Effect of long term no tillage on the spatial variability of soybean and maize in São Paulo, Brazil

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Abstract
Crop yield varies in space and in time due to many causes. No tillage preserves soil structure and alters the volume explored by roots and therefore it affects crop yields. The objective of this study was to evaluate the spatial and temporal variability of soybean and maize on a long term no-tillage system. Soybean and maize crops were cultivated under no tillage on a 3.42ha field located at the Campinas Experimental Center of Instituto Agronômico, Campinas, SP, Brazil, from 1985 until 2008 where the soil is a Rhodic Eutrudox with approximately 10% slope. Crop yields were sampled on 2.0x2.5m plots and latter transformed to kg/ha. The length of time with no tillage differently affected the mean values and the spatial variability of soybean and maize but it is not known if the cause is related to the no tillage system or to the variability of weather conditions with time. The spatial dependence for soybean increased with time while for maize it decreased. Uniform management zones could only be established with at least three subsequent crops.

Key Words
Geostatistics, semivariogram, temporal variation, grain crop yield.

Introduction
Long term and frequently monitored no-tillage experiments are rare mostly within tropical conditions. Vieira *et al*. (2002) report on some changes in soil physical properties under no-tillage and crop rotation and concluded that both bulk density and saturated hydraulic conductivity are significantly affected by the changes in organic matter content. Carvalho *et al*. (2002) investigated the effect of soil tillage on the spatial variability of soil chemical properties and concluded that the no-tillage promoted a significant increase in the organic matter content. No tillage system tends to minimize this variability because it preserves soil structure. The amount of variation over an area depends on many environmental conditions and how they acted on soil properties over time. Geostatistics uses a very important component called the semivariogram which is a measure of the similarity between neighboring observations. Long term experiments under tropical conditions using no-tillage are rare. Although it is known that the efficiency of the no-tillage system in conserving soil and water is climate dependent it is still a very recommended management system mainly because it preserves the soil structure. The objective of this study was to evaluate the spatial and temporal variability of soybean and maize on a long term no-tillage system.

Material and Methods
The experimental area is located within the Campinas Experimental Center of Instituto Agronômico, Campinas, SP, Brazil. The soil is a clay texture Rhodic Eutrudox, located in a 3.42ha field of about 10% slope, sampled from 1985 to 1995 at 63 points on a 20m square grid, from 1996 to 2001 at 81 points on a 10m square grid, and from 1997 to 2008 the field was sampled at 302 points on a 10m square grid. Since 1985 this field is being cultivated with grain cereal crops under no-tillage. The climate is subtropical with a mean annual rainfall of about 1500 mm, with 5-6 wet months (November to March) although between year variability may be rather large. The experimental area was regularly sampled every harvest time for the summer and winter grain crops in 2 x 2.5 m subplots, by cutting and weighing all mass above the soil for the last 23 years.
The examination of the temporal evolution of descriptive statistical parameters for the different crops was done in this paper with the purpose of identifying the adequate conditions for future work. The spatial dependence, according to Vieira (2000), can be evaluated by examining the semivariogram and parameters of the model fitted to it. Semivariogram modeling is the foundation for geostatistical analysis, and can also be the most difficult and time consuming portion of the analysis. Vieira (2000) describes the model fitting process and the cross validation of the fitted models. The models fitted are described by the parameters C_0 is the nugget effect, C_1 is the structural variance, *a* the range of spatial dependence Models were fit using least squares minimization and judgement of the coefficient of determination. Whenever there was any doubt on the parameters and model fit,

the jack knifing procedure was used to validate the model, according to Vieira (2000). Cambardella *et al*. (1994) proposed the calculation of a dependence degree (DD) expressed as a ratio between the nugget effect value (C_0) and the sill (C_0+C_1) and classified as Weak if DD>75%, Moderate for 26%<DD<75%, and Strong for DD≤25%. The graphical representation of semivariogram parameters over time can reveal important changes in crop yield as a function of time of using no-tillage system. This kind of analysis can help to explain why crop yield maps quite often do not repeat in time.

One of the major reasons to construct yield maps is to have some indication of the crop yield variability and to delineate uniform regions for management purposes. Comparing maps is not an easy task. In this paper a process of classification of the yield maps is proposed in order to help the delineation of management zones within the field. For this purpose the last two crops of soybean and maize were classified according to the levels low, medium and high of crop yield. After this classification was done, a composed classification of the two crops was done in order to verify the location of places in the field with high yield potential. Thus, the classified maps of soybean and maize were compared at each and every point, creating a new dummy variable with numbers ranging between 1 (lowest yield of both crops) and 9 (highest yield of both crops).

