# PRECISION AGRICULTURE IN SUGARCANE PRODUCTION. A KEY TOOL TO UNDERSTAND ITS VARIABILITY.

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## ABSTRACT

Precision agriculture (PA) for sugarcane represents an important tool to manage local application of fertilizers, mainly because sugarcane is third in fertilizer consumption among Brazilian crops, after soybean and corn. Among the limiting factors detected for PA adoption in the sugarcane industry, one could mention the cropping system complexity, data handling costs, and lack of appropriate decision support systems. The objective of our research group has been to demonstrate to sugarcane growers and society PA economic advantages, environmental gains and yield/quality benefits in order to help boost its adoption. In this article we report an experiment that has been conducted since 2010 in a commercial site of 50 ha, using grid sampling (50 x 50 m – 204 points) and yield monitor. Results show that after two years of fertilizer application using variable rate technology, the amount of P available in the soil for plant nutrition was better distributed, stable and sufficient to supply crop needs. K requires replacing at different rates at each year, and its average availability for plant nutrition is been reduced. We could not find any pattern in soil K extraction, and it was certainly not related to yield. We also detected that on the first year (plant cane) the lowest part of the field presented the highest yield, but in the following year (first ratoon) the same area presented an abrupt reduction in yield. A deep investigation evidenced that this phenomenon could be explained by ratoon damage during the first harvest. This damage, which is almost impossible to repair and will impair the whole sugarcane cycle, could be detected by PA tools, thus demonstrating the usefulness of PA applied to sugarcane.

**Keywords**: Mapping soil properties; yield monitor; grid sampling.

## INTRODUCTION

Precision Agriculture (PA) comprises some management practices to attempt increase productivity, profitability and improve environmental stewardship of rural areas. Essentially, the benefits are achieved by local treatment, considering the spatial variability. The better practices of precision agriculture to manage variability of soil inputs, crop agrochemical, may increase sustainable production, overcoat due to profitability, productivity, crop quality, on-farm quality of life, food safety and rural development (Zamykal & Everingham 2009). Precision Agriculture for sugarcane represents an important tool to manage local application of fertilizers, mainly because among Brazilian crops, sugarcane is third in fertilizer consumption, after soybean and corn (Cantarella & Rossetto 2010). Sugarcane is a high-yielding crop that requires significant amounts of plant nutrients, since mineral elements comprise 3-5% of its dry matter. Average nutrient content per 100 Mg of stalks has been estimated to be N: 100-154 kg; $P_2O_5$: 15-25 kg; $K_2O$: 77-232 kg and S: 14-49 kg (Franco et al. 2007; Moura Filho et al. 2008; Raij et al., 1997; Rossetto et al. 2008). The effect of bad nutrient management control is cumulative and affects crop response especially in sugarcane, a semi perennial crop, which typically grown in cycles of four–seven years. Furthermore, fertilization according to local necessity eases environmental regulation control.

The main technologies available for PA users are yield monitors, remote and proximal sensing, Global Navigation Satellite Systems (GNSS) and Global Information Systems (GIS). However, these technologies are more advanced in cereals and grains, when compared to sugarcane. A survey realized by Silva et al. (2011) in 2008, showed that aside from intensive activity at only a few mills and growers, there was essentially no PA activity in the Brazilian sugar industry. This scenario has not changed much since then and demonstration to growers and society, the economic advantages, environmental gains and yield/quality benefits may help boost adoption of precision agriculture. Therefore, the objective of this paper is to show, based on a three years field experiment, that there are evident contributions that PA could bring to the sugarcane industry, which could lead to better management practices and cost saving if corrected applied.

## MATERIALS AND METHOD

The experiment has been conducted since 2010 in a commercial site of 50 ha in Serra Azul, São Paulo State, Brazil, which belongs to Pedra Sugar Mill. The climate is tropical to subtropical, and mean annual rainfall and temperature are 1560 mm and 22.9 $^{o}$C, respectively. The soil is a typic Oxisoil (Soil Survey Staf 2010). It is clayey and its clay fraction being dominated by kaolinite, and iron and aluminium oxihydroxides mainly. The site had been under continuous sugarcane cultivation (*Saccharum spp.*) for 30 years. Before sugarcane planting a survey of the area was carry out in November 2010 to establish the soil chemical and physical conditions and nutrient need for crop implementation. The area was divided into a regular 50-m grid (204 sample points) and points located in the field using a differential global positioning system (DGPS) (Ag114™, Trimble, Navigation Ltd, Sunnyvale, CA, USA). Soil sample was taken at two depths (0–0.20 and 0.20–0.40 m) at each grid point and a wet-chemical analysis was done to determine soil physical and chemical attributes (pH, macro and micronutrients) (Fig. 1).

