THE FERTILITY STATUS OF SOILS ALONG THE MICROTOPOGRAPHY OF THE RIVER GALMA FADAMA AT ZARIA

BY

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B.Sc. (AGRIC.) A.B.U. 1989

A THESIS

SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER DEGREE IN SOIL SCIENCE

DEPARTMENT OF SOIL SCIENCE
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY, ZARIA

M.Sc/AGRIC/06351/93-94

SEPTEMBER, 1997

DECLARATION

I hereby declare that this thesis was written by me and that it is a record of my own work. It has not been presented in any way in a previous application for a higher degree at the Ahmadu Bello University or any University. All quotations and extraneous sources of information are specifically acknowledged by means of references.

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CERTIFICATION

This thesis entitled "THE FERTILITY STATUS OF SOILS ALONG THE MICROTOPOGRAPHY OF THE RIVER GALMA FADAMA AT ZARIA, by Abdullahi Abubakar Shedi meets the regulations governing the award of the degree of master of science at the Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and its literary presentation.

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This work is dedicated to my sister Mallama Abu Garga and in memories of my grand mother Yakwagu (Ya Haalima) and my aunty Patum

ACKNOWLEDGMENTS

I wish to express my sincere thanks and appreciation for the immense and valuable asistance provided to me by the following; Dr. T. Kparmwang, the Head of Soil Survey Unit, IAR, my major supervisory, for his untiring effort in putting me in order while doing this study.

Dr. J.O. Agbenin for his valuable, objective criticisms and suggestions at various stages of this study. Dr. B.A. Raji for his valuable advise and suggestions. Professor V.O. Chude, the Head of Department of Soil Science, an initiative and charismatic leader who is also a member of the supervisory committee, for his concern and advice. Professor I.E. Esu, the man who taught me what soil actually is during my undergraduate days. Members of the academic staff of Soil Science Department in persons of Dr. E. Uyovbisere, Mr. B.D. Tarfa, Mr. I.Y. Amapu, Dr. Odunze, Drs (Mrs) Babalola, and Oyinlola, staff of Soil Science Laboratory.

Engineer Garba Bukar, a friend indeed, Mal. Mahmud Umar, Alh. Yusuf Garkida, Usman Gur, and colleagues in the Department
My brothers, Mal. Salihu Musa, Mohammed Ali, Mal. Garba Jet Isa Ramat and their families. Mal. Adamu Miringa, Mr. Malgwi W.B.and Mr. Paul Ndahi with their families.

The secretary to the Head of Department Mr. John Ajegena and our dear sister Miss Virginia N. Madu who did the typing.

ABSTRACT

The fertility status of soils of the River Galma Fadama at the Kaduna State Irrigation Scheme site at Zaria was determined along its microtopographical features (MTFs). Moving at right angle away from the bank of the river, the MTFs consist, successively, of the levee, levee-backslope or backslope (BSL), coverplain {CP), and backswamp (BSW). Soil samples were taken from three replicate sites, spaced at 100 m apart in each MTF, at three depths, 0-25, 25-50 and 50-75cm.

Silt was the highest particle-size fraction in all the MTFs, except the levee where sand was the highest. The silt ranged from 12-54% with mean valves of 40, 40 43 and 45% in the levee, BSL, CP and BSW, respectively. The sand fraction followed with a range of 6-58%, and mean values of 43, 28, 37 and 19% for the successive MTFs, while clay was the lowest fraction and ranged from 12-68% and the means for the successive MTFs were 17, 32, 20 and 34%.

Soil reaction varied from extremely acid to slightly acid (pH 3.6-6.0) with mean values of 4.8, 4.1, 4.8 and 4.3 for the levee, BSL, CP and BSW, respectively. The exchangeable bases (Ca, Mg, K and Na) had values whose ranges could be rated as low to high, but the mean values for the individual MTFs could be rated as medium, except K which was high in the levee and Na which was high in all MTFs, except the CP. Exchangeable acidity was relatively high ranging from 0.8-8.6 cmol(+) kg^{-1} soil, with mean values of 3.5, 4.6, 3.6 and 3.1 cmol(+) kg^{-1} in the levee, BSL, CP and **BSW** respectively.

The effective CEC (ECEC) ranged from 3.1-13.0 cmol(+) kg^{-1} with respective mean values of 7.4, 7.8, 7.6 and 7.0 cmol(+) kg^{-1} on the levee, BSL, CP and BSW. The CEC (NH_4OAc) varied from 10.0-

34.0 cmol(+) kg^{-1} and, in the same order as ECEC, the means values were 20.4, 19.5, 16.9 and 15.1 $cmol_{(+)}$ kg^{-1} while base saturation ranged from 22-94% and the mean values for the successive MTFs were 41, 35, 41 and 42%.

Organic C and total N values were generally low (< 1.0% and < 0.2%, respectively) with low mean values in nearly all MTFs, while available P, even though generally low (< 10 mg kg^{-1}) had some exceptionally high values (> 20 mg kg^{-1}) in the Ap horizons of at least one site in each MTF.

Among the MTFs, correlation among soil properties was greatest in the BSL, followed by the levee and CP and was least in the BSW. In decreasing order, ECEC, clay and exchangeable acidity had the highest numbers of correlations, while organic C and pH (water) had fewer numbers of correlation with other soil properties.

From the selected fertility parameters, pH (both water and $CaC1_2$), organic C, total N, CEC, ECEC, clay and exchangeable acidity, the fertility status of the individual MTFs could be placed in the order BSW > CP > BSL > levee. However, due to drainage impairment, which decreased in this order of fertility ranking of the MTFs, and also due to textural variation which affect chemical properties, the intensity of cropping on the fadama was in the order BSL > levee > CP > BSW.

The arithmetic modelling method of land suitability evaluation on the other hand showed that the levee, BSL, and CP were all moderatetly suitable (S2) for arable cropping, while the BSW was curently not suitable (Nl). Liming, organic matter addition and subsequent maintenance and appropriate fertilization were recommended for optimum crop production on the fadama.

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CHAPTER ONE

1.0 INTRODUCTION

Fadama is a terminology in Hausa language which refers to land that is seasonally waterlogged. This essentially includes all areas of wet lands which are waterlogged irrespective of whether they are flood plains or not and which retain moisture within the rooting zone of crops for at least part of the dry season. Thus, they are areas of seasonally or permanently high water tables.

Fadama or wet lands are classified as Hydromorphic soils (Dehoore, 1964). They exhibit gleying characteristics due to impeded drainage which may be due to an impervious stratum of clay or laterite (petroplinthite) or high water table. This results in reducing conditions as the soil air space is saturated by water and the little amount of oxygen left is soon used up by microbial population, thus establishing anaerobic conditions. In the reducing conditions, brought about by the absence of oxygen and in the presence of organic matter, iron compounds are chemically reduced from the ferric to the ferrous state. In the ferrous form iron is much more soluble and is removed from the soil leaving the colourless minerals behind.

Based on the geomorphological and hydrological characteristics, fadama have been classified into two, namely, stream side or flood plain fadama and fadama without stream channels or depressional fadama (Turner, 1977). Jones and Wild (1975) refers to flood plain fadamas as Hydromorphic soils of the valley bottoms along streams and river courses.

Flood plain fadama are intensively cultivated throughout the world. At the beginning of the wet season they may be marked by flush of new vegetation before the uplands turn green, but they are more conspicuous at the end of the rains as they remain green while the surrounding uplands rapidly turn brown.

Flood plain fadama soils have extreme variability in both physical and chemical properties along their MTFs namely, the levee, levee-backslope, or backslope (BSL), cover plain (CP), or flood plain and backswamp (BSW). The nature of this variability has least been investigated.

The objectives of this study were, therefore:-

1. to investigate the variability in particle-size distribution (texture) and chemical properties of the River Galma fadama along its microtopography
2. to evaluate the suitability of the MTFs of the fadama for arable cropping.
3. to profer management recommendations for the fadama.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Fadama Microtopography

Fadama along the courses of large rivers or streams exhibit microtopographical features (MTFs). Starting from the bank of the river and moving at right angles to it, the MTFs are in the sequence levee, levee-backslope or backslope (BSL), cover plain (CP) and backswamp (BSW). Figure 3 and 4 . These component features have complex vertical and horizontal variations in depositional environment and sediments. Soil variability can range from minor to extreme extents depending upon the real association of the depositional environment to each other (Raymond and Richards, 1992)

Friedman and Sanchers (1978) divided the sediments of flood plain rivers into channel, channel margin and over-bank deposits. Channel deposits (levee) are coarse to fine sand, while channel margin (CP) have fine sand to silt materials. Over-bank deposits (backswamp) are ponded areas of the flood plain and have fine grained deposits and can cover broad areas and develop thick clay deposits rich in organic matter (Raymond and Richard, 1992).

The most important aspects of the MTF of a fadama are the slope, its magnitude and direction (Ipinmidum, 1971) because the flooding period and the physical and chemical properties of fadama soils are dependent upon these three aspects. It was observed by Ipinmidum (1971) that the direction of the slope of a floodplain fadama depends on the size of the stream or river and that along the courses of small streams such as Bomo and Maigana, the fadama slopes steeply towards the streams and as the stream becomes bigger, e.g. the Gangara, the slope becomes gentle towards the stream. Along larger streams such as the Hunkuyi, the microtopography of the fadama becomes more complex, rising fairly steeply from the stream with some pronounced depression in some places and then sloping gently away from the stream.

In the Donga/Suntai fadama, which are much larger streams than those reported by Ipinmidun (1971), five components of microtopography were identified by MRT Consultants (1978). These consist of the levee, the BSL, fringe-BSW, CP and basin depressions. The BSL is more pronounced where the stream is narrower. In much larger or broader rivers, the BSL gives way to essentially flat but dissected areas of CPs. Changes in the course of the river make the microtopographical patterns of the fadama much more complex. There is usually a build up of a complex of levees as reported for the Hadejia river and the Delta of the Yedseram and Aloa (Caroll and Klinkenberg, 1972; LRD, 1973).

2.2 Flooding Period

The duration of flooding in fadama is quite variable depending among other things, upon the length of the rainy season, the MTF and the texture of the soil. Ipinmidun (1971) reported a flooding period of about 3 months for fadama in the Zaria area. He found that portions of the fadama closest to the river are flooded for the longer period where the microtopography slope towards the river, while portions further away are flooded for longer periods where the microtopography slopes away from the river. In Kaduna area, it was observed that BSWs within fadama were waterlogged during the entire rainy season and a considerable part of the dry season (Esu, 1986).

On the Donga/Suntai fadama, MRT Consultants (1978) reported that the flooding period is generally two months in a year. Forthe various MTFs the Consultants said that the levees and BSLs including CPs undergo flooding for few weeks. This is due, obviously, to their slopy and rather coarse textured nature (excluding CPs) (Kparmwang and Esu, 1991). Basin depressions and BSWs on the other hand are flooded for more than six months in a year, due to their depressed and predominantly clayey nature.

2.3 Characteristics of Fadama Soils

2.3.1 Physical properties

2.3.1.1 Soil texture

Soil texture along the microtopography of the fadama is very variable and is related to the speed of the stream water during deposition. Levees and narrow CPs receive coarse sediments which are deposited when the speed of the river water is still relatively fast. They are therefore generally coarse textured ranging from sands to loams.

The BSLs and CPs receive annual or periodic additions of medium sized sediments, deposited by water of decreased speed spilling over the levees. Their textures are therefore, medium, ranging from loams to clay loams but generally, there is no evidence of clay illuviation.

The BSWs and basin depressions receive fine sediments from slow flowing or stagnant water and their textures are fine, ranging from sandy clays through silty clays to clays (Caroll and Klinkenberg, 1972; MRT Consultants 1978; Esu, 1982). Figure 5.

2.3.1.2 Bulk density

Due to the variation in the texture of fadama soils, the bulk density also varies considerably. It ranges from 1.0–1.5 g cm^{-3} for fine and medium textured soils and 1.1–1.65 g cm^{-3} for coarse textured soils. The values of Esu (1982) on the river Kaduna fadama which ranged from 1.01-1.58 g cm^{-3} seems favourable while that for the Donga/Suntai fadama which ranges from 0.72-1.75 g cm^{-3} (MRT Consultants, 1978) fall outside the favourable range.

The bulk density values were found to be lowest in the surface layers of fadama where textures were medium and organic matter content high and to increased with increase in clay content attaining the highest values in poorly structured heavy clays (MRT Consultants, 1978).

2.3.2 Chemical and fertility properties of fadama soils

Variability in the chemical properties of fadama also exists just as in the case of physical properties and this accounts for the differences in their fertility levels. Plates 1 to 4.

2.3.2.1 pH of fadama soils

Although the pH values of fadama soils vary from one fadama to the other, they almost always fall within the acid range, particularly surface soils (Klinkenberg and Hildebrand, 1964; Klinkenberg and Higgins, 1968; Ipinmidun, 1970, 1971; MRT Consultants, 1978; Esu, 1982; Esu et al, 1987).

