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Use of Statistical and Spatial Variability Analyses for Investigating Variations of Soil Nitrate in Irrigated Corn Fields

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THE OBJECTIVES of this study were to examine field variability soil NO_3-N content with respect to their management and inherent dependence and to improve sampling strategies of soil NO_3-N for future studies on N balance and validation of solute transport models. Two 50x50m plots (control and N-fertilized) in an irrigated corn (*Zea mays* L., hybrid cultivar 10) field were randomly surface (0-15cm) and subsurface (15-30 cm) sampled according to a 2x2m grid system after the first dose of the N fertilizer was applied. Descriptive statistical and spatial variability analysis of soil NO_3-N, soil moisture and soil organic nitrogen contents were used to determine the different components responsible for field soil NO_3-N variability. Significant field variations in soil NO_3-N were found within the studied field. Nonuniformity of N-fertilizer application accounted for 84-89% of the total soil NO_3-N variability. Soil moisture and soil organic nitrogen contents had significant contribution to soil NO_3-N variability in the control plot (57-72%). Geostatistical analysis of the spatial variability indicated that soil NO_3-N, soil moisture and soil organic N contents of the surface and subsurface layers confirmed to the Gaussian or spherical semi-variogram models. The calculated variograms were used to establish kriging maps of the studied variables. Sampling strategies were determined and were variable between the control and the N-fertilized plots as well as between the surface and subsurface layers.

Most plant-soil systems are spatially heterogeneous and therefore considerable efforts has been invested in quantifying the field scale variability (1-100 m) of biologically important soil properties. Even in fields, presumably homogenized by cultivation, variability can be substantial at small spatial scales (Webster and Butler, 1976; Marriott *et al.*, 1997).

One approach to determine the fate of nitrogen in agricultural systems is by developing N balances (Lund, 1982; Lund *et al.*, 1978; Fried *et al.*, 1976). The most difficult sinks to measure for N balances are leaching and gaseous losses. An important line of research dealt with the intrinsic spatial variability of soil hydraulic properties and transport behavior of salts and inorganic ions (Freebairn *et al.*, 1989; Pikul *et al.*, 1990; Unger, 1992; Poletika and Jury, 1994). Several field-scale studies have shown that movement of water and solutes through unsaturated soil often is highly variable in space even when surface inputs are spatially nearly uniform (Biggar and Nielsen, 1976; Van De Pol *et al.*, 1977; Jury *et al.*, 1982; Tabor *et al.*, 1985). Tabor *et al.* (1984) reported that many factors affect spatial and temporal variability of nitrate content in cropped fields, such as soil properties, cultural practices and physiological maturity. Thus, the interpretation of irregular flow patterns resulting from surface management practices will often be complicated by the large amount of intrinsic variation in transport properties present in field soils (Poletika and Jury, 1994). Validation of the recently used solute transport models to field conditions is also necessary to improve their predictability (Huwe and van der Pleog, 1988; Hutson and Wagenet, 1992; Huwe, 1992; Jabro *et al.*, 1993; Hedia, 2000). Researchers are then faced by spatial and temporal variations in the field solute concentration.

Classical statistical tests assume that observations are independent. However, many soil properties vary continuously over space, with contiguous samples being the most similar. These are, therefore, not independent from each other at some scales. However, geostatistical analyses provide the means to interprete the spatial dependence among soil samples (Burgess and Webster, 1980a; Webster, 1985; Webster 2001). Hence, statistical analysis along with geostatistics can be used as a useful tool to quantify management and inherent spatial dependence of soil moisture and nitrate contents (Burgess and Webster, 1980a, b; Vieira *et al.*, 1981; Russo, 1984; Ramadan and Abdel-Kader, 1995; Ramadan, 2001).

The objectives of this study were (i) to examine field variability of soil moisture, NO_3-N and soil organic N contents with respect to their management and inherent dependence and (ii) to improve sampling strategies of soil NO_3-N for future studies on N balance and validation of solute transport models.

Material and Methods

1- Study area

This study was conducted on a 2.5 faddan furrow irrigated corn (*Zea mays* L., hybrid cultivar 10) field located in the Experimental Station of the Faculty of Agriculture, Alexandria University at Abis. Corn was sown on 19 May 2001 and harvested on 10 August 2001. The field was chosen because of its apparent uniformity and size. The soil is a sandy clay loam, (Lacustrine) Aquic Torrifluvents. Some selected chemical and physical characteristics of the soil were determined according to the standard methods outlined by Page *et al.* (1982) and are listed in Table 1.

TABLE 1. Some selected chemical and physical characteristics of the studied soil.

Characteristics	Depth (cm)	
	0-15	15-30
pH (1:2.5)	7.68	7.72
E.C. (dSm^{-1})	1.29	1.35
CaCO3 ($g\ kg^{-1}$)	92.0	111.2
OM ($g\ kg^{-1}$)	25.8	19.5
CEC ($cmolc\ kg^{-1}$)#	35.73	31.32
Clay% (<0.002 mm)	32.45	28.37
Textural Class +	SCL	SCL
Ks ($m\ d^{-1}$)x	0.097	0.085
F.C. (%v)*	41.4	35.9
Bulk density ($Mg\ m^{-3}$)	1.29	1.36
Available ($mg\ kg^{-1}$)		
N	1.57	1.07
P	22.6	12.6
K	7.7	3.2

Cation Exchange Capacity.
+ SCL= Sandy Clay Loam.
x Saturated hydraulic conductivity.
* Field capacity on volume basis.

2- Field layout

Two 50x50 m plots were set up in the center of the field with a 5.0 m width buffer zone from all directions. The rows were spaced at 0.70 m apart. One plot received the recommended fertilization rate for corn (N-fertilized plot). Nitrogen was applied as ammonium nitrate fertilizer (33.5% N) at 150 kg/fad., phosphorus was applied as superphosphate fertilizer at 100 kg P_2O_5/fad., and potassium was applied as potash salt (52% K_2O) at 50 kg/fad. The second plot received the same fertilization rates of phosphorus and potassium but did not receive any N fertilizers (control plot). Corn was sown after winter wheat which received 70, 80 and 0 kg/fad. of N, P and K, respectively. The field was conventionally surface-irrigated and common practices were similarly applied to both plots.

3- Soil sampling and laboratory analysis

Using a random-number generator, 50 sites were chosen in each plot from the intersections of a 25x25 regular grid. After the first dose of the N fertilizer, the surface (0-15cm) and subsurface (15-30 cm) layers were randomly sampled according to a 2x2m grid system from both plots. Composite samples were consisted of four soil cores. Samples were collected with a 7.5 cm diameter cores. Samples were packed in polyethylene bags, immediately transported to the laboratory and stored deep-frozen until subsequent analysis carried out.