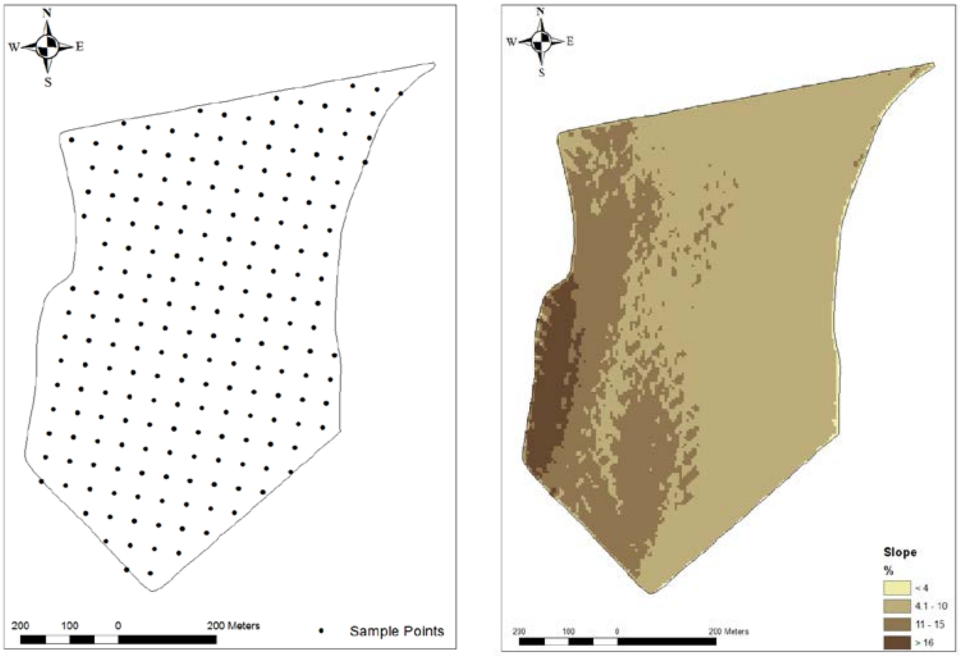

**Fig. 1. Grid (204 points) for soil and planting data collecting (left) and soil slope (right).**

Based on soil survey results, we made corrections for soil acidity and fertiliser recommendations for variable rate application prescription maps for lime, potassium (K) and phosphorus (P). After that, the field was disc ploughing, subsoiling and disc harrowing. Solid fertilisers were applied during the furrow-opening operation using potassium chloride (KCl) and monocalcium phosphate $(Ca\ (H_2PO_4)^2)$ under variable rate technology (VRT) and nitrogen (N) (urea, 140 kg $ha^{-1}$) and micronutrients (zinc, sulphate, 0.15 kg $ha^{-1}$; ammonium molybdite and boric acid 0.4 kg $ha^{-1}$) at uniform rate. Sugarcane variety CTC09 was planted in April 2011, in a semi-mechanized operation, where sugarcane stalks are laid in the furrow and cut manually, followed by a mechanical operation for furrow closing.

The area was harvested in August 2012 (plant cane) and August 2013 (first ratoon) using a John Deere sugarcane harvester equipped with auto-guidance system with a RTK signal (Trimble, Navigation Ltd, Sunnyvale, CA, USA) and a yield monitor (Simprocana, Enalta, São Carlos, Brazil). Annually, after harvest, soil samples were taken again at same grid to diagnose some deficiency and recommend fertilizer application using VRT prescribed based on soil survey (P and K) and on yield of the previous year (N).

## Statistical and geostatistical analysis

Outliers were removed from datasets as a data preparation step prior to geostatistical analysis. For each attribute measured at a given time, any entry deviating from the mean by more than three standard deviations was removed as an outlier. The outlier removal routine was applied iteratively, recalculating mean and standard deviation until no additional outlier could be identified. Maximum of 7 % of entries were removed as outliers from soil data measured by sampling at grid points. and 3% for yield monitor data. The Shapiro-Wilk statistic was also calculated for the data to test for normality. If the calculated W value was significant at $P \leq 0.05$, the distribution was considered non-normal. Soil attributes was then converted to the logarithm of concentrations since its reduced the positive skewness from concentration distributions.

We used Moran´s I to evaluate the spatial autocorrelation for each one of the measured attributes. The spatial autocorrelation for the attribute j, $I_j$, was calculated by (eq 1) (Cliff & Ord 1973).

$$I_j = \mathbf{z_j}^T L \, \mathbf{z_j}, \qquad \textbf{eq 1.}$$

In Eq. 1, $\mathbf{z_j}$ is the vector of attribute values at grid points, with attribute values mean-centered and normalized to unit variance. The matrix L is derived from the connection matrix M whose elements equal one for neighbour grid points and zero otherwise. L is obtained from M by normalizing each line to sum to unit. $I_j \approx 0$ evidence random spatial distribution, indicating an attribute j that cannot be used to justify any site-specific intervention on the field. On the other hand, greater values of $I_j$ imply some clustering in space of the high and low values of $\mathbf{z_j}$, indicating an attribute bringing potentially valuable information for PA.

To obtain yield values at the same sampling grid from which soil samples were collected, we used the cleaned dataset of each year and estimate the value at a grid point by employing linear regression to fit a plane within a circle of 25 m radius centered at each grid point, forming a single sheet with all the information. For all attributes the experimental and theoretical semivariograms were constructed for data interpolation, using a regular grid of 5 meters and applying ordinary kriging. All these analyzes were performed using ArcGIS 10.2 (ESRI, Environmental Systems Research Institute, Redlands, CA, USA) using the Spatial Analyst Tools and Geostatistical Analyst Tools extensions.

## RESULTS and DISCUSSION

### Temporal stability and descriptive statistics of soil properties

The degree of in-field variability depended on the specific attribute (Table 1). As expected its calculated mean increases after soil fertilization for the applied macro and micronutrients, and reduced or remain almost the same in the following year as the nutrient is extracted by the plant and, with the exception of P and K, they are not replaced between successive sugarcane crop seasons (Fig.

2). During the three years of evaluation, only Ca and B exhibited normal distributions. The remaining soil properties did not have normal distributions as determined from the Shapiro – Wilkes statistic. The majority of these properties also exhibited a not significant skew or kurtosis values, with the exception of Cu during the whole period and Mg, S and Z in 2012 and 2013 analysis and Mg in the last year which have a significant skew. P and Fe possessed significant kurtosis values only in 2012. Special attention should be paid to some soil attributes which presents a high value of CV of such as K, P, Mg, B, Cu and Z indicating that the data could be composed by noise more than useful information for PA. Another interesting observation was that the data was consistently expressed over time, maintained means and CV on the same range.

