

The Spatial Variability of Upper and Lower Limits of Available Moisture Content as Affected by Different Tillage Systems

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ABSTRACT

To evaluate the effect of conventional tillage (CT) and zero tillage (NT) on the extent of available moisture; field capacity (FC) and permanent wilting point (PWP) and characterize the spatial variations of these soil properties, a field experiment was conducted at Al-Mishkhab Rice Research Station at Al-Najaf province during 2019-2020 rice season. The experimental site was located between N 0°17'4.5075 and E 40°54'29.6959. The moisture contents between FC and PWP designate available moisture profile and are determinants of crop production. Spatial variability of soil physical properties are studied, using geological statistics. The upper limit of moisture content at FC gave the highest C.V of the CT after harvest, which was 15.42% compared with the NT before planting, which gave the lowest CV of 8.86%, The moisture content at PWP gave the highest C.V of 34.94% for the NT soil before planting compared with the CT before planting, which gave the lowest CV of 28.13%. Strong spatial dependences of FC and PWP were found in the field. The application of Geostatistics methods with respect to statistical models showed that the spherical outperformed all other models (76.67%), Gaussian model (20.00%) and exponential model (3.33%).

Keywords: spatial variability, tillage soil, non-tillage soil, water content, C.V.

1-Introduction

Tillage is the mechanical manipulation of soil for changing its conditions in order to enhance crop production. Conventional tillage is a tillage system based on the plowing, and combines primary and secondary operations usually performed to prepare a seedbed for a given crop and area (ASAE, 2016). Primary tillage (PT) constitutes the first major soil working operation, and is normally designed to reduce soil strength, cover plant and insect materials, and rearrange soil aggregates using moldboard plow, chisel plow, or disk plow). Secondary tillage (ST) is a group of different operations, which follows primary tillage and is designed to create refined soil conditions before seed planting using disk harrow, cultivator sweeps, and roller harrow (ASAE,2016). No tillage (NT) is a minimum tillage practice in which the crop seeds are planted directly into the stubble and residue of the previous year's crop. NT has gained favor on many farms to restore soil organic carbon stocks and to improve soil properties (Blanco-Canqui et al., 2009). NT systems produce less compression and breaking down of soil aggregates, and greater amounts of organic residue on and near the soil surface Piccoli et al. (2016) resulting in less surface-sealing by rainfall, reduced soil erosion, enhanced moisture retention, and more organic matter accumulation (Ali et al., 2017). In the medium to long-term, crop yields in NT can be close to those in conventional tillage (CT) with even higher yields in relatively dry regions. There are several spatially variable factors influencing soil moisture content.

Knowledge of the spatial variation of soil properties is important in agricultural management systems for high crop production. It has been known that most soil properties are spatially variable in a field (Gülser, 2016). Soil physical and hydraulic properties can change drastically over space and time and their evaluation is essential for a rational soil management. Spatial variability of soil properties is inherent in nature and some of the variability may be induced by tillage and other management practices (Iqbal et al., 2005). Soil tillage system practices causes changes to soil structure and hydraulic properties dynamically in space and time (Strudley et al., 2008). The ordinary kriging is one of the most common methods in spatial interpolation of soil properties after estimating semivariogram parameters of soil properties using geostatistical tools (Zhao et al., 2015). Strudley et al. (2008) reported that the tillage effects on soil hydraulic properties in space and time, and stated that zero tillage practices generally increase macropore connectivity and saturated hydraulic conductivity while generating inconsistent responses in total porosity and soil bulk density compared with conventional tillage practices. Specific management effects are often over shadowed by spatial and temporal variability, and differences in temporal variability depend on spatial locations between rows, within fields at different landscape positions, and between sites with different climates and dominant soil types.

2-Material and Methods

1-2 Study area

A field trials were conducted at Al-Mishkhab Rice Research Station at Najaf province during 2019-2020 rice season, which is located between N 31536.17 and E 44306.02. The trial was performed as split split plot based on a randomized complete blocks design (RCBD) having three replications. Soil samples were taken from the surface layer 0-30 cm before planting, before harvesting and after harvesting. Samples were air-dried, then milled and passed through a manual sieve with a diameter of 2 mm aperture, then mixed well and samples were taken from them for the purpose of conducting physical and chemical analyzes, as shown in table 1.

