OSUN GEOGRAPHICAL REVIEW
Published by the Department of Geography, Osun State University, Osun State, Nigeria
ISSN: 2695 - 1959 Volume 7, 2025; 18 - 24

SOIL PHYSICAL CHARACTERISTICS AND CONSTRAINTS TO CROP PRODUCTION IN NORTHERN YOBE STATE, NIGERIA

[1]K. M. Kazeem, [1]B. Boso, [2]A. Saleh

[1]Department of Geography and Environmental Management, Yobe State University, Damaturu, Nigeria
[2]Federal University Gashua, Yobe State, Nigeria
Corresponding Email: bosobabagana@gmail.com

Abstract

Soil fertility is declining in northern Yobe State due to land degradation resulting from the combined effect of natural environmental processes and human activities in the area. The objective of the study is to assess the physical characteristics of the soil of the area for constraints to crop production. The study area was divided into six physiographic units. Composite samples were taken in each of the physiographic unit following the flexible grid and stratified sampling procedures and analyzed. The results revealed that the soil of the area is medium to coarse textured, has mean bulk density of 1.6 g/cm^3, mean soil moisture percentage of 5.354 %, and mean infiltration rate of 1.30 cm/minute. However, variation in these parameters was observed among the different physiographic units. The dune field is essentially silty in texture with smaller pore diameter and high crop root penetration resistance, while the plain and plain/hill areas are sandy and are associated with rapid to very rapid infiltration rates and downward leaching of soil nutrients. The observed mean bulk density of soils of the area is a condition that may restrict root growth, while wind erosion and poor soil drainage are prominent physical restrictive features to crop production in the area. It is recommended that improving soil condition in the area for sustainable crop production requires an integrated approach involving vegetation regeneration to increase soil organic matter and reduce soil erosion by wind, shifting from the use of inorganic to organic fertilizers, controlled harvesting of vegetal resources, adopting agroforestry practices and providing soil management education for the farmers in the area.

Keywords: Soil; Physical Characteristics; Constraint; Crop production; Northern Yobe

Introduction

Nigerian Government has renewed efforts, since 2016, at increasing food production and ensuring food security for her growing population and invariably contributing the country's Gross Domestic Product (GDP). However, in spite of these renewed efforts, food production has not significantly improved. The contribution of agricultural production to the country's GDP in the first quarter of 2020 stood at 21.96 percent. This is just a little higher than 21.66 percent recorded in the first quarters of 2019 (Okoje, 2020). By 2023, it's only a marginal increase as it stood at 26.36 percent (National Bureau of Statistics, 2023).

In Yobe State, Nigeria, crops yield has been on the decline (National Food Reserve Agency, 2007). More recent report indicated that yields of most cultivated crops in the area, especially in the northern part, have not significantly improved (FAO, 2020). This area is characterized by high temperature, low rainfall and poor soil (FAO, 2020). Perhaps, the poor soil condition could be one of the limiting environmental factors to crop production in the area. Current information on the physical characteristics of soil of the area is limited. For effective agricultural planning for the area therefore, there is the need to find a scientific explanation to the poor soil condition and invariably the declining crop yield in the area. Perhaps the soil physical characteristics of this area may be partly responsible for poor soil condition and invariably declining crop yield. The objective of this paper is to assess the soil physical condition of northern Yobe State, Nigeria, for sustainable crop production.

Materials and Method

The study area is characterized by a hot and dry climate for most part of the year. It lies between latitudes $11^{0}\ 30^{1}$ and $13^{0}30^{1}$ N, and longitudes $9^{0}15^{1}$ and $12^{0}\ 30^{1}$ E, covering an area of 23,668.10474 square kilometers. It consists of areas that have been severely affected by desertification, covering nine (9) Local Government Areas of Yobe State. (Figure 1). Annual rainfall in the area is in the region of 250 – 300 mm. Maize, sorghum, groundnut, bambara nut, sesame, guna seed, onions are among the crops grown in the area (FAO, 2020).

The area was divided into six physiographic units following the stratified sampling procedure– plain, flood plain, dune field, ridge, plain and hill, and valley. Composite samples of soils at 0-25cm depth were then taken from each of these units following the flexible grid method. A total of forty (40) composite samples were taken from the six physiographic units. The samples taken were then air-dried for laboratory analyses. However, physical restrictive features, which were product of natural environmental processes, were physically observed on the field.

