commercial rice lots with a total of 8.89 ha, located at the Costeña Farm in the Guanacaste Province of Costa Rica (Figure 1) at Lat N10° 05'12" and Long W85°28'.38" and an elevation of 160 masl. For this region, the average annual temperature is 28.5°C and the annual rainfall is 143.7 mm IMN (2017). The study consisted of two treatments (business as usual and optimized) in dry rice production (Figure 2) The conventional treatment had a total of 4.33 ha corresponding to the practices that the company has historically developed (business as usual) and the optimized one with 4.56 was managed according to the spatial variability of the soil measured by different PA techniques.

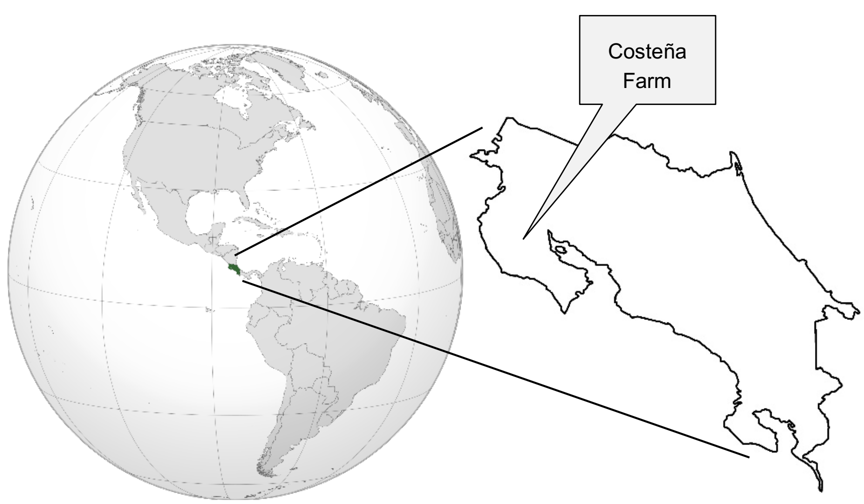


Fig 1. Location of the experiment at Costeña Comercial Farm in Guanacaste, Costa Rica

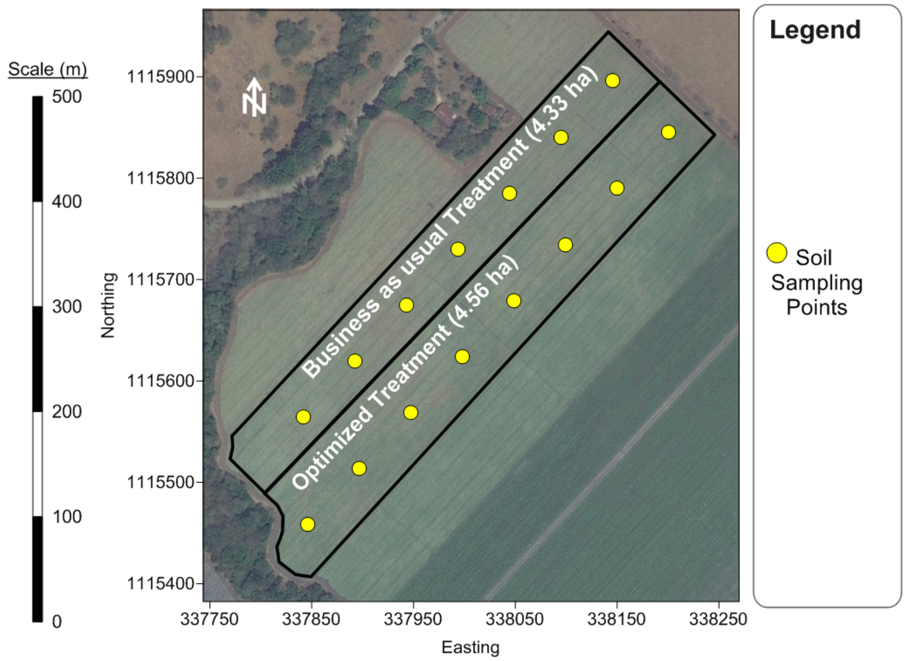


Fig 2. Sampling points of the two treatments (business as usual and optimized) in dry rice production at Costeña Farm

A sampling grid of 75 mx 75 m (1.7 samples / ha) was used in order to determine the spatial variability of soil bulk density, soil compaction, texture, nutrient content and pH. The soil nutrient level were measured with a Perkin Elmer Optima Inductively-Coupled Plasma Optical Emission Spectrometer (ICP-OES). The soil nutrient extraction was done using a Mehlich III solution. Using the results of the soil analysis and based on the optimal ranges (Table 1), the pertinent amendment and corrections were applied.

