# Comparative environmental analysis of soil sampling methods in precision agriculture for lime application in Paraná State, Brazil

J.R.M.R. Gonçalves[1], G.A.S. Ferraz[2,*], D.B. Marin[2], E.F. Reynaldo[3], P.F.P. Ferraz[2], D. Sarri[4] and M. Vieri[4]

[1]IBMR Laureate International - IBMR, Departamento de Engenharia e Arquitetura - Avenida das Américas 2603, BR22631-002 Barra da Tijuca-RJ, Brazil
[2]Federal University of Lavras, Department of Agricultural Engineering, University, Campus, BR37.200-000 Lavras-MG, Brazil
[3]Field Equipment Manager - Syngenta - Rua Providence 236, BR38407-744 Uberlândia-MG, Brazil
[4]University of Florence, Department of Agricultural, Food, Environment and Forestry (DAGRI), Biosystem Engineering Division, Piazzale delle Cascine 15, IT50144 Florence, Italy
*Correspondence: gabriel.ferraz@ufla.br

**Abstract.** Precision agriculture (PA) provides techniques that favour the localized application of inputs allowing their rational use. This makes the PA a potential indicator of reduced operational costs, input volume, and environmental impacts. The objective of this study was to evaluate and compare the environmental effects of three different sampling methods used in PA for the lime application. The first sampling method evaluated was the grid sampling (GS). It was performed at a density of one sample per hectare in a 100×100 m georeferenced grid. The second method was the directed sampling, that was performed after defining the management zones by soil apparent electrical conductivity (ECa) using a soil electrical conductivity sensor. The lest sampling method was the Altitude-based management zone (AMZ) sampling that was developed based on altitude maps of the field. These sampling methods were tested in three different areas in the south of Brazil. This study evaluated the spatial variability of the lime volume in the soil and compared quantitatively and spatially the recommended application volumes achieved by each sampling method. Results highlighted that the sensor-directed soil sampling method was the alternative that would generate the lowest environmental impact.

**Key words:** environmental impact, management zones, sample grids, soil apparent electrical conductivity.

## INTRODUCTION

Liming is a common and well-established practise in many agricultural Brazilians regions where is generally made on a single composite sample unit representing supposedly homogeneous areas of ten or more hectares (Hurtado et al., 2009). Thus,

uniform lime applications can result in areas with levels below or above what is necessary, damaging crop development and/or negatively impacting the environment.

Brazil is a tropical country that has typically acid soils and with high aluminium content which is toxic and influences directly on the nutrients available for crops (Rodriguero et al., 2015). One of the ways to correct this problem is to promote liming since it is a natural, low-cost and widely available input (Rodriguero et al., 2015; Melo et al., 2019).

Applying variable soil amendment rates based on precision agriculture (PA) is an alternative for enhancing production and minimizing the impact of agricultural activity on the environment (Oliveira et al., 2008; Temizel, 2016). For this purpose, the spatial variabilities of soil attributes must be characterized by different soil sampling strategies that can represent such variations (Bottega et al., 2013).

The most commonly used soil sampling methods to identify soil properties in PA include grid sampling (GS) and management zone sampling (Ragagnin et al., 2010). In GS sampling method, the area is divided into square or rectangular sections of equal or reduced size so farmers can sample each section (Morgan & Ess, 1997; Zinkevičius, 2008). In management zone sampling, an area is divided into subareas or homogeneous areas to apply uniform input doses (Prado et al., 2015). These management zones can be obtained via relief, productivity, and soil attribute maps (Alves et al., 2013; Bernardi et al., 2015).

Several studies have compared the quality and optimal size of different sampling grids and management zones (Peralta et al., 2015; Tripathi et al., 2015; Ferraz et al., 2017; Ferraz et al., 2018). However, according to Keskin & Sekerli (2016), soil sampling methods are an important part of the PA it is, sometimes, not well known and corrected used. So, it is interesting to carry out studies to understand better the soil sampling methods.

