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ASSESSING THE LAND AND CROP SUITABILITY AS A BASIS FOR SELECTION OF AN OPTIMAL CROP PATTERN AND CROP ROTATION MODEL TO BE APPLIED TO DEEP RESIDUAL SOILS OF DONGOLA REGION (NORTH SUDAN–DONGOL)

ISTRAŽIVANJE POGODNOSTI ZEMLJŠTA I BILJNIH VRSTA, KAO OSNOVE ZA IZBOR OPTIMALNE STRUKTURE I MODELA ROTACIJE USEVA, SA PRIMENOM NA DUBOKA REZIDUALNA ZEMLJIŠTA REGIONA DONOGOLA (SEVERNI SUDAN–DONGOL)

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SUMMARY

The aim of the study was to scan land suitability for Agriculture i.e. land utilization types which is, partly described by the FAO (1976), the fitness of a specific tract of land for a specified kind of land use under a stated system of land management, but mainly and fulfilled by the results of the subjective study.

There are two specific objectives:

I. Soil survey: soils characterization - soils classification according to the USA Soil

Taxonomy - soils database (Profiles and routine observations with Excel) - soils mapping (scale 1:25,000).

II. Land evaluation: physical suitability of the soils of the project area for irrigated agriculture according to Sys *et. al.* (1991) for a number of selected crops, commonly grown in the surrounding areas.

The obtained field and laboratory investigation and results have introduced and then evaluated a three main soil groups (Typic/Litic Torriorthens, Litic Haplocamids and Typic Haplocamids). Aiming the most adequate cropping pattern and crop rotation models of the North Sudan land areas, based on detailed "Land and Crop suitability models optimization".

By the use of these models, a different Farms, Vegetable and Orchards-Fruits crop varieties, have been evaluated and finally chosen and presented as a general cropping management use, within the sustainable and integrated Agriculture production.

Key words: Land evaluation, crop suitability, land suitability, Residual soils, land reclamation, salt leaching.

1. INTRODUCTION

As a first step towards assessing the land suitability of Dongola Experiential and Training Fields Areas**,** at Northern State, Sudan survey of the Study area have been conducted during 2018 by Orgamed Farms Company Ltd. (leaded by the study author), with the help in field and laboratory works by Department of Soil & Environment Sciences, Faculty of Agriculture, Sudan University for Science and Technology University.

The experimental field is the part of "Berlin Agriculture Project and is situated on the eastern bank of the River Nile approximately 60 km from Dongla along Dongla-Kreima highway (Fig.1.). The long axis lies in East to West direction (≈4 km). Figure 1. Depicts the location of the study area (2,000 fedans).

The aim of the study is to scan land suitability for Agriculture i.e. land utilization types which is, as described by the FAO (1976), the fitness of a specific tract of land for a specified kind of land use under a stated system of land management.

There are thee specific objectives:

III. Soil survey: soils characterization - soils classification according to the USA Soil (FAO, 1976).

IV. Taxonomy - soils database (Profiles and routine observations with Excel) - soils mapping (scale 1:25,000).

V. Land evaluation: physical suitability of the soils of the project area for irrigated agriculture for a number of selected crops, commonly grown in the project area and surrounding areas (Allison, L.E., 1956).

According to the study area falls in a desert climate-summer rains and cool winters (Van der Kevie, 1976). Table 2.1 shows the meteorological data of Kareima area sixty km to the east of the study area. Mean annual temperature is 29.1°C. Average maximum temperatures in the hottest months (April – June) are 39.0 to 43.3°C while the minimum temperature for the same period is 21.3°C to 26.6 °C. The minimum temperature during the winter (Dec – Feb) is 13.8ºC to 12.2ºC. The relative humidity fluctuates during the day (GMT) and during the year (seasons). The mean annual relative humidity ranges between 29-22% (Jan to Feb), 17-15% (March to June) and 24-31% (July to December).

