MAGNESIUM STATUS OF THE SAVANNAH SOILS OF NIGERIA IN RELATION TO TOBACCO PRODUCTION

BY

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Declaration

I hereby declare that the whole of the work now submitted as a thesis for the Ph.D degree of Ahmadu Bello University is the result of my own investigations. The work embodied in this thesis has not been already submitted in substance for any degree, and is not being concurrently submitted in candidature for any other degree.

Candidate.....

Date .....

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ABSTRACT

Under a system of continuous cultivation in northern Nigeria, a number of nutrients which were hitherto considered adequately supplied by the soil are becoming deficient, one such nutrient is Mg. There is need to establish the various availability indices for the nutrient under the semi-arid savannah conditions.

Six extraction procedures of analysis involving two extractants (Ammonium acetate and Calcium chloride) were used. The amounts of magnesium extracted by these various methods differed significantly. Increasing extraction time or the concentration of the extractant tended to increase the Mg extracted. Plant uptake of Mg correlated well with Mg extracted by all methods, though, repeated and single extraction with 1 N NH_4 OAc appeared the most suitable.

Magnesium status of the surface soils of different locations as assessed by the single extraction with ammonium acetate procedure showed that the savannah soils of northern Nigeria are generally low in Mg. The mean values of Mg of the Sudan savannah, Guinea savannah, and southern savannah zones were 0.54; 0.96 and 0,56 meq/ lOOg respectively. Regression analysis showed linear relationships between exchangeable Mg and soil CEC, clay Ca, organic matter and silt in descending order indicating their relative importance in predicting Mg levels of these soils.

Profile sampling in some tobacco growing areas revealed that Mg content increased with depth, the top soil containing the lowest amount. This distribution pattern is attributed to leaching and clay illuviation. High correlation existing between Mg content and each of organic matter and clay at all depths stresses their importance and the need to maintain the organic matter content of these soils. Magnesium content of field tobacco was considered low averaging about 0.26% and there was no correlation between plant and soil Mg which suggests that the latter may not be the only factor controlling Mg uptake under field condition. However, in the green house, Mg uptake was largely dependent upon soil Mg status.

Application of Mg to generally acid scils, sandy to silty loam, low in organic matter, CEC, and nutrient status, particularly Mg and K improved the growth of tobacco plants and increased the leaf yield most especially at 24 kg Mg/ha, Magnesium content of leaves was increased but that of calcium, potassium, nicotine, total nitrogen and reducing sugar were not significantly affected, though there was a tendency tof decrease of reducing sugar with Mg application. There was no interaction between Mg and K on the chemical components of tobacco leaves and yield within the range of application of both elements.

The generally low level of plant - available Mg in the soils studied coupled with the significant response obtained to Mg application suggest that Mg deficiency may attain wide scale importance in the semi-arid savannah zone of Nigeria in no distant future.

CERTIFICATION PAGE

We certify that this work was carried out by Mr. F. A. Elkased in the Department of Soil Science, Ahmadu Bello University, Zaria.

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THESIS APPROVAL

This thesis by F.A. ELKASED meets the regulations governing the degree of Doctor of Philosophy of Ahmadu Bello University and is approved for its contribution to scientific knowledge and literary presentation.

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INTRODUCTION

Until fairly recently, maintenance of soil fertility in the West African savannah region has been mainly through the traditional bush fallowing which helps to recycle nutrients from the sub-soil and to increase top-soil organic matter and C.E.C. Lately however, population pressure and other socio-economic forces have tended to reduce fallow lengths drastically and in many places, eliminated them altogether (Lombin and Abdullahi; 1977). This has forced a change from the bush fallowing system to more intensive continuous cultivation which invariably calls for sustained fertilizer use to ensure high yields.

However, fertilizer work in northern Nigeria has so far been largely confined to the two most limiting nutrients N and P. The gradual shift towards continuous intensive cultivation coupled with the introduction of improved crop varieties and better crop management practices leading to high yields has brought into focus the necessity to give attention to not only the major nutrients but also some of the minor ones as well. One such element is magnesium. The widespread use of K fertilizers in the absence of magnesium fertilization will, conceivably, have an adverse effect on magnesium availability in view of the well-known ionic antagonisms between Mg and K in plant nutrition (Jacob, 1958 and

Welte and Werner, 1963). Plants require greater amounts of Mg than normal to prevent deficiency under conditions of high soil K (Ulrich and Ohki, 1956 and Kabu et al., 1970). Therefore soils hitherto considered to be adequately supplied with magnesium may well be suffering from induced Mg deficiency under the present fertilizer programme which involves only K as the major cation.

The savannah soils of northern Nigeria are generally coarse textured, slightly to moderately acid, poorly buffered and low in potential fertility. Reporting on the effects of continuous fertilizer use on exchangeable cation ratios and crop nutrition in northern Nigeria, Jones and Stockinger (1976) observed that one of the nutrient elements most at risk of being deficient was Mg. A soil nutrient survey by Lombin (1979) has since confirmed this assertion. It would seem therefore that the magnesium fertility of northern Nigeria Savannah soils can no longer be taken for granted

The principal objective of this study is to assess the magnesium fertility of the agriculturally important Nigerian savannah soils using tobacco as a test crop.

Specifically the study aims to:-

(1) Establish a suitable soil test method for plants - available magnesium under the seasonally dry, semi-arid Nigerian savannah conditions.

(2) Evaluate through laboratory and greenhouse studies, the magnesium-supplying powers of representative soils of the area covered by the study.

(3) Study the effects of magnesium fertilization on yield, yield components and leaf quality of tobacco.

Chapter 1

AREA COVERED BY THE STUDY

SOILS AND CLIMATE OF NORTHERN NIGERIA

Northern Nigeria covers an area of 675,840 square kilometres lying between latitudes 7^{o}N and 13^{o}N and longitudes 3^{o}E and 15^{o}E. In such a vast area, considerable variation in soil forming factors and range in soil type is encountered. The effects of geology and topography on the soils are often striking and these tend to obscure any climatic effects which may be present (Tomlinson, 1965).

The topography of the area is predominantly one of very gently undulating plains. In the central part of the country the Zaria and Bauchi plains have occasional steep rocky hills; these plains have been correlated with the continental "African" erosion surface (Pugh and King, 1952). Similar topography with somewhat lower relief is found in the north-west. In the north-east the plains forming part of the Chad Basin show very little relief. Near the centre of the country is the 1200m high Jos Plateau. From the plateau isolated hill ranges rise to nearly 1800m. Similar heights are reached at a few points in the hills which mark the eastern frontier of northern Nigeria, but areas where altitude has a significant effect on soils are of

negligible extent. Further north-east, there are two small plateaux built up of superimposed lava flows, the larger and higher of these is the Bui Plateau at about 750m. Other minor volcanic structures are common locally in this area as well as on and around the southern edges of Jos Plateau.

The geology of the area has been summarized by Tomlinson, (1965). Basement complex is dominant and exhibit great variation in rock type and structure. Various kinds of granite have been found in some areas and in others more intricate mixture of gneisses, schists, quartzites and other metamorphic rocks are also found. Over large areas, mixtures of granites and metasediments which comprise alternating sandstones and shales are found. Recent deposits of both aeolian and alluvial origin are found as fixed sand dunes in the extreme north-east, as alluvium in the areas immediately south of Lake Chad, and to varying extents along the major rivers.

Climate and Vegetation

The general features of the vegetation of northern Nigeria have been described by Keay(1959). The major vegetation/climatic zones are:

1. Sahel: Rainfall less tham 500mm, 8 months with less than 25mm. Open thorn Savannah with sparse annual grasses and a number of unpalatable perennial grasses.

2. Sudan: Rainfall 500 - 1000mm, 6 - 7 months with less than 25mm. Open woodland generally much degraded by burning and overgrazing.

3. Northern Guinea: Rainfall 1000-1250mm, 5 months with less than 25mm. A well-marked vegetation type comprising open or closed woodland.

4. Southern Guinea: Rainfall 1125 - 1375mm, 4 - 5 months with less than 25mm. Numerous vegetation communities can be recognized, some are closed woodland, others are rather indeterminate shrub woodlands.

5. Derived Savannah: Rainfall 1250-1750mm, 3 months with less than 25mm. The vegetation resembles that of the southern Guinea zone.

6. Jos Plateau: Rainfall 1125-1375mm, 4 - 5 months with less than 25mm, as in the south Guinea zone. The effect of the climate on the vegetation cannot be observed because the latter has been almost completely destroyed by human interference. Fig. No.1 shows the boundaries of each zone.

Soils

The main climatogenic type of soils is the ferruginous type. Much of these are formed on crystalline acid rocks and cover a large area in the centre of the country, notably the Sudan, Northern Guinea, Southern Guinea and Derived Savannah Zones. The parent rocks give rise to a large variety of parent material in an intricate pattern. Indurated ironpan is found throughout the area, but it is much more extensive in some localities than in others, and its distribution may be connected with the various erosion surfaces.

Soils formed from sandy parent materials are found mainly in the Sahel and Sudan Zones. Those in the Sahel zone exhibit a very regular catenary pattern; calcium carbonate concretions are often found in the lower slope soils in the east of the area and ironstone concretions also occur while those in the southern end of the Sudan zone are characterized by rolling plains with indurated ironpan which is more extensive in the north than in the south of this zone. Regional and local variations do occur in the dominant soil types mentioned above. The regional variations are mainly due to the differences in parent material, while the local variations are mainly due to effects of the generally undulating topography on drainage and erosion. These variations have contributed

to the existence of Entisols; Vertisols; Inceptisols and Oxisols.

Entisols or weakly developed soils (Soil Survey Staff, 1975) are characterized by having no recognizable genetic horizons and the parent materials is recently deposited on its present site and thus the effect of climate, physical and chemical properties of the parent material on the characteristics of these soils are not yet developed. As a result these soils show great variations in many of their properties, particularly texture.

Vertisols are dark-coloured soils with large proportions of the expanding lattice clay-type. The main characteristic of the parent material which encourages the formation of these soils is impermeability, although high base content and poor drainage of the site facilitate this process.

Inceptisols are also a product of regional variations. The two common types of the inceptisols in northern Nigeria are the brown and reddish brown soils of arid and semi-arid regions; and the Eutrophic brown soils. The Brown and Reddish Brown soils as the name implies, are brown or brownish coloured in the main part of the profile and the organic matter content is nearly constant to a considerable depth. The expanding lattice type of clay is common and calcium carbonate concretions may be

present. The Eutrophic brown soils are developed from basic parent materials; most of the known occurrences of Eutrophic soils in northern Nigeria are derived from basalts. The clay is mainly expanding lattice type and the exchange complex is saturated with bases. The organic matter content is generally low.

Oxisols (Soil Survey Staff, 1975) or red ferallitic soils are generally deep soils with little horizon differentiation. There is little or no reserve of weatherable materials; the clay is of the 1:1 lattice type and in general, considerable quantities of free iron and aluminium oxides are present. The parent material is always a coarse sand, usually overlying and derived from a coarse permeable sandstone of Cretaceous and Excene age.

The local variations contributed to the development of the weakly developed soils (Lithosols) or Entisols which are normally very stony, having solid rocks within 30cm depth and are mostly found on the upper slopes. They may be found on crystalline basic rocks, ironpan and undifferentiated rocks. Juvenile soils are also developed in many areas along minor rivers and streams. Hydromorphic soils, also developed on poorly drained sites, are most commonly found on lower slopes. They occur to varying extents in all areas except those underlain by the most permeable parent materials.

Chapter 2

REVIEW OF LITERATURE

2.1 MAGNESIUM IN SOILS

(a) Total magnesium

The magnesium content of soil is heavily dependent upon the chemical composition of the parent material. The common Mg-bearing minerals in soils are dolomite ($MgCO_3 . CaCO_3$), serpentine ($Mg_6Si_4O_{11}(OH)_6 . H_2O$), and olivine ($MgFeSiO_4$). The total amount of Mg in soil ranges from 0.1% in highly weathered soils such as the heavily leached sandy tropical soils to as high as 4% in semi-arid savannah soils. When solubilized from soil minerals by weathering, magnesium may be held on clay or organic matter in exchangeable form. Rice and Kamprath (1968) reported total Mg values ranging from 0.73 to 2.48 meq/100g in the fine sandy coastal soils of North Carolina. In some of these soils, the exchangeable Mg varied from 3.8 to 9.4 percent of the total.

Secondary factors affecting the Mg status of the soil include climate (especially rainfall), organic matter level and stage of maturity of the soil (Mokwunye and Melsted, 1972). High temperature and heavy rainfall in the humid tropics promote weathering and subsequent

removal of Mg from the soil profile through leaching. The 2:1 type clays especially montmorillonite, chlorites, vermiculites contain appreciable amounts of Mg (Thompson, 1957; and Buckman and Brady, 1969). Longstaff and Graham (1951); and Salmon (1963) observed that these clay types had the highest Mg content per gramme of clay. In British soils, Salmon (1963) reported that most of the soil magnesium was in silicate minerals, with only small amounts in exchangeable and water - soluble forms.

The Mg status of northern Nigeria soils have not been extensively studied but Jones and Wild (1975) indicated a wide range of total Mg ranging of 1 - 20 meq/100g of soil.

(b) Exchangeable magnesium

Plants take up their magnesium from the exchangeable and soil solution phases, but the magnesium in the silicate clays may be released to help in replacing the losses by leaching or plant uptake. The exchangeable Mg is in rapid equilibrium with the soil solution form because the former replenishes the latter and the exchangeable Mg is held rather loosely by electrostatic charges on the exchange sites of the colloidal complex of the soil, it can easily be extracted by plant roots (Corey and Schulte, 1973).

The absorption of Mg by plants depends on the amount available, the degree of Mg saturation, the nature of the

other exchangeable ions and the type of clay. Entrapment of Mg ions between expanding and contracting sheets of the clay minerals may contribute to the presence of a relatively unavailable form of Mg, though the extent to which this happens is not actually known (Tisdale and Nelson, 1975). Cooke (1967) explained that in British soils most of the magnesium released to become exchangeable is likely to come from the micas and chlorites, and from secondary clay minerals which contain some magnesium in their crystal lattices. Muscovite, micas and montmorillonite may have Mg substituting isomorphously for aluminium so that they contain up to 6 per cent of Mg. Chlorite, biotite and illites contain about 23%, 17% and 1% magnesium respectively. In vermiculites, the greater hydration of interlayer magnesium ions leads to wider spacing between the silicate layers and the magnesium is more easily exchangeable than interlayer potassium (Barshad, 1949). Unlike the calcium ion, the non-hydrated magnesium ion is small enough to fit into octahedral spaces in mineral structures, this may explain the slow release of Mg to plants (Thompson and Troch, 1978).

Exchangeable magnesium levels in soils are as variable as those of total magnesium. For the coastal plain soils in the U.S. Rice and Kamprath (1968) reported a range of 0.05 to 0.73 meq/100g. Sinha and Singh (1966) reported a range of 0.18 to 6.3 meq/100g

in certain Indian Bihar soils. The values were highest in the alluvial soils and lowest in calcareous soils. Harrod and Caldwell (1967) reported a range of 0.17 - 0.29 meq/100g (20-35ppm) magnesium in the top soil for the light sandy soils of East Anglia in Britain. Purvis (1963) reported that exchangeable Mg in cultivated soils in Britain ranged from 0.17 - 5.33 meq/100g (20 - 640ppm). Lombin and Fayemi (1975) reported that the exchangeable magnesium averaged between 1.13 - 1.45 meq/100g in soils of western Nigeria.

Percent Mg saturation of CEC has often been used in assessing soil Mg availability by some investigators. Prince et al.,(1947), used alfalfa as a test crop for twenty virgin soils from New Jersey, and concluded that if magnesium constituted less than 6 per cent of the exchangeable cations in a soil, crops growing on that soil were likely to respond to applications of soluble magnesium. Graham et al., (1956) also showed that, soils that had less than 10 per cent of the total exchange capacity saturated with magnesium responded to additions of magnesium. Severe Mg deficiency in plants was noticed when leaf Mg was less than 10% of total cations (K, Ca and Mg) contained in plant tissue. The Mg status of a soil is heavily influenced by its texture. The presence of the clay minerals in the soil is related to parent materials, and the degree of

weathering (Thompson, 1957; Brady, 1974; Mengel and Kirkby, 1979). When a soil is limed, some of the exchangeable magnesium is replaced by calcium and the former may be leached out from the root zone. This explains how soils tend to be depleted of magnesium somewhat sooner than they are depleted of the more resistant potassium, sodium and calcium minerals. Olson et al., (1971) stated that when soluble forms of magnesium compounds are applied, most of the magnesium remains in the exchangeable form except on sandy soils of low CEC where it is leached out.

The significance of soil organic matter as a source of inorganic plant nutrients has been well established (jones, 1973; Jones and Wild, 1975; Sanchez, 1976). Soil organic matter releases plant nutrients as it decomposes. The contribution of organic matter to cation exchange capacity is perhaps of greater significance in tropical than in temperate regions (Jones and Wild, 1975). In well-leached intensively weathered tropical soils with clay minerals of the kaolinite group, organic matter can make all the difference to soil fertility. The dependence of cation exchange capacity and thus the Mg status on organic matter in tropical soils means that when organic matter reserves are low, retention of plant nutrient cations is poor.