Lombardo et al. (2018) and Bambi et al. (2019) stated that rural areas are facing different challenges, and according to Barbari et al. (2014a, 2014b) and Conti et al. (2017) it is needed to use technologies with less environmental impact and more sustainable. According to Kanal (2004), agronomic practices need to be better understand to be more environmentally friendly. The soil sampling methods based on PA technologies are used to determine the amount of product to be applied to the soil. The incorrect application rate of products can result in the increased cost of fertilizers and correctives, reduction of crop growth and also negative environmental effects (Šima et al., 2013; Ferraz et al., 2019). So, regarding environmental analysis, gaps in knowledge must be filled to demonstrate and consolidate the positive environmental impacts of PA soil sampling technologies.

Therefore, this study evaluated and compared the environmental effects of three sampling methods used to apply lime in PA.

## MATERIALS AND METHODS

### Study site
The present study was conducted at Cupim Farm (25°32'66" South and 51°34'65" West) and Juquiá Farm (25°16'45" South and 52°6'01" West) in the municipalities of Guarapuava and Cantagalo, respectively, in the central-southern region of the state of Paraná, Brazil. The experiments were conducted in three distinct areas of the farms: A1

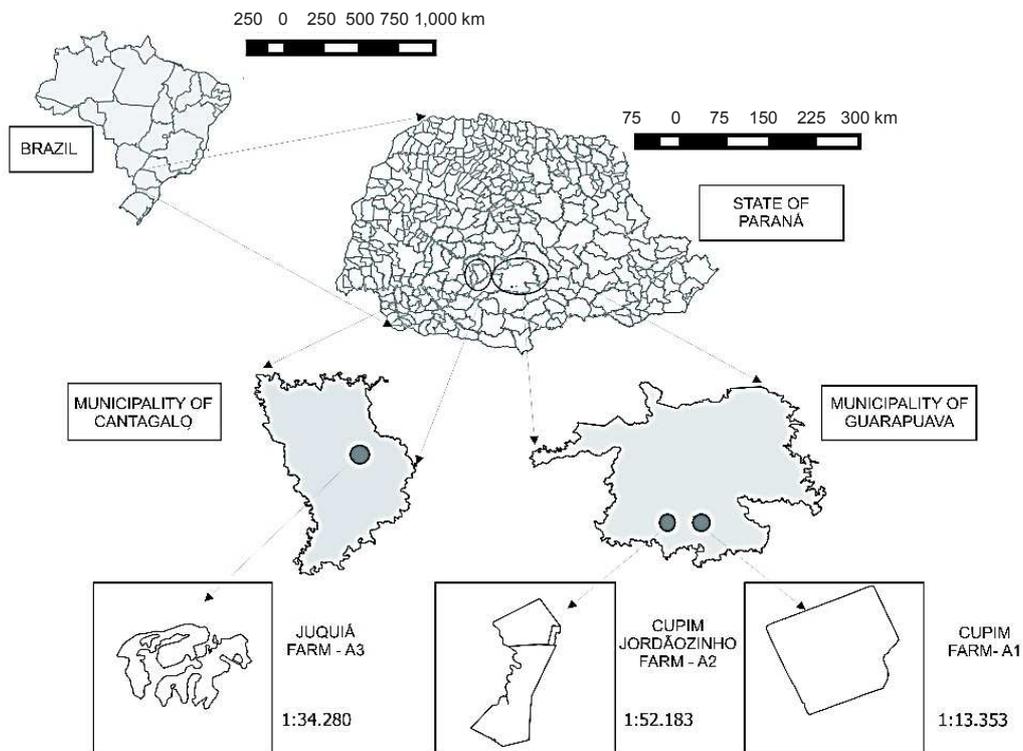(Cupim Farm, 154.82 ha), A2 (Cupim Farm, Jordãozinho, 18.64 ha), and A3 (Juquiá Farm, 62.63 ha) (Fig. 1).



**Figure 1.** The geographical location of study areas.

The climate in Guarapuava and Cantagalo is Köppen classification type Cfa, characterized as subtropical humid, with a mean annual temperature of 18 °C, a maximum temperature of 36° C, and minimum temperature of 6.8 °C. The experimental area soils were classified as cambic aluminic dark latosol (per the Brazilian Soil Classification), with prominent A horizon, smooth undulating relief, and basalt substrate and a textural class varying from clayey to very clayey (Fontoura et al., 2015).