Table 1. Optimal ranges for macronutrients with Mehlich III extraction

Range	pH	K	Ca	Mg	Na	Ca/Mg	Ca/K	Mg/K	(Ca+Mg)/K	P
		------------- cmol+/kg -----------								mg/kg
Low	5.5	0.5	6.0	3.0	0.3	2.0	5.0	2.5	10.0	20.0
High	6.5	0.8	16.0	6.0	0.7	5.0	25.0	15.0	40.0	50.0

Fe	Cu	Zn	Mn	S	B
-------------------------mg/kg--------------------------					
50.0	1.0	3.0	10.0	20.0	0.5
100	20	10	50	50	20

In order to facilitate the interpretation of nutrient deficiencies and to generate site-specific application maps, each soil sample was georeferenced and incorporated into a soil database. Golden Surfer 13 software (2017) was used to interpolate data and generate soil management maps using the Kriging interpolation method (linear model) a grid interpolation of 1200 per 1200 nodes.

The Veris MSP3 platform was used to evaluate the soil apparent conductivity (CEa in mS / m), the soil reflectance in the Vis-NIR and NIR bands and the soil pH with antimony sensors. Figure 3 shows MSP3 working in the field.

Fig 3. Veris MSP3 equipment working in the Costeña field

The MSP3 was set to make an average of 380 readings of CEa and reflectance per hectare on 10 transect lines each separated by approximately 15 m (readings every 1.75 m on average). The CEa was measured at two depths: shallow from 0 to 30 cm (CEa-sh) and deep from 0 to 90 cm (CEa-dp). The reflectance were evaluated at 7.5 cm depth. The data collected were processed in the Veris Mapping Center (Data Processing Center of the Veris Technologies company) to eliminate irregular field measurements and outliers.

The sowing date was July 15, 2017 using 115 kg / ha of seed and a row separation of 0.17 m, under the direct sowing system with a TDNG type seeding machine (SEMEATO) with the Garabito FL 163 variety. This variety is characterized for its high yield. For the optimized treatment, the fertilization was based on the nutrient absorption curves developed by Chavarría (2011) for rice variety Palmar 18, since both varieties have similar characteristics and no absorption curve has been reported for Garabito FL 163. Rice was harvested 111 days after sowing.

Foliar tissues were sample in grid at the physiological stage R1-R2. Drone flights were carried out using a Sensefly eBee equipped with a Parrot Sequoia multispectral camera (Figure 4). The camera integrates a GPS/light sensor, four narrowband imagers (Green, red, red edge, near IR (global shutter, narrowband), and an RGB camera for digital crop scouting. The flight were performed at a 120 altitude above the ground allowing a resolution of 12.6 cm per pixel (per band). A thermal camera was also flown on the eBee at the same altitude using the ThermoMap thermal sensor with the following specifications: image size: 640 x 512 pixels / ground resolution of 20 cm/pixel / scene temperature resolution of 0.1 °C.

