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Mapping and modeling soil characteristics to evaluate precision farming.

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Abstract

The study was carried out on the southern sector of Kalubia Governorate, Egypt, with an area of 89512.86 Feddans (93988.50 acres). The general objective of this study was to obtain accurate and timely information about the spatial variability and status of the soil characteristics using geographic information system (GIS) and remote sensing techniques. Collection of soil data were conducted by systematic sampling and a global positioning system (GPS) was used to precisely determine site locations of the samples. All samples were analyzed to determine selected soil properties of CEC, EC, organic matter, $CaCO_3$, ESP and gypsum. Soil mapping variability was later analyzed using the geostatistics software. Kriging analysis was used to determine the value of each point in the area of study. A semi variogram was developed to describe the spatial relationship between the locations where the value of a soil property was estimated and characterized. Semi variogram analysis using geostatistics produced kriged map for CEC (6.09 – 57.14). Calcium carbonate, organic matter and gypsum contents were 2.35 - 45.38 g/kg, 1.80 - 12.07 g/kg, and 6.51-34.68 g/kg respectively. The EC value ranged between 0.83 and 44.51 dS/m. The ESP value ranged between 2.84 and 79.30. The study implies that site-specific or precision agriculture provides a useful management tool in the forecasting of crop yield and future market intelligence. Further research with respect to integrating the use of remotely sensed data with GPS and GIS to improve accuracy of systematic variability mapping in the studied area should be carried out.

Keywords: Spatial variability, Geostatistical analysis, soil, SPOT, precision farming, kriging.

Introduction

Spatial variability of soil properties has been one of the major objectives in investigations related to agricultural and environmental sciences. Webster (1980) reported that Geostatistics is a method to analyze spatial variability of soil properties. It provides the basis for describing spatial variation in soil quantitatively, for estimating soil properties and mapping them, and for planning rational sampling schemes that make the best use of manpower. Information on soil properties in crop field is very important and useful for not only fertilizer requirement but specific management of the crop and soil. Behind a locally erratic aspect, some spatial structure is often discerned and may be related to the combined action of several physical, chemical or biological processes that act at different spatial scales. Precision farming is the term used to describe the goal of increased efficiency in the management of agriculture. It is a developing technology that modifies existing techniques and incorporates new ones to produce a new set of tools for the manager to use (Blackmore, 1994, Rains and Thomas, 2000 and Stombaugh, *et al., 2001).* Precision farming is the process of managing variability, which in turn, improves the overall efficiency of the agronomic process. This improved efficiency is beneficial to the farm both economically and environmentally (Blackmore, 1996). For that purpose the geographic information system (GIS) is a kind of computerized map, the real role of which is using statistics and spatial methods to analyze characters and geography; further information is extrapolated from the analysis (ESRI, 2002).

The objective of the current study is to throw light on the spatial variability of soil characteristics as a supporting tool in the evaluation of precision farming application in south Kalubia.

Materials and methods

Location of the studied area : The investigated area is located between longitudes 31° 05` and 31° 25` east, and latitudes 30° 07` and 30° 35` north representing the southern part of Kalubia Governorate with an area of 89512.86 feddans (93988.50 acres). As shown in Figure 1.

Satellite imagery:

Data of the SPOT 5 were used. The SPOT5 sensors have the ability to image from vertical viewing (nadir) up to plus or minus 27 degrees off-nadir. Satellite ground control can steer a plane mirror to achieve the off-nadir viewing capabilities. It is therefore possible for the sensors to image any point within a strip 475 km to either side of the satellite ground track. The satellite has 2 sensors, and when used in dual mode, both sensing instruments can be pointed to cover adjacent ground areas, while viewing the earth from the vertical (nadir) position. Spot 5 image was used to perform data fusion.

Field work:

A rapid reconnaissance survey was firstly made throughout the investigated area in order to gain an appreciation of the broad soil patterns, the landform and landscape characteristics.