In these areas crop rotation has been the management method performed for at least 16 years, with rotational planting of soybeans, oats, corn, wheat, and barley. Seedings are performed twice yearly in June through November, with harvests in November, February, and March.

### Grid sampling

In the GS method, the sampling grids were defined as 100×100 m, (1 point per hectare), using the sampling grid generation tool in the software, SMS Advanced (Advanced Spatial Management System), version 15.1 (AgLeader Technology, 2019). Thus, 158 georeferenced sampling points were obtained for area A1, 23 points for area A2, and 65 points for area A3 (Fig. 2).
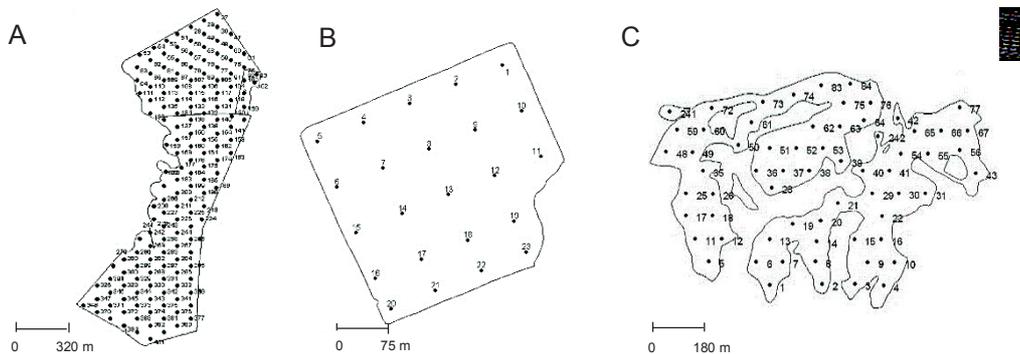
**Figure 2.** Representation of the areas A1 (A), A2 (B), and A3 (C) sampling grids.

After defining the sampling grids, from 11 to 15 subsamples were collected at each georeferenced point and duly homogenized, forming a composite sample representative of the sampling point.

### Directed soil sampling (DS)

For the DS method, the apparent electrical conductivity (ECa) of the soil was obtained using a Veris PMC® electrical conductivity sensor coupled to an agricultural tractor. The ECa sampling density for each sampling area was 200 to 320 points per hectare. After collection, outliers were removed from the dataset using the standard deviation (SD) method, i.e. data with values above or below 2.5 SD were removed. Subsequently, the data were interpolated using the punctual kriging method in Vesper 1.6. Besides, experimental semivariograms were constructed for each point, which was automatically interpolated by the software to generate spatial variability maps of the ECa data obtained by the sensor to direct the soil sample collection (Fig. 3).
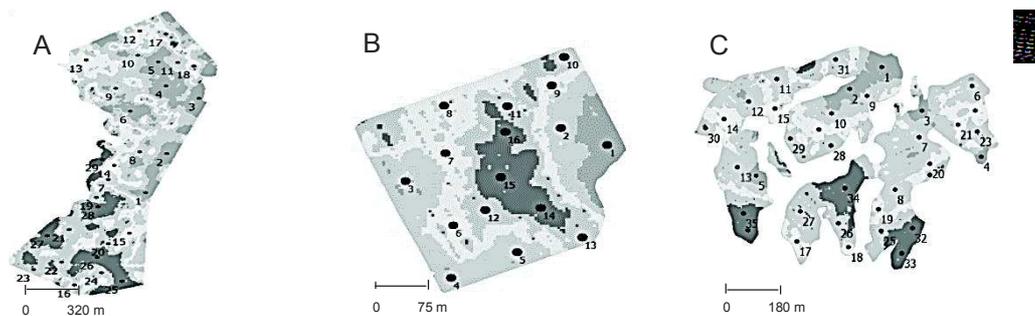


**Figure 3.** Directioning of collection points by management zone for areas A1 (A), A2 (B), and A3 (C).

Once the management zones were defined, samples were collected in a zigzag pattern in each zone (Silva et al., 2015). A variable number from 11 to 15 subsamples were collected and homogenized, yielding composite samples representing each zone.