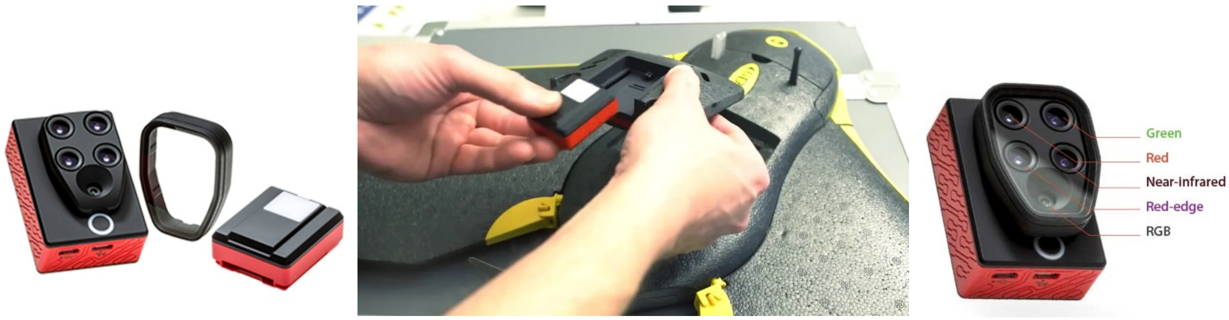


Fig 4. eBee drone equipped with a Parrot Sequoia Multispectral camera and GPS/light sensor

The number of productive tillers per plant was determined by counting them in-situ in a linear meter in the physiological stage R2-R4, with six sampling points for each treatment (Business as usual and optimized) distributed along the contour intervals of soil apparent electrical conductivity elaborated with the Veris MSP3 equipment (Figure 5).

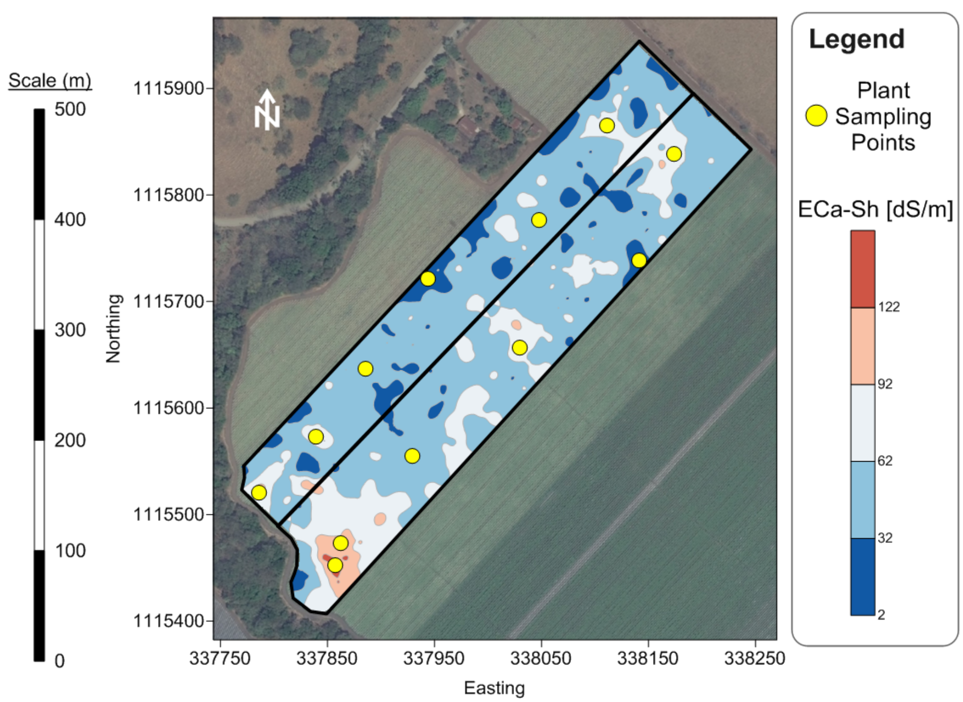


Fig 5. Sampling points for *In Situ* plant measurements in different soil apparent conductivity areas for the two treatments.

An analysis of variance was applied with the t-Student difference test for the foliar nutrient concentrations and of significance with Fisher's LSD comparison ($p < 0.05$) for the number of productive tillers per plant with the statistical software InfoStat (Di Renzo *et al.*, 2017).

