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General Information

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"Soil Studies (SoilSt)" is the successor to the "Soil Water Journal (Toprak Su Dergisi)" which has been published since 2012. Based on the experience and strengths of its predecessor, SoilSt has been developed to create a truly international forum for the communication of research in soil science. SoilSt is a refereed academic journal has been published free of charge and open accessed by Soil, Fertilizer and Water Resources Central Research Institute. The journal will be published 2 issues (July & December) starting from 2022. It covers research and requirements of all works within the areas of soil.

Aims and Scope

Soil Studies is an international peer reviewed journal that aims to rapidly publish high-quality, novel research of studies on fertility, management, conservation, and remediation, physics, chemistry, biology, genesis, and geography of soils. In addition, the main purpose of Soil Studies is to reveal the influences of environmental and climate changes on agroecosystems and agricultural production. In this context, Soil Studies publishes international studies address these impact factors through interdisciplinary studies. In the journal, articles on hypothesis-based experimental observation of the interactions of all components of agricultural ecosystems, field trials, greenhouse or laboratory-based studies, economic impact assessments, agricultural technologies, and natural resources management will be accepted within the peer-reviewed process. Topics include, but are not limited to:

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RESEARCH PAPER

Determination of the direct runoff using the soil conservation service curve number method and its applicability to Lüleburgaz Sub-Basin (Thrace Region)

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Abstract
Lüleburgaz Sub-basin, located within the Ergene Basin in the Thrace Region which is designated by the State Hydraulic Works. The Soil Conservation Service Curve Number (SCS-CN) Method was used to determine the runoff for the basin. In basins where flow values are not recorded for a long period, the SCS-CN is frequently used to obtain the flow indirectly. For this investigation, the land cover data was sourced from the Corine Cover Database, while the hydrological soil groups were acquired from the ORNL Distributed Active Archive Center for Biogeochemical Dynamics. Daily precipitation data were obtained from Lüleburgaz Meteorological Station for the years 2013-2017. All values were entered as data into the geographic information system-based software and analyzed with raster calculation. The SCS-CN method was employed to calculate the average runoff value for the basin, yielding a result of 157.6x10^6 m^3/year. Meanwhile, at the Lüleburgaz flow observation station, the average runoff was recorded as 135.8x10^6 m^3/year in between 2013 and 2017. It was determined that the runoff measured by the SCS-CN method was merely 1.16 times greater than the runoff recorded at the flow observation station. This shows that the SCS-CN method may be suitable for use in basins with similar characteristics where there is no flow observation station.

Introduction

Lüleburgaz Sub-basin is a part of the Ergene Basin, one of Turkey's most important basins. It is very close to one of the world's leading metropolises such as Istanbul and has a very important position due to its dense population (Edelman, 2021). In Turkey, where the water problem is increasing with global warming, it is of great importance to investigate the ground and surface waters, to determine the amount of water, and increase the water quality of this large basin. Determination of surface runoff, which is one of the hydrological variables, is also very important in water quantity calculation studies.

The SCS-CN method is a highly effective approach commonly employed to assess runoff resulting from rainfall. This model finds extensive application for rainfall-runoff modelling of small sub-basins worldwide (Beven, 2001; Das and Paul, 2006). The calculated runoff serves as a crucial factor in implementing effective land management and water planning strategies within the study area. This model, widely used in countries facing water scarcity and water quality problems (Muthu and Santhi, 2015; Rawat and Singh, 2017; Raju et al., 2018), has been the subject of extensive research. The applicability of SCS-CN management has been addressed in these studies. It is also highlighted that runoff resulting from precipitation plays a pivotal role in numerous water resources development and management endeavors, including flood control, irrigation planning, designing irrigation and drainage networks, and hydropower generation. In their study, Soulis et al. (2009) observed that, employing CN values generated through the standardized procedure, the SCS-CN method consistently overpredicted runoff for events with high rainfall depth and underpredicted runoff for events with low rainfall depth. On the other hand, Shadeed and Almasri (2010) demonstrate that when combined with GIS, SCS-CN method constitutes a potent tool for estimating runoff volumes in catchments across the West Bank, which encompass arid to semi-arid regions of Palestine. In the Liudaogou catchment in China, the SCS-CN model projected a gradual increase in runoff with rising rainfall when precipitation values were below 50 mm. However, the predicted runoff amount showed a rapid increase when rainfall exceeded 50 mm, as noted by Xiao et al. (2011). Fan et al. (2013) demonstrated the suitability and effectiveness of the enhanced SCS-CN method, which incorporates remote sensing variables for estimating surface runoff, in Guangzhou, China. Taher (2015) found an estimated total runoff volume of 75.80 mm^3 using the same method, which corresponds to 76% of the total annual rainfall. In their study, Satheeshkumar et al. (2017) established that the runoff in the Vaniyar sub-basin accounts for 6.6% of the total annual precipitation when employing the SCS-CN method. Lian et al. (2020) gathered an extensive dataset of rainfall-runoff monitoring data to recalibrate CN values across 55 study sites in China. Employing the revised CN method, they concluded that this approach offers a more accurate reference, particularly suitable for the prevailing natural conditions in China. In their study, Kumar et al. (2021) discovered that the overall average runoff volume amounts to 35.04x108 m³, equivalent to 17.21% of the total average annual rainfall in the Sind River Basin, India.

Ultimately, the studies mentioned above have proven the accuracy of the SCS-CN method for determining surface runoff due to precipitation. Therefore, this study aims to ascertain the runoff amount of the Lüleburgaz Sub-basin using the SCS-CN method. The runoff amount calculated by this method was compared with the data measured at the streamflow observation station, and the method's applicability was tested in similar basins without streamflow observation data.

Study Area

The study area covers a large part of Lüleburgaz and Pınarhisar districts of Kırklareli province in the Marmara Region and is located within the coordinates N5011100-N5104560 and E3033610-E3106660 (Figure 1). The lands of Lüleburgaz 80 district is flat and generally has a hilly terrain. The most important plain and valley of the region is Ergene. The Ergene Plain, with a minimum height of 35 m and an average height of about 100 m, is very fertile and its northern border is defined by the Yıldız Mountains, which are about 1000 m high. The most important river of the study area is the

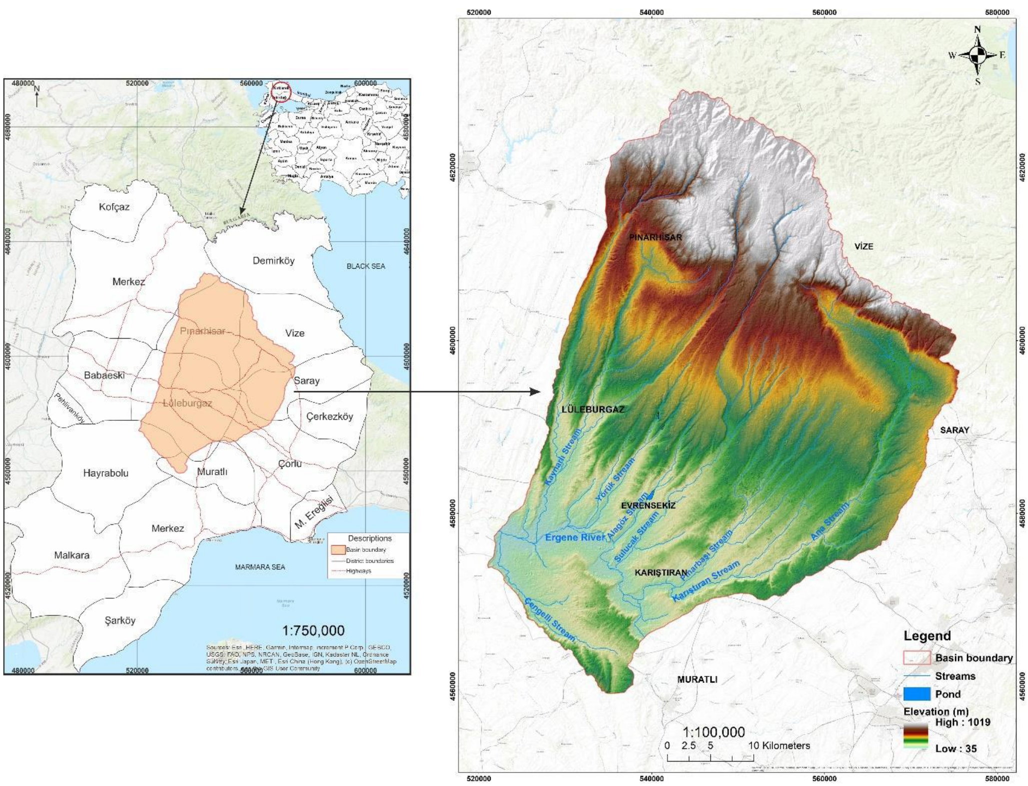

Figure 1. Location and elevation map of the study area

Ergene River passing through Lüleburgaz district (Ministry of Environment and Urbanization, 2014).

In the Ergene Basin, summers are hot and dry while winters are cold and snowy. Although the temperature difference varies from year to year, some years may have warmer winters than Central Anatolia. The reason for this is the mixture of the continental climate of Central Europe with the Mediterranean, Black Sea and Marmara climates. The precipitation catcment area of the study area is approximately 2150 km^2. The region experiences an average annual precipitation of 581 mm, with the highest average temperature typically occurring in August at 41°C, and the lowest in February at -20°C (General Directorate of Meteorology, 2017).

Materials and Methods

Materials

The SCS-CN (Curve Number, SCS 1986) is an empirical rainfall-runoff model utilized for calculating the excess water lost through infiltration following precipitation. Primarily employed for estimating water quantities in small catchments, this model focuses on the computation of infiltrated water (McCuen, 1982; Mishra & Singh, 1999). For this model;

-Daily precipitation data (2013-2017)

-Land use/land cover

-Hydrological soil groups (HSG)

-Parameters such as Antecedent Moisture Content (AMC) are used.

In order to calculate the average precipitation, monthly average precipitation data of 5 meteorological stations in the basin were evaluated (Table 1). Land use/cover data for the SCS Runoff Curve Number Method was obtained from the Corine Cover Data base, and hydrological soil groups were obtained from ORNL DAAC (Distributed Active Archive Center For Biogeochemical Dynamics) at 250 m resolution. Various soil types and minimum infiltration rates for Türkiye were suggested by Özer (1990) (Table 2). Land Use/Cover was downloaded and prepared from the 2018 Corine Cover Data base.

Table 1. Meteorological stations within the study area

Station Number	Station Name	X	Y	Z (m)	Average precipitation (mm)
19320	Vize	564145	4601931	150	535.6
17631	Lüleburgaz Tigem	526138	4577713	45	589.6
18398	Pınarhisar	543598	4608907	266	602.8
1045	Dambaslar	520947	4564503	76	586.6
18796	Ahmetbey	548543	4587310	118	576.6

Land cover encompasses the vegetation that blankets the land surface, including forests, soil, agricultural areas, and various land uses such as settlements, mining sites, dumping areas, etc. As defined by Halley et al. (2000), it also involves human activities associated with the land. (Table 3).

Table 3. Map codes of land use cover

Land use	Map code
Urban fabric (continuous)	111
Urban fabric (discontinuous)	112
Industrial and Commercial areas	121
Roads and railway networks	122
Mining and dump sites	131, 132
Agricultural fields	211, 212, 213, 222
Pastures, meadows and grazing lands	231, 242, 243
Forests	311, 312, 313
Transitional wood and shrub	321, 324, 333
Wetlands	511, 512

Table 2. Hydraulic Soil Groups (Özer, 1990)

Soil Group	Description	Minimum Infiltration Rate
A	Medium degree of infiltration, well drained. Mainly sandy and gravelly soils with low runoff potential and high waterpermeability.	7,6-11 mm/h
B	Medium infiltration degree, medium drainage. Soils with medium fine to medium coarse grain size with normal flowpotential and medium degree of water permeability (silty soils).	3,8-7,6 mm/h
C	Low drainage with slow infiltration. Soils with high runoff potential and slow water permeability (sandy clay)	1,2-3,8 mm/h
D	Low drainage with very slow infiltration. High clay soils with very high runoff potential and very slow water permeability(silty, sandy clay, clay)	0-1,2 mm/h

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Methods

The Soil Conservation Service Curve Number Method is commonly employed in basins where extended flow data is unavailable. This method serves to indirectly acquire the necessary flow information essential for designing structures like flood control and water storage. The current data required to determine the surface flow can be obtained quickly and reliably with Remote Sensing and Geographical Information Systems.

The curve number, denoted as CN, is a numerical value determined based on the catchment's topography, soil type and land cover. This number ranges from 0 to 100. A value of 100 represents completely impermeable surfaces or the surface portion of water bodies, while CN values for other surfaces are less than 100 and generally range between 55-95 (Hawkins et al., 2002). According to this method, the relationship between precipitation (P) and runoff (Q) is expressed as;

$$Q = \frac{(P - Ia)^2}{((P - Ia) + S)}$$

$$S = \frac{25400}{CN} - 254$$

Where P is precipitation (mm), Q is flow (mm), S is water retained by the soil (mm), Ia: λS, "Ia" represents the water quantity prior to runoff, including factors like initial abstraction, infiltration, or rain interception by vegetation, while "CN" stands for the surface runoff curve number. CN, as already mentioned, is determined by factors such as land cover, hydrological soil groups, and Antecedent Moisture Condition (AMC) values within the catchment, as specified by Johnson (1998). For AMC, SCS (1972) considered three different conditions (Dry (I), Normal (II) and Moist (III)) according to the moisture condition of the soil before the onset of rainfall and proposed three different CN (CN I, CN II and CN III) values according to these conditions (Table 4). AMC II, also known as CN II, can be synonymous with average soil moisture. Additionally, there are dry conditions, labeled AMC I or CN I, and moist conditions, denoted as AMC III or CN III.

Table 4. CN values according to the AMC

CN	Total precipitation values for the previous 5 days (mm)	
	Dry season	Wet season
I	< 12.7	< 35.5
II	12.7-28	35.5-53
III	>28	>53

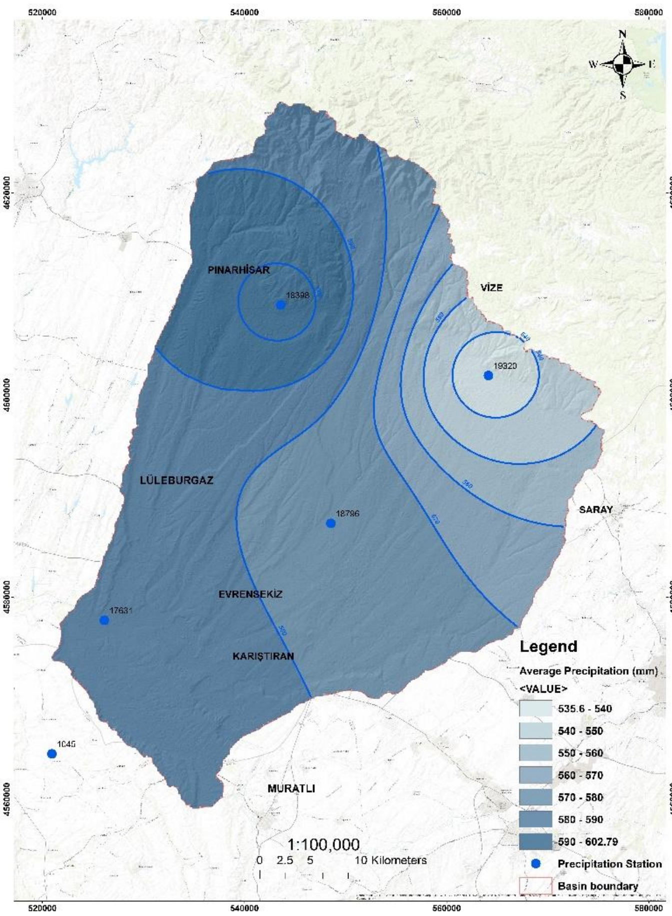

Figure 2. Average precipitation of the study area

To calculate the CN value for AMC II, it is multiplied by an adjustment factor determined by the current AMC, thereby establishing the adjusted number of curves;

$$CNII = \frac{\sum_{i=1}^{n}(CN_i * A_i)}{\sum_{i=1}^{n} A_i}$$

Where CN II is CN II value for the catchment, for each land use/cover and hydrological soil group, CNi represents the corresponding CN value, while A_i represents the area associated with each land use/cover and hydrological soil group.

Results and Discussion

The SCS-CN method is used with high accuracy, especially in semi-arid regions such as Asia (Kumar and Jhariya, 2017; Raju et al., 2018; Al-Ghobari et al., 2020; Rao, 2020; Shi and Wang, 2020). According to Kumar and Jhariya (2017), using the SCS-CN method, the accuracy assessment of the areas suitable for recharge structure potential maps of the Bindra basin was found to be 82.60%. Raju et al. (2018) found that over the past 20 years, the ungauged watershed has shown annual averages of 688.82 mm of rainfall, 478.06 mm of runoff, a runoff volume of 699.75 m³, and a runoff coefficient of 0.69. Al-Ghobari et al. (2020) reported that using the SCS-CN method for rainfall-runoff linear regression analysis demonstrated a strong correlation of 0.98 in Saudi Arabia. Shi and Wang (2020) used a modified SCS-CN method and the results demonstrated that the model efficiencies of the proposed method increased to 80.58% during the calibration period and 80.44% during the validation period.

The SCS-CN method has recently been used in other continents besides Asia and has yielded highly accurate results (Caletka et al., 2020; Walega et al., 2020; Soulis, 2021). Walega et al. (2020) compared the SCS-CN method with other modified methods and found that direct runoff calculated using the modified Sahu-Mishra-Eldho method and the original SCS-CN method was close to each other for the Coweeta watershed. According to Caletka et al. (2020), the acquired findings for the five basins in Czechia indicate the necessity for a systematic yet site-specific revision of the traditional CN

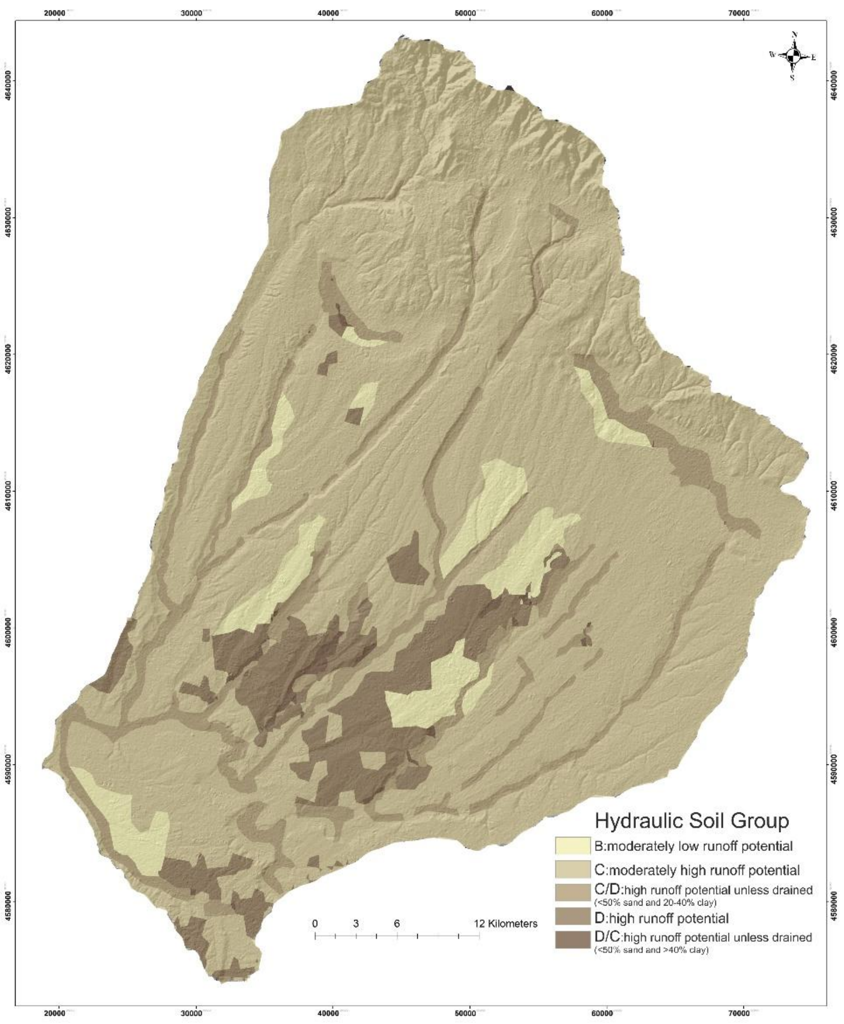

Figure 3. Hydraulic soil groups of Luleburgaz Sub-basin

method, which could help enhance the accuracy of CN-based rainfall-runoff modeling. As with many studies mentioned above, the original SCS-CN method was used in this study, and data with 86% accuracy was obtained using actual flow data.

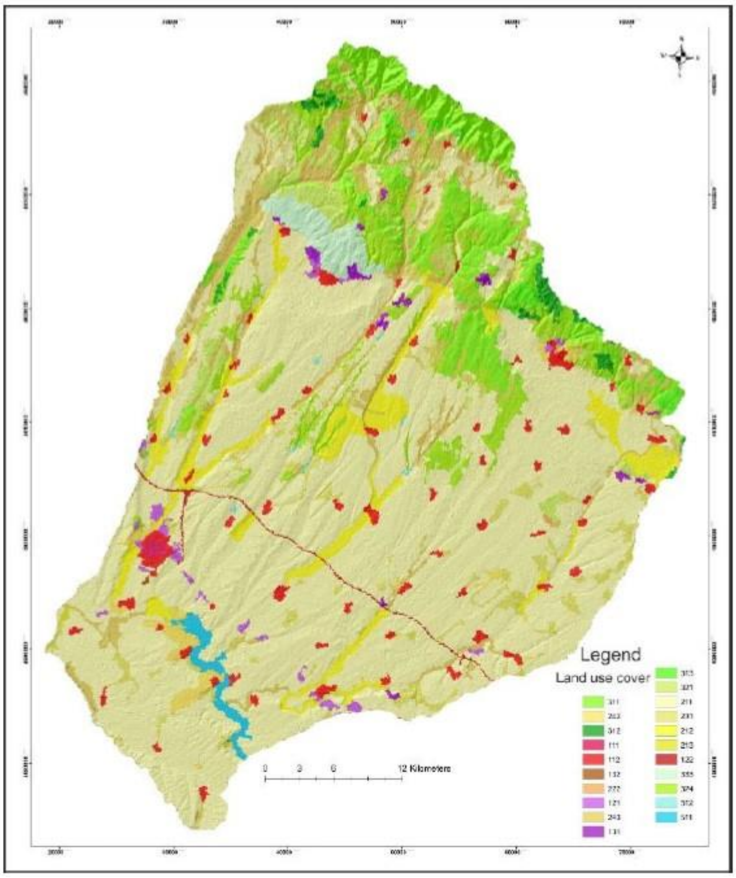

Figure 4. Land-use cover map of Luleburgaz Sub-basin

Upon evaluating the precipitation data from five meteorological stations in the study area, the basin's average precipitation was determined to be 581.4 mm, as illustrated in (Figure 2). HSG map for the study area was created based on the data acquired from the ORNL DAAC regarding hydraulic soil groups. The HSG data in vector format was converted to raster format with

Table 5. The CN values were calculated according to the land cover and hydrological soil groups

Land Use Cover	CN Values according to Hydrological Soil Groups			
	A	B	C	D
Industrial areas	81	88	91	93
Commercial areas	89	92	94	95
High-density settlement	77	85	90	92
Medium-density settlement	57	72	81	86
Low-density settlement	51	68	79	84
Well-covered forest	25	55	70	77
Poorly covered forest	45	66	77	83
Pasture, grazing land	49	69	79	84
Agricultural fields	72	81	88	91
Mining sites	76	85	89	91
Open areas (park, garden)	39	61	74	80
Roads, streets	98	98	98	98
Wetlands	100	100	100	100

25x25 m pixels. Hydraulic soil groups in the study area were determined as B, C, C/D, D and D/C (Figure 3).

The land use cover codes for the study area were generated using a GIS-based program with Corine Land Cover (2018). A detailed description of the land use cover codes in the study area is given in Table 3. Notably, agricultural areas and forested regions form a significant portion of the study area, as depicted in Figure 4.

In the GIS database, CN values and areal data are available in the map produced with the cross function. CN values of sub-basins according to different AMC classes were calculated by some formulae. Among these, CN II values according to AMC II class are given in Table 5 and shown in Figure 5 on the map.