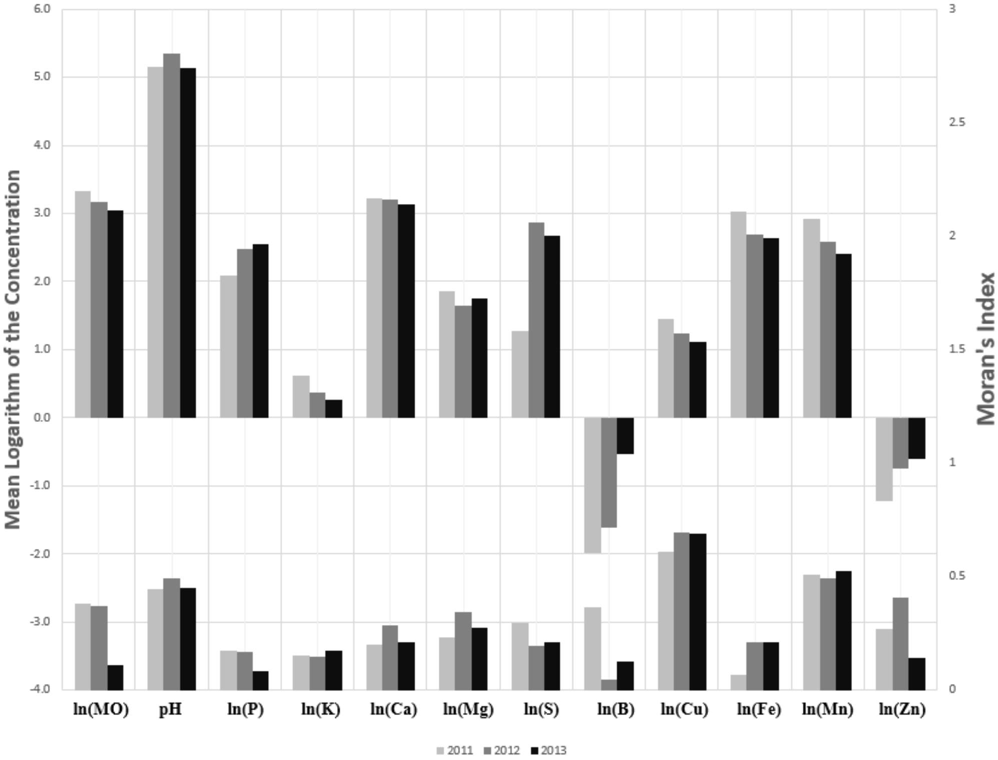

**Fig. 2. Mean logarithm concentration of soil attributes for successive years (top) with the respective Moran's Index (bottom), been 2011 data collected before soil preparation and fertilization.**

Fig. 3 presents data in a way to evidence the temporal stability (or the lack of it) in the spatial distribution of each attribute. Temporal stability is measured by a simple correlation between a given attribute in two successive years calculated from attribute values in the vector of grid points. Perfect temporal stability would imply correlation equal to one, but in practice correlation is reduced by noise in measurements. Moran's I spatial autocorrelation, which is also reduced by noise in measurements, serves as a control for distinct noise levels in the data. Hence, in Fig. 3 attributes that are close to the diagonal line are consistent with temporal stability, and the reduced correlations could be attributed to measurement noise. Therefore, measurement noise is an issue to be carefully considered for all inferences made from PA experiments.