2.3.2.2 Organic carbon and nitrogen levels

Organic carbon and nitrogen levels of fadama soils are also quite variable. For surface soils organic carbon content may range from less than 0.4% to greater than 2% and total nitrogen levels may be any thing from 0.03 to greater than 0.2%. Thus organic carbon generally decreased irregularly down the profile, while the decrease in nitrogen content is more regular within the profile (Klinkenberg and Higgins, 1968; Ipinmidun, 1970; MRT Consultants, 1978, Esu, 1982). However, earlier reports suggest that organic carbon contents of fadama soils are usually higher than those of the surrounding up- land soils (Dehoore, 1964; Ipinmidun, 1970;

Esu, 1982).

2.3.2.3 Exchangeable bases and cation exchange capacity

The exchangeable bases and cation exchange capacity of fadama soils have been reported to be generally higher than the surrounding uplands with calcium and sometimes magnesium dominating the exchangeable cations. The cation exchange capacity, just like the exchangeable bases, ranges from low to high (less than 4 cmol (+)kg^{-1} soil to greater than 25 cmol (+)kg^{-1} soil) (Klinkenberg and Higgins, 1968; MRT Consultants, 1978; IAR, 1982; Esu, 1982).

2.3.2.4 Exchangeable acidity

Exchangeable aluminium together with exchangeable hydrogen, responsible for soil acidity, are quite high in some fadama soils and thus constituting toxicity problems in some cases (MRT Consultants, 1978). Some horizons contain up to 8 cmol (+) kg^{-1} exchangeable aluminium in the fadama, but in some sites in the same fadama values could be as low as 0.07 cmol (+) kg^{-1} (Kparmwang and Esu, 1990).

2.3.2.5 Base saturation

The base saturation values of fadama soils are as variable as the exchangeable cations and cation exchange capacity, with values ranging from very low (less than 20%) to very high (greater than 80%). Profiles containing $CaCO_3$ have been observed to have high base saturation. (Caroll and Klinkenberg, 1972; Klinkenberg and Higgins, 1972; Ipinmidun, 1970; Esu, 1982; Ment Int. Ltd, 1987).

2.3.2.6 Available phosphorus

Available phosphorus is the most deficient nutrient in fadama soils (Ipinmidun, 1970). It could be anything from trace amounts to about 15 mg kg^{-1} and distribution is very irregular within profiles (Ipinmidun, 1970; MRT Consultants, 1978; IAR, 1982; Esu, 1982; Ment Int. Ltd, 1987). The poor availability of P is attributed to the high exchangeable aluminium and the acid nature of the fadama soils (Ipinmidun, 1970; MRT Consultants, 1978, Esu, 1982; Ment Int. Ltd, 1987). High calcium content can also lead to non-availability of phosphorus in fadama soils.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of the project area

The project area is a fadama land within the River Galma flood plain at the Kaduna State Irrigation Schemes Site (latitudes 10^0 28' and 11^0 17' North and longitudes 7^0 45' and 8^0 45' East)(Fig. 1 & 2). It is situated at about 3 kilometres from Kofar Doka Zaria, at a bridge along Zaria - Jos road at an elevation of about 604.51 m. The mean annual rainfall for Samaru area is 1060 mm. Figure 1, 2 and Plates 1, 2, and 3 show the overhead views and crops grown at the site.

3.2 Sampling

Soil samples were taken from within the four MTFs, namely: levee, BSL, CP and BSW. The graphic representation of the MTFs is given in Figs. 3 & 4. The samples for each feature was replicated 3 times giving a total of 12 auger points, i.e. three for each MTF. The replicates were spaced at a distance of 100 m. Soil samples were taken at three depths, namely, 0-25 cm, 25-50 cm and 50-75 cm. Figure 3 and 4.

3.3 Laboratory analysis

The soil samples collected were air dried, ground and passed through a 2 mm sieve. Routine physico-chemical analyses were determined on the fine earth separate (< 2 mm soil portion).

3.3.1 Particle-size analysis

Particle-size distribution was determined by the hydrometer method using sodium hexametaphosphate as dispersant as described by Day (1965). Sand, silt and clay were determined with the aid of the Bouyoucos hydrometer. The textural class determinations were carried out using the USDA textural triangle.

KADUNA PLAINS – PHYSIOGRAPHIC UNITS

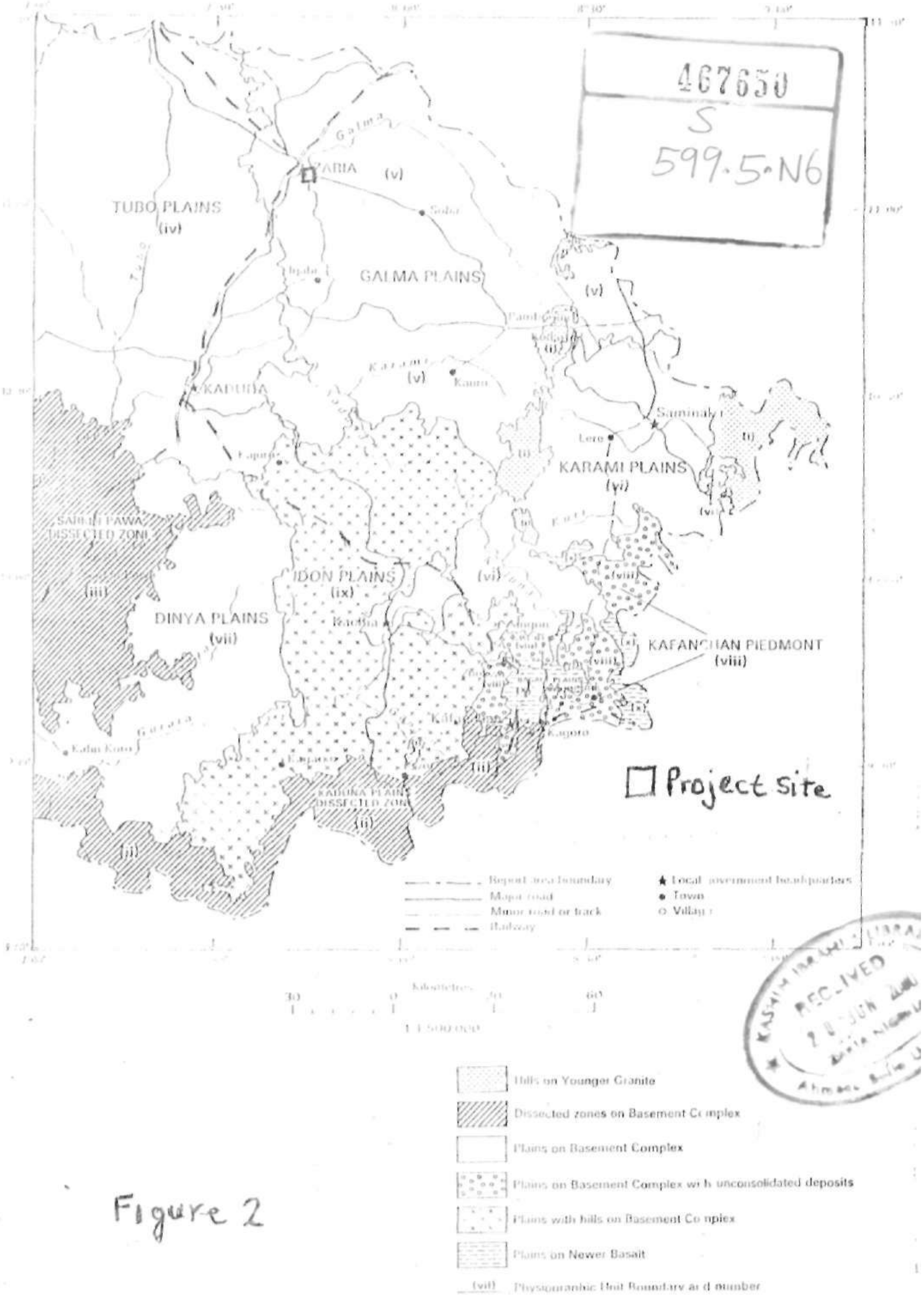

Figure 2

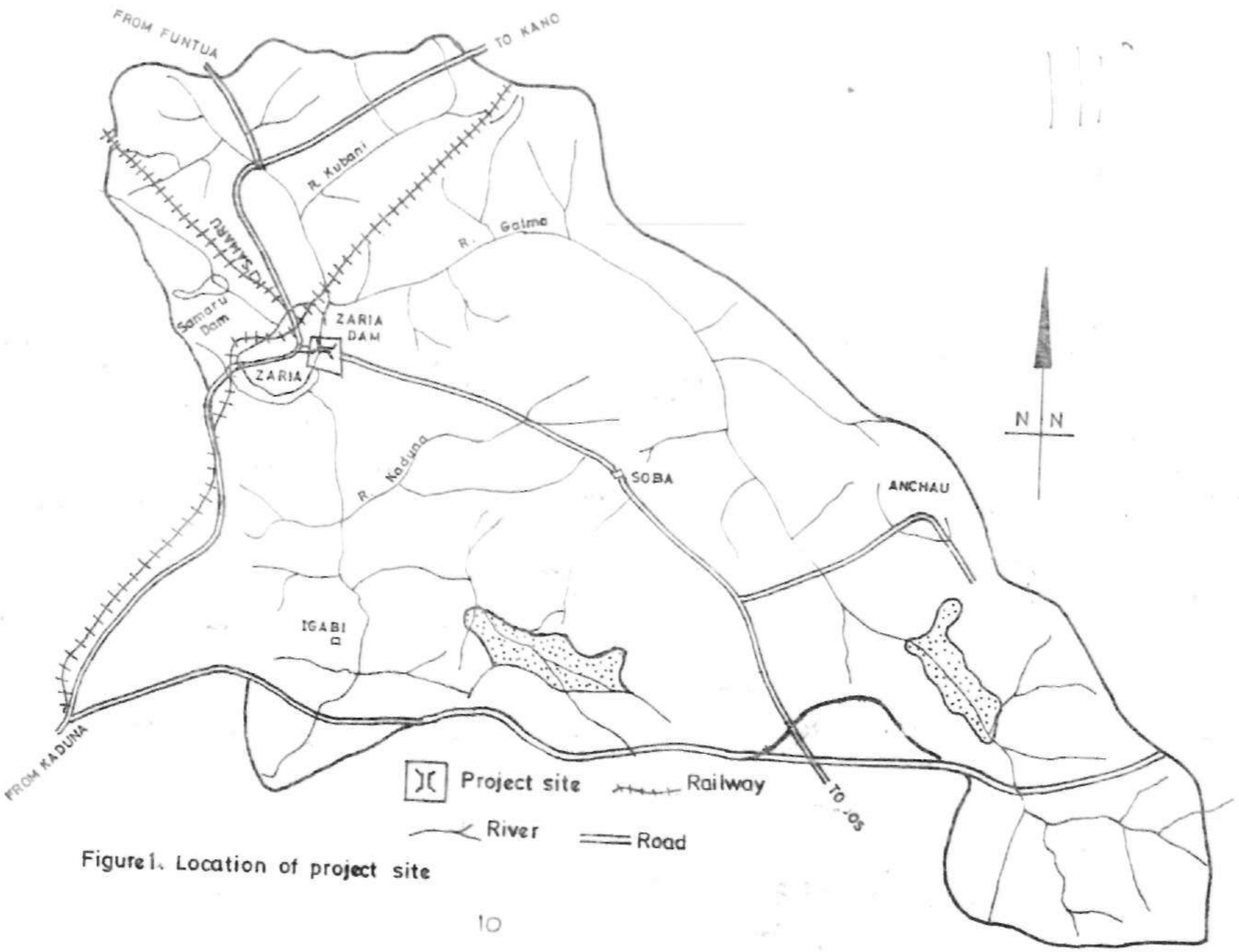

Figure1. Location of project site

Plate 1. The study area under cultivation with maize and vegetables.

Plate 2. Overhead view of the study area showing maize and vegetable crops.

Plate 3. Far view of the study area in the east.

Plate 4. Tomatoes harvested by farmers at the study site.