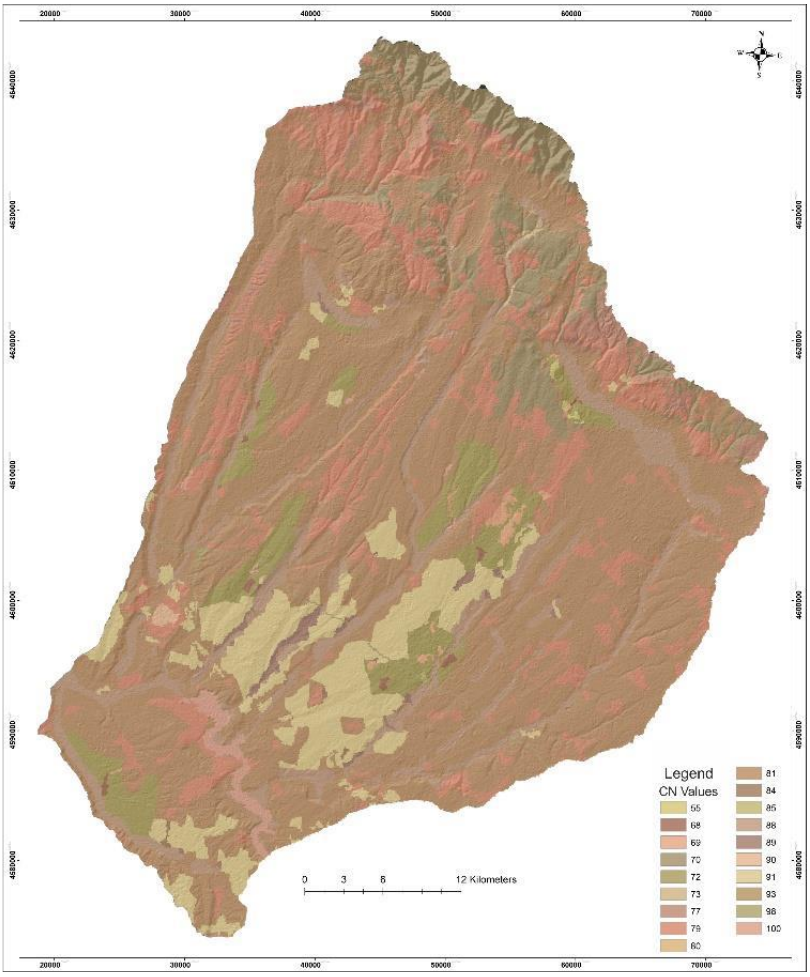

Figure 5. Map showing the CN values generated according to land use cover and hydrological soil groups

CNI, CNII and CNIII values for the basin were calculated from CN formulas (Table 6).

Table 6. CN values calculated for Lüleburgaz Sub-basin

Basin	CNI	CNII	CNIII
Lüleburgaz Sub-basin	63.44	80.51	90.48

The SCS-CN method was used to calculate the average surface runoff for the catchment over the last five years, resulting in a determination of 73.3 mm. Then, these calculated flow data were compared with the flow measurements of Lüleburgaz Current Observation Station located at the outlet of the basin.

The data between 2013-2017 for the flow observation station in the basin were evaluated, and the total flow and calculated base flow graphs were drawn with 3 methods (Local Minimum Method, Fixed Interval Method, Sliding Interval Method) determined by Pettyjohn and Henning (1979). The flow and base flow graph of Lüleburgaz station for the period 2016-2017 is shown in Figure 6. In the average of the three methods, the base flow was found to be approximately 223x106

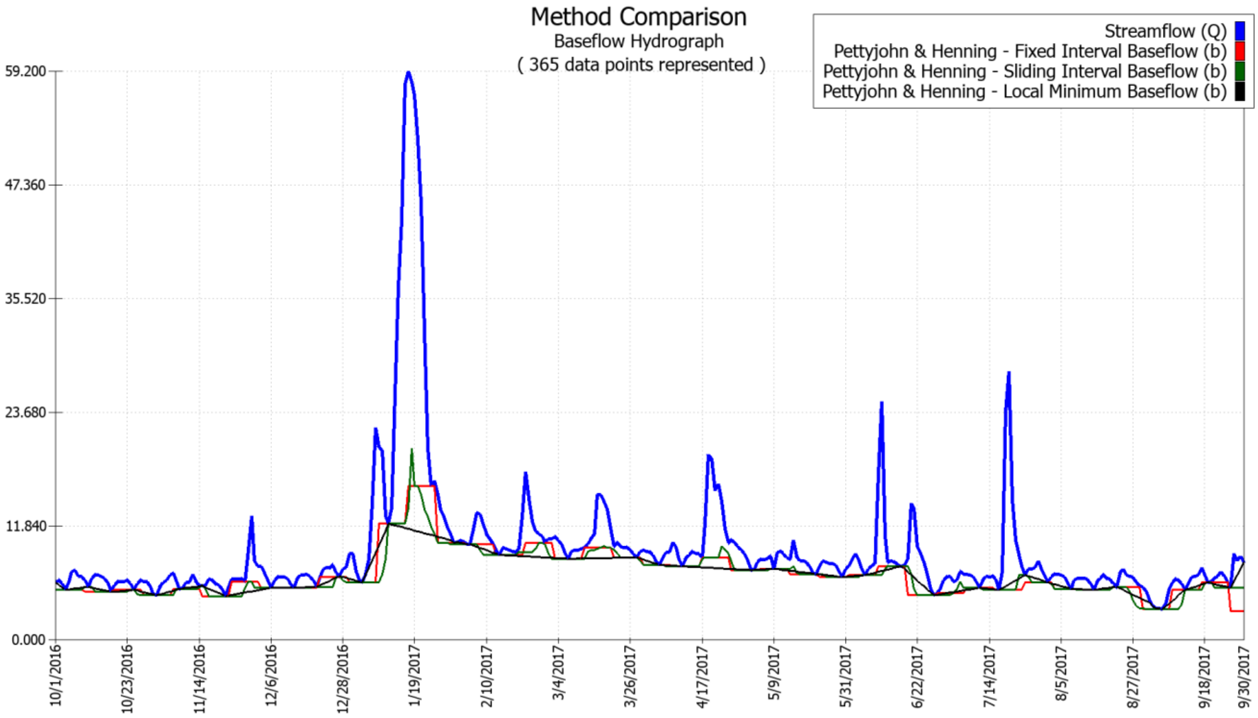

Figure 6. Total flow and base current graphs (Pettyjohn and Henning, 1979).

Table 7. Flow values measured at D01A008 Lüleburgaz station for the last 5 years (x10^{6}m^3/year)

Time	2013	2014	2015	2016	2017	Average
Total flow	371.25	427.88	268.68	241.38	366.16	335.07
Base flow	212.43	261.63	158.54	139.86	223.82	199.26
Surface flow	158.82	166.25	110.14	101.52	142.34	135.81

m^3/year and the surface flow was found to be 143x106 m^3/year (Table 7).

Conclusion

The Soil Conservation Service Curve Number (SCS-CN) method is extensively employed as a straightforward approach to the estimation of direct runoff volume resulting from a specific precipitation event. In this study, the runoff value was computed using the SCS-CN method and subsequently compared with the observed data recorded at the flow observation station. The findings from this study emphasize the effectiveness and accuracy of the SCS-CN method for determining surface runoff in ungauged watersheds. As a result, average precipitation in Lüleburgaz Sub-basin is calculated as 1250 x 10^6 m^3/year. At the flow observation station, the total runoff was measured to be 335 x 10^6 m^3/year, with surface runoff at 135.8 x 10^6 m^3/year. Utilizing the SCS-CN method, the average runoff was determined to be 157.6 x 10^6 m^3/year. Applying this method to the Lüleburgaz Sub-basin achieved an 86% accuracy rate when compared with actual flow data, validating its applicability in similar basins lacking streamflow observation data.

The study emphasizes the critical role of accurate precipitation data, hydrological soil group classifications, and land use cover information in enhancing the precision of the SCS-CN model. These elements are crucial in determining the Curve Number (CN) values, directly influencing the runoff calculations. Furthermore, the obtained findings highlight the necessity for a systematic yet site-specific revision of the traditional CN method. Adjusting the CN values to more accurately reflect local conditions can significantly improve the model's performance. This study supports the notion that while the traditional CN method provides a solid foundation, adapting it to specific site conditions can yield better results in rainfall-runoff modeling.

The successful application of the SCS-CN method in the Lüleburgaz Sub-basin also provides a framework for future research and practical applications in water resource management, especially in regions facing water scarcity and quality issues. The model's ability to predict runoff with high accuracy makes it a valuable tool for planning and implementing effective land and water management strategies.

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Author Contributions

MB: Conceptualization, Investigation, Writing-Original Draft Preparation, Writing-review and editing, Methodology- creation of models, Formal Analysis. **HH:** Writing-review and editing, Resources, Project Administration

Conflicts of Interest

The authors declare no conflict of interest.

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RESEARCH PAPER

Development and dissemination of precision agriculture practices for wheat in Central Anatolia

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Abstract
According to the results of the analysis of the soil samples taken from the production field in the Research and Application Farm of the Central Research Institute of Field Crops in 2021, a significant relationship was found between yield and NDVI and between yield and organic matter at 0.01 level. There was a significant negative relationship between lime and NDVI at 0.01 level. Increasing lime content negatively affected plant growth, which resulted in a decrease in NDVI. The positive significant correlation between NDVI, organic matter and yield indicates that NDVI value increases with increasing plant biomass. Increased biomass has added more soil organic matter. In 2021, when the yield change depending on NDVI was examined; it was observed that the yield was higher in the central and western parts of the plots where NDVI was higher, and the yield decreased in the eastern parts where the lakeshore strip was located due to the decrease in NDVI. According to the correlation results between the analysis results of soil samples taken from the farmer's field in 2021, yield values and NDVI data; a significant relationship was found between yield value and NDVI, water saturation, EC, organic matter and potassium at 0.01 level. Again, the relationship between yield and phosphorus was determined at 0.05 level. There was a significant negative relationship between yield and lime at 0.05 level.

Introduction

The effects of fertilizers, one of the indispensable inputs of agriculture, on environmental pollution has become a current issue of intense debate in recent years. It is known that organic and inorganic fertilizers contain some substances that may cause environmental pollution. Some of these substances are essential nutrients for plants, while others are naturally occurring in the raw materials used in fertilizer production and are not absolutely essential for plants. Fertilizers applied to the soil to meet the nutrient requirements of plants carry the risk of environmental pollution when they are used unconsciously and excessively due to the pollutants, they contain

(Köseoğlu, 1995). Today, excessive and unconscious use of chemical fertilizers and pesticides is the most important factor in the pollution of underground and surface water resources. It should not be forgotten that this pollution disrupts human health. As a result, since climate and soil characteristics differ in all regions of the country, it would be useful to carry out such studies in every region in order to prevent fertilizer losses and environmental pollution (Bellitürk, 2008). When any nitrogen fertilizer is added to the soil, some of the nitrogen evaporates away in the form of NH_3 depending on the type of fertilizer, soil conditions and climatic events in the region. Under some circumstances, the amounts lost can reach quite significant values and cause great economic losses. It is neither theoretically nor practically possible to stop the losses completely. However, it is possible to reduce losses at certain rates, in which case the amount of fertilizer to be applied to the soil will decrease and the income to be obtained from the unit area will increase (Sağlam, 2005). Remote sensing methods are widely used for modern agricultural studies and have become an important component of precision agriculture studies aimed at increasing productivity (Idso et al., 1977; Wiegand et al., 1979; Carley et al., 2008). The near infrared region of the electromagnetic spectrum is sensitive to plant structure, and it is possible to study changes in vegetation with satellite systems that include this region (Sabins, 1987; Jensen, 1996).

Remote sensing data can be used to determine plant nutrient levels, areal distribution of plants, whether plants are diseased or healthy, and biomass. Using satellite imagery of different resolutions, areas of high or low crop yields can be easily identified (Morgenthaier et al., 2003). Guozheng and Maohua (1999) worked to develop a yield mapping system for cereals. Three main yield mapping approaches are introduced. The first method is the collection and weighing method. The second method is parceling type yield mapping, and the third method is instantaneous yield mapping. Many different grain flow sensors have been analyzed and their characteristics compared. The quality of grain yield information is influenced by the quality and moisture content of the flowing material. Radiometric sensors are fully accurate and recommended. Vellidis et al. (2000) stated that the most important component of precision agriculture is yield maps obtained by mounting sensors or groups of sensors on a harvester. Yield maps were created using data from the fields and color-coded images were used in the maps to make them more useful for farmers. The system was extensively and fully tested over a period of more than 3 years and evaluated by 11 users during 1999.

Lee et al. (2005) designed a silage yield mapping system using a DGPS receiver, load cells, amaster switch, Bluetooth modules for data transfers and a moisture sensor. In total, 13 cars of silage were harvested from the commercial silage field during the test period. The weights of full and empty cars were measured with the help of a platform before and after harvesting and compared with the values obtained from the load cells of the silage yield mapping system. System yield losses were 5% less in the whole harvested crop than those measured on the platform. Blackmore (1994) stated that precision agriculture interacts with many components and that not all components of the relationships between the various elements that make up precision agriculture serve only one main purpose, and that measures to minimize environmental pollution and cultural practices should be taken into account as well as those that increase productivity. According to Blackmore and Marshall (1996), with the introduction of DGPS systems in the agricultural sector, it has become possible to prepare yield maps using yield and location information. These maps have become important elements of a new management system, called precision agriculture, which allows better use of information to manage variable features in the landscape. Güçdemir et al. (2010) observed that the coefficient of variability in crop yield was more than 19% in their study conducted under farmer conditions in Adana and determined that there were different yield areas ranging between 9 tons/ha and 19 tons/ha. In this study, temporal and spatial information about the physical and chemical properties of soils were obtained and their relationship with yield was examined. In this way, real-time maps encouraging rational fertilizer use were obtained and farmers were encouraged to turn to variable level input applications in terms of business management. As a result, it was recommended to use fertilizer effectively and as much as necessary in agricultural production. With this study, firstly, the nutrient elements in the soil were revealed depending on the location by using soil analysis and sensors, and then, with the variable level fertilizer application method, it was recommended to apply as much fertilizer as needed. In this way, agricultural inputs will be used more rationally, imports will be reduced, profits of enterprises will increase and contribution will be made to the national economy. Therefore, it will be inevitable to put forward adaptation strategies suitable for the region in the dissemination of precision agriculture practices for each region of our country.

Material and Methods

Description of the Research Site

The project was carried out in 2 plots in 2021. For the project, the institute production parcel located in the Central Research Institute of Field Crops İkizce Enterprise in Gölbaşı district of Ankara province and a farmer's parcel from Gökçehöyük village representing the farmers' fields within the borders of the same district were selected (Figure 1 and Figure 2).

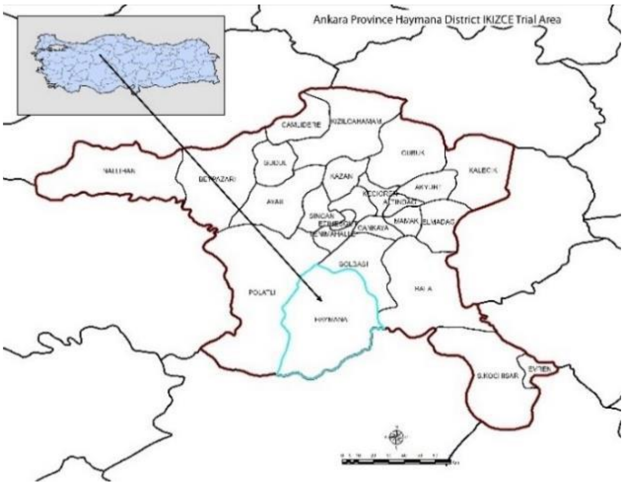


Figure 1. Study area parcels (ANKARA)

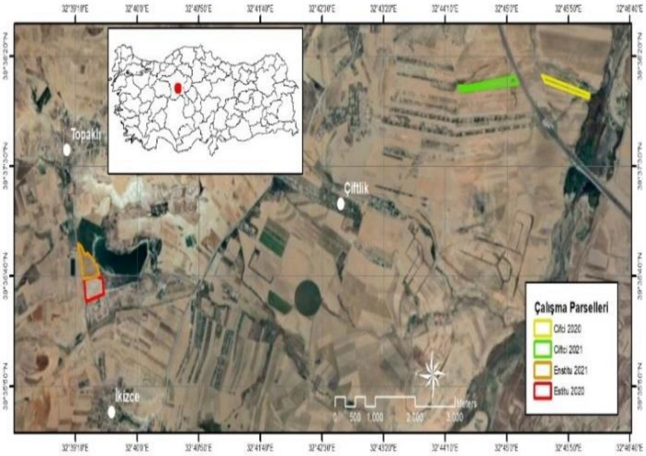


Figure 2. Farmer parcel sampling points in 2021

The climate of Ankara is continental. Generally, summers are hot and dry, winters are cold and rainy. The total annual precipitation of the province is 300-350 mm on average for many years. 32% of the total precipitation falls in winter, 25% in spring, 17% in summer and 26% in autumn. Again, thev average temperature for many years is 13.2.

Sampling Studies

The study was carried out in 2021 in 2 different locations: institute and farmer plots. Gridding method was used for sampling the plots, soil and plant samples were collected at 50x50 m from the institute plots, and 25x50 m from the farmer plots to represent the plots. After the parcels were identified in the study, the parcel boundaries were digitized using ArcGIS, a Geographic Information Systems (GIS) software. In order to reveal the variability within the parcel, 50*50 m and 50*25 m grid sampling patterns were created with the help of ArcGIS 9.2 program Fishnet plug-in (Figure 3, 4).

The coordinates of the sampling points determined in Parcels were uploaded to GPS and made suitable for field studies. Before planting in the field, soil samples were taken from 0-30 cm by going to the sampling points with the help of GPS. At harvest time, samples were collected from the same points with the help of a circle with an area of 0.25 m^2 for yield calculation. Within the scope of the project, 37 soil and yield samples were taken from the institute plots (Figure 3) and 42 soil and yield samples were taken from farmer plots (Figure 4) in 2021. The plots and sampling design is shown below.

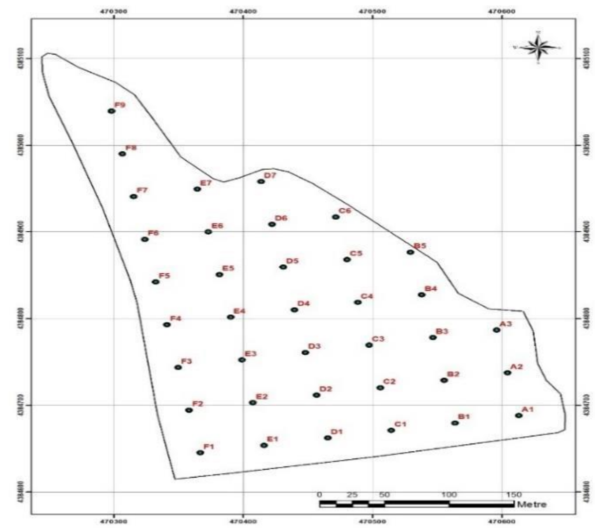


Figure 3. Institute parcel 2021 sampling points

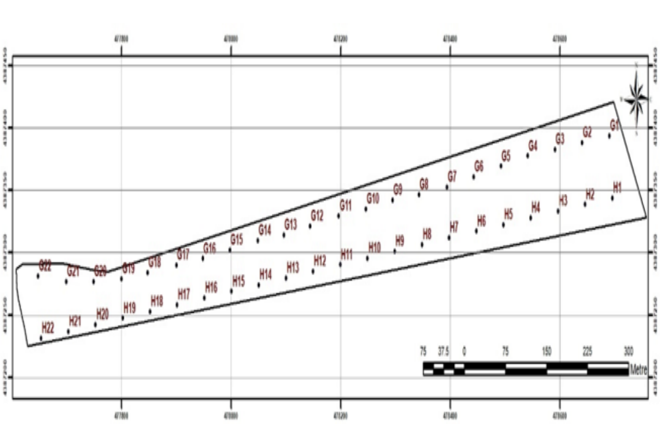


Figure 4. Farmer parcel sampling points in 2021

Modelling of Spatial Distribution of Crop Yield and Soil Characteristics

In the sampling arrangement, which was determined at an average of 50 m grid intervals in the study area, transect application was carried out in lengths varying between 25-28 m at certain locations where there are variability transitions on the naked satellite image of the land. A regular grid pattern covering 79 samples in total was formed and some soil analyses and yield values were determined at the sampling points. Within the scope of geostatistical modelling, firstly, the data structure of each parameter was examined and the parameters requiring data transformation were determined. In line with the descriptive statistics, if kurtosis and skewness are high, the data structure is transformed to transform the data structure into a normal distribution, and spatial distribution surfaces are determined over non-transformed values.

Creation of Fertilisation Zones for Variable Level Fertilisation

Yield, Normalized Difference Vegetation Index (NDVI), lime, water saturation, organic matter and EC layers were used to create fertilization zones. In determining the fertilization classes of these layers, expert opinions were used to determine the weight ratio for each layer. Analytic Hierarchy Process (AHP) method was used to determine the importance of the layers (Bouzekri and Benmessaoud 2015; Negaresh et al., 2016; Arami and Ownagh, 2017). The AHP is a powerful mathematically based multi-criteria decision-making technique that enables the organisation and analysis of complex decisions and ensures consistency in decision-making (Saaty, 1977). The scale of preference between 1-9 developed by Saaty (2008) was utilized in the weighting of the layers relative to each other (Table 1). Consistency Ratio is calculated to test the reliability of experts' decisions. In order to accept the weight value obtained for each indicator because of the evaluations made by decision makers with the AHP method, the consistency ratio must be less than 10% (Satty, 2008; Negaresh et al., 2016).

In the analytical hierarchy process, the objective of the problem is at the top of the hierarchy. In the lower step, there are main criteria related to the problem, and in the lower step of the main criteria, there are sub-criteria of the relevant criterion. At the bottom step of the hierarchy, there are options related to the problem. After the hierarchy table of the decision problem is formed, the next step is to determine the weights of the criteria with the same degree of importance relative to each other (Table 1).

For the plots, 4 different fertilization classes were formed. In the 1st group the most fertilizershould be used while in the 4th group the least fertilizer should be used. While forming the regions, it was thought that the highest fertilizer should be applied to the region with the highest yield, NDVI, water saturation and organic matter. Again, in the 1st group, the regions with the lowest lime and EC were included. In the region where the least fertilizer should be applied, the opposite values of the layer values were taken according to the 1st group. These values change gradually from group 1 to group 4 (Table 2).

Table 1. 1–9-point preference scale (Saaty, 2008)

Importance Rating	Definition	Description
1	Equally Important	Both factors are of equal importance
3	Moderately Important	One factor is slightly more important than the other
5	Strongly Important	One factor is strongly more important than the other
7	Very Strongly Important	One factor should be strongly preferred over another
9	Absolutely Important	One factor is very highly important relative to the other
2-4-6-8	Intermediate Values	Used when there are small differences between two factors

Results

Descriptive statistics

Descriptive statistics were made on soil analysis results and yield values obtained from four plots in two different years. In the evaluation, it was found that the yield variability was high in the parcels. It was determined that the CV value was 31.41 in the Institute 2021 parcel and 47.1 in the farmer 2021 parcel. In this case, it is seen that it is economical to carry out precision agriculture practices in these parcels.

Descriptive statistics of the Institute 2021 study parcel

Descriptive statistics of soil analysis results and yield values taken from 37 points in the institute parcel in 2021 are shown in Table 3. In the parcel, yield value (31.4%), water saturation (16.18%), lime (19.36%), available phosphorus (27.4%) and available potassium (22.2%) showed moderate variability, while EC (8.1), pH (0.69), Organic matter (12.4) showed low variability.

Farmer 2021 study plot descriptive statistics

Descriptive data of soil analysis results and yield values obtained from 42 points in farmer parcel in 2021 statistics are shown in Table 4. Yield (47.1%), EC (123.85 Ds/m), available phosphorus (66.3%) and available potassium (41.9%) were classified as high variability. pH, lime and organic matter were classified as low variability.

Table 2. Determination of the amount of fertiliser to be applied according to soil, yield and NDVI parameters

Parameter	Class Range	Fertilization Region Code
Yield (kg da^{-1})	400 <	1
	300 - 400	2
	200 – 300	3
	< 200	4
NDVI	0.65<	1
	0.55-0.65	2
	0.5-0.55	3
	<0.5	4
Lime (%)	<20	1
	20-25	2
	25-30	3
	30<	4
Water Saturation (%)	65<	1
	62-65	2
	58-62	3
	<58	4
Organic matter (%)	1.7 <	1
	1.6 -1.7	2
	1.5 -16	3
	<1.5	4
EC (dS m^{-1})	<0.92	1
	0.92-0.95	2
	0.95 -0.98	3
	0.98 <	4

Table 3. Descriptive statistics of the Institute 2021 study parcel

STAT n=37	Yield (kg da^{-1})	Water Saturation (%)	EC (dS m^{-1})	pH	Ca_2CO_3 (%)	Organic Matter (%)	Available (P_2O_5) (kg da^{-1})	Available (K_2O) (kg da^{-1})
Mean	295.71	0.65	0.94	7.75	24.28	1.63	3.66	141.81
Std. D	92.87	0.11	0.08	0.05	4.70	0.20	1.01	31.57
CV (%)	31.41	16.18	8.13	0.69	19.36	12.40	27.45	22.26
CV class	Medium	Medium	Low	Low	Medium	Low	Medium	Medium
Kurtosis	-0.07	-0.66	0.27	-0.83	0.24	-0.11	0.96	0.39
Skewness	-0.18	-0.16	-0.31	2.32	0.12	-1.02	1.85	-0.67
Variance	8625.22	0.01	0.01	0.00	22.09	0.04	1.01	996.64
Lowest	72.80	0.37	0.81	7.58	16.16	1.24	2.04	92.70
Highest	490.40	0.79	1.14	7.88	36.30	1.96	6.95	209.10

CV=%0-15 low, CV=%16-35 medium, CV= %> 36 high (Wilding 1985; Mulla ve McBratney 2000; Karabulut 2010).