**Table 1** – Descriptive statistics and Moran's Index of soil attributes in the layer 0.00-0.20 m

| | **ln(MO)** | **pH** | **ln(P)** | **ln(K)** | **ln(Ca)** | **ln(Mg)** | **ln(S)** | **ln(B)** | **ln(Cu)** | **ln(Fe)** | **ln(Mn)** | **ln(Zn)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2011** | | | | | | | | | | | | |
| **Valid N** | 203 | 204 | 202 | 199 | 200 | 201 | 204 | 201 | 203 | 201 | 203 | 200 |
| **Mean** | 3.329 | 5.144 | 2.085 | 0.624 | 3.218 | 1.849 | 1.271 | -1.979 | 1.446 | 3.024 | 2.925 | -1.224 |
| **SD** | 0.154 | 0.279 | 0.383 | 0.516 | 0.307 | 0.313 | 1.218 | 0.208 | 0.284 | 0.181 | 0.396 | 0.525 |
| **CV** | 4.617 | 5.431 | 18.350 | 82.735 | 9.534 | 16.903 | 95.778 | -10.518 | 19.653 | 5.992 | 13.553 | -42.868 |
| **Kurtosis** | -0.178 | -0.268 | 0.280 | 0.132 | 0.012 | -0.218 | -0.455 | 0.245 | -0.136 | -0.172 | -0.119 | 0.238 |
| **Skewness** | 0.102 | -0.072 | 0.235 | -0.426 | -0.104 | -0.226 | -0.180 | -0.029 | 0.422 | 0.079 | -0.229 | -0.121 |
| **Normality** | 0,988 | 0,985 | 0,976 | 0,986 | 0,995 | 0,967 | 0,996 | 0,995 | 0,971 | 0,098 | 0,978 | 0,988 |
| **Significance** | ns | * | ** | * | ns | * | ns | ns | * | ** | ** | ns |
| **Moran's I** | 0.382 | 0.446 | 0.174 | 0.152 | 0.199 | 0.233 | 0.294 | 0.362 | 0.607 | 0.069 | 0.506 | 0.267 |
| **2012** | | | | | | | | | | | | |
| **Valid N** | 203 | 204 | 203 | 200 | 201 | 203 | 200 | 203 | 204 | 203 | 202 | 188 |
| **Mean** | 3.172 | 5.343 | 2.481 | 0.373 | 3.202 | 1.647 | 2.865 | -1.620 | 1.245 | 2.693 | 2.589 | -0.747 |
| **SD** | 0.192 | 0.288 | 0.463 | 0.374 | 0.263 | 0.331 | 0.319 | 0.465 | 0.343 | 0.223 | 0.440 | 0.428 |
| **CV** | 6.051 | 5.391 | 18.674 | 100.142 | 8.227 | 20.113 | 11.144 | -28.702 | 27.529 | 8.285 | 16.981 | -57.240 |
| **Kurtosis** | 0.417 | -0.476 | 1.592 | -0.177 | -0.075 | 0.108 | 0.171 | 0.023 | 0.498 | 0.846 | 0.162 | 0.362 |
| **Skewness** | 0.246 | -0.105 | 0.060 | 0.086 | -0.167 | -0.495 | 0.477 | -0.001 | 0.383 | -0.182 | -0.240 | 0.495 |
| **Normality** | 0,985 | 0,983 | 0,965 | 0,992 | 0,991 | 0,949 | 0,976 | 0,991 | 0,977 | 0,973 | 0,990 | 0,949 |
| **Significance** | * | * | ** | ns | ns | ** | ** | ns | ** | ** | ns | ** |
| **Moran's I** | 0.369 | 0.492 | 0.169 | 0.149 | 0.286 | 0.343 | 0.197 | 0.044 | 0.695 | 0.209 | 0.494 | 0.409 |
| **2013** | | | | | | | | | | | | |
| **Valid N** | 197 | 197 | 194 | 195 | 194 | 196 | 191 | 197 | 197 | 196 | 195 | 195 |
| **Mean** | 3.052 | 5.142 | 2.548 | 0.264 | 3.136 | 1.758 | 2.667 | -0.541 | 1.121 | 2.630 | 2.410 | -0.606 |
| **SD** | 0.171 | 0.256 | 0.692 | 0.550 | 0.299 | 0.380 | 0.321 | 0.276 | 0.367 | 0.265 | 0.392 | 0.217 |
| **CV** | 5.598 | 4.970 | 27.177 | 208.209 | 9.524 | 21.621 | 12.053 | -51.037 | 32.694 | 10.077 | 16.260 | -35.779 |
| **Kurtosis** | 0.486 | -0.243 | -0.578 | -0.440 | -0.369 | 0.303 | 0.391 | -0.139 | 0.173 | 0.216 | -0.305 | 0.845 |
| **Skewness** | -0.179 | 0.269 | 0.657 | -0.146 | -0.008 | -0.458 | 0.421 | 0.083 | 0.379 | 0.058 | -0.399 | -0.554 |
| **Normality** | 0,983 | 0,978 | 0,929 | 0,986 | 0,987 | 0,965 | 0,980 | 0,991 | 0,983 | 0,988 | 0,981 | 0,909 |
| **Significance** | * | ** | ** | * | ns | ** | ** | ns | * | ns | ** | ** |
| **Moran's I** | 0.110 | 0.451 | 0.081 | 0.172 | 0.211 | 0.276 | 0.213 | 0.123 | 0.688 | 0.212 | 0.522 | 0.140 |

* Significant at the 0.05 probability level. ** Significant at the 0.01 probability level. Normality from the Shapiro–Wilk test. If the test statistic is significant, then the distribution is not normal.

Interestingly, there are a few attributes that more clearly deviate from the diagonal trend, suggesting that their spatial distribution varied significantly between successive years (2011 to 2012 or 2012 to 2013). We observed that those are mainly Zn, S, B, and yield. The most challenging was to explain the lack of temporal stability in yield since yield has been observed by several authors to be temporally stable (Bramley 2009; Johnson & Richard Jr. 2005; Lawes et al., 2004; Zamykal & Everingham 2009).

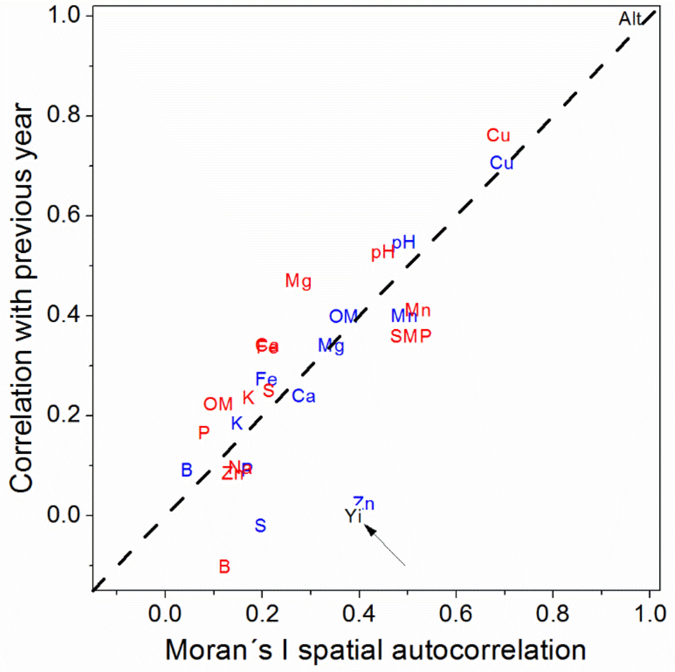

**Fig. 3: Correlation with previous year against Moran´s I spatial autocorrelation for attributes of soil chemistry from 2012 (correlated with 2011, blue) and 2013 (correlated with 2012, red) in soil layer 0-0.20 m. Altitude (Alt) and Yield (Yi, pointed by arrow) measured during the 2013 harvest (correlated with the 2012 harvest, black) are also shown.**

## Yield temporal and spatial variability

The yield data provided by the yield monitor were used to quantify and characterize the within-field yield spatiotemporal variability. Whole field yield monitor data ranged from 38 to 140 Mg ha$^{-1}$ on cane plant and from 62 to 127 Mg ha$^{-1}$ in first ratoon with average 109 and 93 Mg ha$^{-1}$, respectively. As expected, the yield was great in the cane plant (~15%) and presented a higher yield in the west part of the field, where the slope is great (Fig. 1 and Fig. 4).

