PRECISION AGRICULTURE FOR COFFEE IN BRAZIL

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ABSTRACT

Mechanized coffee harvesting started in Brazil in 1979 and precision agriculture techniques related to coffee only recently became an important issue. Industry and university started a project in 1999 aiming to monitor two experimental fields and test precision agriculture tools in coffee plantations. Soil sampling techniques for row permanent crops were studied, defining the position and number of subsamples. A regular grid soil sampling with 50m cells was taken and the data analyzed with geostatistical techniques to produce the soil fertility maps. A yield monitor that measures volume of grain was specifically developed for coffee harvesters and the first prototype was installed in a machine and used during the 2000 harvesting season. As grain maturity varies along each field, several georeferenced samples were collected, classified in different maturity stages, dried for determining grain moisture and processed. A correction factor was defined for each field and the volumes were converted to commercial grains. Yield maps were generated and correlated with soil fertility components resulting in low correlation coefficients but with important indications related to differences between the two fields. The investigation continues and the objective is to define zones with low yield variability for future specific management.

Keywords: yield map, zone management, yield monitor

INTRODUCTION

Technology for measuring the flow of solids under field conditions is a recent challenge. In the end of the eighties appeared the first market attempts for measuring the flow of grains in combines. More recently, with the advances of precision agriculture, several other crops have received attention on yield monitoring developments (Molin, 2000).

An equipment specifically developed for monitoring coffee yield mechanically harvested, and producing yield monitors, was tested in the field in 2000 and presented by Sartori et al. (2001). It consists on a sensor that measures volume, integrated into the harvester at the conveyor belt at the end of the internal transporting system. Balastreire et al. (2001) describe the generation of a yield map of coffee using a reservoir mounted on four load cells on a cart that runs lateral to the harvester machine.

The information of productivity on any crop represents destructive sampling and it is not valid for farmer that wants to interfere on their field for controlling or acting on any factor during the current cycle of the crop. Productivity also presents temporary variability and its space behavior, normally, does not repeat with the different annual crops. Though, yield maps contain valuable and almost irreplaceable information (Molin, 2000).

Investigations that try to relate the space and temporal variability of yield and the involved factors have been carried out by research groups on different countries. Difficulties have been observed in expressing the existent relationships supposedly between the highs and low yields and the responsible factors. Emphasis has been given to the components of soil fertility and correlations between the dependent variable (yield) and those factors are usually very low and attempts of explaining the local phenomena with some few factors are frustrated (Molin et al., 2001). However, it is possible to detect deficiencies of one or more components of soil fertility or other soil factors and so manage them or even develop strategies to live with those limitations. Acock and Pachepsky (1997) consider that the domain of the relationships among soil, plants and atmosphere has been better understood by the use of modeling tools. However, as the knowledge of plants behavior is not sufficiently dominated, those models still do not answer satisfactorily.

Marques Junior et al. (2000) investigated the space variability of chemical and texture attributes of the soil on a coffee plantation divided in two geomorphologic surfaces and observed strong dependence of the topography in those characteristics. Although it is not described how yield was taken, they observed space dependence on it.

Field monitoring for precision agriculture is related to soil sampling in a regular base. The method usually adopted is the regular grid (Morgan and Ess, 1997). However, in some perennial crops, as coffee, that procedure is hindered by the lines of plants that block the free movement of the samples vehicle or crew in the field. Another peculiar difficulty on perennial crops is the fact that fertilizer application is always located and in strips at the same relative position. It causes traverse gradients that deserve all attention of who collects the samples and analyzes its results. Frazen and Cihacek (1998) alert that the local variability in the space where soil samples are collected should be compensated by sub-sampling and producing a composed sample.

This work aims to present and to discuss a study that has been accomplished in two coffee fields related to the intensive monitoring made to detect the space variability of several components of the chemical soil fertility and coffee yield. An analysis of correlation between the components of soil fertility and coffee yield tendencies is also presented.

MATERIAL AND METHODS

The study has been conducted on two fields, one of 8.2 ha (field 1) and the other of 5.3 ha (field 2), both in São Paulo State, Brazil. The first soil sampling was done in April, 1999, applying a regular grid plan adjusted and drifted to the plant rows using an automated ATV carried soil sampler. On field 1, 32 samples were collected, resulting in approximately 3.9 samples/ha and on field 2, 38 samples were collected, resulting in approximately 7.2 samples/ha. Each sample was obtained from a composition of 9 sub-samples. The samples were sent for laboratory analysis of sulfur (S), borum (B), manganese (Mn), cooper (Cu), phosphorus (P), iron (Fe), zinc (Zn), calcium (Ca), magnesium (Mg), potash (K), sum of basis (SB), CEC, base saturation (V), hydrogen plus aluminum (H+Al), organic matter (OM), and pH. The data were submitted to a geostatistical analysis to define the interpolation parameters using kriging.