### Altitude-based management zone (AMZ) sampling

The AMZs for the areas were obtained by harvest maps and interpolated with the punctual kriging method using Vesper 1.6. After kriging, the maps were divided into three altitude classes high, medium and low respectively to define the collection classes. Thus, no fixed scale was defined, since each area was evaluated by its degree of inclination, and three zones were defined. Generating and interpreting these maps enabled identifying areas with the same altimetric profile to collect the samples (Fig. 4).
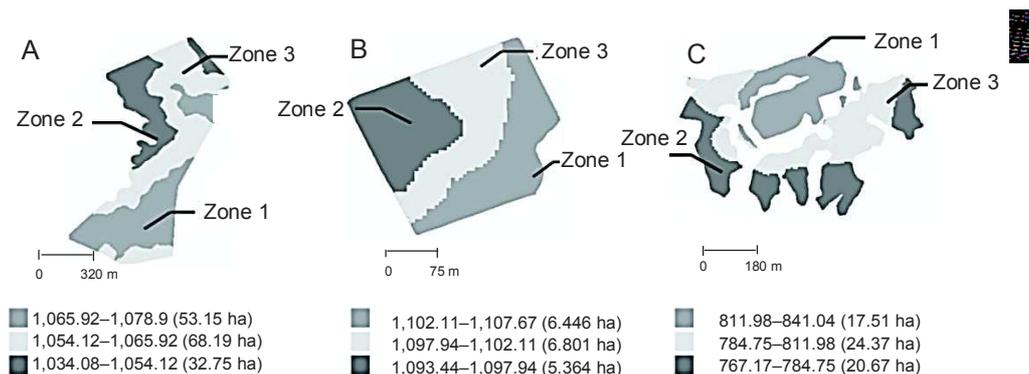


| | | |
|---|---|---|
| 1,065.92–1,078.9 (53.15 ha) | 1,102.11–1,107.67 (6.446 ha) | 811.98–841.04 (17.51 ha) |
| 1,054.12–1,065.92 (68.19 ha) | 1,097.94–1,102.11 (6.801 ha) | 784.75–811.98 (24.37 ha) |
| 1,034.08–1,054.12 (32.75 ha) | 1,093.44–1,097.94 (5.364 ha) | 767.17–784.75 (20.67 ha) |

**Figure 4.** Representation of the altitude-based management zones of areas A1 (A), A2 (B), and A3 (C).

After creating the maps, the same procedure for the DS method was followed. Specifically, from 11 to 15 subsamples were collected in a zigzag pattern in each zone (Silva et al., 2015), which were homogenized to form a composite sample representing the area being studied.

### Chemical analyses and liming recommendations

Soil chemicals properties from layer ranging from 0.0–0.2 m deep were analyzed. The lime dose recommendations applied for each method followed the methodology proposed by EMBRAPA (1997). This procedure was used for all three sampling methods (AMZ, GS, and DS).

According to (Fontoura et al., 2015) the liming application needs to ensure a greater residual effect, which means, greater number of years in which the acidity levels of the soil will be above the values determined as critical (4,9 for pH-CaCl and 60% of V). It is indicated that the desired base saturation value in liming should be 70% (equivalent to pH CaCl of 5.2), according to Eq. 1:

$$N/C(t\ ha^{-1}) = [(V2 – V1) \times CTC_{ph7} \times f] / 100 \qquad (1)$$

where NC – liming requirement, in t ha$^{-1}$, for the soil layer 0–20 cm; V2 – value that you want to increase base saturation (in this case, 70%); V1 – base saturation value obtained by the soil analysis; f – correction factor based on limestone PRNT (f – 100/PRNT).

According to Fontoura et al. (2015), the application of lime, to be carried out in the doses calculated by the Eq. 1, must be carried out on the soil surface, without the incorporation of the lime by the ploughing and harrowing. The same authors infer that the effects of this lime application can be observed in the correction of pH and base saturation in the first year after liming and up to 60 cm in depth.