The average annual rainfall is about 25.9 mm falling mainly in July and August with very low amounts in September. The rainfall is erratic in quantity, intensity and distribution. The area falls under the effect of northeasterly winds in October through May and southwesterly winds as from late June through October. The high temperatures coupled with strong solar radiation result in values of potential evapotranspiration exceeding by far the rainfall almost throughout the year, except in August (Table 1.; Fig. 2.), a phenomenon which is not unexpected for a desert climate which typifies the study area.

Table 1. Climatological normal (1941-2003) of Kareima Station

Months / Temp. °C	Jan	Feb	Mar	Apr	May	June
Mean	20.3	22.0	25.8	30.1	33.7	34.9
Mean Max	28.4	30.5	34.6	39.0	42.2	43.3
Mean Min	12.2	13.5	17.1	21.3	25.2	26.6
Av. annual R F(mm)	0.0	0.0	0.0	0.0	0.6	0.0
Evap. Piche (mm)	5.8	7.1	8.5	9.5	10.2	9.7
Mean R. H. (%)	29	22	17	15	15	15
Wind speed and Direction	247N	275N	276N	262N	260N	232N

Table 1. cont. Climatological normal (1941-2003) of Kareima Station

Months / Temp. °C	July	Aug	Sep	Oct	Nov	Dec	Annual
Mean	34.5	34.3	34.4	31.7	26.0	21.6	29.1
Mean Max	42.0	41.4	41.9	39.4	33.6	29.4	37.2
Mean Min	27.0	27.2	27.0	24.1	18.4	13.8	21.1
Av. annual R F(mm)	8.0	13.9	2.8	0.6	0.0	0.0	25.9
Evap. Piche (mm)	8.9	8.6	8.7	8.1	6.8	5.8	2.97
Mean R. H. (%)	24	28	21	22	27	31	22
Wind speed and Direction	205N	206N	219N	234N	249N	249N	243N

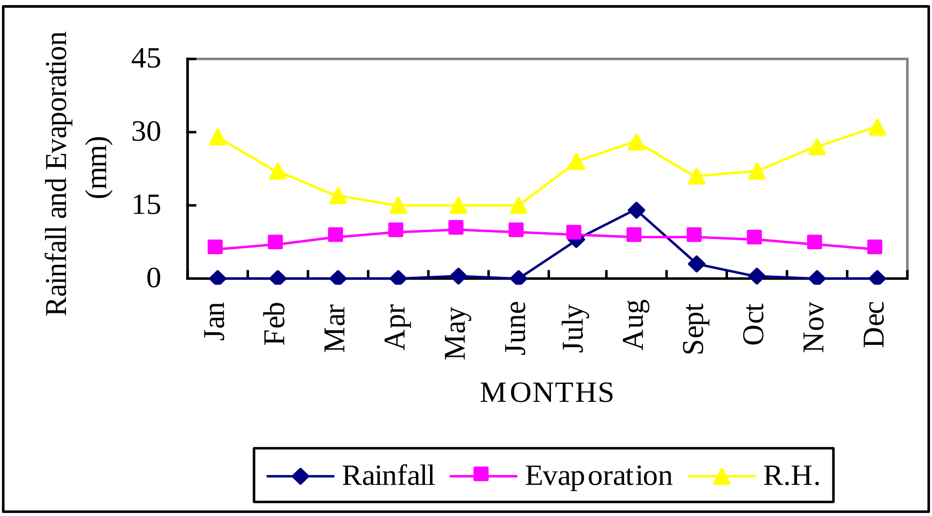

Fig. 2. Rainfall, evaporation and relative humidity of Kareima area during the period 1941 – 2003

The main geological formations in the area are Basement complex and Nubian Sandstone formation. Basement complex rocks outcrop only at small batches. The study area can be divided into the following physiographic units:

- Slightly elevated undulated areas: these are flat/concave plains. They are covered with sand sheets of varying depths and underlain by fluviatile deposits- siltstone, mudstone and sandstone (Geological map of Sudan, 1981).
- Abandoned wades and chord channels: these are flat plains with alluvial origin covered invariably with thin sheets of sands.
- *Galaa*: these are elevated convex areas consisting of gravel boulders stones and rock fragments. They seem to have resulted from the physical weathering of the parent material followed by deflation of the fine material leaving gravels and boulders behind (Boul, S. Et.all., 1956).

