An Acad Bras Cienc (2020) 92(suppl.1): e20190277 DOI 10.1590/0001-3765202020190277
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

AGRARIAN SCIENCES

Comparative economic analysis of soil sampling methods used in precision agriculture

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Abstract: Precision agriculture is an alternative for reducing costs. This study evaluated and economically compared three sampling methods used in precision agriculture with respect to the acquisition of inputs and machines and equipment. The sampling methods used were zone management by elevation (ZME), grid sampling (GS) and sampling guided by apparent electrical conductivity of the soil (OS). Soil samples for the ZME were collected after the definition of zones according to the elevations of the plots. The sample mesh was in a georeferenced mesh of 100 x 100 m. The targeted sampling was performed after a ground proximity sensor was used to identify the apparent electrical conductivity of the soil to define the management areas. From the results of the laboratory tests, the application costs were calculated for lime, phosphorus, potassium and nitrogen to allow a comparison between the methods, volumes and costs. This approach considered the costs of depreciation, insurance, interest, operating costs, labor, maintenance and fuel. With this study, it was possible to compare the volumes of the recommended fertilizers and estimate the overall economic cost of using the technology via sensor. Taking the GS as a reference, the ZME presented as the best alternative compared to other methods.

Key words: Management zones, sample grids, sensor, electrical conductivity.

INTRODUCTION

Precision agriculture (PA) is a modern concept of agricultural management that allows decisions to be made assertively, fertilizers to be applied in the correct locations, and production costs to be reduced (Servadio et al. 2011). PA uses intensive data collection (Harmon et al. 2005), which provides accurate tracking and adjustment of production (Goswami et al. 2012), enabling the definition of management zones for the custom management of inputs (Mulla 2013).

PA involves the application of technology and agronomic principles to manage the spatial and temporal variation of all aspects of agricultural production to improve crop performance and environmental quality (Oliver et al. 2013).

According to Pierpaoli et al. (2013), PA is a relatively new concept of agricultural administration that was developed in the mid-1980s, and according to Crookston (2006), PA can be considered one of the ten greatest revolutions in agriculture.

The collection of soil samples constitutes one of the steps of the PA cycle and can be considered one of the most important in defining the proper management of a given area. Soil sampling is the removal of a small portion of soil from the area (Cardoso 2013). Traditional sampling considers the entire study area as homogeneous, and chemical recommendations are based on the average of the results (Ferraz

2012). In precision agriculture, some different ways are used to collect the soil samples, and grid sampling, management zone sampling, and sensor guided sampling can be highlighted.

In the study of sampling grids, samples are collected from regular grids and predefined georeferenced sampling points (Stepien et al. 2013, Montanari et al. 2012).

For a sampling to be representative, identifying the field variability is necessary (Cambardella et al. 1994) before the samples are taken for analysis (Lund et al. 1999), as the efficiency of the sample design is closely related to the variability of the attributes investigated (Montanari et al. 2012). This approach may lead to reduced costs through defining the lowest number of samples (Stepien et al. 2013). Management zones can be defined as the division of a given area into sub-areas or homogeneous management areas (Mzuku et al. 2005).

Currently, in PA, the use of apparent electrical conductivity (ECa) has been suggested to define management zones and produce maps. ECa can be obtained from magnetic induction and direct contact systems (Lund et al. 1999) and has been widely used for spatial variability studies of soil properties (Molin & Faulin 2013, Singh et al. 2016).

The characterization of the soil variability can be improved by using different ECa sensors (Kitchen et al. 2003, Mahmood et al. 2013). Bramley et al. (2005) suggested the possibility of replacing conventional analysis laboratories with new methods and sensors for data processing.

The main factor related to cost reduction is the premise of the localized application of inputs, since applications occur only in places of real need (Leão et al. 2011). Studies by various authors on coffee (Ferraz et al. 2011); soybean (Artuzo 2015); soybean, oats and wheat (Fiorin et al. 2011); corn, soybean and wheat (Fregonezi et al. 2014); and wild blueberry (Esau et al. 2016) agriculture show economic advantages for PA compared to conventional crop management methods. However, no study has attempted to economically compare the different soil sampling methods applied in precision agriculture, as the studies were restricted to comparisons between PA and the conventional method of managing an area.

Thus, the aim of the present study was to compare three different soil sampling methods used in precision agriculture and their economic impact on the agricultural production environment.

MATERIALS AND METHODS

This study was conducted on two farms (Termite and Juquiá), active in Guarapuava and Cantagalo, both in the state of Paraná, Brazil. According to the Köppen climatic classification, the climate of this region is characterized as humid subtropical (Cfa). The average annual temperature is 18ºC, with a maximum of 36ºC and a minimum of 6.8ºC. The elevation in the area is between 800 to 1200 m (Bortolini 2004). The soil of the areas under study is characterized as bruno aluminum podzolic latosol, with a prominent A horizon, gently undulating topography and a substrate of basalt (Fontoura et al. 2015), with textural class ranging from clayey to very clayey.