### Recommendation maps

The chemical recommendation maps were generated based on the laboratory analysis results obtained from the sampling methods. This step provided the amount of lime associated with the levels. These results were input and compiled using SMS Advanced (Advanced Spatial Management System), versions 15.1 (AgLeader Technology, 2019), to generate the recommendation/application maps. Each map shows interpretation ranges on per cent scales of lime dosage distribution by colour. Thus, correlating the colours with the percentages enables spatially differentiating the dosages. The interpolator used for the GSs was kriging. The semivariograms were constructed using GS+ 7.0 software (Dalchiavon et al., 2012; Dalchiavon et al., 2013; Dalchiavon et al., 2015), and the interpolations were performed using SSToolBox 4.0 (SST Development Group, Stillwater, OK, USA) (Molin & Faulin, 2013; Sana et al., 2014).

## RESULTS AND DISCUSSION

Analyzing the liming recommendation maps for area A1 (Fig. 5) obtained from the three sampling methods revealed low spatial variability for the lime doses in the AMZ and DS methods compared with the GS method. Larger lime doses were recommended for the AMZ and GS methods (Figs 5, A and 5, B), ranging from 981.63–1,392.04 kg ha$^{-1}$ and 1,392.04–1,802.45 kg ha$^{-1}$, respectively, with a more uniform spatial distribution in these ranges in the AMZ method. For the DS method (Fig. 5, C), the most recommended lime doses ranged from 0–571.22 kg ha$^{-1}$ and 571.22–981.63 kg ha$^{-1}$.



A

0   300 m

□ 1,802.45 (0.00 ha – 0.0%)
□ 1,392.04–1,802.45 (34.41 ha – 22.2%)
□ 981.63–1,392.04 (120.26 ha – 77.8%)
□ 571.22–981.63 (0.00 ha – 0.0%)
■ 0.00–571.22 (0.00 ha – 0.0%)

B

0   300 m

□ 1,802.45 (9.65 ha – 6.2%)
□ 1,392.04–1,802.45 (70.25 ha – 45.4%)
□ 981.63–1,392.04 (68.76 ha – 44.5%)
□ 571.22–981.63 (5.43 ha – 3.5%)
■ 0.00–571.22 (0.58 ha – 0.4%)

C

0   300 m

□ 1,802.45 (0.00 ha – 0.0%)
□ 1,392.04–1,802.45 (0.00 ha – 0.0%)
□ 981.63–1,392.04 (1.98 ha – 1.3%)
□ 571.22–981.63 (25.29 ha – 16.3%)
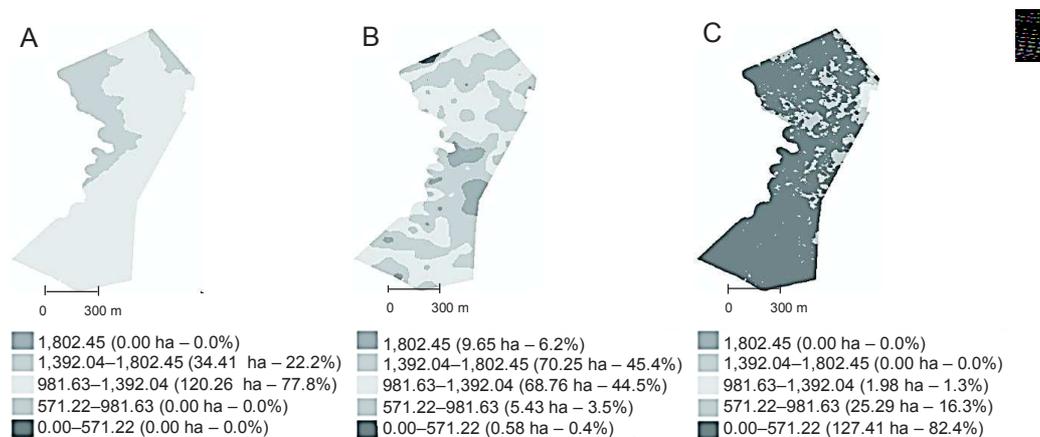■ 0.00–571.22 (127.41 ha – 82.4%)

**Figure 5.** Liming recommendation maps of area A1 obtained by altitude-based management zone sampling (A), grid sampling (B), and directed sampling (C).