2. MATERIALS AND METHODS

This stage started by entering the coordinates of the boundaries of the study area into a satellite image. Then a square grid was set up to represent the location of the auger sites and/or representative soil profiles. The grid was aligned so that in the field the auger sites were 250 m apart (i.e. scale 1:25,000 and density of observation of 1observation/cm^2 on the map) in all directions. At this density of observation the total number of check sites (auger sites + representative) in the field was 107 sites.

The locations of the auger sites, within the boundaries of the study area, were given serial numbers and their coordinates were recorded printouts of this grid were reproduced to be used for navigation and location of the check sites by the different auger description and sampling groups in the field.

The grid was superimposed on the satellite image (False colors composite (FCC) composed of three bands) and the image plus the grid were color-printed in A0 sheets.

The following materials were consulted or used:

- Coordinates of the study areas.
- False colors composite (FCC) composed of three bands from the wavelength of the electromagnetic spectrum acquired by Enhanced Thematic Mapper Plus (ETM+).
- Hardware and Software:PC Intel Core^{TM}Duo 80 GB.HD, 2.32 MHz speed and 256 RAM, Scanner Genius Color page-HR5 30-Bit optical resolution 600X1200 DPI SCSI, Color printer HP Desk jet 7000 series, Digital Cameras, Erdas Imagine 8.5., ArcGis, Microsoft Excel 2007, Microsoft Word 2007, GARMIN eTrex Venture HC GPS receiver.

Besides the ougers, 9 soil profiles at the above-mentioned density of observation. Table 2 gives a summary of the scope of the field work in the study area.

Table 2. The scope of the targeted and achieved field work

Item	**Targeted**	**Achieved**
Area (feddans)	≈ 2000	≈1650
Number of auger sites	107	107
Number of soil samples from auger sites	321	310
Number of representative soil profiles	9	9
Number of soil samples from representative soil profiles	27	26

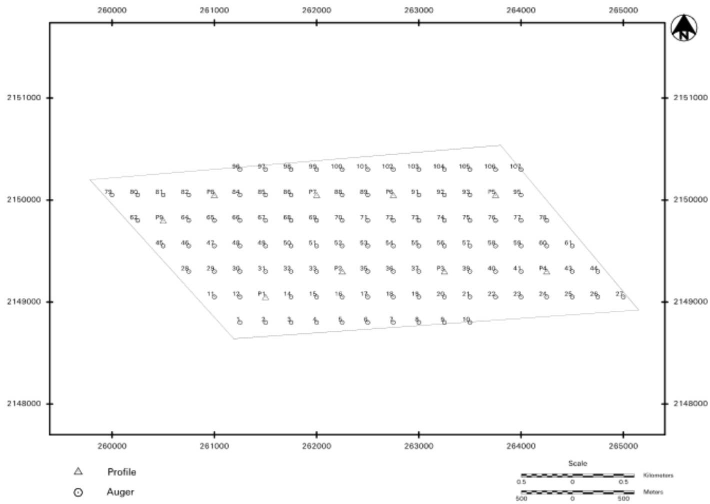

Figure 3. The grid showing the location of the auger and representative soil profile sites

The tentative locations of the soil profiles were again checked on the basis of a quick tour in the field made one day before each group of soil profiles were to be dug. Representative soil profiles were later selected from among these soil profiles to determine crop suitability for different mapping units. At each soil profile site a pit (1x 1x1.5 m) was manually dug. Each horizon or layer was photographed. Each profile was then tentatively classified down to the subgroup level or phases of sub groups according Keys to Soil Taxonomy (USDA, 2010) on the bases of its morphological properties (FAO, 1985).