Particle size distribution was determined by the Hydrometer method of Bouyoucos (1951) and textural class was read from the textural classification triangle illustrated by Forth (1978). The hydrometer method adopted is basically a measurement of the density of the suspension which is a function of the concentration and kind of particles present (after a certain time of setting). After shaking with dispersion

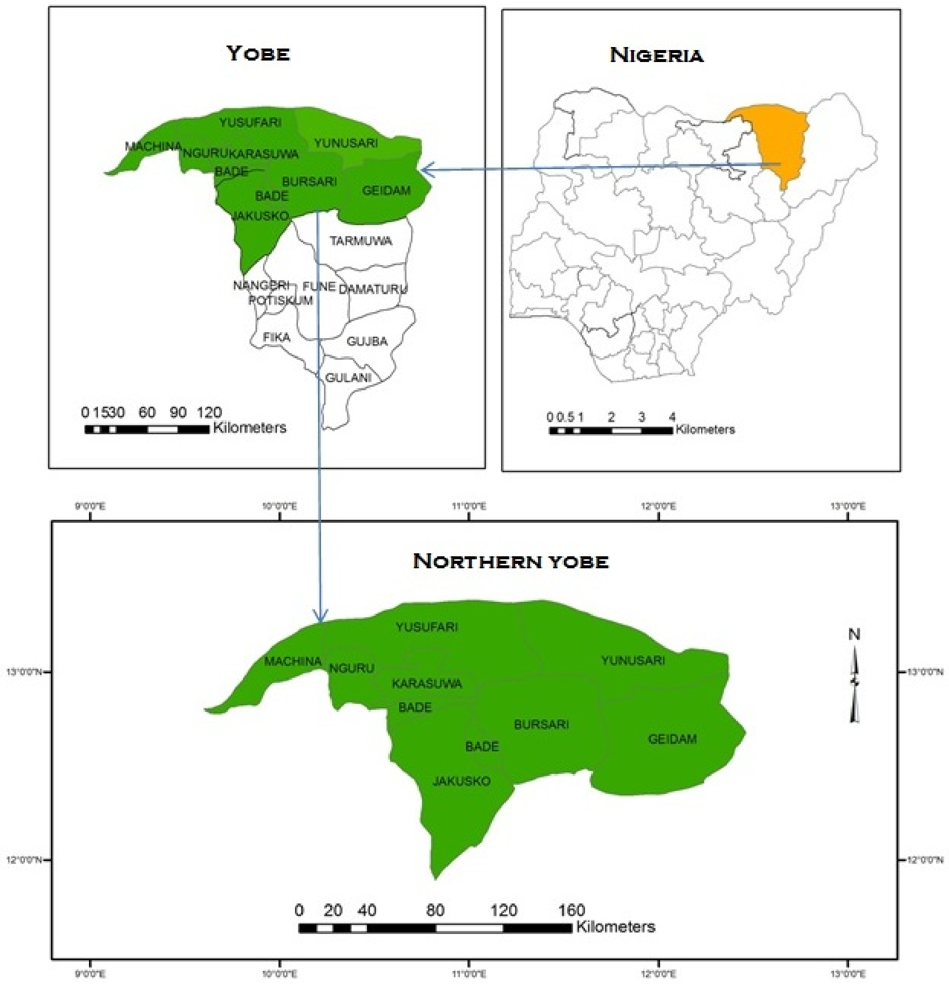

Figure 1: Map of Yobe State, showing the study area (Nine LGAs affected by desertification in northern Yobe).

agent, sand was fractionated by dry sieving; the clay and silt fraction were then determined by hydrometer readings.

Following the procedure explained by Van Reeuwijk (2002) for determining moisture content, approximately 5g (each sample) of soil was transferred to tared moisture tin and weighed with 0.001 g accuracy (A gram). It was then dried overnight at 105 ^{0}C (with lid removed). Tin was removed from

oven and closed with lid. It was then cooled in dessicator and weighed (B gram). Percent moisture content was then obtained using the relationship:

Moisture (wt. %) = A – B/B – tare tin x100 %

For all the samples analysed, a moisture correction factor was then applied thus;

Moisture correction factor = 100 + % moist/100

Bulk density was determined using oven drying method as explained by Van Reeuwijk (2002). A cylindrical or core sampler was driven into the soil to collect surface soil samples. The samples were then oven-dried at 105 ^{0}C for 48hrs to obtain dry mass. The bulk density was then calculated as ratio of mass of oven-dry soil to the volume of the core cylinder (g/cm^3).