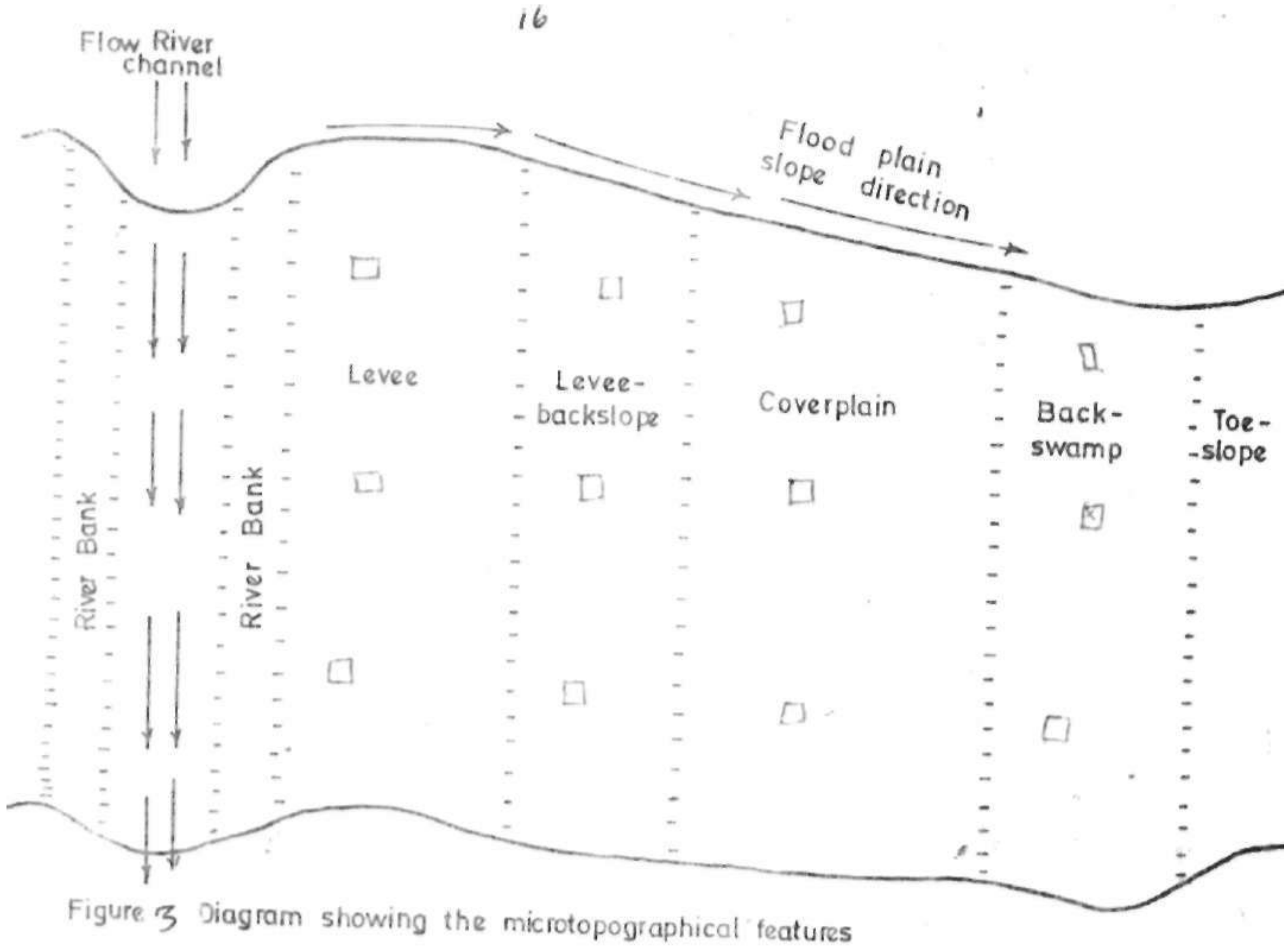

Figure 3 Diagram showing the microtopographical features

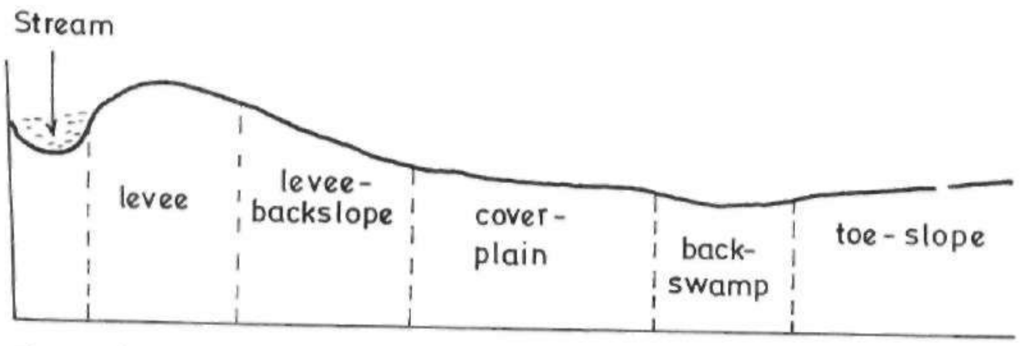

Figure 4 Cross section of the microtopographical features above

3.3.2 Soil pH

Soil pH was determined potentiometrically after equilibration with water and with 0.01M $CaCl_2$ at a 1: 2.5 soil to solution ratio using a Coleman Merion pH meter.

3.3.3 Available phosphorus

Available phosphorus was extracted by the Bray No 1 method and P in solution was determined by the ammonium molybdate-blue method (Murphy and Riley, 1962).

3.3.4 Organic carbon

Organic carbon was determined by the Walkley-Black method (Allison, 1965). The method involved the digestion of the soil organic matter by 1N $K_2Cr_2O_7$, using concentrated sulphuric acid to increase the temperature and hasten the reaction.

3.3.5 Total nitrogen

Total nitrogen was determined by the salicyclic acid-thiosulphate digestion method followed by the distillation method using the modified micro-Kjeldahl method (Bremner, 1965).

3.3.6 Exchangeable basic cations

Exchangeable Ca, Mg, K and Na were extracted with IN NH_4OAC (pH 7.0). Calcium and Mg were determined by atomic absorption spectrophotometry while Na and K were determined by flame emission spectrophotometry (Chapman, 1965a).

3.3.7 Exchangeable acidity (H+Al)

Exchangeable acidity was determined by successive leaching of soil with 1N KCl using a 1:10 soil solution ratio. The amounts of exchangeable H and Al in the leachates were determined by the titration method procedure outlined by McLean (1965).

3.3.8 Effective cation exchange capacity

The effective cation exchange capacity was calculated after obtaining the bases (Ca, Mg, K and Na) and exchangeable acidity by summing the bases and acidity.

3.3.9 Cation exchange capacity

Cation exchange capacity (CEC) was determined by the 1N NH_4OAC (pH 7.0) saturation method (Chapman, 1965b).

3.3.10 Base saturation

Percentage base saturation was calculated by dividing the total exchangeable bases (Ca, Mg, K, Na) by the cation exchange capacity and multiplying the result by 100.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Particle-size distribution

The data on particle-size distribution is presented in Table 1.

In the levee, the sand fraction ranged from 28-76% with a mean value of 43.1% the silt ranged from 12-50% (mean, 40.2%) and the clay from 12-28% (mean, 16.3%). The mean values indicate that the sand fraction dominated the fine earth separate (< 2 mm portion). This was closely followed by the silt fraction, while the clay fraction was the lowest. Soil texture in the levee was loamy, namely; sandy loams and silt loams, i.e the levee was medium-textured in contrast to the predominantly coarse texture reported by other workers (MRT consultants, 1978; Esu, 1982). This is due to the relatively high content of silt in the sediment deposited by the river.

In the levee-backslope or, simply, backslope (BSL), the sand, silt and clay fractions ranged from 6-50%, 26-54% and 12-68%, respectively with corresponding mean values of 27.9, 40.0 and 31.7% The mean values indicated that the silt fraction was clearly dominant over the sand and clay fractions which were in turn statistically similar. Textures in the BSL was loamy to clayey (loam, sandy loam, silt loam, silty clay loam, silty clay and clay). Thus, the BSL was medium to fine textured. The medium texture of the BSL is expected, but the fine texture is probably due to reduction in slope due to land levelling during the establishment of the irrigation scheme. This would reduce the speed of water overflowing the river bank and thus allow the deposition of fine materials.

Within the CP, the sand fraction ranged from 26-58% (mean, 36%), the silt fraction from 32-56% (mean, 43.1%) and the clay fraction from 14-28% (mean, 20.1%). The silt fraction was, thus also clearly dominant in the CP. Textures in the CP were mainly loamy, being loam, sandy loam, silt loam and clay loam, i.e. medium. The medium texture of the CP which makes it generally coarser than the BSL is also attributable to land levelling, in which coarser materials from the levee and BSL were moved to the CP position.

The BSW had sand ranging from 8-30% (mean, 19.2%), silt from 32-54% (mean, 45.1%), and clay from, 20-56% (mean, 34%). Again the mean values indicate that the silt fraction dominated the fine earth separates.

Table 1: Particle-size distribution

Depth (cm)		Clay	Silt	Sand	Textural class (USDA)
		---------- % ----------			
Levee					
I.	0-25	12	50	38	silt loam
	25-50	14	48	38	loam
	50-75	14	46	40	loam
II	0-25	12	12	76	sandy loam
	25-50	18	36	46	loam
	50-75	16	38	46	loam
III	0-25	16	38	46	loam
	25-50	28	44	28	loam
	50-75	20	50	30	silt loam
x		16.3	40.2	43.1	
O		4.8	11.0	13	
Levee-BSL					
I	0-25	14	36	50	loam
	25-50	12	34	54	sandy loam
	50-75	14	36	50	loam
II	0-25	18	52	30	silt loam
	25-50	24	54	22	silt loam
	50-75	30	50	20	silty loam
III	0-25	68	26	6	clay
	25-50	58	32	10	clay
	50-75	48	42	10	silty clay
X		31.7	40.0	27.9	
O		19.9	9.2	17.9	

Table 1: Continued particle-size distribution

	Depth (cm)	Clay	Silt	Sand	Textural class USDA
			%		
Cover Plain					
I.	0-25	16	56	28	Silt loam
	25-50	19	55	26	Silt loam
	50-75	24	50	26	Silt loam
II	0-25	14	32	54	Sandy loam
	25-50	16	36	58	Loam
	50-75	18	40	42	Loam
III	0-25	28	38	34	Clay loam
	25-50	24	42	34	Loam
	50-75	22	44	34	Loam
X		20.1	43.1	36.9	
O		4.3	8.8	11	
Back Swamp					
I	0-25	32	42	26	Clay loam
	25-50	32	46	22	Clay loam
	50-75	30	48	22	Clay loam
II	0-25	20	50	30	Silt loam
	25-50	24	54	22	Silt loam
	50-75	26	54	20	Silt loam
III	0-25	56	36	8	Clay
	25-50	45	45	10	Clay
	50-75	54	32	14	Clay
X		34.2	45.1	19.2	
O		13	7	6	

Soil texture in the BSW was loamy to clayey, as it was in the BSL, being silt loam, clay loam and clay.

Statistical analysis showed that particle-size distribution and, therefore, soil texture varied among replicates (sites), with depths and among the MTFs. The ranges and mean values of particle-size distribution by site and by depth are given in Appendix A.

In the levee, the mean values of clay increased downstream from site 1 to 3. The mean values at site 1 was significantly lower than at sites 2 and 3, whose means were in turn similar (< 0.05). There were no significant differences in the means of the silt and sand fractions with site and no significant differences in the mean values of clay, silt and sand by depth in the levee.

In the BSL, the clay, silt and sand fractions all showed significant differences in their mean values with site. For clay, the means at sites 1 and 2 were similar, but were both lower than at site 3 ($P < 0.01$). Thus, the content of clay in the BSL also increased downstream as in the levee. For silt, the mean values for sites 3 and 1 were similar, that for site 1 was in turn similar to that of site 2, but the mean value for site 3 was lower than for site 2 ($P < 0.05$). Silt, therefore, showed an erratic distribution with site. The mean values for sand was in the order site 1 > site 2 > site 3, i.e. it decreased downstream ($P < 0.001$), in contrast to clay. Just as in the levee, there were no significant differences in the mean values of the particle-size fractions with depth in the BSL.

Within the CP, variation in the particle-size fractions was also significant only with site as was the case in the levee and BSL. In fact, clay did not significantly vary with either of them. The mean values of the silt fraction were similar at sites 2 and 3, but were both lower than the values at site 1 ($P = 0.01$), while the means for the sand fraction were similar at sites 1 and 3 but both lower than at site 2 ($P < 0.01$). Both silt and sand fractions were therefore, erratically distributed with site in the CP. This could partly be a result of land levelling, which in most cases is far from being uniform.

The situation in the BSW was similar to that of the CP, i.e. variation in the contents of the particle-size fractions was only with site, but in this case, without exception. The mean values of clay were similar at sites 2 and 1, but both significantly lower than at site 3 ($P = 0.01$). The silt was similar at sites 3 and 1, with the mean value at site 1 in turn, being similar to that at site 2, but the value at site 2 was higher than at site 3 ($P < 0.05$). The sand fraction had an identical distribution pattern to the silt in the BSW, i.e. an erratic pattern as in the CP.

Because of these distribution trends soil textures were uniquely similar at each site but different from other sites especially in the CP and the BSW positions. The variation in soil texture with sites testifies to the extreme variability in fadama soils even within a very small area. Kparmwang and Esu (1990) reported that textures in fadama vary along the microtopography, but this study revealed that it also varies within the same microtopographical feature. This poses a complicated problem in management of fadama lands.

