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Mapping Nutrient Energy Embodiment in a Variable and Fixed Rate Fertilization in Orange

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ABSTRACT

Precision Agriculture techniques have been studied for Brazilian citrus to improve input use efficiency. Yet no study has approached the impact of variable rate application on energy efficiency and sustainability in these systems. This study aimed to understand how energy is used spatially in a citrus orchard and how variable rate fertilization influences energy efficiency. Two orange plot orchards were submitted to variable and fixed rate fertilization treatments in alternating rows. Georeferenced yield data was collected during two seasons to evaluate yield response to variable and fixed rate applications. Energy assessment was combined with Geographic Information System (GIS) to determine site specific energy indicators throughout the orchards. Energy and yield maps were analyzed to infer about energy efficiency and sustainability. Maps of nutrient energy embodiment reveled that energy performance varied spatially due to yield variation. Energy embodiment was higher in the fixed rate treatment, since it generally used higher quantity of fertilizer without raising fruit yield. Variable rate technology showed more efficient regarding energy use.

Keywords: Energy assessment, precision agriculture, geographic information system, Brazil.

1. INTRODUCTION

Information technology is a crucial tool in Precision Agriculture (PA). PA suggests a management system in which inputs are applied according to field spatial variability using variable rate technology. All information from the field is processed in Geographic Information Systems (GIS). GIS allows interpretation over crop spatial data and provide means to generate variable rate prescriptions of inputs. The main objective of PA is to provide economic and environmental benefits. Research has shown that PA can reduce environmental harm by reducing the excess of fertilizer and chemical applications (Bongiovanni and Lowenberg-Deboer, 2004).

Energy assessment is a suitable method to understand environmental sustainability in agriculture systems since it translates the material demand of a given production system into energy demand. The input and output energy is used to calculate energy indicators

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to evaluate energy use efficiency and sustainability (Silva et al., 2010, Romanelli and Milan, 2010).

This method was recently combined with GIS to assess sustainability in a PA system (Colaço et al., 2012). Energy indicators were calculated in each 10 x 10 m pixel area in a wheat field to generate maps of energy efficiency. Results showed that energy indicators varied spatially and that variable rate nitrogen application was more efficient regarding energy use then the fixed rate application. Authors concluded that environmental and sustainability analyses of PA can benefit from site specific energy assessment.

Citrus is one of the most energy demanding crops in the Brazilian agriculture. PA technologies have been tested in this crop to improve efficiency of inputs and profitability (Molin et al., 2012; Colaço and Molin, 2012). Yet, the impact of variable rate fertilization on sustainability and energy use was not measured.

This study aimed to understand how energy is used spatially in a citrus orchard and how variable rate fertilization affects energy efficiency. Two supplementary objectives are stated: i) to develop energy embodiment maps using GIS; and ii) to compare the nutrient energy embodiment in fixed and variable rate fertilization in orange orchards.

2. MATERIAL AND METHODS

Two 25.7 ha citrus groves were used in this study. Variable (VR) and uniform rate (UR) fertilizer treatments were established in intercalated pair of tree rows (Figure 1). In the VR strips, applications of N, P and K fertilizers followed variable rate prescription maps. Fertilizer rates were calculated based on soil fertility, leaf nutrition (only for N) and yield maps. In the UR strips, fertilizers were applied uniformly throughout the field according to traditional prescription used by growers. Yield data from each treatment was interpolated separately to cover the entire field. Data from two seasons was collected (2008/2009 and 2009/2010).

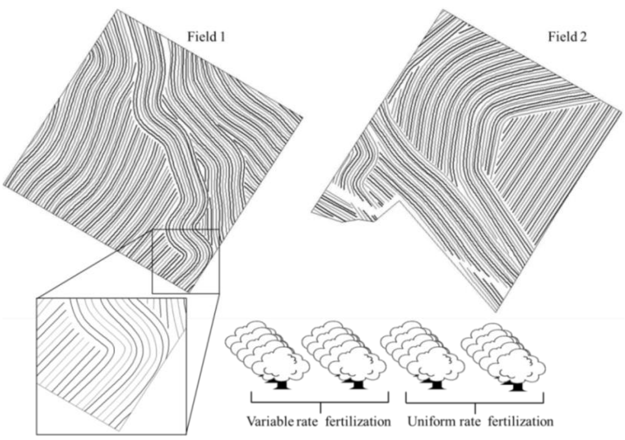

Figure 1. Experimental design of intercalated treatments in two orange orchards.