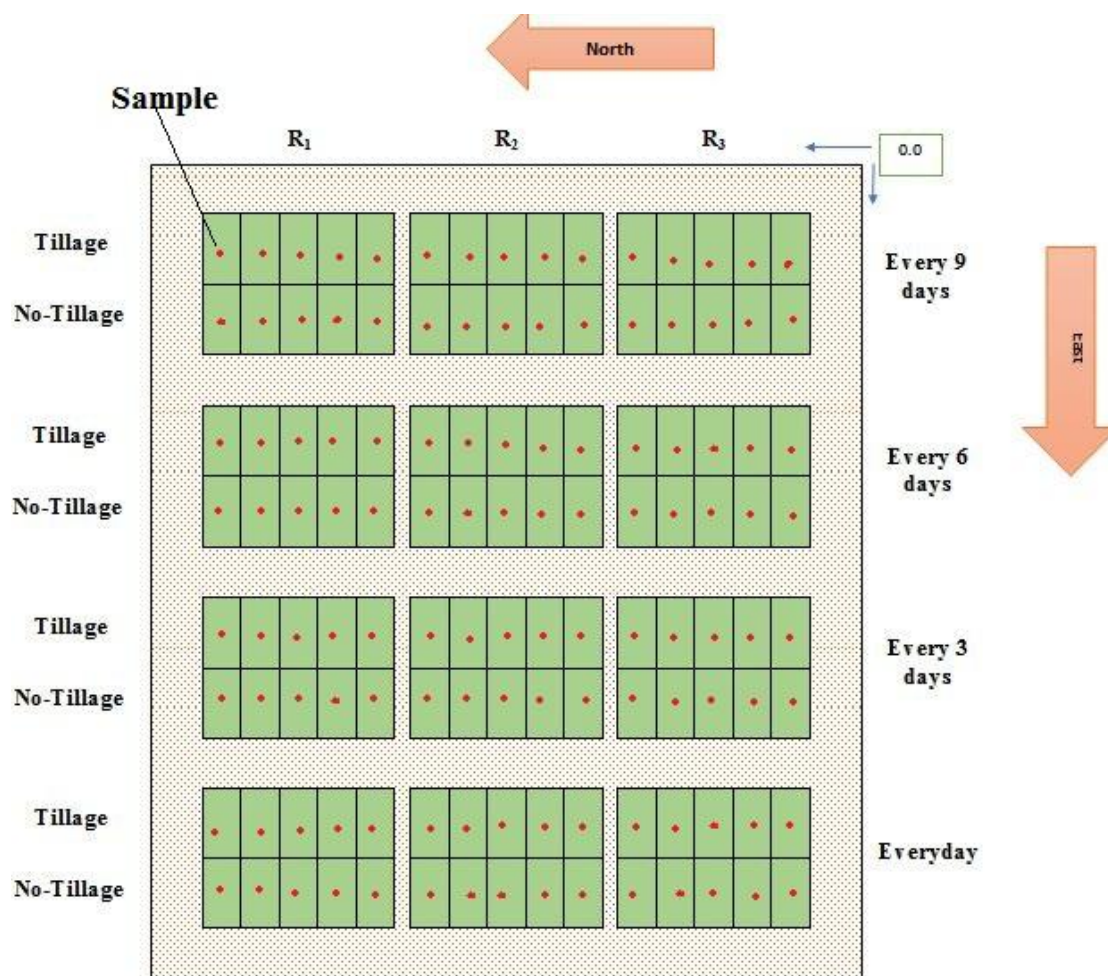
Table 1: Some physical and chemical characteristics of the study soil before planting

Value	Unit	Physical and chemical properties
7.1	-	pH 1:1
3.8	Ms/cm	1:1 Ec
77.0	Ppm	N-available
560.0	Ppm	k-available
35.6	Ppm	P-available
1.65	%	O.M

0.91	%	CaSO₄
8.5	%	CACO₃
2.0	Meq/L.	HCO₃⁻²
12.5	Meq/L.	CL⁻¹
20.0	Meq/L.	Ca⁺²
42.5	Meq/L.	Mg⁺²
25.26	Meq/L.	Na
0.5	Meq/L.	CO₃
28.0	Meq/L.	SO₄
285	gm.Kg⁻¹ Soil	Clay
476	gm.Kg⁻¹ Soil	Silt
239	gm.Kg⁻¹ Soil	Sand
Clay Loam		
0.25123	Cm³.Cm⁻³	Moisture at Fc
0.097668	Cm³.Cm⁻³	Moisture at P.W.P
0.153562	Cm³.Cm⁻³	Available water
0.45	Cm³.Cm⁻³	Moisture content at saturation
1.50	Mg/m³	BD
2.65	Mg/m³	Ps
0.43	Cm³.Cm⁻³	Porosity

2-2 Soil tillage and sampling design

A 34 m × 34 m plot, representing the subjected soils, was used for this study (Fig1). the study area was divided into three different tillage systems: Non- tillage and conventional tillage (ploughing at the depth of 0-30cm. Measurements of FC and PWP, were made in each plot .making total sampling points, 30 for tillage soil and 30 for NT soil, Total samples 120 for all the field.the purpose of designing such sampling schema was to adequately model the semivariance around the origin, and to have at least 30 samples, as is required to safely model semivariogram as suggested by (Mullaand McBratney,2000). The moisture content at FC (-330 cm H₂O) and the moisture content at PWP (-15000 cm H₂O) were measured using pressure plate.

**Fig1:Experiment Fig****3-2 Statistical analyses**

The effect of Non- tillage , and tillage soil on Fc and P.W.P was analysed by GS + 10.0 (Gamma Design Software) program to get Mean, standard deviation, minimum, maximum, and coefficient of variation. The spatial structure of variables was characterised using their experimental semivariograms, expressed as:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} (Z_{(xi+h)} - Z_{(xi)})^2$$

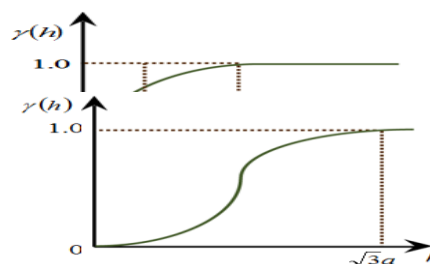
where $z(x_i)$ and $z(x_i+h)$ are the variables of interest at locations x_i and x_i+h , respectively, and $n(h)$ is the number of pairs on the locations separated by distance h . One of the spherical, exponential, or gaussian models was fitted to the experimental semivariograms of Fc, P.W.P, and BD obtained under Non- tillage , and tillage soil.

Spherical Model is:

$$\gamma(h) = \begin{cases} 0, & h=0 \\ C_0 + C \left(\frac{3}{2} \frac{h}{a} - \frac{1}{2} \frac{h^3}{a^3} \right), & 0 < h \leq a \\ C_0 + C, & h > a \end{cases}$$

$$\lambda(h) = \begin{cases} 0, & h=0 \\ C_0 + C \left(1 - e^{-\frac{h^2}{a^2}} \right), & h > 0 \end{cases}$$

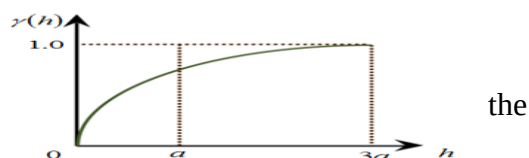
Gaussian Model:



Exponential Model :

$$\gamma(h) = c * \left[1 - \exp\left(-\frac{(3h)^2}{a^2}\right) \right]$$

where, C_0 is the nugget effect, C is structural



component, (C_0+C) is the sill of the semivariogram, and a is the range of the semivariogram. The best fit model selection for experimental semivariogram of each tillage system was spherical outperformed all other models (76.67%), Gaussian model (20.00%) and Exponential model (3.33%). Ordinary point kriging methods, were used with isotropic semivariogram models in preparation of interpolation maps in the plots for the soil properties investigated.