Collected samples were analyzed for their gravimetric water content (θ) using the loss in weight method. Soil mineral N content (N_{min}; NO_3-N and NH_4-N) was extracted using 2.0*M* KCl and analyzed for NH_4-N and NO_3-N concentrations. Total soil-N content (N_t) was also analyzed using Vapodust 50 nitrogen distillation unit (Page *et al.*, 1982). Soil organic N content (N_{org}) was calculated as $N_{org} = N_t - N_{min}$

4- Methods of data analysis

To study the contribution of the different variation sources to the field distribution of NO_3-N content, descriptive statistical analysis of the obtained data was carried out using the SPSS Software package, Version 9.0 (SPSS, 1999). Calculations of the minimum, maximum, range, mean, variance (σ^2), standard deviation (SD) and coefficient of variation (CV%) were evaluated.

Geostatistical analysis of the obtained data was also performed. Geostatistics is based on the theory of regionalized variables. Extensive background material in the soils literature includes articles by Burgess and Webster (1980a,b), Warrick and Nielsen (1980) and Vieira *et al.* (1981). Unlike most classical statistics, the assumption of independence is not made. A variogram function $\gamma(h)$ (which is basic to geostatistics) is defined from

$$2\,\gamma(h) = \mathrm{Var}\,[Z(x) - Z(x + h)] \; \ldots\ldots \; (1)$$

where Z(x) and Z(x+h) are random variables corresponding to sites separated by a vector h.

Mathematical models that are fitted to variograms are useful for subsequent applications, *e.g.* kriging. Valid possibilities include linear, spherical, exponential, gaussian and power models (Warrick *et al.*, 1986; Oliver and Webster, 1991). To date, there is no foolproof, pure objective method for fitting models to sample variograms. As a result, models are fitted subjectively but weighted more heavily on distances for which large number of sample pairs are available and for which pairs are relatively close together.

An idealized, linear variogram model is given in Fig. 1. The semivariogram starts at C_0 for $h = 0$. The limiting "*nugget*" value C_0 is due to inherent variability of the characteristic type of sampling and/or laboratory analysis error. From C_0 the value increases linearly with distance between samples (h) to a maximum "*sill*" value ($C_0+\Delta C$). The semivariance remains constant with intersample distances greater than or equal to the "*range*" (a). Thus, samples close together have small semivariances and are more alike than samples further apart which have larger semivariance. Samples are dependent for distance up to range "a" where the semivariance then remains constant with increasing distances between samples and samples achieve independence.

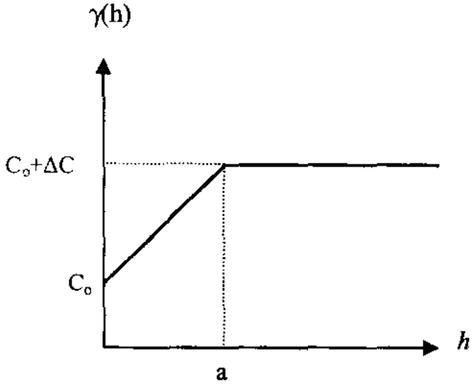


Fig. 1. A linear variogram model (Oliver and Webster, 1991).

Kriging is an optimal linear interpolation method used to predict unknown site values by appropriately weighting the known values on the predicted site through the use of the variogram (Burgess and Webster, 1980a,b). This estimation is unbiased with minimum variance. This method of analysis can be used to prepare maps of predicted site values with a variance for each site. The variance maps can be used to determine where more sampling sites could be located to improve overall estimates.

Results and Discussion

1- Analysis of variance

One of the initial causes of soil NO_3-N variability in a field soil is due to the nonuniform addition of fertilizers (Cameron *et al.*, 1979). The total variance of NO_3-N content due to fertilizer application (σ_T^2) can be calculated by assuming that variation on the N-fertilized plot was due to inherent variation (σ_h^2) already present before fertilization (as measured by the control plot) and variation caused by the nonuniform application of fertilizer (σ_F^2) namely;

$$\sigma_T^2 = \sigma_h^2 + \sigma_F^2 \quad ...... (2)$$

The percent of the variability due to fertilizer application is thus calculated as

$$\%\sigma_F^2 = \frac{(\sigma_T^2 - \sigma_h^2)}{\sigma_T^2} \times 100 \; ... (3)$$

Descriptive statistical analysis of soil NO_3-N content (kg/fad./15cm) variability is presented in Table 2. In general, the minimum, maximum, range, mean and SD values of NO_3-N content in the N-fertilized plot were higher than those in the control plot. Similarly, these parameters had higher values in the surface layers than in the subsurface layers for both plots. On the other hand, the CV% values took the reverse order for plots and layers.

Calculated values of the total variance (σ_T^2) of the field variability of NO_3-N content in the N-fertilized plot were 161.7 and 58.0 (kg/fad./15cm)^2 in the surface and subsurface layers, respectively. The inherent variability of the soil NO_3-N content is represented by the variance of the control plot (σ_h^2); 18.0 and 8.9 (kg/fad./15cm)^2 in the surface and subsurface layers, respectively. The percent variance of NO_3-N content due to nonuniformity of N-fertilizer application (%σ_F^2) was calculated using Eq. (3). The results in Table 2 show higher %σ_F^2 value (88.9%) in the surface layer of the N-fertilized plot than in the subsurface layer (84.6%). As the fertilizer dissolves and ions disperse, one might expect a small decrease in the variation between the surface and subsurface layers (Cameron *et al.*, 1979; Poletika and Jury, 1994). This means that percent variability of NO_3-N content due to nonuniformity of N-fertilizer application accounted for > 84% of the total variability. These findings are in a good agreement with those obtained by Cameron et al. (1979), Lund (1982) and Poletika and Jury (1994). Since the present work was conducted on a corn cultivated field, the obtained values of variation in NO_3-N content due to nonuniformity of N-fertilizer application were lower than those obtained by Cameron *et al.* (1979) for bare soils (>98%). This might indicate that the presence of plants added other sources of variation to the total variance.

TABLE 2. Descriptive statistics of soil NO_3-N content (kg/fad./15cm) in the surface and subsurface layers for the control and N-fertilized plots.