Among the MTFs, the sand content was similar in the levee and CP but significantly higher than in the BSL, where it was in turn higher than in the BSW ($P < 0.001$). The general trend, therefore, is a decrease in sand content as one moves from the levee to the BSW in agreement with the findings of MRT Consultants (1978), Esu

(1982) and the review by Kparmwang and Esu (1990). The clay content exhibited an exact opposite trend, being highest in the BSW, where the mean value was similar to that in the CP, and it was lowest in the levee where the mean value was similar to that in the BSL ($P < 0.001$). The silt content was, however, a clear exception, it was not significantly different in any of the MTFs. The mean values, however, was slightly higher in the BSW than in the CP, which was in turn slightly higher than in the levee, where it was the same as in the BSL. The relatively high silt content of fadama soils was earlier reported by Esu (1982) who quoted values which were mostly 40% or higher.

4.2 Soil Chemical Properties

The data on soil chemical properties are presented in Table 2, while ratings for interpretation of soil properties are presented in Table 3.

4.2.1 Soil pH

The soil pH (water) in the levee ranged from 3.6-5.8 (mean, 4.8), indicating an (extremely to moderately acid) soil reaction range. In the BSL it ranged from 3.9-4.8 (mean, 4.1) (extremely to very strongly acid), in the CP, from 3.9-6.0 (mean, 4.8) (extremely-to moderately acid), and in the BSW from 4.0-4.5 (mean, 4.3) (extremely to very strongly acid).

The pH values in 0.01M $CaCl_2$ in all cases were lower than those in water, corroborating the depressional effect of the cations of the salt on soil pH measurement. The values ranged from 3.3-4.8 in the levee, 3.0-3.9 in the BSL, 3.1-5.6 in the CP and 4.0-4.5 in the BSW. The corresponding mean values for the MTFs were 4.0, 3.5, 4.3 and 3.8.

Both pH (water) and pH ($CaCl_2$) varied significantly only with site in the levee. The mean values of pH (water) were similar at sites 3 and 1, that for site 1 was in turn similar to the value at site 2, but the value at site 3 was lower than at site 2 ($P < 0.01$). The pH ($CaCl_2$) on the other hand, had similar values at sites 3 and 1, which were both lower than that at site 2.

In the BSL, pH (water) was not significantly different both with site and depth, but pH ($CaCl_2$) varied significantly, only with site. The mean values at sites 1 and 3 were similar to those at sites 3 and 2, which were in turn similar, but that at site 1 was lower than that at site 2 ($P < 0.05$).

Table 2: Soil chemical properties

Depth (cm)	pH (H_2O)	pH ($CaCl_2$)	Avail. P	O.C (%)	TN (%)	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS (%)
						cmol(+) kg^{-1}							
						Levee							
0-25	4.8	4.0	22	0.9	0.2	3.0	0.6	0.1	0.2	1.2	5.1	10	39
25-50	4.6	4.1	12	0.3	0.1	2.6	0.4	0.1	0.3	1.0	4.4	10	34
50-75	5.0	3.3	0.0	0.2	0.1	4.0	0.3	0.1	0.2	2.6	7.2	13.2	72
0-25	5.3	4.3	11.7	0.8	0.13	2.7	0.3	1.2	0.5	2.4	7.1	15	47
25-50	5.4	4.8	4.5	0.7	0.1	3.0	0.3	0.9	0.4	2.6	7.2	16.2	46
50-75	5.8	4.7	2.7	0.4	0.04	2.0	0.2	0.3	0.8	3.6	6.9	16.9	33
0-25	4.5	3.7	16.1	0.5	0.1	3.2	0.3	0.1	0.3	6.6	9.9	17.5	39
25-50	3.6	3.3	7.2	0.4	0.04	1.8	0.2	0.12	0.8	6.2	9.1	20.3	29
50-75	4.0	3.5	2.7	0.3	0.03	2.2	0.1	0.1	0.4	5.2	8.0	16.2	28
X	4.8	3.9	3.7	0.5	0.09	2.7	0.3	0.3	0.4	3.4	7.2	13	40.8
σ	0.6	0.5	8.6	0.2	0.05	0.6	0.19	0.4	0.2	1.9	3.6	3.8	28
						Levee-BSL							
0-25	4.8	3.2	4.8	0.6	0.05	2.6	0.3	0.1	0.2	2.8	6.0	12	32
25-50	4.2	3.2	1.6	0.04	0.04	1.8	0.2	0.1	0.12	3.0	5.2	11.8	22
50-75	4.0	3.0	1.6	0.02	0.04	2.0	0.2	0.1	0.1	2.4	4.8	10.6	24
0-25	4.4	3.9	23.3	1.0	0.2	2.6	0.2	0.14	0.5	5.4	8.8	20.1	34
25-50	4.0	3.7	6.3	0.4	0.8	2.0	0.14	0.09	0.5	4.0	3.1	17.1	27
50-75	4.0	3.7	5.4	0.4	0.2	1.0	1.2	0.3	0.5	4.4	7.4	22.2	30
0-25	3.7	3.7	2.7	1.6	0.14	4.5	0.68	0.22	0.9	6.2	12.5	25.8	64
25-50	3.9	3.2	3.6	0.7	0.1	3.2	0.5	0.2	0.9	7.2	13.0	28.6	48
50-75	4.1	3.7	2.7	0.4	0.04	2.7	0.32	0.2	0.3	5.6	9.1	27.3	35
X	4.0	3.4	10	0.5	0.2	3.4	0.4	0.2	0.4	4.6	7.8	19.5	49
σ	0.2	0.2	13.8	0.5	0.2	1.3	0.3	0.08	0.24	1.5	8.2	6.6	27.3
						Cover Plain							
0-25	4.7	4.0	37.0	1.2	0.13	3.0	0.7	0.5	0.14	8.6	12.1	22.4	43
25-50	4.2	3.5	13.0	0.6	0.1	8.0	1.1	0.1	0.2	0.8	10.2	19.4	94
50-75	4.5	4.1	1.2	0.3	0.1	4.0	0.5	0.1	0.3	2.0	6.9	14.1	49
0-25	6.0	5.5	7.2	1.0	0.1	3.2	0.2	0.1	0.2	5.0	8.7	18.3	37
25-50	5.7	5.6	6.3	0.6	0.1	3.0	0.2	0.2	0.2	2.4	6.0	14.0	36
50-75	5.5	5.2	4.5	0.4	0.14	2.0	0.2	0.1	0.1	2.4	4.8	14.3	24

Table 2 continued: Soil chemical properties

Depth(cm)	pH (H_2O)	pH ($CaCl_2$)	Avail. P	O.C (%)	TN (%)	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS (%)
						cmol(+) kg^{-1}							
0-25	4.7	3.9	16.1	0.7	0.04	2.7	0.2	0.2	0.2	4.2	7.5	11.3	33
25-50	4.1	3.9	9.0	0.3	0.1	2.2	0.2	0.1	0.3	3.0	5.8	19.9	28
50-75	3.9	3.1	3.6	0.3	0.03	1.8	0.1	0.1	0.3	4.0	6.3	20.3	23
X	4.8	4.2	10.8	0.6	0.1	3.3	0.3	0.2	0.2	3.6	7.6	17.1	40.7
0	0.7	0.9	10.3	0.3	0.03	1.8	0.3	0.1	0.2	1.2	5.5	3.4	42.9
							Back swamp						
0-25	4.1	4.0	19.9	1.1	0.1	4.6	1.5	0.2	0.7	3.0	9.9	16.4	70
25-50	4.2	3.9	1.2	0.3	0.14	4.2	0.9	0.1	0.7	2.4	6.3	14.4	59
50-75	4.2	3.5	1.29	0.2	0.04	2.8	0.5	0.1	0.5	1.8	5.5	10.7	38
0-25	4.2	4.0	10.8	0.6	0.04	2.0	0.2	0.2	0.3	3.2	5.9	20.0	27
25-50	4.5	4.0	3.1	0.2	0.04	2.0	0.1	0.1	0.3	3.4	5.9	17.9	25
50-75	4.5	3.9	2.7	0.2	0.04	2.2	0.13	0.1	0.8	3.0	6.2	19.0	32
0-25	4.0	3.5	7.2	1.3	0.1	4.0	0.5	0.2	0.5	4.4	9.6	19.8	52
25-50	4.3	3.6	2.7	1.2	0.1	3.2	0.4	0.1	0.5	3.8	8.0	34.0	42
50-75	4.3	3.6	2.7	0.4	0.1	2.0	0.5	0.2	0.4	3.0	6.1	31.7	31
X	4.3	3.7	3.7	0.6	0.07	3.0	0.5	0.1	0.5	3.1	7.0	20.4	41.8
0	0.2	0.2	6	0.4	0.25	0.98	0.4	0.07	0.2	0.7	4.2	7.1	37.8

Within the CP, pH (water) varied significantly both with site and with depth. The mean values at sites 3 and 1 were similar but both were lower than at site 2 ($P = 0.001$). The means for the 50-75 cm and 25-50 cm depths were similar, but both lower than for the 0-25 cm depth. The pH (water) thus, decreased with increase in soil depth. The pH ($CaCl_2$), on the other hand, only varied significantly with site. The mean values for sites 3 and 1 being similar, but both lower than the value at site 2 ($P < 0.01$).

Within the BSW, pH (water) also varied significantly both with site and depth. The mean values for sites 1 and 3 were similar, those of 3 and 2 were in turn similar, but that of site 1 was lower than that of site 2 ($P < 0.05$). With depth, the mean for the 0-25 cm was lower than for the 25-50 cm and 50-75 cm, which were in turn similar ($P < 0.05$). There was no significant difference in the mean values of pH ($CaCl_2$) with both site and depth in the BSW.

Along the MTFs pH (water) was highest in the CP where its mean was similar to that of the levee, but both were higher than in the BSL and the BSW, whose means were in turn similar ($P < 0.001$). The pH $CaCl_2$ was also highest in the CP, but unlike pH (water) it was significantly higher than in the levee in addition to the BSW, both of whose mean values were similar and in turn significantly higher than in the BSL.

The observed acidic nature of the soils in all the MTFs of the fadama corrroborates the results of earlier workers (Ipinmidun, 1970, 1971; Esu et al., 1987; Kparmwang and Esu, 1990).

4.2.2 Available phosphorus

Available P ranged from 0.0–22.0, 1.6–23.3, 1.2–37.0 and 1.2–19.9 mg kg^{-1} soil in the levee, BSL, CP and BSW, respectively, with corresponding mean values of 8.8, 5.7, 10.9, and 5.7 mg kg^{-1}.

Available P in the levee varied with depth but not with site. The mean value for the 0–25 cm depth was higher than for the 25–50 cm and 50–75 cm depths, the means of the last two were in turn similar ($P < 0.05$). However, from the BSL down to the BSW, available P did not vary significantly with both site and depth. But in all MTFs, the highest available P occurred in the 0–25 cm depth. Distribution with site was erratic with the highest values occurring randomly.

Table 3. Ratings for interpretation of soil chemical properties

Soil Reaction Rating

Extremely acid	< 4.4
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	> 9.0

Available P (Bray 1)

Low	0-10 mg kg^{-1}
Medium	10-20 mg kg^{-1}
High	> 20 mg kg^{-1}

Organic Matter

Low	< 2% or < 1% carbon (< 10 g kg^{-1})
Medium	2-3% or 1.0-1.5% carbon (10-15 g Kg^{-1})
High	> 3% or 1.5% carbon (> 15 g kg^{-1})

Total Nitrogen

Low	0-0.15% (< 1.5 g kg^{-1})
Medium	0.15-0.2% (> 2.0 g kg^{-1})

Exchangeable cations (cmol (+) kg^{-1} soil)

	Ca	Mg	K	Na
Low	0-2	0-0.3	0.0.15	0-0.1
Medium	2-5	0.3-1.0	0.15-0.3	0.1-0.3
High	>5	> 1	> 0.3	> 0.3

Exchange acidity (H+AL) (cmol(+) kg^{-1} soil)

Low	< 60% of CEC
Medium	-
High	<, 60% CEC

Cation exchange capacity (cmol(+) kg^{-1} soil)

	NH_4OAC (CEC)	ECEC
Low	< 6	< 4
Medium	6-12	4-10
High	> 12	> 10

Base saturation %

	NH_4OAC	ECEC
Low	< 50	< 70
Medium	50-80	70-90
High	> 80	> 90

The medium to high levels of available P in the 0-25 cm (plough layer) is apparently due to use of phosphatic fertilizers. The fadama is fragmented into small plots used by farmers whose abilities to purchase and their choice of fertilizer types vary considerably. Except for the incidences of application of phosphatic fertilizers which raises the levels of available P in the surface soils in the river Galma fadama, P has been reported to be the most deficient element in fadama soils in Zaria area (Ipinmidun, 1970; Kparmwang and Esu, 1990).

4.2.3 Organic carbon

The organic carbon contents of the soils varied from 0.20-0.90% (mean 0.50%) in the levee, 0.02-1.00% (mean, 0.57%) in the BSL, 0.30-1.20% (mean, 0.60%) in the CP and 0.20-1.30% (mean, 0.61%) in the BSW. The contents of organic carbon were generally low as can be seen from the mean values (Table 2). The highest values can only be rated as medium.