Results and discussion

Figure 1 shows the temporal evolution of the mean and CV values for soybean and maize. Standard deviation bars were added above and below the mean values of soybean and maize yield in order to evaluate adequately the trends expressed by the data. It can be clearly seen that soybean showed a decrease in yield with time while maize showed completely the reverse. Although these results simply represent a general trend with some degree of uncertainty the reasons for this unique and distinct behavior for soybean and maize yields is not known. It is quite possible that the crop reactions to the unchanging soil structure due to the no tillage system are opposite for these two crops in particular when considering their distinct root system. Notice that if it was not for the first point of maize yield for 1986 with approximately 6000 kg/ha the function relating maize yield with time would simply be linear showing a much more pronounced increase with time. The uncertainty on the crop yields, represented by the error bars of one standard deviation above and below the mean value, is also very distinct between the two crops, in general much larger for soybean than for maize. This result agrees with the CV values which increased for soybean and decreased for maize with the time which means that soybean yield not only decreased with time of no tillage but it also became more variable. On the other hand, maize yield increased with the time of no tillage and it also became more uniform.

The temporal evolution of the spatial variability for soybean and maize were evaluated through an analysis of the semivariogram parameters for each harvest. The graphs of the semivariogram parameters as a function of time of no tillage are shown in Figure 2. The nugget effect values for soybean yield decreased linearly with time of no tillage which means that the crop yields became spatially more continuous with time. On the other hand, the maize crop became less continuous with time of no tillage as the nugget effect values show a linear increase with time (Figure 2). The dependence degree for soybean yield showed a very small change with time with a linear relationship almost leveled with the time, whereas for maize yield there was an increase in this parameter with time. The linear relationship between dependence degree calculated according to Cambardella *et al*. (1994), is not very clear although it shows a linear increase with time. As can be seen in Figure 2, if it was not for the last data point, the linear relationship would be much more clear and steep. The general magnitude of the dependence degree indicates that the confidence in the maps generated with values interpolated by the kriging method will be at most medium (Vieira, 2000). The range of dependence increased with time for soybean yield and decreased for maize (Figure 2). This is an indication that the size of the regions considered uniform gets larger wit time for soybean and smaller for maize Vieira *et al*. (2002).

In order to illustrate the comparison of soybean and maize yield maps, a classification of the last two harvest data was done for each one of the two crops. After this classification was done, a composed classification of the two crops was done in order to verify the location of places in the field with high yield potential. Using this composed classified variable it possible then to establish homogeneous zones within the field for future management application. Figure 3 shows the semivariograms and the maps for soybean, maize and for the dummy variable identified in this work as class. Spherical models were fitted to soybean and to maize yield and exponential to the dummy variable class. The yield map for maize shows a very well defined high yield region on the left hand side. The soybean showed very low yield values near the middle of the field, possibly