3- Results And Discussion**1-3 The spatial variability at the field capacity(F_c) Under Tillage Soil**

The results of the statistical analysis were given in Table 2 for the tillage soil that the coefficient of variation is C.V. of the moisture content at the field capacity was 11.48--15.42%, as the sample after harvest gave the highest coefficient of variation compared with sample before planting, gave the lowest coefficient of variation, and this indicates the existence of a variation between samples for the coefficient of variation after harvest, and this indicates that the coefficient of variation The difference is for a sample after harvesting with high variation, compared with a sample before planting, as it gave less variation. The results in Table 2 and Supplement 1 showed that the effective distance value for describing the variation of moisture content at field capacity was between 2.00 -4.81 m, as a sample after harvest gave the least effective distance compared with sample before planting as it gave the highest effective distance, where the smaller the value of the effective distance, the greater the variance. Figures 2,3,4 showed the spatial distribution of the field capacity values for a sample before planting, before harvest and after harvest, the field capacity values of a sample before planting from 0.222 to 0.248 $\text{cm}^3 \text{cm}^{-3}$ was the highest of its dominance as it occupied 50%, as for a sample before harvest The spatial distribution of moisture content at field capacity 0.220-0.240 $\text{cm}^3 \text{cm}^{-3}$ was the dominant one at a rate of 50%. While after harvest, gave values from 0.206-0.234 $\text{cm}^3 \text{cm}^{-3}$ and the percentage of dominance in it was 70%. Table 2 shows that the Spatiality dependent values of the moisture content at the field capacity of the samples were strong, was before planting 1.947%, 6.185% before harvest, 8.626% after harvest.

Table 2: Statistical analysis of the spatial variation data of the characteristic of the moisture content at the field capacity of a sample (tillage soil)

Field capacity $\text{cm}^3 \text{cm}^{-3}$			
Tillage			
Information	before planting	before Harvest	After Harvest
Depth	0-30 cm	0-30 cm	0-30 cm
Sample size	60	60	60
Mean	0.235	0.226	0.214

Standard deviation	0.027	0.031	0.033
C.V %	11.4893	13.7168	15.4205
Minimum	0.17	0.17	0.14
Maximum	0.3	0.29	0.3
Skewness	0.25	0.36	0.65
Kurtosis	-0.09	-0.63	0.37
Variogram type	Spherical	Spherical	Spherical
Nugget(C_0)	1.4E-05	0.00006	9.8E-05
Sill(C_0+C)	0.00072	0.00097	0.00114
Nugget ratio%	1.9471	6.1855	8.6267
Class of Spatiality dependent	Strong	Strong	Strong
Range(m)	4.81	3.68	2
RSS(m)	1.153	3.629	4.27

Fig2: Spatial distribution map of the characteristic of the moisture content at the field capacity before planting (for tillage soil)

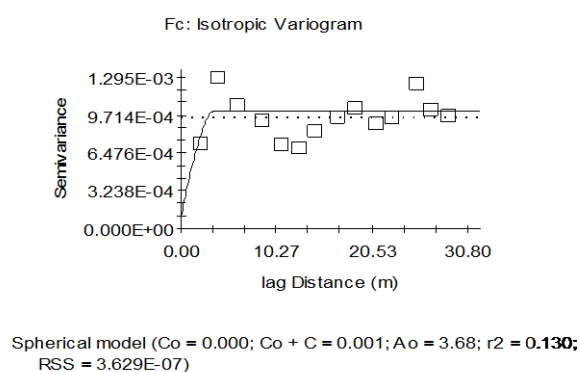
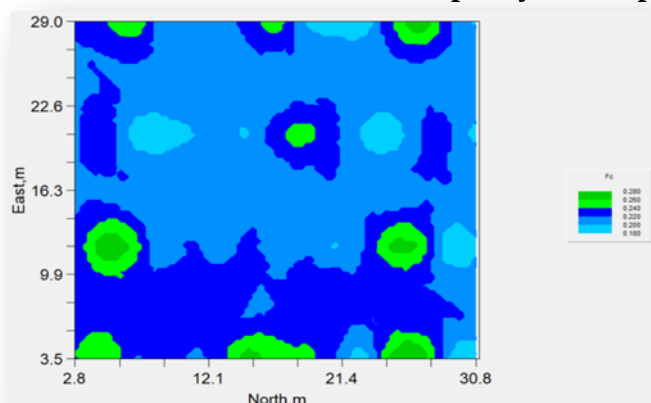
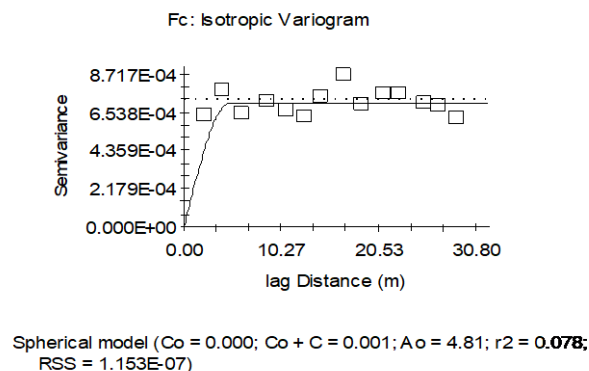
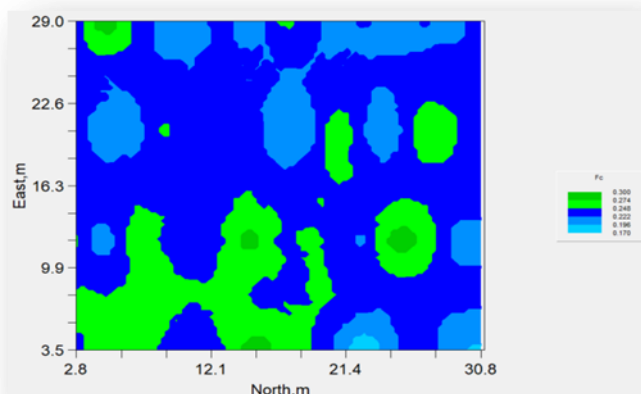