2.2 ASSESSMENT OF AVAILABLE MAGNESIUM IN SOIL

Numerous extracting solutions and procedures are employed in extracting plant available soil Mg in various parts of the world. Pitts and Hanway (1971) stated that none of the existing methods extract exactly the same amount that was available to plants. Most of the extractants remove certain portions of the various compounds and these extracted quantities may be related to the crop responses obtained from fertilizer application. They further reported that different extractants removed different portions of the elements, and there was no constant relationship between the extractants with respect to the Mg they removed.

Some of the methods may indicate how much magnesium may become available during several seasons, but they do not predict how much is replaced as crops remove it, or the effects of supplying fertilizers (Salmon, 1963). Lombin and Fayemi (1975), suggested that a comparison of soil test results with the analyses of plants grown on the soil offered a simple and rapid method of evaluating the soil tests under a wide variety of conditions especially where the information regarding the response to fertilizer treatment was inadequate or lacking.

The degree of success or otherwise of using one extractant or another varies from one place to another

depending on the physical and chemical properties of the soil and the procedure adapted. It would appear that no single extractant or extraction procedure could be considered universal. In the present investigation an attempt has been made to assess the reliability of a few of the easily adaptable extraction procedures.

(a) Salt solutions

Buffered solutions like N ammonium acetate have been used at different soil-solution ratios by a number of workers (Peech, 1939; Salmon and Arnold, 1963; Mclean and Carbonell, 1972; and Christenson et al., 1973). Peech (1939) reported that neutral NH_4OAc was superior to N NaCl, N NaOAc and the Morgan's reagent (10 percent NaOAc in 3% HOAc). However, other workers have considered NH_4OAc rather unreliable (Nearpass and Drosdoff, 1952; Reith, 1963; Hooper, 1967 and Shone, 1967). Comparing a wide range of extractants, Williams et al., (1966) concluded that ammonium nitrate was the most consistent extractant over a wide range of soils.

Morgan's solution though widely accepted as a reliable extractant (Bear et al., 1951) could give misleading results in certain cases. In calcareous soils for example, it dissolves large quantities of dolomite and other neutral salts and thus gives much higher values than the actual amounts available to the plant.

Unbuffered salt solutions such as NaCl have been successfully used (Peech, 1939; Peech, 1948; Jacob, 1958; Sluijsmans, 1959; and Rice and Kamprath, 1968). Calcium chloride has also proved to be a reliable extractant for Mg (Hoffman et al., 1959; Jacob, 1958; Sluijsmans, 1959; Salmon, 1963; and Malinska and Lipska, 1971). The method adapted by Schachtschabel, (1954) as explained by Salmon, (1963) in which the soil was shaken with 0.025 N calcium chloride solution, was less arbitrary than most. This is because calcium is the dominant cation in many soils, and during extraction the soil is changed less from its original state than when other more concentrated extractants are used (Salmon, 1963). Although, Welte et al., (1960) found it unreliable particularly over long cropping periods, the method is extensively used in some European countries. Alston, (1972) reported that $CaCl_2$ was a satisfactory extractant for soils in which Ca was the dominant exchangeable cation. He found that the amounts of magnesium removed by $CaCl_2$ were only slightly lower than that removed by ammonium acetate for the majority of soils tested, although considerably smaller amounts were removed from the basaltic soils.

(b) Acid solution

Dilute mineral acids have also received attention as extractants (Graham et al., 1956; Welte et al., 1960, and McConaghy and McAllister, 1967). Graham et al.,

(1956) reported that magnesium extracted by 0.05N hydrochloric acid, measured the amount available to plants. McConaghy and McAllister (1967) successfully used 0.025N H_2SO_4 to extract available Mg.

Organic acids have also been used to extract available Mg. Reith (1967) used 2.5% acetic acid (CH_3COOH) at a soil:extractant ratio 1:40.

2.3 CROP RESPONSES TO MAGNESIUM APPLICATIONS

Being a constituent of chlorophyl, magnesium is needed by all green plants. It also plays an important role in the transport of phosphate in the plant (Russell and Russell, 1977). It appears to be specific in the activation of a number of plant enzyme systems (Sparge, 1964; Tisdale and Nelson, 1966), and also essential for the biosynthesis of vitamins in plants. It plays a significant role in cell division and development. However, several workers have reported that the non-chlorophyl function of magnesium requires a much greater amount of the element than does the chlorophyl role.

Magnesium deficiencies have been reported on over 80 plant species, ranging from cereals to vegetables and fruit crops in different parts of the world (Adams and Pearson, 1967; Weeks and Lathwell, 1967; Woodruff, 1967).

The soil magnesium content at which deficiency symptoms occur may vary considerably. McMurtrey (1947) observed deficiency symptoms on tobacco plants grown on a light sandy soil containing 0.24 per cent magnesium. Climate particularly rainfall appears to be as important as soil texture in influencing soil Mg status and availability. The most severe deficiencies have occurred during seasons of high rainfall (McCants and Woltz, 1967). According to Kamprath and Foy (1971) the conditions which may lead to the development of Mg deficiency in plants are; acid, sandy, highly leached soils having low CEC values; calcareous soils having inherently low Mg levels, and soils heavily limed with calcitic limestone and high rates of ammonium and potash fertilizations. Appreciable responses to magnesium were also reported by Cooke (1975) on soils that were either acid or had been recently limed; exchangeable magnesium in soil provides no guide to these responses. Draycott and Durrant (1970) reported a profitable response to magnesium fertilizer on soils containing less than 20ppm Mg extracted with ammonium nitrate but very little response on the same soil when soil magnesium was 20-35 ppm.

Different reports have shown different degrees of responses to magnesium application with different crops on different soils. In Britain, Garner (1941) reported small increases in yields of potatoes on only few sandy

soils. Yields were also raised in the potato growing on soils in four of the thirty experiments conducted from 1954-7 by Holmes (1962), who found that the largest individual gain was 2.2 t/ha. Application of 24kg Mg/ha increased the tuber yield on alluvial soils in Yugoslavia (Chodan and Szurpicki, 1981). An interesting result was obtained in Yugoslavia by Krstic (1981) who reported that the application of magnesium to a light soil at a rate of 10 kg/ha increased the tuber yield of potatoes by 10.6% but higher amounts decreased the yield. In field trials on potatoes, Chodan and Szurpick (1981) reported that application of Mg increased the proportion of large tubers and decreased the proportion of small and medium-sized tubers.

Several reports on the effect of Mg application on different annual crops have been reported. The effect of Mg application on tomato yield and quality have been reported by several workers. Working on the response of tomato to Mg application, Jones and Jones (1978) reported significant yield responses to Mg on loamy sand soils. They further reported that tomato leaf content of magnesium was significantly increased by the application of Mg fertilizers at a rate of 20 kg/ha. Studying the role of magnesium on some growth components and yield of tomato plants in Nigeria, Agbede and Aduayi (1978) reported that plant height increased at high rates of Mg.

Response of perennial crops to magnesium application have also been reported. At Calabar in eastern Nigeria, application of magnesium sulphate significantly increased yields of fruit bunches of palm (Bull and Chapas, 1956). Application of as much as 30k kg Mg/ha were effective in increasing the yield of tobacco leaves on Mg-deficient tobacco fields in western Japan (Ishitoy et al., 1958). Tabin et al., (1969) reported that independent of the variety and weather conditions, a favourable influence of Mg fertilizing on the yield of tobacco leaves was observed in an experiment carried out in a slightly acid podzolic soil. On the other hand, Simley et al., (1971) who worked on the effect of minor elements in seven countries in Kentucky reported that yield data did not indicate a response to magnesium. No deficiency symptoms were apparent nor was there any indication of toxicity to the tobacco from the use of this element. Work by Hawks et al., (1973) on soils of northern Carolina showed that there was no significant response of the flue-cured tobacco to magnesium application.

2.4 MAGNESIUM NUTRITION OF THE TOBACCO PLANT

Tobacco is generally rated as a high-Mg demanding crop (Adams and Pearson, 1967). The growth characteristics of the crop (enormous leaf development and rapidity of plant growth) make it an excellent crop to study the phenomena associated with Mg. An

abnormality in the growth of tobacco, which later became known as "sand drown", was first observed at the Tobacco Research Station at Oxford, North Carolina, in 1912. The disorder was so named because of its frequent occurrence on tobacco grown on sandy soils, especially during periods of excessive rainfall. The abnormality was later found not to be pathological but to be due to magnesium deficiency. Mg deficiency in tobacco is characterized by a loss of green colour in the lower leaves beginning at the leaf tip and progressing inward along the margins and between the veins. It may be evident on plants at any stage of growth from the small seedling to maturity. Chlorosis would be expected to be one of the first symptoms of magnesium deficiency but in the extreme cases the leaf may become practically white, suggesting a breakdown of the yellow pigment also. Even in these cases, rarely do the leaves develop dead spots as a result of the deficiency. Differences among varieties of tobacco in their expression of magnesium deficiency has been observed by Takahashi and Kono (1957) and McCants and Woltz (1967). They found that with certain varieties of flue-cured tobacco, magnesium deficiency occurred much easier than with others. Garner et al., (1930) reported that of under magnesium deficiency conditions the upper leaves of the tobacco plant contain considerably more of the element than the lower ones but with a more liberal supply of available magnesium, the lower leaves contain considerably more than the upper

leaves. A normal tobacco plant may contain up to 0.66 per cent Mg in the leaves; field grown plants generally show a range of 0.24 to 0.90 per cent of Mg (Garner, 1951). According to Reith (1963), plant tissue magnesium of between 0.15 and 0.50 per cent was necessary for efficient photosynthetic activity. Olson et al., (1971) reported that if the magnesium concentration in mature tobacco leaves was above 0.2% most species would usually not exhibit Mg deficiency. This agrees with the range of 0.15 - 0.25% given by McMurtrey (1947) and Chapman (1966b) as critical values.

Higher values were reported by McEvoy (1954) who indicated that tobacco leaves would show magnesium deficiency when the average content of the top leaves ranged from 0.41 - 0.47% and when the bottom leaves contained 0.57 - 0.60% Mg with an intermediate level put at 0.48 - 0.98% in the top leaves and 0.60 - 1.22% in the bottom leaves. Garner et al., (1930) used the whole tobacco plant and suggested a critical value of about 0.21%. It must be emphasised that the minimum plant tissue concentration of magnesium which may prevent the appearance of deficiency symptoms, may not necessarily be sufficient for the maximum growth of the plants.

The quality of tobacco leaves has been shown to be dependent on their cation nutrient balance (Nessler,

1867; Attoe, 1942; Johnson and Attoe 1944; and Sastry et al., 1957). These findings suggest the need to not only apply adequate quantities but also to ensure a proper balance between the various nutrients for high yield and quality.

A high quality tobacco is that which is high in soluble carbohydrates and potash, but relatively low in crude fibre, nicotine, nitrogen, calcium, ash and acids. An extremely low content of nitrogen (1 to 1.3 per cent) is detrimental to leaf quality. Yoshida (1957) reported that the nonprotein nitrogen concentration was higher in magnesium deficient plants and increased with stage of growth. A low nicotine content is desired in tobacco grown for smoking. McMurtrey (1947) and Yoshida (1957) reported that Mg deficiency was associated with a decline in sugar and starch content in plants. Breland and Pritchet (1956) reported that an increase in the amount of magnesium in the leaf decreased the rate of burn of cigar tobacco. Tanconge and Chouteau (1979) found that application of magnesium limestone improved the combustibility of tobacco leaves. However, Elliot and Birch (1958) could not establish any significant relationship between Mg and Ca levels in tobacco leaves and the burning quality of the latter.

2.5 INTERACTION BETWEEN MAGNESIUM AND OTHER NUTRIENT CATIONS IN CROP NUTRITION

The absorption of cations by plants is more or less a non-specific process, depending mainly on the concentration of the cation species in the nutrient medium and in some cases also on the specific permeability of membranes to particular cation species. For this reason nonspecific competition between the cation species for the negative charges of the cell may occur. Mengel and Kirkby (1979) gave a full account on the mechanism of ion uptake and stated that increasing the supply of one cation species in the nutrient medium can depress the levels of other cation species in the plant since the total sum of cations in a plant or plant tissue is little changed despite the nutrient medium. The phenomenon in which an excess of one nutrient ion decreases the uptake of other ions having the same electrical charge is referred to as "ion antagonism" (Cooke, 1967). The physiological basis of ion antagonism is not yet clear. Some investigators explain it in terms of the relative abilities of the various ions to compete for absorption sites or on ion carriers within the plant system (Legett and Gilbert, 1969 and Mengel and Kirkby, 1979). It is worth mentioning at this juncture that solution concentrations of ions are influenced mainly by the nature of the colloidal fraction of the soil and the degree to which these colloids are saturated with

basic cations. Another phenomenon affecting the population of ions in the soil solution, known as 'complementary ion effect' is defined as the influence of one adsorbed ion on the release of another from the surface of a colloid (Tisdale and Nelson, 1966). The antagonistic effect of potassium on the uptake of Mg and Ca often observed is better explained by the complementary ion effect phenomenon. Examples of antagonisms between Mg^{++} ion on the one hand and Na^{+} and Ca^{++} ions on the other hand have been demonstrated by Scharrer and Jung (1955) and explained by Mengel and Kirkby (1979). In a sand culture experiment Welte and Werner (1963) demonstrated physiological antagonism between Mg ion on the one hand and NH_4^{+} and Ca^{++} ions on the other hand.

Effects of cation competition on ion uptake are of particular importance for Mg^{++} because most cases of Mg deficiency can be traced to this phenomenon.

(a) Potassium/Magnesium Interaction

It is widely accepted that available soil potassium status is one of the most important factors which determines magnesium availability (McColluch et al., 1957; Hovland and Caldwell, 1960; Salmon, 1963; Welte and Werner, 1963; Semb, 1965; Delas, 1970; Agboola and Corey, 1973 and Addiscott, 1974). Magnesium reaches the plant root mostly by the process of mass flow which is mainly

governed by the concentration of the element in soil solution and the rate of water movement. Diffusion may contribute appreciably only in cases where the soil is acutely deficient in Mg (Barber, 1962; Graham-Bryce, 1967; and Corey and Schulte, 1973). Nutrient depletion depends on the balance between the supply from the soil and the demand by the plant. Thus a high plant requirement or a high root absorbing power gives rise to a high rate of ion diffusion towards the root site.

Many investigators consider exchangeable Mg/K ratio to be as good as or even better than exchangeable Mg in predicting the Mg availability (Walsh and O'Donohoe, 1945; McColluch *et al.*, 1957; and Stenuit, 1959). Hossner and Doll (1970) reported that the yield response to Mg fertilizer was related to both level of exchangeable soil Mg and to soil Mg and to soil Mg/K ratio. Lombin and Fayemi (1976b) showed that the two criteria were generally important with respect to the soils of western Nigeria. Welte and Werner (1963) explained that the K/Mg antagonism is of importance mainly in low-Mg soils. According to them, exchangeable K/Mg ratio should be lower in soils than in plants because K is more easily absorbed by plants as soil colloids generally tend to retain divalent cations more tightly than monevalent cations and moreover Mg uptake is inhibited by other

cations such as NH_4^+. If the exchangeable bases on a soil colloid consist of large amounts of K in proportion to the amount of magnesium and calcium, the monevalent K ions will be replaced more easily than the divalent cations. Consequently the plant absorption of the divalent cations will be less and in extreme cases, deficiency of the divalent cations may be induced. The effect of applied magnesium therefore generally depends mainly upon the exchangeable magnesium - potassium ratio in the soil rather than upon the total exchangeable magnesium per se (McColluch et al., 1957).

Plants growing on soils having 0.5 to 1.0 meq/100g of soil of exchangeable magnesium showed Mg deficiency symptoms when available potassium was excessive but not when the latter was moderate. Jones and Wild (1975), reported that the amount of exchangeable Mg and the balance between Mg/K are important in Samaru soils in assessing the availability of soil Mg and hence the response of plants to magnesium application. Bear et al., (1951) reported that Mg deficiency was more likely to develop where, on an equivalent basis, the K/Mg ratio of the soil exceeded 1:2. McColluch et al., (1957) reported that when the soil Mg/K ratio was less than 2:1, available Mg was required to prevent deficiency from developing in citrus. Jones and Haghiri (1963); and Hossner and Doll (1970) reported

that yields were not affected by either level of soil Mg or Mg/K ratio when soil Mg was above 0.3 meq/100g, but when soil Mg was below 0.3 meq/100g, yields decreased markedly when the soil Mg/K ratio fell below 0.8. In soil low in available magnesium, magnesium deficiency in tobacco was promoted by application of excessive potassium. Associated with the deficiency symptoms was an increase in the potassium content of leaf, a decrease in the magnesium content, and decrease in leaf quality (Takahashi and Kono, 1957; and Takahashi and Yoshida, 1958). Hutcheston et al., (1959) reported that magnesium tended to accumulate in the upper leaves of flue-cured tobacco grown in fields and greenhouses, as the supply of K was decreased. However, Batey (1967) concluded that Mg deficiency in field crops was more often induced by adverse soil conditions or low soil Mg levels rather than by a wide K/Mg ratio. In a large number of experiments to test sugarbeet response to magnesium sulphate on fields where magnesium deficiency was suspected, Draycott and Durrant (1970) found that the concentration of other soil cations (Na, K and Ca) did not affect the response to magnesium fertilizer. They however obtained the largest yield from plots given sodium and potassium fertilizer together with a dressing of magnesium.

