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Modeling Soil Erodibility by Water (Rainfall/Irrigation) on Tillage and without Tillage Plots of a *Helianthus* Field Utilizing Soil Analysis, Precision Agriculture, GIS and Kriging Geostatistics †

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Abstract: The aim of our study is the modeling at field level of soil erodibility (K factor) by water (rainfall and irrigation) on traditional tillage (CoT) and without tillage (NoT) plots cultivated with *Helianthus annuus* utilizing plots observations, soil sampling laboratory analyzes, GIS, precision agriculture (PA) and Kriging geostatistical modeling. A split-plot layout consisting of 4 handlings × 3 replicates of trial blocks (with a south-east facing 7.5% slope) was used. Grid template surface soil cores (0.0–5.0 cm) samples were taken to characterize textures (sandy, silty, clayey, very fine sandy and gravely), organic matter (OM) concentrations, soil's microstructure and water permeability categories. A GPS satellite tracker system was utilized to define the sampled positions and 40 soil cores were air-dried and sieved with a 2 mm sieve to identify soil's mechanical microtexture using Bouyoucos methodology. Organic matter extracted by chemical oxidation with 1 mol L^{-1} $K_2Cr_2O_7$ and titration of the remaining reagent with 0.5 mol L^{-1} $FeSO_4$. Soil's microstructure and water permeability categories have been defined following the USDA classification system. Soil erodibility by water modeling of K factor (Mg ha h ha^{-1} MJ^{-1} mm^{-1}) was derived according to the Wischmeier nomograph method by incorporating it in a developed GIS geospatial model using Kriging geostatistics. Statistical results of the ANOVA test (p = 0.05) among soil erodibility datasets showed significant differences between the 2 tillage systems, as well as between the 4 management treatments. Moreover, it was found that without tillage (NoT) plots and treatment-Without Tillage plus Vegetative Coverage were the best tillage and agricultural practices for hillslope farmfields, and can be regarded as potential ecological good agricultural practices to curb soil erodibility by water, reduce runoff risk and to maintain soil's environment and its beneficial nutrients.

Keywords: soil's erodibility by water (rainfall/irrigation); tillage; soil analyses; spatial analysis; precision agriculture and kriging geostatistical models; *Helianthus annuus* crop; organic matter.

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1. Introduction

Erosion of soil is the phenomenon of soil particles being separated and transported by water or wind [1]. Nowadays, it is a major issue for agricultural growth and food safety at peripheral, country and world levels [2,3]. Greece has a developed agricultural sector with a declining farmers population and heavy farming operations that have led to increased erosion of soils. In an effort, to study new ways to decrease soil erosion and preserve precious soil reserves, several erosion models have been successfully deployed and widely tested all over the world. Soil's erosion and risk are considered major problems of the environment in Greece. Soil's erodibility (K) is a fundamental parameter in erosion forecasting methods like the USLE (Universal Soil Loss Equation) [4] and RUSLE (Revised USLE) [5,6]. The K factor is a complicated soil attribute which is the easiness of the soil been degraded by water splashing during a rainfall or irrigation (mostly with sprinklers or waterjets) event or by water run-off or their combination [3]. It is considered hard to capture the principal variables of erosion forecasting models, like soil's erodibility, represented as K [7]. To overcome this issue, implicit methods are used to assess the K factor and allow these studies to be carried out [8]. The aim of our study is the geospatial modeling at field level of soil erodibility by water on traditional tillage (CoT) and without tillage (NoT) in *Helianthus* plots utilizing observations, soil laboratory analyzes, precision agriculture, Kriging geostatistics and GIS mapping under climate change in Greece.