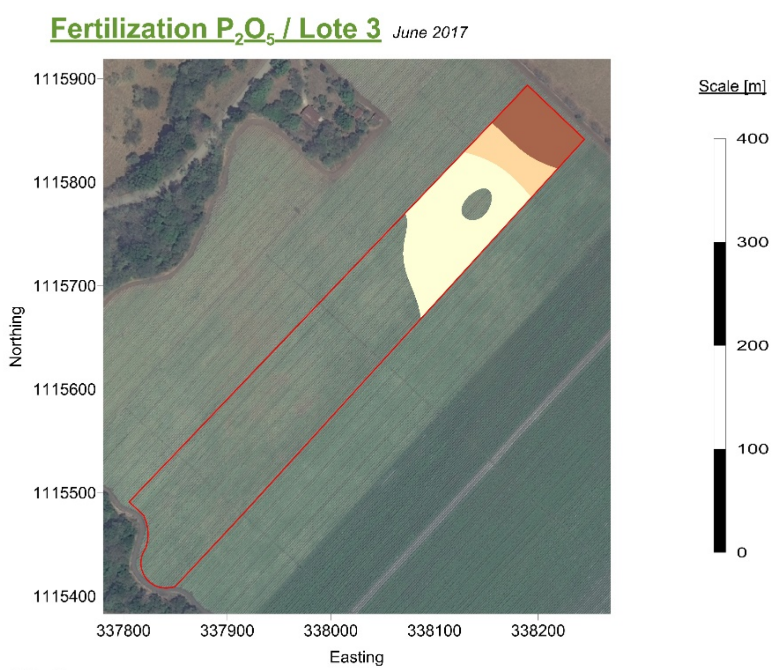
The total cost for the optimized treatment was calculated by summing cost of the laboratory analysis, the cost of corrective fertilization plan (fertilizers and application cost) and the cost for the time of two agronomists during two days. The value of the technical advice within the optimized treatment is based on the minimum salary established by law for an agronomist, according to the Presidency of the Republic (2016) in Executive Decree 40022-MTSS.

For the projection of gross income per hectare of each treatment, the final wet and dirty crop data were collected in hoppers harvested and multiplied by the conversion factor developed by SEPSA (2016) to transform it to dry and clean rice.

The transformed data was taken to units of bags of 73. 6 kg (Dry and Clean), to then calculate the gross income taking as reference the price for base / bag established by Law 8285 of the Presidency of the Republic (2007) through the Decree number 34487- MEIC-MAG-S and technical regulation 406/2007.

Results and Discusion

The study area was defined as a clayey textural soil at 30 cm, with no compaction measured by the apparent density and penetrometer (kPa). All the nutrients, pH and extractable acidity had optimal ranges or excesses in the case of Ca and Mg, with the exception of P with a deficiency zone. To correct the P deficiency in the soil, a correction map of P_2O_5 was elaborated (Figure 6). In the case of the excesses of Ca and Mg, the ratio of cations to K were unbalanced, the excess of these cations can lead the plant to a deficiency in K+, since the cations compete with each other to be absorbed by the roots (Brady and Weil, 2008).