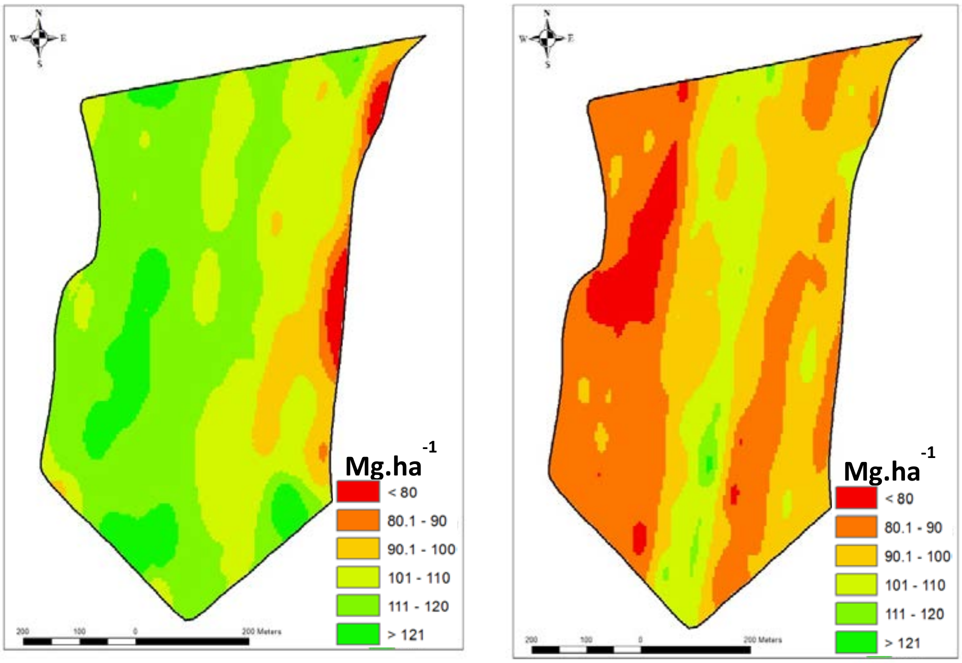

**Fig. 4. Sugar cane yield in 2012 cane plant (left); 2013 first ratoon (right) in Mg ha$^{-1}$.**

Analysing the in-field spatial yield patterns, their lack of temporal stability is a critical first step in evaluating the appropriateness of precision management. A field survey realized in November 2013 to investigate the causes of abrupt reduction in yield reported that in the area where the slope is more preeminent (> 10%) the percentage of gaps in cane row was greater. This probably was caused by ratoon removal and damage to it during the first harvest operation. Pronounced sugarcane lodging during cane-plant and shallow planting system adopted by the mill favored ratoon uprooting promoted by harvester base cutter, and on the top of that, there is the difficulty for the operator to maintain the harvester travelling straight, even with the support of an automatic steering.

To confirm this observation the yield data was further analysed. Yield estimates at grid points could be divided in three groups in Fig. 5: i) normal areas corresponding mostly to the central part of yield distributions (green points); ii) areas (east of the field) where we have evidence of failure of the yield monitor during the 2012 harvest (black points); and iii) areas with slope greater than ~10% (red points), where loss of yield is, on average, more pronounced. In the first group, yield decreases within the expected range (14 Mg ha$^{-1}$ average), while for steeper slopes yield decreases more substantially (32 Mg ha$^{-1}$ average). Further, recalculating the yield correlation between successive years, but now keeping only the "normal" areas (green points), a correlation of 0.32 is obtained. This recalculated inter-year correlation for yield would bring the yield point upwards in Fig. 3, which would be now close to the diagonal trend and, therefore, consistent with yield temporal stability. That is, failure of yield monitor and, more importantly, real yield loss due to crop damage by harvester at steeper slopes could be identified as causes for the lack of temporal stability in sugarcane yield.