The harvest that proceeded was done in the months of June and July of 2000 and accomplished with a harvester Jacto KTR pulled and powered by a 52kW tractor. The yield monitor prototype was integrated to the machine and measures the grain volume flow (Sartori et al., 2001). During the harvesting, geo-referenced samples of 1,000 ml were collected for classification from harvesting stage (mixture of green, cherry, "passa" and "coco" fruits). Each sample was processed (dried and peeled) for obtaining a conversion factor of grains maturity. On field 1, 178 samples were collected and on field 2, 127 samples. Still, on field 2, due to the great amount of green grains during the first harvest, a second pass was necessary and in this case only 6 samples were collected.

Raw data from the field were analyzed for frequency distribution and filtering, and points with values considered unlikely possible, with very low or very high values were considered as errors and eliminated. Data from field 2 were added after the transformation of the crop points on surface maps through interpolation, using SSToolbox GIS (SST Development Group) and by using the inverse distance method (Moore, 1998). The same was done for the grain maturity factor that was applied to each 10 by 10 m cell of the surfaces and from the raw yield, the dry and peeled coffee yield maps were generated.

Soil fertility data and those of yield, all represented on surfaces from cells of 100 m^2, were used for the correlation analysis, resulting in 820 points for field 1 and 530 points for field 2.

RESULTS AND DISCUSSION

The geostatistical analysis results from field 1 is presented on Table 1 and the results from field 2 are presented on Table 2. It is observed that, except for the component Cu on field 1, all presented space dependence. It can be inferred that the samplings obtained at closer distances resulted in more similar values for the fertility components. All components were adjusted for the exponential or spherical models, except for the component Ca from field 2, that was better adjusted to the gausian model.

The lag distances varied from 25 to 600 m among the several components of soil chemical fertility on field 1 and from 55 to 365 m on field 2. The values are larger than those observed by Marques Junior et al. (2000) with a similar grid and to those observed by Souza et al. (1999), with a greater dense grid, and resemble values observed on annual crops and with similar grid samplings (Vieira and Molin, 2001). However all cases were characterized by different soil conditions and are not directly comparable.

The column that presents that has the continuity ratio $CR=C_0/(C_0+C_1)*100$, expresses the proportion of the nugget effect to the sill variance, i.e., the proportion of unresolved variation relative to the total variation. Obviously, the smaller this value is the greater the point to point continuity. On field 1 some CR values were very low (smaller than 1%) for some of the components as P, S and K. On field 2, only SB and OM presented value on that order and CEC and P presented values below 6%.

Table 1. Synthesis of the results from geostatistical analysis of the chemical fertility soil components from field 1.

Factor			Model	Nugget effect Co	Sill C	Range A (m)	CR[1]
pH			Exponential	0.076	0.22	25.3	25.9
Organic matter	OM	g/dm^3	Exponential	2.61	6.66	43.9	28.2
Cation exchange capacity	CEC	mmolc/dm^3	Spherical	75.7	247.4	88.2	23.4
Hidrogen+ Aluminum	H+Al	mmolc/dm^3	Exponential	7.24	19.36	32.3	27.2
Calcium	Ca	mmolc/dm^3	Exponential	29.6	74.1	34.3	28.5
Sum of bases	SB	mmolc/dm^3	Exponential	107.2	275.4	30.1	28
Phosphorus	P	mg/dm^3	Spherical	0.1	117.7	89.5	0.08
Zincum	Zn	mg/dm^3	Exponential	0.204	0.56	51.7	26.6
Boron	B	mg/dm^3	Exponential	0.00308	0.03	98.9	9.1
Copper	Cu	mg/dm^3	-				
Potash	K	mmolc/dm^3	Spherical	0.0001	0.122	128.4	0.08
Sulfur	S	mg/dm^3	Spherical	0.01	13.79	117	0.07
Magnesium	Mg	mmolc/dm^3	Exponential	42.3	243.2	599.5	14.8
Manganese	Mn	mg/dm^3	Spherical	2.48	8.28	312.8	23
Iron	Fe	mg/dm^3	Spherical	67.0	573.8	105.9	10.4
Base saturation	V%	mmolc/dm^3	Exponential	156.5	279.4	323.2	35.9

[1]CR = C0/(C0+C)*100

Figures 1 and 2 present the yield maps of dry and peeled coffee of the two experimental areas. Significant variability is observed on yield from field 1 ranging form 26 up to 85 bags.ha^{-1} (1560 to 5100 kg ha^{-1}). Part of the upper area, from the center to north, presents higher yields and from there to south, an opposite low yield area. The lowest yields coincide with an intense erosion that happened several years ago, according to the farmer. The two areas – high and low yield - may characterize two managing zones, if those tendencies confirm. As they are areas with accentuated differences, they should be treated differently.