Fig3: Spatial distribution map of the characteristic of the moisture content at the field capacity before harvest (for tillage soil)



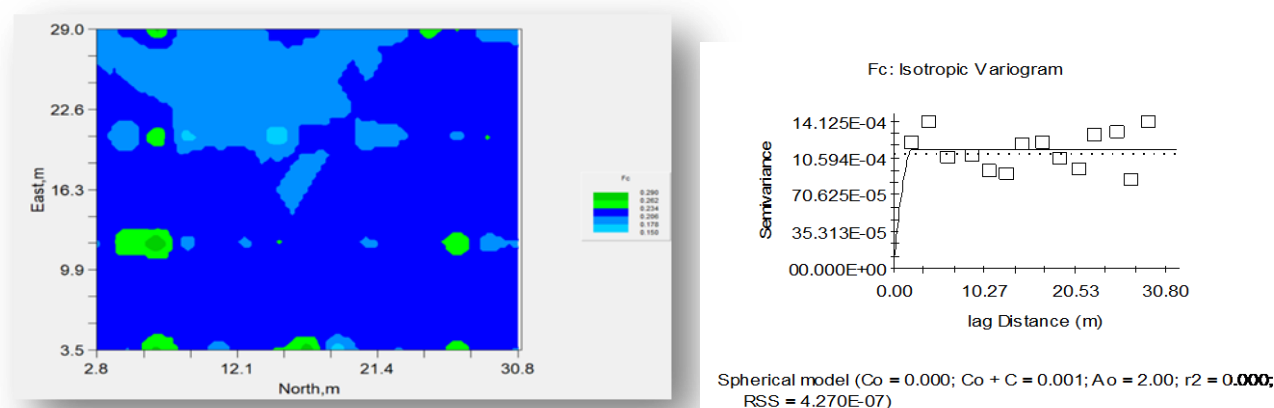


Fig4:Spatial distribution map of the characteristic of the moisture content at the field capacity after harvest (for tillage soil)

2-3 The spatial variability at the field capacity(Fc) Under Non-Tillage Soil

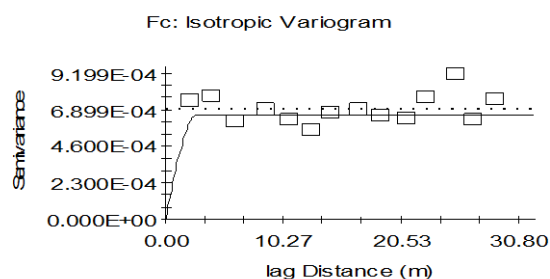
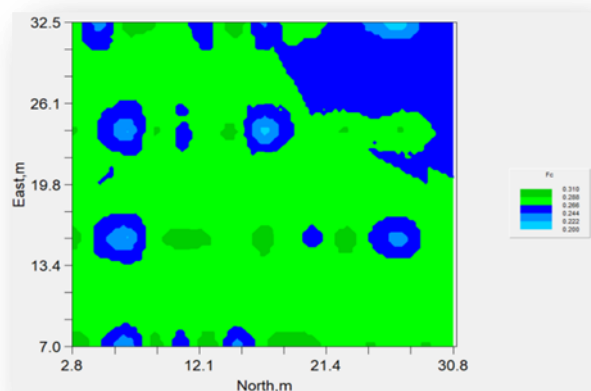
The results of the statistical analysis in Table 3 for the non-tillage soil are given coefficient of variation is C.V. of the moisture content at the field capacity 8.85-10.00%, as the sample after harvest, gave the highest coefficient of variation compared to the sample before planting, gave the lowest coefficient of variation. The results showed in Table 3 and Supplement 2 that the effective distance value for describing the variation in moisture content at field capacity between 2.50 -2.84 m, as a sample after harvest, gave the least effective distance compared to a sample before planting, gave the highest effective distance, when the effective distance be smaller, the variation will be higher. The reason for this is due to the effect of the penetration of the roots of the rice plant into the soil with the increase in the moisture content, which led to the deep penetration of water into the bed of the soil compared to a sample before planting, which was not affected by the agricultural operations and was preserved in a coherent structure that gave less variation. The best model for describing the variation of moisture content at field capacity (before planting, before harvest, and after harvest) is the Spherical model. Fig. 5,6,7 shows the spatial distribution of the field capacity values for a sample before planting, before harvest and after harvest. The field capacity values for a sample before planting was 0.276 to 0.298 $\text{cm}^3 \text{cm}^{-3}$ It was the highest dominant 40%. The spatial distribution of moisture content at field capacity 0.266-0.288 $\text{cm}^3 \text{cm}^{-3}$ was the dominant one, with 80%, while the sample after harvest gave 0.248-0.272 $\text{cm}^3 \text{cm}^{-3}$ and the prevalence rate was 90%. Table 3 shows that the spatial distribution values of the field capacity of the samples were very strong, as the before planting sample 6.597%, before harvesting 5.428%, and 2.469% after harvest.