Geostatistical model parameters

Geostatistical techniques were used to determine and map the variability of soil properties in the study area. Geostatistics is an applied science that quantifies the spatial structure and spatial dependence of a measured property and predicts the value of that property at unsampled points using the relationship obtained (Goovaerts, 1999; Mulla and McBratney, 2000). The percentage expression of the ratio of nugget semivariance to total semivariance is used to classify the areal dependence of soil variables. If this ratio is ≤25%, the variable is classified as strongly are dependent, if it is between 25% and 75%, it is classified as moderately areally dependent. If this ratio is more than 75%, the variable is classified as weakly spatially dependent (Cambardella et al., 1994; Trangmar et al., 1985). The ordinary kriging method was applied to produce the maps with a maximum of 12 neighbouring points. Maps belonging to the semivariogram models tested for each feature were produced, the error values of the maps were recorded, and these values were compared with each other in the selection of the correct model. These operations were performed with -ArcGIS 9.2. Geosatistical Extension‖ programme.

Institute 2021 Study Parcel Geostatistical Model Parameters

In 2021, Kriging interpolation method was used to make maps of the analysis results of 37 soil samples in the Institute parcel. The models and parameters in Table 5 were used to create Kriging interpolation maps. Available potassium (18.0%), pH (12.9%), available phosphorus (14.6%), water saturation (13.5%) and EC (24.8%) show strong spatial dependence with nugget/sill ratio. Yield (27.7%), lime (25.7%), organic matter (25.0%) shows moderate areal dependence (Table 5).

Table 4. Descriptive statistics of farmer 2021 study parcel.

STAT n=37	Yield (kg da^{-1})	Water Saturation (%)	EC (dS m^{-1})	pH	Ca_2CO_3 (%)	Organic Matter (%)	Available (P_2O_5) (kg da^{-1})	Available (K_2O) (kg da^{-1})
Mean	288.45	60.71	1.16	7.54	25.13	1.71	3.86	131.49
Std. D	135.86	4.63	1.44	1.20	5.20	0.26	2.56	55.11
CV (%)	47.10	7.62	123.85	15.95	20.68	15.00	66.30	41.91
CV class	High	Low	High	Low	Low	Low	High	High
Kurtosis	1.29	0.42	5.88	-6.29	1.13	0.10	1.56	0.40
Skewness	1.83	-0.64	36.37	40.37	2.15	0.59	2.30	-0.80
Variance	18457.16	21.43	2.07	1.45	27.00	0.07	6.56	3036.59
Lowest	63.60	54.00	0.53	0.00	16.50	1.05	0.59	56.60
Highest	706.80	72.00	9.96	8.23	43.05	2.26	11.52	244.10

CV=%0-15 düşük, CV=%16-35 orta, CV= %> 36 yüksek (Wilding 1985; Mulla ve McBratney 2000; Karabulut 2010)

Table 5. Geostatistical model parameters for Institute 2021 study parcel

Parameter	Transform	Model type	Major range	Lag size	Number of lags	Nugget (C0)	Partial sill (C0+C)	RMSE	ABD (%) (C0/C0+C)
				Ordinary Kriging					
Yield (kg da^{-1})	-	Exponential	499.7	41.64	12	3299.8	8813.2	86.06	27.2
Water Saturation (%)	-	Exponential	338.6	28.23	12	1.52	9.76	2.41	13.5
EC (dS m^{-1})	-	Exponential	504.5	42.04	12	0.041	0.124	0.079	24.8
pH	-	Exponential	973.9	49.9	12	0.0016	0.0108	0.05	12.9
Ca_2CO_3 (%)	log	Gausian	4426	14.1	12	0.205	0.593	3.43	25.7
Organic Matter* (%)	-	Spherical	4454	15.39	12	0.065	0.195	0.2	25.0
P_2O_5 (kg da^{-1})	log	Exponential	1370	14.27	12	0.047	0.275	1.05	14.6
K_2O (kg da^{-1})	-	Gausian	1072	14.1	12	0.041	0.187	27.04	18.0

Geostatistical Model Parameters for Farmer 2021 Study Parcel

In 2021, Kriging interpolation method was used to make maps of the analysis results of 42 soil samples in the farmer's parcel. The model and parameters in Table 6 were used to create Kriging interpolation maps. Before creating the maps, it was checked whether the data showed normal distribution by considering the kurtosis and skewness values. Transformation process was applied for EC and phosphorus data for the farmer plot. Available potassium (3.1%), yield (12.5%), water saturation (8.5%) and lime (16.0%) showed strong spatial dependence with nugget/sill ratio. pH (29.0%), available phosphorus (34.6%), EC (26.1%), organic matter (25.2%) showed moderate spatial dependence.

Maps of Yield and Some Soil Properties Obtained as a Result of Geostatistical Modelling

One of the most important steps in precision agriculture applications is to determine the variabilityof nutrients in the field. Since the 1970s, geostatistics has been used to determine the variability of nutrients in the landscape (Burgess and Webster, 1980). Accurate determination of the variability of a nutrient element in the field gives us information about how the agricultural land should be sampled for that feature. Accurate mapping of the nutrient content in the field is a necessary step in order to distribute the fertilizer to be applied to the land in an orderly manner. In this way, the farmer will benefit more from unnecessary and inadequate fertilizer use and will prevent environmental problems caused by excessive fertilizer use.

Geostatistical Maps of Some Soil Properties of Institute 2021 Study

The analysis results of 37 soil samples taken from the institute parcel and the maps obtained by kriging interpolation method of the yield values are shown in Figure 5. Yield values decrease from south-west to north-east of the parcel. Water saturation values show a similar distribution. EC is highest in the northwestern part of the plot. pH values are between 7.7 and 7.8 and the variability in the plot is very low. Lime content is relatively lower in the center and east of the parcel and decreases up to 15%. Organic matter decreases towards the north-west.

Table 6. Geostatistical model parameters for farmer 2021 study parcel

Ordinary Kriging									
Parameter	**Transform**	**Model type**	**Major range**	**Lag size**	**Number of lags**	**Nugget (C0)**	**Partial sill (C0+C)**	**RMSE**	**ABD (%) (C0/C0+C)**
Yield ($kg\ da^{-1}$)	-	Spherical	1544	10.68	12	6200	43500	96.6	12.5
Water Saturation (%)	-	Spherical	444	53.64	12	2.86	30.71	2.71	8.5
EC ($dS\ m^{-1}$)	log	Exponential	6150	46.13	10	0.06	0.17	1.39	26.1
pH	-	Spherical	141.6	17.7	12	0.0056	0.0137	0.17	29.0
Ca_2CO_3 (%)	-	Circular	188.1	23.5	12	4.4	23.17	3.64	16.0
Organic Matter* (%)	-	Gausian	69.67	8.7	12	0.014	0.0415	0.22	25.2
P_2O_5 ($kg\ da^{-1}$)	log	Exponential	333.4	25.92	13	0.18	0.34	2.49	34.6
K_2O ($kg\ da^{-1}$)	-	Spherical	586.1	54.1	12	154.3	4847.6	31.7	3.1

US<25% high, US=25-75% medium, US>75% low areal dependence (Trangmar 1985; Cambardella et al. 1994; Karabulut 2010)

Geostatistical Maps of Some Soil Properties of Farmer 2021 Study Parcel

The results of the analysis of 37 soil samples taken from the institute parcel and the maps obtained by kriging interpolation method of the yield values are shown in Figure 6. In the farmer's plot, the highest yield value (602 $kg\ da^{-1}$) is located on the west side and reaches the lowest values in the middle of the plot. Water saturation values are also the lowest in the middle of the plot. Lime content is highest in the central part of the plot. pH and EC also decrease in the central part of the plot. Potassium and phosphorus maps also show that potassium and phosphorus values decrease in the central part of the parcel.

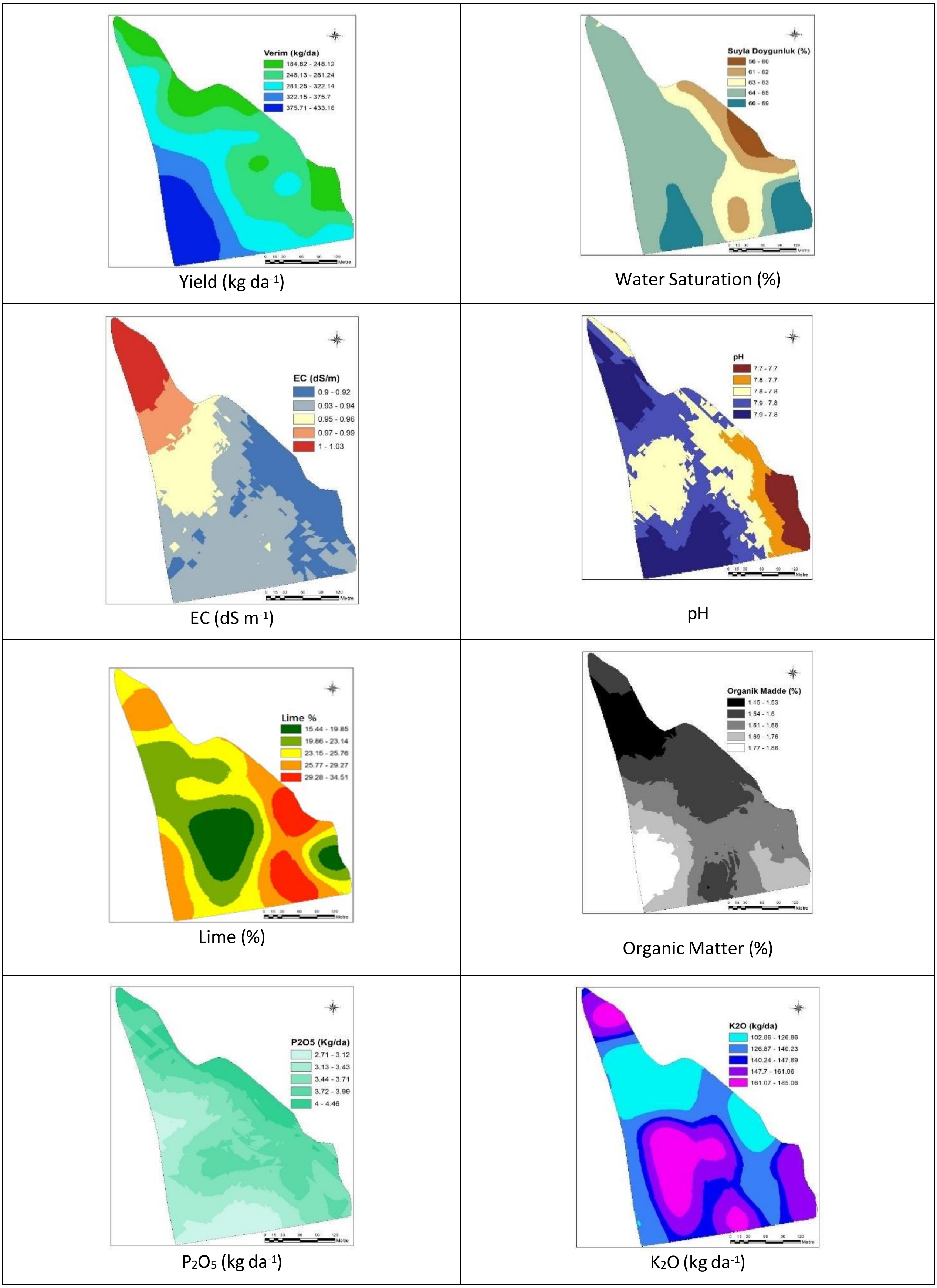
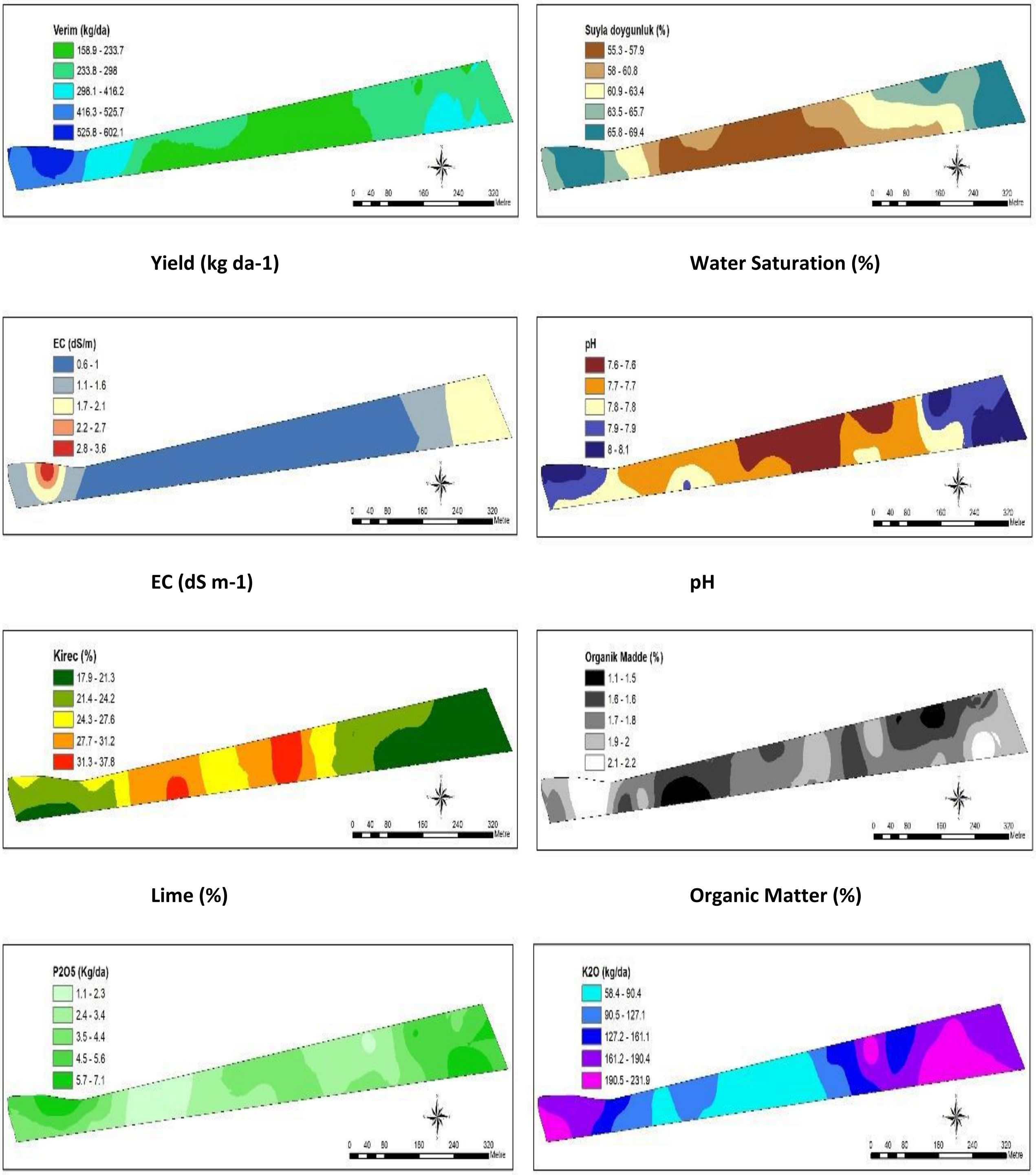


Figure 5. Yield, water saturation, Maps (EC, pH, Lime, OM, P_2O_5, K_2O maps of the Institute 2021 study plot



Yield (kg da-1) **Water Saturation (%)**

EC (dS m-1) **pH**

Lime (%) **Organic Matter (%)**

P_2O_5 (kg da^{-1}) **K_2O (kg da^{-1})**

Figure 6. Yield, water saturation, EC, pH, Lime, OM, P2O5, K2O maps of farmer 2021 study plot

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Statistical Relationships between Yield, NDVI and Soil Properties

The correlation table between the results of soil sample analysis, yield values and NDVI data obtained from the production field at the Central Research Institute of Field Crops Research and Application Farm in 2021 is given below. The correlation table between the analysis results of soil samples taken from the farmer's field in 2021, yield values and NDVI data is given below (Table 7). According to these results, a significant correlation was found between yield value and NDVI, water saturation, EC, organic matter and potassium at 0.01 level. Again, there was a relationship between yield and phosphorus at 0.05 level. There was a significant negative relationship between yield and lime at 0.05 level.

Table 7. The relationship between soil sample analysis results, yield values and NDVI data for farmer 2021 parcel

	Yield (kg da^{-1})	NDVI	Water Saturation (%)	EC (dS m^{-1})	pH	$CaCO_3$ (%)	Organic Matter (%)	P_2O_5 (kg da^{-1})	K_2O (kg da^{-1})
Yield (kg da^{-1})	1	.618**	.569**	.507**	.009	-.370*	.583**	.389*	.410**
NDVI	.618**	1	.634**	.311*	- .256	-.599**	.271	.254	.588**
Water Saturation (%)	.569**	.634**	1	.514**	- .030	-.518**	.427**	.494**	.681**
EC (dS m^{-1})	.507**	.311*	.514**	1	.040	-.162	.395**	.526**	.212
pH	.009	-.256	-.030	.040	1	.111	-.005	-.026	-.178
$CaCO_3$ (%)	-.370*	-.599**	-.518**	-.162	.111	1	-.245	-.154	-.693**
Organic Matter (%)	.583**	.271	.427**	.395**	-.005	-.245	1	.533**	.344*
P_2O_5 (kg da^{-1})	.389*	.254	.494**	.526**	-.026	-.154	.533**	1	.314*
K_2O (kg da^{-1})	.410**	.588**	.681**	.212	-.178	-.693**	.344*	.314*	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

One of the most widely used tools for monitoring green vegetation in remote sensing studies is the NDVI data. NDVI is calculated from the near infrared (NIR) and red (RED) light wavelength bands of satellite imagery. NDVI is considered as the main indicator of plant biomass and leaf area index value and is used for monitoring plant development and yield estimation during the growth period (Yıldız et al., 2012).

NDVI= (NIR – RED) / (NIR + RED)

Here, NIR represents the near infrared wavelength of the light spectrum (0.68 - 0.78 µm), RED represents the red region wavelength (0.61 - 0.68 µm) and NDVI (unitless) represents the vegetation index value (Tucker, 1979). In this study, NDVI data obtained from Sentinel 2 satellite images were utilized. Satellite images of May, when the biomass of wheat covering the field reaches the highest level, were downloaded for both years. NDVI data were truncated according to the classes of the plots where the study was conducted. Maps of yield values obtained from the field and NDVI data obtained from satellite images are shown in Figures 7, 8. In general, where yields are high, NDVI values are also high. This relationship is also seen in the correlation tables above. The most important reason that decreases the relationship between NDVI and yield is the presence of weeds in some parts of the plots. Where weeds are dense, wheat yield decreased while NDVI value was high. When the 2021 yield change depending on NDVI in the institute plots is analyzed; it is seen that the yield is high in the central and western parts where NDVI is higher, and in the eastern parts where the lakeshore strip is located, the yield decreases due to the decrease in NDVI (Figure 9). In 2021, when the NDVI change in the farmer plots was analyzed, it was observed that the yield was generally high in the western and eastern parts where NDVI was high (Figure 10).

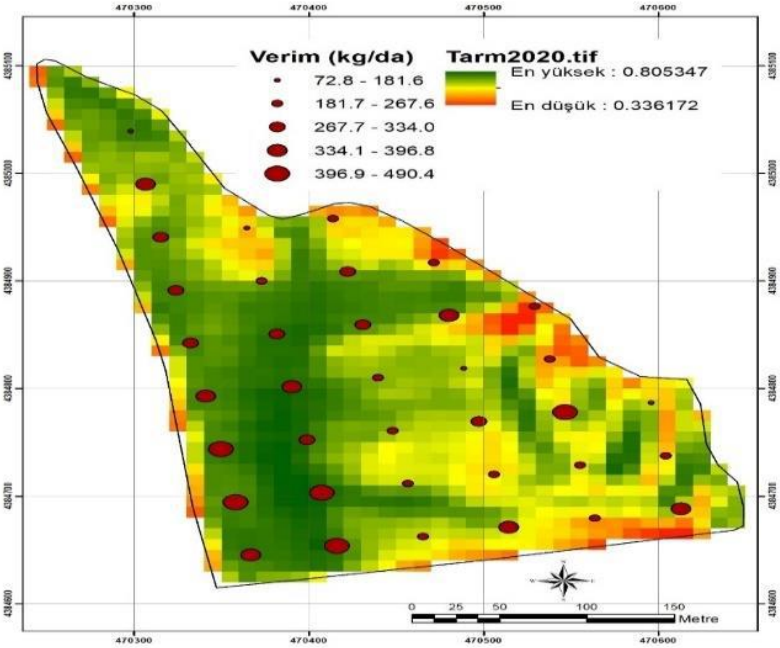

Figure 7. Institute 2021 parcel data- NDVI map Figure

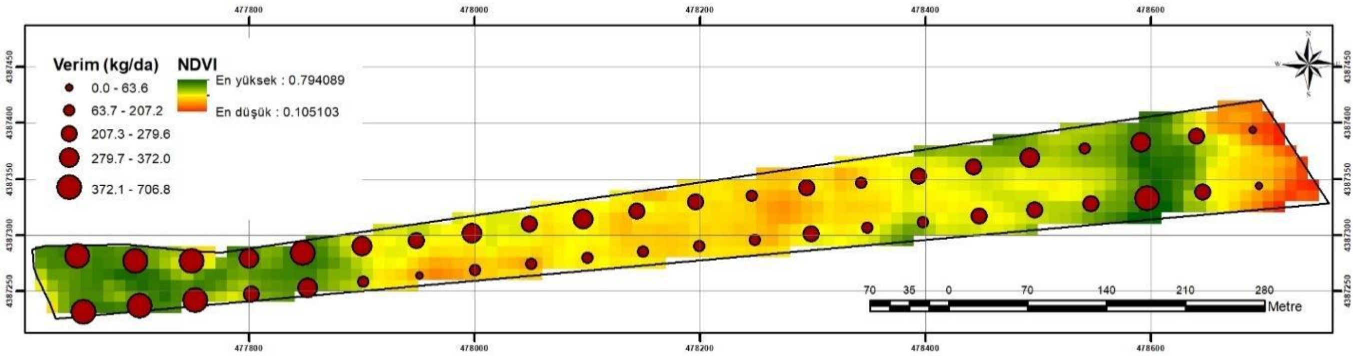

Figure 8. Farmer 2021 parcel yield - NDVI map

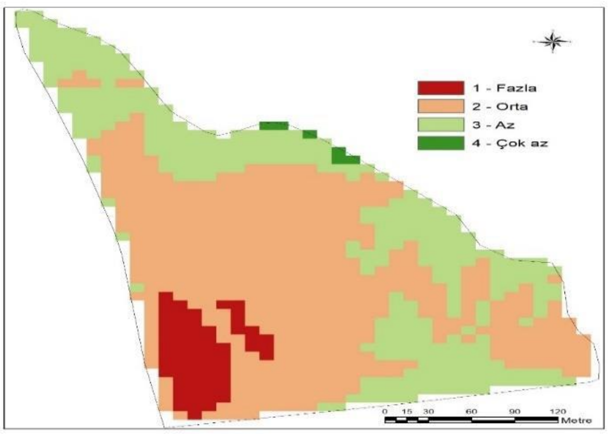

Figure 9. According to Institute parcels fertilization zones (2021)

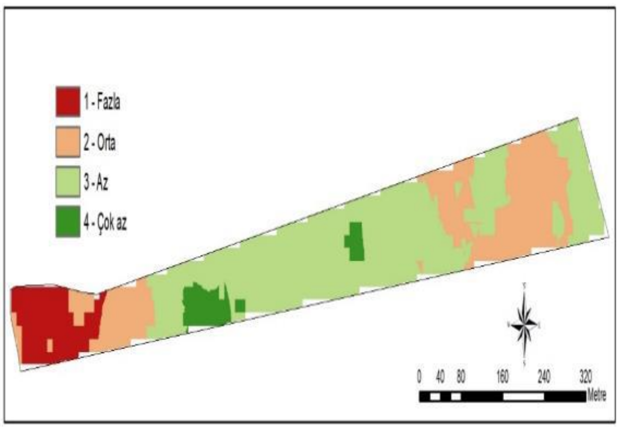

Figure 10. According to farmer parcels recommendation fertilization zones (2021)

Creation of Fertilization Zones for Variable Level Fertilization

In variable level fertilizer application, NDVI, yield, EC, water saturation, lime, pH, organic matter, available phosphorus and available potassium raster layers were created. By scoring, the weight ratios of the layers that will affect the fertilization zones, 4 fertilization classes were formed (Table 8).