The experiments were conducted in three distinct areas. For better understanding of the comparison and analysis of the results, the areas were named as areas A1 (Termite Farm with an area of 154.82 hectares, geographic coordinates 25° 32’ 66” S and 51° 34’ 65” W Gr., and average elevation 1054.65 m), A2 (Termite Farm, Jordãozinho plot with an area of 18.64 ha, the geographical coordinates of 25° 31’ 74” S and 51° 30’ 49” W Gr., and average elevation of 1100.83 m) and A3 (Farm Juquiá, with an area was 62.63 ha, 25° 16’ 45.40” S and 52° 6’ 01” W Gr., with average elevation of 798.85 m).

The agricultural practices developed in these areas involve the rotation of cultures for at least 16 years following a rotating planting of soybeans, oats, corn, wheat and barley. Sowing takes place twice a year in the months from June to August and October to December, and the crops are harvested in November, February and March, according to plant rotation.

In the areas under study, three sampling methods were used to allow the comparison between them: zone management sampling by elevation (ZME), grid sampling (GS) and oriented sampling (OS).

For the collection of soil samples for the ZME method, first, the zones that were set from area altimetry data obtained from harvest maps were defined. So, we divided the area into three management zones: high, medium and low elevation. After the definition of management zones, samples were collected along a zigzag traversed in each zone (Silva et al. 2015), with 11 to 15 subsamples being collected and homogenized, after which representative samples were composed from those obtained from each zone.

In the case of the soil sampling method by means of grids (GS method), this was carried out by setting the first sampling grid of 100 x 100 m, or 1 (one) collection point per hectare. Thus, for the A1 area, 158 georeferenced sample points were obtained. For the A2 area 23 sampling points were georeferenced, and for the A3 area 65 sampling points were georeferenced. In each georeferenced point, 11 to 15 subsamples were collected on zigzag that have been properly mixed, and these were used to form a representative composite sample of the sample point. The subsamples were taken from the depth of 0 to 0.2 m by auger type collector and containers for homogenization.

For the oriented sampling method, the management zones were first set using a sensor of apparent soil electrical conductivity (ECa). The sensor works were coupled to and pulled by an agricultural tractor equipped with the same discs that cut soil with vertical movements, collecting apparent electrical conductivity from wavelengths sent to the ground and reflected to the machine. The ECa of the data are properly georeferenced, which allowed the definition of five management zones for each area. The traversed zigzag was done in each management area, similarly to the ZME method, by collecting 11 to 15 subsamples that were homogenized and used to form a composite sample representative of the management area in question. The subsamples were also obtained between 0 and 0.2 m deep using collector auger and mixing containers.

To define the levels of chemical elements necessary for the corrections of acidity and soil fertility, we used the recommendations suggested by the Embrapa Manual (1997). To obtain chemical recommendations for all methods, we evaluated the chemical elements of ground lime, phosphorus, potassium and nitrogen according to the recommendation of the methodology proposed by Fontoura et al. (2015). With these analyses, we were able to obtain the spatial distribution map of these chemical elements, as well as maps of the soil correction recommendation and soil fertilization for the three areas of study and for the three sampling methods.

Through the analysis of soil correction, recommendation maps, and fertilization, comparisons were possible for the quantities of each fertilizer recommended for each sampling method by total area of each plot studied.

The calculated values were converted from Reals to Dollar based on the listing on the day (11/01/2016) where each dollar was worth R$3.20.

The acquisition costs of inputs and freight followed the values shown in Table I.

For the collection of samples, the labor costs varied according to the sampling method and was determined by multiplying the total area (number of hectares in each study area) by the individual value of each collection. The amounts charged for the sample collection were US $10.31/ha for the method of sampling grids and US $6.88/ha for zones managed by elevation and targeted sampling. The costs of the laboratory tests were calculated by multiplying the number of samples by a single analysis value.

For evaluations of the implementation of corrective actions and fertilizers by means of agricultural machinery, the fixed costs and variable costs were defined by the sampling method (Cunha et al. 2016). Fixed and variable costs with machinery and equipment followed the methodology proposed by Balastreire (1994).

The implement used to apply lime and fertilizer was a fertilizer trailer with a volumetric metering system and double disc centrifugal distributor mechanism coupled to a tractor. The trailers were equipped with controllers for variable rate application of the lime and nitrogen. The application of phosphorus and potassium was performed by means of precision sowing. Costs were calculated in dollars per hectare.

Factors considered for the economic evaluation of the use of agricultural machinery and implements were depreciation, insurance, interest, operating costs, labor, maintenance and fuel.