Spinach yields in a water-cultured experiment, increased with increasing rates of calcium only when the

supply of magnesium was high, but it decreased a little when Mg supply was low (Harra et al., 1977). Similar results were obtained in Finland by Jokinen (1977), who found that K, Ca and N decreased the yield of oats if the plants were deficient in Mg but increased yields when applied together with Mg.

(b) Calcium/Magnesium Interaction

In general, relatively little attention is paid to Ca as a plant nutrient because its supply is usually adequate for most crops grown on soils above pH 5. Also when lime is required to correct soil acidity, the applied Ca is considered as a liming agent rather than a plant nutrient. Raising the pH of an acid soil by liming was found to have increased the plant content of Mg (Bender and Eisenmenger, 1941), increased Mg uptake by plants, (Alten and Warner), 1960), and corrected Mg deficiency (Salmon, 1963). However these findings may not be true when Mg deficiency is acute. In such cases, the deficiency may be aggravated (Chambers and Gardner, 1951). It is therefore, generally recommended that dolomite (which contains Mg) should be used as a liming agent for acid soils low in Mg. McCart and Kamprath (1965) reported that cotton growth was slightly better when dolomite rather than calcite was the liming agent.

The antagonism between Ca and Mg has been investigated by many soil and plant scientists but there appears to be little agreement on the effect of Ca on Mg availability to plants. Takahashi and Yoshida (1958) reported that by increasing the supply of potassium and calcium in the culture solution, the contents of the respective elements increased in the tobacco plant but the magnesium content decreased and magnesium deficiency symptoms appeared. A similar result was reported by Harra et al., (1977) who found that the contents of Ca and Mg in spinach increased with increase in the rate of each element, but an antagonistic effect was observed between the two of them. This effect was also demonstrated by Jacoby (1961), who found that citrus seedlings grew satisfactorily when exchangeable Mg and Ca were both small, but became Mg deficient when the Ca was increased by liming. The detrimental effects of lower soil pH were less important here than the increased competition from calcium at high pH. Thus effects of liming on Mg deficiency are likely to depend on both the pH and Mg contents of soils. Similarly Reith (1963), showed that high leaf calcium and magnesium were often associated with low Mg and Ca respectively. In Nigeria, Moehansyah (1977), reported

that liming the soil to pH above 6 may cause a decrease of Mg availability to crops. The antagonistic effect is usually more pronounced in water cultures than in the field experiments.

In his review Salmon (1963) stated that several workers had found little or no effect on crop yields from varied Ca/Mg ratios, but plant Mg contents usually decreased as the exchangeable Ca/Mg ratio increased suggesting that under certain circumstances addition of Ca may induce Mg deficiency. Truog (1948) suggested a Ca : Mg ratio of about 7:1 for an ideal soil. Magnesium: calcium ratio of between 0.3 and 1.00 in the plant leaf was considered by Reith (1963) to be necessary for high photosynthesis rate. Salmon, (1964) reported a close correlation between millet response to applied Mg and Ca: Mg ratio in soil. Chapman (1966a) reported that Ca:Mg ratio in the ash of oil palm leaves was more highly correlated with Mg chlorosis than was the content of magnesium in the ash.

It may be concluded from this review that the magnesium contents of plants are decreased as the ratio of exchangeable Ca/Mg increases, so that liming on some soils may induce magnesium deficiency. However, many workers have reported that yields of crops were not affected by wide ranges in Ca:Mg ratios and thereby disputed the necessity of maintaining any definite

ratios for better plant growth (Hunter, 1949; Foy and Barber, 1958; Key et al., 1962 and Martin and Page, 1969).

(c) Hydrogen/Magnesium Interaction

It is generally agreed that an increase in the hydrogen ion concentration in the soil, will induce or aggravate magnesium deficiency in plants (Ferrari and Sluijsmans, 1955; Mulder, 1956; and Chapman and Carter, 1976). This is because under acid conditions, particularly when the pH falls between 5 to 5.5 Mg ions absorbed by the soil colloids are readily exchangeable with H^+ ion so that the Mg ions are subjected to leaching. Application of Mg alone in such cases may not remedy the situation but the addition of lime at the same time will help in reducing H^+ ions and thus eliminate the unfavourable effects of low pH on plant growth. With equal amounts of available magnesium present in the soil, more severe deficiency symptoms will occur at low pH than at higher pH. Jones and Haghiri (1963) found that severe Mg deficiency symptoms and low Mg content of sweet corn were associated with low pH and high K availability in the soil. Greenhouse experiments with corn, ryegrass and potatoes on acid soil low in available Mg, showed that correction of Mg deficiency was difficult if the soil pH was not increased. They stated that Mg uptake would be increased by adding $MgSO_4$ but that large amounts were necessary. Rice and Kamprath (1968) reported that

with sandy soils of the coastal plains of southern United States, Mg deficiencies were corrected when the soil acidity was neutralized with $CaCO_3$ even though the exchangeable Mg contents were low.

The depressive effects of different cations on Mg uptake by plants are additive. For instance K:Mg antagonism seems to be more pronounced where the soil pH is low. In a green house experiment using an acid sandy soil, Welte and Werner, (1963) found that increasing application K in form of KCl caused severe Mg deficiency and considerable loss in yield as compared with addition of the same amount of K as $KHCO_3$ which simultaneously improved the soil reaction and increased the Mg uptake and yield. They explained that H/Mg antagonism was diminished more than K/Mg antagonism was increased by the addition of $KHCO_3$, and concluded that the antagonistic effect of the H^+ ion on Mg absorption by plants might be stronger than that of K.

(d) Magnesium/Ammonium

The competitive effect of NH_4^+ on Mg^{++} uptake was observed by Mulder (1956). The mechanism of the competition between NH_4^+ and Mg^{++} is not clear. It probably depends on both the H^+ released during NH_4^+ incorporation, as well as on the direct effect of the NH_4^+ itself (Mengel and Kirkby, 1979). Mulder (1956)

as quoted by Salmon (1963) reported that Mg deficiency was intensified by adding ammonium, whereas adding nitrate diminished the symptoms. The effects of ammonium fertilization, however, are likely to depend on the rate of nitrification and the changes in soil pH. Mulder (1956) reported that the acidifying effect of ammonium sulphate was probably not the main reason for the occurrence of Mg deficiency in acid soils. He further explained that in most plant tissue the NH_4^+ ions absorbed are assimilated into the cytoplasm. This assimilation process involves an exchange with H^+ ions within the cytoplasm and as a result, a high concentration of H^+ ions will be found on the outer cells of plants supplied with ammonia fertilizers. The high concentration of H^+ and NH_4^+ ions at the root cell surface and within the cytoplasm of root cells was the most reasonable explanation of the occurrence of Mg deficiency in plants growing in acid soils dressed with ammonium sulphate. Both H^+ and NH_4^+ ions have a higher competitive ability and can displace Mg on the root surface and on the soil colloids and as a result expose the displaced Mg to leaching. Bache and Heathcotte (1969) reported that at Samaru low rates of ammonium sulphate (11 and 22 kg H/ha), applied annually for 15 years, had seriously reduced the amounts of exchangeable Ca and Mg in the topsoil, although this effect was less serious where farmyard manure had also

been applied. It would appear, therefore that the antagonism between NH_4^+ and Mg may create serious practical problems most especially in the acid soil and where the level of available Mg is inherently low.

Chapter 3

MATERIALS AND METHODS

3.1 SOIL, TOBACCO PLANT - MAGNESIUM SURVEY

(a) Soil Sampling

Two sets of soil Mg survey were conducted in the savannah zone of Nigeria. The first involved 49 surface soils (0 - 20cm) representing a wide range in available magnesium status (Fig.1). Out of these samples, 25 samples were used for evaluating the various soil analytical procedures for available Mg. They were first pulverised, and then air dried and screened to pass through a 2mm sieve, prior to being used for laboratory analysis and greenhouse cropping.

The second survey involved a profile sampling of 24 soils taken from selected tobacco areas (Fig.2). Soil samples from four depths (0 - 20; 20 - 40; 40 - 60; and 60 - 80cm) were collected, air dried, sieved ($\leq$ 2mm) and analysed for Mg.

(b) Tobacco Plant Sampling

Tobacco index leaves were collected from farmers' fields at the same time as the profile sampling was carried out. Plant samples comprised both top and lower leaves. The term 'top leaves' as used here means the three youngest fully expanded top leaves, while the

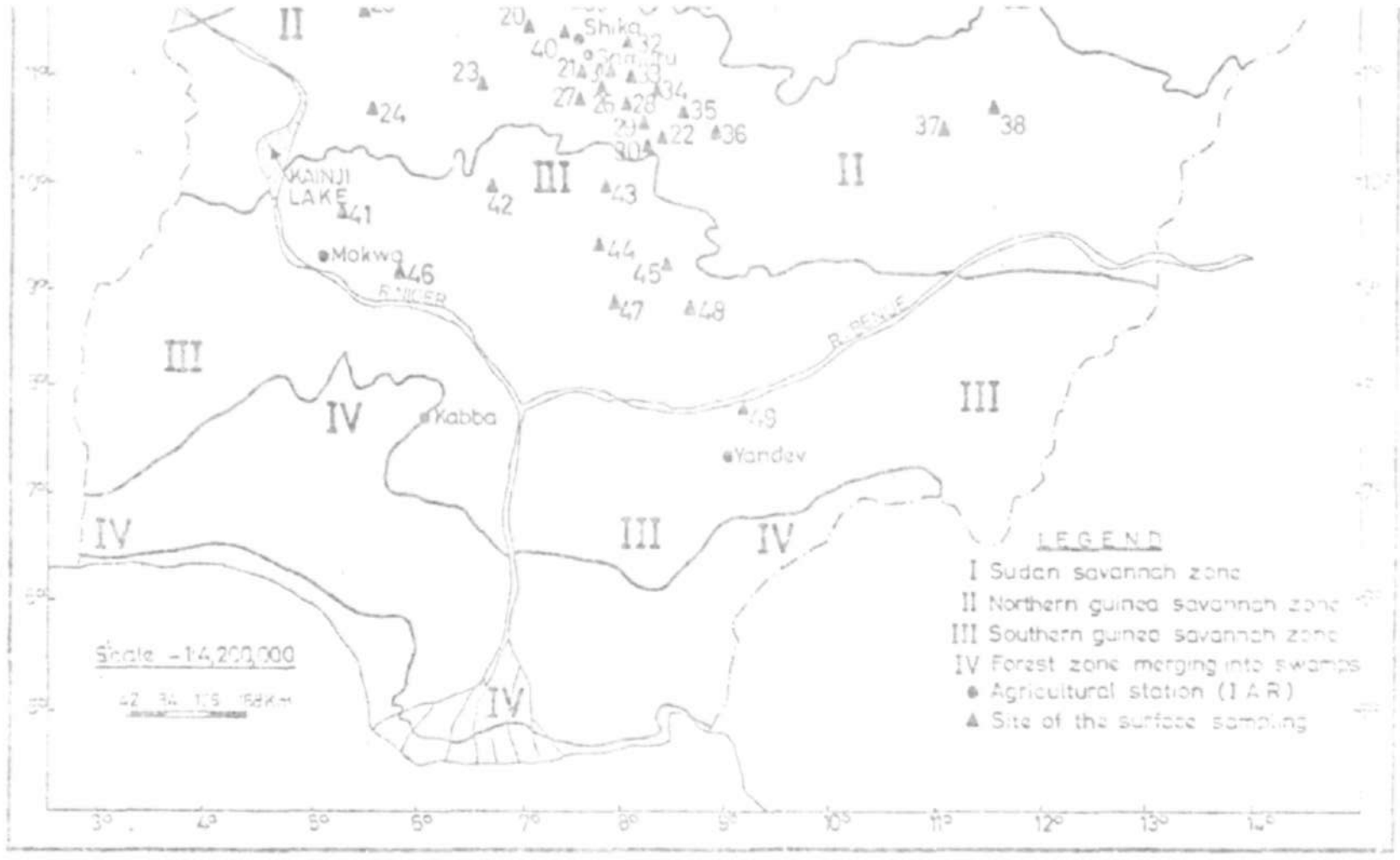


FIG.1:MAP OF NIGERIA SHOWING THE MAIN ECOLOGICAL ZONES AND THE SURFACE SOIL SAMPLING SITES

term'lower leaves' indicates the three lowest leaves on the stalk that are located just above the trash lugs.

The leaves were oven-dried at 70°C to constant weight and milled with a Wiley mill for chemical analysis.

3.2 EXHAUSTIVE GREENHOUSE CROPPING

The 25 surface soils referred to in (a) above were exhaustively cropped to maize in the greenhouse and the Mg taken by maize correlated with soil test values for the various extractants. Triplicate 1 - kg weights sub-samples of each soil were measured out in plastic pots, supplied with the apporpriate rate of fertilizer (reagent grade chemicals) (Table 1) and watered to field moisture capacity. The pots were laid out in completely randomised design.

Eight fairly uniform maize kernels (Var. TZB) were planted in each pot and the latter kept at field capacity throughout the course of each cropping. The plants were thinned to six per pot a week after planting during each cropping.

After 42 days of each cropping the plants were cut at the soil level with a stainless steel blade.

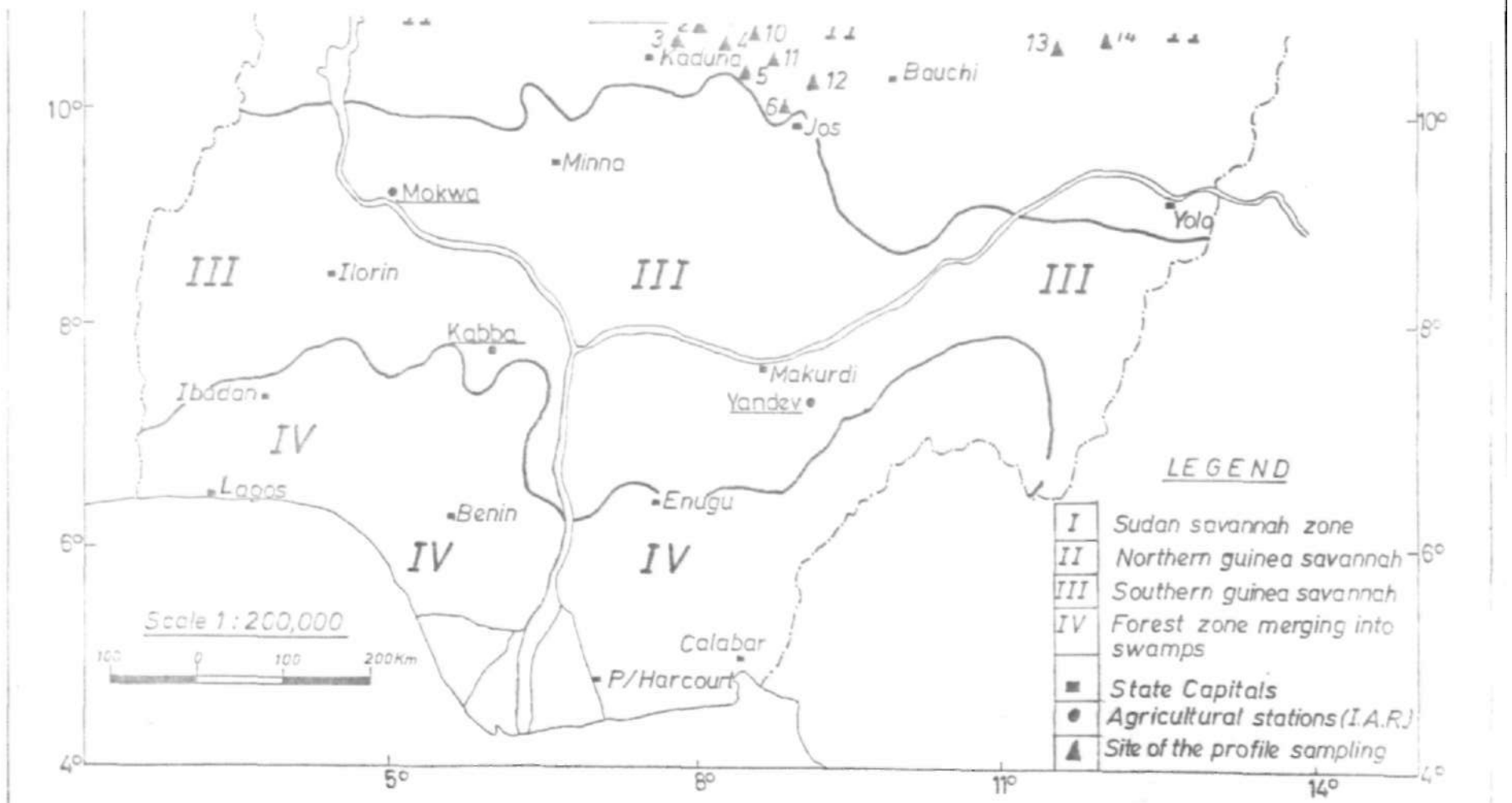


FIG. 2 : MAP OF NIGERIA SHOWING THE MAIN TOBACCO GROWING AREAS AND THE SITES OF THE PROFILE SAMPLING.