The organic carbon content of the soils did not vary significantly with either site, depth or along the MTFs. An exception was in the BSL where it varied significantly with site and depth. The mean value at site 1 was similar to that at site 2, which was in turn similar to that at site 3 but mean value at site 1 was lower than at site 3 ($P < 0.05$). The mean for the 0-25 cm depth in the BSL was higher than for the 25-50 cm and 50-75 cm depths, whose means were in turn similar ($P < 0.01$). The other exception was the CP where organic carbon varied, but only with depth, in a pattern identical to that in the CP, including the probability limit.

As an exception to the rule that organic matter decreases irregularly with depth (Ipinmidun, 1970; MRT Consultants, 1982;

Esu, 1982; Esu et al, 1987), a regular decrease was observed in this study. However, this might be related to the rather shallow depth of sampling (maximum depth of 75 cm) and to the fact that the samples were not taken from natural layers but from pre-determined depths.

4.2.4 Total nitrogen

Total nitrogen ranged from 0.03-0.20, 0.04-0.14, 0.03-0.14 and 0.04-0.10% in the levee, BSL, CP and BSW respectively; the corresponding mean values being 0.09, 0.18, 0.09 and 0.07%. The mean values indicate that total N, as was the mean values of organic carbon, was generally low with the highest values also rated only as medium. The highest values were frequently in the 0-25 cm depth and they generally decrease with increase in soil depth. The range in the values of total N agrees almost completely with that presented in the review by Kparmwang and Esu (1990), i.e. from 0.03 to 0.20% or greater for fadama soils of the Nigerian savanna.

Total nitrogen did not vary significantly along the MTFs, but it varied significantly with both site and depth only in the levee and BSW. In the levee, the mean value for site 3 was similar to that at site 2, which was in turn similar to that at site 1 but the mean value of site 1 was higher than that of site 3 ($P < 0.05$). The mean value for the 0-25 cm depth was similar to that of the 25-50 cm depth which was in turn similar to that of the 50-75 cm depth, but the mean for the 0-25 cm depth was higher than for the 50-75 cm depth ($P < 0.05$).

In the BSW, the mean value for site 2 was similar to that of site 1, which was in turn similar to that at site 3 but the mean for site 3 was higher than for site 2 ($P < 0.05$).

4.2.5 **Exchangeable bases**

Exchangeable Ca ranged from 1.80-4.00, 1.00-4.50, 1.80-8.00 and 2.00-4.60 cmol(+) kg^{-1} soil in the levee, BSL, CP and BSW respectively. The corresponding mean values were 2.72, 2.49, 3,32 and 3.00 cmol(+) kg^{-1}. In the same order exchangeable Mg varied from 0.10-0.60, 0.20-1.20, 0.10-1.10 and 0.10-1.50 cmol(+) kg^{-1} soil, the corresponding mean values being 0.30, 0.42, 0.38 and 0.53 cmol(+) kg^{-1}. Similarly exchangeable K ranged from 0.10-1.20 (mean, 0.34), 0.09-0.30 (mean, 0.16), 0.10-0.50 (mean, 0.17) and 0.10-0.20 (mean, 0.14) cmol(+) kg^{-1} soil respectively, from levee to BSW, while exchangeable Na ranged from 0.20-0.80, 0.10-0.90, 0.10-0.30 and 0.30-0.80 cmol(+) kg^{-1} from levee to BSW, with respective mean values of 0.43, 0.45, 0.22 and 0.52 cmol(+) kg^{-1} soil. Exchangeable Ca, Mg, K and Na were all medium in the MTFs.

In the levee exchangeable Ca and Na did not vary significantly with either site or depth, Mg varied with both, while K varied only with site. The mean value of Mg at site 3 was similar to that at site 2, which was in turn similar to that at site 1, but the mean value at site 1 was higher than at site 3 ($P < 0.05$). By depth, the mean value of Mg at the 0-25 cm was similar to that at 25-50 cm, which was in turn similar to that at 50-75 cm but that at 0-25 cm was higher than the mean at 50-75 cm ($P < 0.05$). Potassium mean values were similar at sites 1 and 3, both of which were lower than at site 2 ($P < 0.05$).

In the BSL, Mg, K and Na did not vary with either site or depth, but Ca varied with both. The mean values of Ca at sites 2 and 1 were similar, but both were lower than at site 3 ($P < 0.05$), and by depth, the mean for the 0-25 cm was higher than for the 25-50 cm and 50-75 cm, whose means were in turn similar ($P < 0.05$).

Within the CP, exchangeable bases did not vary significantly with both site and depth. The only exception was Mg which even then, varied significantly only with site, sites 3 and 2 mean being similar, but both lower than site 1 mean ($P < 0.05$).

Within the BSW, Ca and Na did not vary significantly with either site or depth. But Mg varied significantly with site and K with depth. The means for Mg were similar at sites 2 and 3, that of site 3 was in turn similar to that of site 1, but site 1 mean was higher than site 2 mean ($P = 0.05$). The mean values of K at the 0-25 cm depth was higher those at the 50-75 cm and 25-50 cm depths, the latter two's means were both similar ($P = 0.05$).

Along the MTFs, Ca and Mg did not vary significantly, but K and Na did. The K was highest in the levee, where its mean value was higher than for the rest of the MTFs (BSL to BSW) ($P < 0.05$). The mean values of Na were similar in the BSW, BSL and levee, where they were all higher than in the coverplain ($P < 0.001$). For the bases as a whole, the general pattern of distribution was a decrease with increase in soil depth. Calcium was the dominant exchangeable basic cation followed by Mg, then Na, and K was the lowest. The distribution pattern and the magnitude of the content of the various bases were in agreement with what was reported in the review by Kparmwang and Esu (1990).

4.2.6 Exchangeable acidity (H + Al)

This ranged from 1.0-6.6, 2.4-7.2, 0.8-8.6 and 1.8-4.4 cmol(+) kg^{-1} soil in the levee, BSL, CP and BSW, respectively, with corresponding mean values of 3.5, 4.6, 3.6 and 3.1 cmol(+) kg^{-1}. The values were relatively high as invariably reported for fadama soils (MRT Consultants, 1978; Esu et al, 1987). However, due to the high CEC of the soils, the aluminium saturation is low.

In all MTFs, exchangeable acidity varied significantly only with site except in the CP where it did not vary with site either. In the levee, the means for sites 1 and 2 were similar, but both were lower than at site 3. In the BSL, the means for sites 1 and 2 were similar, those of sites 2 and 3 were in turn similar but the mean for site 3 was higher than for site 1, both at $P < 0.01$. In the BSL the trend was identical to that of the BSL, but at $P < 0.05$. Exchangeable acidity did not vary significantly among MTFs.

4.2.7 Effective cation exchange capacity (ECEC)

The ranges in ECEC values and the corresponding mean values (in parentheses) for the levee, BSL, CP and BSW are 4,4-9.9, (7.4), 3.1-13.0 (7.8), 4.8-12.1 (7.6) and 5.5-9.9 (7.0) cmol(+) kg^{-1}, respectively. The soils therefore had medium to high levels of ECEC.

Effective CEC varied significantly only with site in the BSL, with both site and depth in the CP and with neither of them in the levee and BSW. In the BSL, the means for sites 1 and 2 were similar, but were both lower than for site 3 ($P = 0.05$). In the CP, the mean values of ECEC were similar at sites 2 and 3, both of which were lower than at site 1 ($P < 0.05$), while with depth the mean values for the 0-25 cm and 25-50 cm were similar, those for the 25-50 cm and 50-75 cm were in turn similar, but the mean for the 0-25 cm was higher than for the 50-75 cm ($P < 0.05$). The ECEC did not vary among the MTFs.

4.2.8 Cation exchange capacity (CEC)

The CEC values ranged from 10.0-20.3, 11.8-27.3, 11.3-22.4 and 14.4-34.0 cmol(+) kg^{-1} soil in the levee, BSL, CP and BSW respectively with corresponding mean values of 20.4, 19.5, 16.9 and 15.1 cmol(+) kg^{1-}. The CEC values were relatively high, apparently due to the presence of 2:1 clay minerals, most probably montmorillonite. Kparmwang and Esu (1990) stated that the CEC values of fadama soils fall mainly within the medium to high range and reflect the content of organic matter and clay mineralogy; it is therefore usually higher in the surface soils and in soils high in montmorillonitic clays.

In the levee and BSL, the CEC values varied significantly only with site; in the CP and BSW, it did not vary significantly with either of them. In the levee, the mean values for sites 1 and 2 were similar, those for sites 2 and 3 were in turn similar, but the mean for site 3 was higher than for site 1 ($P < 0.05$). In the BSL, the magnitudes of the mean values of CEC were in the order site 3 > site 2 > site 1 ($P < 0.01$).

Along the MTFs, the mean CEC values for the BSW and BSL were similar, that for the BSL was in turn similar to that of the CP, which was lower than for the BSW. Thus, CEC generally increased along the MTFs from levee to BSW, following an identical trend with clay content. This suggests that clay is responsible for the greater proportion of the CEC. The trend of organic C was also close to that of the clay being higher in the

BSW and lowest in the levee indicating that it also contributed substantially to the CEC.

4.2.9 Base saturation

The values ranged from 28-72% (mean, 41%) within the levee, 22-64% (mean 35%) in the BSL, 23-94% (mean, 41%) in the CP, and 27-70% (mean, 42%) in the baskswamp. The values were generally low, i.e. less than 50%. Kparmwang and Esu (1990) stated that the base saturation of fadama soils ranged from less than 20% to higher than 80%. This agreed to a large extent with what is obtained here, except that all the values, at the lowest, were more than 20%, and only one was greater than 80%, at the highest.

Base saturation did not vary significantly with either site or depth in all MTFs except in the BSL where it varied significantly with site. The means for sites 1 and 2 were similar, those of sites 2 and 3 were in turn similar, but the mean for site 3 was higher than for site 1 ($P < 0.05$). Base saturation did not vary significantly along the MTFs either.

4.3 Correlation matrix

Results of correlation, i.e. the r values and probability levels are presented in Table 4.

4.3.1 Simple correlation among soil properties within the MTFs.

In the levee pH (water) was positively correlated with pH ($CaCl_2$) at $P < 0.01$ (Table 4a), which shows that the trend in soil pH in the levee was the same when measured in water or $CaCl_2$, except for the depressional effect of the salt solution on the values of pH. The pH (water) was negatively correlated with clay ($P < 0.05$) probably due to the negative charge on clay. Organic carbon was positively correlated with only total N ($P < 0.05$) which agrees with the fact that both come largely from soil organic matter.

The CEC of the soil was positively correlated with clay, exchangeable Ca and Na ($P < 0.05$) and with exchangeable acidity and ECEC ($P < 0.01$ and $P < 0.001$, respectively). The CEC of the soil is due to the negative charge on soil colloids, especially clay in soils low in organic matter such as those used in this study.

The relationships with exchangeable cations indicates that they are largely held by the clay fraction. The CEC was, however, negatively correlated with exchangeable Mg and total N. It is possible that Mg; as total N, was, sourced largely from organic colloids rather than clay.

The clay fraction in the levee was negatively correlated with pH (water) as explained earlier and with total N as explained for CEC. It was however positively correlated with exchangeable acidity and CEC because of the charge relationship explained for CEC. All correlations with clay was at $P < 0.05$.

Table 4a: Coefficient of correlation for soil properties in the levee.

	pH(1)	pH(2)	Av.P	OC	TN	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS	Clay	Silt	Sand
pH(1)	-															
pH(2)	0.809**	-														
Av. P	-0.110	0.049	-													
OC	0.288	0.489	0.654	-												
TN	0.283	0.175	0.745*	0.720*	-											
Ca	0.286	-0.142	0.085	0.053	0.563	-										
Mg	0.230	0.173	0.766*	0.577	0.931***	0.443	-									
K	0.524	0.622	-0.054	0.579	0.198	0.017	-0.040	-								
Na	-0.032	0.194	-0.355	-0.111	-0.647	-0.810**	-0.579	0.164	-							
H+Al	-0.586	-0.459	-0.188	-0.316	-0.627	-0.328	-0.667*	-0.270	0.421	-						
ECEC	-0.428	-0.393	-0.232	-0.185	-0.495	-0.096	-0.628	-0.031	0.333	0.937***	-					
CEC	-0.303	-0.157	-0.436	-0.205	-0.700*	-0.417	-0.771*	0.105	0.698*	0.861**	0.888***	-				
BS	0.397	-0.111	-0.247	-0.049	0.632	0.873**	0.216	0.205	-0.495	-0.352	-0.070	-0.233	-			
Clay	-0.680*	-0.382	-0.363	-0.347	-0.696*	-0.588	-0.601	-0.241	0.611	0.700*	0.583	0.756*	-0.461	-		
Silt	-0.449	-0.441	-0.042	-0.465	-0.128	0.009	0.119	-0.880**	-0.270	0.038	-0.182	-0.242	-0.184	0.259	-	
Sand	0.623	0.509	0.165	0.518	0.357	0.203	0.114	0.830**	0.010	-0.282	-0.055	-0.065	0.320	-0.576	-0.937***	-

The silt fraction was positively correlated with only exchangeable K ($P < 0.01$). This is probably due to the release of exchangeable K from micaceous minerals in the silt fraction.