The AHP method, which is used to solve a problem that depends on multiple criteria, was used to reveal the effect of layers on the formation of fertilization classes (Özcan et al., 2009). In order to determine the layer weights, the following table was created based on expert opinions (Table 9).

In order to calculate the Consistency Ratio, first the consistency indicator is calculated and then the Consistency Ratio is calculated.

$$Consistency\ Indicator(CI) = \frac{\lambda max\ n}{-1}$$

$$Consistency\ Ratio(CR) = \frac{Consistency\ Indicator(CI)}{Randomness\ Indicator}$$

Consistency Ratio (CR) was checked by pairwise comparison (Table 8). Wind and Saaty (1980) suggest an upper limit of 0.10 for the conservatism ratio. In this study, the consistency ratio was calculated as 0.58. As a result of the calculations made by AHP method, the weight values of the layers were found as lime 0.16, water saturation 0.11, organic matter 0.08, yield 0.36, NDVI 0.24 and EC 0.025, respectively. Because of the calculations made by AHP method, the weight values of the layers were found as lime 0.16, water saturation 0.11, organic matter 0.08, yield 0.36, NDVI 0.24 and EC 0.025, respectively. Layers were created using these weight values, merged using the "overlay" module in ArcGIS 9.2 program, and a map of fertilizer application zones was created. As can be seen in Figures 9 and 10, the maximum fertilizer application was recommended where indicated with 1 and the minimum fertilizer application was recommended where indicated with 4.

Relationships between fertilizer and soil parameters 2021 Institute and Farmer Parcel Evaluation

In 2021 when the data obtained from the sampling points of the Institute's land were evaluated, it was determined that the areas with low fertilization needs were the sampling points taken from the areas close to the pond. It was recommended that moderate fertilizer should be applied where the sampling points are located in the central parts and more fertilizer should be applied where the land falls to the south-west.

In 2021, it was revealed that the least fertilizer should be applied to the areas with the highest yield in the institute lands. There was a need to apply moderate fertilizer to the central parts of the plot and more fertilizer to the western and southern parts. These areas were observed to be the parcel sections falling on the northern parts of the lakeshore. Fertilizer should be applied at medium and higher levels where water saturation is high and at lower levels where water saturation is lowest. Medium and more fertilizer should be recommended where EC is low and less fertilizer should be recommended where EC is high. Medium and high levels of fertilizer should be applied to the northern and southern parts where pH is high, and low levels to the remaining parts. Less fertilizer should be applied to places with high lime content (29.28-34.51%), medium fertilizer should be applied to places with low lime content (15.44%-23.14%) and more fertilizer should be applied to places with medium lime content (23.15%-2-29.27%).

Table 8. Layers affecting the fertilization zones

	Yield (kg da^{-1})	NDVI	$CaCO_3$ (%)	Water saturation (%)	Organic matter (%)	EC (dS m^{-1})
Yield (kg da^{-1})	1	2	3	3	4	5
NDVI	1/2	1	2	3	3	4
$CaCO_3$ (%)	1/3	1/2	1	2	3	3
Water saturation (%)	1/3	1/3	1/2	1	2	3
Organic matter (%)	1/4	1/3	1/3	1/2	1	2
EC (dS m^{-1})	1/5	1/4	1/3	1/3	1/2	1

Table 9. Randomness Indicator

n	1	2	3	4	5	6	7	8	9	10
RG	0	0	0.58	0.9	1.12	1.,24	1.32	1.41	1.45	1.49

Fertilizer should be applied at a high level to places with high organic matter (1.77-1.86%), at a low level to places with low organic matter (1.45-1.60%), and at a medium level to places with medium organic matter (1.61-1.76%). Where phosphorus is high (3.72-4.6 kg da^{-1}), fertilizer should be applied at low and medium levels, where phosphorus is low (2.71-3.71), fertilizer should be applied at medium and high levels. Medium and high amounts of fertilizer should be applied to the middle of the plot where potassium is high (140.24-185.06 kg ha^{-1}) and low and very low amounts should be applied to the northern and eastern parts of the plot where potassium is low (102.86-140.23 kg ha^{-1}) (Figure 9).

In 2021, more fertilizer should be applied to the areas in the western parts of the parcel where the yield is high, and medium and low fertilizer should be applied to the other parts in the farmer lands. More and medium fertilizer should be applied to the western and eastern parts of the plot where water saturation is the highest and less fertilizer should be applied to the inner and central parts where saturation is low. More and medium fertilizer should be applied to the western and eastern parts where EC (dS m^{-1}) is high and dense, and less and very little fertilizer should be applied to the inner parts where EC is low. More fertilizer should be recommended for the western and eastern parts where pH is high and less and medium level fertilizer should be recommended for the inner parts where pH is low. Fertilizer should be added at low and very low levels to the inner and central parts of the parcel where lime is high, and at high and medium levels to the western and eastern parts where lime is low. Less fertilizer should be applied where organic matter is low and more fertilizer should be applied where it is high. More fertilizer should be applied to the northern and southern parts where phosphorus is high and less fertilizer should be applied to the central parts where phosphorus is low. It was recommended to apply more fertilizer to the southern and northern plots where potassium was high and less fertilizer to the central parts where it was low (Figure 10).

Conclusion

Precision agriculture is an agricultural system based on integrated knowledge and production to increase sustainable production, yield and profitability with minimum impact on the environment. In the world of environmental pollution and environment, precision agriculture is the most important phenomenon that supports environmentally friendly and sustainable agricultural production, especially it enables reduced input applications. For this reason, it is important to support research, publication and infrastructure studies on precision agriculture in all sensitive countries, including our country. Many studies to be carried out in this field within the scope of smart agriculture applications are waiting for the actors of the agricultural ecosystem**.** As a result of the developments in agricultural technologies, studies on the environmental impacts of agriculturblackal production inputs and the reduction of input costs are increasing day by day. These studies show an increasing intensity in the face of physical and geographical variability of agricultural lands, non-uniform soil, crop and environmental factors, environmental impact of inputs and increasing costs.

The most important objective of this study is to establish fertilisation zones for variable level fertiliser application, which is a subject of precision agriculture studies. The agricultural parcels where this study was carried out are heterogeneous in a way that can make a difference in economic terms. Fertilisation zones were created in the study, but fertilisation application could not be made. A variable level fertiliser machine is needed for fertilisation application.

In the study, yield maps were produced by interpolation by cutting the plants within one square metre from the determined sampling points. Although it was aimed to create yield maps with the integrated kit of the yield harvester at the beginning of the study, it could not be done due to impossibilities. In order to carry out such studies in our country, it is necessary to improve the tools and equipment used in precision agriculture.

Author Contribution

The authors declare the contributions to the manuscript such as the following sections: **TP:** Investigation, Review of relevant literatures, **HY:** Methodology, **MA**: Writing, review and editing, **MK:** Review of relevant literatures, **AKA:** Review of relevant literatures, **ÖU**: Review of relevant literatures, **AÇ**: Review of relevant literatures**, BA:** Review of relevant literatures, **UT:** Review of relevant literatures, **UY:** Review of relevant literatures

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might appear to influence the work reported in this paper.

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(TAGEM/TSKA/16/A13/P08/01/A.P.8") Using "Planning, Development and Dissemination of Precision Agriculture Practices in Crop Production HASTARIM Entegre Project (2018-2021).

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RESEARCH PAPER

Impact of climate change on olive suitability areas

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Abstract

The impact of climate change is being felt more and more by everyone. This effect is particularly observed in crop production in agricultural areas. The region where olive cultivation is most widespread and where the effects of climate change are felt the most is the Mediterranean region. Olive cultivation in Türkiye is mostly carried out in the Aegean and Mediterranean regions. This study aims to determine the changes in olive suitability areas according to climate change projections. Three different global climate models (HadGEM2-ES, GFDL-ESM2M and CSIRO) were used in the study. The average of each dataset was calculated according to bioclimatic parameters. WorldClim data was used as reference climate data. The studies were conducted with RCP 4.5 and RCP 8.5 projection data. Data for three different periods-the reference period, the years of 2050s and 2080s- were used. Maxent and BioClim species distribution models were used to produce suitability maps for olive. In the BioClim Model, in the RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050 periods, there was a decrease of 8%, 18.6%, 20% and 23.4% in very suitable areas compared to the reference period, respectively. In the Maxent model, there was a decrease of 59.3%, 40.6%, 69.7% and 5.8% in very suitable areas in RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050, respectively, compared to the reference period. The mean AUC value for olive was 0.874 with a standard deviation of 0.002. The AUC test value obtained shows that the model is sensitive and descriptive for olives.

Introduction

Almost all of the world's production of olives (Olea europaea L) is realized in Mediterranean countries. Spain, Italy, Greece, Türkiye, Syria, Morocco, Portugal, Egypt and Algeria are the leading countries where olive production is intense (Aygün et al., 2019). Olive cultivation is practiced in five regions in Türkiye: Aegean, Marmara, Mediterranean, Southeastern Anatolia and Black Sea Regions. Approximately 75% of olive groves are located in mountainous rural areas, and 85% are not irrigated (Aşık et al., 2011; Özaltaş et al., 2016).

The olive tree (Olea europaea L.) is an ancient traditional crop best suited to and best adapted for the Mediterranean-type climate of the Mediterranean region (Fraga et al., 2021). It has been reported that these regions where olives are grown will be most affected by climate change (Giorgi, 2006; Türkeş, 2008).

Temperatures in the Mediterranean region have risen faster than the global average in recent decades, and model projections agree that the future will involve warming and drying, with heat waves and droughts likely to increase. Environmental problems are

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exacerbated from a societal perspective, as the entire region is densely populated and many countries are expected to double their populations by the middle of the twenty-first century. The growing dependence on irrigation in the countries in these countries will increase their economic and social vulnerability due to reduced total future water availability and rapidly increasing competitive urban water demands (Lionello et al., 2014). Numerous studies have indicated that the climate of the Mediterranean region in the twenty-first century will experience a decrease in precipitation and widespread warming in most areas (Planton et al., 2012). This makes the Mediterranean a potentially vulnerable region to climate changes triggered by increasing concentrations of greenhouse gases (Lionello et al. 2006; Ulbrich et al., 2006).

Olive trees are known to be drought tolerant. However, excessive drought stress during growth periods causes negative effects on crop yield and development in olive trees (Varol and Ayaz, 2012). The areas where olive cultivation is practiced in Türkiye are semi-arid and arid regions. Especially in recent years, there has not been enough rainfall in these regions during the periods when olives need it. Olive cultivation will become more difficult in the coming years due to increasing warming, the increased frequency of extreme weather events such as droughts and heat waves.

This study aims to determine the changes in olive suitability areas, which are important for the economy of our country and which are thought to be most affected by climate change, according to current and future projections.

Materials and Methods

In this study, BioClim and Maxent models were used to identify suitable areas for olive cultivation. SDMs utilize the location information of the species and environmental factors as input data. As environmental variables, bioclimatic data covers the reference period, 2050s and 2080s, RCP 4.5 and RCP 8.5 projections.

The bioclimatic variables are calculated from monthly minimum and maximum temperatures and monthly precipitation data. These data are as follows (Anonymous, 2024): B01: Annual average temperature; B02: Average diurnal range (Monthly average (maximum- minimum temperature)); B03 Isothermality (P2/P7) (* 100) (Annual average temperature/monthly temperature range); B04: Seasonal temperature (standard deviation * 100); B05: Maximum temperature of the hottest month; B06: Minimum temperature of the coldest month; B07 Annual average temperature range; B08: Average temperature of the wettest quarter; B09 Average temperature of the driest quarter; B10: Average temperature of the warmest quarter; B11: Average temperature of the coldest quarter; B12: Average annual precipitation; B13: Precipitation of the wettest month; B14: Precipitation of the driest month; B15: Seasonal precipitation; B16: Precipitation of the wettest quarter; B17 Precipitation of the driest quarter; BI18 Precipitation of the warmest quarter; B19 Precipitation of the coldest quarter.

WorldClim data was used as reference data in this study. WorldClim has a spatial resolution of 30 seconds in scale. These data can be downloaded from http://www.wordclim.org for the whole world. These data are derived from climate data measured at meteorological stations around the world. It mostly covers the years between1950-2000 and consists of average monthly climate data.

Climate Requirements of Olives

The Mediterranean climate, which represents the transition between the arid climate of North Africa and the temperate rainy climate of Central Europe, has the most favorable climatic conditions for the cultivation of the olive tree, (Moriondo et. al., 2013). The olive tree typically cannot withstand temperatures below 8 °C for more than a week (Palliotti and Bongi, 1996). Very high summer temperatures (higher than 30 °C) can limit their yield performance. Generally, in regions where olive cultivation is practiced, annual average temperatures between 15-20°Care desired. The average temperature requirements of olive trees according to phenological periods are 5-10°C from shoot initiation to the next formation (February-March), 15-20°C during flowering (May-June), 20-25°C during fruit formation and growth (May-June), and 5°C from full ripening to the end of harvest (November-January) (Sevim et al., 2022).

Meeting the chilling requirement plays an important role in determining olive flowering (Ayerza, and Sibbett, 2001). Olive can only meet its chilling requirement at temperatures between 7ºC and -7ºC. In the period from January to April, chilling (at least 50-60 hours below 7.2 ºC and up to more than 1200 hours) is required (Ayaz and Varol, 2015).

Approximately 90% of olive trees grown in the Mediterranean Basin are primarily under rain-fed conditions (Gómez et.al. 2001). Although olive trees are drought-tolerant, their distribution in arid regions is limited by annual rainfall of less than 350 mm (Ponti et. al., 2014), and water availability remains important resource to increase final yields.

Climate Projection Data

Climate projection data is a set of data that shows how the climate of a given region is expected to change in the future. This data is typically produced by running climate models, which are computer programs that simulate the behavior of the atmosphere and oceans.

There are four different RCP scenarios (RCP 2.6, 4.5, 6, and 8.5). Projections 2.6, 4.5, 6 and 8.5 represent radiative forcing in units of watts per square meter. The relationship between the energy that reaches the Earth from the sun and the energy that is reflected back forms the global energy balance (Wayne, 2013). RCP 4.5 and

RCP 8.5 projection data for the 2050s and 2080s were used in the study. These data were downloaded from http://www.ccafs-climate.org/ as raster data. Each parameter has a spatial resolution of 30 seconds.

Global Climate Models (GCM)

Global climate models are simulations of the Earth's climate system using mathematical models. These models attempt to predict future climate changes by considering the interactions of Earth's atmosphere, ocean, glaciation and other factors. These models use computer-based data to generate possible future climate scenarios, taking into account the physical properties of the planet, the impact of human activities and other variables.

The average of three global climate models was calculated for each climate parameter in order to reduce the deviations caused by the differences in the methods and data used in the production of climate models. These models are HadGEM2-ES (Collins et al., 2008), GFDL-ESM2M (Dunne et al., 2012) and CSIRO (Whetton et al., 2015).

Species Distribution Models (SDM)

Species Distribution Models calculate the suitability of the species to grow by evaluating the relationship between the location of the species and environmental data (Guisan and Thuiller, 2005). In this study, the coordinates of the places where olives are grown were utilized from previous studies such as "Project for Determination of Potential Suitability Areas of Agricultural Ecological Regions and Crops in Türkiye (KAMAG1007_105G077)". Bioclimatic variables were used as environmental data. The most commonly used BioClim and Maxent models were used in the study to determine olive suitability areas.

BioClim establishes a set of thresholds covering the minimum and maximum value of each environmental variable and predicts that species can be found in all locations within these thresholds. To estimate the probability of a species' distribution in a given area, BioClim compares the values of environmental variables at the location of the species and summarizes climatic parameters within the known distribution range of the species, calculating their suitability for the species (Nix, 1986). The BioClim model can be run within the Diva-GIS software. Diva-GIS is an easy-to-use and free computer program (Hijmans et al., 2012).

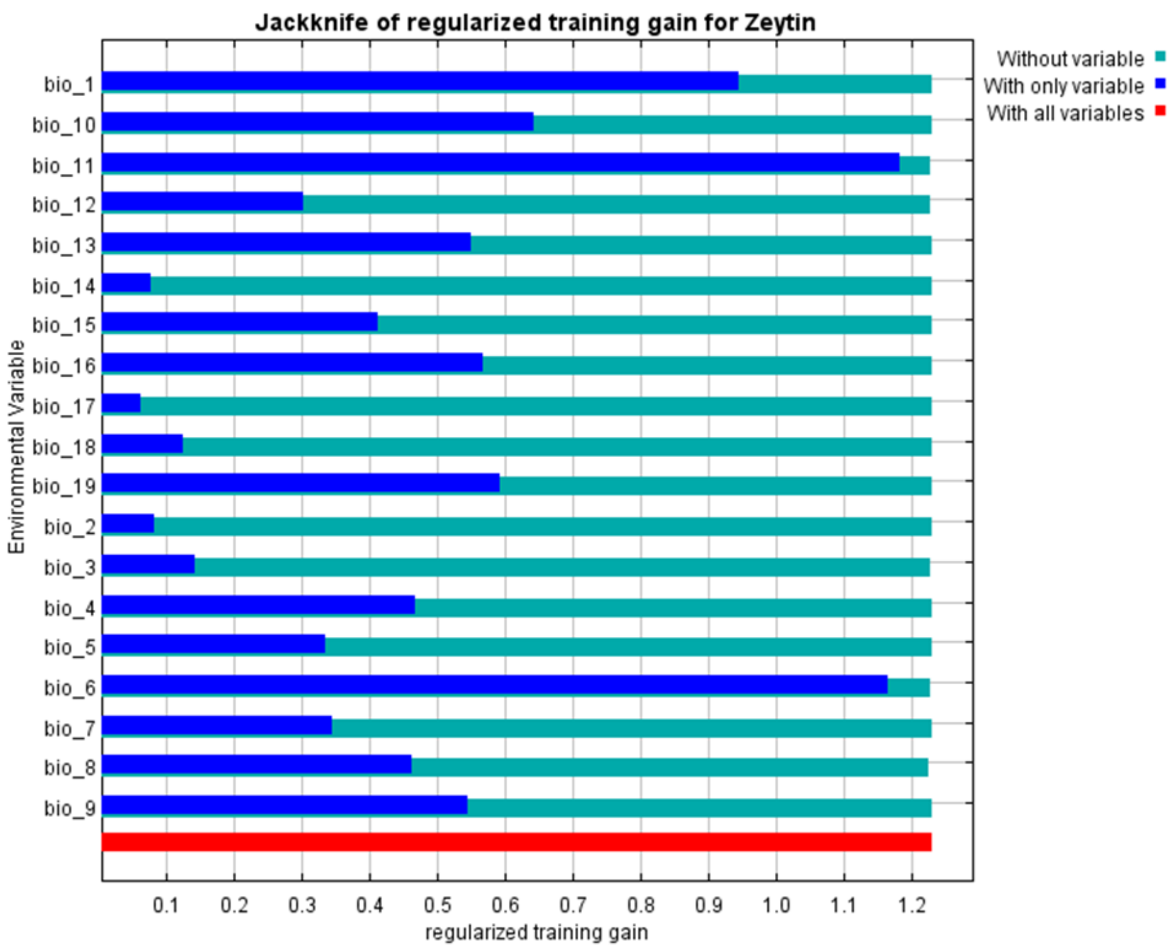

Figure 1. Jackknife test of variable importance

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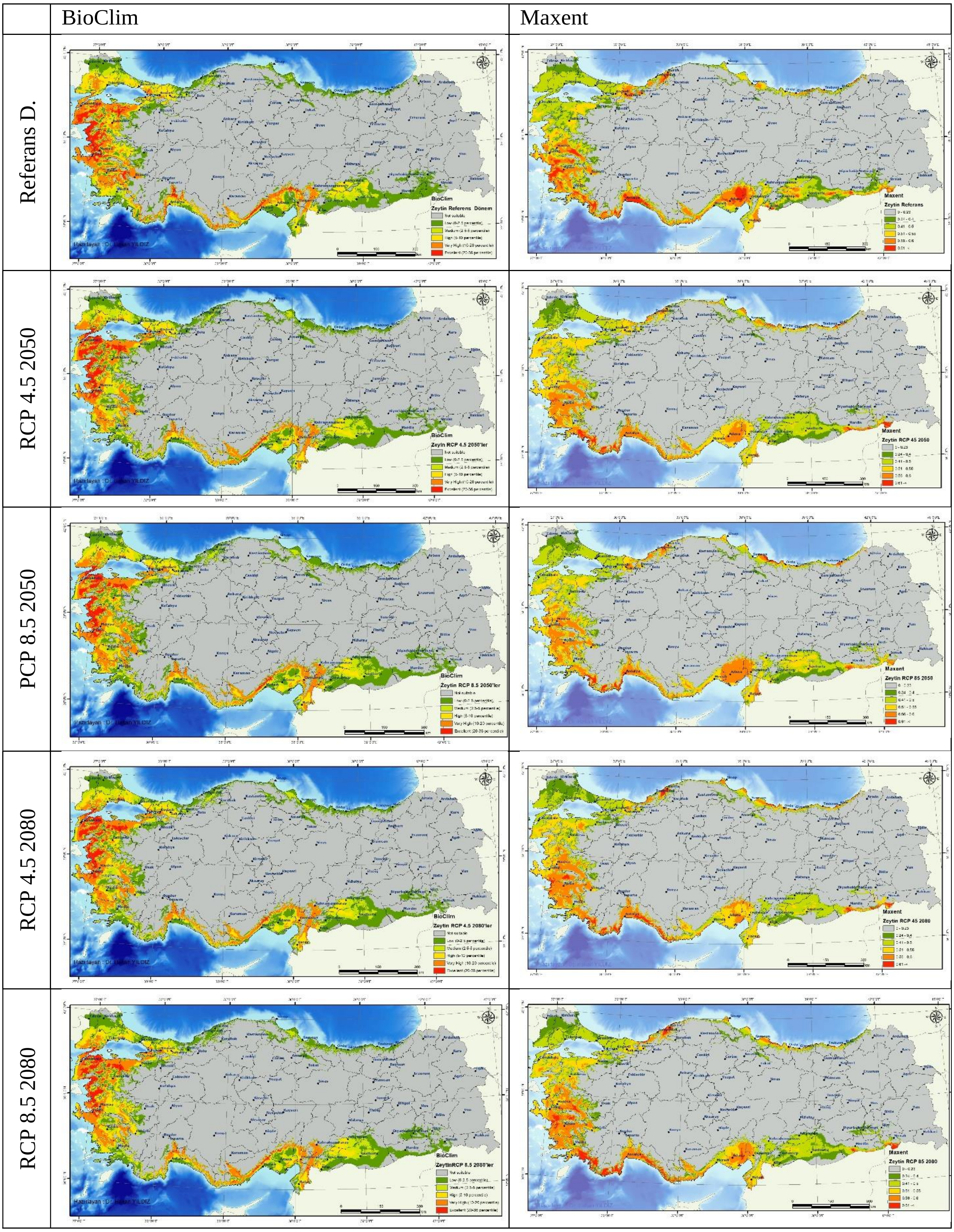

Figure 2. Olive suitability areas and changes according to projection

The Maxent Model works on the principle of maximum entropy (Phillips, 2006). Maxent is an algorithm that uses only available data and compares the location of a species with all available environments in the study area. It samples and identifies a large number of points throughout the study area. These points are called background points. For calculating the potential distribution of a species, Maxent calculates the probability of suitability of the total achievable environment for all points and the probability of suitability of the environment for the points present. The ratio between these two probability densities is calculated, and this gives the relative environmental suitability for the presence of a species in the study area.

The average of the five layers obtained by repeating the Jacknife probability 5 times is used in the study. The 'jackknife test' excludes one environmental variable in each iteration. In this way, the success of each variable in explaining the species distribution and the informative performance of the model result is ensured. Analysis was performed five times. Thus, all locality data were divided into 5 groups in each replicate and one group was accepted as 'training data'. By selecting a different group in each replicate, sampling bias was prevented (Baldwin, 2009).

Figure 1 shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is bio_11, which therefore appears to have the most useful information by itself. It is followed by bio_6 and bio_1 respectively. Values shown are averages over replicate runs.

Results and Discussion

In order to determine the areas suitable for olive cultivation, the coordinates of olive cultivated areas were obtained from previous studies. The obtained coordinates and environmental parameters were evaluated together in BioClim and Maxent species distribution models and suitable areas were calculated based on the reference period, future periods and climate projections. For the evaluation of the changes in the obtained maps together (Figure 2).

On the maps, the probability of areas suitable for olive cultivation increases towards dark red and decreases towards dark green. In the BioClim model, the most suitable areas are concentrated in the North Aegean region, while in the Maxent model, they are towards the South Aegean and Mediterranean regions (Figure 2). The raster suitability maps produced according to different projections and periods were classified according to the threshold values of the assumption in order to see the changes between each other and their areas were calculated.