Table 3: Statistical analysis of the spatial variation data of the characteristic of the moisture content at the field capacity of a sample (non-tillage soil)

Field capacity $\text{cm}^3 \cdot \text{Cm}^{-3}$			
NonTillage			
Information	before planting	before Harvest	After Harvest
Depth	0-30 cm	0-30 cm	0-30 cm

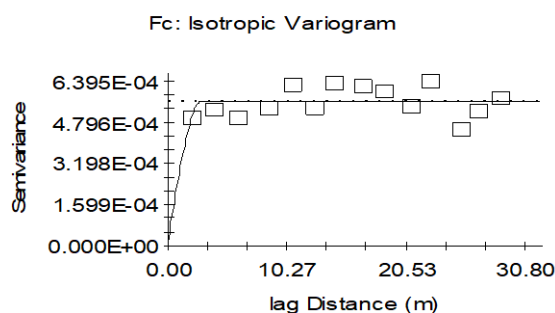
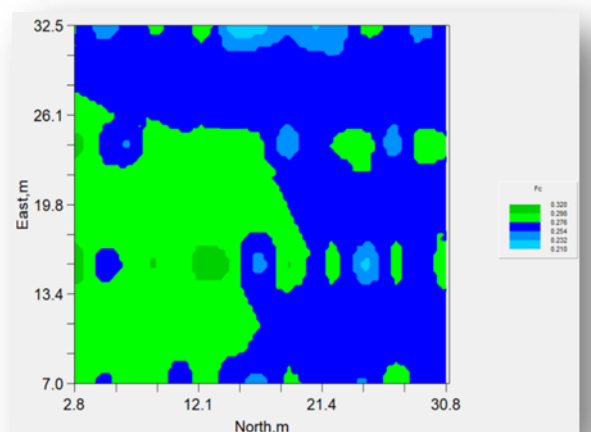
Sample size	60	60	60
Mean	0.271	0.27	0.26
Standard deviation	0.024	0.026	0.026
C.V %	8.856	9.6296	10
Minimum	0.21	0.2	0.2
Maximum	0.33	0.31	0.32
Skewness	-0.32	-0.67	-0.49
Kurtosis	0.27	-0.13	0.32
Variogram type	Spherical	Spherical	Spherical
Nugget(C_0)	2.1E-05	3.8E-05	1.6E-05
Sill(C_0+C)	0.00056	0.0007	0.00065
Nugget ratio%	6.5978	5.4285	2.4691
Class of Spatiality dependent			
	Strong	Strong	Strong
Range(m)	2.84	2.7	2.5
RSS(m)	3.913	1.415	8.413

Fig5: Spatial distribution map of the characteristic of the moisture content at the field capacity before planting (for non- tillage soil)



Spherical model ($C_0 = 0.000$; $C_0 + C = 0.001$; $A_0 = 2.70$; $r^2 = 0.032$; $RSS = 1.415E-07$)

Fig6: Spatial distribution map of the characteristic of the moisture content at the field capacity before harvest (for non-tillage soil)



Spherical model ($C_0 = 0.000$; $C_0 + C = 0.001$; $A_0 = 2.84$; $r^2 = 0.089$; $RSS = 3.913E-08$)

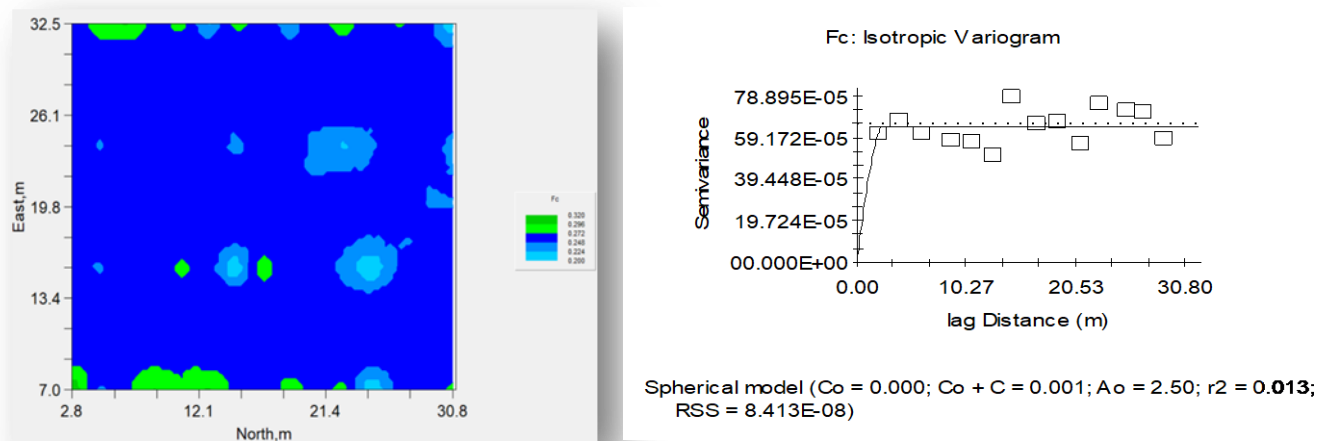


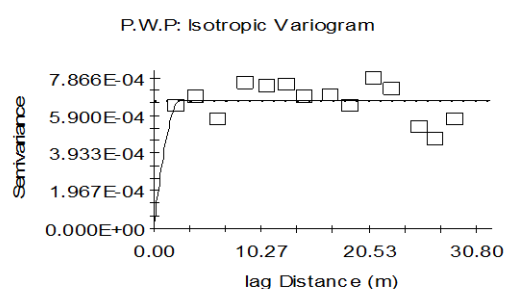
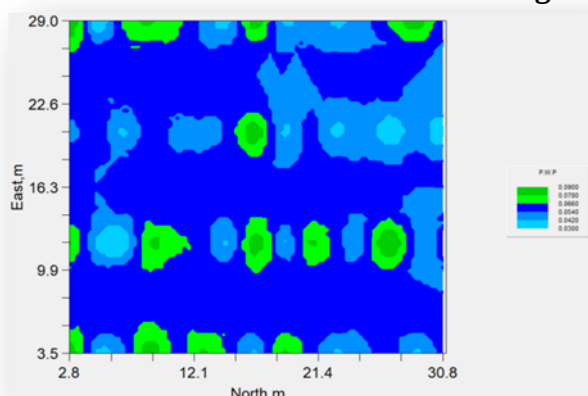
Fig7: Spatial distribution map of the characteristic of the moisture content at the field capacity after harvest (for non-tillage soil)