Statistics	0 –15 cm		15 – 30 cm	
	Control	N-Fertil.	Control	N-Fertil.
Minmum	2.2	23.0	1.7	4.7
Maximum	19.8	62.1	13.1	36.9
Ramge	17.6	39.1	11.5	32.2
Mean	9.2	38.4	6.6	20.3
SD	4.2	12.7	3.0	7.6
CV%	46.3	33.1	45.0	37.4
σ_T^2	---	161.7	----	58.0
σ_h^2	18.0	---	8.9	----
%σ_F^2	---	88.9	----	84.6

TABLE 3. Descriptive statistics of volumetric soil moisture content (%) and soil organic nitrogen content (kg/fad./15cm) of the surface and subsurface layers for the control plot.

Statistics	(θ)		N_{org}	
	0-15	15-30	0-15	15-30
Minmum	0.21	0.32	691.0	401.1
Maximum	0.57	0.59	2308.0	1703.3
Ramge	0.36	0.27	1617.0	1302.2
Mean	0.36	0.46	1428.5	997.7
SD	0.11	0.06	417.7	319.7
CV%	33.1	25.2	29.2	32.0
σ^2	1.2E-02	3.17E-3	1.7E+05	1.0E+05

A further detailed statistical analysis of volumetric soil moisture (θ) and soil organic nitrogen (N_{org}) contents of the control plot (no N-Fertilizer applied) are presented in Table 3. In this plot, the residual N_{min} and mineralization of the soil organic N-pool are the main sources of NO_3-N. Hansen and Jensen (1995) reported that variability in NO_3-N concentration in such plots are mainly due to (i) variation of sources (residual NO_3-N and mineralization) and (ii) variation of sinks (leaching, uptake, denitrification, etc.). The results showed that the mean volumetric soil moisture content (θ) in the surface layer (0.36%) was lower than that in the subsurface layer (0.46%). However, the variation in (θ) distribution was higher (CV%= 33.1) in the surface layer than in the subsurface layer (CV%= 25.2). On contrast, the mean N_{org} in the surface layer (1428.5 kg/fad./15cm) was higher than that in the subsurface layer (997.7 kg/fad./15cm). N_{org} was less variable in the surface layer (CV%=29.2) compared with the subsurface layer (CV%= 32.0). As soil moisture content and soil organic nitrogen content are independent, it can be said that the variation in soil moisture and organic nitrogen contents were responsible for > 62% and >57% of the NO_3-N variability in the surface and subsurface layers, respectively. Other sources of variation such as plant distribution, preferential flow of water and NO_3-N through cracks, can also have substantial contribution which needs further future investigations.

2- Geostatistical analysis

The 3D-distribution of soil nitrate, soil moisture and soil organic nitrogen contents using the Surfer Software Inc., Version 6.1 (Golden Software, 1995) are presented in Fig. 2-9. Spatial variability analysis was carried out using the GSPLUS software (Gamma Design, 1991). Parameters of the obtained semi-variogram and the best fitted models to these variables are listed in Table 4.

The Gaussian model were the best fitted model to describe the spatial variability of soil nitrate content in the surface (0-15 cm) and subsurface (15-30 cm) layers of the N-fertilized and control plots (R^2 = 0.864 and 0.921; 0.948 and

TABLE 4. Semi-variogram parameters and fitted models of soil nitrate, moisture and organic nitrogen contents.

Variables	Model	C_o	$C_o + C$	a	R^2
Nitrate					
Fertilized Plot: 0-15 cm	Gaussian	127.81	181.80	35.95	0.864
15-30 cm	Gaussian	40.03	65.96	35.14	0.921
Control Plot: 0-15 cm	Gaussian	13.63	19.17	26.23	0.948
15-30 cm	Gaussian	7.18	9.85	35.82	0.997
Moisture Content					
Control Plot: 0-15 cm	Gaussian	0.093	0.012	17.03	0.955
15-30 cm	Spherical	0.001	0.003	12.26	0.763
Organic Nitrogen					
Control Plot: 0-15 cm	Gaussian	1.40E+05	2.11E+05	33.83	0.953
15-30 cm	Spherical	1.02E+05	1.50E+05	74.98	0.643

0.997, respectively). The same trend was also observed with the soil moisture and soil organic nitrogen contents of the surface layer in the control plot (R^2 = 0.955 and 0.953, respectively). However, data of soil moisture and soil organic nitrogen contents of the subsurface layer in the control plot confirmed better to the Spherical model (R^2 = 0.763 and 0.643, respectively) than the Gaussian model. Kriging maps of the studied variables were also established (Fig. 2-9).

In general, the "*nugget*" variance (C_o) of the three variables studied in the surface layer (0-15 cm) of the N-fertilized and control plots were always larger than those in the subsurface layer (15-30). This can indicate higher inherited spatial variability of these variables in the surface layer than in the subsurface layer for both plots. Similarly, the "*sill*" variance ($Co + \Delta C$), which illustrates the structural variability of the studied variables, was also larger in the surface layers than for the subsurface layers. The spatial dependence of a variable over a specific lag distance is described by the "*range*" (a). Sampling the soil at a distance less than or equal to "a" comprises a spatial-dependent variability of the measured variables. The best fitted models to the studied variables showed considerable differences in the range values of the soil nitrate content of the surface layer of the N-fertilized and control plots (35.95 m and 26.23 m, respectively). The difference in range values between the surface and subsurface layers of the N-fertilized plot was negligible (0.81 m), whereas this difference was considerable in the control plot (9.58 m). The readily soluble NH_4NO_3 fertilizers made it easy for the nitrate to move to the subsurface layer in the N-fertilized plot. On the other hand, nitrate content in the control plot is highly dependent on the mineralization of the soil organic pool which had its own spatial variability. It can be noticed that the range values of the soil nitrate and organic nitrogen contents of subsurface layer in the control plot (35.82 and 74.98

m, respectively) is higher than those of the surface layer (26.23 and 33.83 m, respectively). It can also be noticed that range values of the soil moisture content of the surface and subsurface layer in the control plot (17.03 and 12.26 m, respectively) is the lowest compared with those for soil nitrate and organic nitrogen contents.