A total of 300 auger samples and 26 soil profile sample were analyzed. The analysis run and methodology adopted in the auger and soil profile samples are shown in Tables 3. and 4. respectively.

Table 3. Soil analysis and analytical methods for auger samples

• **Soil pH** Determined in the saturated soil paste. The pH was read by a glass/calomel electrode (concentrated KCL) system (Model Superfit TM Digital pH Meter).
• **Electrical Conductivity (ECe) dS/m at 25°C** Determined in saturation extract. The ECe of the suspension was read using a digital EC conductivity meter (Model Jenway 4510 Conductivity Meter)
• **Sodium Adsorption Ratio (SAR)** SAR = $Na/\sqrt{(Ca+Mg)/2}$, soluble Na, Ca and Mg substituted in this equation are in Mmole+ / L
• Soluble Na and K were determined using flame photometer, Ca and Mg by titration with EDTA.

Table 4. Soil analysis and analytical methods for soil profile samples

• **Particle Size Analysis** All results refer to oven dry soil. The soil was treated with HCl to destroy calcium carbonate, washed to remove soluble salts and dispersed chemically with calgon and mechanically with a dispersion machine. The pipette method was used to determine the clay fraction and wet sieving for the separation of the sand fraction. The silt fraction was obtained by subtraction from 100%. Sand fractionation was done using the appropriate set of sieves.
• **Soil Textural Class** The USDA textural triangle was used to determine the textural class of the soils
• **%Organic Carbon (OC),** Determined by the modified Walkly – Black method. The sample was oxidized with potassium dichromate + sulphuric acid and the excess potassium dichromate that was back titrated with ferrous ammonium sulphate. Recovery factor was 0.77
• **Total Nitrogen (N), %** Modified Micro Kjeldahl method. Pre-moistened soil was digested with concentrated sulphuric acid Distillate, using ammonium hydroxide to liberate ammonia, was received in 2% boric acid and titrated using 0.01 M sulphuric acid
• **Available phosphorus (P), ppm** Determined by Olsen sodium bicarbonate extraction method.
• **Soil pH** Determined in the saturated soil paste. The pH was read by a glass/calomel electrode (concentrated KCL) system (Model Superfit TM Digital pH Meter).

• **% Calcium Carbonate (CaCO3),** Determined by titration. The soil was boiled with 1N HCL. Excess acid was titrated versus 1N NaOH using phenolphthalein indicator.
• **Electrical Conductivity (ECe) dS/m at 25° C** Saturated soil paste was prepared by adding a known weight of soil to a known quantity of water to paste consistency. Saturation extract was sucked off using a vacuum pump. ECe of the saturation extract was read with a conductivity meter ((Model Jenway 4510 Conductivity Meter) .
• **Soluble Cations, mmol+/l** Soluble anions and cations were determined in mmol+/L. Soluble Na was determined in the saturation extract by the flame-photometer. Ca and Mg were determined by titration with EDTA. Soluble K, which is usually cited as traces or in negligible values, was determined using the flame-photometer.
• **Sodium Adsorption Ratio (SAR)** SAR = $Na / \sqrt{(Ca + Mg)/2}$. Soluble Na, Ca and Mg substituted in the equation, are in Mmol+./litre.

3. RESULTS AND DISCUSSIONS

Land form units identified in the study area include the following:

1. Slightly elevated undulated areas: these are flat plains between abandoned wades and chores. They are covered with sand sheets of variable depths. In some places they were underlain by fluviatile deposits (siltstone, mudstone and sandstone).
2. Abandoned *wades* and *chores* channels: these are seasonal wades and chores, in this area are small seasonal water courses i.e. rills, they transected the land and constitute a very complex structure.
3. Galaa: These are elevated convex areas consisting of gravel, boulders and rock fragments. They seem to have resulted from physical weathering of the parent materials followed by deflation of the fine materials which left gravel and boulders behind.