In the BioClim model, in the RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050 periods, there was a decrease of 8%, 18.6%, 20% and 23.4% in very suitable areas compared to the reference period, respectively. Likewise, suitable areas decreased by 0.1% to 7.9%, while medium suitable areas decreased by 14.5% on average. The BioClim model showed an average increase of 19.3% in less suitable areas compared to the Maxent model. Not much change was observed in very little suitable areas and unsuitable areas (Figure 3).

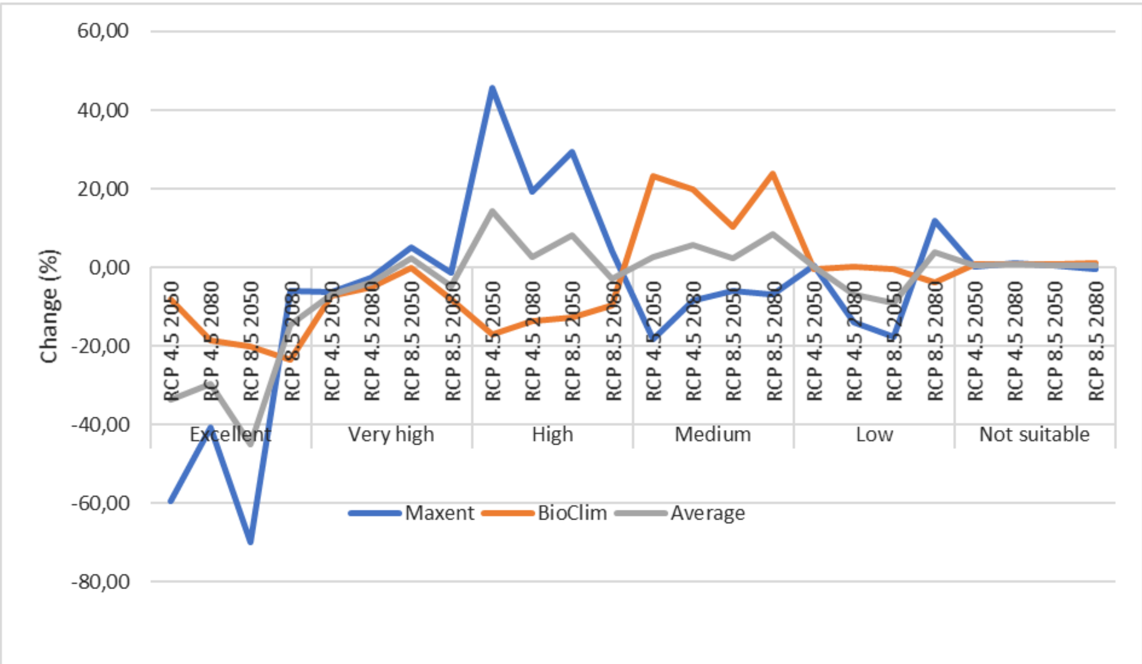

Figure 3. Changes in the % change of olive suitability areas of Maxent and BioClim models compared to the reference period.

Table 1. BioClim Model product and AUC values according to bioclimatic factors

bio1	bio2	bio3	bio4	bio_5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
0,87	0,39	0,63	0,26	0,72	0,90	0,28	0,67	0,79	0,81	0,90	0,73	0,81	0,43	0,72	0,80	0,46	0,38	0,81

In the Maxent model, there was a decrease of 59.3%, 40.6%, 69.7% and 5.8% in very suitable areas in RCP 4.5 2050, RCP 4.5 2080, RCP 8.5 2080 and RCP 8.5 2050, respectively, compared to the reference period. In suitable areas, there was an increase of 5% in RCP 8.5 2050, while there was a decrease of 6.2%, 2.4% and 1.3% in RCP 4.5 2050, RCP 4.5 2080 and RCP 8.5 2080, respectively. Medium suitable areas generally increased compared to the baseline period, reaching 45.7% at RCP 4.5 2050. Less suitable areas decreased by 9.8% on average. Very little suitable areas increased by 0.4% in RCP 4.5 2050 and 11.9% in RCP 8.5 2080, while decreasing by 13.7% in RCP 4.2080 and 17.7% in RCP 8.5 2050. There was no significant change in unsuitable areas. Similar to these results, Fraga et al. (2021) noted that the Mediterranean Basin is considered a climate change "hub" and that climate change could be particularly challenging for olive growers, with increasing evidence of significant climate change in the coming decades requiring adaptation measures to be taken.

To determine the performance of the model, the AUC (Area Under the ROC Curve) value obtained from Receiver Operating Characteristic (ROC) analysis was used (Wang et al., 2007a; Phillips, 2017). The AUC value obtained can be interpreted as the estimated probability of the presence of a randomly selected grid cell in a correctly tuned model. The AUC describes the success of the model with all possible thresholds. If this value is AUC > 0.5, it means that the model performs better than a random guess (Phillips and Elith, 2010). The closer the AUC test value is to 1, the better the separation, the more accurate and descriptive the model is (Phillips et al., 2006). AUC values are a numerical evaluation that shows the reliability and accuracy of the analysis result, and the reliability increases as it approaches 1 according to the evaluation between the numbers 0-1. AUC values above 0.90 indicate that the analysis gives a very good result.

In the BioClim model, AUC values are generated on a variable basis. Table 1 shows the AUC values of olives according to bioclimatic variables. The highest AUC values were obtained in bio_11, bio_1 and Bio_ 6.

In Maxent model the mean AUC value for olive was 0.874 with a standard deviation of 0.002. The AUC test value obtained shows that the model is sensitive and descriptive for olives (Figure 4).

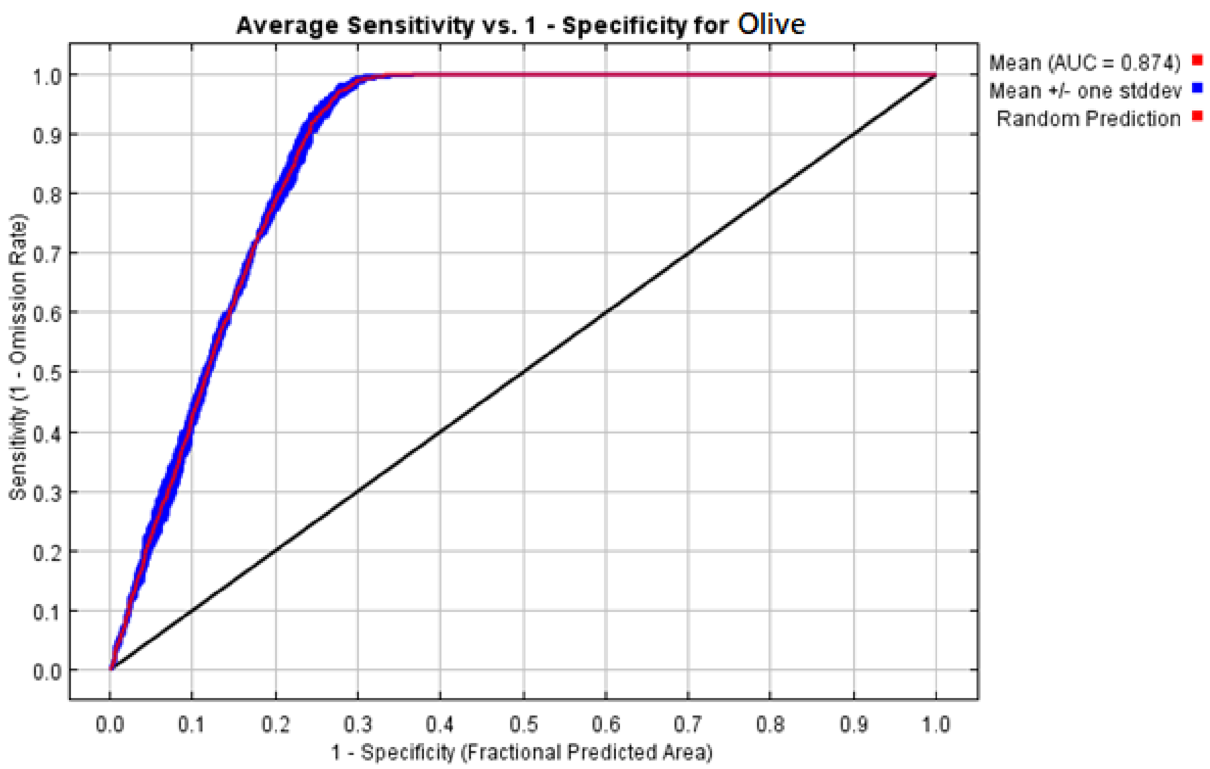

Figure 4. Olive sensitivity analysis graph according to the Maxent model

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Conclusions

Human impact on the natural environment is increasing due to increasing population, growth in human needs, the need for more energy, higher industrial production and the expansion of settlements. As a result of these effects, greenhouse gas emissions increase. Greenhouse gas emissions negatively affect the climate. One of the most important factors affecting agricultural production is climate. The agricultural sector is the most vulnerable to the impact of climate and is most affected by climate change. Adams et al. (1998) reported that climate change is expected to affect crop and livestock production, hydrological balances, input supplies and other components of agricultural systems. Therefore, it is critical to understand and predict the impacts of climate change on production and food supply.

In determining the impacts of climate change on agriculture, raster climate parameters produced by considering climate projections are used with SDM. SDMs calculate the probability of species distribution for present and future periods by modeling the relationships between species location and environmental factors. Miller (2010) states that the use of SDM to map and monitor animal and plant distributions is becoming increasingly important in the context of awareness of environmental change and its ecological consequences.

Species coordinate information, raster environmental factors and digital maps can be used in GIS (Geographic Information Systems) software to calculate maps of changes in species distributions. GIS software consolidates, making it easier to visualize and analyze species distributions over time. This information can be used to determine how species respond to habitat changes and species adaptation.

This study concludes that very suitable areas for olives are decreasing. It is understood from the results that the regions where plant species grow comfortably will turn into more stressful regions due to climate change. As temperatures rise and weather conditions change, it can lead to potentially more distressing conditions for the olive. To mitigate the impact of climate change on plant species, scientists and researchers need to work on strategies such as conservation efforts, breeding programs and sustainable land management practices. While climate change poses challenges, research and collective efforts are needed to understand and address its impacts on plant species.

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Author Contribution

HY: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Resources, Supervision, Visualization, Writing -original draft. **BS:** Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Resources, Visualization, Writing -review and editing. **DD:** Data Curation, Formal Analysis, Investigation, Methodology, Resources, Writing -review and editing. **MA:** Data Curation, Formal Analysis, Investigation, Methodology, Resources, Writing -review and editing

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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RESEARCH PAPER

Evaluation of some physical properties of cattle manure

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Natural angle of repose

Abstract

Cattle manure, which is obtained from cattles and is a biological material, goes through many basic processes such as collection from animal shelters, transportation, storage and distribution as animal fertilizer. The physical properties of manure are of great importance in the manure processes and the design of farm manure machinery. In this study, animal manure with and without bedding was considered as material. Manure bedding was selected from sawdust and straw. Among the characteristics effective in the mechanization of the applications; dry matter ratio, volumetric weight and natural repose angle were determined. As a result, it was determined that the type of bedding used, manure moisture content and repose angle were effective on the physical properties of manure. In addition, it was found that the dry matter ratio of farm manure changed with the type of bedding used and the dry matter content of straw-based manure was higher. When the volumetric weights were examined, the average volumetric weight of the manure without bedding was 857.48 kg/m³, the sawdust manure was 653.84 kg/m³ and the straw manure was 590.37 kg/m³. Moreover, it was obtained that the angle of repose values was lower in the bedding manure.

Introduction

Agricultural mechanization systems have processes that come into contact with biological materials and interact with natural environments such as soil and water during the agricultural process. Farm manure equipments are also a tool and machine that are considered in both animal husbandry mechanization and soil fertilization mechanization. On the other hand, the chemical, physical and mechanical properties of cattle manure must be known from the animal shelters to the collection, transportation and application to the soil as fertilizer when necessary. These properties are also the basic characteristics required for the design parameters of the mechanization tools that interact and the optimization of manure processes.

Farm manure used without considering its physical and chemical properties creates great pollution especially in air, water and soil resources. In order to make better use of manure, reduce pollution risks and apply a manure usage technique determined according to standards, it is essential to know its physical properties. In the process of collecting, storing and transporting manure from the barn, it is necessary that the facilities used be designed in accordance with the basic properties of the manure in order to preserve plant nutrients, obtain energy and prevent environmental pollution (Yaldız, 1996).

In the use and management of organic and animal fertilizers, the principles to be followed at institutional and legal levels have been determined in our country. The most prominent of these is the 'Implementation Directive on Organic Fertilizers and Soil Enrichers Produced from Animal By-Products and Their Derivative Products'. In this legislation, the necessary conditions for some physical and chemical properties addressed in the management and dispatch of animal fertilizers are given; pH, EC and moisture values are considered as important physical parameters (Anonymous, 2024a). In addition, there are many action plans and legislation adopted by the European Commission on this subject. The European Union Directive 91/676/EEC is used regarding the production methods of farm manure in enterprises in terms of nitrogen cycle, environmental factors and pollution. In the position paper related to this directive, the product and quality criteria of the animal manure to be obtained, storage and transportation conditions, biogas production, soil application and certification necessary legal and technical conditions are reported (Anonymous, 2024b).

In agricultural product processing, the volume and specific gravity values of materials are considered as important parameters (Mohsenin, 1980). In the transmission of agricultural materials, physical properties such as bulk density, angle of repose, moisture content and fluidity have been emphasized (Deligönül, 1995). It has been reported that dry matter content has gained importance in the transmission of farm manure and in processes such as phase separation. It has been indicated that these characteristics determine the rate at which these types of materials will be diluted and the capacity of the facility in the transmission of liquid menure with pumps (Safley and Fairbank 1983). Some physical characteristics of dairy and beef cow manure are given in Table 1 (Anonymous, 1985).

In the sources where the testing principles and methods of agricultural mechanization systems are determined to the design and test parameters for scrapers, manure separators, discharge pumps, farm manure mixers, biogas plants, liquid farm manure injection systems and farm manure spreaders used in cleaning liquid and solid feces in barns. Among the design and test parameters, the bulk density, dry matter ratio and repose angles of farm manure were considered (Anonymous, 2024c), (Onurbaş et al., 2011).

In a study conducted by Özbek et al.,(2015) the effects of mineral fertilizer and liquid barn manure applications with a grain sowing machine on grain yield were investigated. It was reported that the positive effects of liquid barn manure on soil structure and yield were due to the fact that it provided the most suitable environment for manure nutrients, soil compaction and aeration. The properties of the liquid barn manure used in the study were given as bulk density 1.04 ton/m^3, knematic viscosity 1.5 mm^2/s, pH 6.98 and EC value 17.1 ms/cm (Özbek et al., 2015).

Table 1. Manure production and characteristics of dairy and beef cows (Anonymous, 1985)

Animal type	Animal weight (kg)	Manure production (kg/day)	Bulk density of manure (kg/m³)	Total dry matter content (kg/day)
Dairy cow	113	9	994	1.2
	227	19		2.4
	454	37		4.7
	635	52		6.6
Beef cow	227	14	962	1.6
	340	20		2.4
	454	27		3.1
	567	34		3.9

Material and Methods

Material

The manure of dairy cows in the Cattle Farm of the Animal Husbandry Department of the Faculty of Agriculture of Ankara University was used as farm manure. The values of the bedding used and the total manure amounts taken from the animals are given in Table 2. The manure collected from 26 cows in 1 day was mixed with a shovel to ensure homogeneity. After that, it was freely filled into tin cans with dimensions of 24x24x35 cm.

Table 2. Total amounts of litter and manure used in the experiments

Material	Amount (kg)
Sawdust [1]	9.2
Straw [2]	6.2
Manure without bedding	66.1
Sawdust + Manure	60.3
Straw + Manure	72.5
Total manure	198.9

[1]: Poplar sawdust, [2]: Wheat-Barley straw

In order to determine the physical properties of the collected manure, 3 experimental groups (manure without bedding, manure with sawdust and manure with straw) were created. A total of 15 tin cans of material were prepared for the measurements, with 5 replications in each group. 10 kg of manure was filled into each can.

Method

One-day manure wastes of cattles were filled into tin cans on the same day. The aim here was to determine the physical properties of immature fresh manure. Considering the agricultural mechanization processes, the manure is in an immature fresh form during the stages of collection, loading, transportation, separation and transfer to storage areas of farm manure. The mature form of this animal waste is valid during its use in biogas and compost facilities and its use for fertilizer purposes. Therefore, the scope of this study was the physical measurements of the fresh manure form, which can be considered the first stage in farm manure mechanization.

In this study, some basic physical properties of farm manure, which has a rather heterogeneous structure, such as dry matter ratio, volumetric weight and natural repose angle (static and dynamic), were determined. In addition, the relationships between these properties were examined.

Determination of dry matter ratio

Each fertilizer sample was dried in a 105 °C oven for 24 hours. The amount of water in the material was taken as m_w and the amount of dry matter as m_{dm} ; the dry matter ratio (DMR) (%) was found with the following formula number 1 (Ayık 1984):

$$DMR = \left(\frac{m_{dm}}{m_w + m_{dm}}\right) * 100 \qquad (1)$$

Determination of volumetric weight

Volumetric weight (VW) (kg/m³) was found by dividing the weight values of manure placed in equal amounts (10 kg each) into each can by the volume they occupy place. The volume they occupy was calculated by measuring the distance between the upper surfaces of the manure freely poured into the can and the upper surface of the can.

Determination of natural repose angle

Natural repose angle is measured as static and dynamic repose angle:

1. *Finding the static repose angle:*

The fertilizers, which are emptied into a cylinder with a volume of five liters and open on both sides, are emptied on a horizontal plane in a free state without shaking, and a conical heap is formed. The height of this cone, (h), and the lateral side length of the cone (l) are taken as hypotenuse. The angle that the cone makes with the horizontal (βs) (°) is defined as the static angle of repose and is found from equation no. 2 (Deligönül 1995, Sağlam and Dikilitaş 1998, Tunalıgil and Eker 1985):

$$Sin\ \beta s = h / l \qquad (2)$$

2. *Finding the dynamic repose angle:*

The dynamic natural heaping angle (repose angle) is determined by taking into account the vibration movement of the horizontal plane in the vertical direction. With a theoretical approach, the dynamic repose angle (βd) is taken as 70% of the static repose angle (βs). Accordingly, the dynamic repose angle is calculated with equation number 3 (Mohsenin 1980):

$$\beta d = 0.7\ x\ \beta s \qquad (3)$$

Results and Discussion

Results Regarding the Dry Matter Ratio of Manure

The determined dry matter values are given collectively in Table 3. Accordingly, it was concluded that the dry matter ratio of farm manure changes with the type of bedding used. In the calculations, the dry matter content of straw manure was found to be higher; with an average value, it was determined that the non-bedding manure contained 16.79% dry matter, sawdust manure 20.03% dry matter and straw manure 20.42% dry matter. After all, the dry matter ratio of bedding manure is higher than that of non-bedding manure.

Results Regarding Volumetric Weight

The volume weight of the material is effected by the properties such as bedding material, density and humidity. Materials such as straw and straw absorb moisture well, but since they have a flexible structure, they create voids in the manure mass, causing the volumetric weight to decrease. The volumetric weight of 1 m³ of 80-87% moist and straw manure is 780-980 kg. As the bedding in its composition increases, the volume weight and humidity ratio decrease (Önal 1995).

Among the manure tested, the volume weights of the samples taken from sawdust manure were found to be lower (Table 4). The average volume weight of the manure without bedding was calculated as 857.26 kg/m³, sawdust manure as 590.51 kg/m³ and straw manure as 653.78 kg/m³. It was determined that the non-bedding manure occupies less volume than the bedding manure and is heavier.

The relationship between volumetric weight (VW) and dry matter ratio (DMR) was determined statistically through variance analysis; the analysis results are shown in equation number 4 and Table 5. According to the results obtained, the difference between dry matter ratio and volumetric weight was found to be statistically significan (p<0,05).

$$DMR = 28.7 - 0.0137 \, x \, VW$$

and; $r^2 = 79.4$ (4)

Results Regarding Natural Angles of Repose

Table 4. Volumetric weights of manure with and without bedding

Gübre	Sample no.	Manure volume (m³)	Volumetric weight (kg/m³)	Mean of volumetric weight (kg/m³)	S.D
Manure without bedding	M1	0.0119	840.34	857.47	15.31
	M2	0.0114	881.06		
	M3	0.0118	850.34		
	M4	0.0116	862.07		
	M5	0.0117	853.52		
Sawdust manure	SAW1	0.0169	592.07	597.67	18.56
	SAW2	0.0161	619.96		
	SAW3	0.0167	614.07		
	SAW4	0.0173	577.03		
	SAW5	0.0171	585.21		
Straw manure	ST1	0.0155	644.33	655.38	19.27
	ST2	0.0146	684.46		
	ST3	0.0158	632.91		
	ST4	0.0152	658.62		
	ST5	0.0152	656.60		

Table 5. Variance analysis of the relationship between dry matter ratio and volumetric weight

Variable	S.D	Sum of Squares	Mean of Squares	F Value	p (%)
Regression	1	37.057	37.057	50.11	0.00
Error	13	9.614	0.740		
Total	14	46.671			

The magnitude of repose angle depends on the frictional abilities of the material particles with each other, in other words, on their viscosity. As viscosity increases, this angle decreases and increases as friction increases (Deligönül 1995). Malgeryd and Wetterberg (1996), who grouped the relationship between the visually defined consistency of the manure and the angle of repose, divided the manure into 8 main groups: Normally dry manure (35^0-40^0), solid manure (30^0-35^0), slurry-like manure (20^0-30^0), compact manure (15^0-20^0), normal manure (10^0-15^0), mushy manure (5^0-10^0), pulp manure (around 5°) and liquid manure (<5^0).

The repose angle of the manures without bedding, with sawdust bedding and with straw bedding measured in the study are shown in Table 6. Accordingly, the angle of repose angle values of the non-bedding manure were found to be higher, while those of the bedding manures were found to be lower. Among the bedding manures, sawdust manure had a higher angle of repose. The average static angle of repose values were calculated as 23.04^0 for the non-bedding manure; 21.55^0 for the sawdust manure, and 18.54^0 for the straw manure.

As a result, many factors affect the physical properties of manure, such as the type of animal, its nutritional content, age and weight; the moisture

Table 6. Farm manure repose angle values

Material	**Sample no.**	**Static repose angle (β_s) (^{0})**	**Dynamic repose angle (β_d) (^{0})**	**Mean of dynamic repose angle (^{0})**	**S.D**
Manure without bedding	M1	23.22	16.25	16.13	1.66
	M2	26.25	18.38		
	M3	20.45	14.32		
	M4	24.22	16.95		
	M5	21.04	14.73		
Sawdust manure	SAW1	21.83	15.28	15.09	0.67
	SAW2	23.02	16.11		
	SAW3	20.45	14.32		
	SAW4	21.23	14.86		
	SAW5	21.23	14.86		
Straw manure	ST1	19.86	13.90	12.98	0.56
	ST2	17.73	12.41		
	ST3	18.11	12.68		
	ST4	18.50	12.95		
	ST5	18.50	12.95		

content of manure, its fluidity, the way it is collected and stored, the type of bedding used in animal shelters and even the ambient temperature. This study has concluded that the physical properties of bedding and non-bedding manure differ from each other and that the type of bedding used also affects these properties. As the results of this research, the physical properties of manure and their average values are given collectively in Table 7.

During the research process, due to the sawdust and straw in their content, it was easier to collect and transport bedding manures with high dry matter content. On the other hand, while the fluidity feature of bedding-free manure provides an advantage, it was observed that it caused stickiness and contamination on the surfaces it contacted; it also caused leakage and loss of liquid material. Although the average dry matter ratios of bedding manure are approximately close to each other; both the volumetric weight (590.37 kg/m³) and the angle of repose values (βs = 18.54^0 and βd = 12.98^0) of the straw-based manure were lower than those of the sawdust manure. The average volumetric weight of the sawdust manure was measured as 653.84 kg/m³; the static and dynamic repose angle values were βs = 21.55^0 and βd = 15.09^0, respectively.

In the literature research on farm manure, mostly studies were found examining the chemical properties of manure, nutritional values, yield effects on soil and

Table 7. Average values of some physical properties of cattle manure

Properties	**Manure without bedding**	**Sawdust manure**	**Straw manure**
Average dry matter content (%)	16.79	20.03	20.42
Volumetric weight (kg/m³)	857.48	653.84	590.37
Static repose angle (^{0})	23.04	21.55	18.54
Dynamic repose angle (^{0})	16.13	15.09	12.98

plants, pathogens and microbes in its content and environmental greenhouse gas effects. Academic studies conducted in terms of mechanization systems that come into contact and interact with biological materials are quite insufficient. Some of the existing designs were made based on the results of academic studies conducted abroad. For this reason, throughout the entire agricultural production chain, there is a need to evaluate the biological, chemical, rheological and physical properties of cattle manure in our country. Using this data, it will be easier to design, construct and disseminate national farm manure mechanization tools.