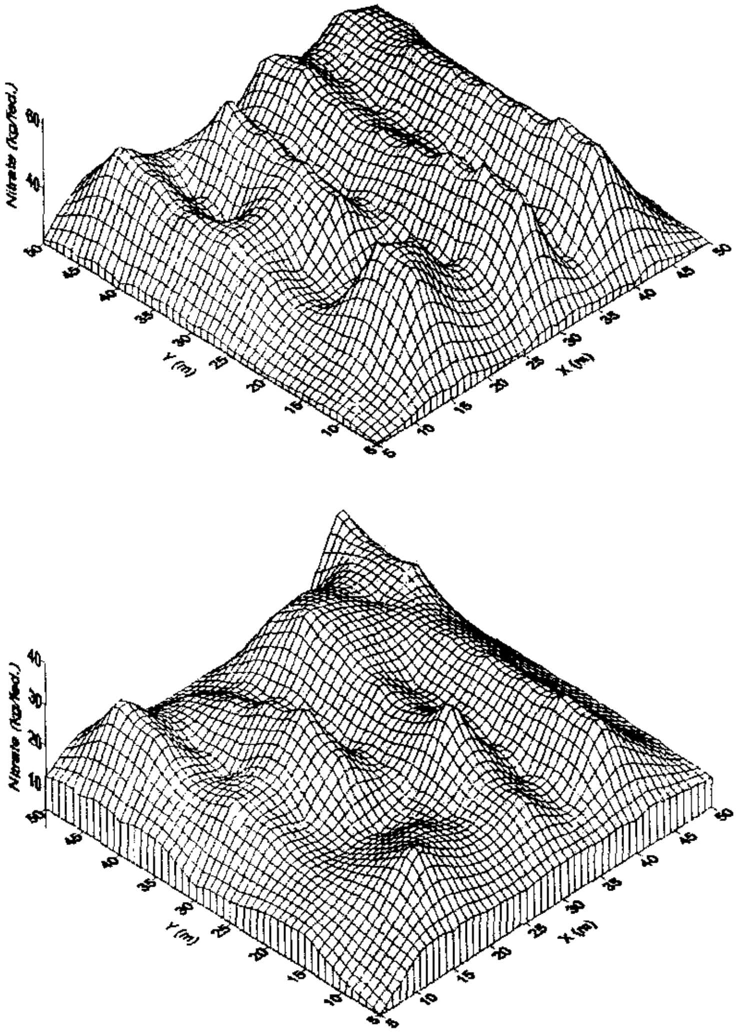


Fig. 2. 3-D distribution of soil nitrate content (kg/fed./15 cm) in the surface (upper) and subsurface (lower) soil layers for the N-fertilized plot.

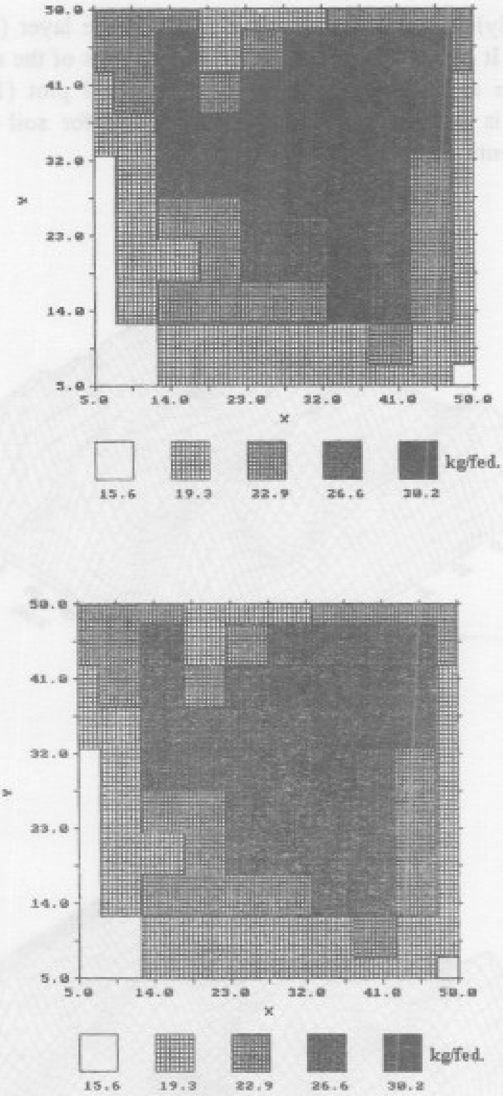


Fig. 3. Kriging maps of soil nitrate content (kg/fed./15 cm) in the surface (upper) and subsurface (lower) soil layers for the N-fertilized plot.

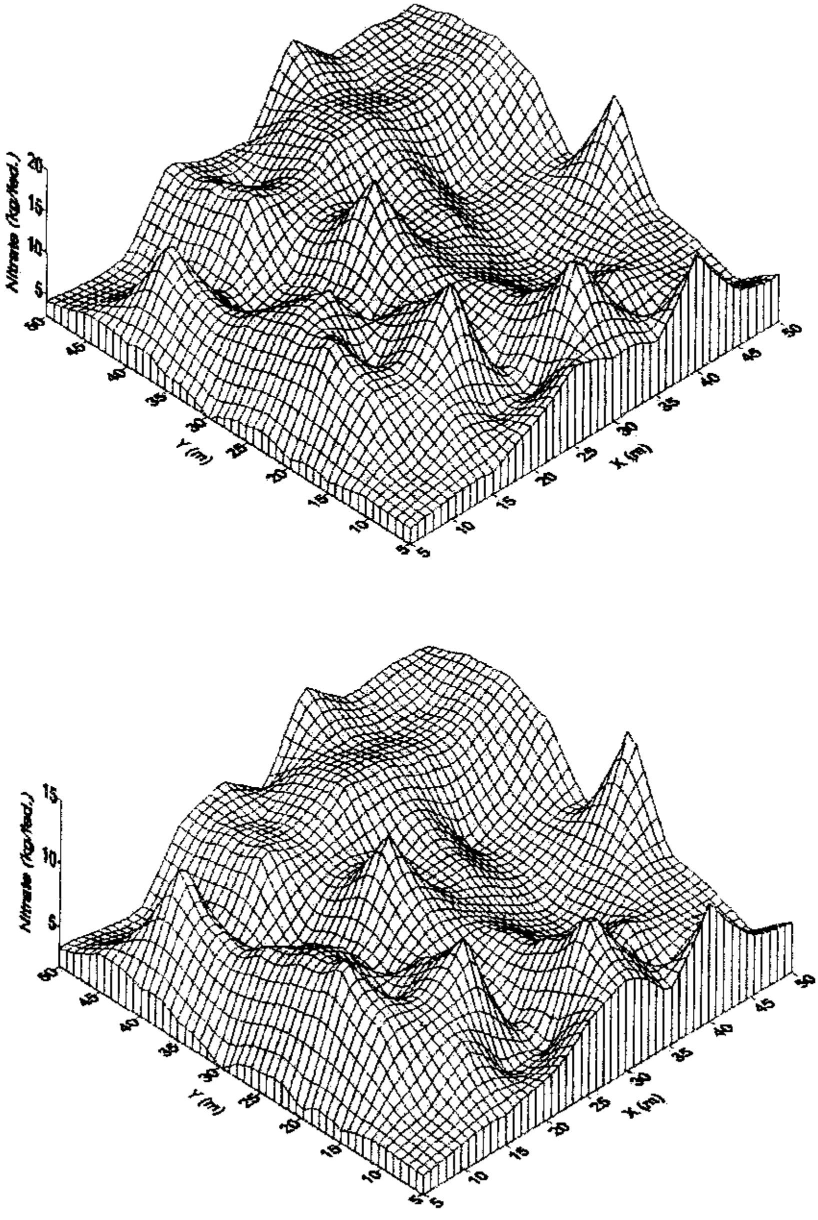


Fig. 4. 3-D distribution of soil nitrate content (kg/fed./15 cm) in the surface (upper) and subsurface (lower) soil layers for the unfertilized plot.