For the whole lime to be applied in area A1, the DS method presented the lowest value per specific area with 154 t. The AMZ and GS methods yielded similar values of 213 and 219 t, respectively. Therefore, environmentally evaluating the three methods showed that DS was a more viable alternative compared with the AMZ and GS sampling methods, which may permit excess limings of 59 t for AMZ and 65 t for GS.

Fig. 6 shows the liming recommendation maps for area A2. Similar to area A1, the lime doses presented low spatial variability for the AMZ and DS methods relative to the GS method.

Like in the area A1, the most recommended lime dosages produced by the AMZ and GS methods (Figs 6, A and 6, B) ranged from 981.63–1,392.04 kg ha$^{-1}$ and 1,392.04–1,802.45 kg ha$^{-1}$, respectively, with a more uniform spatial distribution in these ranges for the AMZ method. In contrast, the opposite was observed for the DS method, with most liming recommendations in the range of 1802.45 kg ha$^{-1}$ and no recommendations in the range of 0–571.22 kg ha$^{-1}$ (Fig. 6, C).



A

B

C

1,802.45 (0.00 ha – 0.0%)
1,392.04–1,802.45 (7.24 ha – 38.9%)
981.63–1,392.04 (11.37 ha – 61.1%)
571.22–981.63 (0.00 ha – 0.0%)
0.00–571.22 (0.00 ha – 0.0%)

1,802.45 (1,494 ha – 8.0%)
1,392.04–1,802.45 (8.92 ha – 47.9%)
981.63–1,392.04 (7.66 ha – 41.1%)
571.22–981.63 (0.54 ha – 2.9%)
0.00–571.22 (0.00 ha – 0.0%)

1,802.45 (17.95 ha – 96.4%)
1,392.04–1,802.45 (0.01 ha – 0.1%)
981.63–1,392.04 (0.02 ha – 0.1%)
571.22–981.63 (0.63 ha – 3.4%)
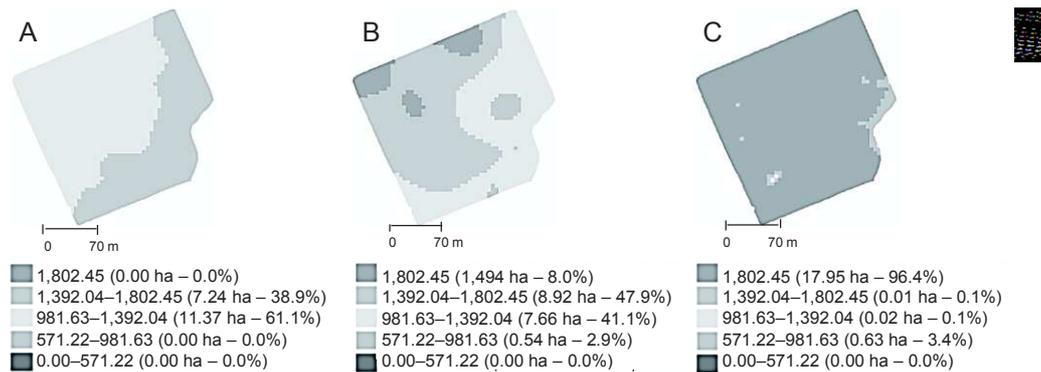0.00–571.22 (0.00 ha – 0.0%)

**Figure 6.** Liming recommendation maps of area A2 obtained via altitude-based management zone sampling (A), grid sampling (B), and directed sampling (C).

The total recommended a lime application for area A2 for both the GS and AMZ methods was 27 t area$^{-1}$. For the DS method, the total application was 40 t area$^{-1}$. Thus, based on a general comparison of the methods and considering the environmental impact, the DS method is a less viable alternative, since it indicated a smaller spatial distribution of lime in the area and recommended a lime volume of 13 t area$^{-1}$ higher than that recommended by the AMZ and GS methods. In its turn, the GS method is the much more achievable viable environmental alternative because, although it recommended the same total lime application as the AMZ method, it indicated a more varied lime spatial distribution.