Table 1. Rates and sources of nutrients used in the greenhouse experiments

Nutrients	Source of Nutrients	Rate
Nitrogen	Ammonium sulphate, $(NH_4)_2SO_4$ Ammonium dihydrogen phosphate, $NH_4H_2PO_4$	250ppm
Phosphorus	Ammonium dihydrogen phosphate, $NH_4H_2PO_4$	120ppm
Potassium	Potassium dihydrogen phosphate, KH_2PO_4	100ppm
Zinc	Zinc sulphate, $ZnSO_4 . 7H_2O$	10ppm
Boron	Boric acid crystals, H_3BO_3	1ppm

The dried plant matters were then weighed and later ground in a Wiley mill for chemical analysis.

To prepare the soils for each of the subsequent croppings, the soil in each pot was emptied on to a clean polythene sheet, air-dried and sieved back into the appropriate pot. Nutrients were supplied at the appropriate rate, the soils watered to field capacity and re-seeded to maize.

3.3 FIELD STUDIES

Three field experiments were carried out in selected tobacco growing areas in northern Nigeria in order to evaluate the effect of Mg application on yields, yield components and quality of tobacco. The first was conducted during the rainy season of 1980 at Maigana, Kaduna State (11^{o} 02'N), the second was a dry season crop grown in 1980/81 in a low level seeasonally flooded land (locally known as "fadama"), also at Maigana while the third was carried out at the Institute for Agricultural Research farm at Kano (12^{o}N) during the rainy season of 1981. The climatic and soil conditions of the three locations and the cropping history of the fields used for the investigation are shown in Tables 2 and 3.

(a) Design, layout, treatment and cultural practices

The experiments were laid out in randomized block design (RBD) of four replications with twelve combinations of four levels of Mg and three levels of K. Details of treatments are shown in Table 4.

Seedlings of 6 - 7 weeks old and of about 10 - 15cm in height were produced in nursery beds for the second and third experiments. Seedlings of the same age and height for the first experiment were obtained from the Nigerian Tobacco Company's experimental station at Wanka, Kaduna State. The same variety RIY was used in the three experiments. Seeds were sown for the second and third

Table 2. Cropping history and climatic conditions of sites used for field experiments.

Expt. No.	Season	Location	Previous crops	Rainfall distribution (mm)								
				April	May	June	July	August	September	October	November	Total
1	Rainy 1980	Maigana	Fallow for 3 years	47.2	168.9	59.1	223.7	207.5	82.7	50.0	-	839.10
2	Dry*	Maigana	Fallow for 3 years	47.2	168.9	59.1	223.7	207.5	82.7	50.0	-	839.10
3	Rainy 1981	Kano	Millet and maize	8.0	56.1	89.7	176.6	152.8	77.2	-	-	560.4

*Low level area, depends on underground water.

Table 3. Locations and soil description of experimental area

Site	Location	Ecological Zone	Soil Description
Maigana I	11°02'N	Northern Guinea Savannah	Grayish brown loamy acidic soils which are broadly classified as Alfisols (D'Hoore, 1964 and Tomlinson, 1965).
Maiganna II	11°02'N	Northern Guinea Savannah	Grayish brown juvenile soils (D'Hoore, 1964), that are mainly located in lower slopes in alluvial areas in association with weakly developed profile.
Kano	12°00'N	Sudan Savannah	Brownish yellow sandy loam textured soil, derived from aeolian materials and may be classified as Inceptisols (D'Hoore, 1964).

experiments on September 10, 1980 and June 14, 1981 respectively.

The land in each of the three experiments was ploughed twice, harrowed once and then ridged (90 cm between ridges). Superphosphate was applied (broadcast) at 80kg P_2O_5/ha and worked into the soil before final ridging. The gross plot size was 5.4 x 8m (6 ridges) and the net plot size was 4.5 x 7m. The number of plants per plot was 80.

Uniform and healthy seedlings of about 6 - 7 weeks were selected and transplanted 60cm apart on ridges. Where the seedlings failed to establish, these were re-transplanted about 4 days later. A basal dose of 100kg/ha N, in form of $(NH_4)_2SO_4$ was applied within four days of transplanting. Magnesium and potassium were side-dressed 6 cm apart two days after. The field was hand-weeded two to three times before harvest commenced.

(b) Field Measurements

At the beginning of flowering plant height and leaf area per plant were measured.

Ten plants were selected at random from each plot. The leaves of each plant were categorised into two groups, small and large sizes. The total product of average length and average width of the small leaves

Table 4. Treatments used in the field experiments

No.	Treatment	Mg rates in Kg/ha	K rates in Kg/ha
1	Mg_0 K_0	0	0
2	Mg_0 K_1	0	41.5
3	Mg_0 K_2	0	83.0
4	Mg_1 K_0	24	0
5	Mg_1 K_1	24	41.5
6	Mg_1 K_2	24	83.0
7	Mg_2 K_0	48	0
8	Mg_2 K_1	48	41.5
9	Mg_2 K_2	48	83.0
10	Mg_3 K_0	72	0
11	Mg_3 K_1	72	41.5
12	Mg_3 K_2	72	83.0

and that of the large leaves were calculated for each plant. The proportionality constants suggested by Suggs et al., (1960) of 0.7028 for small leaves and 0.6343 for large leaves were used to calculate the leaf area (in cm^2) per plant and the average of ten plants was finally obtained. Leaf yields in kg/ha and stem dry weight in gram/plant were estimated for each plot at the harvest.

(c) Index-leaf sampling

A representative sample of the upper and lower leaves (as defined earlier) were collected from each plot. The samples were washed clean, rinsed twice in distilled water and air-dried for 12-15 days and then dried in an electric oven at $70^{o}C$. The dried plant materials were then ground with a Wiley mill for chemical analysis.

3.4 LABORATORY ANALYSIS

(a) Soils

The soil pH was determined in a 1:1 soil : water and 1:2 soil: 0.01M $CaCl_2$ suspensions using a glass electrode. Organic matter was determined by chromic acid wet combustion procedure of Walkley and Black (Allison, 1965). Cation exchange capacity was determined by leaching the soil with neutral ammonium acetate and displacing the ammonium from the exchange using magnesium oxide. The displaced ammonium was absorbed in a boric acid solution and then titrated with 0. IN HCl (Jackson,

1958; Chapman and Pratt, 1961). Exchangeable bases were extracted with N neutral NH_4OAc as follows:

Five grammes of air-dried soil were shaken with 30 ml of extractant for two hours, centrifuged (2000 r.p.m. for 5 - 10 minutes) and the supernatant liquid filtered into a 100ml volumetric flask. Another 30ml of NH_4OAc solution was added and shaken for 30 minutes; centrifuged and filtered into the same volumetric flask. The last was repeated once more and the filtrate made to a final volume of 100ml with NH_4OAc. Potassium, magnesium and calcium in the extracts were determined using atomic absorption spectrophotometer model 290B. To prevent interference by other ions, addition of 5 ml of 5% strontium chloride solution to every 100 ml of diluted liquid was made. Lithium chloride was added to the extracts in which K was determined to prevent the ionization of the latter under the high temperature produced by the used acetelene gas (Juo, 1975).

Particle size distribution was determined by the hydrometer method as described by Day (1965).

(b) Evaluation of various methods of extracting available magnesium

Various methods were used to extract available Mg as follows:

b.1) Repeated extraction with calcium chloride and ammonium acetate solutions

Neutral, IN ammonium acetate, 0.01M and 0.05 M $CaCl_2$ solutions were used. In each case, 5g of soil were shaken with 30 ml of the extractant on a reciprocating mechanical shaker for 2 hours then centrifuged and filtered into a 100 ml volumetric flask. The same sample was further shaken with another 30 ml of extractant for 30 minutes and filtered into the same flask. The last step was repeated once more and the combined extracts in the volumetric flask made up to mark with the appropriate extractant (Juo, 1975).

b.2) Single extraction with normal neutral ammonium acetate

Five grammes of air-dried soil were shaken with 100 ml of N ammonium acetate for one hour, centrifuged and filtered (Peech and English, 1944).

b.3) Single extraction with 0.01M calcium chloride

Five grammes of air-dried soil were shaken with 100 ml of 0.01M calcium chloride on a reciprocating mechanical shaker for two hours, centrifuged, and filtered (Schachtschahel, 1954).

b.4) Single extraction with 0.05M calcium chloride

Five grammes of air-dried soil were shaken with 100 ml of $CaCl_2$ solution on a reciprocating mechanical shaker

for two hours; centrifuged and filtered. (Schachtschahel, 1954).

An aliquat of each extract was diluted and magnesium determined by the atomic absorption spectrophotometer as earlier described. Interference by other ions was suppressed by addition of lanthanum solution to each diluted extract in which the cations were determined.

(c) Plant tissue analysis

A two-gram owen -dry milled sample from each pot or plot as the case may be, was wet-ashed fwith a three-acid mixture of sulphuric acid, perchloric acid, and nitric acid (1:2:5 ratio) and the digest diluted with water, filtered and made up to volume in a 100 ml volumetric flask (Chapman and Pratt, 1961). Magnesium, calcium and potassium in the digest were determined by atomic absorption spectrophotometry.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 EVALUATION OF VARIOUS SOIL TESTS FOR PLANT AVAILABLE MAGNESIUM

The data presented in Table 5 indicate that the soils were generally low in most plant nutrients. The soil pH was generally on the acid side. The particle size analyses showed that most of the soils were sandy loams, sandy clay loams or loamy sands. The complete analytical data for the soils are presented in Appendix Table 1.

Table 5. Selected properties of some Nigerian savannah soils

Soil property	Values*	
	Range	Average
pH ($CaCl_2$)	3.10 - 5.44	4.59
pH (H_2O)	3.60 - 7.00	5.26
Organic matter %	0.17 - 1.86	0.69
CEC (meq/100g soil)	1.24 - 16.50	5.15
Exch Mg (")	0.03 - 2.00	0.72
Exch K (")	0.03 - 0.79	0.15
Exch Ca (")	0.20 - 5.92	2.07
Silt %	1.60 - 42.4	19.66
Clay %	3.60 - 60.40	16.38

*Average figures of 49 samples.

Data presented in Table 6 show the average values of available Mg contents in the various samples as extracted by various methods.

From the point of view of the amounts of Mg extracted, the methods differed significantly. Repeated shaking for a total of three hours with neutral ammonium acetate removed more Mg than shaking for one hour with the same extractant.

Table 6 Average values of available magnesium extracted by various methods

No.	Description of Methods*	Available Mg Extracted (meq/100g)
1.	IN NH_4OAc (pH7) - Repeated extraction	0.522
2.	IN NH_4OAc (pH7) - Shaking one hour	0.479
3.	$CaCl_2$(0.01M) - Repeated Extraction	0.501
4.	$CaCl_2$(0.01M) - Shaking two hours	0.455
5.	$CaCl_2$(0.05M) - Repeated Extraction	0.545
6.	$CaCl_2$(0.05M) - Shaking two hours	0.459

LSD = 0.029

*A soil extractant ratio of 1:20 was used for all of the methods.

Repeated extraction with 0.05M or 0.01M $CaCl_2$ for a total of three hours gave significantly higher values than the two-hour single shaking. These results suggest that increasing extraction time through repeated extraction procedure tended to extract more Mg than shaking once for shorter total time, at the same soil : solution ratio..

With the repeated extraction the more concentrated solution of 0.05m $CaCl_2$ extracted significantly higher amounts of soil Mg than did the 0.01M $CaCl_2$. However, the two solutions extracted essentially the same amounts of Mg at the 2-hour single extraction. It seems therefore increasing the time of shaking from two to three hours increased the amount of Mg extracted with all the methods, while increasing the concentration of $CaCl_2$ from 0.01M to 0.05M increased the Mg extracted only under the repeated extraction procedure. This suggests that both the time of shaking and the concentration of the extractant are important in determining the amount of Mg extracted.

The amount of Mg extracted were in the following descending order: Repeated extraction with 0.05M $CaCl_2$ > repeated extraction with neutral 1N ammonium acetate > repeated extraction with 0.01M $CaCl_2$. The difference between the first and second was insignificant, and so also was that between the second and the third, but

there was a significant difference between the first and the third.

Comparison of different methods of extraction of a plant nutrient is only useful if such comparison is related to plant uptake or crop yield. A good soil extractant is that which removes the amount of nutrient that correlates well with plant uptake. The relationship between the various soil tests and plant uptake of Mg are shown in Table 7 and graphically in Figs. 3-8.

The correlation data in Tables 7 and 8 seem to suggest that:-

1. The neutral 1 N ammonium acetate and the 0.01M $CaCl_2$ extractions compare favourably and both appear more suited for the soils in question than the 0.05 M $CaCl_2$.

2. The degree of correlation between plant uptake of Mg and that extracted chemically increased as the amount of soil Mg decreased. This must be so because in all methods the highest correlation was obtained at the third cropping where it was expected that the level of Mg in the soil was much lower (owing to plant uptake) than that at the initial stage.

Table 7. Correlation coefficient between Mg taken up by maize and extractable Mg under intensive greenhouse cropping

Description of Analytical Method	Simple Correlation Coefficients (r)		
	First Crop	Second Crop	Third Crop
1. NH_4OAc (pH7) – Repeated Extract.	0.76**	0.73**	0.90**
2. NH_4OAc (pH7)– Shaking for 1 hr,	0.76**	0.74**	0.91**
3. $CaCl_2$ 0.01M– Repeated Extract.	0.79**	0.66**	0.82**
4. $CaCl_2$ 0.01M– Shaking for 2 hrs.	0.78**	0.76**	0.91**
5. $CaCl_2$ 0.05M– Repeated Extract.	0.74**	0.74**	0.91**
6. $CaCl_2$ 0.05M Shaking for 2 hrs.	0.66**	0.77**	0.93**

* Soil Extractant Ratio was 1:20

** Significant at 1% level

3. Using the correlation data (Table 8) for the relationship between the total uptake and soil analytical procedure all methods appeared satisfactory but the repeated extraction with NH_4OAc, 0.05 M $CaCl_2$, and the two hours single extraction with 0.01 M $CaCl_2$ appears most suitable.

However, as already indicared earlier, correlation coefficients alone especially where they do not differ significantly, cannot form a satisfactory basis for making a choice of an extraction procedure. Other associated factors such as laboratory convenience, availability of facilities e.g. equipment and chemicals, adaptability, time saving factor and suitability for routine use all form an important part of the consideration of a soil analytical procedure. The degree of accuracy required and the needs and preferences of the researcher are also important considerations.

On this score, it would seem that the repeated extraction with ammonium acetate and the 2-hour single extraction with 0.01 M $CaCl_2$ offer themselves as suitable alternatives. However, since the correlation coefficient value obtained with the one-hour single shaking did not differ significantly from those other [illegible] would appear that it is the one that may be most suited for

Table 8 Relationship between total Mg rtaken up by maize and extractable Mg as measured prior to cropping

Method of Analysis	Correlation Coeffieient	Regression Equations
N NH_4OAc (pH7) - Repeated Extraction (1:20)	0.857**	Y = 1.175 + 4.695X
N NH_4OAc (pH7) - Shaking one hour (1:20)	0.837**	Y = 1.164.+ 5.170X
$CaCl_2$ 0.01M - Repeated Extraction (1:20)	0.837**	Y = 1.130 + 4.785X
$CaCl_2$ 0.01M - Shaking two hours (1:20)	0.879**	Y = 0.885 + 6.022X
$CaCl_2$ 0.05M Repeated Extraction (1:20)	0.853**	Y = 1.228 + 4.398X
$CaCl_2$ 0.05M Shaking two hours (1:20)	0.814**	Y = 1.192 + 5.301X

Y = Mg taken up by maize (dependent variable)
X = Mg extracted by various methods (independent variables)
** = Significant at 1% level.

routine work where large number of samples may be involved. If only a few samples are involved then the repeated extraction with NH_4OAc seems an attractive choice.

The choice for a suitable extraction procedure for the soils under investigation seems to be between the 0.01 M $CaCl_2$ (single extraction for 2 hours); N NH_4OAc (repeated extraction); and N NH_4OAc (single extraction for one hour).

Ammonium acetate extractant beside being widely accepted, is regarded as a highly buffered salt solution and thus its interference in analytical procedures is easily eliminated. With $CaCl_2$, it is impossible to determine Ca in the same extractant, a problem that would not arise when NH_4OAc is used. Repeated extraction and single extraction with NH_4OAc appear equally satisfactory.