The sand fraction was also postively correlated with exchangeable K ($P < 0.01$) probably for similar reasons as silt, i.e. due to the release of exchangeable K, in this case, from micaceous minerals in the sand fraction. The sand fraction was, however, negatively correlated with the silt fraction ($P < 0.01$) which is related to their inverse distribution trends in the levee.

In the BSL, pH (water) was negatively correlated with clay ($P < 0.05$) but not with pH ($CaCl_2$) (Table 4b), which means that the depressional effect of the salt on pH was not a simple mathematical function as was in the levee. Organic carbon was positively correlated with exchangeable Ca ($P < 0.001$), exchangeable Na, exchangeable acidity and effective CEC, all at $P < 0.05$, and with base saturation ($P = 0.01$). This shows that organic matter contributed significantly to charge and the retention of cations in the BSL.

The CEC of the soil was positively correlated with exchangeable K and Na ($P < 0.05$), exchangeable acidity ($P < 0.001$), effective CEC ($P < 0.01$) base saturation ($P < 0.05$), and clay ($P < 0.01$) and was negatively correlated with sand ($P < 0.001$). These are similar to what was obtained in the levee.

The clay fraction was negatively correlated with pH (water) ($P < 0.05$) and positively correlated with exchangeable Ca ($P < 0.05$), exchangeable Na, exchangeable acidity and effective CEC ($P < 0.01$)

and with CEC ($P < 0.001$), most of which have been explained at the levee. The difference is mainly in the probability levels which is higher in the BSL than in the levee.

Table [illegible]. Coefficient of correlation for soil properties in the BSL

	pH(1)	pH(2)	Av.P	OC	TN	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS	Clay	Silt	Sand
pH(1)	-															
pH(2)	0.152	-														
Av. P	0.360	0.577	-													
OC	0.201	0.521	0.340	-												
TN	-0.189	0.439	0.205	0.020	-											
Ca	0.261	0.117	-0.025	0.812**	-0.182	-										
Mg	-0.366	0.262	-0.163	0.261	-0.133	-0.091	-									
K	-0.469	0.426	-0.070	0.358	-0.196	0.078	0.914**	-								
Na	-0.567	0.402	0.126	0.768*	0.218	0.617	0.439	0.553	-							
H+Al	-0.480	0.469	0.198	0.660*	0.002	0.607	0.312	0.594	0.871**	-						
ECEC	-0.376	0.217	0.061	0.717	0.397	0.723*	0.404	0.625	0.782*	0.889**	-					
CEC	-0.522	0.520	0.057	0.558	-0.014*	0.486	0.460	0.744*	0.790*	0.952***	0.832**	-				
BS	-0.460	0.282	-0.048	0.888***	-0.138	0.890**	0.354	0.488	0.849**	0.774*	0.873**	0.0712*	-			
Clay	-0.662*	0.282	-0.254	-0.645	-0.083	0.724*	0.420	0.633	0.821**	0.857**	0.851**	0.886***	0.891	-		
Silt	0.214	0.577	-0.590	-0.245	0.629	-0.622	-0.021	-0.011**	-0.169	-0.125	-0.471	-0.060	-0.530	-0.433	-	
Sand	0.623	-0.612	-0.024	-0.589	-0.234	-0.481	-0.455	-0.696*	-0.823**	-0.886***	-0.700	-0.951***	-0.713*	-0.885*	-0.039	-

The silt fraction was not related to any soil property in the BSL including exchangeable K. The sand fraction on the other hand was negatively correlated with several soil properties including exchangeable Na and the silt fraction ($P < 0.01$), and with exchangeable acidity and CEC ($P < 0.001$). With silt, this is also related to inverse distribution trends as in the levee and with exchangeable cations, base, saturation and CEC, this is probably due to the low charge characteristic of the sand fraction.

In the CP, pH (water) was positively correlated with pH ($CaCl_2$) at $P < 0.001$ (Table 4c), as in the levee and with sand ($P < 0.01$). Thus, as in the levee, only the depressional effect of the salt on pH measurement was operative but trends in the soils are similar for both pH (water) and of pH ($CaCl_2$). The high positive correlation of pH (water) with sand is probably related to the acid nature of the sand fraction usually exhibited in sandy soils.

Organic carbon was positively correlated with available P. exchangeable Na and acidity ($P < 0.05$) and with effective CEC ($P < 0.01$). These suggest that most of the available P was held in organic matter, and similarly the cations, and that organic matter contributed significantly to the negative charge of the soils of the CP. Surprisingly, however, CEC was not significantly related to any soil property in the BSL.

The silt fraction was positively correlated with exchangeable Mg ($P < 0.01$) with no clear explanation except that some clay might have aggregated into silt-size and exhibited adsorption affinity for Mg. The sand fraction was positively correlated to pH (water) and pH ($CaCl_2$) ($P < 0.01$) and negatively with the silt fraction. In the BSW, pH (water) was negatively correlated with exchangeable Ca and base saturation ($P < 0.05$) (Table 4d).

Table 4c: Coefficient of correlation for soil properties in the coverplain

	pH(1)	pH(2)	Av.P	OC	TN	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS	Clay	Silt	Sand
pH(1)	-															
pH(2)	0.965**	-														
Av. P	-0.102	-0.289	-													
OC	0.432	0.266	0.771*	-												
TN	0.433	0.518	0.230	0.265	-											
Ca	-0.188	-0.223	0.094	0.113	0.149	-										
Mg	-0.306	-0.348	0.446	0.280	0.348	0.885**	-									
K	0.042	-0.039	0.917***	0.738*	0.260	-0.112	0.267	-								
Na	-0.591	-0.490	-0.451	-0.568	-0.566	-0.042	-0.183	-0.438	-							
H+Al	-0.104	-0.023	-0.761*	0.749*	0.058	-0.419	-0.090	0.889**	-0.276	-						
ECEC	-0.102	-0.252	0.803**	0.794**	0.175	0.521	0.729*	0.659	-0.273	0.556	-					
CEC	-0.380	-0.391	0.433	0.281	0.157	0.127	0.350	0.308	0.120	0.436	0.531	-				
BS	-0.226	-0.264	0.185	0.162	0.175	0.994***	0.929***	-0.016	-0.056	-0.342	-0.589	0.183	-			
Clay	-0.638	-0.604	-0.180	-0.548	-0.601	-0.122	-0.169	-0.258	0.532	-0.256	-0.328	-0.383	-0.127	-		
Silt	-0.600	-0.623	0.492	0.091	0.214	0.543	0.829**	0.416	-0.009	0.104	0.610	0.456	0.619	0.043	-	
Sand	0.845**	0.854**	-0.319	0.190	0.095	-0.334	-0.561	-0.149	-0.295	-0.019	-0.347	-0.295	-0.391	-0.552	-0.808**	-

Table 4d: Coefficient of correlation for soil properties in the BSW

	pH(1)	pH(2)	Av.P	OC	TN	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS	Clay	Silt	Sand
pH(1)	-															
pH(2)	0.341	-														
Av. P	-0.488	0.428	-													
OC	-0.642	-0.265	0.541	-												
TN	-0.538	-0.308	0.196	0.639	-											
Ca	-0.704*	-0.065	0.428	0.586	0.682*	-										
Mg	-0.603	0.113	0.613	0.384	0.631	0.831**	-									
K	-0.601	-0.012	0.681*	0.490	0.350	0.136	0.322	-								
Na	-0.047	0.108	0.095	0.027	0.251	0.549	0.483	-0.251	-							
H+Al	-0.136	-0.103	0.210	0.704*	0.331	0.077	-0.214	-0.366	-0.245	-						
ECEC	-0.619	-0.117	0.653	0.900***	0.658*	0.755*	0.602	0.467	0.300	0.589	-					
CEC	0.179	-0.294	-0.141	0.379	0.439	-0.263	-0.228	0.191	-0.272	0.528	0.129	-				
BS	-0.672*	0.009	0.503	0.532	0.690*	0.981***	0.913***	0.197	0.611	-0.011	0.738*	0.256	-			
Clay	-0.357	-0.592	-0.055	0.587	0.802**	0.272	0.146	0.418	-0.023	0.602	0.527	0.654	0.246	-		
Silt	0.605	0.570	-0.161	-0.150	-0.789**	-0.340	-0.417	-0.657	0.070	-0.275	-0.474	-0.437	-0.367	-0.862**	-	
Sand	0.117	0.762*	0.399	-0.458	-0.543	-0.138	0.162	-0.022	-0.006	-0.572	-0.364	-0.586	-0.050	-0.854**	0.558	-

These are also inexplicable correlations as they go contrary to the known chemistry of Ca, i.e. its adsorption is expected to be higher at higher pH values; the base saturation is expected to follow the same path.

The clay fraction was positively correlated with total N ($P < 0.01$), also for no apparent reason. The silt fraction was negatively correlated with total N and the clay fraction ($P < 0.01$), both of which are expected. The sand fraction was positively correlated with pH ($CaCl_2$) ($P < 0.05$) as was the case in the CP, but not with pH (water) and, as expected, it was negatively correlated with the clay fraction ($P < 0.01$).

4.3.2 Simple correlation among soil properties spanning the MTFs.

The results (Table 5) show that soil properties which had significant correlations with pH (water) were CEC and clay, which showed negative correlations, and sand, which gave a positive correlation. As explained for the individual MTFs, the CEC of the soil normally has an inverse relationship with soil pH, and the higher the clay content, the higher the pH, due first to the negative charge carried by the clay and also to its buffering action on soil pH. In comparison, sandy soils, because of their low buffering capacity, are often low in pH.

Several soil properties were significantly correlated with organic carbon, including available P, exchangeable Ca and Mg, exchangeable acidity, effective CEC, CEC, base saturation and clay. The correlations were positive in each case for all the parameters, the positive correlations were expected, as organic matter is either a source or adsorption site for all of them including clay with which it forms organo-clay complexes.

Clay was also related to quite a number of soil properties, namely, pH(water) and sand, with which it had negative correlations. Others are exchangeable Na, exchangeable acidity, effective CEC, and CEC, all with positive correlations. Clay is also a source and/or an adsorption site for the parameters it had positive correlations with.

Silt had a positive correlation with only K, and as explained for the individual MTFs, it is probably due to the release of exchangeable K from micaceous minerals in the silt fraction.

Sand, the inactive fraction, had significant correlation with more soil properties than the active fractions (clay and organic carbon). The correlations were positive, with pH(water), pH($CaCl_2$) and exchangeable K, as earlier explained at soil pH above, and that of K, of as explained at silt above. Other correlations, which were all negative were with exchangeable Mg and Na, effective CEC, CEC, clay and silt. These are in contrast to the positive correlations of the same parameters with clay. Sand actually has the opposite properties to clay.

Table 5: Coefficient of correlation for soil properties spanning the MTFs

	pH(1)	pH(2)	Av.P	OC	TN	Ca	Mg	K	Na	H+Al	ECEC	CEC	BS	Clay	Silt	Sa
pH(1)	-															
pH(2)	0.846***	-														
Av. P	0.092	0.127	-													
OC	0.045	0.202	0.492	-												
TN	-0.069	0.040	0.133	0.113	-											
Ca	-0.026	-0.009	0.163	0.389*	-0.048	-										
Mg	-0.246	-0.097	0.278	0.340*	0.036	0.551***	-									
K	0.351*	0.282	0.202	0.266	-0.004	-0.034	0.050	-								
Na	-0.302	-0.129	-0.193	0.241	0.063	0.043	0.235	0.101	-							
H+Al	-0.250	-0.148	0.298	0.391*	0.034	-0.174	-0.078	-0.038	0.292	-						
ECEC	-0.204	-0.118	0.326	0.634***	-0.229	0.477**	0.393*	0.152	0.381*	0.701***	-					
CEC	-0.340	-0.191	-0.058	0.371*	0.009	0.027	0.138	0.026	0.398**	0.521***	0.520***	-				
BS	-0.027	-0.049	0.134	0.403*	-0.027	0.931***	0.659*	0.122	0.208	-0.126	0.529***	0.528	-			
Clay	-0.493**	-0.271	-0.248	0.419**	-0.005	0.170	0.272	0.094	0.558***	0.381*	0.505**	0.735***	0.228	-		
Silt	0.237	-0.152	0.224	-0.237	0.189	0.045	0.123	0.491**	0.121	0.058	0.157	0.049	-0.018	-0.225	-	
Sand	0.640***	0.400*	0.106	-0.220	-0.098	-0.175	-0.333*	0.386*	-0.460**	-0.307	-0.361*	-0.637***	-0.195	-0.788***	-0.403*	-

4.4 Suitability Classification of the Microtopographical Features for Arable Crops.

Suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. The first step in classifying suitability is to decide which factors should be used to define each suitability class. Upper and lower limits for each relevant land characteristic or quality are then set for each class. The properties of each land unit are reviewed and compared to the class limits. Each land unit can then be assigned a suitability classification.