3-3 The spatial variability at the Permanent Wilting Point (P.W.P) Under Tillage Soil

The results of the statistical analysis in Table 4 for the tillage soil are given the coefficient of variation is C.V. of the moisture content at the Permanent Wilting Point 28.12-32.25%, as the sample after harvest, gave the highest coefficient of variation compared to a sample before planting, gave the lowest coefficient of variation. In Table 4 and Supplement 3 showed that the effective distance value for describing the variation in moisture content at the Permanent Wilting Point ranged between 2.7600 - 3.1200 m, as a before planting sample gave the highest effective distance compared to a sample after harvest, which is gave the least effective distance. The reason for this is due to the effect of tillage in the soil as it increased the surface area exposed to air, wind movement and falling sunlight, which led to water evaporation as well as downward flow of water, and the decrease in humidity resulted in soil changes at the Permanent Wilting Point, compared to a sample before planting, which gave less variation due to the soil's ability to retain soil moisture. The best model for describing the variation in moisture content at the Permanent Wilting Point (before planting, before harvest, and after harvest) is the Spherical model. Figures 8,9,10 showed the spatial distribution of the moisture content at the Permanent Wilting Point, for a sample before planting, before harvest and after harvest, the values of a sample before planting 0.058-0.072 $\text{cm}^3 \text{cm}^{-3}$, the highest prevalence 80%, as for a sample before harvest The spatial distribution of the moisture content at the Permanent Wilting Point 0.066-0.254 $\text{cm}^3 \text{cm}^{-3}$ was the dominant one 60%, while the sample after harvest gave values 0.058-0.072 $\text{cm}^3 \text{cm}^{-3}$ and the prevalence percentage was 50%. Table 4 showed that the spatial variation values of the moisture content characteristic at the Permanent Wilting Point of the samples were strong, as the before planting sample 4.985%, 7.027% before harvest, 5.000% after harvest.

Table 4: Statistical analysis of the spatial variation data of the characteristic of the moisture content at Permanent Wilting Point of a sample (tillage soil)

Permanent Wilting Point			
Tillage			
Information	before planting	before Harvest	After Harvest
Depth	0-30 cm	0-30 cm	0-30 cm
Sample size	60	60	60
Mean	0.064	0.059	0.062
Standard deviation	0.018	0.019	0.02
C.V %	28.125	32.2033	32.258
Minimum	0.03	0.03	0.03
Maximum	0.1	0.1	0.1
Skewness	0.43	0.51	0.46
Kurtosis	-0.83	-0.71	-0.97
Variogram type	Spherical	Spherical	Spherical
Nugget(C_0)	1.7E-05	2.6E-05	0.00002
Sill(C_0+C)	0.00034	0.00037	0.0004
Nugget ratio%	4.985	7.027	5
Class of Spatiality dependent			
	Strong	Strong	Strong
Range(m)	3.12	3	2.76
RSS(m)	1.968	4.721	3.511

Fig8: Spatial distribution map of the characteristic of the moisture content at the Permanent Wilting Point before planting (for tillage soil)

Spherical model ($C_0 = 0.00003$; $C_0 + C = 0.00067$; $A_0 = 2.36$; $r^2 = 0.003$; $RSS = 1.210E-07$)

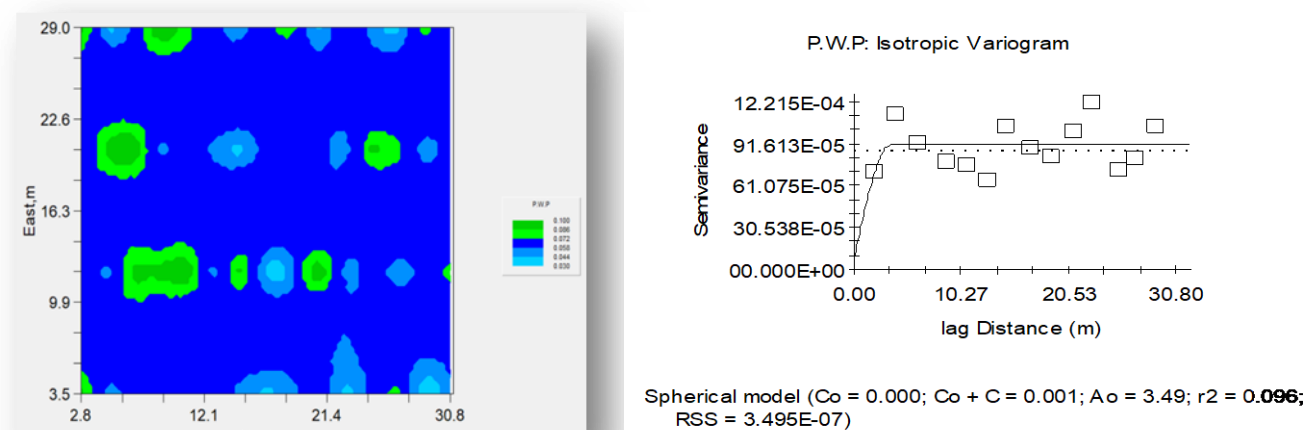


Fig9:Spatial distribution map of the characteristic of the moisture content at the Permanent Wilting Point before harvest (for tillage soil)