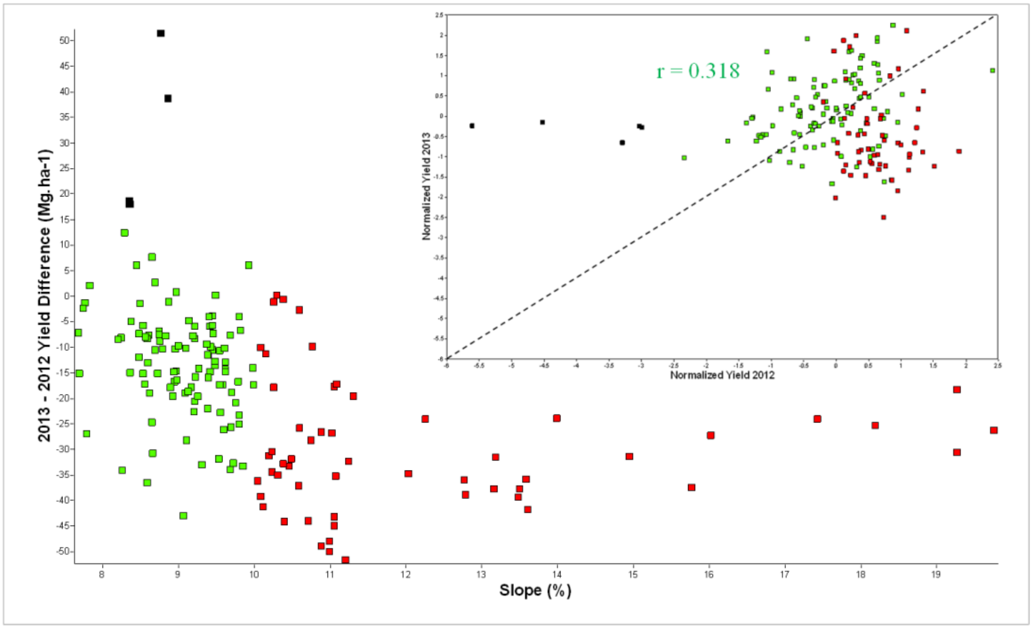

**Fig. 5 – Yield decrease between successive years as function of the field slope and the Person´s correlation between the successive years yield normalized data.**

## Fertilizer application using VRT

Soil fertilization using VRT was efficient and may contributes to the reduction of the amount of fertilizers applied in the field. Liming applied before soil preparation was effective and after 18 months, pH values reached expected and BS was below but close to the expected value of 60%. However, we notice that in the second year, pH reduced to values close to 2011, suggesting an additional liming will be necessary after the next harvest in 2014, mainly in the west part of the field (Fig. 6), again, VRT should used. Before cane planting the concentration of P in soil was below recommendation (7-15 mg dm$^{-3}$) in many parts of the field. After Ca $(H_2PO_4)^2$ application in 2011 and 2012, as the main source of P, the field was partially recovered in 2012 and in 2013, concentration of P reached expected level, presenting more than 50% of the area with values in the 16-40 mg dm$^{-3}$ range, considered ideal for sugarcane crop (Raij et al. 1997), therefore P was not applied in 2013 (Fig. 7). There was an increase in the amplitude of P concentration after application of phosphate using VRT, due to higher maximum values, with an increase in the SD and CV, but with a significant reduction in Moran´s I, was the concentration amplitude increases.

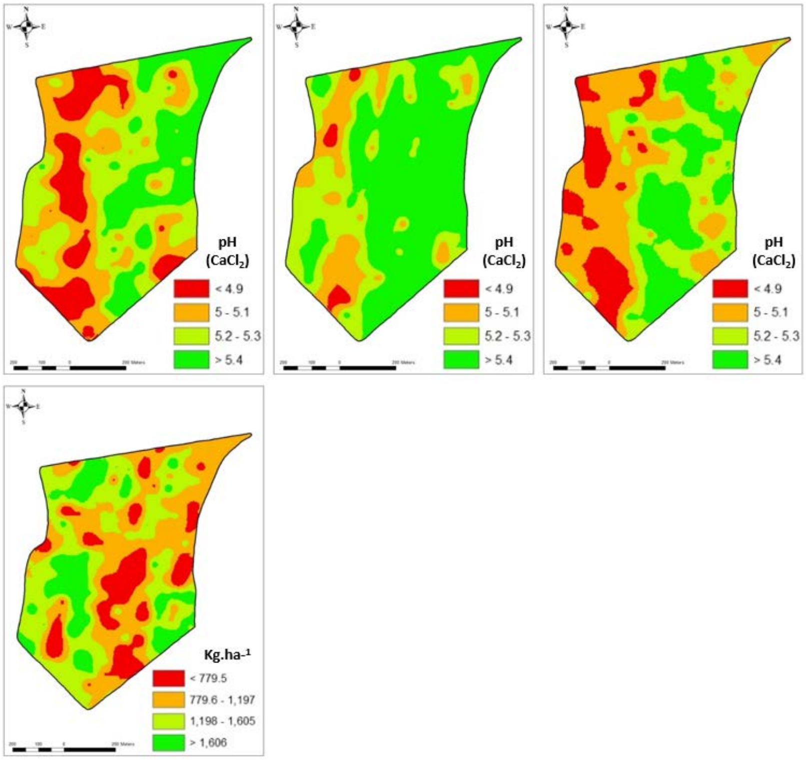

**Fig. 6 - pH in the field (top) for 2011, 2012 and 2013 (from left to right) and lime as applied in 2011 using VRT (bottom).**