The prescription maps of N, P and K given in kg ha^{-1} in a 10 x 10 m pixel scale were converted into input energy maps in MJ ha^{-1} by multiplying the fertilizer rate by its energy index (Table 1). The total input nutrient energy was given by summing the three input energy maps (Equation 1).

Table 1. Energy indexes for N, P_2O_5 and K_2O (Pellizi, 1992)

Nutrient	Energy index (MJ kg^{-1})
N	74.0
P_2O_5	12.5
K_2O	6.7

Energy embodiment is the amount of energy needed to produce one unit of final product. In this study, the nutrient energy embodiment was calculated by dividing the total energy in nutrients by the fruit yield in each pixel (Equation 2).

$$INE_i = EN_i + EP_i + EK_i \tag{1}$$

$$NEE_i = \frac{TEN_i}{Y_i} \tag{2}$$

Where,

INE_i = input nutrient energy at pixel i, in MJ ha^{-1};
EN_i = applied energy in nitrogen at pixel i, in MJ ha^{-1};
EP_i = applied energy in phosphorus at pixel i, in MJ ha^{-1};
EK_i = applied energy in potassium at pixel i, in MJ ha^{-1};
Y_i = fruit yield at pixel i, in Mg ha^{-1};
NEE_i = nutrient energy embodiment at pixel i, in MJ Mg^{-1}.

The software SSToolbox® (SST Development Group, Stillwater, OK, USA) was used to process spatial data and generate yield and energy maps. Material and energy flow and energy maps were used to compare variable and fixed rate fertilization.

3. RESULT AND DISCUSSION

Regarding material flows, variable rate provided reduction of input consumption when compared with the conventional fertilization (Table 2). N was applied uniformly in the entire field in the first season because previous georeferenced leaf nutrition data was not collected. At this occasion the total amount of N fertilizer used in each treatment was equal.

In the first field, VR fertilization resulted on savings of 51% and 65% on N and K respectively, after two years of application (Table 2). In the second field, N, P and K applications were reduced by 78%, 10% and 41% respectively (total savings after two seasons). Average yield was higher ($p < 0.05$) in VR in field 1, in both seasons. In field 2, average yield in this treatment was lower ($p < 0.05$) in 2008/2009 and it was similar between treatments in the second year.

Table 2. Fertilizer consumption and average fruit yield during two seasons

Field	Season	Treatment	N	P_2O_5	K_2O	Average Fruit Yield ($Mg\ ha^{-1}$)
			----------	kg	----------	
1	2008/2009	VR	1625	671	751	38.1*
		UR	1625	1128	1692	36.3*
	2009/2010	VR	2210	1783	952	25.4*
		UR	4578	1080	3224	22.4*
2	2008/2009	VR	1125	351	958	20.8*
		UR	1125	1068	1602	21.3*
	2009/2010	VR	940	1501	1571	22.5
		UR	4332	993	2716	23.0

* Averages are different between treatments ($p < 0.05$)

Energy in nutrients was spatially distributed throughout the fields in VR fertilization (Figures 2 and 3). Less energy in nutrients was applied in this treatment in both fields.

In the first field, even with lower fertilizer rates and less input energy, the fruit yield in VR strips was higher in both seasons. Embodied energy was lower in this treatment because it used less input to produce more fruit. In the second field, VR did not provide yield increment but still energy embodiment was lower due to less input energy. Results indicate that variable rate technology was more efficient regarding energy use.

Colaço et al. (2012) also found that variable rate technology was more energetically efficient in wheat crop. Variable rate nitrogen application resulted in higher energy balance and less embodied energy.

Nutrient energy embodiment varied spatially (Figures 2 and 3). In the UR treatment energy embodiment varies according to yield spatial variation. Less energy was embodied in places where the yield was higher. In variable rate fertilization, besides yield variation, spatial distribution of inputs also contributes to energy embodiment variation throughout the field.