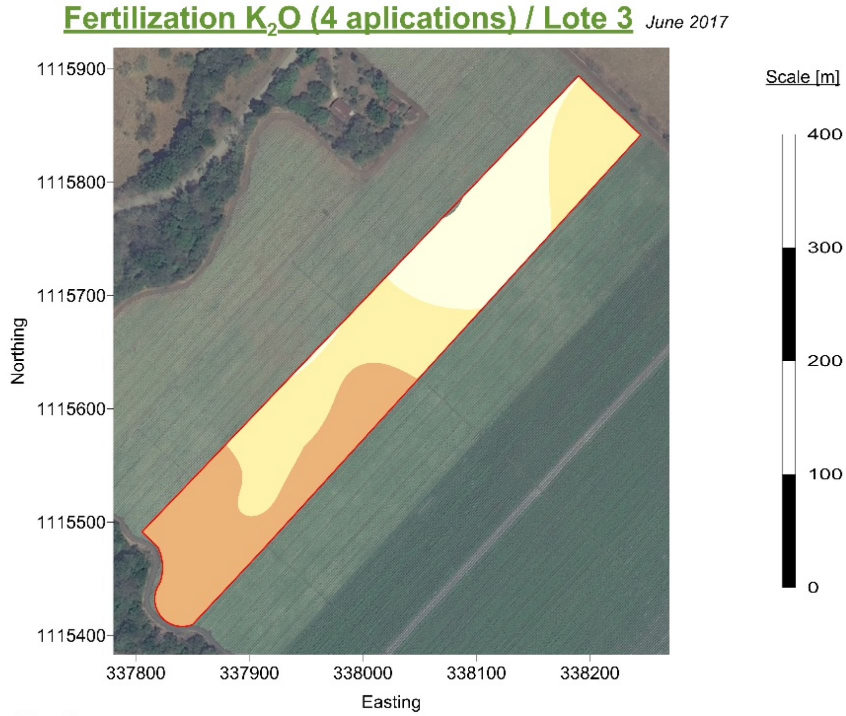
Fertilization

Zonification	Surface [ha]	Aplication Rate [kg P_2O_5/ha]	Fertilization [kg P_2O_5 / Zone]	Fertilization [kg DAP / Zone]	Fertilización [Bags / Zone]	Fertilization [Cost USD / Zone]
	0.95 ha	8 kg/ ha	7.6 kg	16.5 kg	0.4 sacos	$ 11
	0.23 ha	15 kg/ ha	3.45 kg	7.5 kg	0.2 sacos	$ 6
	0.36 ha	22 kg/ ha	7.9 kg	17.2 kg	0.4 sacos	$ 11

Fig 6. Phosphorus correction map for the optimized treatment

The corrections of the cationic ratios are justifiable to propitiate the availability of K^+ for the cultivation of rice and to minimize possible negative effects. In this study, 25% of the nutritional imbalance was corrected, since the application of K correction was planned for a period of four years.

A map of K correction according to the cationic imbalance was elaborated (Figure 7).



Fertilization

Zonification	Surface [ha]	Aplication Rate [kg K_2O/ha]	Fertilization [kg K_2O / Zone]	Fertilization [kg KCl / Zone]	Fertilización [Bags / Zone]	Fertilization [Cost USD / Zone]
	1.28 ha	115 kg/ ha	147.2 kg	245.3 kg	5.45 sacos	$ 109
	1.88 ha	140 kg/ ha	263.2 kg	438.7 kg	9.75 sacos	$195
	1.58 ha	165 kg/ ha	260.7 kg	434.5 kg	9.66 sacos	$ 193

Fig 7. Potassium correction map in the optimized treatment

Based on the soil nutrient corrections and the nutrient uptake curve, two new fertilizer formulas were developed and produced specifically for the optimized treatment namely Formula 1: 22.5-10.2-11.1-0.17 (B)-2.6 (S)-7.4 (SiO2)-0.22 (Zn) and Formula 2: 21-5-25.4-2.4 (S). Formula 1 was sprayed using the site-specific application rates presented earlier 1 week before and 5 weeks after sowing. Formula 2 was applied 44 days and 55 days after sowing. The difference between the fertilization packages of the two treatments are presented in Table 2.

Table 2. Difference in Fertilization between the Business as usual and Optimized treatments

Elements	Difference in Fertilization between Treatments (kg/ha) †
N in form of NITRO-XTEND	25.6
P_2O_5	4.4
K_2O	20.4
MgO_2	-19.8
Ca	0.0
S	-15.3
B	-0.9
Zn	-0.4
SiO_2	1.0

† Positive values indicate additional application in optimized treatment compared to the business as usual treatment while the negative values mean less application in optimized treatment.

Drone flights were realized on September 21st 2017 (67 days after planting). The orthomosaic reconstructed images of the thermal band, near-infrared band and Normalized Difference Vegetation Index (NDVI) are presented below. There is a clear contrast between the two treatments indicating that the optimized fertilization has an effect on the density of plant growth as illustrated with a photo from the ground during the same day (Figure 11).