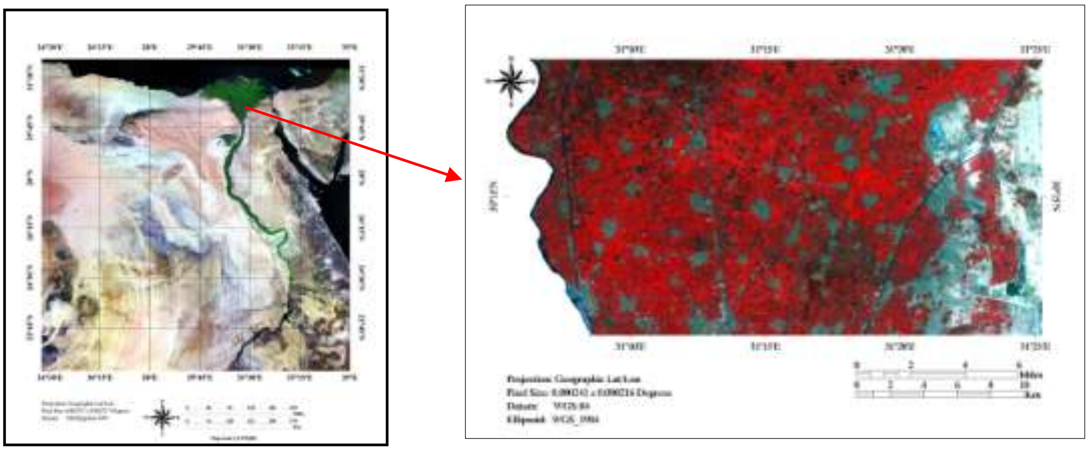

Figure 1: Location of the studied area of south Kalubia.

Longitudes and latitudes as well as elevation are defined in the field by using global positioning system (GPS) "system corporation MAGELLAN" - GPSNAV DLX-10 TM for recognizing and appointment the sample areas and profiles locations; within the delineated mapping units. Secondly, based on the pre-field interpretation and the information obtained during the reconnaissance survey, 18 soil profiles representing the different landforms were made and described on the basis outlined by FAO (1990).

Laboratory analyses:

The collected soil samples were airdried, ground gently, then sieved through a 2 mm sieve. Soil salinity, $CaCO_3$, organic matter, exchangeable Na, gypsum, and CEC were all determined according to Black (1965).

Geostatistical analysis:

Interpolation between sampling locations was made as ordinary kriging (1) interpolation method performed using the Geostatistical Analyst extension available in ESRI© ArcMap™ v9.2. Precision farming spatial model (PFSM) was designed using spatial analyst model ArcMap™ v9.2.The model inputs are electric conductivity (EC), exchangeable sodium percentage (ESP), cation exchange capacity (CEC), gypsum content, calcium carbonate content and organic matter (OM) content. Model processes included input reclassification, weighted overlay, conditional sentences, converting raster to vector and smoothing vector

Results and discussions

Soil characteristics vary spatially, and have strong fluctuations over long and short distances (Trangmar et al. 1985;and Warrick et al. 1986).

The characterization of the spatial variability of soil characteristics is essential to achieve a better understanding of complex relations between soil properties and environmental factors.

The spatial variability analyses were conducted for weighted average values of the soil profiles concerning calcium carbonates, EC, ESP, gypsum and OM. Calcuim carbonates is a common substance found in the rocks in all parts of the world, and it is the active ingredient in soil lime.The spatial variability of soil calcium carbonates in the study area was shown in the following lines and Figure 2a. The semivariogram model for soil calcium carbonate content of the studied area shows that, the major distance at which the model reaches its limiting value is 29360.5 m and the minor range is 26636.4 m. with direction angle of 13.3^{O} Soil calcium carbonates content distribution in the studied area can be expressed by the following formula: 7.9491*Spherical (29361, 26636, 13.3) +36.53*Nugget (2)

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(1) Kriging is a moderately quick interpolator that can be exact or smoothed depending on the measurement error model. It is very flexible and allows you to investigate graphs of spatial autocorrelation. Kriging uses statistical models that allow a variety of map outputs including predictions, prediction standard errors, probability, etc. The flexibility of kriging can require a lot of decision-making. Kriging assumes the data come from a stationary stochastic process, and some methods assume normally-distributed data

(2) The nugget represents measurement error and/or microscale variation (variation at spatial scales too fine to detect). It is possible to estimate the measurement error if you have multiple observations per location, or you can decompose the nugget into measurement error and microscale variation using the Error Measurement control.