In addition to the limited production of agricultural tools and machines used in farm manure mechanization in our country; it is also possible to say that domestic manufacturers cannot develop designs that comply with the standards in this regard. When the number of agricultural machinery test reports, which can be considered as an indicator of production levels, is examined; in the 2018-2023 period, it was determined that among the total of 7845 test reports certified, there were only 83 test reports (approximately 1.1%) belonging to farm manure mechanization vehicles (Anonymous, 2023).

As a result, farm manure is a biological resource that we benefit from in a very wide area as a natural fertilizer source for soil and plant nutrition, and as a source of electricity and fuel energy for natural gas production. The manure management process of this biological resource is a critical activity for the economic and environmental sustainability of large cattle farms. In a study, it was reported that the annual approximate cost per cow in the most common usage methods for manure was 306 US dollars. While manure provides valuable nutrients for soil health and plant production in one aspect, it also causes high costs and greenhouse gas emissions in the collection, transportation and manure processing. It has been stated that there is a great need for the development and implementation of mechanization technologies that optimize all these benefits and minimize their harmful effects (Wang, H. et al., 2019).

In continuation of this research, it is suggested that the effects of animal biology, chemical composition of manure, environmental parameters such as temperature and humidity on the physical properties of manure should be investigated in a well-rounded approach. The physical, rheological, chemical and technical design parameters to be determined in this field will form the basis for the establishment of valid legislation and standards for farm manure properties in manure management processes in our country.

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Ethical statement

Any animal experiment was made in this research.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might appear to influence the work reported in this paper.

Author Contributions

ZDA: Data Curation, Formal Analysis, Investigation, Methodology, Supervision, Resources, Writing -original draft, Writing -review and editin. **ÖA**: Conceptualization, Decision to publish, References, Computer hardware and applications, Gramarly Editing.

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REVİEW PAPER

Soil and water management perspectives for tropical and dryland areas of Africa

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Abstract

Soil and water are two natural resources that deliver various functional services to humanity. Advanced soil and water management is highly needed in the tropics. This revision focused on soil and water management issues in the tropics, soil and water management linkages to major soil functional groups (soil health, soil quality, soil fertility, water quality, and soil function), soil quality management and rehabilitation, and soil quality assessment. This study revealed that soil indictors are physical, chemical and biological, reflecting a better understanding of the major soil functional groups in an integrated soil water assessment for better soil and water management in the tropics. Regular checks and balances of comprehensive soil water management can lead to reduced soil erosion, increased water use efficiency, enhanced soil nutritional content, improved infiltration and water holding capacity, minimized runoff and surface soil leaching of pesticides and inorganic chemicals to groundwater reservoirs, increased decomposition and soil organic matter, enhanced soil biodiversity, and increased plant health and food security. To make this viable, an integrated assessment of soil water indicators and the application of sustainable soil water management approaches are needed. Regular checks and balances of the current status of soil and water quality and soil fertility must be given permanent priority.

Introduction

Soil is a natural resource that delivers various functional services to humans (Brady and Weil, 2021). In tropical and dryland areas of Africa, soil plays a key role for the management of various organic and inorganic materials and the overall systems that take place between the atmosphere (air), lithosphere (rocks), biosphere (organisms), and hydrosphere (water) (Harnung and Johnson, 2012). This role is not only limited to food production and diverse natural materials for industrial development (USDA-NRCS, 2008). However, there is increasing acknowledgement that the array of other soil functional services (nutrients supply, erosion control, soil quality etc), which are much broader, received significant recognition from various soil conservation and soil management studies (Andrews et al., 2004; Bekunda et al. 1997; Delgado et al., 2020; Greenland and Lal, 1977; Jat et al., 2023; Karlen and Peterson, 2014; Pierce, 2020; Ssali et al., 1986). Tropical and dryland areas of Africa were regarded as important regions that require regular adaptation of soil and water management (Usman and Kundiri, 2016). This is essential because of the fact that the extent of soil degradation in these areas was reported to have accounted for 37.5% severity, 4.3% moderate, 26.3% high, and 27.9% very high (FAO, 2005). Human population is increasing on daily basis and the need for food security is become a challenge (Global Center on Adaptation, 2021). Soil erosion and nutrient depletion are soaring due to deforestation, poor vegetation cover, poverty and climate change impact (Usman et al., 2024). The use of pesticide chemicals had caused many contamination problems, which also affected soil and water quality in tropical and dryland areas of Africa (Usman, 2024). These problems, demanded for advanced innovative development to help ensure adequate soil and water management in the regions (Hillel, 2008; Lal, 2010). This innovative development is driven by a comprehensive soil conservation package that provides integrated support for ensuring functional services within the soil medium (Kassam et al., 2014). This puts soil and water management at the core of food security and sustainable livelihoods in the tropics (Panda, 2022). Soil and water are vital resources that deserve to be managed in all aspects, including the environment, agriculture, and human development (Huang et al., 2022). Managing soils and water to address food security issues of the twenty-first century in Africa has been emphasized and is necessary for all aspects of agronomic and environmental resource production (Lal, 2010).

In African tropical and dryland regions, soil and water qualities have been affected, and their potential support for ensuring food security and economic development has declined (Hartemink, 2006a). According to Delgado et al. (2020), soil and water management practices, which have evolved since the 1930s and have been adopted around the world, are responsible for the decline in soil and water quality in tropical and dryland environments. Many studies have focused on providing better protection to soil and water in the tropics (Oweis and Hachum, 2003; Usman, 2013; Piemontese et al., 2020; Wolka et al., 2018). Similarly, issues of high concern regarding the management and rehabilitation of soil and water resources have been covered in many recent studies (Jamaluddin et al., 2013; Mahajan et al., 2021; Panda, 2022). Therefore, this paper addressed soil and water management issues for the benefits of tropical and dryland soils in Africa. This paper also covered other important issues related to soil quality assessment and soil rehabilitation, the design and management of soil and water conservation practices, the management of nutrient-depleted lands, soil water management approaches, and water quality improvement.

Theory of tropical and dryland soils

Tropical and dryland areas of Africa are home to over 525 million people (Global Center on Adaptation, 2021). However, when considering soil and water management in the tropical and dryland areas of Africa, it is important to embrace the theory of tropical and dryland soils and how they related well to soil and water management. The tropics are low-latitude sand seas (ergs) that are considered extensive areas of sand dunes located in the tropical and subtropical deserts of the world (Lancaster, 2013). Tropical regions receive greater amounts of solar radiation per unit area and per unit time than any other ecosystem in the world, primarily due to a spherical Earth, where light energy at higher latitudes intercepts the Earth's surface at a more oblique angle (Roxburgh and Noble, 2001). The landscapes in regions with a tropical climate are typically characterized by deeper regolith mantles influenced by the local rock composition and structure couple with chemical and physical properties of the weathering products, the type and intensity of the soil processes, and the slope gradient (Dewitte et al., 2022). The farming systems are characterized by an enormous disparity of crops such as cereals (millet, sorghum, rice, and maize), groundnuts, soybeans, sugarcane, cocoa, coffee, oils, and fruit, which are cultivated year-round, providing the possibility for several harvests per year (Pröhl et al., 2012). The tropics contain dryland areas, which play key roles in global agricultural production (Peterson 2018). However, the name dryland was derived from the word arid, which implies prolonged dryness (Usman, 2017). According to the United Nations Convention to Combat Desertification (UNCCD, 1997), drylands include arid, semiarid, and sub-humid zones, which cover approximately 54 million km^2 of the globe. The African drylands occupied significant part of this land area, estimated to be around 19.6 million km^2 (46% approximately) (FAO, 2019). This means that drylands cover approximately 41% of the terrestrial land and are inhabited by more than one-third of the global population, supporting mainly grazing, crop cultivation, and natural forests (Biazin et al., 2023).

Drylands are characterized by a scarcity of water, which affects both natural and managed ecosystems and constrains the production of livestock as well as crops, wood, forage and other plants, affecting the delivery of environmental services (FAO, 2023). They have been shaped by a combination of low precipitation, droughts and heat waves, as well as human activities such as fire use, livestock grazing, the collection of wood and non-wood forest products, and soil cultivation (FAO, 2023). These areas are home to more than a quarter of the global population, including millions of biological organisms and their biodiversity, with over a quarter of the world's forest area accommodating various farming activities called 'dryland farming' (Usman, 2017; FAO, 2023). Dryland farming is a crop production practice in dryland areas with less than 500 mm of annual precipitation and where the annual potential water evaporation exceeds the annual precipitation (Peterson, 2018). Tropical and dryland soils tend to be vulnerable to wind and water erosion, subject to intensive mineral weathering, and have low fertility due to the low content of organic matter in the topsoil (FAO, 2023). They are also susceptible to various degradation processes (e.g. physical, chemical) as a result of frequent deforestation, desertification, lack of awareness, and poverty (Usman et al., 2017).

Soil and water management issues in the tropics and drylands of Africa

Tropical and dryland soils are vulnerable to soil erosion and nutrient depletion (FAO, 2023). They are also susceptible to various types of soil degradation (Usman et al., 2017). The impact of climate change has amplified the soil degradation to cause more damage to soil quality and soil fertility in the tropics and drylands (Usman et al., 2024). Soil cover and surface land quality are affected by combination of environmental problems (Mishra et al., 2021). These problems include mismanagement of vegetation and forest areas, untenable land use practices, deforestation and poverty (Usman et al., 2016). These problems are factors, which put the tropical and dryland soils at a very high risk of soil erosion and nutrient depletion (Abbass et al., 2020). The nature and condition of the soil are deteriorating (Ezeh et al., 2024). This soil condition in the tropics and drylands of Africa, require appropriate adaptation of soil management to ensure food security for the growing population (FAO, 2019; Yang et al., 2020). Soil and water management is a general concept applicable to the administration and supervision of soil water resources for optimum utilization for agricultural and non-agricultural purposes. Loiskand and Kammerer (2014) defined soil water management as active involvement in controlling soil water content at an optimal state for all given purposes, including environmental needs. This optimal state involves regular cooperation between competing uses and needs to account for the long-term sustainability of soil water management (Loiskand and Kammerer, 2014). This is important for all the terrestrial ecosystems of the biosphere and hydrosphere (Gusev and Novak, 2007). This means that the management of these spheres depends on how well the soil (pedosphere) is conserved to improve soil properties and biodiversity. This entails the importance of soil water management in agriculture (Usman, 2013). According to the Soil Science Society of America (SSSA), soil management is defined as the sum of all tillage and planting operations; cropping practices; fertilizer, lime, herbicide and insecticide applications, and irrigation and other treatments conducted on or applied to a soil for the production of plants (Karlen and Peterson, 2014). Baumhardt and Blanco-Canqui (2014) noted that farming operations and management strategies could be conducted with the goal of controlling soil erosion by preventing or limiting soil particle detachment and transport in water or air. The Twelve definitions describe the position of a comprehensive soil and water conservation package that always focuses on ensuring better soil and water quality. However, regarding 'soil quality', Doran and Parkin (1994) noted that it is the capacity of a soil to function within the ecosystem and land use boundaries to sustain productivity, maintain environmental quality, and promote plant and animal health. In 'water quality', Delgado et al., (2020) reported that advances during the last 75 years in soil and water conservation have contributed greatly to protecting water quality and purity for both soil and human health. This confirmed that the concept of soil and water management broadly includes all activities at the local level that maintain or enhance the productive capacity of the land in areas affected by or prone to degradation (WOCAT, 1992). Lal (1990) suggested that these soil and water management activities are based on six attributes: (a) soil erosion control, (b) improvement in soil organic matter content, (c) enhancement of soil structure, (e) increase in soil biodiversity, (f) strengthening of nutrient cycling mechanisms, and (g) increase in soil resilience.

Soil and water conservation has recently celebrated 75 years in history (Delgado et al., 2020). In a detailed compilation, Delgado and his co-workers deliberated on key issues of soil and water management throughout these 75 years of history. They covered the major subject areas that summarized what soil conservation/management entails and the kinds of contributions it has made to global agricultural and environmental development. They discussed the concept of soil and water conservation with respect to the evolution of soil and water conservation, the importance of social and economic factors influencing conservation practices, managing water quantity and quality challenges, advancing assessments of erosion and implementation of soil and water conservation on the ground, climate change creating new challenges in soil and water conservation for food security, the future of conservation, mitigating soil losses to adapt to climate change will provide billions of dollars in returns, forecasting future conservation developments, and a bright future in soil and water conservation (Delgado et al., 2020). According to their overall observations, conservation management of soil and water needs to be at the center of land use to develop sustainable agricultural systems for food security, and history shows that when we develop or implement new agricultural advances, we must conserve soil, water, and biological resources to provide solutions for wise land use (Delgado et al., 2020). In this regard, there is a need for cooperation and reassurance from all bodies involved, and this entails that local, national and international institutions at high levels, such as the UN and its research bodies (FAO, IPCC, IAEA), must come together to help achieve the combined goals of the UN: ending poverty, achieving zero hunger, clean water, and sanitation (Lal, 2020). Therefore, as stressed by Delgado et al. (2020), all working in the conservation of soil and water needs to be mindful to develop systems to maximize productivity and reduce environmental impacts in the future. This advice may help achieve the UN goals and will ensure best management practices in conserving and managing soil water for food security, environmental health and human development in the tropics (Jat et al., 2023).

Developments and challenges

There have been significant developments in technological efforts to conserve soil and water in tropical dryland's areas (Gusev and Novak, 2007; Loiskand and Kammerer, 2014; Oweis and Hachum, 2003; Piemontese et al., 2020; Wolka et al., 2018). The tropical dryland and farming systems require a sustainable framework for long-term management of soil and water (Usman, 2017). Improving the water use efficiency of dryland soils is also needed on a regular basis (Stroosnijder et al., 2012) and has been regarded as an important way to conserve water (Delgado et al., 2020). Advancements have been made in many areas of agriculture and non- agriculture to enhance the potential of soil and water through conservation techniques (Pierce, 2020). Numerous studies have contributed to these advancements. These studies include those of Pratt (1994) and Singletary (2009) on water banking (a new tool for water management), Wolka et al. (2018) on the effects of soil and water conservation techniques on crop yield, runoff and soil loss in sub-Saharan Africa, Biazin et al. (2023) on tackling crop water stress through soil water conservation by the integrated use of organic and chemical fertilizers, Morton (2020) on agricultural management and conservation of soil and water resources, and Mahajan et al. (2021) on soil and water conservation measures to improve soil carbon sequestration and soil quality. These various landscape-scale soil and water management studies are vital for soil security and for meeting increasing global demands for food, feed, fiber, and fuel (Karlen and Peterson, 2014).

The most important developments and influences determining soil and water management in tropical and dryland soils for the last 50 years have been covered by many researchers. One of the outstanding works in this field has been the effort of Pierce (2020), an author of 'Advances in Soil and Water Conservation'. His work addressed many fundamental aspects of the subject matter and addressed the technological developments of erosion processes, methods for their control, policy and social forces shaping the research agenda, and future directions. It covered key issues related to the processes of soil and water degradation, control practices and soil quality enhancement, conservation tillage, the connection between soil and water conservation and sustainable agriculture, and the effects of technology and social influences on soil and water conservation in the tropics (Pierce, 2020). Global achievements in soil and water conservation are another effort made by Kassam et al. (2014). This work provided an overview of achievements in soil and water conservation on agricultural lands through experience derived from the adoption and spread of conservation agriculture globally. They considered conservation agriculture an agro-ecological approach to sustainable production intensification that involved the application of locally formulated practices, mainly permanent no or minimum mechanical soil disturbance (direct seeding through mulch into no-till soils), maintenance of soil shields with crop residues and green manure crops (legumes), and diversified cropping systems involving annuals and perennials in rotations (sequences and associations) (Kassam et al., 2014). According to these authors, conservation agriculture offers environmental, economic and social advantages that are not fully possible with tillage-based production systems, as well as improved productivity and resilience and improved ecosystem services while minimizing the excessive us of agrochemicals, energy and heavy machinery (Kassam et al., 2014).

However, complex challenges are facing tropical and dryland areas in Africa, which are more or less due to natural and anthropogenic causes affecting sustainable livelihoods, environmental resources and social resilience (Biazin et al., 2023). These challenges have put the management of soil and water into many setbacks (Bouwer, 2000; Karlen and Peterson, 2014). Factors that threaten the conservation and management of tropical and dryland soils and water resources include persistent drought and water scarcity exacerbated by climate variability and changes, land and soil degradation caused by deforestation, loss of organic matter resulting from inappropriate land use practices and mismanagement, and soil erosion caused by the combined effect of water and wind, which is worsened by the degree of desertification (Ahmed Hayat et al., 2022; Bouwer, 2000; Davies et al., 2015; James and Reynolds, 2007; Marques et al., 2016). Poverty, deforestation and multiple land use practices are also challenges facing better adaptation of soil and water management in the tropics, and these have been understood long time ago in the history of soil and water conservation (Greenland and Lal, 1977).Lack of adequate soil testing prior to the application of a given conservation approach (Usman et al., 2024), soil and land pressures (Toor et al., 2021), are also factors diminishing the effectiveness of soil water management in the tropics.

Approaches for soil and water management

Many approaches have been used for soil and water management in the tropics (Doran and Michael, 2000; Jatet et al., 2023; Lal 2000, 2017). These approaches are considered physical, chemical and biological soil water management approaches (Usman, 2013). These soil and water management approaches are noted to improve soil texture, soil structure, soil colour, soil organic matter, macro (e.g. nitrogen, potassium, phosphorus) and micro nutrients (e.g. calcium, magnesium, sodium), and overall soil biota and biodiversity (Bünemann et al., 2018). In this regards, the physical soil conservation was regarded as methods, which involved the management of soil aggregate and soil structural formation; the biological approaches enhance the activities of soil biota and biodiversity; and chemical approaches improve the nutrient content of the soil (Usman, 2013). Physical conservation methods such as manure application, surface terracing, planting shelter belts, contour farming, land ridges, planting cover crops, and mixed cropping, are noted to have significant positive impact on soil properties and food security (Usman, 2017; Lal, 2017). The biological conservation methods build soil organic matter, enhances aggregate stability, binds soil particles, and control soil erosion (Simpson and Simpson, 2017). The chemical conservation methods include the addition of organic and inorganic fertilizers, which are considered useful for soil fertility development and soil carbon cycling. The broad benefits of these conservation methods have been described as reservoir for soil productivity, plant growth, animal production, and sustainable human development.

Largely, there have been significant advancements regarding the physical, biological and chemical conservation approaches in recent years (Delgado et al., 2020). The primary aim of these set of approaches, was to improve and enhance soil quality, soil fertility and control soil erosion and nutrient depletion in the tropics and drylands (Toor et al., 2021). The global achievements with respect to soil and water management are much clear (Kassam et al., 2014). Practically, approaches such as manure application, surface soil terracing, planting shelter belts, afforestation, forest regeneration, drainages, contour farming, surface land ridges, planting cover crops, and inter- and mixed cropping systems are considered vital for soil and water management in the tropics (Usman, 2017). Hence, the adaptation of these conservation techniques in the tropics and drylands of Africa would help protect soil against erosion, increase food security and enhance agricultural economic development. For example, Huang et al. (2022) studied soil and water management techniques in the tropics and subtropics and reported that compared with other land use practices, contour tillage, ridge farming, and reduced tillage are more efficient at reducing soil loss. Their observation noted that the combination of engineering and biological techniques could be more effective in reducing soil and water loss than the application of contour tillage, ridge farming, or reduced tillage (Huang et al., 2022). Liang et al. (2023) studied four different tillage practices (longitudinal ridge tillage, cross ridge tillage, flat tillage and hole sowing) under three rainfall intensities (60–90–120 mm/h). Their study investigated the changes in hydrodynamic parameters and the response of purple soil slope cropland to erosion to reveal the soil and water conservation benefits of different tillage practices. They reported that longitudinal ridge tillage is more effective than flat tillage, followed by hole-sowing and cross-ridge tillage (Liang et al., 2023).

Advances in soil and water management are crucial for farming systems, and they can be used to improve soil quality and soil fertility in tropics and drylands of Africa. These farming systems are driving economy in many rural areas of Africa and have been challenged by complex environmental problems, such as erosion, fertility decline, and water scarcity (Usman, 2013). Measures to control erosion, enhance soil fertility, and ensure sustainable water use efficiency through soil water management are needed. Hillel (2008) noted that improving soil quality and water-use efficiency in dryland farming requires measures to increase infiltration, avoid runoff losses, and prevent water losses. He highlighted that the following measures should be taken into consideration (Hillel, 2008):

a. Well-structured, aggregated, and porous topsoil was maintained to prevent surface crusting and runoff.

b. The mulch cover (consisting of plant residues) on the soil surface was maintained to shield the soil surface against the aggregate-slaking impact of striking raindrops.

c. Terracing and contouring cultivation to facilitate absorption of rainfall and prevention of runoff.

d. Avoiding mechanical compaction to enhance infiltration and prevent runoff losses.

e. The land was periodically frozen to collect rainwater, which was then stored in the soil for subsequent use.

f. Minimizing surface evaporation of soil moisture by judicious tillage and especially by means of maintaining a diffusion barrier over the surface, e.g., straw mulch.

g. Transpiring weeds were removed to prevent losses of moisture from deeper layers of the soil.

h. Enhancing the rainwater supply by means of water harvesting, i.e., inducing and collecting runoff from adjacent slopes and directing it to planted plots.

i. Suitable (drought resistant, high yield potential) crops should be planted and fertilized at optimal times to ensure germination and establishment and to utilize seasonal rains.

j. Cultured shelter belts or mechanical barriers (perpendicular to the prevailing wind direction) should be established to reduce the wind speed and thereby lower potential evaporation

Soil and water management: its linkage to major soil functional groups

The linkage between soil and water management and other soil functional groups is a relationship that needs to be understood in the 21st century. This relationship is used in this review to explain how connected soil water management is to overall soil rehabilitation and soil functionalities for achieving food security and sustainable livelihoods for the growing population in Africa. Tropical and dryland soils of Africa offered various functions to human development and environmental habitat (Usman and Kundiri, 2016). Management of these soils requires detail understanding of the major soil functional groups, which determine the practical aspects of soil and water management in the tropics (Hillel, 2008). By definition however, soil functional group is a compound term used in this assessment to include combined soil water management terms, such as soil health, soil quality, soil fertility, soil productivity, water quality, and water efficiency. Therefore, to illustrate how advanced soil and water management has played a key role in African agricultural and environmental development over the last 75 years, since the emergence of soil conservation in history (Delgado et al., 2020), some important soil functional groups are taken into consideration. This is in addition to their relevance to crop production, biodiversity, and animal health for diverse economic development in Africa. In this overview, soil functional groups can be defined as the potential stage of soil that receives adequate management to support biological living organisms, manage water efficiency, control soil erosion, enhance nutrient cycles, and ensure food security over a long period of time without decline. The concept described in this definition captured the concept and future prospects of soil health, soil quality, soil fertility and water resources quality (Lehmann et al., 2020).

Soil health is considered the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans" (USDA-NRCS, 2023). This definition emphasizes that soil and water management are necessary because of their vital role in sustaining plants, animals, and humans (Mandal et al., 2016). This suggests that soil health is a system within the soil medium that can be enhanced only through proper soil water management. Karlen (2020) provided an advanced review on the subject of 'the evolution, assessment of, and future opportunities of soil health' and proposed that a focus on soil health evolution and management will improve the potential of soil water management and can help ensure sustainable soil fertility and food security, among other many benefits, such as animal feeds, fiber, and fuel. This entails that soil health and conservation management are interlinked and must be observed on a regular basis. The benefits of this conservation relationship include long-term soil health sustainability for managing the biotic component of soil quality (Doran and Michael, 2000; Lehmann et al., 2020; Toor et al., 2021), which is vital for enhancing dryland and humid tropical soils (Greenland and Lal, 1977). It is also vital for agricultural conservation and for restoring soil health and mitigating climate change (Jat et al., 2023). The management of soil health can be achieved through integrated ideas where various conservation approaches work together to achieve better soil health (Manter et al., 2018). However, Costantini and Mocali (2022) highlighted that soil health has different connotations depending on the environmental setting, as it may show high spatial and temporal dynamics. Their study noted that surface and deep soil genetic horizons are important interpretative tools for soil functional biodiversity and soil health (Costantini and Mocali, 2022). This emphasizes that assessments of soil health should focus on different components of soil, more importantly, on the basis of soil genetic horizons. This is because the loss of natural self-organization of these genetic horizons affects soil health stability (Usman, 2013).