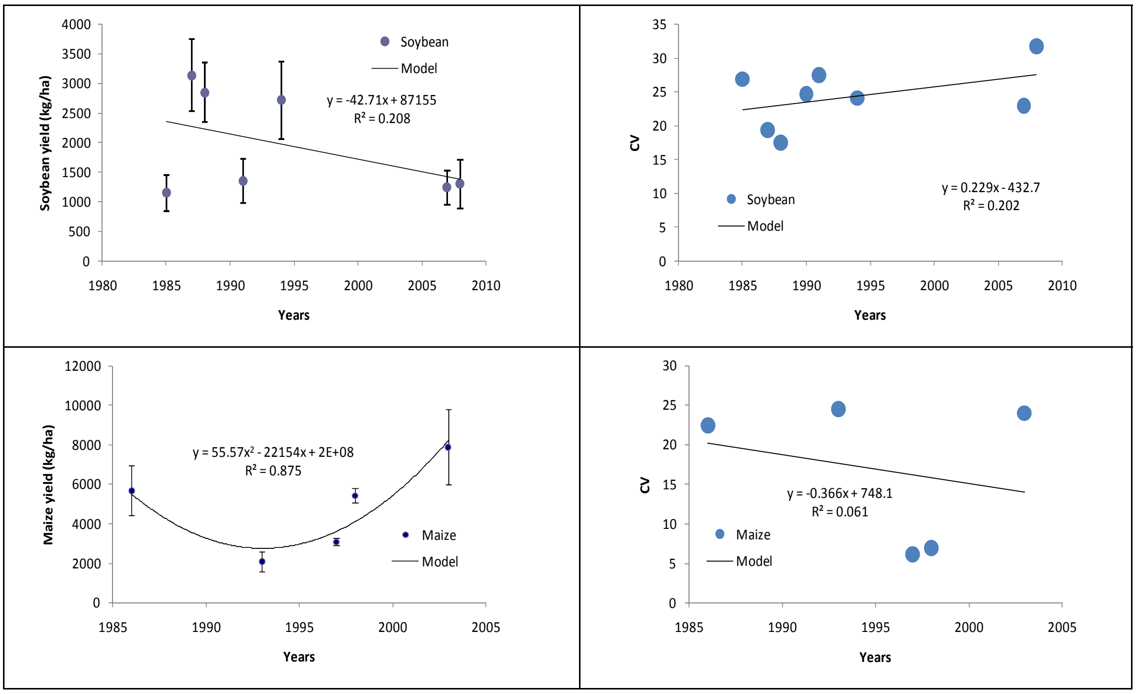

Figure 1. Temporal evolution of mean and CV values for soybean and maize yield. The error bars are one standard deviation above and below the mean value.