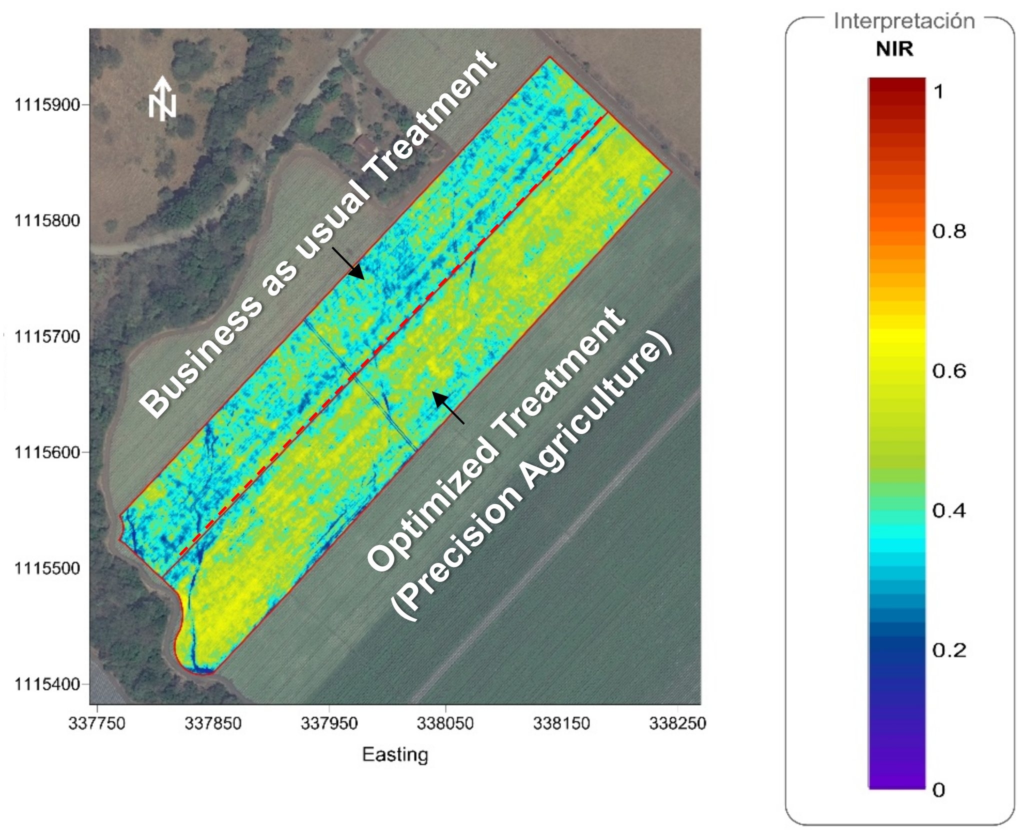


Fig 8. Near-infrared image of rice fields 67days after planting. The optimized treatment shows higher NIR values indicating a better crop performance and vigor compared to the business as usual treatment