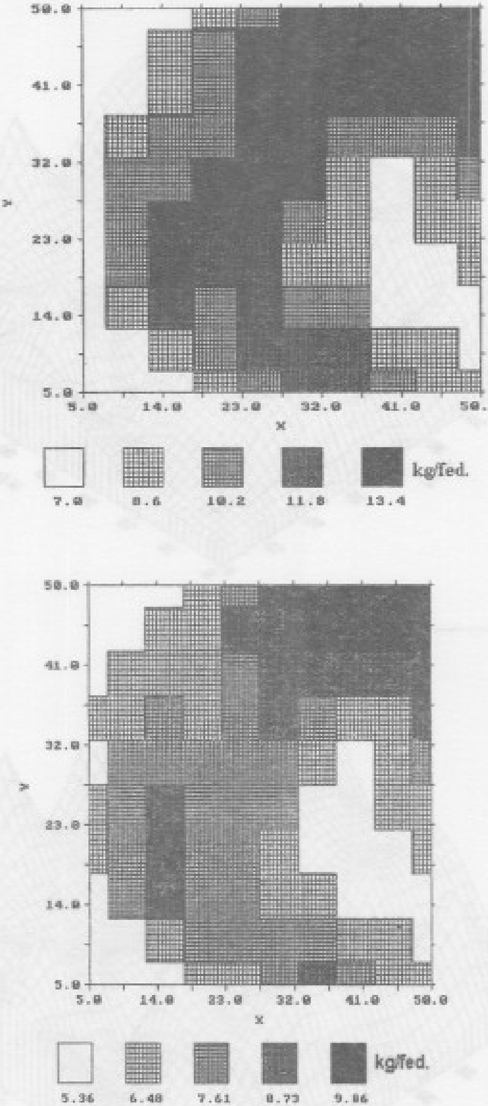


Fig. 5. Kriging maps of soil nitrate content (kg/fed./15 cm) in the surface (upper) and subsurface (lower) soil layers for the unfertilized plot.

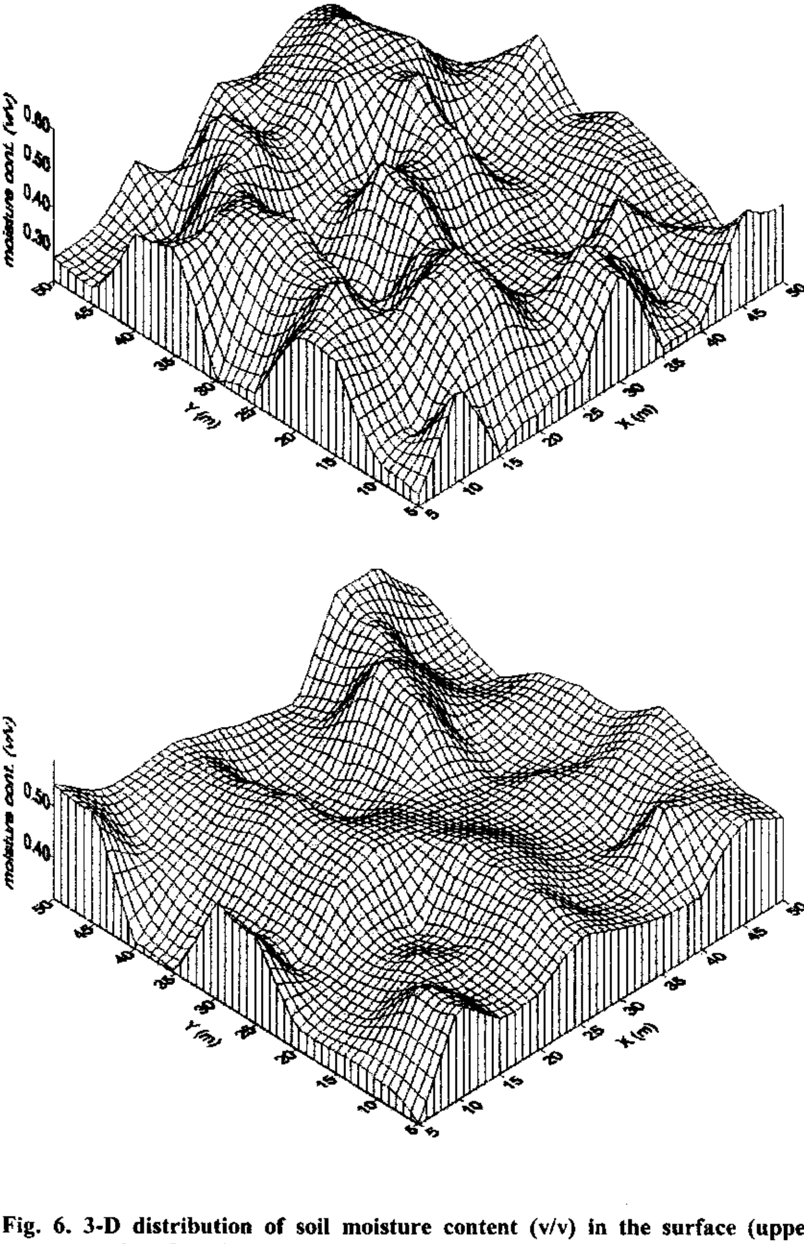
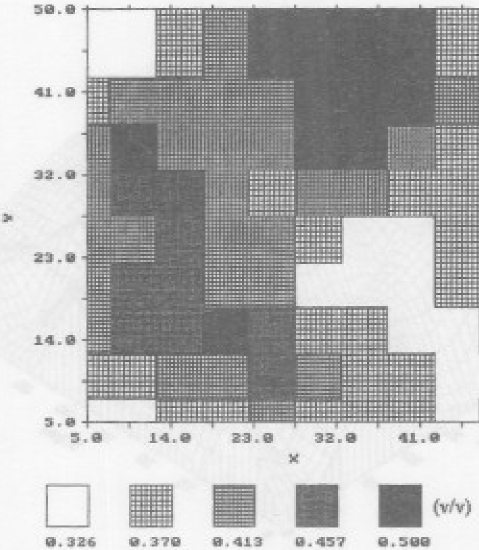


Fig. 6. 3-D distribution of soil moisture content (v/v) in the surface (upper) and subsurface (lower) soil layers for the unfertilized plot.