The Root-Mean-Square-Standerized (RMSS) value is 1.088 for the studied soil profile. From Figure (2a) soil calcium carbonate content ranges between 2.35 and 45.38 g/kg of the fine earth in the surface layer of the study area with regression function y= 0.080 x + 18.963.,where y is the spatial variability and x is $CaCO_3$ presence of $CaCO_3$ in arid and semiarid regions, coating the stones developed in soil on the geomorphic surfaces of coarse clastic sediments contain evident information of age (Xing et al., 2002).

Gypsum content:

The spatial variability of gypsum in the study area is shown in the following lines and Figure 2b. The semivariogram model for gypsum content of the studied area shows that, the major distance at which the model reaches its limiting value is 28852.9 m and the minor range is 24339.8 m. with direction angle of 32.4^O Gypsum content distribution in the studied area can be expressed by the following formula: 2.2642Spherical(28853,24340,32.4)+15.155*Nugget
The Root-Mean-Square-Standerized (RMSS) value is 1.052 for the studied soil profile. From Figure 2b gypsum content ranges between 6.51 and 34.68 g/kg of the fine earth in the surface layer of the study area with regression function y= **0.048 x + 13.033.,** where y is the spatial variability and x is gypsum content. The high values may be due to application of gypsum as an amendment.

Cation exchange capacity (CEC):

The semivariogram model for soil CEC the of studied area shows that, the major distance at which the model reaches its limiting value is 29163.4m and the minor range is 25219.8 m. with direction angle of 10.1 ^{O}. Soil CEC distribution in the studied area can be expressed by the following formula: **15268Spherical(29163,25220,10.1)+44366*Nugget**
The Root-Mean-Square-Standerized (RMSS) value is 0.9752 for the studied soil profile. From Figure 2c, soil CEC values range between 6.09 and 57.14 cmolc/kg of the fine earth in the surface layer of the study area with regression function y= 0.116 x + 290.195 where y is the spatial variability and x is CEC . Generally, CEC of the Nile flood plain soils vary between 35 and 80 cmolc/kg and 11 to 58 cmolc/kg **(Ibrahim et al., 2010).**

Electrical Conductivity (EC):

Soil salinity is expressed as EC for the soil paste extraction. It refers to the movement and concentration of salt in landscapes. Salinity effects could be recognized as reduction in the productive capacity of affected land (eg. crop yields), degradation of the environment and wildlife habitats, deterioration of quality of domestic water supplies, production losses causing economic hardship. In the Nile Delta, productivity has been partly decreased by soil salinity and urban encroachment onto previously productive lands **(Lenney et al. 1996).** The spatial variability of soil salinity in the study area is shown in the following lines and Figure 2d. The semivariogram model for soil salinity of the studied area shows that, the major distance at which the model reaches its limiting value is 28829.8 m and the minor one is 24346.2 m. with direction angle of 33.6 ^{O}. Soil salinity distribution in the studied area can be expressed by the following formula:
6.6574 * Spherical (28830, 24346, 33.6) + 20.525 * Nugget
The Root-Mean-Square-Standerized (RMSS) value is 1.086 for the studied soil profile. From Figure 2d, soil EC ranges between 0.83 and 44.51 dS/m in the fine earth in the surface layer of the study area with regression function **y = 0.007 x + 2.701** where y is the spatial variability and x is EC**.**

Exchangeable Sodium Percentage (ESP):

The cultivated floodplain soils are non-sodic where the ESP values are less than 15 (**Ibrahim et al., 2010)**. The spatial variability of ESP of the study area was estimated as shown in the following lines and Figure 2e. The semivariogram model for ESP of studied area shows that, the major distance at which the model reaches its limiting value is 28973.8 m and the minor one is 24365.2 m, with a direction angle of 34.5 ^{o}. Distribution of ESP in the studied area can be expressed by the following formula : 22.192 * Spherical (28974 , 24365 , 34.5) + 64.753 * Nugget