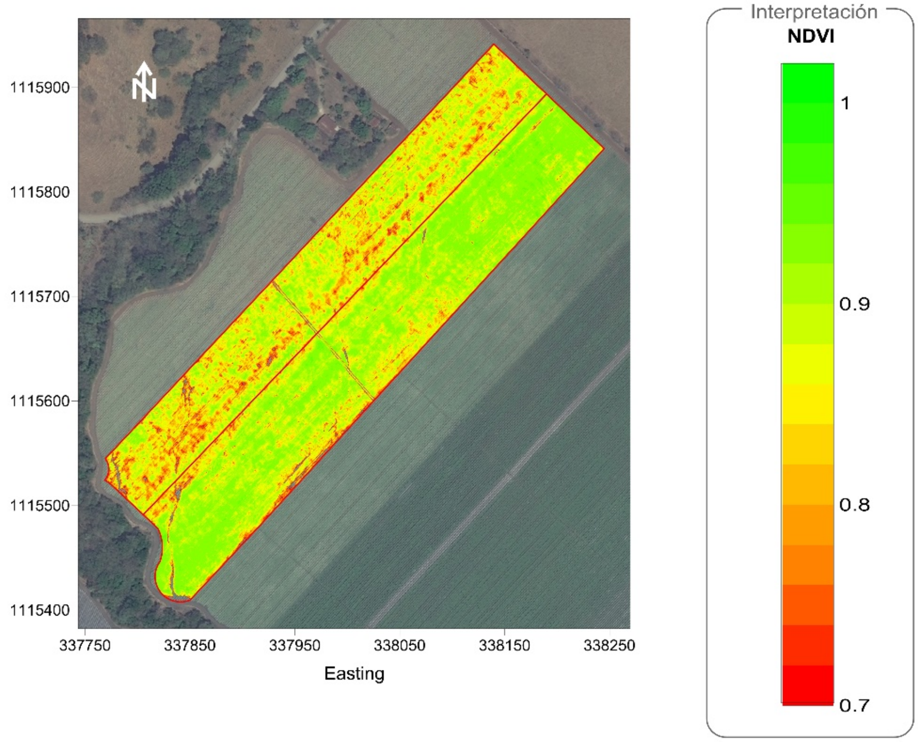


Fig 9. Normalized Difference Vegetation Index (NDVI) image of rice fields 67days after planting. The optimized treatment seems to indicate better plant health compared to the business as usual treatment

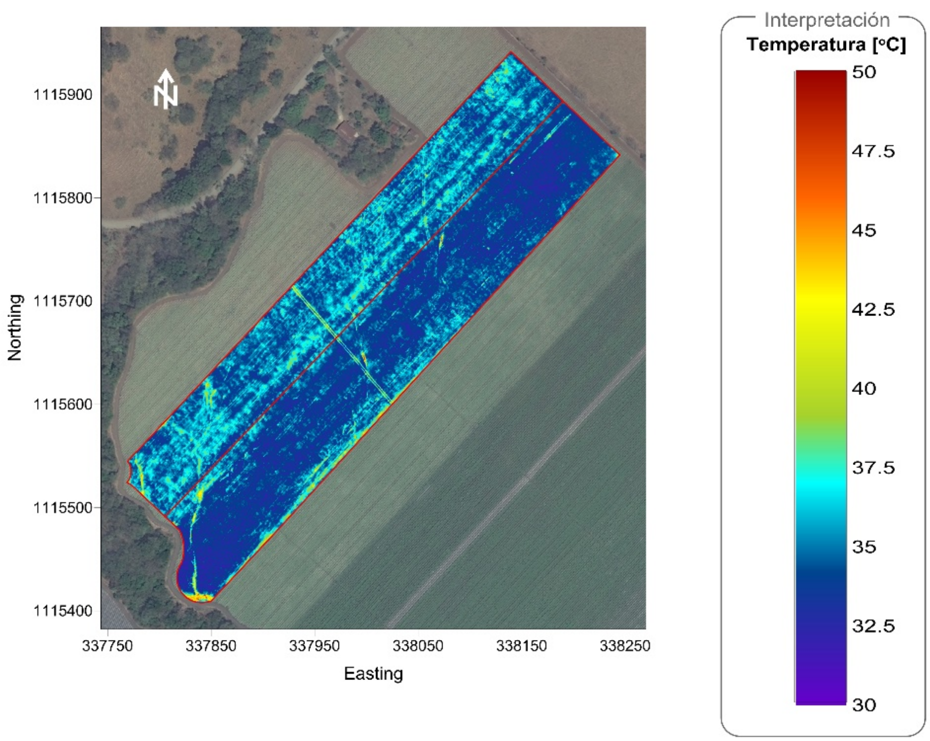


Fig 10. Thermal image of rice fields 67days after planting. The optimized treatment is relatively cooler indicating tighter plants, higher moisture content and higher stomatal evapotranspiration.

Fig 11. Visual inspection of rice field 67 days after planting. The optimized treatment (right) shows darker green and denser crop than the business as usual treatment (left).

As a result of the correction of phosphorus and the cationic relations in the soil and the differences in fertilization, the optimized treatment presented 0.44 more productive tillers per plant than the business as usual. The coefficient of variation was 32.82%, indicating that 67.18% of the difference between tillers can be explained by the optimized management (Figure 12).

Combining the number of productive tillers per plant and the average number of plants per linear meter, the number of productive tillers per square meter was estimated, being 365.65 and 413.40 for the business as usual and optimized treatment respectively.