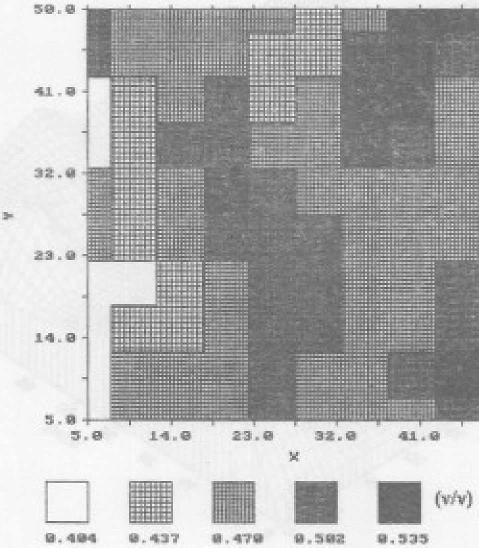


Fig. 7. Kriging maps of soil moisture content (v/v) in the surface (upper) and subsurface (lower) soil layers for the unfertilized plot.

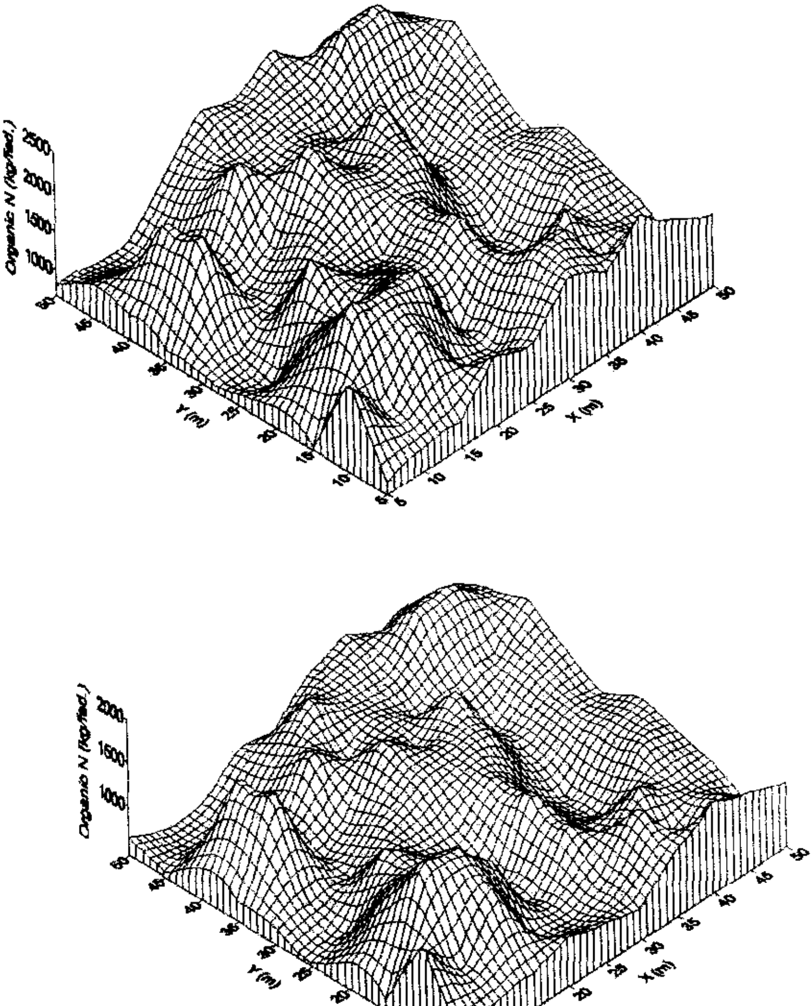


Fig. 8. 3-D distribution of soil organic nitrogen content (kg/fed./15 cm) in the surface (upper) and subsurface (lower) soil layers for the unfertilized plot.

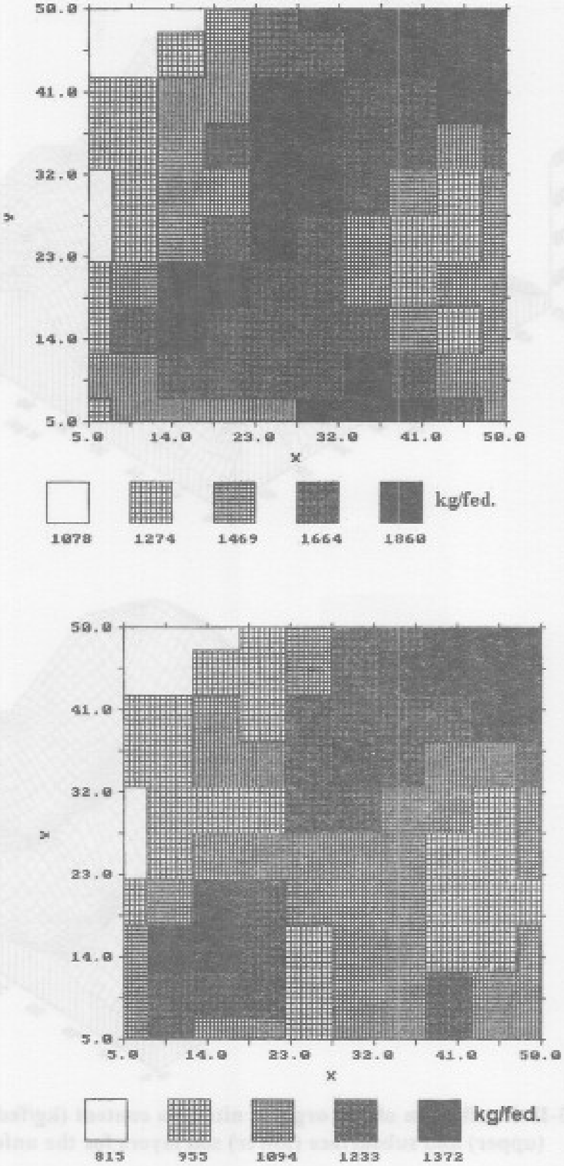


Fig. 9. Kriging maps of soil organic nitrogen content (kg/fed./15 cm) in the surface (upper) and subsurface (lower) soil layers for the unfertilized plot.