Soil quality is a concept that directly affects the persistence of soil and water management. Doran and Parkin (1994) defined soil quality as "the capacity of a soil to function, within the ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health". This definition suggests that any technique that can be used for soil water management has one or more supportive benefits to the empowerment of soil quality to function within the ecosystem to sustain crop production and animal health. For example, organic matter binds soil particles, improves aggregate stability, and enhances water efficiency (Reeves, 1997). The functional services offered to the soil by organic matter rehabilitate the potential quality of the soil and enhance the long-term benefits to soil quality and the soil organic matter relationship (Martins et al., 2017; Simpson and Simpson, 2017). The benefits also extended to the proper management of soil erosion, particularly in the tropics (Lal, 1990).

A fertile soil has been described as a soil with a good supply of available plant nutrients to be drawn upon by plants throughout their growth period (Usman, 2017). This suggests that for a soil to be considered a 'fertile soil', it must contain all the essential nutrients, which could be available in both equitable amounts and an appropriate balance, such that plants can take them from mineral and organic soil fractions and must be located in a climatic zone that provides sufficient moisture, light and heat for the needs of the plants under consideration (Miller, 1963). Soil fertility decline is perceived to be widespread in the upland soils of the tropics, particularly in sub-Saharan Africa (Hartemink, 2006). The pedogenesis processes affecting soil fertility decline include the addition, removal, transformation, and transfer of materials within the soil medium (Brady and Weil, 2021). Addition (input) includes dust, nutrients in the rainfall, symbiotic and asymbiotic N-fixation, and sedimentation; removal (output) includes leaching, volatilization, denitrification, and erosion; transformation includes mineral weathering, organic matter, decomposition, and fixation; and transfer includes deep uptake, clay eluviation and illuviation (Hartemink, 2006a). Many studies have noted that a decrease in soil fertility is a serious threat to soil and water resources in the tropics (Ahn, 1970; Hartemink, 2002, 2003, 2006b; Huang et al., 2022; Kant and Ghosh, 2012; Lucas, 1982; Sanchez, 1976; Ssali et al., 1986). Assessing the soil fertility status of degraded soils will help establish advanced soil and water management practices in the tropics (Bekunda et al., 1997; Jamaluddin et al., 2013).

Water resources are dynamically influenced by several factors, such as human, agricultural, and industrial activities (Quevedo-Castro et al., 2019). The water quality needs to be standardized for a variety of functions. According to the US-EPA (2023), water quality standards consist of three core components, which include the designated uses of a water body, criteria to protect designated uses, and anti-degradation requirements to protect existing uses and high-quality/high-value waters. The designated uses are protection and propagation of water animals and wildlife, recreation, public drinking water supply, and agricultural, industrial, navigational and other purposes, whereas the criteria can be numeric (e.g., the maximum pollutant concentration levels permitted in a water body) or narrative (e.g., a criterion that describes the desired conditions of a water body being "free from" certain negative conditions); additionally, the anti-degradation maintains the chemical, physical and biological integrity of the Nation's waters, and the requirements provide a framework for maintaining and protecting water quality that has already been achieved (US-EPA, 2023). Soil and water contaminated with various concentrated agrochemicals, upstream mining leachates, herbicides, domestic waste, and wastewater discharge may easily lose quality because of toxicity and pollutants (Usman, 2020; Wu et al., 2018). Ensuring water quality is important in the propagation of healthy soil and crop production because when water is in defaces, the biological component of the soil is affected (Usman et al., 2017). Advanced soil and water management approaches are highly needed to maintain the quality of water resources and to ensure sufficient availability of water for crop utilization (Lal, 2010; Panda, 2022). The monitoring and evaluation of water quality involving an analysis of various parameters that indicate the degree of alteration of natural variations in a water body is an advanced method useful for improving the standard quality of water (Quevedo-Castro et al., 2019). Wu et al. (2018) noted that advancement in the analysis of water quality could be achieved through various indicators that quantify water quality for a given use from a complete viewpoint. Reducing the use of highly toxic chemicals such as pesticides and chemical fertilizers can help improve water quality and maintain soil health (Hillel, 2008; Manteret al., 2018).

From the general overviews of how advanced soil and water management support real soil functional services, which are useful for ensuring better soil health, soil quality, soil fertility, water quality and water efficiency, one may agree that efforts to maintain this relationship must be permanent. This will help achieve the United Nations Sustainable Development Goal (SDG 15) for ensuring food security. According to Panda (2022), this SDG 15 for sustainable food security can be assured by plot-wise management of soil erosion, soil organic matter, soil moisture, irrigation water, soil salinity, mulching application, growing cover crops and agro-forestry on each farm. Panda (2022) is optimistic that such combined farming practices would result in regional as well as country-level cumulative impacts on good outcomes of application of plot-level soil water conservation measures in each crop field.

Soil quality assessment and rehabilitation

The concept of soil quality and its assessment and rehabilitation is sometimes challenging for a few reasons, including the issues of climate change and its adaptation policies, the diversification of soil types and definitions of surrounding biomass resources, the complex environmental and social issues in the tropics and drylands, and the limited scientific understanding of the best integrated principles with regard to soil and water management in the tropics and subtropics (Bünemann et al., 2018). This challenge is a knowledge gap (Hopmans et al., 2021) and needs urgent explanation to help address advanced measures and approaches that are more convenient for achieving better soil quality assessment and rehabilitation globally. This would help researchers discover some of the methods of soil quality assessment and management and then describe promising principles for receiving a sustainable set of management packages that could target soil erosion problems, soil quality decline, soil fertility depletion, and water use inefficiency in drylands and other tropical soils (Andrews et al., 2004). If this discovery becomes achievable, it could provide a promising guide towards understanding soil quality as the capacity of a soil to function within the ecosystem and land use boundaries to sustain productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994).

At this junction, soil quality assessments must focus on monitoring and observing soil properties and components via both visual and quantitative concepts (Ball et al., 2007; Basak et al., 2016; Doran and Parkin, 1996; Jamaluddin et al., 2013; Martins et al., 2017; Seybold et al., 1998). This will entail more about what Karlen et al. (1997) considered to be soil quality, which is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. The capacity of a specific soil to function reflects overall inherent soil properties and dynamic characteristics, which change very little or not at all with management as a result of single or combined effects of soil-forming factors (climate, topography, parent material, biota, and time) (USDA-NRCS, 2008). Andrews et al. (2002) described this function as a medium that affects overall environmental quality. They understood that the major components of soil quality are physical, chemical and biological factors, which have effects on soil, air and water, reflecting directly on agricultural sustainability in terms of economic and social viability. In this regard, soil can provide physical stability and support for plants and serves as an engineering medium to support buildings and roads, human development and economic empowerment (USDA-NRCS, 2008).

Soil indicators: a key component of soil quality assessment

To this end, soil quality assessment considers various soil indicators, some of which are physical or biological, while others are chemical or ecological (Table I). These soil quality indicators under assessment are dynamic soil properties used to describe soil function and can help determine how well a soil performs essential ecological functional services to humans and the environment (USDA-NRCS, 2008). Although it is often difficult to clearly separate soil functions into chemical, physical, and biological processes because of the dynamic, interactive nature of these processes (Schoenholtza et al., 2000), some methods of visual soil structure examination enable varieties of semi-quantitative information for use in soil biological and chemical quality assessments, monitoring and modelling soil functions in a quick and reliable manner (Mueller et al., 2010).

The soil quality indicators can be considered basic soil indicators or hazard soil indicators (Figure 1), depending on the nature or objectives of the assessment. However, Nortcliff (2002) suggested that the overall selection of soil indicator attributes, as outlined in Table 1, should be based on key issues relevant to soil and water management, particularly in the tropics. These relevant issues are land use, soil function, measurement reliability, spatial and temporal variability, sensitivity to changes in soil management, comparability in monitoring systems, and skills required for use and interpretation (Nortcliff, 2002). Regardless of the indicator(s) used for a given soil quality assessment, they end in describing soil function and its potential to sustain biological diversity and productivity in soil; regulate and screen water and solute flow; filter and buffer; and degrade, immobilize, and detoxify organic and inorganic materials, including industrial and municipal byproducts and atmospheric deposition (Seybold et al., 1998). They also help to store and cycle nutrients and carbon within the Earth's biosphere, provide physical stability and support for plants, and protect archaeological treasures associated with human habitation (Seybold et al., 1998).

Advanced developments have been made in recent years in soil–water quality assessment and rehabilitation using various soil quality indicators for a particular purpose, although challenges and opportunities are noted (Schoenholtza et al., 2000). These developments include the work of Andrews and

Table I: Grouping type, soil indicators and key indicators

Grouping type	Soil indicators	Key indicators[1]
Physical attributes	Soil texture	**
	Stoniness	
	Soil structure	
	Bulk density	**
	Porosity	
	Aggregate strength and stability	**
	Soil crusting	
	Soil compaction	**
	Drainage	
	Water retention	
	Infiltration	**
	Hydraulic conductivity	
	Topsoil depth	**
Chemical attributes	Color Reaction (pH)	
	Carbonate content	**
	Salinity	
	Sodium saturation	**
	Cation exchange capacity	
	Plant nutrients	
	Toxic elements	**
Biological attributes	Organic matter content	
	Populations of organisms	**
	Fractions of organic matter	
	Microbial biomass	
	Respiration rate	**
	Mycorrhizal associations	
	Nematode communities	
	Enzyme activities	
	Fatty acid profiles	
	Bioavailability of contaminants	

[1]Key indicators according to USDA (2006)

Carroll (2001), who provided an overview of the design of a soil quality assessment tool for sustainable agro-ecosystem management; Hartemink (2006a), who assessed soil fertility decline in the tropics using soil chemical data; Ding et al. (2021), who investigated the use of vermicompost and deep tillage systems to improve saline-sodic soil quality and wheat productivity; Grigget al. (2006), who investigated the effect of organic mulch amendments on physical and chemical properties and re-vegetation; Hafez et al. (2015), who investigated the effect of gypsum application and irrigation intervals on clay saline-sodic soil characterization, rice water use efficiency, growth, and yield; and Meena et al. (2016), who investigated the effects of municipal solid waste compost, rice-straw compost and mineral fertilizers on the biological and chemical properties of saline soil and yields in a mustard–pearl millet cropping system. There are also many comprehensive and critical reviews regarding soil quality assessment and rehabilitation (e.g., Bünemann et al., 2018; Basak et al., 2022) that have focused on multifunctional services of soil management and food security. These studies have provided an advanced understanding of conservation practices, which are involved in the design and management of soil and water in the tropics (Andrew, 2001). They also guided towards better management of sloping lands, especially those that are affected by erosion and surface damage (Andualem et al., 2023).

The methods and techniques involved in soil quality assessments have yielded vital resource information for diverse agricultural and non-agricultural references. Quentin et al. (2018) assessed derelict soil quality using abiotic, biotic and functional approaches, and their results showed that derelict soils may provide a biodiversity ecosystem service and are functional for high decomposition. The method they used assessed the functional parameters (i.e., the macro-decomposer proportion, enzyme activity, average mineralization capacity, and microbial polycyclic aromatic hydrocarbon degraders) by combining abiotic and biotic parameters. The method used by Quentin et al. (2018) can be very useful in tropical dryland soils where the need for high decomposition machinery is increasing due to low

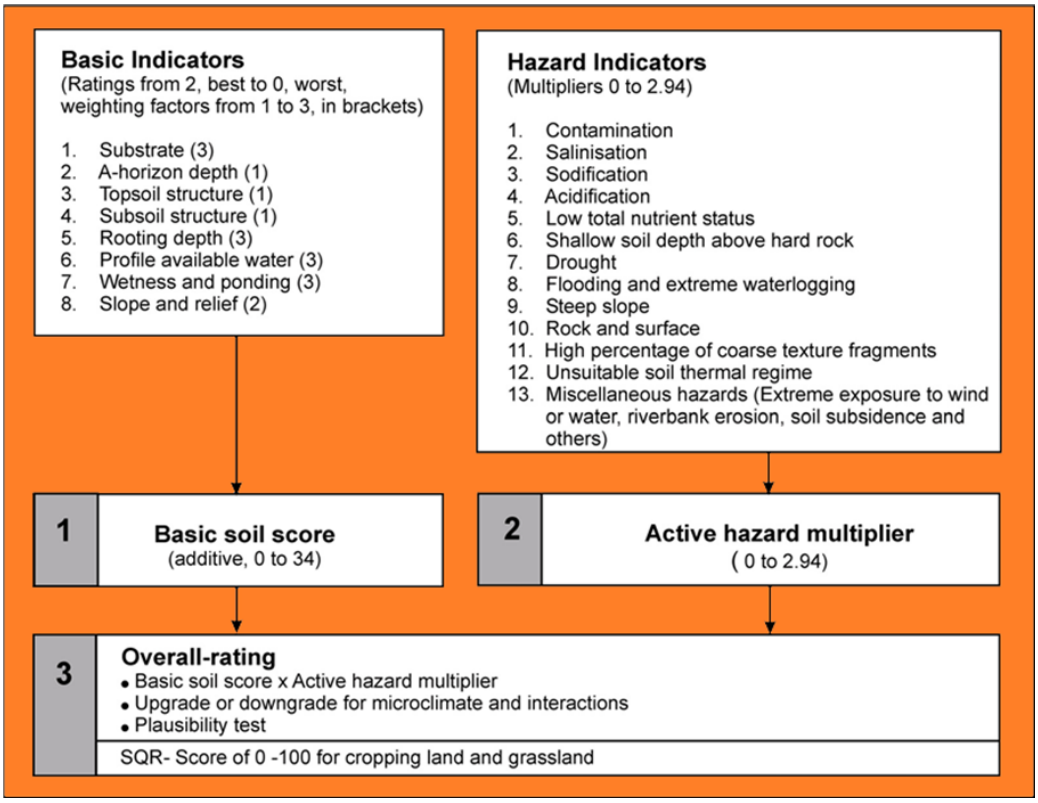

Figure I: Basic and hazard indicators of the soil quality assessment. Indicator system of the Muencheberg Soil Quality Rating (Mueller et al., 2007)

nutrient and organic matter contents (Hartemink, 2006b).

Muñoz-Rojas et al. (2016) used soil quality indicators to assess soil functionality in restored semiarid ecosystems, and the results revealed that biological indicators (microbial diversity and activity in particular), organic C and the C:N ratio are the most sensitive indicators for detecting differences among reconstructed soils and analogous undisturbed soils in semiarid areas. Theresults revealed a positive effect of vegetation on reconstructed soils and a recovery of soil functionality in waste material to levels similar to those of topsoil once vegetation was established (Muñoz-Rojas et al., 2016). The methodology used in this study involved the collection of soil samples collected from two subareas with different soil materials used as growth media: topsoil retrieved from nearby stockpiles and a lateritic waste material utilized for its erosive stability and physical competence. In their narrative, an undisturbed natural shrub-grassland ecosystem dominated by Triodia spp. and Acacia spp. representative of the restored area was selected as the analogue reference site, whereas soil physicochemical analysis was undertaken according to standard methods. Soil microbial activity was measured with a 1-day CO_2 test, a cost-effective and rapid method to determine the soil microbial respiration rate based on the measurement of the CO_2 burst produced after moistening dry soil; at the same time, the soil microbial abundance of specific groups was measured by phospholipid fatty acid analysis. This technique is multifunctional and can be applied effectively in a broad range of restoration projects in arid and semiarid tropics (Muñoz-Rojas et al., 2016).

Johannes and Boivin (2017) studied soil structural quality assessment for soil protection regulation, and the results showed that the relationships between the physical properties and the soil constituents were linear and highly determined, representing the reference properties of the corresponding soils. Their observation also allowed us to define the most discriminant parameters that depart from the different structural qualities and their threshold limits. The method they used employed two steps. In the first step, the structural quality was assessed with field expertise and visual evaluation of the soil structure (VESS), and the physical properties were assessed via shrinkage analysis. In the second step, the properties of the physically degraded soils were analysed and compared to the reference properties. This study can be useful for farmers in the tropics because it provides vital resource information for soil–water quality protection. There are many other studies with similar or closely related approaches. These include the study of soil invertebrates as bioindicators of urban soil quality (Santorufo et al., 2012), which are considered among the most appropriate for soil quality assessment, and the assessment of soil quality indicators under different land uses and soil erosion conditions using multivariate statistical techniques (Nosrati, 2012), which suggests that dehydrogenase and silt are the most sensitive to land use and soil erosion management. However, for the integrated soil quality assessment approach, the development of relationships between all the soil-quality indicators and the various soil functions may be an enormous assessment (Zalidis et al., 2002), although it is very useful in determining the effective quality of soil and water resource management (Bouwer, 2000).

Conclusion

Tropical and drylands soils required management application to support growing population in Africa. This management is important for soil quality improvement and ensuring food security in the region. Despite the vast developments in soil water conservation studies over the last 75 years, the advanced soil and water management requires considerable effort because of the combine environmental challenges, which include climate change impact, poverty, deforestation and contamination. Soil quality, soil health, soil function, and water quality are soil functional groups, which have various linkages to soil and water management in the tropics and drylands. Assessment of soil quality indicators (physical, biological and chemical) is a valuable tool for understanding the management approach suitable for soil and water improvement. This revision demonstrated that soil and water management in the tropics and drylands, are directly related to inherent and dynamic soil properties (physical, biological and chemical attributes), and can be measured and explained through soil quality assessment. The maintenance of soil quality, soil health, and soil fertility depend largely on soil and water management adaptation in the tropical and dryland areas of Africa. This study recommends that soil assessment is needed for sustainable agriculture and for soil and food security in Africa.

Ethics approval and consent to participate

The paper was part of Kebbi Dryland and Fadama research project works approved by the Department of Agronomy, Faculty of Agriculture Nasarawa State University Keffi, and Nigeria. The work is under the supervision of Professor James O. Jayeba – the Director Amina Muhammand Centre of Climate Change NSUK, Nigeria

Conflicts of Interest

The authors declare no conflict of interest.

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REVİEW PAPER

Biostimulants for sustainable agriculture in forage crops

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Abstract

Biostimulants, a promising avenue in agriculture, are substances that significantly enhance plant growth and productivity. They are a rich source of various compounds and microorganisms, including humic substances, amino acids, seaweed extracts, chitin and chitosan polymers, inorganic compounds, seed and root extracts, and organic wastes. Humic substances derived from decomposed organic matter are crucial in improving soil structure and nutrient availability. On the other hand, amino acids and protein hydrolysates promote nitrogen uptake and stress resistance, enhancing plant growth. The rich in polysaccharides and phytohormones, seaweed extracts enhance root development and stress tolerance. Polymers such as chitin and chitosan, derived from crustaceans and fungi, provide protective effects against pathogens and environmental stressors. Inorganic compounds and plant extracts also contribute to growth and resistance. The growing global biostimulants market is a testament to the increasing demand for environmentally friendly agricultural solutions, highlighting the urgency of adopting these solutions. Unlike traditional fertilizers, biostimulants do not directly provide nutrients but improve how plants use available nutrients more efficiently. Research underscores the potential of biostimulants to contribute to sustainable agriculture by increasing yield, quality, and disease resistance. Indispensable in modern agriculture, biostimulants are the key to creating sustainable and productive agricultural systems with more resilient plants by stimulating the development of crops, especially under unfavorable conditions, and improving crop quality.

Introduction

Throughout the development of agricultural production, situations such as biotic and abiotic-related stress factors, incorrect and unconscious agricultural practices, excessive fertilization, and irrigation, as well as the use of chemical substances cause a decrease in productivity and quality in the growing areas (Alfosea-Simon et al., 2020; Gürsoy, 2022a). To reduce or eliminate the adverse effects on yield and quality, research is being conducted on applications that regulate plant development and new cultivation techniques. One of these studies is biostimulant applications. Preparations containing organic and inorganic compounds, such as plant nutrients, some growth regulators, seaweed, etc., can be used as biostimulants. Such widespread applications promote plant development, yield, quality, and resistance to abiotic stresses (Şen et al., 2022). Biostimulants are called variously, such as "Biostimulants" or "Plant Activators" (Du Jardin, 2015; Külahtaş and Çokuysal, 2016; Rouphael, 2018). Because of the increasing use of environmentally friendly agricultural products in recent years, research on biostimulant products is increasing daily, and the trade volume is constantly expanding (Povero et al., 2016). The biostimulant market has grown enormously due to the global shift towards sustainable agriculture. Manufacturers are increasingly emphasizing the benefits of integrating biostimulants with conventional fertilizers due to stringent environmental regulations, and ongoing research and development efforts are resulting in innovative formulations that will enhance biostimulant efficacy and meet the increasing demand for eco-friendly solutions. Due to economic and sustainability challenges, various and numerous research studies are ongoing on biostimulants since they are still new in producing traditional agricultural products. Between 2013 and 2022, 77.3% of the research on biostimulants are distributed as research articles, 11.3% as review articles, 5.3% as conference presentations, 4.4% as book chapters, and 1.7% as other research and publications (Anonymous, 2024a).

This review explains research on commonly used biostimulants and some forage crops and their effects on yield and quality.

Application Areas of Commonly Used Biostimulants

For these products, which are used to increase yield and quality, to be included in the biostimulant group, they must have a combined effect on the plant's abiotic and biotic stress conditions (Bulgari et al., 2019). Researchers have various approaches to classifying biostimulants and have listed different compounds in recent studies. The generally accepted classification is as follows; humic substances, amino acids and other nitrogenous compounds, seaweed and plant extracts, chitin and chitosan-like polymers, inorganic compounds, extracts of seeds, leaves and roots (Yakhin et al., 1998, Ertani et al., 2014, Yasmeen et al. 2014, Lucini et al. 2015, Ugolini et al., 2015), organic wastes (Yakhin et al. 2017), beneficial fungi and bacteria (Du Jardin, 2015). Sample studies showing the general properties of these widely used biostimulants and their effects on forage plants are reviewed below.

Humic Substances

Humic substances are natural organic compounds in soil, water, and decomposed plant and animal matter. They are naturally occurring organic substances in the environment, soil, or surface waters. The most commonly used types are Fulvic and humic acids. Fulvic acid is a water-soluble component of humic substances under all pH conditions. Humic acids are the major organic components in soil, forming humus. Humic acid is the most active humus component and is the main compound obtained from soil. They control plant nutrient availability, facilitate carbon and oxygen exchange between soil and atmosphere, and transform toxic chemicals (Piccolo and Spiteller, 2003). Humic substances, used in granular and liquid forms, improve soil physical properties, increase water retention capacity, affect cation exchange and buffering properties, influence nutrient availability, promote transformation of elements for plant use, and increase plant membrane permeability. Humic substances promote the growth of beneficial microorganisms, stimulate plant root systems, and increase hormone production (Lumactud et al., 2022). In a study by Büyükkeskin et al. (2015), it was observed that humic acid application suppressed the growth-inhibiting aluminum toxicity by nearly 50% in Vicia faba L. seedlings under aluminum stress and increased root growth by 21% compared to controls. In addition to this effect, Khaleda et al. (2017) reported that foliar application of a mixture of humic acid and a biostimulant containing catechol and vanillic acid in the growth of annual ryegrass resulted in up to 30% improvement in plant height and green grass yield before and after mowing compared to control plants, as well as about 15% increase in root growth. Furthermore, Shen et al., (2020) examined the effect of humic acid on the physiological and photosynthetic processes of millet seedlings under drought stress. They found that humic acid enhanced seedling growth by improving osmotic regulation, antioxidant capacity and photosynthesis rate, while growth parameters such as plant height, root length and root dry weight improved by 15-29%. Gürsoy, (2022b) investigated the effect of humic acid doses applied as biostimulants on reducing salt stress in sunflower seedlings and compared to control treatments, approximate germination percentage (13.3% increase), average germination time (13.5% decrease), salt tolerance percentage (16. 7% increase), seed length (16.7% increase), root length (25% increase), relative water content (14.3% increase), actual water content (15.4% increase), total chlorophyll (25% increase) and chlorophyll stability index (20% increase) parameters. Makhlouf et al., (2022), who applied humic acid and chitosan to sugar beet plants under severe drought stress conditions, observed that it caused a 1.8% increase in root length, a 4.2% increase in root fresh weight, a 3.5% increase in leaf area, and 4.2% increase in root yield. Alrubaiee and Al-Sulaiman (2023) investigated the effects of different doses of humic acid applied foliarly to oat varieties on herbage yield and some parameters, and reported that green herbage yield increased from 1500 tons per decare in the control application to 2300 tons with an increase of 47%.