The soils of the area in so far as their origin is concerned can be divided into the following:

1. Sedentary (residual) soils: these soils occupy partially elevated sites. They seem to have being affected by chemical weathering during a former more wet period than the present climate. They are medium textured soils of grayish and dark grayish color.
2. Transported soils: These are soils which have resulted from weathering products transported into the area either by wind or water (colluvial and fluvial processes).

The soils of the study area were classified according to the Soil Taxonomy (Keys to Soil Taxonomy, 2010) from the order down to the subgroup level. The soils were classified mainly on the effect of the soil forming factors and processes on morphology of the soils as reflected in the field. In some cases a saline, sodic, shallow or gravel phase was superimposed on the subgroup level.

The differentiating (diagnostic) characteristics used at the different categorical levels in class included the following:

- Presence or absence of major diagnostic horizons i.e. those which are indicative to the leading soil forming processes that dominated the course of soil formation (ORDERS).
- Presence or absence of properties associated with wetness, soil moisture regime, and major parent material that all reflect genetic homogeneity (SUBORDERS).
- Kind, arrangement and degree of expression of soil horizons, with emphasis on the upper sequm; moisture regime (GREAT GROUPS).
- Expression of central concepts of the great group, deviation (within the great group) from the central concept of the great group or intergradations to other great groups, suborders or orders (SUBGROUPS).

Soil properties and characteristics that were found to be of special use in classifying the soils of the area included:

Lack of horizonation (lack of pedogenic horizons) and presence of transitory properties such as sedimentation layers. Presence of sub-surface diagnostic horizons e.g. Cambic horizon. Degree of horizon differentiation within the soil profile. Presence or absence, nature and distribution of calcium carbonates. Soil depth. Soil color. Presence of gravels. Levels of ECe (salinity) and SAR (sodicity).

Table 5. Classification of the area down to the Subgroup (SG) level

Unit No.	Classification (GG)	Phase	Profile No.
2	Typic/lithic Torriorthents		2
7	Typic Haplocambids	Gravelly reddish phase	1, 3
8	Typic Haplocambids	Greyish reddish phase	4, 5, 6, 7, 8, 9

Soil units are areas of consistent soils or soil patterns. They are either simple units (consociations) dominated by one profile class, or compound units (association or complex) which are dominated by more than one profile class. All the mapping units delineated in the study area are consociations at the sub-group level. Table 6 presents a brief description and classification of the different mapping units.

Table 6. Brief description and classification of the different mapping unit

1	Shallow soils with no horizon differentiation confined to the western and northern peripheries of the project in addition to scatter pockets in the central part of the project. They are covered by superficial gravel and sand, they are sand clay loam and non-saline and non-sodic.	Lithic Torriorthents,
2	Deep residual soils with a cambic horizon scattered as pockets in south and north parts. They are non cracking, non-saline, non-sodic, calcareous sandy clay loam with reddish color.	Typic Haplocambids (Gravelly reddish)
3	Deep residual soils with a cambic horizon covered the rest the project area and extended on the middle of the survey area. They are non-cracking, non-saline, non-sodic, calcareous sandy clay loam with reddish/grayish color.	Typic Halpocambids (Greyish reddish)

The class limits of the soil properties used in the description of the individual mapping units are presented in Table 7.