Conclusion

One of the initial causes of field soil NO_3-N variability is due to the nonuniform addition of fertilizers. Descriptive statistical analysis revealed that the total variance of soil NO_3-N content due to fertilizer application can be calculated by assuming that variation on the N-fertilized plot is due to inherent variation already present before fertilization, which can be measured by the control plot and variation caused by the nonuniform application of fertilizer. Analysis of variance revealed that the percent variability of soil NO_3-N content under irrigated corn due to nonuniformity of N-fertilizer application accounted for > 84% of the total variability. As soil moisture and soil organic nitrogen contents are independent, the variation in soil moisture and organic nitrogen contents were responsible for >62% and >57% of the soil NO_3-N variability in the surface and subsurface layers, respectively. Other sources of variation such as plant distribution, preferential flow of water and NO_3-N through cracks, can also have substantial contribution which needs further future investigations. Further geostatistical analysis of the measured variables gave an insight into the spatial dependence of soil NO_3-N. Such analysis indicated higher inherited and structural spatial variability of soil NO_3-N, soil moisture and soil organic nitrogen contents in the surface layer than in the subsurface layer for both plots. Sampling lag distances of the studied variables were also evaluated. The integration between descriptive statistics and spatial variability analyses proved to be a good approach to understanding field variability of such variables.

The types of variation frequently encountered in the field situation tend to be complicated. The degree of difference observed in nitrate patterns is often great that the meaning of an average is difficult to comprehend. It is obvious that average soil NO_3-N content can mask individual differences in the field. Similarly and when model simulation is in scope, average model parameters and the assumption of uniformity of water and solute distribution mask point to point differences. This fact is often overlooked in examining variable NO_3-N distribution in soil profiles and deriving flux boundaries for transport models.

References

Biggar, J.W. and Nielsen, D.R. (1976) Spatial variability of the leaching characteristics of a field soil. *Water Resour. Res.* **12**, 78.

Burgess, T.M. and Webster, R. (1980a) Optimal interpolation and isoarthimic mapping of soil properties. I. The semi-variogram and punctual kriging. *J. Soil Sci.* **31**, 315.

Burgess, T.M. and Webster, R. (1980b) Optimal interpolation and isoarthimic mapping of soil properties. II. Block kriging. *J. Soil Sci.* **31**, 333.

Cameron, D.R., Kowalenko, C.G. and Campbell, C.A. (1979) Factors affecting nitrate nitrogen and chloride leaching variability in a field plot. *Soil Sci. Soc. Am. J.* **43**, 455.

Freebairn D.M., Gupta, S.C. Onstad, C.A. and Rawls, W.J. (1989) Anticedent rainfall and tillage effects upon infiltration. *Soil Sci. Soc. Am. J.* **53**, 1183.

Fried, M., Tanji, K.K. and Van De Pol, R.M. (1976) Simplified long term concept for evaluating leaching of nitrogen from agricultural land. *J. Environ. Qual.* **5**, 197.

Gamma Design. (1991) GSPLUS: Geostatistics for biological science. Ver. 1.2. A user's manual. Plainwell, Mi., USA.

Golden Software. (1995) The Golden Software of surface mapping system. Ver. 6.01. A user's manual. Col., USA.

Hansen, S. and Jensen, H.E. (1995) Developments in modeling nitrogen transformations in soil. In: P.E. Bacon (ed.). *Nitrogen Frtilization in the Environment.* Marcel Dekker Inc. New York.

Hedia, R.M.R. (2000) Modeling nitrogen dynamics and nitrate leaching in soil environment. *Ph.D. Thesis.* Faculty of Agric., Alexandria Univ., Egypt.

Hutson, J.L. and Wagenet, R.J. (1992) Leaching estimation and chemistry model (LEACHM). User manual. Version 3.

Huwe, B. (1992) A user guide to WHNSIM – A model to simulate water, heat and nitrogen budget of agricultural fields. Version 2. Bayreuth Univ., Germany.

Huwe, B. and van der Pleog. (1988) Modelle zur Simulation des Stickstoffhaushalt von Standorten mit unterschiedlicher landwirtschafter Nutzung. Mitteilungen der bodenkundliche Geselschaft. Institut feur Wasserbau, Sttutgart Univ., Germany.

Jabro, J.D., Jemison, J.M., Lengnick, L.L., Fox, R.H. and Fritton, D.D. (1993) Field validation and comparison of LEACHM and NCSWAP models for prediction of nitrate leaching. Trans. *ASAE* **36**, 1651.

Jury, W.A., Stolzy, L.H. and Shouse, P. (1982) A field test of the transfer function model for predicting solute transport. *Water Resour. Res.* **18**, 363.

Lund, L.J. (1982) Variation in nitrate and chloride concentrations below selected agricultural fields. *Soil Sci. Soc. Am. J.* **46**, 1062.

Lund, L.J., Ryden, J.C., Miller, R.J., Lang, A.E. and Bendixen, W.E. (1978) Nitrogen balance for the Santa Maria Valley. P. 395-413. In P.F. Pratt (ed.). *Proc. National Conference on Mangement of Nitrogen in Irrigated Agriculture.* 15-18 May, 1978. Sacramento, Calif. Univ. of Calif. Riverside.

Marriott, C.A., Hudson, G., Hamilton, D., Neilson, R., Boag, B., Handley, L.L., Wishart, J., Scrimgeout, C.M. and Robinson, D. (1997) Spatial variability of soil total C and N and their stable isotopes in an upland Scottish grassland. *Plant Soil* **196**, 151.

Oliver, M.A. and Webster, R. (1991) How geostatistics help you. *Soil Use Management.* **7**, 206.

Page, A.L., Miller, R.H. and Keeney, K.R. (Eds.) (1982) *Methods of Soil Analysis.* Amer. Soc. Agron. Madison. Wisconson. U.S.A.

Pikul, J.L., Zuzel, J.F. and Ramig, R.E. (1990) Effect of tillage induced soil macroporosity on water infiltartion. *Soil Tillage Res.* **17**, 153.

Poletika, N.N. and Jury, W.A. (1994) Effects of soil surface management on water flow distribution and solute dispersion. *Soil Sci. Soc. Am. J.* **58**, 999.

Ramadan, H.M. (2001) Spatial variability of barely yield and soil properties under saline-calcareous soil conditions at El-Nubaria region, Egypt. *Alex. Sci. Exch.* **22**, 389.

Ramadan, H.M. and Abdel-Kader, F.H. (1995) land variability of Dabaa-Fuka area, north western coast, Egypt. *Alex. J. Agric. Res.* **40**, 243.