The Root-Mean-Square-Standerized (RMSS) value is 1.085 for the studied soil profile. From Figure 2e, ESP ranges between 2.84 and 79.30 of the fine earth in the surface layer of the study area with a regression function of **y= 0.001 x + 8.722,** where y is the spatial variability and x is ESP. The high value in these soils indicates high sodicity that may be due to using irrigation water **(Rodolfo, 2007).**

Organic Matter content:

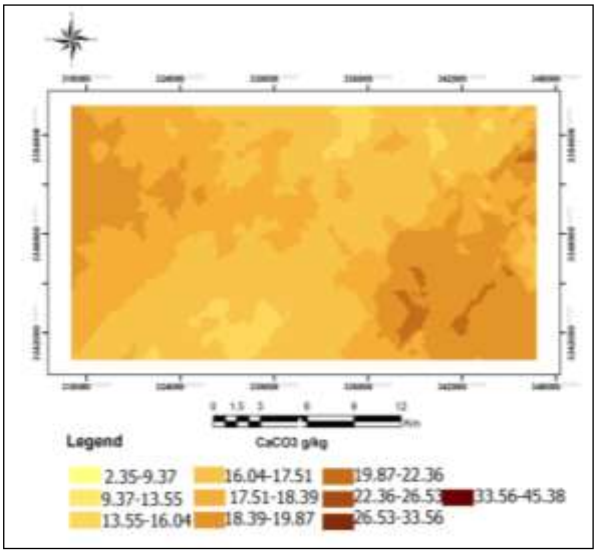
The spatial variability of soil organic matter in the study area was estimated as shown in the following lines and Figure 2f. The semivariogram model for soil organic matter of the studied area shows that, the major distance at which the model reaches its limiting value is 28350 m and the minor one is 20614.4 m. with a direction angle of 81.4^O. The distribution of organic matter content in the studied area can be expressed by the following formula:
0.41114 * Spherical (28350 , 20614 , 81.4) + 7.1883 * Nugget
The Root-Mean-Square-Standerized (RMSS) value is 1.022 for the studied soil profile. From Figure 2f, organic matter content ranges between 1.80 and 12.07 g/kg of the fine earth in the surface layer of the study area with regression function of y = 0.019 * x

+ 7.922, where y is the spatial variability and x is organic matter content. The high value in the surface layer is associated with maintaining good levels and requires sustained effort that includes returning organic materials to soils and rotations with high-residue crops and deep- or dense-rooting crops. It is especially difficult to raise the organic matter content of soils that are well aerated, such as coarse sands, and soils in warm-hot and arid regions because the added materials decompose rapidly. It increased as the soil texture became finer (clay) near the Nile, thus reflecting the same trend observed with clay content. Such a finding could be attributed to the longer cultivation history of land near the Nile and the remains of plants on the surface layers and normal cultivation processes. These results are in agreement with those obtained by **Nofal (1984)**.

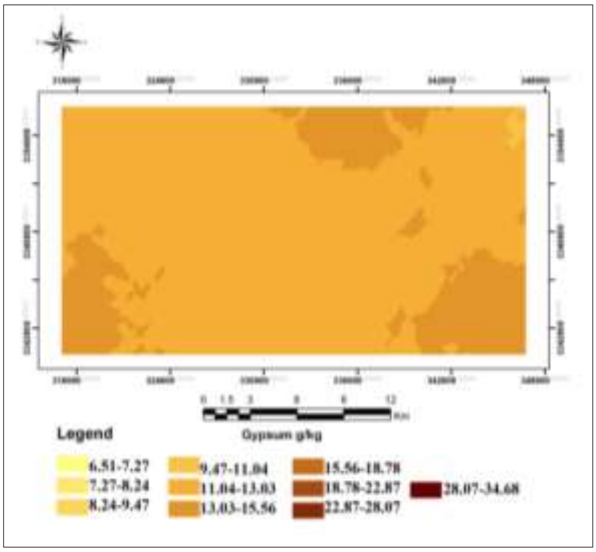
Precision Farming Spatial model (PFSM)