The impact of variable rate application on input energy and energy embodiment was higher in the second year of evaluation in both fields (Table 3). In the first season input energy and energy embodiment was slightly higher in the UR treatment because nitrogen application did not varied between treatments. Differences on energy values between treatments were greater in the second year. In the 2009/2010 season, nitrogen reduction reached 51% (field 1) and 78% (field 2), contributing to a significant improve on the energy performance of the VR treatment. Due to its high energy index, nitrogen was responsible for most of the energy embodiment in this study (78% up to 92% of the total nutrient energy embodiment).

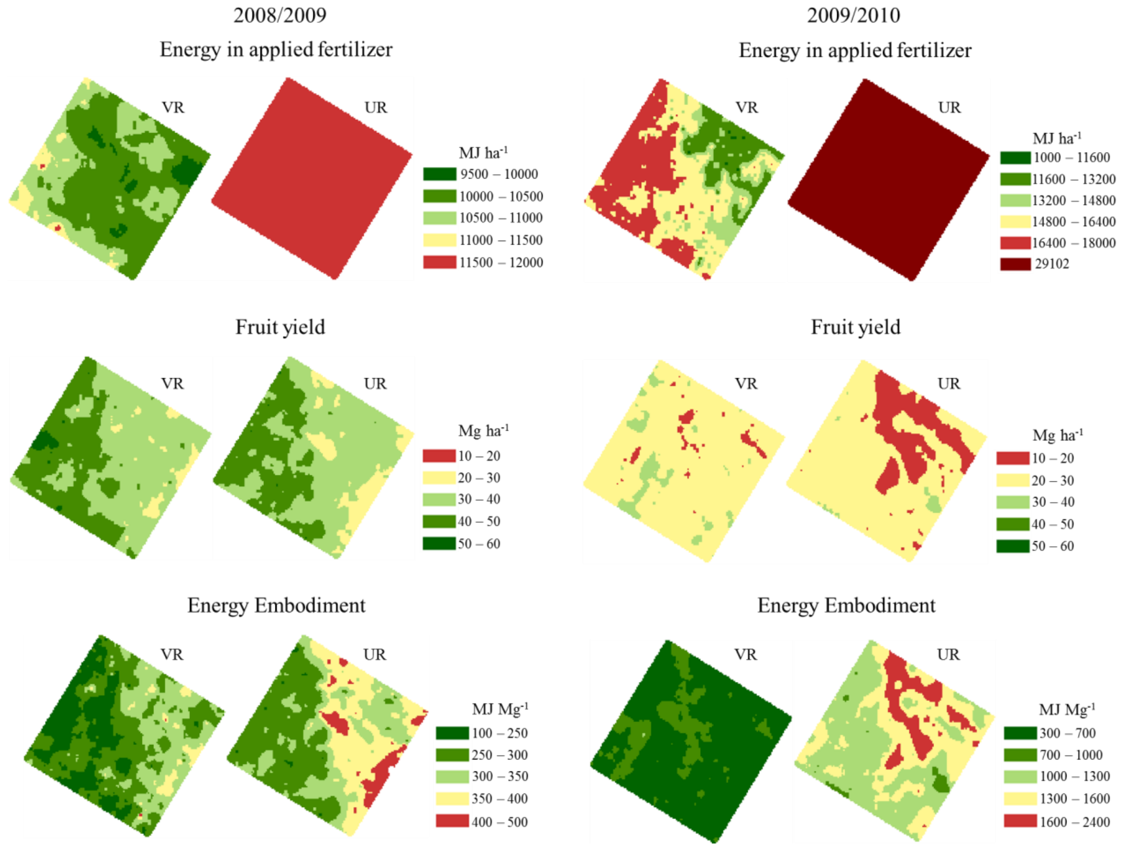

Figure 2: Yield and energy maps from 2008/2009 and 2009/2010 seasons in field 1.