Depreciation (equation 1) was calculated based on information about the average price of the new implement, the scrap value and the useful life. In this case, the average scrap value is subtracted, and the result divided by the useful life of the implements.

$$D^{\frac{US\$}{h}} = \frac{(VS - PM)}{VU} \quad (1)$$

where D is depreciation, VS is the scrap value, PM is the mean price, and VU is the lifespan.

In Brazil, the interest rate varied between 0.75% and 2.0% of the initial cost per year according to the model of the machine and the number of hours worked (Cunha et al. 2016); the interest rate applied in this study was 1.20% (14.40% pa).

To calculate the insurance, the interest rate, the average price of new implement and the scrap value were considered (equation 2). The final amount of insurance was calculated by multiplying the value of the interest rate by the average price and after adding the result to the scrap value. This value was divided by the number of hours worked per year.

Table I. Acquisition costs and freight.

Input	Value (US $)	Shipping (US $)	Total (US $)
Lime	13.18	10.63	23.81
Phosphorus	503.36	20.00	523.36
KCL	354.32	20.00	436.82
Urea	420.31	20.00	440.31

$$S_{US\$/h} = \frac{[(TX \times PM) + VS]}{HT} \quad (2)$$

where S is the insurance, TX is the interest rate, PM is the price mean, VS is the scrap value, and HT is the hours worked per year.

Interest is calculated in dollars per hour, relating the average price of the new implement, the scrap value, the interest rate and the number of hours worked per year (equation 3). The final value was obtained from the sum of the average price and the scrap value, dividing the result by 2 and multiplying by the interest rate. At the end, the value obtained is divided by the number of hours worked.

$$J_{US\$/h} = \frac{\frac{(PM+VS)}{2} \times TX}{HTA} \quad (3)$$

where J is the interest rate, PM is the price mean, VS is the value of scrap, TX is the interest rate, and HTA is the hours worked per year.

The cost of manpower to operate the machines was calculated based on the salary of employees, labor charges and the number of hours worked per month (equation 4). For the purposes of the calculation, the base salary was summed to charges, and the result divided by the number of hours worked per month.

$$MO_{US\$/h} = \frac{(SB+E)}{HTM} \quad (4)$$

where MO is the labor, SB is the salary base, E is the charges, and HTM is the hours worked per month.

The costs and maintenance were calculated based on the average price multiplied by the percentage of spending on preventive and corrective maintenance and the result was divided by the useful life of the equipment (equation 5).

$$GS_{US\$/h} = \frac{(PM \times GMa)}{T_{vida}} \quad (5)$$

where GS is the maintenance, PM is the price mean of equipment, GMa is the percentage of spending on preventive and corrective maintenance, and T_{vida} is the useful lifetime of the equipment (in hours).

Fuel costs were calculated in dollars per hour, with the consumption in liters per hour being multiplied by the cost of diesel per liter which was US $0.86 (equation 6).

$$C_{US\$/h} = (CS \times VAD) \quad (6)$$

where C is the fuel, CS is consumption, and VAD is the purchase price of diesel.

The operating cost relates the cost of hours worked and a piece of equipment and its real capacity to work (Cunha et al. 2016); thus, it was calculated based on the sum of the amounts resulting from the depreciation calculations, interest, maintenance, insurance, fuel and labor (equation 7).

$$CO = D + J + M + S + C + MO \quad (7)$$

where CO is the operating costs, D is the depreciation, J is the interest, S is the insurance, C is the fuel, and MO is the Labor.

To calculate the final cost results in US $/hour, fixed and variable costs and acquisition of inputs were summed (equation 8).

$$CT = CF + CV + AI \quad (8)$$

where CT is the total cost, CF is the fixed costs, CV is the variable costs and AI is the acquisition of inputs.

RESULTS AND DISCUSSION

The results for the purchase of lime for area A1 were 213 t for ZME, 219 t for the GS method and 154 t for OS. Taking ZME as a reference, an increase of 6 t (2.81% more than GS) was realized with a reduction of 59 t (72.30%) for OS.

The final cost of the lime to area A1 can be seen to be US $5,082.67 for ZME, US $5,209.93 for GS (increase of US $127.26), and $3,665.92 for OS (reduction of US $1,416.75).

The results for the purchase of lime for A2 area was 27 t to ZME and GS and 40 t for OS (48.15% higher ZME). The final cost of acquisition of Lime for the A2 area was US $640.15 for ZME, US $644.87 for GS (increase of US $4.72), and US $942.42 for OS (increase of US $302.28).

As in area A1, the first two sampling methods (ZME x GS) showed similar results. Results for the purchase of lime for the A3 area were 108 t for ZME, 114 t for GS, representing a reduction of 6 t (5.56%). For OS, the result was 74 t, which was 34% lower than ZME and 35.09% below the GS.

The final acquisition cost of the lime for the A3 area was $2,578.43 for ZME, US $2,716.83 for GS (increase of US $138.4), and $1,752.17 for OS (reduction of US $826.26).