A precision farming spatial model was developed in the current study to identify the most appropriate areas/fields for precision farming based on the interaction among physical /chemical soil properties using spatial analysis tools in ARCGIS environment. The model input included six variables i.e., EC, ESP, CEC, gypsum, $CaCO_3$ and organic matter. The model resulted in five precision farming classes 1-Farms not meeting the requirements of precision farming., 2-Farms below the threshold of precision farming., 3-Farms meeting the threshold of precision farming practices 4-Farms above the threshold of precision farming., and 5-Farms meeting the requirements of precision farming. Figure 4 shows the model structure; meanwhile Figure 3 shows the precision farming map which resulted from the aforementioned.

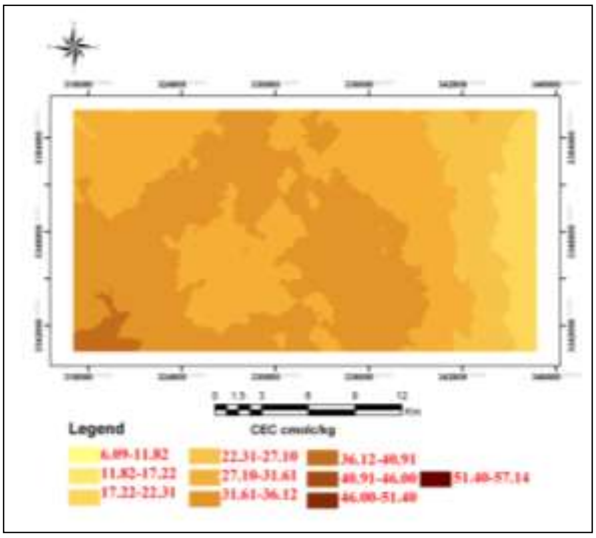
assessments



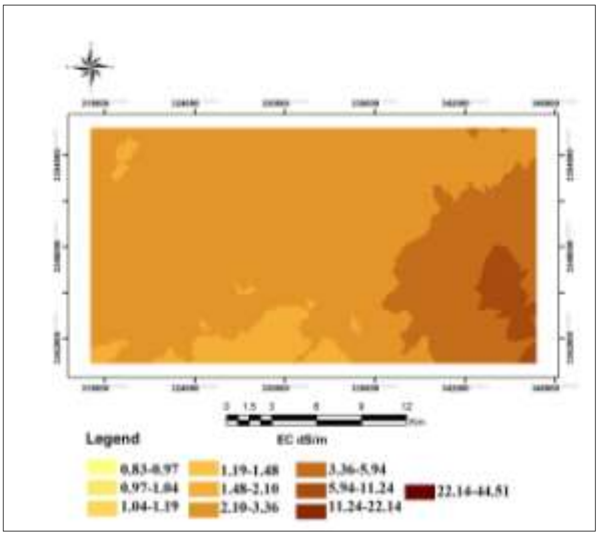
(a) CaCO3



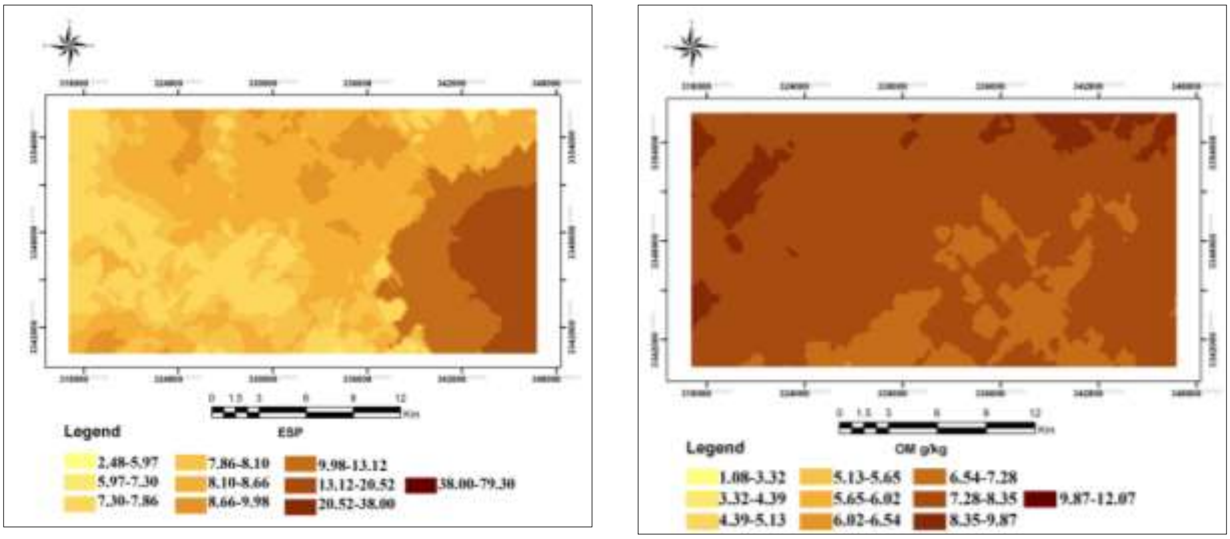
(b) Gypsum



(c) CEC



(d) EC



(e) ESP **(f) OM**

Fig. (2: a, b, c, d, e and f): Spatial variability of soil of the study area.

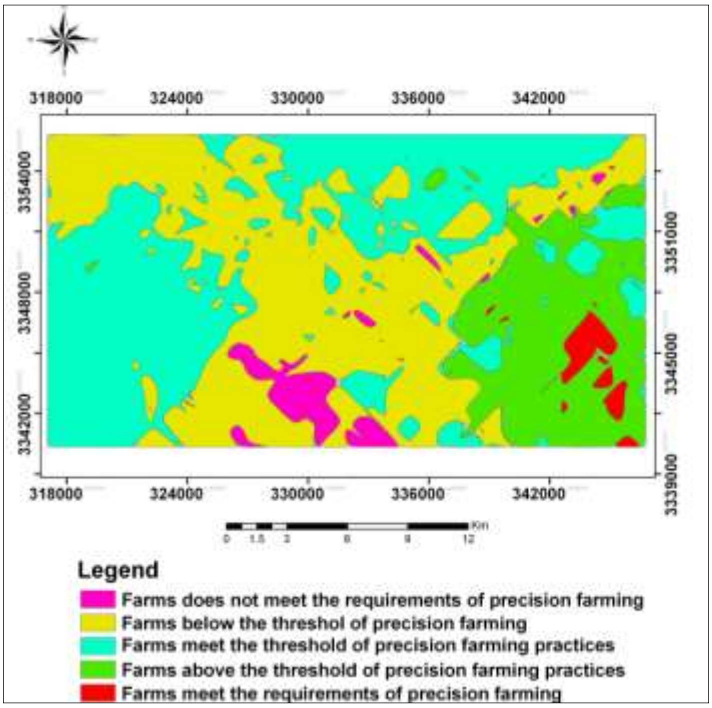


Figure 3: Precision Farming map of the investigated area.