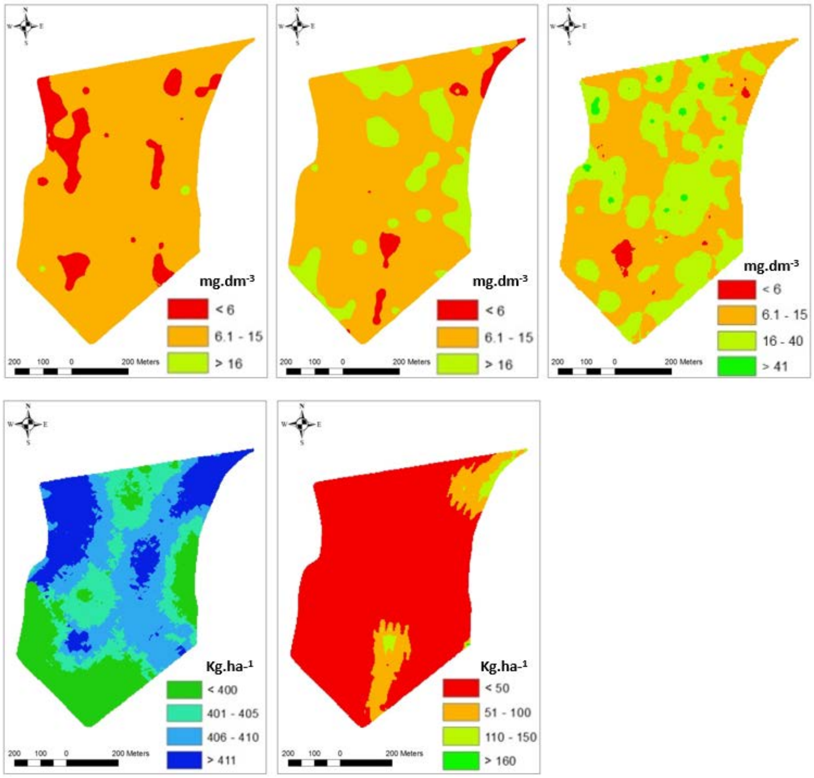

**Fig. 7 – Phosphorus concentration in the field (top) for 2011, 2012 and 2013 (from left to right) and P as applied in the field using VRT (botton).**

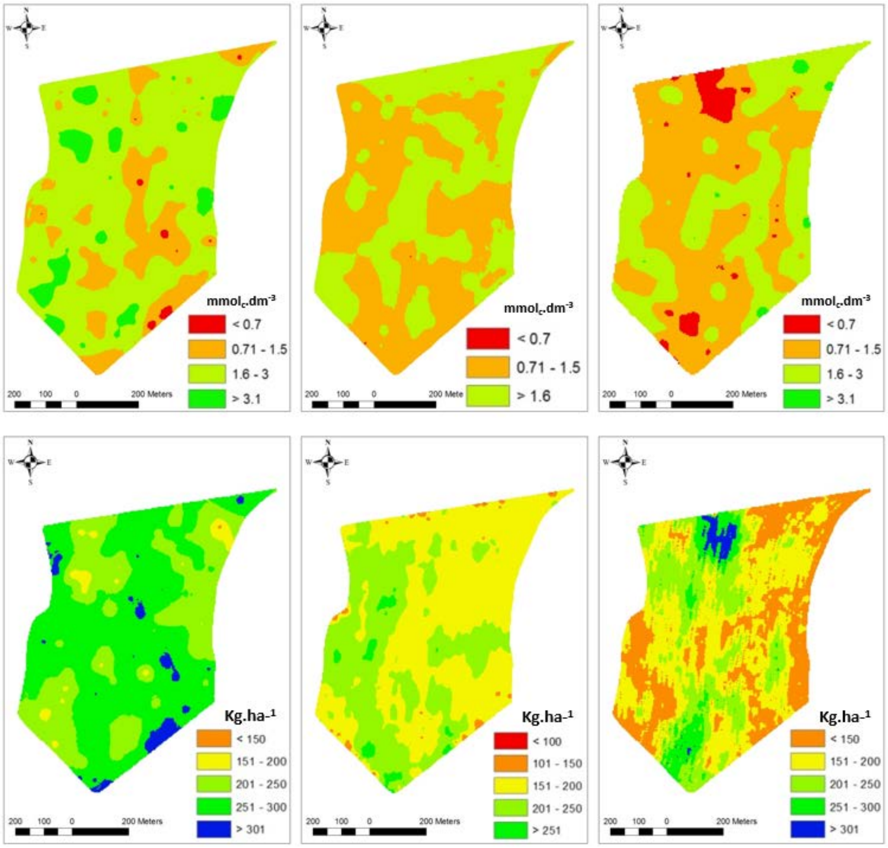

**Fig. 8 Potassium concentration in the field (top) for 2011, 2012 and 2013 (from left to right) and K as applied in the field using VRT (bottom).**

Nitrogen prescription maps was based on previous year yield map (Fig. 9), and was applied 90 days after harvesting using ammonium nitrate ($NH_4(NO_3)$) with 32% of N. The adopted strategy was, on the top of a minimum amount request to supply the sugar cane needs regarding N (60 kg ha$^{-1}$), one kg of N was applied for each Mg of sugarcane yield expected, based on the hypothesis that the yield correlation between following years was significant. As previous discussed this hypothesis was not confirmed and the correlation between 2012 and 2013 yield was only 0.3, even disregarding the area with steep slope, where crop standard was reduced due to ratoon damage. Suggesting that another methodology to produce N prescription maps for sugarcane should be used, probably based on canopy reflectance sensor used on-the-go, as it has been investigated by Colaço, et al. (2012).