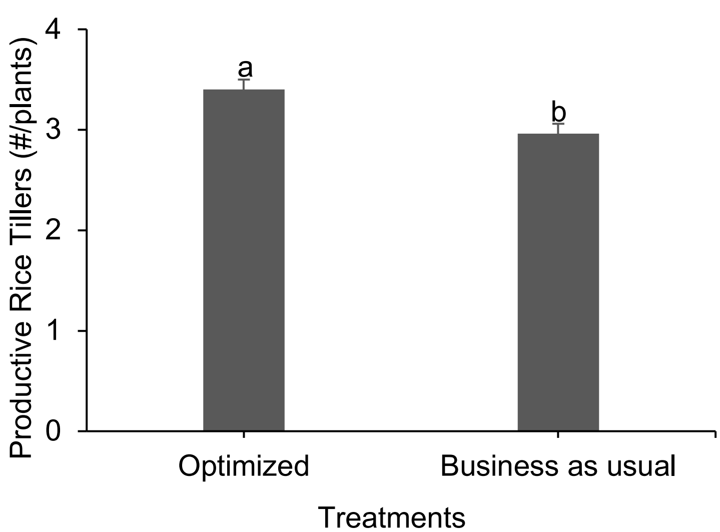


Fig 12. Number of producing tillers per plant ($p \leq 0.05$)

The optimized treatment yield of rice (dry and clean) was 0.89 Mg / ha higher than the business as usual treatment. This represents a yield increase of 18.9%. The yield of the optimized treatment is 42.6% higher than the national rice yield average (1.68 Mg / ha higher) (Figure 13).

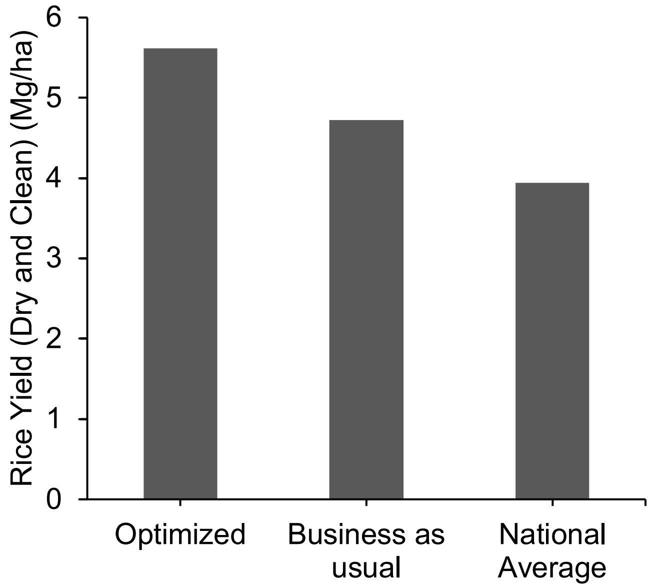


Fig 13. Comparison of rice yield (dry and clean) between treatments and national average

After obtaining the yield per hectare, the gross income, the extra cost of the optimized treatment (including cost fertilizer inputs, application cost and cost for data processing and recommendations) and net profit / ha of the optimized treatment was determined (Table 3).

Table 3. Cost different and net profit between the Business as usual and Optimized treatments.

.Treatment	Net Income (US$/ha)	Cost of fertilization (US$/ha)	Net Utility (US$/ha)
Optimized (AP)	2858.95	616.73	
Business as Usual	2403.89	350.52	
Difference	455.06	266.21	188.85

Table 3 indicates that despites an additional cost of $ 266.21 USD / ha of the precision agriculture management practice (optimized treatment), the PA generated an extra profit of $ 188.85 USD /ha. This demonstrates at the applicability and benefits, at commercial scale, of this new multi-sensor and data fusion approach to improve yield, generate gains (after cost of data generation), and to optimize rice production in Costa Rica.

Conclusions

It was determined that the balance of cations, correction of the deficiencies with the use of applications of variable ranges and fertilization with absorption curve resulted in a higher rice production.

The optimized treatment presented more macronutrients at optimum leaf levels and higher concentrations compared to the business as usual treatment, consequently a greater number of productive tillers per plant.

PA techniques (application of site specific variable rates and fertilization based on soil conditions and crop specific nutrient absorption curves) proved to be economically viable, generating USD $ 188.85 / ha more than conventional management.

Acknowledgements

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