2. Materials and Methods

2.1. Study Area and Site Description

The trial was carried out in the agricultural hilly erosion-prone area of the Gaiopolis University Campus-University of Thessaly (Larissa in Central Greece). The region has a moderate continental climate with a hot arid summer and a gentle winter, that is characterized as Csa (Koeppen climate classification) [2] and is further classified as XERIC MOISTURE REGIME [9], with an average annual temperature and precipitation of 17.35 °C and 380.75 mm, respectively. The highest and lowest average monthly precipitation were pr(hi) = 113.40 mm (May) and pr(low) = 12.20 mm (November), respectively. The cumulative precipitation was 652.40 mm $year^{-1}$. A split-plot layout consisting of 4 handlings (treats) × 3 replicates of trial blocks (with a south-east facing 7.5% slope) was used. *Helianthus annuus* plants were seeded to facilitate plant coverage in a number of treatments: (a) A-treatment was traditional tillage (CoT) with vegetative coverage (VC), (b) B-treatment was CoT without vegetative coverage (NoVC), (c) C-treatment was without tillage (NoT) with vegetative coverage (VC), and (d) D-treatment was without tillage (NoT) and without vegetative coverage (NoVC). The dimensions of the 12 experimental field plots were 6 m × 22.1 m downslope, with an overall plot area of 1591.2 m^2.

2.2. Soil Sampling, Laboratory Analyses and Classification

Grid template surface soil cores (0.0–5.0 cm) samples were taken to characterize textures (sandy (Sa), silty (Si), clayey (Cl), very fine sandy (vfS) and gravely (Gr)), organic matter (OM) concentrations, soil's microstructure and water permeability categories. A GPS (Global Positioning System) satellite tracker 2ystem was utilized to define the sampled positions and 40 surface soil cores were air-dried and sieved with a 2 mm sieve to identify soil's mechanical microtexture using Bouyoucos methodology [10,11]. Organic matter extracted by chemical oxidation with 1 mol L^{-1} $K_2Cr_2O_7$ and titration of the remaining reagent with 0.5 mol L^{-1} $FeSO_4$ [11]. Soil's microstructure (which is the assemblage of soil particles and agglomerates into identifiable particles or granules) categories [9] and water permeability categories have been defined following the USDA classification system [9,12]. Soil erodibility by water modeling of K factor (Mg ha h ha^{-1} MJ^{-1} mm^{-1}) was derived according to the Wischmeier nomograph method [4,12–14], by incorporating it in a developed GIS geospatial model using Kriging geostatistics. The K factor equation (1) [4,12–14] was derived for soils having less than 70% silt plus vfS:

$$K = \left\lfloor \frac{(2.1 \times 10^{-4}\ (12 - OM) M^{1.14} + 3.25(S - 2) + 2.5(P - 3))}{100} \right\rfloor \times 0.1317 \quad (1)$$

where K = soil erodibility of the USLE method (Mg ha h ha^{-1} MJ^{-1} mm^{-1}), M = product of percentage of silt + Vfs and of all soil fractions other than clay (0.05 mm < sand < 0.1 mm, 0.002 mm < silt < 0.05 mm, clay < 0.002 mm), OM = soil's organic matter concentration (%), S = soil's microstructure category, and P = soil's water permeability category.

2.3. Statistical and Geostatistical Data Analysis, Soil Erodibility Modeling and Methodology

Data analysis was performed using the IBM SPSS v.26 [15–21] statistical software package. The results are means of the samples analyses and measurements. Analysis of variance (ANOVA) [14–29] was used to assess tillage systems and treatment effects. The statistical Levene test of Homogeneity of Variances [14–22] was used in order to validate the assumption of variance equality of soil erodibility data groups. Mean separation was made using LSD test [14–22] when significant differences (p = 0.05) between treatments were found. In the present study, we used geostatistics (Kriging) and precision agriculture [14,16–19,21–23,27] for modeling and GIS (Geographical Information System) mapping of soil textural classes, organic matter content, soil structure and permeability categories respectively and also for the soil erodibility. Using the modeled parameters (which were digitally mapped in a GIS environment) as input factors, we delineated soil's erodibility field map with the aid of geospatial analysis, precision agriculture and the use of a GIS software (ArcGIS ©). In addition, the evaluation of K-factor equation requires analysis of residual errors, the difference between predicted and observed values and prediction characterization between over- and underestimates. To that end, we used the statistical parameters described by other studies [14–19,21–23,27,30,31], such as the equations for the Mean Prediction Error (MPE), the Root Mean Square Error (RMSE), the Mean Standardized Prediction Error (MSPE) and the Root-Mean-Square Standardized Error (RMSSE). Soil erodibility modeling results of the plots were used in order to extract the K data for the validation procedure using the training and test soil and K datasets.