In contrast to areas A1 and A2, the recommendation maps for area A3 (Fig. 7) showed high spatial variability in the lime rates using the GS and DS sampling methods, with emphasis on the GS method (Fig. 7, B). In this method, similar proportions of recommendations were observed in the five dosage ranges. For the DS method, most recommendations ranged from 0–837.07 kg ha$^{-1}$ and 1,952.06–2,733.98 kg ha$^{-1}$ (Fig. 7, C). For the AMZ method, most recommendations ranged from 837.07–1,356.59 kg ha$^{-1}$ and 1,356.59–1,952.01 kg ha$^{-1}$ (Fig. 7, A).

For the total application of lime to area A3, the DS method showed a lower recommendation at 74 t area$^{-1}$, evidencing a possible excess recommendation of 34 t for the AMZ method and 40 t for the GS method. Besides, the DS method presented a better spatial distribution, thus being a more viable environmental alternative.

Per Ribeiro et al. (1999), the amount of lime to apply depends on the soil analysis, which may prevent overdosage. These authors indicate that excessive liming is as harmful as high acidity, which may make soil corrections more difficult by precipitating several soil nutrients, such as P, and inducing a higher predisposition to damage the

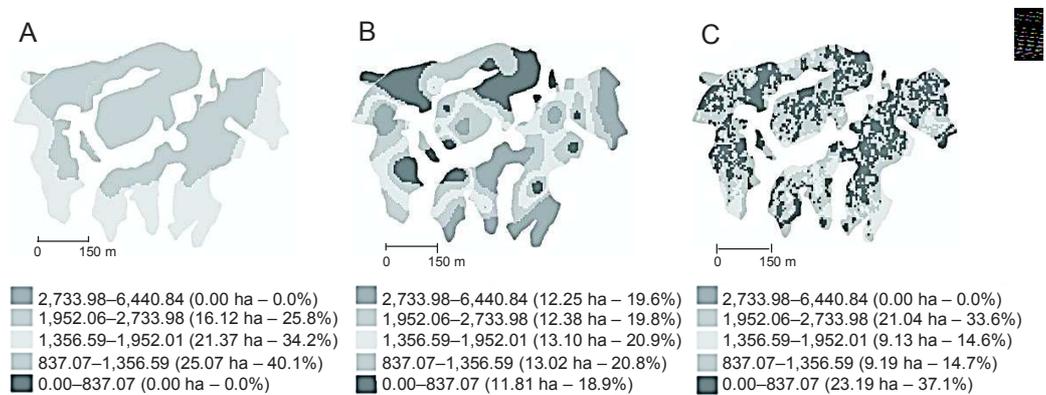physical properties of the soil. This finding highlights that aspects related to liming must be considered.



**Figure 7.** Liming recommendation maps of area A3 obtained via altitude-based management zone sampling (A), grid sampling (B), and directed sampling (C).

Moreover, although lime is not a fertilizer but rather functions to correct pH, its excess dosage may indirectly affect the environment, for example, by facilitating herbicide leaching. Refatti et al. (2014) assessed the effect of liming on leaching the herbicides, imazethapyr, and imazapyr and found that the soil is the final destination of most herbicides and that these herbicides increase groundwater contamination after a lime overdosage due to the increased pH.

In addition to the aspects mentioned above, lime applications using PA methods can bring economic benefits. Schadeck (2015), found that when fixed-rate and varied-rate lime applications were compared in soybean, oat, and wheat cultivation areas in the city of Santo Ângelo, Rio Grande do Sul, Brazil, there was a 43% reduction in the use of lime.

Thus, these previous findings on lime application corroborate this study, since, in addition to the possibility of reducing costs using localized dosages, soil contamination with other nutrients or chemical products that may act in association with the overliming conditions may be prevented.

**CONCLUSIONS**

The environmental effects of AMZ sampling, GS, and directed sampling by soil ECa methods were compared.

When comparing the recommendations by sampling method, differences were identified among the lime dosages that each method suggested, thus indicating the need to improve soil sampling techniques, because, regardless of the technology chosen, uncertainty will remain regarding deficits or overdosages in input applications.

When the environmental effects were evaluated, the ECa sensor-directed soil sampling method was found to be the alternative that would have fewer environmental impacts as a function of the applied lime volume.

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