Within each of the PUs, infiltration rate was determined using a double-ring infiltrometer. The double ringed infiltrometer was driven into the soil to a depth of 6 inches. This was done with the help of a wood-block to achieve uniform penetration.

Table 1: Distribution of Soil Composite Samples by Physiographic Units in Northern Yobe State

PU/SMU	Farm Village/Settlement	CS
Plain	Kelluri/Afnori/Kachalari	7
Dune Field	Lantewa/Matti/Dapchi	7
Flood Plain	Dagona/Gashua	7
Hill	Lamisu/GonaSariki/Machina	7
Ridge	Gumari/Futchiimiram	5
Valley	Gumsa/Turbangida/Muguram	7
Total	**6** **20**	**40**

PU- Physiographic Unit; SMU - Soil Mapping Unit; SP – Soil Profile; CS – Composite Sample.

Caution was taken to ensure minimal disturbance of the soil during the driving of the infiltrometer into the soil. A pail (bucket) was then used to fill both rings (outer and inner) with water to the desired depth in each ring. Initial readings were taken (i.e. initial time and water level (height) in the inner ring of the infiltrometer) and final readings were also taken after 15min or less, depending on the observed rate of flow as the area is essentially sandy. The differences in these two parameters – initial/and final time, initial/and final water level in inner ring, were obtained. Infiltration rates were then determined for all soil units as ratio of time taken (in minutes) to the difference in water level in the inner ring of the Infiltrometer, while soil temperatures were measured at depth of 10cm and the mean value determined for each physiographic unit.

Results and Discussion

Table 2. presents the results of the laboratory determination of the physical characteristics of the soil of northern Yobe State.

The soil is medium to coarse textured. It is mostly characterized by silty loam on the plain, the flood plain and the dune field, while the ridge, plain and hill and the valley are essentially sandy. Similar observations have been made for Nigerian semi-arid soils by Maharazu, (2001) and Usman (2020).

By physiographic units, the highest mean bulk density of 1.697 and 1.70 g/cm^3 were observed in the soils of the flood plain and that of the plain and hill respectively (see Table 2). However, the mean bulk density of soils of the area was observed to be 1.41 g/cm^3. These values are just a little at variance with 1.48 mg/m^3 reported for Maiduguri, semi-arid area of Nigeria and that of (1.39 mg/m^3) reported for Nigerian savanna. The observed mean value of bulk density in northern Yobe State is also just slightly higher than the 1.34g/cm^3 previously observed by Alhassan et al (2018) for Nigerian semi-arid savanna. While recent report of Usman (2020) indicated median value of 1.63 Mgm-3 and mean values of 1.3 – 1.6 g/cm^3 respectively for selected parts of Yobe State. while bulk density of 1.80 and 1.45 gcm^3 have been recently reported for cultivated land and grass land respectively in Gashua, northern Yobe State (Alhassan and Audu, 2023).

Mean soil moisture percentage in the soils of the area was observed to be 5.354 %. However, the highest soil moisture percentage (22.20 %) was observed on the flood plain. The lowest percent moisture content (1.010 %) was observed in the soil of the dune field. However, recent study of Alhassan and Audu (2023) reported mean soil percent moisture of 13.01 for cultivated rain fed agricultural land in Gashua, Yobe State. However, the mean soil moisture percentage