3. Results and Discussion

Soil erodibility depends on 4 parameters: soil texture, soil structure, permeability and organic matter concentration. Soil analyses results showed that sand and very fine sand contents ranged 26.47–46.34% and 21.73–22.08% respectively. The mean silt and clay contents were 19.91% and 20.22% respectively. The soil's organic matter [14,17–19,21–23,27] modeling results are depicted in Figure 1a–c. Its concentration classes range from 1.44% to 3.22% (Figure 1b), indicating soil's OM with medium to high content.

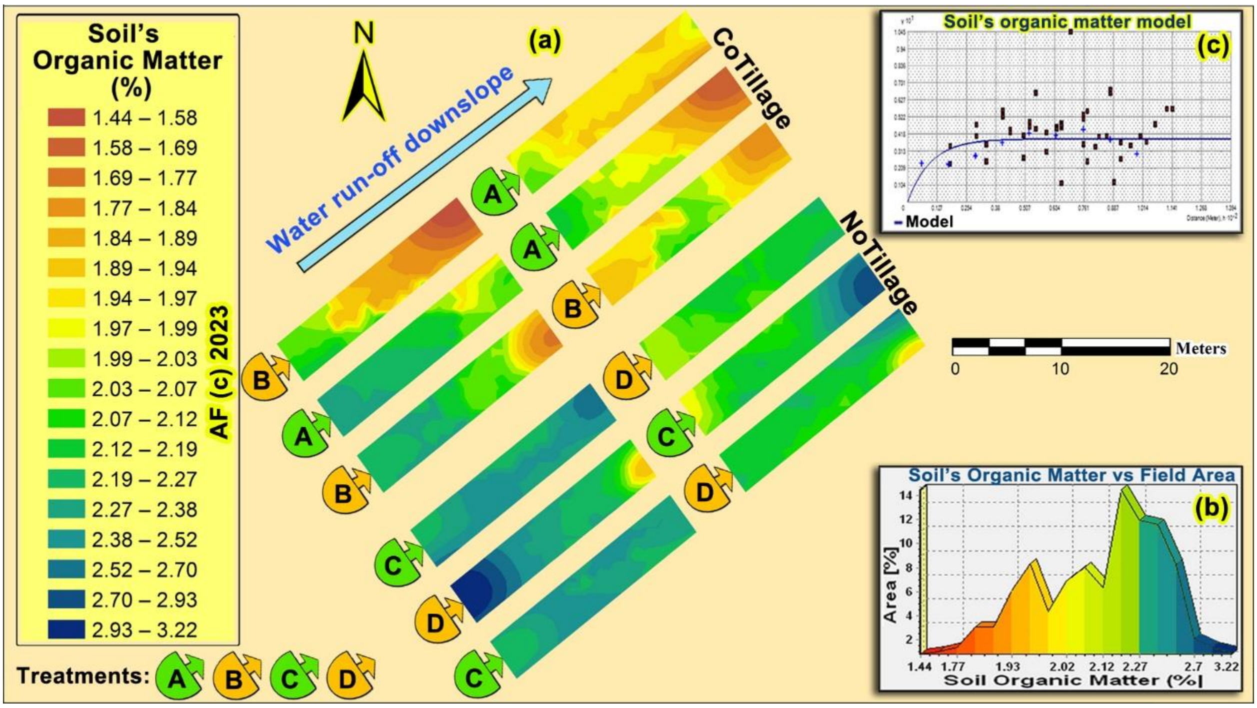

Figure 1. (**a**) Modeling outcomes on a soil's organic matter digital GIS map of the *Helianthus* plots, (**b**) Diagram of soil's organic matter classes vs. percentage of *OM* area, and (**c**) Semivariogram of the model.