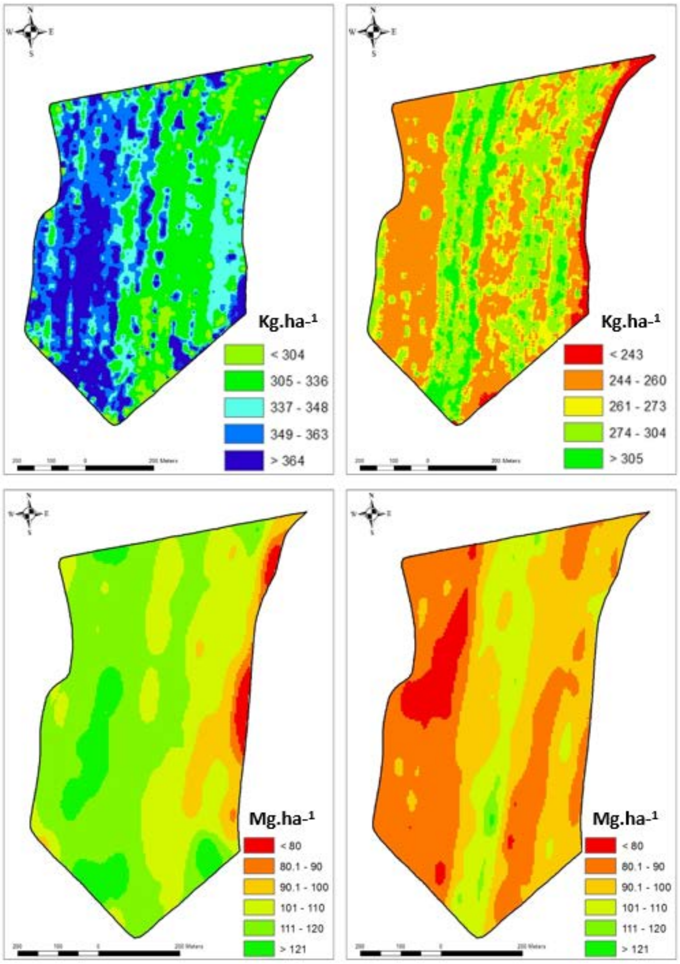

**Fig. 9. N as applied in the field using VRT (top) and sugarcane yield (bottom), 2012 (left) and 2013 (right).**

# CONCLUSIONS

We demonstrated here that PA can be a useful tool for the sugarcane industry. The appropriate fertilizer management helps to equilibrate and stabilize soil attributes, providing to the crop sufficient nutrients. VRT was efficient for lime and P application, but for N and K the strategy for nutrient replacement should be revised. For K it was possible to identify through maps of exchangeable potassium content in soil that its concentration is reducing to levels below recommendation, and therefore K must be replaced at great rate. For N recommendation, the hypothesis of significant correlation between successive yields was not verified, and other mean of detecting N needs for the crop should be used. Thematic maps of yield and soil attributes are a powerful tool for crop management, providing useful information about the crop standard and soil characteristics across the field. Without this tool, it will be almost impossible to detect field problems which are affecting productivity and consequently economically return.

# REFERENCES

Bramley, R. G. V. (2009). Lessons from nearly 20 years of Precision Agriculture research, development, and adoption as a guide to its appropriate application. *Crop and Pasture Science*, *60*(3), 197–217. doi:10.1071/CP08304

Cantarella, H., & Rossetto, R. (2010). Fertilizers for Sugar Cane. In L. A. B. Cortez (Ed.), *Sugarcane Bioethanol* (First., pp. 405–422). Editora Blucher, São Paulo.

Cliff, A. D., & Ord, J. K. (1973). *Spatial autocorrelation* (p. 178). London : Pion.

Colaço, A. F., Povh, F. P., Molin, J. P., & Romanelli, T. L. (2012). Energy assessment for variable rate nitrogen application. *Agric Eng Int: CIGR Journal*, *14*(3), 85–90.

Franco, H. C. J., Bologna, I. R., Faroni, C. E., Vitti, A. C., & Trivelin, P. C. O. (2007). Acúmulo de macronutrientes em cana-de-açúcar em função da adubação nitrogenada e dos resíduos culturais incorporados ao solo no plantio. *Bragantia*, *66*(4), 669–67.

Johnson, R. M., & Richard Jr, E. P. (2005). Sugarcane Yield, Sugarcane Quality, and Soil Variability in Louisiana. *Agronomy Journal*, *97*(3), 760–771. doi:10.2134/agronj2004.0184

Korndörfer, G. H., & Oliveira, L. A. (2005). O potássio na cultura da cana-de-açúcar. In T. Yamada & T. L. Roberts (Eds.), *Potássio na agricultura brasileira.* (pp. 469–490). Potafós, Piracicaba, SP.

Lawes, R. A., Wegener, M. K., Basford, K. E., & Lawn, R. J. (2004). The evaluation of the spatial and temporal stability of sugarcane farm performance based on yield and commercial cane sugar. *Australian Journal of Agricultural Research*, *55*(3), 335.

Moura Filho, G., Silva, L. C., Almeida, A. C. S., Souza, J. L., Teodoro, I., Barbosa, G. V. S., … Moura, A. B. (2008). Extração e exportação de nutrientes pelas cultivares RB92579 e RB93509 no ciclo de cana-planta. In *9. STAB National Congress* (pp. 307–311).

Raij, B. van., Cantarella, H., Quaggio, J. A., & A. M. C. Furlani. (1997). *Recomendações de adubação e calagem para o Estado de São Paulo.* (p. 285). Instituto Agronômico; Fundação IAC, *Campinas, SP.*

Rossetto, R., Dias, F. L. F., Vitti, A. C., Cantarella, H., & Landell, M. G. A. (2008). Manejo conservacionista e reciclagem de nutrientes em cana-de-açúcar tendo em vista a colheita mecânica. *Informações Agronômicas*, 8–13.

Silva, C. B., Moraes, M. A. F. D., & Molin, J. P. (2011). Adoption and use of precision agriculture technologies in the sugarcane industry of São Paulo state, Brazil. *Precision Agriculture*, *12*(1), 67–81. doi:10.1007/s11119-009-9155-8

Soil Survey Staf. (2010). *Keys to Soil Taxonomy* (p. 346).

Zamykal, D., & Everingham, Y. L. (2009). Sugarcane and Precision Agriculture: Quantifying Variability Is Only Half the Story – A Review. In E. Lichtfouse (Ed.), *Climate Change, Intercropping, Pest Control and Beneficial Microorganisms* (pp. 189–218). Dordrecht: Springer Netherlands.