Russo, D. (1984) Design of an optimal sampling network for estimating the variogram. *Soil Sci. Soc. Am. J.* **48**, 708.

SPSS. (1999) SPSS Base 9.0. Application guide. SPSS Inc., Chicago, U.S.A.

Tabor, J.A., Warrick, A.W., Pennington, D.A. and Myers, D.E. (1984) Spatial variability of nitrate in irrigated cotton: I. Petioles. *Soil Sci. Soc. Am. J.* **48**, 602.

Tabor, J.A., Warrick, A.W., Myers, D.E. and Pennington D.A. (1985) Spatial variability of nitrate in irrigated cotton: II. Sol nitrate and correlated variables. *Soil Sci. Soc. Am. J.* **49**, 390.

Unger, P.W. (1992) Infiltration of simulated rainfall: Tillage system and crop residue effect. *Soil Sci. Soc. Am. J.* **56**, 283.

Van De Pol, R.M., Wierenga, P.J. and Nielsen., D.R. (1977) Solute movement in a field *soil. Soil Sci. Soc. Am. J.* 41, 10.

Vieira, S.R., Nielsen, D.R. and Biggar, J.W. (1981) Spatial variability of field-measured infiltration rate. *Soil Sci. Soc. Am. J.* **45**, 1040.

Warrick, A.W. and Nielsen, D.R. (1980) Spatial variability of soil physical properties in the field. In: D. Hillel, *Applications in Soil Physics*. Academic Press, New York.

Warrick, A.W., Lyers, D.E. and Nielsen, D.R. (1986) Geostatistical methods applied to soil science. In: A. Klute (ed.), Methods *of Soil Analysis. Part 1. Physical and mineralogical Methods.* 2nd ed. *Agronomy* **9**, 53.

Webster, R. (1985) Quantitative spatial analysis of soil in the field. *Adv. Soil Sci.* **3**, 1.

Webster, R. (2001) Statistics to support soil research and their presentation. *Eur. J. Soil. Sci.* **52**, 331.

Webster, R. and Butler, B.E. (1976) Soil classification and survey studies at Ginninderra. *Aust. J. Soil Res.* **14**, 1.

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إستخدام طرق التحليل الإحصائى وتحليل الإختلافات المكانية لدراسة الإختلافات فى محتوى الأرض من النترات فى حقول الذرة المروية

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تتميز النظم الزراعية الحيوية، وخاصة نظام الأرض مع النبات بوجود قدر كبير من التباين فى خواصها المميزة. فعند دراسة سلوك واتزان النيتروجين فى الحقل بإستخدام النماذج الرياضية Models فى التوقع بكميات النترات المفقودة بالغسيل عادة ما يتم الإعتماد على قيمة وحيدة أو متوسط لمجموعة محدودة من القياسات لصفات الأرض. فى حين أنه يجب الأخذ فى الإعتبار تأثير الإختلافات فى توزيع هذه الصفات فى الحقل لوصف النظام بصورة أقرب ما تكون إلى الواقع. وقد كان لهذه الدراسة هدفان. الأول هو دراسة التباين Variation فى محتوى الأرض من النترات وعلاقته بعدم انتظام إضافة السماد النيتروجينى والتباين فى محتوى الأرض من الرطوبة والنيتروجين العضوى، وذلك عن طريق استخدام طرق التحليل الإحصائى الوصفى Descriptive Statistical Analysis لتحديد مكونات النظام المسئولة عن التباين فى محتوى الأرض من النترات، وكذلك استخدام وسائل التحليل الإحصائى الأرضية Geostatistics لدراسة التغيرات المكانية Spatial Variability Analysis للصفات المدروسة. والثانى هو الإستعانة بنتائج هذه التحليلات فى وضع استراتيجية لعملية أخذ عينات الأرض Sampling Strategy لتقدير محتوى الأرض من النترات والرطوبة والنيتروجين العضوى فى الدراسات المستقبلية.

وقد تم تنفيذ التجربة الحقلية فى أرض المزرعة البحثية لكلية الزراعة- جامعة الإسكندرية بمنطقة أبيس. حيث تم زراعة محصول الذرة (Zeamaize L., hybrid cultivar 10) على مساحة ٢,٥ فدان. قسمت هذه المساحة إلى شريحتين بأبعاد ٥٠x٥٠ متر. تم تسميد أحد الشريحتين بالمستويات الموصى بها من عناصرNPK. والأخرى تم تسميدها بعناصر PK فقط (Control). وبعد إضافة الدفعة الأولى من السماد النيتروجيني تم أخذ عينات أرض سطحية(صفر-١٥ سم) وتحت سطحية(١٥-٣٠ سم) بطريقة عشوائية وذلك بنظام شبكة Grid System من رؤس مربعات بأبعاد ٢x٢ متر. وتم تحليل محتوى العينات من الرطوبة والنيتروجين المعدنى(نترات وأمونيوم) والنيتروجين الكلى، وتم حساب محتوى الأرض من النيتروجين العضوى.

وقد دلت نتائج التحليل الإحصائى الوصفى على وجود تباين كبير فى توزيع النترات فى الحقل المدروس. ومن خلال مقارنة التباين لكل من الشريحة المسمدة بالنيتروجين (σ_T^2) والأخرى الغير مسمدة به (σ_h^2) أمكن حساب النسبة المئوية للتباين فى محتوى الأرض من النترات نتيجة لعدم انتظام إضافة السماد النيتروجينى($\%\sigma_F^2$). ووجد أن عدم إنتظام توزيع السماد النيتروجينى هو المسئول عن ٨٤-٨٩% من الإختلافات فى محتوى الأرض من النترات، وأن التباين فى محتوى الأرض من الرطوبة والنيترجين العضوى ساهمت بنسبة ٥٧-٧٢% من الإختلافات فى محتوى الأرض من النترات فى الشريحة الغير مسمدة بالنيترجين. ومن خلال دراسة الإختلافات المكانية لمحتوى الأرض من النترات والرطوبة والنيتروجين العضوى أمكن وصف تغيرها مع المسافة باستخدام النموذج الرياضى من النوع Gaussian فى الطبقات السطحية. وكان النموذج الرياضى من النوع Spherical هو الأنسب فى وصف تغيرات محتوى الأرض من الرطوبة والنيتروجين العضوى فى الطبقات التحت السطحية. وبذلك أمكن تحديد المسافات التي يجب عندها أخذ عينات الأرض من الطبقات السطحية والتحت السطحية فى الحقل لتقدير محتوى الأرض من النترات والرطوبة والنيتروجين العضوى. وقد ساعد ذلك فى رسم خرائط تقسيمية Kriging Maps للصفات المدروسة.