Soil's organic matter geospatial analysis showed that 34.887% of the soil plots area have medium OM content (1.44–2.00%), while the rest 65.113% have high OM content (2.00–3.22%). The modelling and statistical outputs revealed that K factor over the measuring time span ranged from a min 0.025 to a max 0.043 Mg ha h ha^{-1} MJ^{-1} mm^{-1} (average K = 0.034, StdD = 0.0062). Soil's characteristics of the Helianthus plots were sampled, analysed and digitised in accordance to their GPS field positions in the WGS 1984 geographic coordinate system (CS) and stored in a geodatabase. Soil's parameters, tillage and treatment datasets were projected to the WGS 1984 UTM Zone 34N CS (Greece's zone). The outputs of the geospatial erodibility modeling are visualized in a digital GIS map of the field in Figure 2a–c. Furthermore, the outcomes of the erodibility categories in relation to the percentage of the K factor area are illustrated in Figure 2b. The validation of the geospatial soil erodibility modeling (Figure 2c) resulted in the following geostatistical outcomes: Mean prediction error (MPE) = −0.000000924, root mean square error (RMSE) = 0.00598019, mean standardized prediction error (MSPE) = −0.00518898 and root mean square standard error (RMSSE) = 1.0498154. These results are highly acceptable considering that the MPE, RMSE and MSPE scores should be close to zero for an optimal forecast and the RMSSE scores should be close to unity, suggesting an accurate estimate of the forecast variability. The above-mentioned results confirmed the reliability and accuracy of the generated soil's erodibility digital GIS map for the trial hillslope field of *Helianthus annuus*. Furthermore, these outcomes have proven that the ordinary Kriging exponential model demonstrated a good performance and is regarded as highly appropriate for geospatial modeling and mapping of the K-factor as well as other soil parameters (clay, sand, silt, organic matter, very fine sand, etc.). The output of ANOVA test (p = 0.05) between soil erodibility dataset in relation to tillage method showed that the 2 tillage systems [traditional (CoT) and without tillage (NoT)] differ significantly in certain manner, so it was necessary to further investigate the pattern of their differences. Therefore, in order to validate the hypothesis of equality of variance for the erodibility dataset, the Levene statistical test for homogeneity of variances was conducted.