Field 2, in the same way, presents great variation on yield, with limits similar to those of field 1, varying from 26 to 77 bags. ha^{-1} (1560 to 4620 kg.ha^{-1}). however it does not present areas with abrupt variations as on field 1. There is an area of higher yields close to the southwest corner and if confirmed in futures maps, it can be characterized as a separate zone. On the left border of the field, the map shows the influence of a row of trees outside the area that resulted in lower yield.

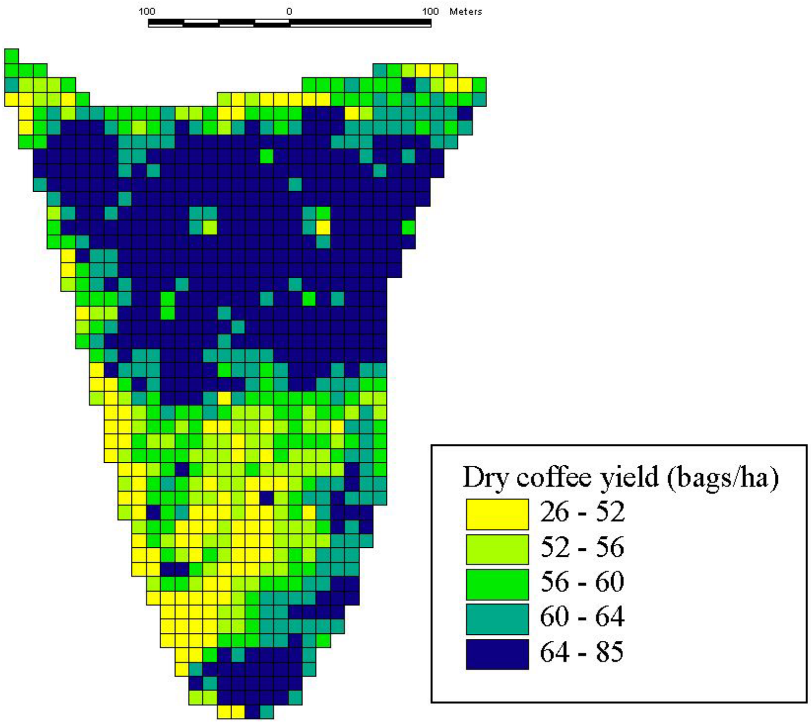

Figure 1. Yield map of dry and peeled coffee grains from field 1.

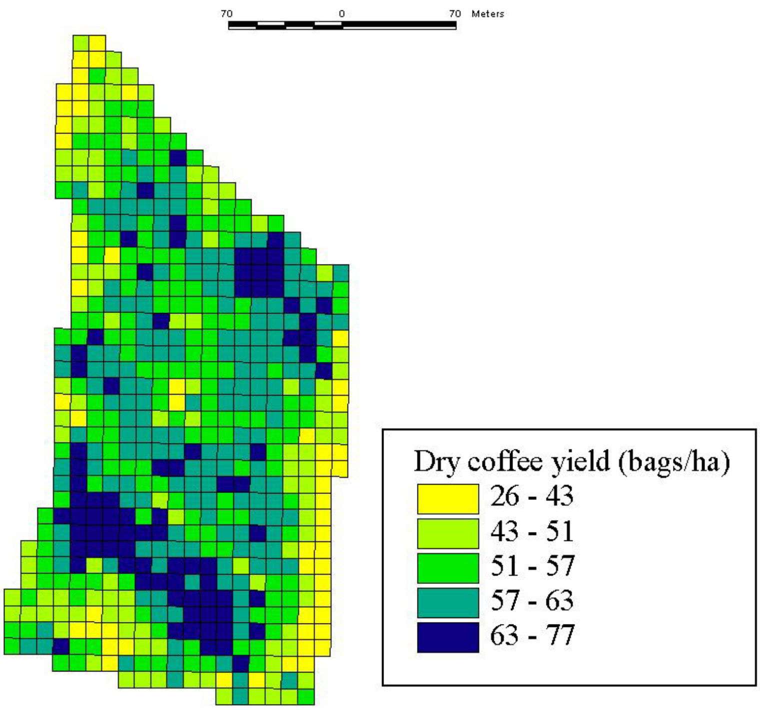

Figure 2. Yield map of dry and peeled coffee grains from field 2.