When potassium doses per hectare were evaluated for area A1, increasing doses could be seen between the methods. Results for the potassium purchase for area A1 was zero for ZME, that is, no addition of KCl occurred. For GS, the value was 1.3 t, and for OS, it was 10.4 t. The final cost of acquisition of potash for area A1 was zero for ZME, US $558.92 for GS (increase of US $558.92), and $4,542.73 for OS (increase of US $4,542.73).

Just as in area A2, when the acquisition of potash was evaluated, the KCl values remained zero for ZME, 0.1 t for GS, and 2.5 t for OS. The final cost of potassium for area A2 was null for ZME, US $31.29 for GS (up US $31.29), and $1,102.06 for OS (increase of US $1,102.06).

The results for the acquisition of potash for the A3 area were 0.8 t for ZME and 2.8 t for GS (350% more than for ZME). The final cost of potassium to the A3 area stood at US $358.73 for ZME, US $1,227.73 for GS (increase of US $869.00), and $1,847.08 for OS (increase of US $1,488.35).

When the results for phosphate fertilizer recommendation were assessed, a small, although growing, variation was observed between the methods. The results for the acquisition of total phosphorus for area A1 were 32.6 t to ZME; 34.3 t for GS (05.21% more than ZME) and 36.9 t for OS (13.19% higher than ZME).

The final costs for the acquisition of triple super phosphate for area A1, were $17,046.62 for ZME, US $17,972.76 for GS (increase of US $926.13), and $19,308.81 for OS (increase of US $2,262.18).

The results for the acquisition of phosphorus for the A2 area were 1.1 t for ZME; 1.3 t for GS (18.18% more than ZME) and 2.8 t for OS (154.55% more than ZME). Final costs of the acquisition of triple super phosphate for the A2 area were US $556.90 for ZME, US $695.50 for GS (increase of US $138.6), and $1,440.25 for OS (increase of US $883.34).

When the results in area A3 were assessed, behavior similar to the results obtained from the A2 area were observed, with values increasing over the methods evaluated. The results for the acquisition of phosphorus for the A3 area were 7.5 t to ZME; 8.2t for GS (17.33% more than ZME) and 15.3 t for OS (104% more than ZME).

The final cost of the triple super phosphate A3 area was $3,948.60 for ZME, US $4,309.57 for GS (increase of US $135.96), and $8,024.65 for OS (increase of US $4,076.05).

The results for acquisition of nitrogen for area A1 showed that the quantities of N were 40.1 t for ZME, 40.4 t for GS (0.75% higher than ZME), and 41.3 t for OS (2.99% more than ZME).

The final cost of nitrogen for area A1 was US $17,640.42 for ZME, US $17,781.83 for GS (increase of US $141.41), and $18,195.56 for OS (increase of US $555.15).

Following the trend of the results of area A1, the value indicating the dosage increased. The results for the acquisition of nitrogen for the A2 area were 4.8 t for ZME, 4.9 t for GS (2.08% more than ZME), and 4.9 t for OS (1.93% higher than ZME). The final cost of nitrogen for area A2 was $2,129.35 for ZME, US $2,140.16 for GS (up US $10.81), and $2,170.48 for OS (up US $41.13).

The results for the acquisition of nitrogen for the A3 area show that the quantities of N were 16.3 t for ZME, 15.9 t for GS (-2.45% below ZME), and 16.5 t for OS (1.69% higher than ZME). The final cost of nitrogen for the A3 area was $7,160.80 for ZME, US $6,999.20 for GS (decrease of US $161.6), and $7,281.80 for OS (increase of US $121.18).

Mechanized sets

In Table II, which shows costs of depreciation, interest and insurance, the interest costs shown are those with the most impact on the economic evaluation. This difference between the other evaluated items was due to the inclusion of the interest rate in the calculations; these are shown because in Brazil, the interest rates are high. According to Oliveira et al. (2007), studying the coffee harvest costs, interest costs are among the factors with the greatest impacts on spending in mechanized harvesting.

The average price of equipment directly influences the calculation of maintenance costs. Table III, which deals with maintenance costs, shows greater impact on costs of phosphorus and potassium applications from the machine mean price that was 191.11% higher than the average price for lime and nitrogen applications. The percentage calculations of 80% and 81% refer to the cost of corrective and preventive maintenance over the lifetime of the equipment; that is, 80% and 81% of the average prices of the equipment is spent on preventive and corrective maintenance over five years, including the cost of lubricants.

The applied dose has a fundamental paper in increasing fuel consumption, due to as much as the dose increases at variable rate more the fuel consumption will increase. According to on-site surveys, the increase in consumption may be 26.3% higher at higher doses.

The fuel consumption is directly related to power. In Table IV, which deals with the cost of fuel consumption, for the applications of phosphorus and potassium, the total cost for

Table II. Costs of depreciation, interest and insurance.