To simplify this stage, all known information is first set out as a table that shows, for each land utilization type, the class rating of each class determining factor together with any qualifying information or comment. The final assessment of suitability is usually based on three principles (FAO, undated).

1. The limiting conditions principle. This states that the most unfavourable quality determines the suitability classification.

2. The subjective (combination) assessment. In this principle, suitability classes are raised or lowered on the basis of judgements of the importance of different factors. Because subjective assessments are risky, the relevant factors are weighted and account is taken of special limitations that may occur if two or more negative factors occur together.

3. The principle of arithmetic modelling. This is based on the fact that each land quality has an independent influence on suitability and it, therefore, means that land qualities can be

assigned values and manipulated arithmetically to provide numerical assessment of overall suitability.

In practice, a combination of these approaches is often employed.

The suitability of the river Galma fadama for arable crops, namely cereals and vegetables was assessed separately using the limiting factor and the arithmetic modelling principles (1 and 3) and the results compared. In each case the subjective assessment, principle (2) was tacitly involved, especially, in selecting land characteristics.

The limits of land characteristics are adapted from FAO (1976) with few modifications (Table 6). The more straightforward limiting factor method is presented first (Table 7). In the levee and CP the most limiting factor is rated as S2. Thus, both have a suitability of S2 (moderately suitable). In the BSL and BSW, the most unfavourable factor is rated as S3 both, therefore, have a suitability of S3.

Table 6: Ratings of some soil characteristics for fertility evaluation according to FAO (1976)

Soil characteristic	Rating		
	S1	S2	S3
Texture	l, scl	cl, c	s, ls, sc, c
CEC (cmol(+) kg^{-1})	> 20	15-20	< 10
Organic carbon	1.0-1.5	0.5-1.0	< 0.5
Bray 1 P (mg kg^{-1})	> 20	10-20	< 10
Exch. K (cmol(+) kg^{1-})	0.2-0.4	0.1-0.2	< 0.1
pH (water)	5.5-7.5	4.5-5.5 or 7.5-7.8	4.0-4.5 or 7.8-8.0

S1 = Highly suitable for cultivation of arable crops.
S2 = Moderately suitable for cultivation of arable crops. S3
= Marginally suitable for cultivation of arable crops.

Table 7: Suitability classification of the MIFs based on the limiting condition principle.

Soil property	Levee		Backslope		Cover plain		Backswamp	
	Mean Value	Rating	Mean Value	Rating	Mean Value	Rating	Mean Value	Rating
Texture	L	S1	cL	S2	L	S1	sicL	S1
CEC	20.4	S1	19.5	S2	16.9	S2	15.1	S2
Organic C	0.5	S2	0.5	S2	0.6	S2	0.6	S2
pH (water)	4.8	S2	4.1	S3	4.8	S2	4.3	S3
Drainage *	WD	S1	WD	S1	MWD	S2	PD	S3
Overall suitability		S2		S3		S2		S3

*: Mean value irrelevant; WD = well drained, MWD = moderately well drained PD = poorly drained.

Using the arithmetic modelling, individual assessments, expressed numerically are combined by multiplication or by addition. In the method of multiplication each suitability class is assigned a value ranging from 1.0 for S1 to 0.0 for n (FAO, 1983). The following suggested values by FAO, 1983) were adapted

S1 = 1.0

S2 = 0.8

S3 = 0.5

n = 0.0

These values are multiplied for all the selected land qualities. The product is then converted to an overall suitability, on a different scale to reduce an unduly large number of S3 results. The scale below, also suggested by FAO (1983) was again adapted.

0.8-1.0 = S1

0.4-0.8 = S2

0.2-0.4 = S3

0.0-0.2 = N

Thus for the levee, the overall suitability would be 1.0 x 1.0 x 0.8 x 0.8 x 1.0 = 0.64 = S2. The results for the entire MTFs are presented in Table 8 The results show that all MTFs had a moderate suitability (S2) for arable crops except the BSW which was not suitable (N). This can be specified as N1 because if drainage is provided, the BSW would be at best moderately suitable.

Table 8: Suitability classification of the MTFs by the arithmetic modelling method.

Soil property	Levee	Backslope	Coverplain	Backswamp
Texture	S1	S2	S1	S1
CEC	S1	S2	S2	S2
Organic C	S2	S2	S2	S2
pH (water)	S2	S3	S2	S3
Drainage	S1	S1	S2	S3
Overall suitability	S2	S2	S2	N

Comparing the limiting condition method with the arithmetic modelling method, the latter appears to be more appropriate for assessing the suitability of the MTFs of the river Galma Fadama at Zaria. The results agree with the intensity of cropping on the MTFs of fadama.

4.5 Management Recommendations

Because the fadama is at an irrigation site, land levelling has been carried out.

This has tempered with the general appearance and physical composition of the MTFs to some extent. Since some levelling has been done, the management recommendations are now mainly on soil organic matter, liming and fertilizer use.

Organic matter

The mean values of organic carbon, the main index of organic matter (OM) content is low in all the MTFs of the fadama. Organic matter addition and maintenance is therefore mandatory for profitable agriculture on the fadama. Apart from being an adsorption site for nutrient ions, OM is also a major source of N, P, and S and also Ca, Mg and micronutrients. It gains prominence in this regard when mineral fertilizers are scarce or of prohibitive price, as is the situation in the country currently.

The most feasible source of OM is farm yard manure (FYM) since farmers use crop residues as animal feeds, and as bedding, roofing and fuel materials. Apart from the well known cow dung, chicken dropping is gaining prominence because it has a high concentration of nutrients and is therefore required in smaller quantities than cow dung and other FYM sources. The FYM's efficacy is greatly enhanced when mixed with mineral fertilizers. Farmers have adapted this method to the best of their advantage.

Liming

This is aimed at raising the soil pH to 5.5 and not higher because of the poorly buffered nature of the soils and the problems associated with overliming, namely; micronutrient and P unavailability. The mean pH (water) values are the BSL and BSW respectively. Based on these and the mean clay contents, the lime requirements of the MTFs are presented in Table 9. The lime requirement is inversely proportional to soil pH and directly proportional to clay content.

Thus, the BSL and BSW with low pH values and high clay contents require about 3 to almost 5 times the amount of lime required by the levee and CP with higher pH values and lower clay contents.

Table 9: Lime requirement for the MTFs of the River Galma fadama at Zaria

MTF	Mean pH (water)	Mean clay content (%)	kg pure lime/ha (to doing pH to 5.5)
Levee	4.8	16.3	1568.9
Backslope	4.1	31.7	7396.7
Cover plain	4.8	20.1	1934.6
Backswamp	4.3	34.1	6840.0

Fertilizer Recommendation

The soils of the fadama are deficient in N and P and medium in K, Ca and Mg. Thus, complete compound fertilizers containing N, P and K would be required. Fertilizers containing low or no K would however, be clay on the fadama for some years. If such are used, the K level should be assessed after 3-5 years of intensive cropping.

The full recommended dose of N and P for each crop should be applied. If liming is done, there would be no need for fertilizers containing Ca and/or Mg. Thus dolomitic lime should be used so that ameliorated. If however, lining is not done, then fertilizers carrying Ca and Mg should be preferred on the fadama.

CHAPTER FIVE

5.0 SUMMARY AND CONCLUSIONS

The present fertility status of the River Galma fadama was investigated vis-a-vis its microtopographical features (MTFs). The suitabilities of the MTFs for arable cropping were evaluated and management recommendations profered for them. The succession of the MTFs from the river bank and proceeding at right angles to it, is in the order, levee, BSL (BSL), coverplain (CP) and BSW (BSW).

The site is currently used for irrigation and, therefore, the MTFs have been disturbed to varying extents by land levelling, depending on the intensity of cropping on each. However, their salient features namely, slope, drainage and texture are still largely in place.

Soil properties varied mainly with site within each MTF, and very little with depth. This depicts a carpet-like pattern of heterogeneous soil types within each MTF, each soil type, however, being more-or-less homogeneous in profile characteristics. As expected, the only properties that varied significantly with depth were organic C, available P, total N and pH (water), and these were, in at most two, MTFs each.

Overall, the soils could be rated as moderately high in fertility status due to medium to high values of effective ECE and CEC (NH_4OAc) and medium levels of Ca, Mg and K. The soils can, therefore, sustain intensive agriculture with recommended rates of N and P on crops, coupled with the use and maintenance of organic matter.

The present fertility status of the various MTFs could be ranked in the order BSW > CP > BSL > levee. But, because drainage increased in this direction (from poorly drained to well drained) and due to textural variability, the intensity of cropping along the MTFs was in the order BSL > CP > LEVEE > BSW.

Using the arithmetic modelling method, however, the levee, BSL, and CP were found to be moderately suitable (S2) for arable cropping, while the BSW was currently not suitable (N1). But if drained, it would be upgraded to at least moderately suitable.

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APPENDIX A1: Ranges and mean values for particle-size fraction by replication (site)

	Clay %		Silt %		Sand %	
	Range	Mean	Range	Mean	Range	Mean
Levee						
Site I	12-14	13	46-50	48	38-40	38.7
Site II	12-18	15	12-38	28.7	46-76	56
Site III	16-28	21	38-50	44	28-46	34.7
Grand	12-28	16	12-50	40	28-76	43
BSL						
Site I	12-14	13	34-36	35	50-54	51
Site II	28-30	24	50-54	52	20-30	24
Site III	48-68	58	26-42	33	6-10	8.7
Grand	12-68	31.7	26-64	40	6-54	27.9
CP						
Site I	16-24	19.6	50-56	53.6	26-28	26.7
Site II	14-18	16	32-40	36	42-58	51
Site III	22-28	24.6	38-44	40.7	32-34	33
Grand	14-28	20	32-56	43	26-58	36.9
BSW						
Site I	20-32	28	42-48	45	22-26	23
Site II	20-26	23	50-54	52.7	20-30	24
Site III	45-56	51.7	32-45	37.7	8-14	10.7
Grand	20-56	34	32-54	45	8-30	19

APPENDIX A2: Ranges and mean values for particle-size fraction by depth

	Clay %		Silt %		Sand %	
	Range	Mean	Range	Mean	Range	Mean
Levee						
0-25cm	12-16	13	22-50	33	38-76	53
25-50cm	14-28	20	36-48	42.7	28-46	37
50-75cm	14-20	16.7	38-50	44.7	30-46	38.7
Grand	12-28	16.6	12-50	40	28-76	42.9
BSL						
0-25cm	14-68	33	26-52	38	6-50	28.7
25-50cm	12-58	31	32-54	39	10-54	28.7
50-75cm	14-48	30.7	36-50	42.7	10-50	26.7
Grand	12-68	31.6	26-54	39.9	6-54	28
CP						
0-25cm	14-28	19	32-56	42	28-54	38.7
25-50cm	16-24	19.7	36-55	43.7	26-58	38.7
50-75cm	18-24	21	40-50	44.7	26-42	34
Grand	14-28	19.9	32-56	43.5	26-58	37
BSW						
0-25cm	20-56	36	36-50	42.7	8-30	21
25-50cm	24-45	33.7	45-54	48	10-22	18
50-75cm	20-54	33	32-54	44.7	14-22	18.7
Grand	20-56	34	32-54	45	10-30	19

APPENDIX B1

Ranges and mean values for soil chemical properties by site

	Levee			BSL			CP			BSW		
	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III
pH(H_2O)												
Range	4.8-50	5.3-5.8	3.6-4.5	4.0-4.8	4.0-4.4	3.7-4.1	4.2-4.7	5.5-6.0	3.9-4.7	4.1-4.2	4.2-4.5	4.0-4.3
Mean	4.9	5.5	4.0	4.3	4.1	3.9	4.5	5.7	4.2	4.2	4.4	4.2
Grand			3.6-5.8 4.8			3.7-4.8 4.1			3.9-6.0 4.8			4.0-4.5 4.3
pH($CaCl_2$)												
Range	3.3-4.1	4.3-4.8	3.3.-3.7	3.0-3.2	3.7-3.9	3.2-3.7	3.5-4.1	5.2-5.6	3.1-3.9	3.5-4.0	3.9-4.0	3.5-3.6
Mean	3.8	4.6	3.5	3.1	3.8	3.5	3.9	5.4	3.6	3.8	4.0	3.6
Grand			3.3-4.8 4.0			3.0-3.9 3.5			3.1-5.6 4.3			3.5-4.0 3.8
Av.P mg kg^{-1}												
Range	0-22	2.7-11.7	2.7-16.1	1.6-4.8	5.4-23.3	2.7-3.6	1.2-37	4.5-7.2	3.2-16.1	1.2-19.9	2.7-10.8	2.7-7.2
Mean	11.3	6.3	8.7	2.7	11.7	3.0	17.1	6.0	9.6	7.4	5.5	4.2
Grand			0-22 8.8			1.6-23.3 5.7			1.2-37.0 10.9			1.2-19.9 5.7
Org. C (%)												
Range	0.2-0.9	0.4-0.8	0.3-0.5	0.02-0.6	0.4-1.0	0.4-1.6	0.3-1.2	0.4-1.0	0.3-0.7	0.2-1.1	0.2-0.6	0.4-1.3
Mean	0.5	0.6	0.4	0.2	0.6	0.9	0.7	0.6	0.4	0.5	0.3	1.0
Grand			0.2-0.9			0.02-1.6			0.3-1.2			0.2-1.3
			0.5			0.5			0.6			0.6