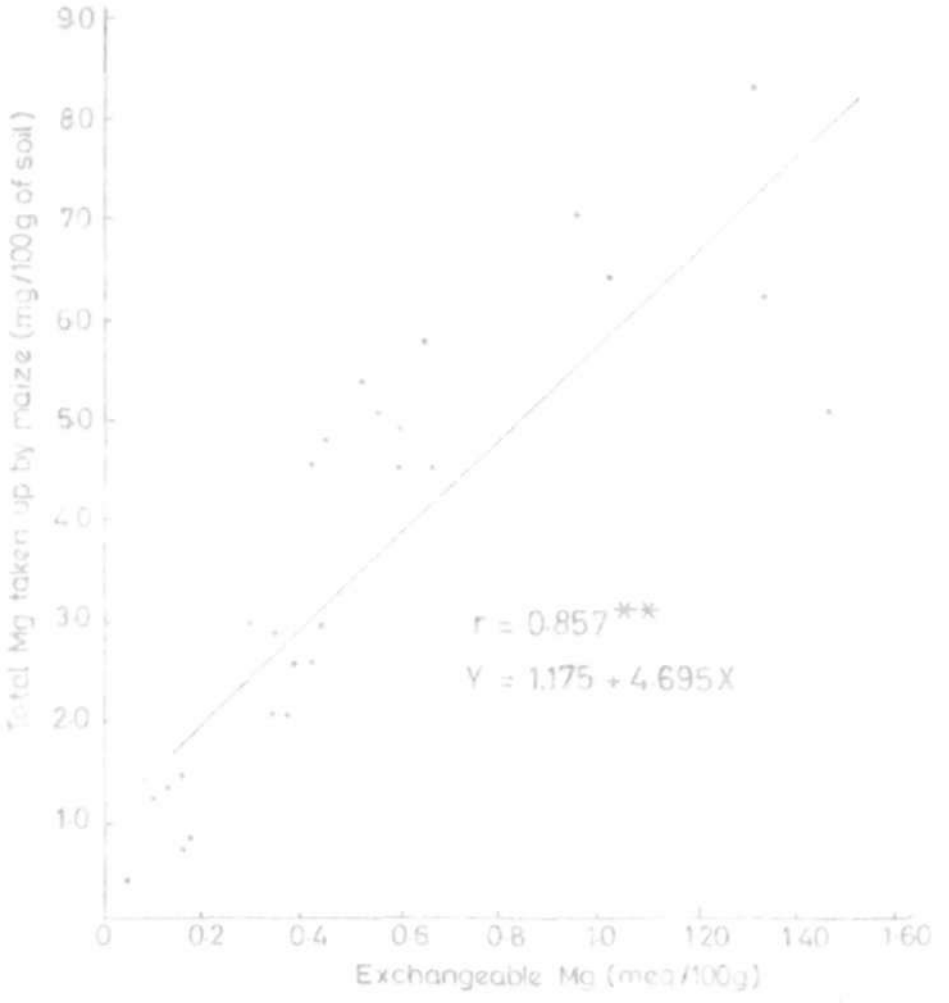


FIG 3. RELATIONSHIP BETWEEN NH_4OAC EXTRACTABLE Mg (REPEATED EXTRACTION) AND Mg TAKEN UP BY MAIZE

FIG 4. RELATIONSHIP BETWEEN NH_4OAC EXTRACTABLE Mg (SHAKING FOR ONE HOUR) AND Mg TAKEN UP BY MAIZE

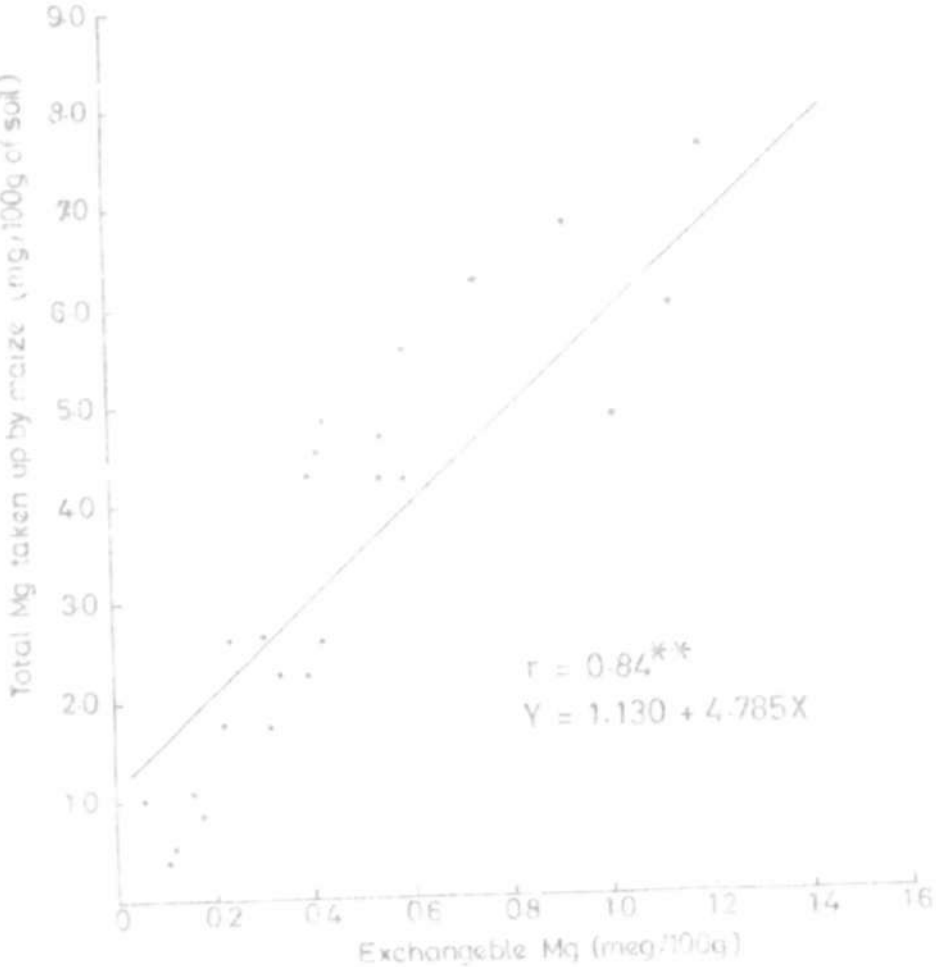


FIG.5. RELATIONSHIP BETWEEN 0.01M $CaCl_2$ EXTRACTABLE Mg (REPEATED EXTRACTION) AND Mg TAKEN UP BY MAIZE

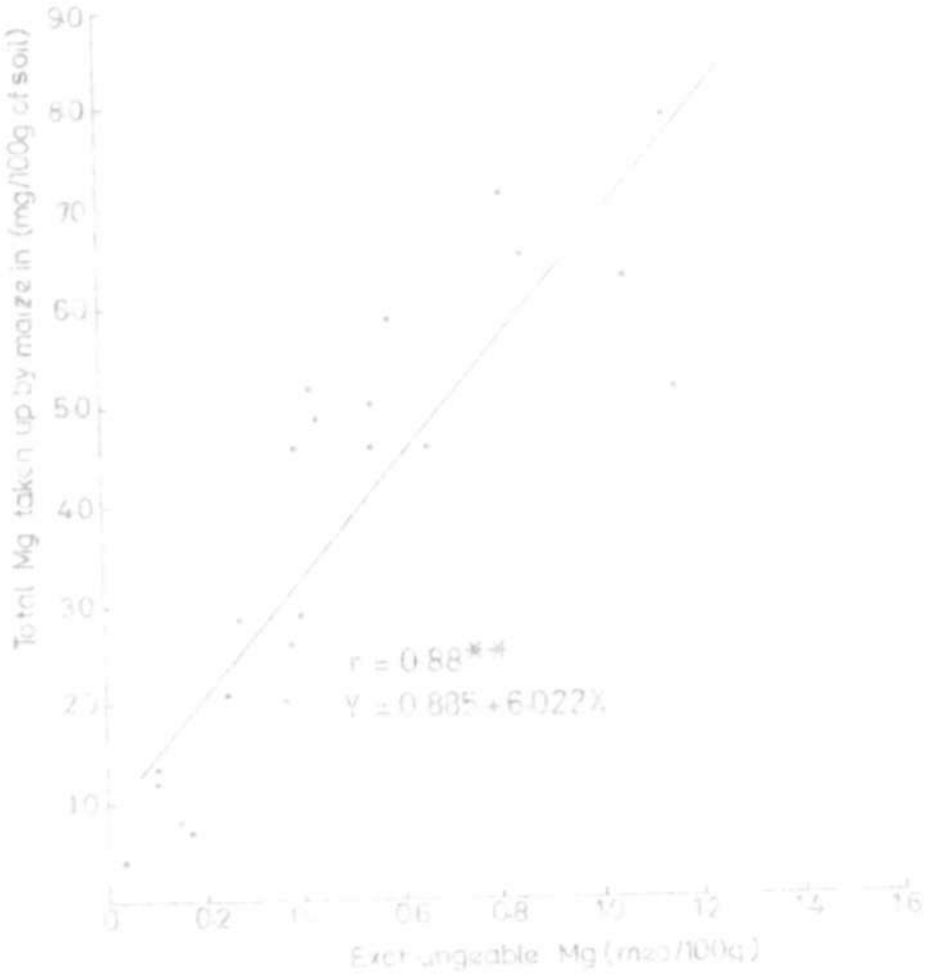
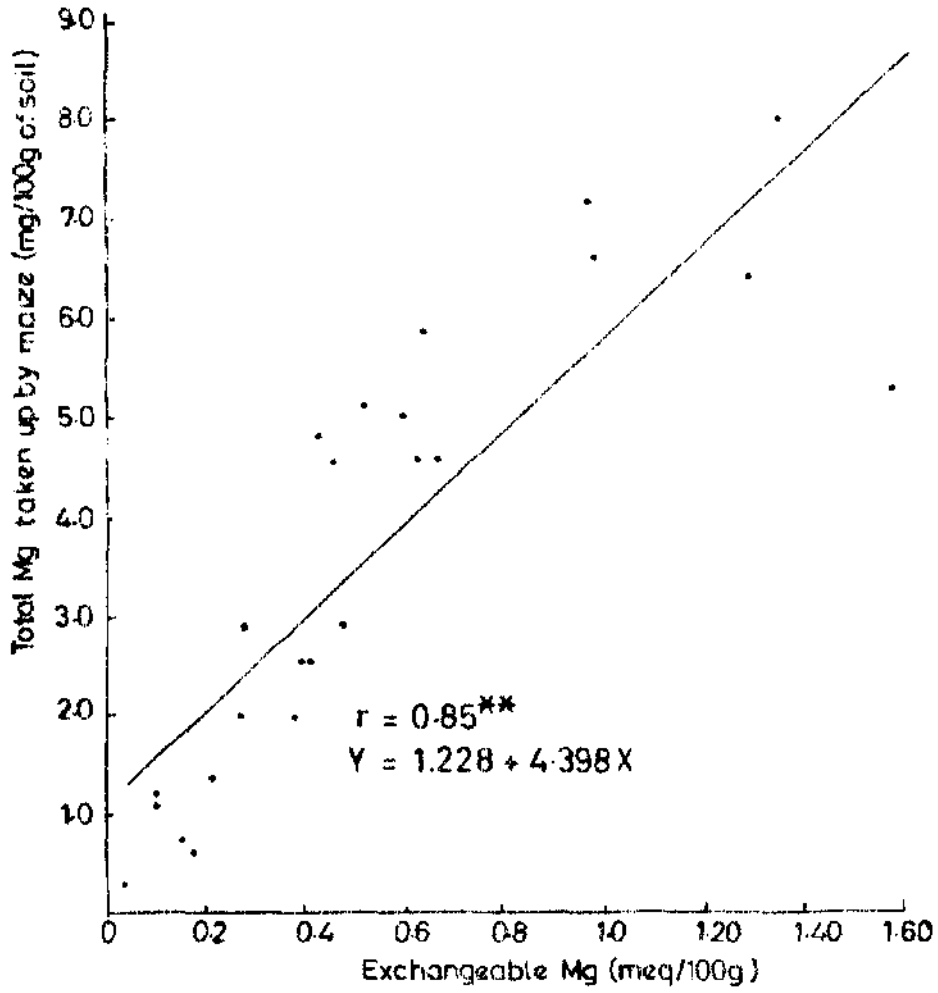


FIG. 6 RELATIONSHIP BETWEEN 0.01M $CaCl_2$ EXTRACTABLE Mg (SHAKING FOR TWO HOURS) AND Mg TAKEN UP BY MAIZE



RELATIONSHIP BETWEEN 0.05M $CaCl_2$ EXTRACTABLE Mg (REPEAPTED EXTRACTION) AND Mg TAKEN UP BY MAIZE

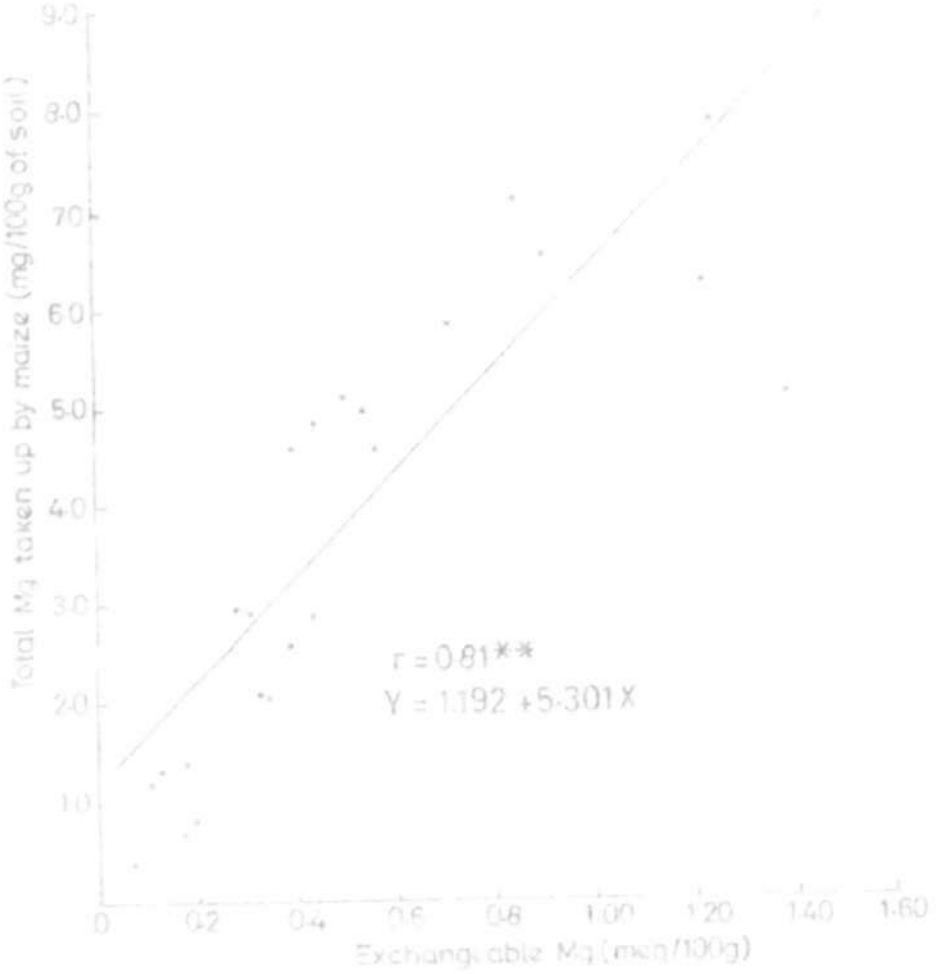


FIG 8 RELATIONSHIP BETWEEN 0·05M $CaCl_2$ EXTRACTABLE Mg (SHAKING FOR TWO HOURS) AND Mg TAKEN UP BY MAIZE

4.2 SOIL MAGNESIUM SURVEY OF NORTHERN NIGERIA AND FACTORS INFLUENCING Mg AVAILABILITY AND UPTAKE

(a) Surface soil survey (0-20cm)

The exchangeable Mg data for the various locations (Fig.1) are shown in Appendix (1). Average values for Mg and the other soil properties for the different ecological zones of northern Nigeria are presented in Table 9. The mean value of the exchangeable Mg of the Sudan savannah soils (Zone 1, essentially Inceptisols derived from aeolian deposits) was 0.54 meq/100g.

Critical Mg levels in soils from the point of view of plant needs falls within the range of 0.20 and 0.42 meq/100g of soil (Key and Kurtz, 1960; Mazaeva, 1967; Reith 1967; and Lombin and Fayemi 1975). Based on this critical value, about 52 per cent of the samples may be considered low in Mg content (with less than 0.42 meq/100g). About seventy-nine per cent of the locations have less than 0.83 meq/100 and are placed just above the critical level. A wide range (0.03-2.0 meq/100g) of exchangeable magnesium was recorded in the soils, variability that could be attributed to the differences in organic matter contents. The mean values of silt, clay and organic matter were 13.99; 12.04 and 0.48% respectively (Table 9).