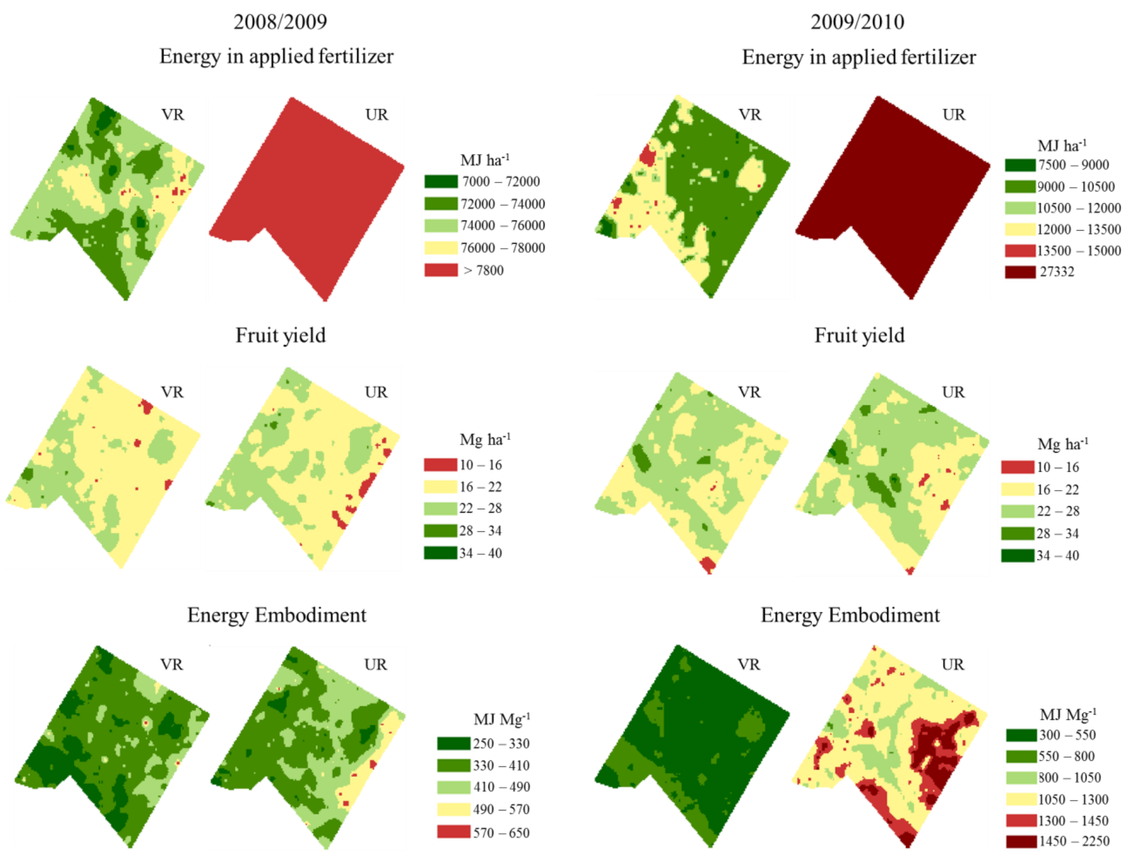

Figure 3: Yield and energy maps from 2008/2009 and 2009/2010 seasons in field 2.

Table 3. Input nutrient energy (INE) and nutrient energy embodiment (NEE) averages

Field	Season	Treatment	Average INE MJ ha^{-1}	Average NEE MJ Mg^{-1}
1	2008/2009	VR	10459.8	280.8*
		UR	11605.2	327.5*
	2009/2010	VR	15366.4*	616.3*
		UR	29102.3*	1335.3*
2	2008/2009	VR	7458.2*	364.1*
		UR	8539.2*	408.9*
	2009/2010	VR	10696.8*	481.6*
		UR	27332.0*	1219.6*

* Averages are different between treatments ($p < 0.05$)

4. CONLUSIONS

Maps of nutrient energy embodiment reveled that energy performance varied spatially even when the treatment is in fixed rate, which is due to yield variation. Less energy is embodied in places where the yield is higher. Mapping energy embodiment using GIS tools provided understanding of how energy is required in an orange orchard. Energy assessment was a method that properly compared environmental sustainability between two fertilization options because it fuses input with output results in one single indicator of efficiency. Energy indicators pointed that variable rate fertilization was more efficient regarding energy use in an orange crop.

For further studies we suggest that energy embodiment is determined for the whole system itself, since variable rate technology demands distinct sampling method and specialized machinery. Besides, longer evaluation periods are also relevant as perennial crops may respond to fertilization treatments in long term.

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