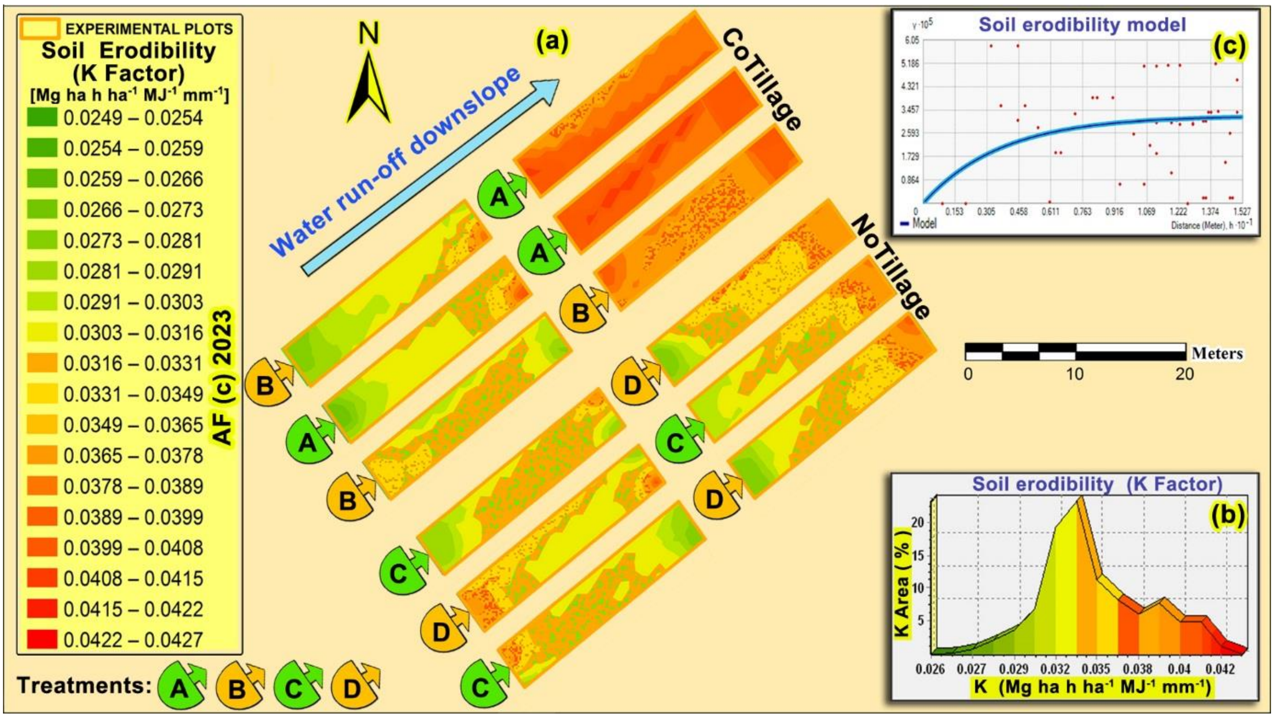

Figure 2. (**a**) Soil's erodibility modeling results on a digital GIS map of the Helianthus plots, (**b**) Diagram of soil's erodibility categories vs. percent of K factor area, and (**c**) Semivariogram of the model.

The outcomes of the Levene statistics for soil erodibility on tillage systems and treatments established that the K factor homogeneity variances across tillage systems (CoT and NoT) and also across treatments (A, B, C and D) data groups are not significantly different meaning that the assumption of variance equality was found true. Since the assumption was found true, ANOVA and LSD (Least Significant Differences) statistical tests were performed to assess treatment effects and mean separation of treatment effects. The best tillage system in Central Greece for hilly farmfields on high erosion risk with a slope ≥ 7.5% downslope was found to be tillage NoT. The results of ANOVA (p = 0.05) showed that treatments (A, B, C and D) data groups of soil erodibility are significantly different (Sig. = 0.029). The best treatment in order to curb soil erodibility (K factor) and preserve soil's environment was found to be treatment C [(NoT-VC) (without Tillage with Vegetative Coverage)] for hilly farmfields on high erosion risk with a slope ≥ 7.5% downslope.

4. Conclusions

The prediction errors result of geospatial and geostatistical modeling validation for soil erodibility GIS mapping confirmed the validity and precision of the produced K factor digital GIS map of the *Helianthus annuus* trial plots. These results proved that the ordinary kriging exponential model performed well, and it is considered as very suitable for soil erodibility and other soil parameters (clay, sand, silt, organic matter, very fine sand, etc.) modeling and digital mapping. Considering the ANOVA test results of tillage systems and treatment effects on soil erodibility, the best tillage system found was the NoT (without tillage) and the best treatment was C [(NoT-VC) (without Tillage with Vegetative Coverage)] for hilly farmfields on high erosion risk with a slope ≥ 7.5% downslope. These can be regarded as potential ecological good agricultural practices to curb soil erodibility by water, reduce runoff risk and to maintain soil's environment and its beneficial nutrients.

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