Table 9 Chemical and physical properties of savannah soils of northern Nigeria

Zone	Number of samples	pH		CEC	Mg	Ca	K	Silt	Clay	Silt + Clay	O.M.%	Cation Ratios			
		$CaCl_2$	water	meq/100g soil				%				Mg:K	Mg:Ca	$\frac{Mg+Ca}{K}$	Mg:CEC
Sudan Savannah	1 - 19	4.60	5.35	4.15	0.54	1.61	0.17	13.99	12.04	26.03	0.48	3.18	0.33	12.65	0.13
Northern Savannah	20 - 40	4.43	5.14	6.42	0.96	2.74	0.16	27.02	21.78	48.80	0.69	6.00	0.35	23.13	0.15
Southern Savannah	41- 49	4.94	5.45	4.32	0.56	1.56	0.13	14.49	12.93	27.42	1.15	4.32	0.36	16.31	0.13

The mean value of the exchangeable Mg of the Northern Guinea savannah soils (Zone II, predominantly Alfisols with a small proportion of Ultisols) was 0.96 meq/100g with a range of 0.43 - 1.87 meq/100g. About 38 per cent of the locations have less than 0.83 meq/100g Mg and therefore approaching the critical level. The mean values of silt, clay and organic matter are 27.02 per cent; 21.78 per cent and 0.69 per cent respectively which are generally higher than the corresponding values of the Sudan savannah zone. As a result there was an increase in the cation exchange capacity and subsequently a proportion increase in the exchangeable Mg level. The same trend was observed with Ca while K remained almost constant. The magnesium/potassium ratio increased from 3.18 in Zone I to 6.00 in Zone II due to the increase in Mg content while the K content remained fairly constant over the various zones. However Mg/ca and Mg/CEC remained almost unchanged. The wide range of exchangeable Mg in this zone could be attributed to the differences in parent material and to some extent, the effect of local variations particularly the undulating topography as well as the management practices and the cropping history. Soils formed in valley bottoms or lowland areas often contain higher amounts of nutrients due to the effect of erosion and drainage condition. Changes in the pH of the soils of this zone were very slight when compared with Zone I.

The mean value of the exchangeable Mg of the southern Guinea savannah soils (zone III, which may be classified as Ultisols and Oxisols) was 0.56 meq/100g with a range of 0.12 - 1.27 meq/100g. This shows a similarity with values recorded in the soils of zone I, though the rainfall in the two zones differ in intensity and distribution. The mean values for other cations show almost the same trend with almost constant values of K and Ca with the corresponding values of zone I. Silt and clay contents were about the same as those of zone I. The mean value of CEC was slightly higher than that in zone I due most probably to the sharp increase in organic matter content. The mean values of organic matter was 0.48% and 1.15% in the Sudan and Southern Guinea savannah soils respectively. About 44% of the locations of zone III have exchangeable Mg of less than 0.42 meq/100g soil and therefore are considered low in Mg contents, while about 77% of the locations have less then 0.83 meq/100g and thus very close to the critical level.

It may be concluded from the foregoing discussion that the savannah soils of northern Nigeria are generally low in Mg. However, it must be emphasized that measurement of exchangeable Mg alone is not enough in predicting its availability status. The importance of soil texture, organic matter content, soil reaction and CEC and above all, the balance between Mg and other cations, cannot be

over-emphasised in this regard. Below is an attempt to highlight the association of exchangeable Mg and some pertinent soil characteristics.

ASSOCIATION BETWEEN EXCHANGEABLE MAGNESIUM AND DIFFERENT SOIL CHARACTERISTICS

Soil chemical and physical properties have considerable influence on Mg availability. Simple correlation coefficients between NH_4OAc - extractable Mg and some physical and chemical properties of the soils are shown in Table 10. High significant correlation was recorded between exchangeable Mg and other soil characters. The highest correlation recorded was with CEC ($r = 0.85^{**}$) followed by that with Ca ($r = 0.84^{**}$) and then by potassium ($r = 0.67^{**}$) among the chemical properties. Just significant but negative correlation was recorded between exchangeable Mg and the soil pH measured in $CaCl_2$ and in water ($r = -0.30^{*}$ and $r = -0.29^{*}$) respectively. A high and significant correlation existed between exchangeable Mg and clay ($r = 0.75^{**}$) and also between exchangeable Mg and organic matter ($r = 0.56^{**}$), and relatively lower but highly significant value (0.49^{**}) with silt (Table 10).

In an attempt to clarify the above mentioned associations between exchangeable Mg and soil characters, linear functions were worked out between Mg as dependent variable (Y) and different physical and chemical properties of the soils as independent variables (Xs). The linear equations are given in Table 10.

Table 10 Relationship between exchangeable magnesium and selected soil chemical and physical properties

Soil property	Correlation Coefficient	Regression Equation
Soil pH ($CaCl_2$)	-0.30*	Y = 2.095 - 0.2984X
Soil pH (water)	-0.29*	Y = 1.771 - 0.1988X
Organic matter %	0.56**	Y = 0.2698 + 0.6587X
C.E.C.(Meq/100g)	0.85**	Y = 0.0198 + 0.1446X
Exch.K(Meq/100g)	0.67**	Y = 0.3313 + 2.471X
Exch.Ca(Meq/100g)	0.84**	Y = 0.1338 + 0.2863X
Silt %	0.49**	Y = 0.3619 + 0.0185X
Clay %	0.75**	Y = 0.2065 + 0.0317X
Mg : K	0.59**	Y = 0.3011 + 0.0815X
Mg : Ca	0.44**	Y = 0.1649 + 1.5796X
(Mg + Ca)/K Ratio	0.44**	Y = 0.3844 + 0.0165X
Mg Saturation of CEC(%)	0.63**	Y = 0.0910 + 6.0276X
Silt + Clay %	0.64**	Y = 0.1854 + 0.0149X

* Significant at the 5% level. Y = Soil exchangeable Mg (dependent variable)

** Significant at the 1% level X = Independent variables.

a.1) Soil Exchangeable Mg and Organic Matter

Significant correlation (r = 0.56**) was obtained between exchangeable Mg and soil organic matter. This is in agreement with the widely held view that organic matter makes an important contribution to the cation exchange capacity of soils (Kalpage, 1974). Although the average organic matter level recorded for these soils was generally low (0.69%), yet its function on the cation exchange capacity and thus on exchangeable Mg, is apparent. This is clear from the higher correlation coefficient recorded between the exchangeable Mg on one hand, the organic matter, Clay and CEC on the other hand.

The constant term in the statistical equation (Y = 0.2689 + 0.6587X) which shows the relationship between the exchangeable Mg and the organic matter content of these soils (Fig.9), is an estimate of the exchangeable Mg of the mineral portion of the soil. This result is an evidence to illustrate the effect of organic matter on the exchangeable Mg in the soil, and therefore, stresses the need for increasing the organic matter content of these soils if a high fertility level is to be reached or at least the present fertility level, though low, to be maintained.

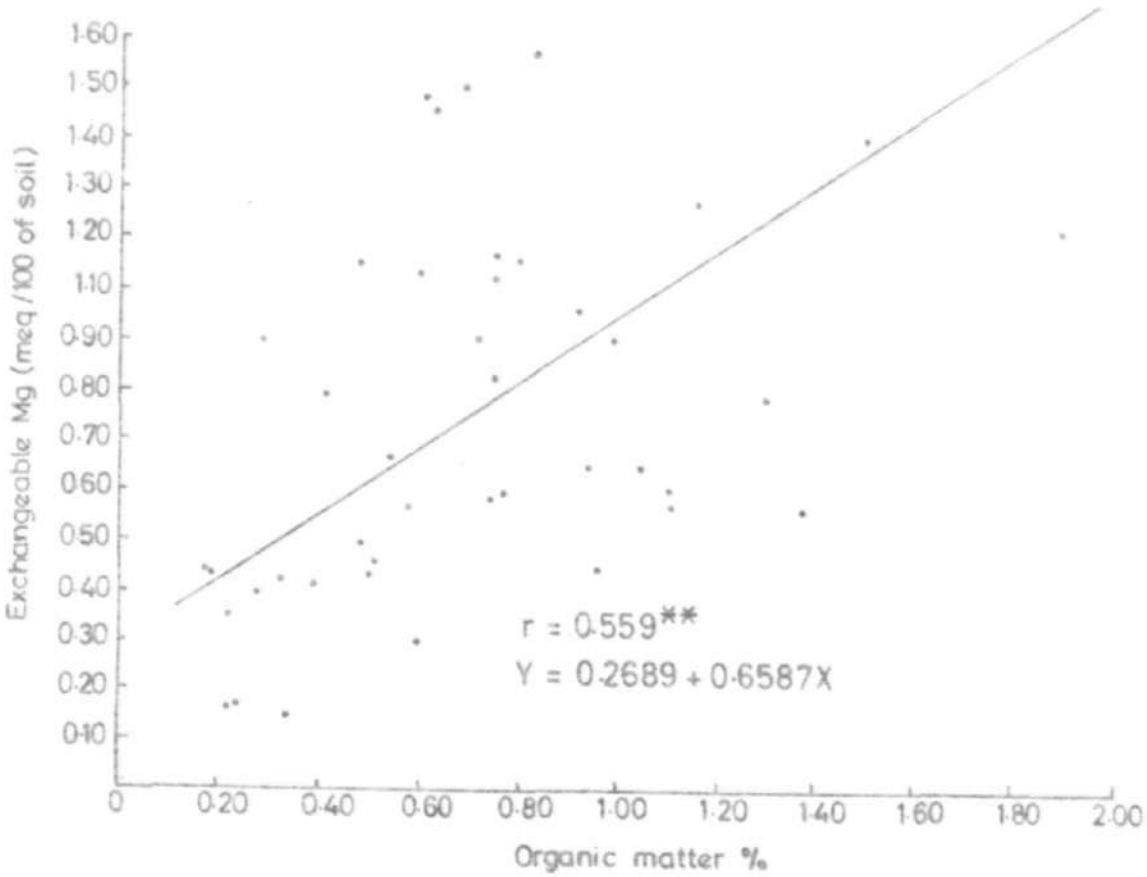


FIG. 9 : RELATIONSHIP BETWEEN EXTRACTABLE Mg AND SOIL ORGANIC MATTER

a.2) Soil Exchangeable Mg and Other Selected Soil Properties

Highly significant correlation coefficient (0.85**) was recorded between the exchangeable Mg and the cation exchange capacity of these soils. (Fig.10). A similar correlation (0.75**) was also recorded between exchangeable Mg and clay content. (Fig.11). This indicates that because clay is the main contributor to CEC, the amount of exchangeable cations may be expected to be highly correlated with the amount of clay in the soil, and to a lesser extent with the amount of silt (r = 0.496*).

The correlation between exchangeable Mg and soil pH within the range used was just significant (Table 10). However, this relationship could be misleading since the range of pH obtained in this investigation was small, (3.10 - 5.44 ($CaCl_2$) and 3.6 - 7.00 (H_2O) and all fell mainly on the acidic side. However, the pH of any soil is influenced by numerous factors, therefore its association with Mg should be interpreted with caution. The same view was expressed by Rursell and Russell (1977), who stated that correlation of pH with soil properties are strictly empirical since small differences cannot be interpreted with certainty.

Highly significant correlations were also recorded between exchangeable Mg and some other pertinent

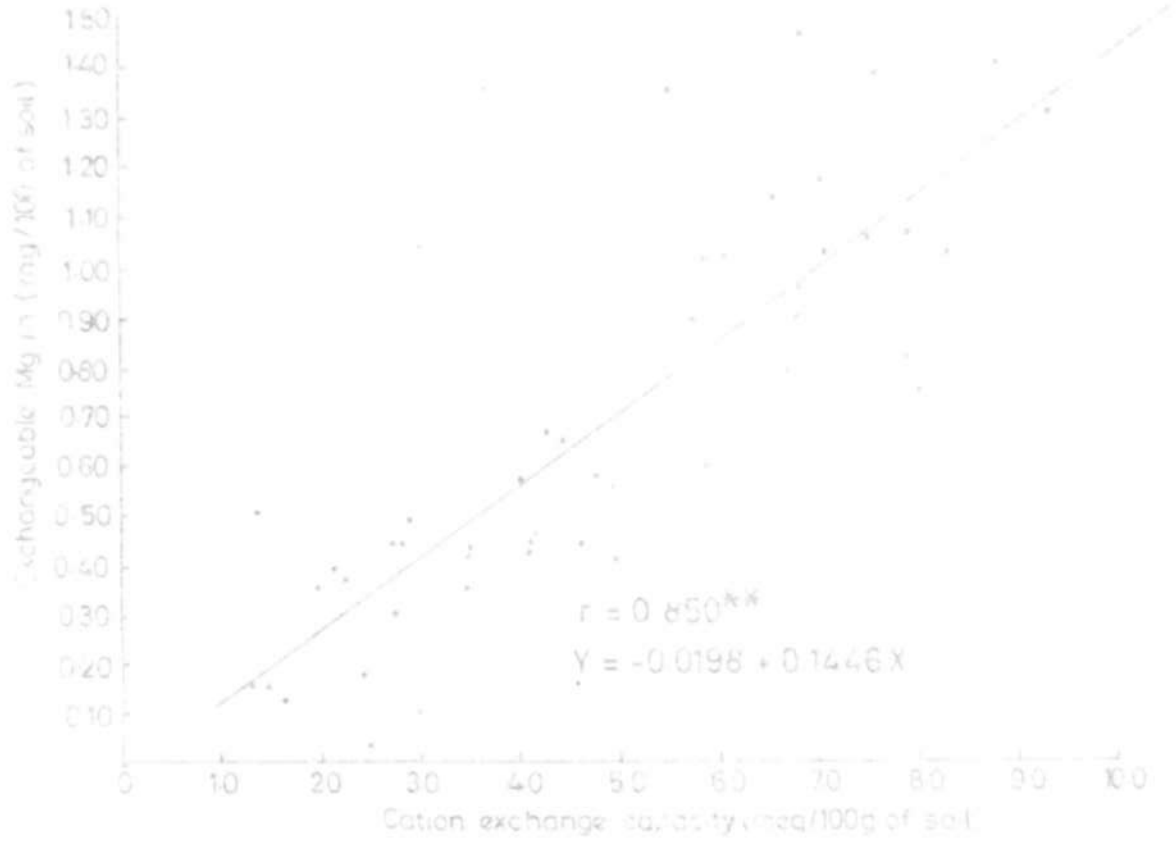


FIG.10: RELATIONSHIP BETWEEN EXTRACTABLE Mg AND CATION EXCHANGE CAPACITY

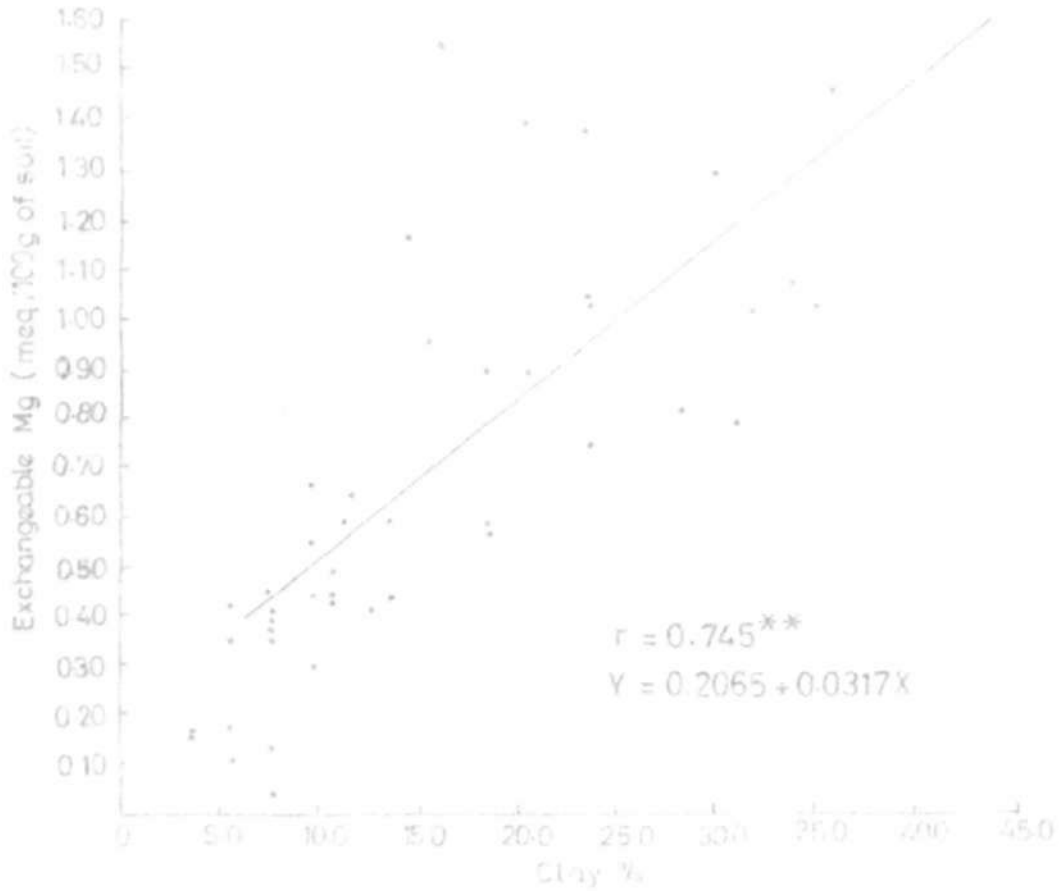


FIG.11 : RELATIONSHIP BETWEEN EXTRACTABLE Mg AND CLAY

parameters of the soil, namely Mg:K, Mg:Ca, Mg + Ca: K and Mg:CEC ratios. The correlation coefficients were 0.59**; 0.44**; 0.44** and 0.63** respectively (Table 10). This was probably not unexpected since each individual element was significantly correlated with exchangeable magnesium. The linear equations and values showing these relationships are given in Table 10.