Table 7. Class limits of the soil properties

pH (H_2O) (top soil)	
class	values
NE neutral	6.6-7.5
AL alkaline	7.5-8
MA m. alkaline	8 - 9
VA v. alkaline	> 9

Sodicity		Salinity	
class	(SAR)	Class	(EC) (dS/m)
NSOD Non-sodic	<13	NS Non-saline	< 4
SSOD Slightly sodic	13-23	SS Slightly saline	4 -8
SOD Sodic	23-33	MS Moderately saline	8-12
STSOD Strongly sodic	33-48	S Saline	12 -16
VSTSOD Very strongly sodic	>48	VS Very saline	16 - 32
		ES Extremely saline	> 32

Organic Carbon (topsoil)		Calcium Carbonate (topsoil)	
class	values (%)	class	values (%)
VL very low	< 0.4	N very low	< 5
LO low	0.4-0.8	S low	5-10
ME medium	0.8-1.2	M moderate	10-20
HI high	> 1.2	H high	20-35
		V very high	> 35

Texture						
S sandy	S	Sand		Si silty	Si	Silt
	LS	Loamy Sand			SiL	Silty Loam
L loamy	L	Loam		SiC silty clayey	SiCL	Silty Clay Loam
	SL	Sandy Loam			SiC	Silty Clay
	SCL	Sandy Clay Loam		C clayey	SC	Sandy Clay
	CL	Clay Loam			C	Clay

The characteristics and properties of these taxonomic units are summarized below:

Lithic Torriorthents

Profile No.	Depth	SAR	SO4	HCO3	Cl	CaCO3	P	N	O.C
	cm		meq/l	meq/l	meq/l	%	ppm	%	%
P2	0-30	0.40	1.01	6.0	22.0	3.9	1.5	0.42	0.10
	30-65	2.04	34.16	4.0	60.0	4.9			
	average	1.22	17.59	5.00	41.00	4.37	1.50	0.42	0.10

Profile No.	Depth	Caly	Silt	Sand	Gravel	texture class
	cm	%	%	%	%	
P2	0-30	20.1	8.4	71.5	28.9	sandy clay loam
	30-65	12.6	13.4	74.0	44.43	sandy loam
	average	16.33	10.93	72.74	36.71	

Litic Haplocambids

Profile No.	Depth	SAR	SO4	HCO3	Cl	CaCO3	P	N
	cm		meq/l	meq/l	meq/l	%	ppm	%
p1	0-40	1.00	25.12	5.00	30.00	5.04	1.70	0.42
	40-70	1.72	264.70	5.00	370.00	4.95		
	70+	3.25	194.10	4.00	270.00	4.05		

Profile No.	Depth	O.C	Clay	Silt	Sand	Gravel	Texture class
	cm	%	%	%	%	%	
p1	0-40	0.03	20.09	15.94	63.97	43.31	sandy clay loam
	40-70		32.62	8.42	58.96		sandy clay loam
	70+		30.12	15.94	53.94		sandy clay loam
	86+		17.58	20.95	61.46		sandy loam

Typic Haplocambids (Greyish reddish)

Profile No.	Depth	SP%	pH	EC e	Ca+Mg	Ca	Na	K
	cm	%		dS/m	meq/l	meq/l	meq/l	meq/l
p4	0-35	47.37	8.16	0.24	6.50	2.00	0.48	0.11
	35-90	42.32	7.94	0.72	5.00	2.50	2.13	0.10
	90+	55.79	8.14	0.56	7.00	2.00	1.17	0.10

Profile No.	Depth	O.C	clay	Silt	Sand	Gravel	Texture class
	cm	%	%	%	%		
p4	0-35	0.03	20.09	18.45	61.46		sandy clay loam
	35-90		40.14	3.41	56.45		sandy clay
	90+		22.60	15.94	61.46		sandy clay loam

The suitability of the land to different crops is determined for field and horticultural crops (vegetables and fruits) according to Table 9.