Table 2: Physical Characteristics of Surface Soils in Northern Yobe State

PU/SMU	Texture (%) Sand	Silt	Clay	T.C	$D_{b(g/cm)}$	M_p(%)	T_s(°C)	I_r(cm/s)
Plain (Kelluri, Afnori, Geidam and Kachallari)								
PL/Lp1	87.50	2.70	9.80	S	1.67	1.025	31.20	1.90
PL/Lp2	87.50	2.70	9.80	S	1.76	1.045	30.50	1.89
PL/Lp3	81.00	9.00	9.70	SL	1.51	3.039	29.90	1.83
PL/Lp4	71.50	14.70	13.80	SL	1.53	3.051	29.80	1.98
PL/Lp5	74.20	18.00	7.80	SL	1.69	3.036	29.70	1.91
PL/Lp6	89.50	2.70	7.80	S	1.49	1.035	32.70	1.94
PL/Lp7	81.30	9.30	9.70	LS	1.59	3.040	31.10	1.87
Sub-mean	82.04	8.16	9.80	S	1.53	2.181	30.70	1.90
Flood Plain (Dagona, near Gogoram and near Balle)								
FPL/Fp1	61.00	25.00	13.70	L	1.82	23.20	26.60	0.19
FPL/Fp2	68.20	22.00	10.00	SL	1.58	21.46	26.20	0.17
FPL/Fp3	67.80	21.30	10.90	SL	1.67	20.89	25.40	0.18
FPL/Lp4	62.30	24.80	10.90	L	1.75	22.80	26.90	0.16
FPL/Fp5	68.20	22.00	9.50	SL	1.69	21.77	26.30	0.20
FPL/Fp6	69.00	15.30	15.70	SL	1.79	22.69	26.40	0.16
FPL/Lp7	70.10	15.90	14.00	SL	1.71	23.15	25.50	0.19
Sub-mean	66.60	23.40	11.80	SL	1.78	22.30	26.20	0.19
Dune Field (Lantewa, Matti and near Dapchi)								
DF/Df 1	83.00	2.70	13.80	SL	1.47	2.033	34.30	1.67
DF/Df2	70.20	18.80	11.00	SL	1.53	2.027	30.80	1.74
DF/Df3	69.10	17.80	13.10	SL	1.59	2.031	31.70	1.69
DF/Df4	42.10	24.60	33.30	CL	1.49	1.010	33.20	1.59
DF/Df5	81.00	9.30	9.70	LS	1.46	1.041	31.83	1.83
DF/Df6	85.00	7.30	7.70	LS	1.47	1.038	30.99	1.91
DF/Df7	87.00	7.30	5.70	LS	1.49	1.040	32.67	1.97
Sub-mean	73.90	15.77	16.30	SL	1.49	1.460	32.20	1.77
Ridge (Gumari and near Futchimiran)								
RD/Rg1	85.50	6.70	7.80	LS	1.57	3.027	29.95	1.73
RD/Rg2	85.50	6.70	7.80	S	1.57	1.032	32.76	1.78
RD/Rg3	71.50	14.70	13.80	SL	1.64	3.031	31.50	1.73
RD/Rg4	85.50	6.70	7.80	S	1.54	1.035	30.51	1.82
RD/Rg5	83.50	8.70	7.80	S	1.59	1.273	29.95	1.79
Sub-mean	82.30	8.70	9.00	LS	1.59	1.879	32.17	1.78
Plain and Hill (Gona Sariki, Lamisu and Gumsa)								
PLH/Lh1	90.20	2.00	7.80	S	1.73	1.034	31.40	1.77
PLH/Lh2	89.10	3.30	7.60	S	1.65	1.033	32.60	1.84
PLH/Lh3	91.30	2.40	6.30	S	1.70	1.031	32.50	1.72
PLH/Lh4	90.20	2.00	7.80	S	1.69	1.029	32.30	1.78
PLH/Lh5	90.20	2.00	7.80	S	1.68	1.037	31.50	1.71
PLH/Lh6	88.90	2.00	9.10	S	1.56	1.035	31.50	1.76
PLH/Lh7	88.20	4.00	7.80	S	1.67	1.034	30.10	1.77
Sub-mean	89.70	2.60	7.70	S	1.60	1.033	32.17	1.78
Valley (Gumsa, Turbangida/Mugaram)								
VL/Va1	68.10	22.30	13.80	S	1.50	1.260	31.55	0.45
VL/Va2	70.10	14.90	15.00	S	1.49	1.280	29.90	0.23
VL/Va3	68.90	16.10	15.20	S	1.55	1.110	31.50	0.45
VL/Va4	61.00	25.30	13.70	L	1.51	4.130	30.53	0.71
VL/Va5	67.00	23.30	9.70	SL	1.58	4.220	31.61	0.46
VL/Va6	79.00	11.30	9.70	SL	1.56	4.520	31.22	0.37
VL/Va7	87.00	7.30	5.70	LS	1.49	4.350	30.90	0.55
Sub-mean	71.70	16.20	12.10	SL	1.54	3.268	31.40	0.43
Mean	**77.70**	**12.50**	**11.1**	**S**	**1.60**	**5.354**	**30.80**	**1.30**