It may be concluded here, that any changes in any of these properties will be accompanied by some proportional changes in the exchangeable Mg status of the soil. Moreover any of these properties could be conveniently used to predict the available Mg status of the soils in question.

(b) Mg SURVEY IN SELECTED SOIL PROFILES

Table 11 presents a summary of the pertinent chemical and physical properties of the different depths (0-20, 20-40; 40-60; 60-80cm) of the soils sampled. The average exchangeable Mg in the top soil (0-20cm) for the entire area covered by the survey is 0.94 meq/100g with a range of 0.50 to 1.38 meq/100g. Corresponding values for the 20-40; 40-60 and 60-80 depths are 1.15; 1.33 and 1.24 meq/100g with ranges of 0.65-1.65; 0.63-2.03 and 0.53-1.95 respectively. These data indicate soil Mg content increases with depth, the highest amounts being in the 20-40 and 40-60cm depths.

Table 11 Physical and chemical properties of different depths of all soil profiles

Variables	0 - 20cm	20 - 20 cm	40 - 60 cm	60 - 80 cm	All Depths
pH in $CaCl_2$	4.20 ± 0.65	4.13 ± 0.68	4.12 ± 0.61	4.03 ± 0.61	4.13 ± .63
pH in water	5.00 ± 0.74	4.96 ± 0.67	5.03 ± 0.61	4.89 ± 0.59	4.96 ± .64
O.M. %	0.66 ± 0.31	0.44 ± 0.22	0.30 ± 0.13	0.24 ± 0.10	0.41 ± 0.26
C.E.C.(meq/100g)	6.55 ± 2.66	7.84 ± 2.50	7.74 ± 2.53	7.13 ± 2.73	7.32 ± 2.61
Mg (meq/100g)	0.94 ± 0.44	1.15 ± 0.50	1.33 ± 0.70	1.24 ± 0.71	1.16 ± 0.61
K (meq/100g)	0.20 ± 0.15	0.22 ± 0.28	0.22 ± 0.25	0.20 ± 0.17	0.21 ± 0.22
Ca (meq/100g)	2.61 ± 1.44	3.00 ± 1.56	3.38 ± 2.02	3.16 ± 2.07	3.04 ± 1.79
Mg : K	5.89 ± 3.19	7.32 ± 4.37	8.12 ± 3.97	7.72 ± 4.29	7.26 ± 4.00
Mg : Ca	0.40 ± 0.15	0.43 ± 0.16	0.46 ± 0.29	0.45 ± 0.29	0.44 ± 0.23
Mg + Ca:K	22.25 ± 13.74	28.64 ± 18.98	28.96 ± 15.82	27,29 ± 15.04	26.78 ± 15.88
Mg / CEC	0.14 ± 0.04	0.16 ± 0.03	0.59 ± 2.05	0.17 ± 0.06	0.26 ± 1.03
Sand %	53.12 ± 16.23	46.70 ± 14.94	45.28 ± 17.04	47.49 ± 17.60	48.15 ± 16.50
Silt %	24.6 ± 10.45	21.07 ± 7.29	20.57 ± 7.39	19.65 ± 6.97	21.48 ± 8.24
Clay %	22.03 ± 10.82	32.27 ± 11.67	34.23 ± 12.52	32.94 ± 12.39	30.37 ± 12.66

Beside Mg, the levels of each of the other bases in the top soil (0-20cm) was significantly lower than the corresponding values within the 20-40; 40-60 and 60-80cm layers. However, the contents of each of these exchangeable bases in the three lower depths did not differ sifnigicantly. It would appear that cations have been moved down the profile particularly from the top soil into the sub-soil. Leaching has been shown to be an important feature of the Nigerian Savannah soils (Jones and Wild, 1975). The results are now considered in relation to other soil variables.

b.1) Relationship Between Soil Mg and Organic Matter

Correlation matrices showing the relationship between the various soil variables are presented in Tables 12, 13, 14 and 15.

The highly significant correlations between the exchangeable Mg and the organic matter content of the soil in all the depths (0.644**; 0.586**; 0.529** and 0.476** for 0-20; 20-40; 40-60 and 60-80cm respectively) suggest that the Mg status in these soils is profoundly influenced by soil organic matter.

1. p^H in $CaCl_2$	-	0.911**	0.029	-0.136	-0.403	0.309	0.124	-0.110	0.193
2. p^H in water		-	0.053	-0.239	-0.182	0.185	-0.003	-0.138	-0.153
3. O.M.%			-	0.747**	0.644**	0.421*	0.545**	0.144	0.046
4. C.E.C.				-	0.763**	0.210	0.707**	0.337*	-0.125
5. Mg					-	0.204	0.737**	0.547**	0.220
6. K						-	0.223	-0.530**	-0.119
7. Ca							-	0.427	-0.452
8. Mg : K								-	0.120
9. Mg : Ca									-
10. Mg + Ca:K									
11. Mg / CEC									
12. Sand %									
13. Silt %									
14. Clay %									
15. Silt+Clay %									

1. p^H in CaCl$_2$	-								
2. p^H in water	-	-0.060	-0.184	-0.901	0.489**	0.162	0.114	-0.179	-0.
3. O.M.%		-	0.633**	0.586**	0.365*	0.358*	0.071	-0.003	0.
4. C.E.C.			-	0.793**	0.085	0.675**	0.381*	-0.013	-0.
5. Mg				-	0.038	0.702**	0.488**	0.144	0.
6. K					-	0.066	-0.446**	-0.108	-0.
7. Ca						-	0.567**	-0.509**	0.
8. Mg : K							-	-0.100	0.
9. Mg : Ca								-	0.
10. Mg + Ca/K									
11. Mg / CEC									
12. Sand %									
13. Silt %									
14. Clay %									
15. Silt + Clay									

2. p^H(in water)		-	0.268	-0.155	-0.160	0.5[illegible]**	-0.054	[illegible]	[illegible]	-
3. O.M.%			-	0.412*	0.529**	0.270	0.418*	0.449**	-0.111	0.1
4. C.E.C.				-	0.694**	0.128	0.876**	0.338*	-0.123	0.1
5. Mg					-	0.029	0.720**	0.644**	0.024	0.1
6. K						-	0.031	-0.458**	-0.149	-0.1
7. Ca							-	0.433*	-0.382*	0.
8. Mg : K								-	0.123	0.
9. Mg : Ca									-	-0.
10. Mg + Ca/K										
11. Mg / CEC										
12. Sand %										
13. Silt %										
14. Clay %										
15. Silt + Clay										

1.p^H in $CaCl_2$									
2.p^H in water	-	0.368*	-0.272	-0.224	0.208	-0.162	-0.091	-0.140	-0.0
3.O.M.%		-	0.412*	0.476**	0.143	0.381*	0.432*	0.033	0.3
4.C.E.C.			-	0.676**	0.168	0.906**	-0.272	0.183*	0.4
5.Mg				-	0.047	0.565*	0.593**	0.078	0.3
6.K					-	0.168	-0.465**	-0.157	-0.4
7.Ca						-	0.222	-0.372	0.5
8.Mg + K							-	0.045	0.8
9.Mg : Ca								-	-0.2
10.Mg:: Ca/K									-
11.Mg /CEC									
12.Sand %									
13.Silt %									
14.Clay %									
15.Silt + Clay %									

Table 11 shows that the average organic matter contents of the soils decrease with depth (0.66; 0.44; 0.30 and 0.24% for the 0-20; 20-40; 40-60 and 60-80cm respectively. Corresponding ranges of the same order were 0.35 - 0.97; 0.22 - 0.66; 0.17 - 0.43 and 0.14 - 0.34% respectively). The higher content of organic matter of the top soil was accompanied by higher correlation coefficient between the former and the exchangeable Mg (r = 0.640**). The decrease of organic matter content with the depth along the profile was accompanied by proportional decrease in the correlation coefficients between the two variables (0.586**; 0.529** and 0.476**).

The equations showing the relationship between soil exchangeable Mg and organic matter are presented in Table 16. The constants shown in all these equations estimate the available Mg attributed to other factors especially clay and to a lesser extent, silt content. In the surface soil (0-20), the organic matter content was relatively high and correlated best with exchangeable Mg (r = 0.644**). In the next lower depth (20-40cm), the organic matter content decreased by about 33% while clay content increased (from 22 to 32.27%) and as a result the constant in the statistical equation increased (from 0.342* to 0.566**). This of course reduced the correlation between exchangeable Mg and organic matter, though it remained significantly high

Table 16 Changes in the relationship between exchangeable Mg and organic matter with soil depth

Soil Depth (cm)	Correlation Coefficient (r)	Linear Equation
0 - 20	0.644**	Y = 0.342* + 0.898X**
20 - 40	0.586**	Y = 0.556** + 1.342X**
40 - 60	0.529**	Y = 0.463** + 2.900X**
60 - 80	0.476**	Y = 0.429** + 3.310X*

* = Significant at 1% level

** = Significant at 5% level

Y = Exchangeable Mg (dependent variable in meq/100g).

X = Organic matter % (independent variable).

(r = 0.586**). The same trend was also true in the third and fourth depths. The regression coefficients of the statistical equations governing the relationship between exchangeable Mg and organic matter were 0.898; 1.342; 2.908 and 3.310 for the depths 0-20; 20-40; 40-60 and 60-80 respectively (Table 16) which show a regular increase of dependence of exchangeable Mg on the organic matter along the soil profile. The regression coefficient in the equation normally indicates the change in the dependent variable (exchangeable Mg) for each unit change in the independent variable (organic matter). This may explain the role of the sub-soil organic matter in absorbing and maintaining the leached Mg from the top soil against further leaching out of the root zone.

The correlation coefficients between the organic matter and the CEC of different depths along the profile of these soils were 0.747**; 0.633**; 0.412** and 0.412*. These results support the general concept that most Nigerian savannah soils, because of their predominantly kaolinitic nature, are very poorly buffered and organic matter functions as the principal seat of the exchangeable bases and the main source of CEC (Lombin, 1979).

A number of workers have advocated a rational disposal of crop residue in order to sustain the organic matter levels in these soils (Stephens, 1959; Heathcote, 1970; Jones, 1976; Sanchez, 1976 and Lombin, 1979). The use of animal manure, where available and suitable crop rotation together with

good management practices would be helpful in this respect.

b.2) Relationship Between Soil Exchangeable Mg and CEC

Tables 12 to 15 show the association between the CEC and other soil properties in different depths. The correlation between the organic matter content and the CEC in these soils especially in the top two layers support the view that organic matter forms the main source of CEC, and the principal seat of exchangeable bases in these soils (Lombin, 1979). The correlation coefficient obtained between the organic matter and CEC in all the depths of the profile are statistically significant. The higher correlation existed mostly between the organic matter and CEC in the top two depths. It is worth mentioning here that inspite of the high correlation between the organic matter content and CEC, the decrease in the former along the depth of the profile was apparently not reflected in a corresponding decrease in CEC. This suggests that other soil factors notably clay may influence CEC more so than organic matter down the soil profile. The correlation coefficients between the CEC and the clay contents in all the soil depths are presented in Tables (12 to 15). These data show a strong relationship between CEC and clay in the profile. Clay minerals are normally

negatively charged and in a position to absorb cations onto their exchangeable sites. The CEC values along within the profile seem to be more or less constant.

When the total soil content of clay plus silt was correlated with the CEC, the correlation coefficients (0.61**, 0.44**, 0.49** and 0.55** respectively along the profile from top downward) in all the depths were significant but were less than when the correlation was with clay only. The significant correlation recorded here between CEC and silt plus clay seems to be mainly due to the presence of clay rather than the presence of silt since there was nor clear association between the CEC and the silt alone. This study shows clearly the role of clay in controlling the CEC of these soils at lower depths.

Table 17 Relationship between soil exchangeable magnesium and cation exchange capacity with soil depth

Soil Depth (cm)	Correlation Coefficient (r)	Linear Equation
0 - 20	0.763**	Y = 0.113 + 0.126X
20 - 40	0.793**	Y = 0.990 + 0.159X
40 - 60	0.694**	Y = 0.153 + 0.191X
60 - 80	0.676**	Y = 0.140 + 0.175X

** Significant at 1% level

Since CEC is a measure of the exchangeable cations held by a soil the high correlation between exchangeable Mg and CEC (Table 17) is not unexpected.

b.3) Relationship Between Exchangeable Mg and Ca

The distribution of Ca along the profile follows the same pattern as that of Mg (Table 11). The most dominant cations on the exchange complex of most soils are Ca and Mg. The high correlation between them (Table 18) is therefore not surprising. The top soil contains less Ca than the sub-soil, a pattern of distribution that may be associated with clay illuviation.

Table 18 Relationship between exchangeable magnesium and calcium

Soil Depth (cm)	Correlation Coefficient (r)	Linear Equation
0 - 20	0.737**	Y = 0.352 + 0.225X
20 - 40	0.702**	Y = 0.481 + 0.222X
40 - 60	0.720**	Y = 0.489 + 0.248X
60 - 80	0.565**	Y = 0.624 + 0.194X

** Significant at 1% level.

The conclusion from the foregoing discussion may be summarized as follows:

Available Mg increases with depth, the top soil containing the lowest amounts. Leaching may be

responsible for this but clay illuviation may also be a factor. This observation may imply that on the soils used in this study, deficiency of Mg may appear first on the shallow-rooted crops and that the deep-rooted crops may be able to benefit from the sub-soil Mg.

Since clay and soil organic matter are the principal factors influencing Mg contents in these soils and since the amounts of clay in the soils cannot be altered, then efforts must be directed into finding ways of maintaining the soil organic matter.

(c) EFFECTS OF SOME SOIL PROPERTIES ON MAGNESIUM UPTAKE (GREENHOUSE STUDY)

Uptake of Mg by plants depends to a large extent on the total nutrient status of the soil on which the plant is growing. Under greenhouse cropping, total Mg uptake by maize and the exchangeable Mg were highly significantly correlated:

$$R = 0.857^{**} \quad R^2 = 0.734^{**}$$

$$Y = 1.175 + 4.695x \text{ (Equation 1)}$$

where Y = total uptake of Mg in mg per 100g of soil; and x = exchangeable Mg in meq/100g of soil. The linear regression coefficient of this equation shows the role of the cation concentration in the nutrient medium on the uptake of the cation by the plant, and therefore supports the view that the absorption of Mg by plant depends beside other factors on the amount of Mg available in the soil (Tisdale and Nelson, 1966; Lombin, 1979 and Mengel and Kirkby, 1979). Exchangeable Mg measurement seems, therefore, an efficient single measure of the Mg uptake by plant. However the best prediction of the uptake may be provided when other pertinent soil parameters are considered.

To estimate the relative importance of some of the soil properties under northern Nigerian conditions, Mg taken up by maize from soils in the greenhouse

experiment was correlated with a few of the soil properties that were considered most pertinent.

Organic matter, exchangeable Ca; Mg/Ca and clay contents of the soil in a multiple regression analysis to predict the Mg uptake of the first crop of maize gave the following relationship:

Y(Mg uptake of first crop)
= -0.939 + 1.23 (O.M%) + 1.20 (Exch.Ca)
+3.95 (Mg/Ca) - 0.093 (% clay)
R =0.937** R^2 = 0.8780 (Equation 2)

The regression coefficient associated with each of the organic matter, Ca and Mg:Ca show the role of each of these parameters in the uptake of Mg by the plant. The negative regression coefficient of clay in this equation may be attributed to the possible entrapment of magnesium ions by the clay mineral (Tisdale and Nelson, 1966), a condition that has been postulated though the extent to which it takes place is not actually known. The following multiple regression equation was drawn to illustrate the relationship between the Mg uptake of the third crop of maize and the most pertinent soil parameters.

Y (Mg uptake of the third crop)
= 0.192 + 0.432 (exch. Mg) + 0.021 (clay)
R = 0.936* R^2 0.876** (Equation 3)

A comparison between this equation and equation 2 shows that the coefficient of determination in the two equations are the same (R^2 = 0.88) giving equal weight to the two equations. A new dimension appears in the last equation, that is, the positive coefficient associated with clay which demonstrates the possible release of the clay-entrapped Mg. Similar finding was reported by Thompson and Trach, (1978), who suggested that non-hydrated magnesium ion is small enough to fit into octahedral spaces in mineral structures which explains the slow release of Mg to plants.

The relationship between the total magnesium uptake by three maize crops and those selected soil properties are presented in Table 19. The data indicates that besides exchangeable Mg, other factors are also important in Mg uptake by maize in these soils. Below is an attempt to highlight some of these relationships.

c.1) Soil organic matter versus Mg uptake

The uptake of Mg by the three crops of maize was highly correlated (r = 0.635**) with the organic matter content of the soil. The significance of soil organic matter as a source of inorganic plant nutrients has been long established and it seems its role in predicting the available Mg in these soils is particularly critical.