Fertilizer Trailer- Lime and Nitrogen Application									
Values							**Assessed items**		
Average price (US $)	Scrap Value (US $)	Lifetime (h)	Hours worked/ year	Interest Rate (%)	Efficiency (%)	Capacity (ha/h)	Depreciation (US $/h)	Interest (US $/h)	Insurance (US $/h)
22,591.75	4,518.34	3,000	250	14.43	0.6	7.2	6.03	7.68	0.88
Precision seeder - Phosphorus and Potassium Application									
Values obtained							**Assessed items**		
Price Mean (US $)	Scrap value (US $)	Lifetime (h)	Hours worked/ year	Interest Rate (%)	Efficiency (%)	Capacity (ha/h)	Depreciation (US $/h)	Interest (US $/h)	Insurance (US $/h)
65,767.79	65,767.79	5,000	300	14.43	0.6	0.6	10.53	18.63	0.78

Table III. Maintenance.

Mechanized sets			
Applications of Lime and Nitrogen			
Price Mean (US $)	%	Total value (US $)	Total value (US $/h)
22,591.75	81	18,299.32	6.1
Application of Phosphorus and Potassium			
Price Mean (US $)	%	Total value (US $)	Total value (US $/h)
65,767.79	80	52,614.23	10.52

fuel consumption was lower (3.22%) higher. This fact is due to the increased power of the machine, being 76.55 kW compared to 66.19 kW for the applicator machine for lime and nitrogen.

The cost of labor for operation of the machines was US $468.75/month plus 63% of labor benefits (US $295.31), bringing the final amount of US $764.06. Considering the number of hours worked per month to be 186.12, the final value in US $/labor hour was US $4.11.

The final value for the use of implements in US $/ha, with variable rate application, was US $17.06 for Lime, US $56.06 for the application of phosphorus and potassium, and US $8.26 for the application of nitrogen.

The results show that the costs for the application of phosphorus and nitrogen were the most affected in the use of the implements. This finding is primarily attributable to the higher cost of the machine, which was $65,767.79 compared to $22,591.75 for applications of lime and potassium. In addition, the higher priced machine has more power (22.22% higher), and these are factors that directly influence the costs from the use of machinery.

Total costs

Labor costs for collecting the samples varied according to the sampling method used, with the amount being US $6.88 for ZME and OS, and US $10.31 for GS, per sample.

For area A1 (Table V), ZME showed a value of US $20.63; GS, an amount of US $1,629.38; and OS, a value of US $1,064.38. Compared with ZME, an increase was observed of US $1,608.75 in GS and $1,043.75 in OS.

This difference between the total values for sample collection reflects the relationship between the quantities of samples defined by sampling method and their respective costs. For ZME, a decision was made to collect three samples for both areas; for OS, 5 samples; and for GS, 158 samples.

The costs for the analyses were US $81.21 for ZME, US $4,277.36 for GS and US $135.35 for OS, an increase of US $4,196.14 in GS and US $54.14 in OS compared with ZME. Individual costs for analysis of the samples were of US $26.88 for ZME, US $11.25 for GS and US $6.88 for OS.

As in the sample collection, laboratory test costs correlate with the number of samples by multiplying individual costs for samples by the quantity of the collections. For this reason, ZME showed greater difference between the costs.

This difference between the total values for sample collection reflect the relationship between the quantities of samples defined by sampling method and their respective costs. For ZME, a decision was made to collect 3 samples; for OS, 5 samples; and for GS, 158 samples were collected for area A1, 23 samples for A2, and 65 samples for area A3.

Table IV. Fuel.

Mechanized sets		
Applications of Lime and Nitrogen		
Consumption (L/h)	Diesel value (US $)	Total value (US $/h)
15.91	0.86	13.68
Application of Phosphorus and Potassium		
Consumption (L/h)	Diesel value (US $)	Total value (US $/h)
15.40	0.86	13.24

For cost calculations of sets for the mechanized application of lime, the application was considered in variable rates for both methods. The total values were calculated in US$ per hectare, being US $17.06 for the application of lime, US $56.06 for the application of phosphorus and US $8.26 for potassium. Thus, the total costs for the application of lime were $2,641.22 for both methods. The cost of a mechanized set for the application of phosphorus and potassium was $8,679.60 and for the application of nitrogen, the cost was US $1,278.81 for both sampling methods (Table V).

The OS method differs from other methods because it requires the use of sensors and the generation of maps. The cost of the sensor use was US $3.75 per hectare and the generation of maps was $1.25 per hectare. Thus, the total cost for area A1 was US $580.57 for Sensor rental and US $193.53 for the generation of maps.

Evaluating the final cost to area A1, ZME had the amount of US $52,611.18, GS US $60,170.42 and OS the value of US $60,323.98. In this scenario, GS and OS were $7,558.62 and $7,712.18 more expensive than ZME respectively, showing in this case, that ZME is the best alternative from an economic point of view. The items that affected the results were the acquisition costs of raw materials, labor for sample collection and laboratory analysis.