APPENDIX H1 contd: Range and Mean values for soil chemical properties by site

	Levee			Back slope			Coverplain			Back swamp		
	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III
Total N (%)												
Range	0.1-0.2	0.04-0.13	0.03-0.10	0.05-0.04	0.2-0.80	0.04-0.14	0.10-0.13	0.10-0.14	0.03-0.10	0.04-0.10	0.04-0.04	0.10-0.10
Mean	0.13	0.10	0.10	0.04	0.40	0.10	0.10	0.10	0.10	0.10	0.04	0.10
Grand			0.03-0.20 0.10			0.04-0.80 0.20			0.03-0.14 0.10			0.04-0.10 0.10
Ca cmol kg^{-1}												
Range	2.6-4.0	2.0-3.0	1.8-3.2	1.8-2.6	1.0-2.6	2.7-4.5	3.0-8.0	2.0-3.2	1.8-2.7	2.8-4.6	2.0-2.2	2.0-4.0
Mean	3.2	2.6	2.4	2.1	1.3	3.5	5.0	2.7	2.2	3.9	2.0	3.0
Grand			1.8-4.0 2.7			1.0-4.5 2.3			1.8-3.2 3.3			2.0-4.6 3.0
Mg cmol kg^{-1}												
Range	3.3-0.6	0.2-0.3	0.1-0.3	0.2-0.3	0.14-1.2	0.3-0.7	0.5-1.1	0.2-0.2	0.1-0.2	0.5-1.5	0.1-0.2	0.4-0.5
Mean	0.4	0.3	0.2	0.2	0.5	0.5	0.8	0.2	0.2	1.0	0.1	0.5
Grand	0.1-0.6		0.1-0.6			0.2-1.2 0.4			0.1-1.1 0.4			0.1-1.5 0.5

APPENDIX B1 contd: Range and Mean values for soil chemical properties by site

	Levee			Backslope			Coverplain			Backswamp		
	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III
K cmol kg^{-1}												
Range	0.1-0.1	0.3-1.2	0.1-0.12	0.1-0.1	0.1-0.3	0.2-0.2	0.1-0.5	0.1-0.2	0.1-0.2	0.1-0.2	0.1-0.2	0.1-0.2
Mean	0.1	0.8	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2
Grand			0.1-1.2 0.3			0.1-0.3 0.2			0.1-0.5 0.1			0.1-0.2 0.1
Na cmol kg^{-1}												
Range	0.2- 0.3	0.4-0.8	0.3-0.8	0.1-0.2	0.5-0.5	0.3-0.9	0.14-0.3	0.1-0.2	0.2-0.3	0.5-0.7	0.3-0.8	0.4-0.5
Mean	0.2	0.6	0.5	0.1	0.5	0.7	0.2	0.2	0.3	0.6	0.5	0.5
Grand			0.2-0.8 0.4			0.1-0.9 0.4			0.1-0.3 0.2			0.3-0.8 0.5
H+Al cmol kg^{-1}												
Range	1.0-2.6	2.4-3.6	5.2-6.6	2.4-3.0	4.0-5.4	5.6-7.2	0.8-8.6	2.4-5.0	3.0-4.2	1.8-3.0	3.0-3.4	3.0-4.4
Mean	1.6	2.9	6.0	2.7	4.6	6.3	3.8	3.3	3.4	2.4	3.2	3.7
Grand			1.0-6.6 3.0			2.4-7.2 4.2			0.8-8.6 3.5			5.5-9.9
ECEC cmol kg^{-1}												
Range	4.4-7.2	6.9-7.2	8.0-9.9	4.8-6.0	3.1-8.8	9.1-13.0	6.9-12.1	4.8-8.7	5.8-8.7	5.5-9.9	5.9-6.2	6.1-9.6
Mean	5.6	7.1	9.0	5.3	6.4	11.5	9.7	6.5	6.5	7.2	6.0	7.9
Grand			4.4-9.9 7.2			3.1-13.0 8.0			4.8-12.1 7.6			5.5-9.9 7.0

APPENDIX E1 contd: Range and Mean values for soil chemical properties by site

	Levee			Backslope			Coverplain			Backswamp		
	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III
CEC cmol kg^{-1}												
Range	10.0- 13.8	15.0-16.9	16.0-20.3	10.6-12.0	17.1- 22.2	25.8-28.6	14.1-22.4	14.0-18.3	11.3-30.3	10.7-16.4	17.9-20.0	19.8-34.0
Mean	11.3	16.0	17.9	11.5	19.8	27.2	18.6	15.5	17.2	13.8	19.0	28.5
Grand			10-20.3 15.1			10.6-28.6 19.5			11.3-22.4 17.0			10.7-34.0 20
Base sat.(%)												
Range	34.0- 72.0	33.0-47.0	28.0-39.0	22.0-32.0	27.0- 34.0	35.0-64.0	43,0-94.0	24.0-37.0	23.0-33.0	38.0-70.0	25.0-32.0	31.0-52.0
Mean	48.4	42	32	26	38	49	62	32	28	56	28	42
Grand			28.0-71.0 41.0			22.0-64.0 35.0			23.0-94.0 41.0			25.0-70.0 42.0

APPENDIX B2: Ranges and mean values for soil chemical properties by depth

	Levee			Backslope			Coverplain			Backswamp		
	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm
$pH(H_2O)$												
Range	4.8-5.8	3.6-5.4	4.0-5.8	3.7-4.6	3.9-4.2	4.0-4.1	4.7-6.0	4.1-5.7	3.9-5.5	4.0-4.2	4.2-4.5	4.2-4.5
Mean	4.8	4.6	4.9	4.3	4.0	4.0	5.1	5.7	4.6	4.1	4.3	4.3
Grand			3.6-5.8 4.8			3.7-4.8 4.1			3.9-6.0 4.8			4.0-4.5 4.2
$pH(CaCl_2)$												
Range	3.7-4.3	3.3-4.8	3.3.-4.7	3.2-3.9	3.2-3.7	3.0-3.7	3.9-5.5	3.5-5.6	3.1-5.2	3.5-4.0	3.6-4.0	3.6-3.9
Mean	4.0	4.1	3.8	3.6	3.4	3.5	4.5	4.3	4.1	3.8	3.8	3.7
Grand			3.3-4.8 4.0			3.0-3.9 3.5			3.1-5.6 4.3			3.5-4.0 3.8

APPENDIX B2 contd: Ranges and mean values for soil chemical properties by depth

	Levee			Backslope			Coverplain			Backswamp		
	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm
Avail.P mg kg^{-1}												
Range	11.7-20.0	4.5-12.0	0.0-2.7	2.7-23.0	1.6-6.33	1.6-5.4	7.2-37	6.3-13.0	1.2-4.5	7.2-19.9	1.2-3.1	1.2-2.7
Mean	16.6	7.9	1.8	10.2	3.07	3.2	20.0	9.4	3.1	12.6	2.3	2.2
Grand			0.0-22.0 8.8			1.6-6.3 5.9			1.2-37 10.8			1.2-19.9 5.7
Org. C (%)												
Range	0.5-0.9	0.3-0.7	0.2-0.4	0.6-1.6	0.04-0.7	0.04-0.4	0.7-1.2	0.3-0.6	0.3-0.4	0.6-1.3	0.2-1.2	0.2-0.4
Mean	0.7	0.5	0.3	1.1	0.4	0.3	1.0	0.5	0.3	1.0	0.6	0.3
Grand			0.2-0.9 0.5			0.02-1.6 0.6			0.3-1.2 0.6			0.2-1.3 0.6
Total N (%)												
Range	0.1-0.2	0.04-0.1	0.03-0.1	0.05-2.0	0.04-0.08	0.04-0.20	0. 04-0.13	0.10-0.10	0.03-0.14	0.04-0.10	0.04-0.10	0.04-0.10
Mean	0.14	0.10	0.10	0.70	0.3	0.10	0.10	0.10	0.10	0.10	0.10	0.03
Grand			0.03-0.2 0.11			0.04-0.80 0.40			0.03-0.14 0.10			0.04-0.10 0.2

APPENDIX 82 contd: Ranges and mean values for soil chemical properties by depth

	Levee			Backslope			Coverplain			Backswamp		
	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm
Ca.cmol(+)kg^{-1}												
Range	2.7-3.2	1.8-3.0	2.0-4.0	2.6-4.5	1.8-3.2	2.0-2.7	2.7-3.2	2.2-8.0	1.8-4.0	2.0-4.6	2.0-4.2	2.0-2.8
Mean	3.0	2.5	2.7	3.2	2.3	1.9	3.0	4.4	2.6	3.5	3.1	2.3
Grand			1.8-3.2 2.7			1.0-4.5 2.5			1.8-8.0 3.3			2.0-4.6 3.0
Magnesium												
Range	0.3-0.6	0.2-0.4	0.1-0.3	0.2-0.7	0.1-0.5	0.2-1.2	0.2-0.7	0.2-1.1	0.1-0.5	0.2-1.5	0.1-0.9	0.13-0.5
Mean	0.4	0.3	0.2	0.4	0.3	0.6	0.4	0.5	0.3	0.7	0.5	0.4
Grand			0.1-0.6 0.3			0.1-1.2 0.4			0.1-1.1 0.4			0.1-1.5 0.5
Potassium												
Range	0.1-1.2	0.1-0.9	0.1-0.3	0.1-0.2	0.1-0.2	0.1-0.3	0.1-0.5	0.1-0.2	0.1-0.1	0.2-0.2	0.1-0.1	0.1-0.2
Mean	0.5	0.4	0.2	0.2	0.1	0.2	0.3	0.1	0.1	0.2	0.1	0.1
Grand			0.1-1.2 0.3			0.1-0.3 0.2			0.1-0.5 0.2			0.1-0.2 0.1
Sodium												
Range	0.2-0.5	0.3-0.8	0.2-0.8	0.2-0.9	0.12-0.9	0.1-0.5	0.14- 0.2	0.2-0.3	0.1-0.3	0.3-0.7	0.3-0.7	0.4-0.8

APPENDIX B2 contd: Ranges and mean values for soil chemical properties by depth

	Levee			Backslope			Coverplain			Backswamp		
	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm
Mean	0.3	0.5	0.5	0.5	0.5	0.3	0.2	0.2	0.2	0.5	0.5	0.6
Grand			0.2-0.8 0.4			0.1-0.9 0.4			0.1-0.3 0.2			0.3-0.8 0.5
Exch. acidity												
Range	1.2-6.6	1.0-6.2	2.6-5.2	2.8-6.2	3.0-7.3	2.4-5.6	4.2-8.6	0.8-3.0	2.0-4.0	3.0-4.4	2.4-3.8	1.8-3.0
Mean	3.4	3.3	3.8	4.8	4.7	4.1	5.9	2.1	2.8	3.5	3.2	2.6
Grand			1.0-6.6 3.5			2.4-7.2 4.5			0.8-8.6 3.6			1.8-4.4 3.1
ECEC												
Range	5.1-9.9	4.4-9.1	6.9-8.0	6.0-12.5	3.1-13.4	4.8-9.10	7.5- 12.1	5.8-10-2	4.8-6.9	5.9-9.9	5.9-8.0	5.5-6.2
Mean	7.4	6.9	7.4	9.1	7.1	7.1	9.4	7.6	6.0	8.5	6.7	5.9
Grand			4.4-9.9 7.2			3.1-13 7.8			4.8-12.1 7.7			5.5-9.9 7.0
CEC												
Rang	10.0-17.5	10.0-20.3	13.8- 16.9	12.0- 25.8	11.8-28.6	10.6-27.3	11.3- 22.4	14.0-19.9	14.1-20.3	16.4- 20.0	14.4- 34.0	10.0-31.7
Mean	14.0	15.5	15.6	19.3	19.2	20.0	17.3	17.8	16.2	18.7	22.0	20.5
Grand			10-20.3 15.9			10.6-28.6 19.5			13.3-22.4 17.1			10.7-34.0 20.4

APPENDIX B2 contd: Ranges and mean values for soil chemical properties by depth

	Levee			Backslope			Coverplain			Backswamp		
	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm	0-25cm	25-50cm	50-75cm
Base sat. (%)												
Range	39-47	29-46	28-72	32-64	22-48	24-35	33-43	28-94	23-49	27-70	25-59	31-38
Mean	41	36	44	43	32	30	38	53	32	49	42	34
Grand			20-72 40			22-64 35			23-94 41			25-70 42