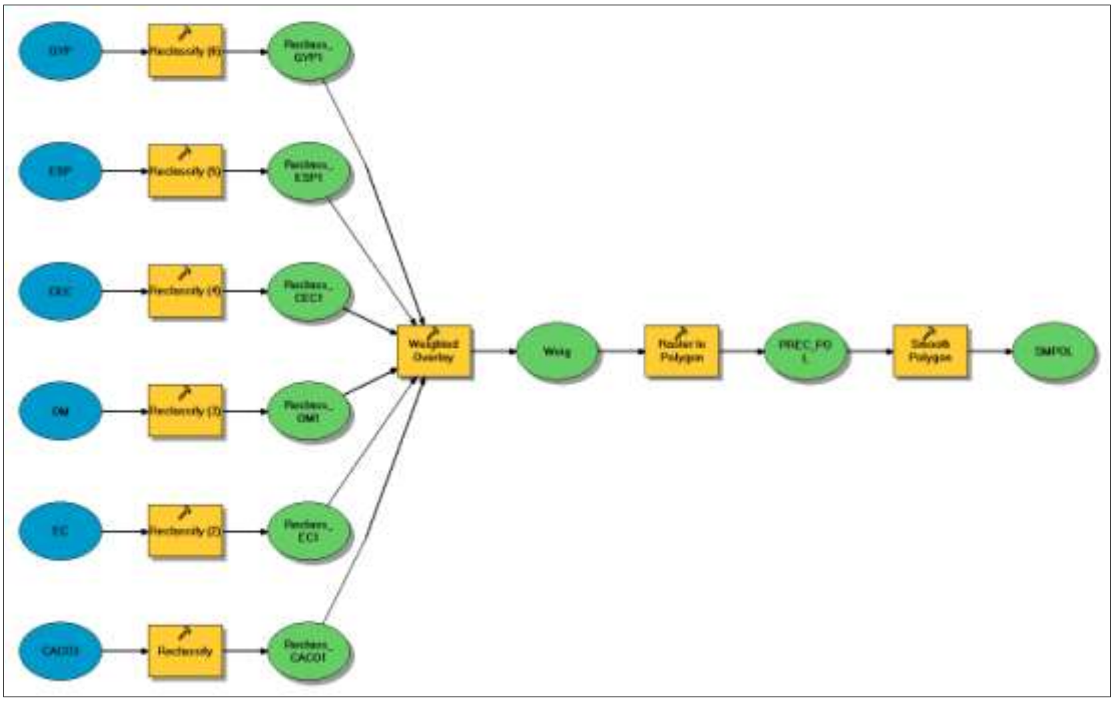


Figure 4: Precision farming model

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الملخص العربى

إعداد خرائط ونمذجة خصائص التربة لتقييم الزراعة المحكمة

عصمت حسن نوفل ، علاء الدين حسن النهرى ، هيثم محمد شحاته سالم ، وسام رشاد زهرة

قسم الأراضي- كلية الزراعة بمشتهر- جامعة بنها و الهيئة القومية للاستشعار من بعد وعلوم الفضاء

تقع منطقة الدراسة فى الجزء الجنوبى من محافظة القليوبية حيث تحتل مساحة تبلغ 89512,86 فدان. هدف هذه الدراسة هو الحصول على معلومات دقيقة للاختلافت الفراغية (المكانية) لصفت وخصائص التربة باستخدام نظم المعلومات الجغرافية و تقنيات الاستشعار عن بعد. تم الحصول على بيانات التربة عن طريق جمع العينات التى تم تحديد مواقع أخذها بدقة باستخدام جهاز التموضع العالمى(GPS) . تم تحليل العينات لتقديرالسعة التبادلية الكاتيونية، التوصيل الكهربى، المادة العضوية، كربونات الكالسيوم، النسبة الادمصاصية للصوديوم و الجبس. تم تحليل الاختلافات وانتاج خرائط لها باستخدام برنامج التحليل الجيواحصائى. تم استخدام تحليل Kriging لتقدير قيمة كل نقطة فى منطقة الدراسة. تم وصف العلاقت المكانية بين المواقع التى تم تقدير الخصائص المختلفة لها.

التحليل الجيواحصائى له القدرة على انتج خرائط للسعة التبادلية الكاتيونية (6,09- 57,14 سنتيمول شحة/كجم). كربونات الكالسيوم (2,35- 45,38 جم/كجم)، المادة العضوية (1,80- 12,07 جم/كجم) والجبس (6,51- 34,68 جم/كجم). تراوحت قيمة التوصيل الكهربى بين 0,83 و 44,51 ديسي سيمنز/ م، بينما تراوحت قيمة النسبة الادمصاصية للصوديوم بين 284 و 79,30. تفترض الدراسة أن الزراعة المحكمة تمثل أداة مفيدة للتنبؤ بالانتاج المحصولى. يجب اجراء المزيد من البحث بالتكامل بين بيانات الاستشعار عن بعد ونظم المعلومات الجغرافية لتحسين انتاج الخرائط التى تعبر عن الاختلافات فى منطقة الدراسة.

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