The total cost of machinery and equipment for area A1 accounted for 23.95% of the final cost to the ZME method, 20.93% for the GS method and 20.71% for the OS method.

Among the variable costs for area A1, inputs accounted for 75.59% of the weight of ZME, 69.01% of GS, and 75.78% of OS. Evaluations of the final cost to area A1 are shown in Table V; ZME presented the cheapest method, and OS the most expensive. The lowest acquisition costs of raw materials, labor, with sample collection and laboratory analysis factors, determined the superiority of the method from the economic point of view.

As for area A1, the cost of labor for collecting samples from area A2 was US $20.63 for ZME (Table VI). For GS the value was US $237.19 and for OS US $128.13. As GS has a larger number of samples by the design of this method, this showed an increase of US $216.57 relative to ZME and an increase of US $109.04 relative to OS. OS was already US $107.53 more expensive than ZME.

This difference between the total values for sample collection reflects the relationship between the quantities of samples defined by sampling method and their respective costs.

Table V. Acquisition costs of raw materials, labor, laboratory analysis, equipment, machinery, sensor use and generation of maps for area A1.

Item - Cost	Area A1					
	Zone Management by Elevation US $	**Percentage (%)**	**Grid Sampling US $**	**Percentage (%)**	**Oriented US $**	**Percentage (%)**
Acquisition of inputs	39,769.71	75.79	41,523.44	69.01	45,713.02	76.07
Labor (collecting samples)	20.63	0.04	1,629.38	2.71	1,064.39	1.77
Laboratory tests	81.22	0.15	4,277.36	7.11	135.36	0.23
Equipment (auger, buckets, etc.)	140.63	0.27	140.63	0.23	140.63	0.23
Mechanized assembly for applying corrective (Lime)	2,641.22	5.02	2,641.22	4.39	2,641.22	4.38
Mechanized assembly for applying fertilizer (P and K)	8,679.60	16.50	8,679.60	14.43	8,679.60	14.38
Mechanized assembly for applying fertilizer (N)	1,278.81	2.43	1,278.81	2.13	1,278.81	1.95
Use of Sensor (Rental)	-	-	-	-	580.57	0.96
Labor (Generation of maps)	-	-	-	-	193.53	0.32
Totals	***52,611.81***	***100.00***	***60,170.42***	***100.00***	***60,323.98***	***100.00***

For ZME, three samples were collected for both areas. For OS, it was 5 samples and GS 23.

When assessing the costs for laboratory tests, we calculated an amount of US $81.22 for ZME, US $622.65 for GS and US $135.35 for OS. In comparing these costs, ZME showed the value of US $541.44 less than GS and US $54.14 less than OS. What determined the difference between the values was the number of samples: 3 samples for ZME, 23 for GS and 5 for OS.

Total values for the application per hectare of lime to the A2 area were US $17.06; for phosphorus and potassium, it was US $56.06, and for the application of nitrogen, it was US $8.26. Thus, the total costs for application of lime were $318.00 for both methods. The cost of the mechanized set for the application of phosphorus and potassium was $1,045.05 and for the application of nitrogen, it was US $8.26 for both sampling methods (Table VI). The average price of equipment, maintenance, insurance and interest had the greatest impact on the results.

The cost of sensor use was US $3.75 per hectare, and the generation of maps was $1.25 per hectare. Thus, the total cost for area A2 was US $69.90 for Sensor rental and US $23.30 for the generation of maps.

The final cost to area A2 was $5,085.28 for ZME, US $6,028.69 for GS and US $7,668.95 for OS. Thus, GS and OS were US $943.42 and US $2,583.67 more expensive than ZME respectively, showing in this case, that ZME is best alternative from an economic point of view.

The items that impacted the results were the acquisition costs of raw materials, labor for sample collection and laboratory analysis.

For the A2 area, 29.60% of the final cost was attributed to the ZME method, 24.96% was attributed to the GS method, and 19.61% to the OS method. Among the variable costs, to the A2

Table VI. **Acquisition costs of raw materials, labor, laboratory analysis, equipment, machinery, sensor use and generation of maps for area A2.**

Item - Cost	Area A2					
	Zone Management by Elevation - US $	**Percentage (%)**	**Grid Sampling**	**Percentage (%)**	**Oriented - US $**	**Percentage (%)**
Acquisition of inputs	3,326.41	65.41	3,511.82	58.25	5,655.21	73.74
Labor (collecting samples)	20.63	0.41	237.19	3.93	128.15	1.67
Laboratory tests	81.22	1.60	622.65	10.33	135.36	1.76
Equipment (auger, buckets, etc.)	140.63	2.77	140.63	2.33	140.63	1.83
Mechanized assembly for applying corrective (Lime)	318.00	6.25	318.00	5.27	318.00	4.14
Mechanized assembly for applying fertilizer (P and K)	1,045.00	20.55	1,045.00	17.33	1,045.00	13.62
Mechanized assembly for applying fertilizer (N)	153.41	3.02	153.41	2.54	153.41	2.00
Use of Sensor (Rental)	-	-	-	-	69,9	0.91
Labor (Generation of maps)	-	**-**	**-**	-	23,3	0.30
Totals	***5,085.39***	***100.00***	***6,028.69***	***100.00***	***7.653,06***	***100.00***

area, the inputs presented weights of 65.41% for ZME, 58.25% for GS and 73.74% for OS.