Pl-Plain; PLH-Plain and Hill; Df-Dune Field; FLP-Flood Plain; VL-Valley; RG-Ridge; Lp1-7: Plain1 to 7; Lh1-7: Plain and Hill1 to 7; Val-7-Valley1 to 7; Rg1-5: Ridge 1 to 5; Df1-7: Dune Field1 to 7; Va1-7: Valley 1 to 7; Rg1-5: Ridge1 to 5; Fp1-7: Flood Plain 1 to 7; T.C-Textural Class; Db-Bulk Density (g/cm^3); Mp-Moisture Percentage; Ts-Mean Soil Temperature at growth at 5 and 10cm; Infiltration Rate (cm/minute): T.C-Textural class; S-Sandy Loam; CL-Clay Loam; PU-Physiographic Unit; SMU-Soil Mapping Unit.

observed in northern Yobe State is close to the values of 4.6, 3.0; 4.9 percent reported for soils under different treatments in semi-arid Kenya. Soil moisture percentage (22.3 %) observed in the soils of the flood plain of northern Yobe State, is just a little higher than the values of 21.6% observed in the area of grassland of semi-arid northern China.

Soil temperatures condition range between 26.0 to 34.3 ^{0}C, while mean soil temperature in the area during the 2022 cropping season was observed to be 30.8 ^{0}C (see Table 2). However, there is variation in the mean soil temperatures from physiographic unit to physiographic unit. Mean soil temperatures of 30.78 ^{0}C, 26.20 ^{0}C, 32.2 ^{0}C, 32.17 ^{0}C, 32.17 ^{0}C and 31.4 ^{0}C were observed in the area of the plain, flood plain, dune field, ridge, plain and hill, and valley respectively (see Table 2). Highest soil temperature (34.3°C) was observed in the soil of the dune field (Df1) while the lowest (25.5 ^{0}C) was in the soil of the flood plain (Fp7).

The mean values of soil temperature observed in northern Yobe State were close to the values of 38.5°C and 27.2°C observed for intercanopy and canopy diurnal temperature in the semi-arid Pinon-juniper woodland in northern New Mexico. The observed range of soil temperature is also within the values of 31.06 °C, 29.11 °C, and 28.16 ^{0}C.

Soil infiltration rate in northern Yobe State is relatively high. The soil is essentially sandy. Invariably, infiltration rates were then measured as rate of flow of water through the soil per minute (and not per hour). The rate of flow per minute was observed to be relatively high except on the flood plain. The highest soil infiltration rate (1.98 cm/min) was observed on the plain while the lowest observed on the flood plain (0.16 cm/min). Similarly, the sub-mean observations taken for these two physiographic units also revealed infiltration rate of 1.9 cm/min and 0.19 cm/min, while 1.78 cm/min was observed for the plain and the ridge respectively. However, generally, mean infiltration rate in the study area was observed to be 1.005 cm/minute (60.3 cm/hr). These observed rates are higher than the value of 43.2 cm/hr and 43.4 cm/hr reported for sandy loam soil in Borno, a semi-arid State of Nigeria, by Sauwa et al. (2013). It is also higher than the value (33.1 cm/hr) reported for semi-arid Alfisol of Bangalore.

Table 3: Physical Restrictive Features to Crop Production in Northern Yobe State

PU/SMU	Features	Current condition	Constraint type/class
PL/Lp1	erosion	prone to deflation	wind erosion limitation
	texture	loose sand material	textural limitation
PLH/Lh1	erosion	prone to deflation	wind erosion limitation
	texture	loose sand material	textural limitation
DF/Df1	erosion	prone to deflation	wind erosion limitation
	texture	loose, sand materials	textural limitation
VL/Va1	drainage	imperfectly drained	drainage limitation
PL/Lp5	drainage	poorly drained	drainage limitation
R/Rg1	erosion	slight water erosion	water erosion limitation
		wind abrasion	wind erosion limitation
PL/Rg3	erosion	prone to deflation	wind erosion limitation
	texture	loose sand material	textural limitation
PL/Lp4	erosion	prone to deflation	wind erosion limitation
PL/Lp6	drainage	poorly drained	drainage limitation
	erosion	prone to deflation	wind erosion limitation
FPL/Fp1	drainage	poorly drained	drainage limitation
DF/Df2	drainage	poorly drained	drainage limitation
	texture	loose sand materials	textural limitation
	erosion	slight deflation	wind erosion limitation
FPL/Fp2	drainage	poorly drained	drainage limitation
PL/Lp6	erosion	wind erosion	wind erosion limitation
RD/Rg2	erosion	slight water erosion	water erosion limitation
		wind abrasion	wind erosion limitation