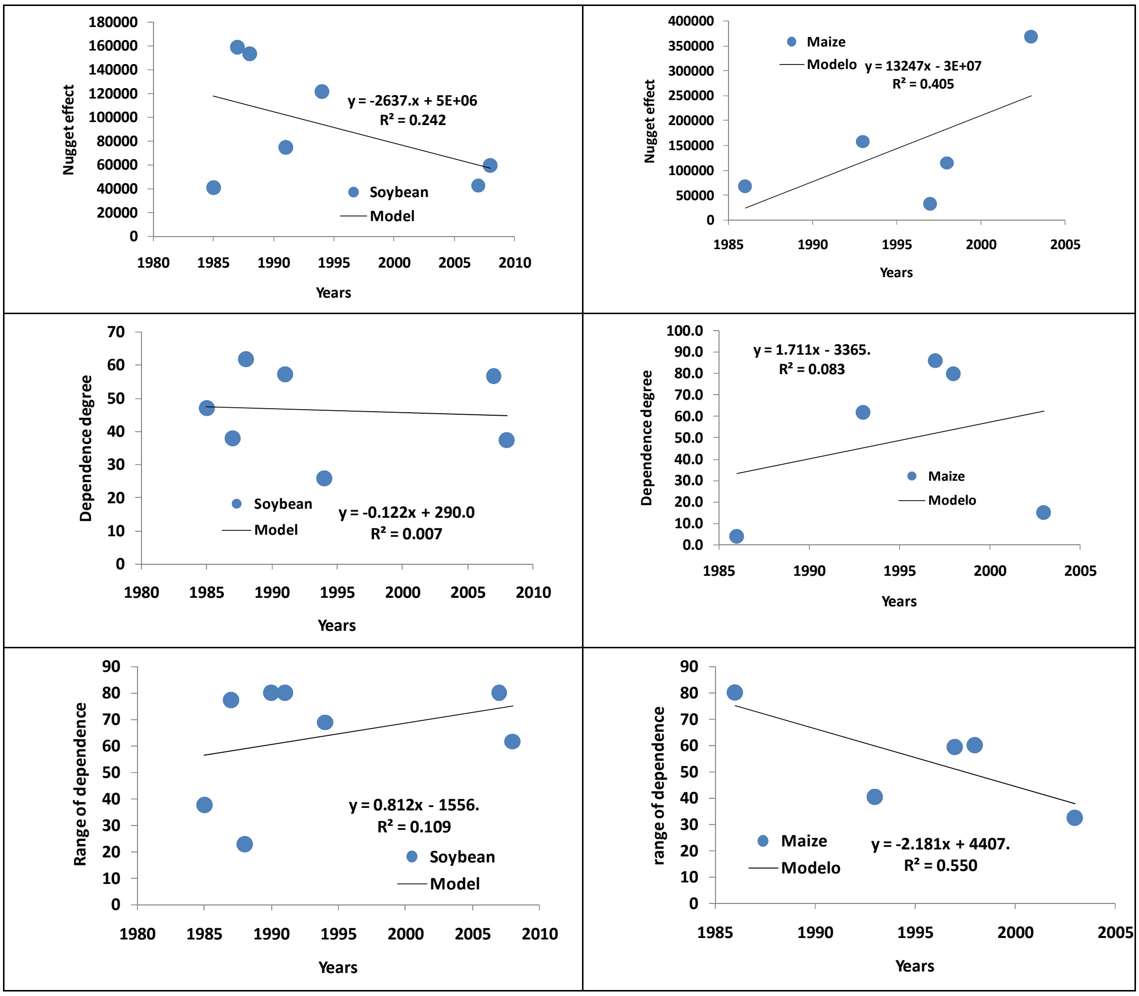

Figure 2. Temporal evolution of semivariogram parameters for soybean and maize.

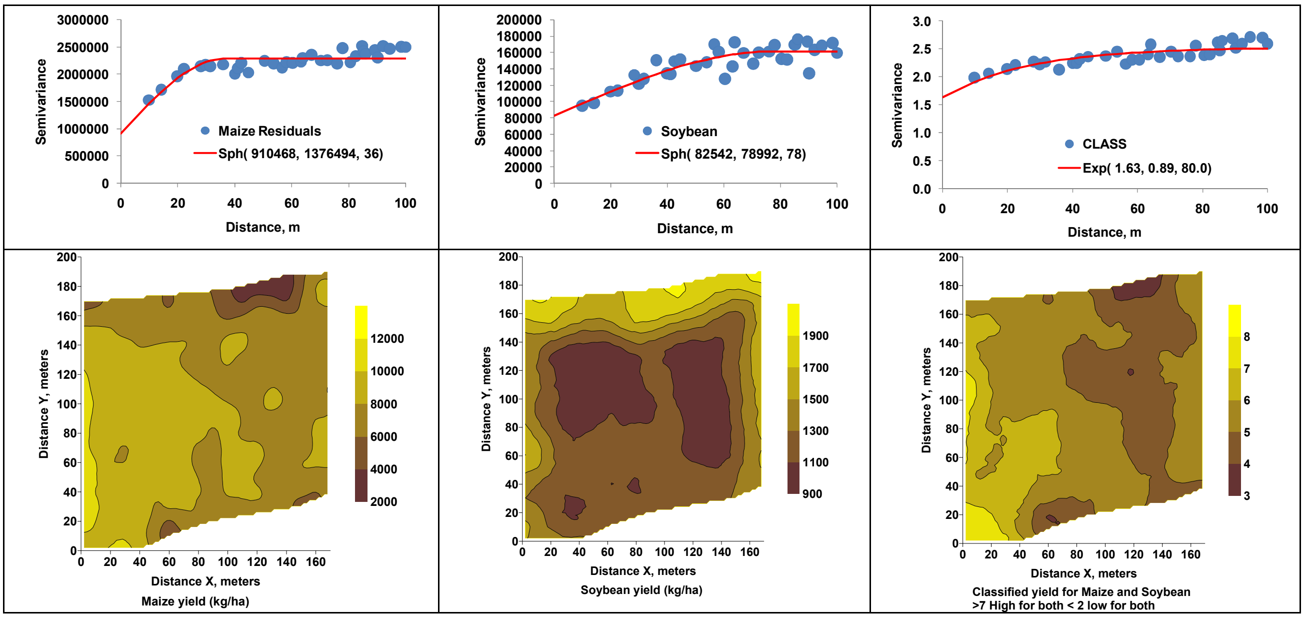

Figure 3. Semivariograms and maps for the last maize and soybean crops and for the variable in low, medium and high yield.

due to bad pest control on this region. The resulting classified map reflects closely the high yield potential of the left side of the field but it also shows regions with lower yield potential near the middle and right side of the field. Although this is a very simple idea, it seems to have potential to be expanded to more yield maps as this would produce a more reliable final result. This idea is yet under development.

Conclusions

Crop yields changed (soybean decrease and maize increase) with time of no-tillage but the real cause was not identified. The yield variability around the mean value showed opposite results as compared to the mean values as soybean became more uniform and maize became more variable with time.

The length of time with no-tillage affected the range of dependence for the both soybean and maize crops and therefore increased the size of the homogeneous management zones.

The classification procedure in order to compare maps and to delineate uniform management zones proved to have potential for future use.

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