The evaluation of the final cost to area A2 is shown in Table VI, ZME is shown to be the cheapest method, with the purchase of inputs, sampling and laboratory analysis being the factors in reducing costs. OS presented the most expensive method because of the increased cost of purchasing inputs.

Just as occurred in areas A1 and A2 (Tables V and VI), the total cost of labor to area A3 was US $20.63 for ZME (Table VII). The GS method showed a value of US $670.31, and OS showed US $430.58, following previous trends. Because of the larger number of samples, GS presented itself as costlier than ZME at US $649.68, with 62 more samples, and costlier than OS at US $238.79, with two more samples.

Evaluating the costs of laboratory analyses, ZME showed a lower value with a total of US $81.22 against US $622.65 for GS and US $135.36 for OS. The GS method was $541.43 more than ZME and US $487.29 higher than OS. The quantity of samples impacted the difference between the cost of the analysis (3 for ZME, 23 for AM and 5 for OS).

Just as in areas A1 and A2, the total amounts were US $17.06 for the application of lime, US $56.06 for the application of phosphorus and potassium, and US $8.26 for the application of nitrogen per hectare. The total costs were $1,068.47 for applications of lime in both methods. The cost of the mechanized set for the application of phosphorus and potassium was $3,511.19, and for the application of nitrogen, it was US $517.32 for both sampling methods (Table VII).

The maintenance costs, fuel consumption and the average price of the equipment determined the difference between the values. The maintenance costs for the P and K application was US $10.53 versus US $6.09 for

Lime and N. Regarding fuel consumption for P and K applications, those expenses were $34.97 per hour versus US $10.41 per hour for applications of lime and nitrogen. The average price of the equipment was $65,767.79 for the applications of P and K and $2,591.75 for the applications of lime and N.

The rental costs of the sensor and generation of maps were US $234.86 and US $78.29 respectively, considering the $3.75 per hectare values for the use of sensors and US $1.25 per hectare to generate the maps.

When the differences between the results for the use of sensors and generating maps for OS were evaluated, the difference between these values was determined to be from the size of the areas.

The final cost to area A3 was $19,386.02 for ZME, US $22,920.92 for GS and $25,022.40 for OS. Thus, GS and OS were $3,534.91 and $5,636.39 more expensive than ZME respectively, showing in this case, that ZME, economically, is the best alternative.

The items that impacted the results were the lower acquisition costs of raw materials, labor for sample collection and laboratory analysis.

For area A1, GS was 14.40% more expensive than ZME and OS was 14.52% costlier than ZME. Despite the small difference, OS showed higher costs between methods. The acquisition of the inputs determined this greater cost by OS.

When assessing the area A2, GS was 18.61% costlier than ZME, and OS was 50.97% costlier than ZME. Furthermore, in area A1, OS showed the higher final cost. As in Area A1, the acquisition of inputs was what determined the higher cost of using OS.

As for the A3 area, GS was 18.29% costlier than ZME, and OS was 29.16% more than ZME, following the trend of the areas and previous methods. As happened in previous areas, the higher cost of acquisition of inputs presented OS as the worst option because of the greater cost from the purchase of inputs.

In an overall economic comparison among the areas A1, A2 and A3 for all covered sampling methods, OS was the costliest alternative in all areas of the study. As for area A3, the cost of the percentage share of machinery and equipment was 26.08% of the final charge for the method ZME, 22.05% for the GS method and 20.19% for the OS method.

Among the variable costs for area A1, inputs accounted for 72.66% of the weight for ZME, 66.71% for GS, and 75.72% for OS. An evaluation of the final cost to area A2 is shown in Table V; ZME is the least expensive method, and OS is the most expensive.

Despite the large number of sub-samples to compose a single sample, possibly, that average results between these figures underestimate the dosage of a given input and overestimate others (Cardoso 2013).

Total costs were calculated according to the sizes of the areas. With regard to the acquisition of raw materials and use of mechanized assemblies, the larger the areas, the higher the costs. Therefore, for the purchase of inputs, a pattern emerged of higher costs for the larger areas, with the A1 area being the most expensive, followed by area A3, and then by area A2.