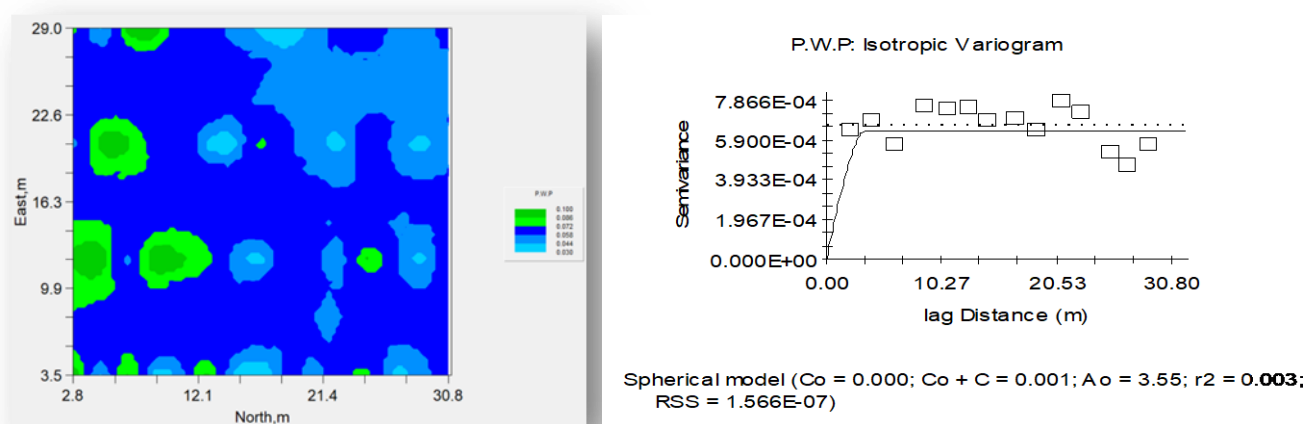


Fig10:Spatial distribution map of the characteristic of the moisture content at the Permanent Wilting Point after harvest (for tillage soil)

4-3 The spatial variability at the Permanent Wilting Point (P.W.P) Under non-Tillage Soil

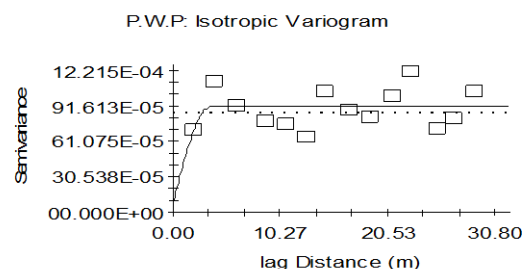
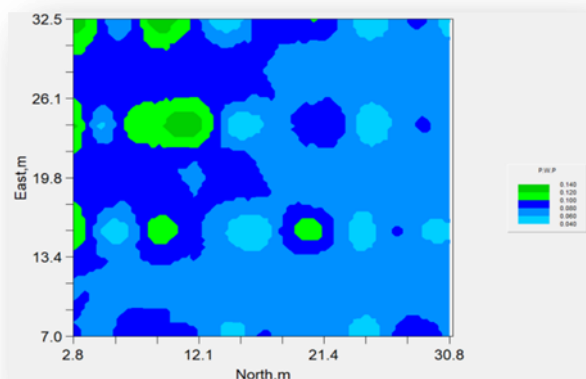
The results of the statistical analysis are given in Table 5 for the non-tillage soil to the coefficient of variation is C.V. of the moisture content at the Permanent Wilting Point 33.3333--34.9397%, where a sample before planting gave the highest coefficient of variation compared with sample before harvest, gave the lowest coefficient of variation, the presence of variation between samples for the coefficient of variation after harvest, and this indicates that the coefficient of variation for a sample Before planting, it had high variation, compared with before harvest sample, which gave less variation. The results in the same table and Supplement 3 showed that the effective distance value for describing the variation in moisture content at the Permanent Wilting Point ranged between 3.4900-3.553 m, of before planting sample, gave the least effective distance compared to a before harvest sample, gave the highest effective distance. This may be due to the fact that the soil was exposed for

compaction processes, which led to the impermeability of water and its accumulation in the soil surface, which led to an increase in the ability of the soil to hold a small part of the soil moisture compared to a sample before harvest that was exposed to the influence of plant roots as well as scheduling irrigation. The best model for describing the variation in moisture content at the Permanent Wilting Point (before planting, before harvest, and after harvest) is the Spherical model. Figures 11,12,13 showed the spatial distribution of the moisture content at the Permanent Wilting Point, for a sample before planting, before harvest and after harvest, the values of a sample before planting was $0.060\text{--}0.080\text{ cm}^3\text{ cm}^{-3}$, it was the highest prevalence as it occupied 50%, for a sample before harvest The spatial distribution of the moisture content at the Permanent Wilting Point was $0.076\text{--}0.094\text{ cm}^3\text{ cm}^{-3}$ It is prevalent at 40%, while the sample after harvest gave values $0.066\text{--}0.084\text{ cm}^3\text{ cm}^{-3}$ and the percentage of dominance in it was 30%. Table 5 showed that the spatial distribution values of the moisture content characteristic at the Permanent Wilting Point of the samples were strong, as the before planting sample was 8.149%, 4.060% before harvest, 3.77% after harvest. %. It is noticed that the highest variation was in sample before planting, and this means less variation, compared with sample after harvest, as it gave a low spatial variation.

Table 5: Statistical analysis of the spatial variation data of the characteristic of the moisture content at Permanent Wilting Point of a sample (non-tillage soil)