Amino Acids and Other Nitrogenous Compounds

This group of biostimulants includes amino acids and peptides derived from plant and animal products. They can enhance plant growth and boost their resistance to stress factors. (Ertani et al., 2009; Malécange et al., 2023). Protein hydrolysates act as plant growth regulators by promoting nitrogen absorption and metabolism in plants (Ryan et al., 2002; Külahtaş and Çokuysal, 2016). They also have indirect

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effects on plants. When used, these products increase microbial activity in the soil (Du Jardin, 2015). Biostimulants contain amino acids that can be part of plant protein structure. Studies show that certain non-protein amino acids when applied externally, protect plants from stress or activate metabolic signaling (Sharma and Dietz, 2006; Forde and Lea, 2007). Chynoweth and Moot (2013) and Macháč (2013) found that trinexapac-ethyl-based biostimulant increased seed yield by up to 30% on annual and perennial grasses and some forage crops. Przybysz et al. (2014) investigated the effects of Atonik, a nitrophenolate-based biostimulant, on the morphology, physiology, biochemistry and yield parameters of *Medicago truncatula*, which resulted in a 20% increase in chlorophyll content and a 15% increase in protein content. In addition, Trethewey et al. (2016) reported that 400 g/ha trinexapac-ethyl application increased seed yield by 65% on annual grass. Altuner et al. (2019), who applied gibberellic acid pretreatment on the germination of triticale under salt stress, observed a positive increase in germination and growth parameters as the application dose increased. Ciepiela and Godlewska (2019) examined the yield and organic components of Asahi brand biostimulant obtained from three phenolic compounds (sodium para-nitrophenolate, sodium ortho-nitrophenolate, sodium 5-nitroguaiacolate) on Lolium multiflorum at varying nitrogen doses and it was observed that Asahi application at 180 kg/ha nitrogen dose had a positive effect of 40% on yield increase, 28% on chlorophyll content and 22% on protein content compared to control application. Radkowski et al. (2020) studied the effects of a biostimulant containing 18 biologically active free amino acids (L-alpha) obtained by enzymatic hydrolysis on the visual quality and disease and pest resistance properties of perennial ryegrass at doses (1, 2, and 3 l/ha). They reported that visual quality, disease, and pest resistance were positively affected as the dose increased. Again, a biostimulant containing a different plant-derived amino acid was applied to sugar beet leaves by Şanlı et al. (2023). As a result, an increase of approximately 8.5% occurred in the root, stem, and raw sugar yields of the varieties.

Seaweed and Plant Extracts

Seaweed has been utilized as organic matter and fertilizer in agriculture since ancient times. However, only recently have the effects of these products, such as biostimulants in agriculture, begun to be recognized. The presence of polysaccharides, alginates, and carrageenan, as well as their by-products, allows the utilization of seaweed in agriculture. (Külahtaş and Çokuysal, 2016). These extracts aid nutrient uptake, improve soil structure and aeration, and regulate plant growth. Seaweed extracts are considered biostimulants as they improve seed germination, plant growth, stress resistance, and post-harvest shelf life (Mancuso et al., 2006; Rayorath et al., 2008; Khan et al., 2009; Craigie, 2011). In some studies, foliar application of seaweed extracts are associated with increased (about 30%) lateral root development, total root volume, length, and phytohormones such as auxin and cytokinins (Mancuso et al., 2006, W. Khan et al., 2011, Z. Khan et al., 2011). Godlewska and Ciepiela conducted a study on an alfalfa variety in 2018 and applied nitrogen fertilization with seaweed-containing biostimulant and as a result, biostimulants together with nitrogen fertilization increased chlorophyll content by 25%, protein content by 18% and dry matter yield by up to 30%. Godlewska and Ciepiela (2020), in their study on annual ryegrass, found that seaweed extracts decreased NDF content by 10-15%, ADF by 8-12% and ADL by 5-10% compared to the control group, and these results indicate that seaweed extract and amino acid-based biostimulants increase the digestibility of grass plants by reducing their fiber content, while Öner et al. (2023) and Nazzal et al. (2023) reported that plant fresh weight and nutrient uptake from the soil increased by 10%-30% at the macro and microelement levels. This study shows that seaweed extract applied at different doses increases the power of P, K, Ca, Mg, Fe, Cu, Mn, Zn, and B nutrients in alfalfa and in annual ryegrass plants. In addition, Gibson et al. (2024), who applied seaweed-based biostimulant on corn stubble, reported a 24% increase in grain yield and a 30% increase in silage yield in corn planted in the same area the following year. Kaya et al. (2024) examined the effects of different doses of liquid seaweed of organic origin on seed germination and root and shoot growth in some wheatgrass species and as a result, in the germination study carried out after soaking in liquid seaweed solution, it was observed that treatments at 1000 and 2000 ppm doses increased the number of germinated seeds, root dry weight and shoot dry weight by 10% to 35%. Kaya et al. (2024) examined the effects of different doses of liquid seaweed of organic origin on seed germination and root and shoot growth in some wheatgrass species and as a result, in the germination study carried out after soaking in liquid seaweed solution, it was observed that treatments at 1000 and 2000 ppm doses increased the number of germinated seeds, root dry weight and shoot dry weight by 10% to 35%.

Chitin and Chitosan-like Polymers

Chitin and chitosan biopolymers are derived from seafood and mushrooms and are used in food, cosmetics, medicine, and agriculture. Some studies have observed the positive effects of chitin and chitosan on plant physiology. These effects include the impact of their ionic structures on DNA, plasma membrane, cell wall, cell parts, stress factors, and the activation of related genes (Hadwiger, 2013; Katiyar and Singh, 2015). The positive effects of chitosan, such as protection from fungal pathogens, resistance to abiotic stress, and improved fruit quality, are increasing daily. Cho et al. (2007) in a study on sunflower seedlings grown at 20°C for 6 days after soaking in 0.5% and 0.5% lactic acid

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solution for 18 hours, reported that total weight increased by 12.9% and germination rate increased by 16% compared to the control group. Choudhary et al. (2017) observed that maize plants treated with Cu-chitosan nanoparticles exhibited a 20-30% increase in antioxidant and defense enzyme activities. Additionally, they reported a 15% increase in plant height in pot experiments and a 25% increase in grain yield in field trials. Chitosan applications increase abscisic acid levels 3- times, decreasing stomatal conductance by 40% and transpiration rate by 30%, causing stomatal closure in plants and helping to develop defense mechanisms against environmental stress factors (Iriti et al., 2009). A new slow-release chitosan-silicon nano-fertilizer (CS-Si NF) specially designed by Kumaraswamy et al. (2021) has promoted growth and yield in corn plants. Seeds coated with CS-Si NF at different concentrations had a 43.4% higher yield, with the seedling vitality index increasing by 3.7 times. Jabeen and Ahmad (2013) in safflower and sunflower, Öner and Cengiz (2023) in maize reported that seed coating with chitosan solutions increased germination rate by 20%, shortened germination time by 15%, increased germination index and root number by 25%, and increased root length and coleoptile length parameters by 15%. In another study, Makhlouf et al. (2022) observed that chitosan application to sugar beet plants under severe drought stress conditions caused a 1.8% increase in root length, a 4.2% increase in root fresh weight, a 3.5% increase in leaf area, and a 4.2% increase in root yield.

Seed, Leaf, and Root Extracts

This biostimulant group is obtained from seeds, leaves, and roots extracts. It is obtained chiefly from higher plants such as *Amaryllidaceae, Brassicaceae, Ericaceae, Fabaceae, Fagaceae, Plantaginaceae, Poaceae, Rosaceae, Solanaceae, Theaceae, Vitaceae* and the biostimulants in this group give positive results in sustainable agriculture in plant growth and development, yield and quality and in combating diseases (Parrado et al., 2008; Pretorius, 2013). As a result of the use of extracts obtained from new shoots of some plants as biostimulants, it has been found that it positively affects alcohol degree, pH, total acidity, volatile acidity, color intensity, variable aroma potential index, phenolic compounds, and yield (Sánchez-Gómez et al., 2016). In a study where an aqueous extract obtained from duckweed (*Lemna minor* L.) was evaluated as a biostimulant in corn, corn seeds were coated with different concentrations of this extract (0.01%, 0.05%, 0.50%, and 1.00%). It improved corn germination, biomass (20%), leaf area (25%), pigment content (18%), and vitality index and stimulated nitrogen (22%), phosphorus (19%), potassium (17%), calcium (15%), magnesium (13%), sodium (16%), iron (16%), and copper (%12) interactions (Buono et al., 2021). Similarly, in a study on corn plants under salinity conditions, Prilo et al. (2024) found that duckweed (Lemna minor L.) extract increased biomass (18-22%), root development (15-20%), photosynthetic pigment (25-30%), and soluble protein levels (20-28%). Umarusman et al. (2019) investigated the antibacterial properties of 34 different plant extracts against the pathogen called *Pseudomonas syringae*, which causes leaf blight in people, applied these extracts to seeds. The pathogen suppression rate was revealed by pot and field experiments, and it was stated that the most effective seeded Clove (*Syzygium aromaticum*) extract prevented the disease by 95% in the pot experiment and 98% in the field experiment. Akdağ and Avcı (2023) investigated the seed yield rates of Italian ryegrass (*Lolium multiflorum* L.) at different planting times and biostimulant (Pi-NFS) doses (0, 100, 250, 500 ml da^{-1}). The highest amount of seed was obtained from the 500 ml da^{-1} dose at the 2nd planting time, while the values obtained from the 250 and 500 ml da^{-1} doses at the 1st planting time had 30% higher seed yield values than the control treatments. As a result of a study conducted by Han et al. on the effects of Polygonum minus extract on maize plants under drought conditions, it was reported that the application of the extract increased the wet and dry weight of maize plants by 33.1-41.4% and 48.0-43.1%, respectively, while increasing the chlorophyll b content by 87.9-100.76%, soluble sugar and protein levels by 23.6-49.3% and 48.6-56.9%, respectively. In a study conducted by Peñas-Corte et al. (2024), application of Lamiales plant extract significantly increased maize growth, increasing plant height by 20.45% and yield by 45.67%, while reducing fumonisin concentrations and improving stress tolerance.

Organic Wastes

Some researchers have included food waste or industrial waste streams, composts and compost extracts, fertilizers, vermicompost, wastewater, and sewage treatments in the biostimulant group (Yakhin et al., 2017). Agricultural organic wastes are divided into three groups: Wastes remaining due to plant production, plant mass occurring in cultivated land, forests, fallow land, and fruit and vegetable cultivated areas that cannot be characterized as a product. Stems, straws, shells, seeds, pruning residues, animal manure, and internal organs from slaughter are all included in this group. Animal manure is used as fuel (dung) and fertilizer. Waste from internal organs can also be used as compost fertilizer, and agricultural product processing results in waste. These wastes result from the processes of agricultural products (grinding, sorting, drying, etc.) before being used directly. These are unused wastes such as stems, straws, shells, and seeds. Understanding the effects of post-processing waste on soil properties is crucial for successful recycling efforts. The material obtained after processing is known as biochar, and it is used as a growing medium, silage additive, in poultry feeds, in food or fabric paint, a feed additive, in the cosmetic industry, aromatherapy, and as fuel from pruning residues (Bekar, 2016). Ferreira et al. (2018) reported that a biostimulant application originating from fish waste in second-crop corn plants would be effective on seed yield (18% higher compared to the control treatments), while Qiu et al. (2020) coated meadow clover and perennial ryegrass seeds with different combinations of soybean meal, diatomaceous earth, micronized earthworm compost and concentrated earthworm compost extract as biostimulants and reported that germination rate increased by 5-10%, seedling height by 12-15%, dry weight by 10-15%, while coatings containing soybean meal increased coating integrity by 20% and extended the dispersal time of coatings by 25% compared to uncoated plants. Godlewska and Becher, who used organic wastes consisting of sewage sludge and coal ash as biostimulants, examined some macroelements in *Dactylis glomerata* and *Zea mays* plants in their research in 2021 and decreased cocksfoot calcium content by 15%, magnesium content by 10%, but increased potassium content by 20%. In maize, it decreased calcium content by 12%, magnesium content by 8% and increased potassium content by 18%. These results indicated that the use of waste materials as agricultural fertilizer can reduce the use of mineral fertilizers and can be a suitable method for sustainable agriculture. In addition, Demiray and Parlak (2023) used farmyard manure (3000 kg da^{-1}), chicken manure (300 kg da^{-1}), leonardite (100 kg da^{-1}), They investigated the effects of biological fertilizer (free-living nitrogen bacteria) and chemical fertilizer (10 kg N da^{-1}) applications on the yield and quality of annual ryegrass and reported that while farm manure increased the green and dry grass yield of annual ryegrass by 35%-30%, chicken manure and leonardite increased the yield by 28-24% and 22-20%, respectively. In another study, Saadat et al. (2023) surveyed flowering and yield parameters in a study on meadow clover. It was observed that the application of vitamin B12 and humic acid delayed the flowering time by approximately 15 days, increased the total number of stems, and resulted in a 30% decrease in leaf trichome density and a 60% increase in root dry weight. In a study conducted by Torres-García et al. (2018) on the foliar application of a biostimulant based on cattle manure vermicompost (VCLB) leachate, including its effect on corn, cotton, and peanut yield, according to the results obtained from VCLB effect on maize plants, igholghOlat was reported that chlorophyll content and crop yield increased by 12%, 15% and 10%, respectively, compared to chemical fertilization.

Inorganic Compounds

Inorganic compounds derived from organic substances can also be used in sustainable agriculture. Inorganic compounds formed by water, minerals, acids, bases, and salts help with the growth and development of plants. These components typically lack carbon, are inorganic, and are not produced within living organisms but are taken from the external environment in a preformed state. They have a structure that allows them to enter cells directly without being digested, and they primarily serve a regulatory function in living organisms (Anonymous, 2024b). Dactylis glomerata L. and Festulolium braunii by Godlewska and Ciepiela in 2013, the effects of different nitrogen doses and the application of a biostimulant containing auxin, gibberellin, cytokinin, polyamine and phytolamine on the actual protein and simple sugar contents were investigated and the biostimulant application increased the protein content by 15% and simple sugar content by 10% in Dactylis glomerata, while the protein content increased by 12% and simple sugar content by 8% in Festulolium braunii. As a result of the research, the average carbohydrate/protein ratio was found to be 1.07 and this ratio was among the optimal values for ruminants. Senthilraja et al. (2013) conducted both pot culture and field experiments on maize (Zea mays) plants to evaluate the effects of brewery wastewater on plant growth and physiological changes and the results showed that plants irrigated with 100% brewery wastewater had a 30% increase in biomass and 25% increase in chlorophyll content compared to the control group. In a 2018 study on alfalfa plants, Tytanite, a titanium-based biostimulant, was tested in combination with nitrogen fertilization and a 10% increase in chlorophyll content and a 9% increase in protein content was observed regardless of nitrogen fertilization (Godlewska and Ciepiela, 2018). In a study conducted by Ağırağaç and Çelebi in 2021, the effects of urban wastewater on heavy metal and nutrient content of Caramba (Lolium multiflorum cv. Caramba) plants were investigated. The results showed that 100% wastewater irrigation increased lead (Pb) content by 150% and cadmium (Cd) content by 120% compared to the control. Furthermore, nitrogen (N) and phosphorus (P) contents increased by 30% and 20% with 50% and 25% effluent treatments, respectively. However, higher effluent concentrations negatively affected plant health and growth rates.

Beneficial Fungi and Bacteria (Inoculants)

The biostimulant group includes especially biological fertilizers. These fertilizers include plant growth-supporting rhizobacteria (PGPR), some fungi, and mycorrhizae, which contain live microorganisms and can be applied to seeds, different surfaces of plants, and soil. When fertilizers in this group are used, an increase is observed in the nutrient uptake in plants, root area, and biomass, as well as the capacity of plants to remove nutrient elements from the soil (Vessey, 2003). These microorganisms are isolated from plant and soil residues, water, and composted organic fertilizers. On the other hand, PGPR (plant growth-promoting rhizobacteria) and PGPB (plant growth-promoting bacteria), among biological fertilizers, have been isolated from the rhizosphere region around the roots of plants. The key factor in the development of microbial inoculants is their commercial formulations. Selectively inoculated microorganisms should maintain their viability in commercial formulations and show the expected effect in the fields where they are inoculated. Similarly, it is also essential that these preparations applied from seeds or leaves are compatible with chemical fertilizers and plant protection products (Külahtaş and Çokuysal, 2016). Beneficial microorganisms, known as PGPRs, act as biostimulants. They perform tasks such as nitrogen fixation, making plant nutrients available, producing siderophores, facilitating iron uptake, and generating volatile organic compounds, and the genera to which these bacteria belong are mostly *Acetobacter, Acinetobacter, Achromobacter, Aereobacter, Agrobacterium, Alcaligenes, Artrobacter, Azospirillum, Azotobacter, Bacillus, Burkholderia, Clostridium, Enterobacter, Erwinia, Flavobacterium, Klebsiella, Micrococcus, Pseudomonas, Rhizobium, Serratia* and *Xanthomonas* (Çakmaçı, 2005). *Azotobacter* bacteria have an important place as they increase the nitrogen cycle by 25-30% compared to normal nitrogen cycle with their different metabolic functions (Sahoo et al., 2013). It is known that these bacteria synthesize vitamins such as thiamine and riboflavin and hormones such as auxin, gibberellin, and cytokinin in addition to nitrogen fixation (Abd El-Fattah et al., 2013). It was reported that *Azotobacter chroococcum* microorganisms around the plant roots increased seed germination by 35% and promoted 40% and 30% improvement in root length and mass, respectively, compared to the control group (Gholami et al., 2009). *Azosprillum* spp. bacteria interact with plant roots and tissues inside the roots. In some studies, the effects of *Azosprillum* species on nitrogen content in plants were investigated. It was determined that 7-12% of the total nitrogen was formed in wheat by the activity of *Azosprillum brasilense* and *Azosprillum lipoferum* (Malik et al., 2002), and 60-80% of the total nitrogen content in sugar cane was formed by nitrogen fixation by *Azosprillum diazotrophicus* (Boddey et al., 1991). These fertilizers, which are especially recommended for plants such as corn, millet, and sorghum, can fix 2-4 kg nitrogen per decare per year, and they also produce plant growth regulators as a result of their metabolic activities (Okur and Ortaş, 2012). On the other hand, this bacterial species does not form nodules in plant roots. It has been known for many years that *Rhizobium* bacteria, due to their symbiotic life with plants, convert nitrogen in the atmosphere into usable nitrogen forms for plants, thus increasing the yield of cultivated plants (Sharma et al., 2011). These bacteria, resistant to different temperatures, generally enter the root from the root hairs, multiply, and form nodules in the root (Nehra et al., 2007). PGPR colonization of plant roots expands root architecture and improves nutrient and water uptake, nitrogen fixation, phytohormone production, enzyme production, photosynthetic activity, and other processes (Chieb and Gachomo, 2023). Some microorganisms increase the uptake of nutrients in the soil in the growth medium, thus allowing plants to take these elements more efficiently. It has been determined because of some studies that these bacteria convert phosphorus in the soil into available forms, and it is reported that microorganisms convert phosphorus forms that plants cannot take up into available phosphorus forms by producing organic acids (Kpomblekou and Tabatabai, 1994). Similar to phosphorus, potassium in the soil is also converted into available potassium, especially by Bacillus bacteria. The mentioned bacteria break down mica, illite, and orthoclase clay minerals in the soil with the help of the organic acids they produce, which release potassium ions (Sheng and He, 2006). Using bacteria that support plant growth in agriculture positively affects plants' nutritional status and protects plants against stress. While Paul and Nair (2008) reported that osmolytes and salt stress-induced proteins produced by Pseudomonas fluorescens bacteria and plants were 35% less affected by salt stress than control treatments, Baharlouei et al. (2011) reported that some Pseudomonas bacterial strains produced IAA, siderophore and ACC deaminase enzymes and protected canola and barley plants from heavy metal stress by promoting 20-40% more root and shoot growth. Sever Mutlu et al. (2019) and De Luca et al. (2020) stated that bacteria-based biostimulant applications positively affect grass quality, color, and density and meet the nutritional needs for post-cutting development in their studies on turf plants. In two separate studies, Sezen and Küçük (2021, 2023) investigated the effects of Microcystis viridis and Aphanizomenon gracile cyanobacteria on plant growth in areas cultivated with vetch (Vicia sativa L.), chickpea (Cicer arietinum L.), barley (Hordeum vulgare L.), maize (Zea mays L.), and lentil (Lens culinaris Medik). The studies demonstrated that cyanobacteria applications increased root length by 15-25%, plant height and root dry and fresh weights by approximately 30%, and green parts weight by 20% compared to untreated plants. These findings highlight the significant positive effects of cyanobacteria applications on plant growth and development relative to control groups. Dağ et al. (2024) conducted a study to determine the effects of microbial fertilizer containing *Azotobacter chrococcum* and *Azotobacter vinelandii* bacteria on yield and some yield components of two different corn varieties, and it was observed that it had significant effects on plant height by 8-11%, the first cob height by 21-24%, the cob length by 5%, the cob diameter by 1-3%, and the grain yield by 9-11% increase.

Mycorrhizae are fungal species that establish a symbiotic relationship with the roots of some plant species, allowing plants to take more nutrients from the soil with the help of mycelia and hyphae, and that play a supportive role rather than being parasitic on the plant. It has been determined that with the help of these effects of mycorrhizae, growth, development, and protection from pathogens and environmental stress factors are encouraged in plants (Lamabam et al., 2011). Studies have shown that these fungi take phosphorus, zinc, and other micronutrients that plants cannot take in the soil through their hyphae and carry them to the cortex cells in the root with the help of their mycelia (Smith et al., 2011). More than 96% of natural plant species are symbiotic with mycorrhizal fungi (Ortaş et al., 1999). The joint application of mycorrhizal fungi with beneficial bacteria positively affects plant growth by 20-40%, yield by 15-30%, nutrient uptake (N, P, K) by 10-25%, and environmental stress tolerance (drought, salinity, etc.) by 15-35% compared to control groups (Bhardwaj et al., 2014). In conditions where soil tillage is not done or is done at a minimum level, *Azotobacter, Azospirillum, Rhizobium*, and *Cyanobacteria* group bacteria in the soil make phosphorus and potassium available, while mycorrhizae increase the uptake of these elements (Doğan et al., 2011; Aziz et al., 2012; Oddi et al.,2024) A study was conducted on an artificial pasture with a mixture of 5 different forage plants using the Mycorrhizae microbial inoculum Micosat F and a chito-oligosaccharide mixture for the nutrient medium, and the seeds were inoculated with this mixture during planting and increased root colonization by 40%, plant species diversity by 25%, productivity by 30%, and weed control efficacy by 20%. In another study, Hai-Yang et al. (2024) concluded that single or combined inoculation of *Paraglomus occultum* and *Rhizobium leguminosarum* bv. *trifolii* significantly enhances nitrogen levels in both plant tissues and soil, with observed increases of up to 55% in plant nitrogen content and improved availability of ammonium and nitrate nitrogen in the soil.

Market Development and Use of Challenges

The biostimulant market has experienced substantial growth due to the global shift towards sustainable agriculture. Producers are increasingly considering the benefits of integrating biostimulants with conventional fertilizers due to oppressive environmental regulations, and ongoing research and development are yielding innovative formulations that will increase biostimulant effectiveness and meet the growing demand for environmentally friendly solutions. The global biostimulant market was valued at USD 3.5 billion in 2022 and is estimated to reach approximately USD 10.25 billion by 2032, with a growth rate of 11.40% from 2023-2032. The European market accounted for the highest revenue share at 38% in 2022, with a market share of USD 1.47 billion in 2023. It is expected to reach USD 3.86 billion by 2032, with a growth rate of 11.30% during 2023-2032 (Anonymous, 2024c). Although the use of pesticides and fertilizers is inevitable as long as agriculture is carried out, the target of reducing chemical pesticides and inorganic fertilizers by 50% by 2030 and developing environmentally friendly products instead has been set within the scope of adaptation to climate change and the European Union Green Deal (Maçin, 2021).

The agricultural use of biostimulants will provide solutions locally and temporally. Longer-term ecological effects should also be assessed and integrated into production. To achieve the benefits biostimulants can provide for profitable and sustainable plant production, stakeholders, farmers, public research, and regulatory institutions will be required to participate. The most critical points in using biostimulants are their application according to soil and plant type. Therefore, detailed research on biostimulants should be carried out effectively, and agricultural applications should be carried out first. Since the definition of biostimulants varies worldwide and legal regulations show profound differences between countries, the amounts of biostimulants used and the areas, where they are used should be precisely determined and added to the relevant legislation. In this long journey, public action is expected to harmonize policies and regulations and establish a robust risk assessment framework that respects the principle of proportionality and prevents duplication of data requirements between rules.

Conclusion

Agricultural production has become increasingly difficult due to stress factors such as drought, high temperature, and salinity, which have increased in recent years due to the effects of climate change. The fertility and structure of soils are deteriorating daily due to drought, salinity, high temperature, environmental pollution, excessive and unconscious chemical use, metal toxicity, and similar reasons, and it is becoming more difficult to obtain quality plant products. Despite this, the world population is increasing, and meeting the nutritional needs of this population is becoming more complex every day. Integrating biostimulants into agricultural production practices benefits plant growth and stress tolerance and contributes to the agricultural ecosystem's overall health. Promoting symbiotic relationships between plants, soil microorganisms, and the surrounding environment promotes soil fertility, improves nutrient cycling, and reduces the adverse effects of agricultural practices on soil health. Understanding biostimulants' mechanisms of action, their interactions with environmental stresses and plant genotypes, and their application in agricultural production is complicated and vital. It is crucial to develop tools to monitor the effectiveness of biostimulants and create management plans to optimize their use. It can be thought that biostimulants can be very useful for a sustainable life by revealing their full potential and having positive effects on plants, the environment, and human health.

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Conflicts of Interest

The authors declare no conflict of interest.

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