Table 9. Land suitability to agricultural crops

Suitability index for a crop or the average for a group of crops	Degree of suitability
0 – 20	Unsuitable
20 – 40	Poor
40-60	**Lytic/TypicTorriorthens** ***MODERATE***: Field crops: Ground nut, Haricot beans Vegetable: Potato Fruits Date palm,Orange **Litic Haplocambis** Fieldcrops:Horicot beans,Chick pea,Lentils,Soya bean **Typic Halocambis** Field crops: Ground nuts Fruits:Grape, Dade, Orange
60-80	**Torriorthens** ***GOOD***: Wheat,Barley,Lentils,Alflfa Vegetable: Onion,Tomato,Sweet paper,Cabbage Fruits: Date palm,Orange, grapes **Litic Haplocambids** Field crops: Soya bean,Ground nut,Sorgum,Maize, peas, Faba bean, Subflower Vegetable:Onion Tomato, Cabbage,Potato,Sweep peper. Fruit: Grapes Data palms,Banana, Guava,Mango, Orange Typic Halocombids Field crops:Haricot beans, Soyabean,Sorgum,Maize,Peas Sunflower. Vegetable:Onion,Tomato, Potato,Sweet peper, Cabbage Fruits: Grapes

4. CONCLUSIONS

1. The level of both macro and micronutrients is low which is not unexpected of such soils that have developed under desert conditions with minimal weathering. This require an effective fertilizer program by addition of nitrogenous, phosphatic and potassic fertilizers, together with foliar spray of micro nutrient fertilizers for successful crop production. The recommended doses are: 100 kg/feddan urea splitted to two doses and/or ammonium sulphate at the rate of 150 kg/feddan applied once and 100 kg super phosphate per feddan before planting every other season.
2. The organic carbon, and hence, organic matter is low as expected. Therefore, addition of organic manures should be entertained. Fresh organic manures (farmyard manure) could be applied at the rate of three to 5T/feddan and chicken manure at the rate of 2T/feddan. Green manure is also beneficial.
3. The infiltration rates of some soils are either high or low. This fact coupled with the undulated topography of the area, might suggest that modern irrigation systems e.g. drip, sprinkler, center pivot…etc. should rather be adopted.
4. Three Soil Groups have been identified; Lytic/Typic Torriorhens, Litic Haplocamids and Typic Haplocamids.

5. LITERATURE

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REZIME

Cilj studije je istraživanje pogodnosti zemljišta za organizaovanje poljoprivrene proizvodnje, te modela korišćenja zemljišta, što je delom opisano od FAO (1976), kao i utvrđivanje specifične pogodnosti zemljišta za specifične načine njegovog korišćenja u sisitemu integrisane poljoprivredne proizvodnje i sisitema savremenog menadženta, što je upotpunjeno rezultatima predmetnih istraživanja.

Utvrđena su dva specifična premeta-cilja:

I. Ispitiv anje karakteristika zemljišta i klasifikacija istih prema (USA Soil Lab.),

Taksonomija zemljišta (Profili i rutinske observacije u Excel) – kartiranje (scl. 1:25,000).

III. Evaluacija zemlji: fizičke osobine projektne zone u uslovima navodnjavanja, prema Sys *et. al.* (1991) za određeni broj odabranih biljnih vrsta, uobičajeno u setvenoj strukturi u okolnoj regiji.

Dobijeni poljski i laboratorijski rezultati istraživanja su utvrdili postojanje 3 grupe zemljišta (Tipic/Litic Torriorthens, Litic Haplocamids and Typic Haplocamids), te je izvršena detaljna evaluacija istih, sa ciljemutvrđivanja naj adekvatnijeg modela setvene strukture i rotacije useva na površinama zemljišta Severnog Sudana, bazirano na "optimizaciji uslova i pogodnosti zemljišta i biljnih vrsta".

Korišćenjem ovog modela izvršena je detaljna evaluacija različitih Ratarskih, Povrtarskih I Voćarski kultura, te izvršen finalni izbor i prezentacija korišćenja osnovnog-detaljnog modela sprovođenja I vođenja biljne proizvodnje, u okviru celovitog programa održive i integrisane poljoprivredne proizvodnje područja.

Ključne reči: Evaluacija zemljišta, reklamacija zemljišta, pogodnost zemljišta, rezidualna zemljišta, ispiranje soli.

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