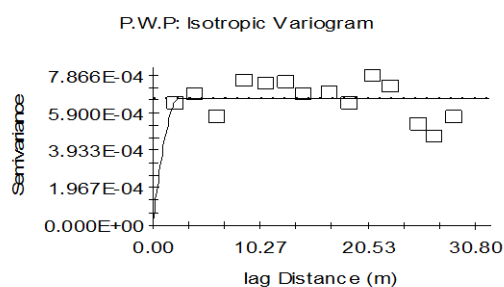
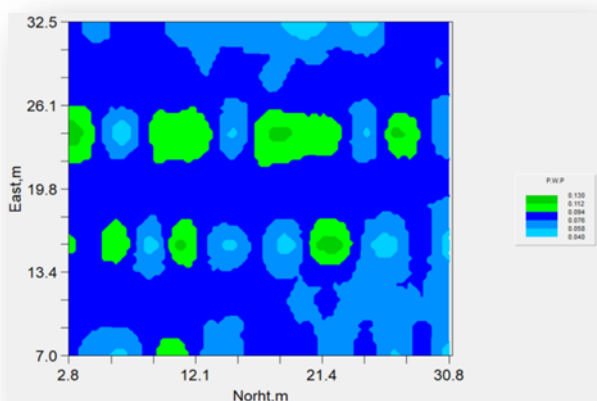
Permanent Wilting Point			
NonTillage			
Information	before planting	before Harvest	After Harvest
Depth	0-30 cm	0-30 cm	0-30 cm
Sample size	60	60	60
Mean	0.083	0.078	0.067
Standard deviation	0.029	0.026	0.023
C.V %	34.9397	33.3333	34.3283
Minimum	0.04	0.04	0.03
Maximum	0.15	0.13	0.13
Skewness	0.31	0.08	0.31
Kurtosis	-0.59	-1.13	-0.52
Variogram type	Spherical	Spherical	Spherical
Nugget(C_0)	7.4E-05	2.7E-05	0.00002
Sill(C_0+C)	0.00091	0.00067	0.00053
Nugget ratio%	8.1497	4.0601	3.77

Class of Spatiality dependent			
	Strong	Strong	Strong
Range(m)	3.49	3.553	3.531
RSS(m)	3.495	1.566	8.018



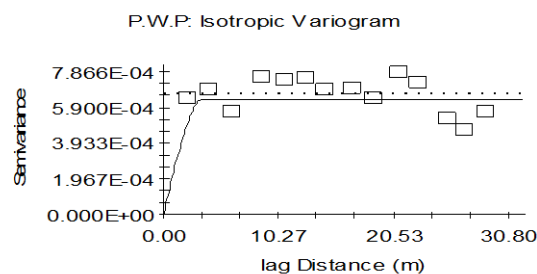
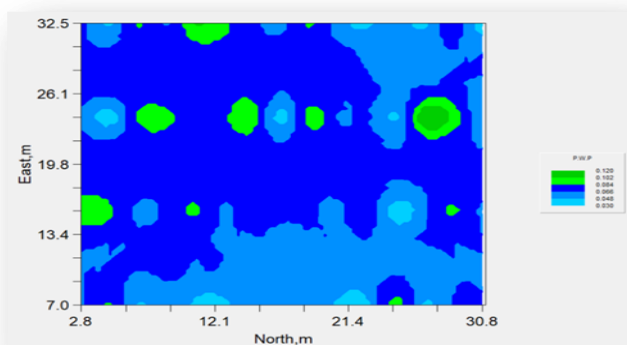
Spherical model ($C_0 = 0.000$; $C_0 + C = 0.001$; $A_0 = 3.49$; $r^2 = 0.096$; $RSS = 3.495E-07$)

Fig11: Spatial distribution map of the characteristic of the moisture content at the Permanent Wilting Point before planting (for tillage soil)



Spherical model ($C_0 = 0.00003$; $C_0 + C = 0.00067$; $A_0 = 2.36$; $r^2 = 0.003$; $RSS = 1.210E-07$)

Fig12: Spatial distribution map of the characteristic of the moisture content at the Permanent Wilting Point before harvest (for tillage soil)



Spherical model ($C_0 = 0.000$; $C_0 + C = 0.001$; $A_0 = 3.55$; $r^2 = 0.003$; $RSS = 1.566E-07$)

Fig13: Spatial distribution map of the characteristic of the moisture content at the Permanent Wilting Point after harvest (for tillage soil)

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تأثير التغيرات المكانية لخصائص التربة الهيدروليكية تحت انماط الحراثة

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المستخلص

تعتبر صفة المحتوى الرطوبي للسعة الحقلية عند شد 330 سم، و صفة المحتوى الرطوبي لنقطة الذبول الدائم عند شد 15000 سم من المحددات المهمة لإنتاج المحاصيل. ان اهداف البحث (1) تقييم تأثير التربة المحروثة والتربة الغير محروثة في (Fc) و (P.W.P) (2) تحديد التغيرات المكانية لهذه الخصائص في محطة بحوث الرز في المشخاب والتابعة إلى قسم بحوث النجف الأشرف - دائرة البحوث الزراعية خلال الموسم الزراعي الصيفي 2019-2020، والواقعة بين خطي عرض 31536.17 N وطول 44306.02 E. تم تقييم تأثير نظام الحرث على عمق تربة (0-30 سم). درس التغيرات المكانية لخصائص باستعمال التحليل الاحصائي الجيولوجي. بينت النتائج تفوق التربة المحروثة بعد الحصاد لصفة المحتوى الرطوبي عند السعة الحقلية اعلى معامل اختلاف 15.42 C.V.%, مقارنة مع التربة الغير محروثة قبل الزراعة والتي اعطت اقل معامل اختلاف بلغ 8.86%. المحتوى الرطوبي عند نقطة الذبول الدائم تحت شد 15000 سم اعطى اعلى معامل اختلاف بلغ 34.94% للتربة الغير محروثة قبل الزراعة، مقارنة مع التربة المحروثة قبل الزراعة والتي اعطت اقل تغير بلغ 28.13%. الاعتمادية المكانية للخصائص المدروسة في الحقل كانت قوية. أظهر تطبيق طرق الإحصاء الجيولوجي فيما يتعلق بالنماذج الإحصائية أن الشكل spherical تفوق على جميع النماذج الأخرى (76.67%). والنموذج Gaussian (20.00%) والنموذج Exponential (3.33%).

الكلمات المفتاحية: المحتوى الرطوبي للسعة الحقلية عند شد 330 سم، صفة المحتوى الرطوبي لنقطة الذبول الدائم عند شد 15000 سم، التربة المحروثة، التربة الغير محروثة