Table 2. Synthesis of the results from geostatistical analysis of the chemical fertility soil components from field 2.

Factor			Model	Nugget effect Co	Sill C	Range A (m)	CR[1]
pH			Exponential	0.1366	0.1376	77	49.8
Organic matter	OM	g/dm^3	Exponential	0.001	2.765	71.4	0.1
Cation exchange capacity	CEC	$mmolc/dm^3$	Spherical	1.6	63.44	57.8	2.5
Hidrogen+ Aluminum	H+Al	$mmolc/dm^3$	Exponential	3.1	9.54	57	24.5
Calcium	Ca	$mmolc/dm^3$	Exponential	26.6	0.79	587.2	9.2
Sum of bases	SB	$mmolc/dm^3$	Exponential	0.1	94.03	55.4	0.1
Phosphorus	P	mg/dm^3	Spherical	208.2	298.8	85.5	41.1
Zincum	Zn	mg/dm^3	Exponential	2.61	8.35	165.8	23.8
Boron	B	mg/dm^3	Exponential	0.00286	0.00445	241	39.1
Copper	Cu	mg/dm^3	-	1.12	8.22	365.4	12
Potash	K	$mmolc/dm^3$	Spherical	0.00178	0.2948	72	5.7
Sulfur	S	mg/dm^3	Spherical	1.198	2.707	208.4	30.7
Magnesium	Mg	$mmolc/dm^3$	Exponential	10.31	17.05	259.6	37.7
Manganese	Mn	mg/dm^3	Spherical	7.28	22.78	63.8	24.2
Iron	Fe	mg/dm^3	Spherical	120	406.9	190.4	22.8
Base saturation	V%	$mmolc/dm^3$	Exponential	196.4	210	104.4	48.3

[1]CR = C0/(C0+C)*100

Table 3. Correlation results between each elements of the soil chemical fertility and yield for the two experimental areas.

Factor			Field 1	Field 2
Sulfur	S	Mg/dm^3	0.21	-0.11
Boron	B	Mg/dm^3	-0.09	-0.09
Sum of bases	SB	$Mmolc/dm^3$	0.05	0.02
Calcium	Ca	$Mmolc/dm^3$	0.03	0.00
Manganese	Mn	Mg/dm^3	0.34	-0.14
Magnesium	Mg	$Mmolc/dm^3$	0.07	0.06
Phosphorus	P	Mg/dm^3	0.09	-0.11
Cation exchange capacity	CEC	$Mmolc/dm^3$	0.06	0.03
Copper	Cu	Mg/dm^3	0.09	0.01
Iron	Fe	Mg/dm^3	-0.36	-0.09
Zinc	Zn	Mg/dm^3	-0.09	0.12
Potash	K	$Mmolc/dm^3$	0.07	-0.20
Base saturation	V%	$Mmolc/dm^3$	0.15	-0.01
Hidrogen + Aluminum	H+Al	$Mmolc/dm^3$	0.01	0.07
Organic matter	MO	g/dm^3	-0.20	0.14
pH			0.08	-0.03

The correlation analysis results between each element of the soil chemical fertility and yield for the two areas is presented in the Table 3. The correlation coefficients resulted in low values, confirming the tendency that has been observed in several works as, for example, the one of Acock and Pachepsky (1997) and Molin et al. (2001). However, those lower correlations still indicate some tendencies. On field 1, some components of the fertility were evidenced with correlation coefficients at the order of -0.39 (Fe), 0.36 (Mn) and -0.24 (OM). On field 2, correlation coefficients of –0.22 for K, –0.14 for P, and –0.14 for Mn indicate some lack of balance. Also, it indicates that the yield on field 1 is more dependent on some of the soil chemical components, even for the most intense yield differences if compared with field 1, where the areas of different yields are less evident. On area 2, correlations with important soil fertility components as K, P and Mn may indicate a condition of inadequate fertilization in the area, resulting in distortions that are evidenced in negative correlation coefficients.

As soon as new yield maps are available and those confirm tendencies of space variability, measures of zone management definition can be implemented, based on yield. Inside those units, fertilizer application may be conducted with more criteria to minimize the evidenced distortions. New soil samplings may be guided by the managing zones and not by grid to rationalize the cost of obtaining information.

CONCLUSIONS

Yield maps characterize an accentuated variability of coffee yield in the two fields and it indicates the need of definition of differentiated managing zones, especially for fertilizer application. Correlations between soil fertility components and yield, although of low values, offered important indications. In the second field there is an accentuated unbalance that resulted in negative correlations for important components of the soil fertility.

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