PU – Physiographic unit; SMU- soil mapping unit; PL-plain; PLH-plain and Hill; VL-Valley; DF-Dune field; RD-Ridge; FPL- Flood Plain; Lp1- plain 1; Lh1- plain and hill 1; Df1- dune field 1; Va1- valley 1; Lp5- plain 5; Rg1- ridge 1; Lp3- plains 3; Lp4 – plains 4; Lp2 – Plain 2; Fp- flood plains 1; Df1- dune field 2; Fp2 - flood plain 2; Lp6- plain 6

Assessment of the Soil Physical Characteristics for Constraints to Crop Production

Textural limitation

The Lantewa dune field where the textural class is essentially silty, crop roots penetration will be constrained by the soil, as the soil of this area is higher in amount of silt, with the implication of smaller pore diameter and higher root penetration resistance (Schuurman, 1965; O'Connel, 1975). Rapid to very rapid infiltration is associated with areas that are essentially sandy such as the area of plain and hill.

Bulk Density in the Area

For the textural characteristics observed for the soils of the area (silty loam, clay loam, sand), the observed mean bulk density of 1.6 g/cm^3 of the soil in the area is a value that may restrict root growth in the area. This observed value is limiting crop production in the area. Except for bulk density of soils of the dune field that can neither restrict root growth nor limit crop production in the area, bulk densities of soils of the area are slightly limiting to maize, millet and sorghum growth.

Soil Moisture Constraint in the Area

It is only on the flood plains that mean soil moisture is relatively higher (22.33 %). Soil moisture percent content in the soils of other physiographic units – dune field; plain and hill; plain; ridge and the valley, are relatively low and thus constitute constraint to crop growth and production in the area. According to the report of the Irrigation Engineering Principle (2015), the optimum moisture range of maize is from 60 % to 100 % while wilting range of most cultivated crops is 11 - 30 % (Hendrickson and Veihemeyer, "n.d."). Also, Furr and Reeve (1945) had noted 19.9 %, 20.2 % and 20.3 % in fall, winter and spring respectively as the first permanent wilting points of crops. However, the observed mean percent moisture content in the soil of northern Yobe State - 0.037, 0.031, .033, 0.033, 3.25 % for plain, dune filed, ridge, plain/hill and valley respectively, are very low. These values are less than the moisture percentage of 3.6 % (Hendrickson & Veihemyer, "n.d.") at which a crop can become permanently wilted. The values observed in northern Yobe State are also below the 10.0 % and 9.6 % established by the same scholars to be the moisture percentage wilting point for sandy soil and sandy loam soil. Soil moisture is therefore a serious limitation to crop production in northern Yobe except on the flood plain. Table 3 presents the different physical restrictive features observed in the different physiographic units and soil mapping units in the area.

Soil Temperature Limitation in the Area

The observed mean soil temperatures of 30.7, 32.2, 31.5, 32.17, 31.4 ^{0}C in soils of the plain, dune filed, plain/hill, ridge and valley respectively constitute slight to moderate limitations to crop production in the area. This is because these observed values are slightly higher than 25 ^{0}C, which Gardener et al (1999) noted to be the optimum soil temperature which a plant can tolerate. However, mean soil temperature of 26.0 ^{0}C observed in soils of the flood plain is marginally tolerable to plant growth in this physiographic unit.

Limiting Infiltration Rate in the Area

The observed mean infiltration rate of 1.30 cm/min (78 cm/hr) in the area is very rapid. It therefore constitutes a severe limitation to crop production in the area.

Conclusion and Recommendations

The soil physical condition of the area constitutes limitation to crop production in the area. Important soil variables such as texture, bulk density, moisture, infiltration rate are limiting to the cultivated crops. Under this condition, sustainable crop production and hence food security cannot be achieved without significant improvement on the soil physical condition of the area. Such improvement can be achieved with integrated approach to soil management in the area, involving vegetation regeneration to increase soil organic matter and reduce soil erosion by wind, the practice of agroforestry, shift from the use of inorganic fertilizers to organic manure and control harvesting of plant cover and vegetal resources in the area, and providing sustainable soil management education to farmers.

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