Just like the acquisition of raw materials, the costs of mechanized sets also followed the standard cost increase according to the size of the areas, as these costs were calculated in dollars per ha and then multiplied by the respective areas.

Artuzo (2015), when evaluating the soybean crop in Rio Grande do Sul on 81 farms, noted that 82% of the producers already do georeferenced sampling; however, only 14.8% do variable rate seeding, and 33.33% showed interest in the recommendation for variable rate fertilizer.

Table VII. Acquisition costs of raw materials, labor, laboratory analysis, equipment, machinery, sensor use and generation of maps for A3 area.

Item - Cost	Area A3					
	Zone Management by Elevation - US $	**Percentage (%)**	**Grid Sampling - US$**	**Percentage (%)**	**Oriented - US $**	**Percentage (%)**
Acquisition of inputs	14,046.56	72.46	15,253.33	66.55	18,905.70	75.56
Labor (collecting samples)	20.63	0.11	670.31	2.92	430.58	1.72
Laboratory tests	81.22	0.42	1,759.67	7.68	135.36	0.54
Equipment (auger, buckets, etc.)	140.63	0.73	140.63	0.61	140.63	0.56
Mechanized assembly for applying corrective (Lime)	1,068.47	5.51	1,068.47	4.66	1,068.47	4.27
Mechanized assembly for applying fertilizer (P and K)	3,511.19	18.11	3,511.19	15.32	3,511.19	14.03
Mechanized assembly for applying fertilizer (N)	517.32	2.67	517.32	2.26	517.32	2.06
Use of Sensor (Rental)	-	-	-	-	234.86	0.94
Labor (Generation of maps)	-	**-**	**-**	-	78.29	0.32
Totals	***19,386.02***	***100.00***	***22,920.92***	***100.00***	***24,967.00***	***100.00***

Sapkota et al. (2014) notes that most farmers tend to often apply higher rates of P and N, making leaching a concern.

The sampling method oriented by sensors (OS) to provide recommendation maps from Apparent Electrical Conductivity (ECa) is shown to be a superior alternative to ZME. This superiority may be observed because OS is an improvement over the traditional conventional method, with zones of Management defined by PA technology, making the recommendations more efficient because not only elevations are considered when the management areas are defined, as proposed by ZME.

In studies conducted by Artuzo (2015), only 51% of producers have expressed interest in the use of ground sensors, indicating the cost of the analysis as a limiting factor of the AP.

When the application of fertilizers is studied using PA, Fregonezi et al. (2014) noted economic gains 13 times more efficient from an economic point of view in corn, soybeans and wheat. Earlier, Artuzo (2015) found gain higher than 13.9% compared to soybean production. Schadeck (2015) found an increase of 19% and 28% in yield and 22% in average economic return in cultures of soybean, oats and wheat. Similarly, Fiorin et al. (2011) found PA economic returns ranging from 9.2 to 13.7%, averaging 11.7% in the planting of corn and soybeans. Esau et al. (2016) found a cost reduction of approximately 37% with application of PA in the wild blueberry crop.

Soares (2013) compared the operating costs of the use of PA to the traditional method for planting soybeans and observed productivity 17.5% higher, costs of inputs lower by 5.56% and the cost of sacks of soybean 11.45% lower with the use of PA.

Santos (2014), found economic gain 2.4% higher with the use of PA in rice planting. Overall, a reduction was observed of 26.6% added N, 13.3% P_2O5 and 22.3% K_2O, representing financial savings of 31.4% just for fertilization.

Due to the recomended dose the cost of precision agriculture system was slightly higher than the conventional system. It can be explaind by the necessity of replenish the machine more often during variable rate applications.

Through the economic analysis developed in this work, the ZME method proved to be the best alternative, in spite of the possibility of having underestimated the real need of the objects of the study areas.

Notably, the studies on PA have evolved and tend to enable economic and environmental benefits for the present and future. However, even though ZME has been, in this study, the better alternative, soil sensor use is shown to be a viable technology that requires further processing in order to provide productivity, cost reduction and consequent economic and environmental gains to provide supplies for present and future generations without exhausting natural resources.

CONCLUSIONS

Economical comparisons of the sampling methods used in management zones established according to elevation, grid sampling and sampling oriented by apparent soil electrical conductivity sensor were possible.

The costs that most impacted the ratings among the methods were the cost of fertilizer and then the cost of using machines and implements.

When the economic issue is evaluated through the feasibility study, the sampling method for zone management by elevation presented as the alternative that had the lowest cost.

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How to cite

GONÇALVES JRMR, FERRAZ GAS, REYNALDO EF, MARIN DB & PATRÍCIA FERRAZ PFP. 2020. Comparative economic analysis of soil sampling methods used in precision agriculture. An Acad Bras Cienc 92: e20190277. DOI 10.1590/0001-3765202020190277.

Manuscript received on March 9, 2019;
accepted for publication on July 5, 2019

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