Table 19 Relation between total mg taken up by three crops of maize and some selected soil properties

Soil property	Linear correlation	Linear Equation
Organic matter %	0.635**	Y = 2.21 + 2.52 x
Clay %	0.661**	Y = 2.34 + 0.154x
Mg : Ca	0.333 n.s.	Y = 1.89 + 6.77 x

** Significant at 1% level

n.s. = Not significant

* Significant at 5% level

Y = Total Mg uptake of three maize crops (dependent variable) measured in mg/100g soil.

X = Independent variables.

A number of workers (Jones and Wild, 1975; and Lombin, 1979) have shown that in savannah soils, the organic matter fraction constitutes the major source of CEC. The results obtained here appear to buttress this view. The linear relationship between Mg uptake by maize and organic matter content of the soil is presented in Table 19. The constant value in the regression equation (Y = 2.21 x 2.52x) shows that there are other important factors that affect the Mg availability to the plant beside soil organic matter. However, the linear regression coefficient of the equation indicates that a small change in the organic matter status of the soil will be accompanied by a relatively large change in the Mg uptake by plants.

As indicated earlier Mg uptake by plants seems to be closely related to the exchangeable Mg status of the soil. This relationship was illustrated by equation I: (Total Mg uptake) = 1.175 + 4.695 (exch.Mg), with a highly significant correlation coefficient of 0.86** (Table 20). The inclusion of organic matter in the above equation gave the following relationship:

Y (total Mg uptake) = 0.443 + 3.43 (exch.Mg)
+ 1.88 (O.M%)
R = 0.92** R^2 0.851. (Equation 4).

Comparison between this equation and equation 1 shows that the constant of the last equation was dropped from 1.175 to 0.443 making a difference that could be attributed to the role of organic matter in controlling the Mg-supplying power of these soils, and thereby confirming that the effect of the two factors (exchangeable Mg and organic matter) on the plant uptake of Mg are additive. This was also supported by the noticeable change of correlation coefficient from 0.86 to 0.92 in the two equations. Such change was caused by the inclusion of organic matter in the equation. Moreover the regression coefficient associated with exchangeable Mg was reduced from 4.695 to 3.43 when organic matter was included in the equation, which adds extra support to the same view, regarding the critical role of organic matter in the Mg fertility of the savannah soils.

c(2) Soil clay versus Mg uptake

The total Mg taken up by the three maize crops was highly correlated (r = 0.66*) with the clay content of the soils (Table 19). This is not unexpected because clay forms a great part of the soil colloids that held the soil nutrients against leaching and subsequently increase the long term supply of nutrients to plant. Cooke (1967), stated that the nature, composition and particle size of Mg containing minerals influence the long term supply of magnesium.

Table 20: Relation between Mg uptake by three maize crops and soil Mg, organic matter and clay

Soil properties	Linear correlation coefficient (R)	Coefficient of determination (R^2)	Linear Equation
Exch. Mg in meq/100g	0.857**	0.734**	Y = 1.175 + 4.695 (Mg)
Exch. Mg (meq/100g) + O.M %	0.922**	0.851**	Y = 0.443 + 3.49 (Mg) + 188 (●.m)
Exch. Mg (Meq/100g) + clay %	0.859**	0.738**	Y = 1.238 + 5.201(Mg) - 0.030 (cla

** Significant at 1% level

Y = Mg uptake in Mg/100g soil as dependent variable.

The regression equation (Y = 2.34 + 0.154X) indicates the role of other soil components on the uptake of Mg. The linear regression coefficient of this equation is much lower than the corresponding figure in the organic matter equation which shows that Mg uptake is more closely related to changes in organic matter content than to clay content of the soil. This comparison brings out the relative importance of the clay fraction and organic matter in so far as Mg fertility of the savannah soils is concerned.

As already mentioned before, Mg total uptake of the plant was dependent mostlyy on the exchangeable Mg $\sqrt{Y}$ (total Mg uptake) = 1.175 + 4.695, (exch.Mg)$\sqrt{}$: R 0.86**. When soil clay content was added to the equation the relationship between the total Mg uptake on one hand and exchangeable Mg and clay on the other hand was illustrated by the following regression equation:

$$Y \text{ (Total Mg uptake)} = 1.288 + 5.2011 \text{ (exch.Mg)} - 0.30 \text{ (clay)}$$

$$R = 0.86^{**} \quad R^2 = 0.74 \qquad \text{(Equation 5)}$$

The two equations gave exactly the same coefficient of determination and therefore showing that the effects of the two factors are not additive but complementary. However, the negative partial regression coefficient associated with clay may be explained by the entrapment of Mg cations by clay and thus the latter's role in

increasing the long term supply of nutrients to plant.

There was no significant correlation between the total Mg uptake and the Mg:Ca ratio (Table 19).

Plant Mg contents usually decreases as the exchangeable Ca/Mg ratio increases which implies that under certain circumstances addition of Ca to correct soil acidity may induce Mg deficiency (Salmon, 1963).

Many workers have reported that yields of crops were not affected by the wide range in Mg:Ca ratio. The necessity of maintaining any definite ratios for better plant growth has thus been questioned. Some other workers on the other hand have shown that low ration of Mg to Ca in soil or liming may induce Mg deficiency (Reith,1963; and Moehansyah, 1977).

By way of summary, it may be said that, uptake of Mg by plants in the soils of northern Nigeria depends largely on the available Mg status which is influenced by organic matter and clay contents of the soil in that order.

(d) Magnesium content of field grown tobacco

The Mg content of the upper and lower leaves of field grown tobacco (sampled at the same time as the soil profile were sampled) averaged 0.22% and 0.31% respectively (Table 21) with an overall mean value of 0.26% which may be considered fairly low since the normal tobacco plant may contain up to 0.66% Mg in the leaves (Carner, 1951). Cognizance must of course be taken of varietal differences and the general biomass production level of the crop in question. For instance McEvey (1954) considered 0.41 to 0.47 per cent magnesium in the top leaves and 0.57 to 0.60 per cent in the lower leaves to be within deficiency range. Garner (1951) reported that field grown tobacco plants generally contain about 0.24 to 0.90 per cent magnesium. Reith (1963) stated that plant tissue magnesium content of between 0.15 and 0.50 per cent was necessary for efficient photosynthetic activity. Critical values ranging from 0.15 to 0.25 per cent were given by Chapman et al., (1966b).

The soil Mg, K and Ca contents of the same locations averaged 0.94 ± 0.44; 0.20 ± 0.15 and 2.61 ± 1.44 meq/100g respectively. The tobacco Mg content of these locations averaged 0.26 ± 0.10% (Table 21), showing a very narrow range of plant Mg content (0.25 - 0.27%) while the soil Mg contents showed a

Table 21. Magnesium, potassium and calcium contents of tobacco leaves grown in farmers' fields

	Mg %	K %	Ca %
Upper leaves	0.218 ± 0.062	2.114 ± 0.890	0.532 ± 0.373
Lower leaves	0.312 ± 0.137	1.832 ± 1.000	1.037 ± 0.563
Mean	0.265 ± 0.102	1.973 ± 0.829	0.788 ± 0.413



correspondingly wide range (0.50 - 1.38 meq/100g). This may explain the absence of a significant statistical correlation between the Mg content of those soils and the Mg content of the tobacco plants grown on them under the field conditions. It is apparent that leaf analysis under this condition reflects the conditions of uptake rather than the soil content of that element. Therefore it is suggested that the magnesium status of the soil may not be the only factor controlling Mg uptake by tobacco plants under field condition.

4.3 FIELD STUDIES

Three field experiments were carried out to study the response of tobacco to Mg application under field conditions. The chemical and physical properties of the soils at the three sites are presented in Table 22.

Soil at site I (Maigana, upland) was an acidic silty loam (pH 4.4 in water) low in both organic matter (0.58%) and CEC (3.86 meq/100g) with low nutrient status particularly Mg and K (0.55 and 0.14 meq/100g respectively). Organic matter decreased with depth from 0.55% in the 0-40cm layer to 0.33% in the 40-80 cm layer. This may be explained by the annual additions of plant residues in the top soil as well as the decomposition of plant roots in the top layer. Clay illuviation from the surface soil to the subsoil was evident. This was probably responsible for the increase in Mg and Ca contents (and to a lesser extent K) with soil depth.

Soil properties at site II (Maigana, lowland) were influenced by seasonal water logging typical of a low level area. The general characteristics of hydromorphic soils in northern Nigeria have been outlined by D'Hoore (1964) and Klinkenberg and Higgins (1968). The soil at the representative selected in the present study considered a typical example, was an acid (pH 4.5 in water) silty loam; low in organic matter (0.72%) and

Table 22: Chemical and physical properties of the sites used in the field experiments

Expt.	Location	Depth (cm)	pH water	pH $CaCl_2$	Organic matter %	CEC	Mg meq	Ca 100g	K	Mg/K	Mg/Ca	Mg+Ca/K	% Mg Sat. of CEC	Sand %	Silt %	Clay %	Textural Class
1	Maigana upland	0 - 20	4.4	3.3	0.58	3.86	0.55	1.06	0.14	3.93	0.52	11.50	14	49.2	35.4	15.4	Silty loam
		20 - 40	4.5	3.7	0.52	6.98	1.17	2.04	0.14	8.36	0.57	22.93	17	31.2	22.4	46.4	Clay
		40 - 60	5.1	3.8	0.39	7.40	1.90	3.46	0.26	7.31	0.55	20.62	26	31.2	22.4	46.4	Clay
		60 - 80	5.1	4.3	0.27	7.65	1.90	3.50	0.26	7.31	0.54	20.77	25	35.2	22.4	42.4	Clay
2	Maigana lowland	0 - 20	4.5	4.0	0.72	5.13	0.69	2.04	0.21	3.28	0.34	13.00	13	45.2	36.4	18.4	Silty loam
		20 - 40	4.4	3.7	0.54	6.87	0.92	3.45	0.26	3.54	0.27	16.00	13	33.4	28.4	38.4	Silty clay
		40 - 60	4.8	3.7	0.30	6.22	0.89	3.75	0.27	3.29	0.24	17.18	14.	25.2	32.4	42.4	Silty loam
		60 - 80	4.8	3.9	0.30	6.42	0.82	3.53	0.24	3.42	0.23	18.13	13	31.2	26.4	42.4	Silty clay
3	Kano	0 - 20	4.7	4.3	0.20	3.44	0.42	1.30	0.27	1.56	0.32	6.37	12	75.2	14.4	10.4	Sandy loam
		20 - 40	5.1	4.3	0.19	6.88	0.72	2.10	0.26	2.77	0.34	10.85	10	67.2	10.4	22.4	Clay loam
		40 - 60	4.8	4.2	0.17	5.96	0.94	2.45	0.16	5.88	0.38	21.19	16	72.2	10.4	19.4	Sandy loam
		60 - 80	4.9	3.7	0.17	4.30	0.61	1.56	0.08	7.63	0.39	27.13	14	72.2	10.4	19.4	Sandy loam

exchangeable cations. The surface soil contents of Mg, Ca and K were 0.69; 2.04; and 0.21 meq/100g respectively. The organic matter level decreased while the clay increased with depth. However, the CEC; Mg and K tended to increase slightly with soil depth.

The third site (Kano) was characterized by an acid (pH 4.7 in water) sandy loam, very low organic matter content (0.20%) and low nutrient status. The surface soil contained 0.42; 1.30 and 0.27 meq/100g of Mg, Ca and K respectively. Movement of clay from the surface to the subsoil was evident, though the clay contents of all the depths were generally low. Organic matter tended to decrease with depth while exchangeable Mg and Ca tended to increase slightly.

The effects of Mg on plant growth, leaf yield, leaf components and quality were investigated. The interactions of Mg and K with all these parameters were also considered.

(a) EFFECT OF MAGNESIUM AND POTASSIUM APPLICATION ON THE AGRONOMIC PERFORMANCE OF TOBACCO

Effects of magnesium and potassiuma application on tobacco were evaluated by measuring the plant height, leaf area, stem dry weight and leaf yield.

a.1) Plant height:

The effect of magnesium on plant height (Table 23) was highly significant in the first (Maigana upland) and second (Maigana lowland) experiments. However the applicatiom of higher rates than 24 kg Mg/ha did not show any further significant increase. In the third experiment (Kano) the Mg effect was not significant. This was probably due to the restricted growth resulting from inadequate rainfall. Records of the rainfall at this site showed a total amount of 560.4 mm with a very poor distribution. Negligible amounts of 8.0, 56,1 and 89.7 mm fell in April, May and June respectively compared with corresponding amounts of 47.2; 168.9 and 59.1 at the site of the first experiment. Rainfall recorded in July and August were comparatively low and amounted to 176.6 and 152.8 mm respectively compared with the fairly distributed amounts of 223.7 and 207.5 mm at the site of the first experiment. With the noticeable decline in the two sitow in September, there was no rainfall in the site of the third experiment in October (Table 2). This view is supported by the data presented

Table 23. Effect of Mg and K application on plant height

Treatment	Plant Height (cm)		
	Maigana upland	Maigana lowland	Kano
Mg kg/ha			
0	102.8	88.7	64.
24	117.3	96.9	67.7
48	121.0	101.3	65.0
72	118.6	95.9	64.0
L.S.D.	7.4**	5.9**	N.S.
K kg/ha			
0	113.4	91.6	61.6
41.5	119.4	98.3	66.4
83.0	112.0	97.2	67.7
L.S.D.	N.S.	N.S.	N.S.

in Table 23 which show that the average height of plants of the third experiment was much lower (65.18cm) than the corresponding averages for the first and second experiments (114.9 and 95.69 respectively). With enormous leaf development and rapid growth rate, tobacco is generally rated as a high - Mg demanding crop (Adams and Pearson, 1967). Under the favourable growth conditions (fertility and rainfall) for tobacco in the first and second experiments it seemed that the rate of Mg uptake by the plant was much higher than the rate of replenishment and as a result, there was some response to the first rate of Mg application. Beside its function in the chlorophyl molecule, magnesium plays a significant role in cell division and development (Sparge, 1964 and Tisdale and Nelson, 1975). Nitrogen metabolism is also influenced by Mg nutrition (Haeder and Mengel, 1969). These explain the physiological effect of Mg on the plant height and thus on plant growth.

Potassium application did not significantly affect the plant height though the soil contents at the three sites were considered low (0.14; 0.21 and 0.27 meq/100g respectively). There was no evidence of any significant Mg x K interaction suggesting that each factor acted independently.

a.2) Leaf area

The application of 24 kg/ha of Mg increased leaf area significantly at sites I and II but, higher rates of magnesium did not show any further significant effect, (Table 24). The increase in the leaf area of tobacco plants may have been due to the well known role of Mg in the formation of chlorophyl, (Neales, 1956). Besides, nitrogen metabolism (Haeder and Mengel, 1969), the assimilation of CO_2, and subsequently the plant metabolism are affected by Mg nutrition (Mengel and Kirkby, 1979). The growth habit of tobacco plant and its high Mg requirement stand as sufficient explanation to the observed increase in the leaf area of tobacco in these soils that contain 0.55 and 0.69 meq Mg/100 of soil.

Application of K at 41.5 and 83 kg/ha significantly increased the leaf area in the three experiments. This was not unexpected since these soils are generally low in K (0.14, 0.21 and 0.27 meq/100g respectively). The critical level of K in the soil was given by Mengel and Kirkby (1979) as 0.21 meq/100g soil. Potassium plays an essential role in protein synthesis, growth rate and supply of cytokinins (Jacoby et al., 1972) which stimulate the protein synthesis and growth rate (Ilan, 1971). Potassium also plays a significant role in stomatal opening and closing (Humble and Hsiao, 1969). Therefore the increase in the leaf area of tobacco in these soils was expected.

Table 24 Leaf area of tobacco plants as influenced by magnesium and potassium application

Treatment	Leaf area (cm^2/plant)		
	Maigana upland	Maigana lowland	Kano
Mg Kg/ha			
0	18,816.25	20,319.17	11,357.11
24	25,565.50	23,616.67	14,306.22
48	25,830.83	24,703.33	13,031.89
72	23,828.83	23,120.83	12,431.56
L.S.D.	1,746.00**	1,710.00**	N.S.
K kg/ha			
0	21,466.00	20,967.50	10,792.33
41.5	24,355.00	23,638.00	13,450.33
83.0	24,768.00	24,215.00	14,102.42
L.S.D.	1,512.00**	1,481.00**	2,485.00**

The K x Mg interaction was again not significant.

a.3) Stem-dry weight

The application of magnesium increased the stem dry weight significantly in the first experiment at the first rate after which there was no further appreciable response. In the second and third experiments Mg effect was not significant, though a trend of response was more evident in the second experiment than in the third. Combined analysis of the data showed that Mg application did not seem to affect the stem dry weight significantly.

Potassium application significantly increased stem dry weight in the first and second experiments (Table 25). In the third experiment, the application of 41.5 kg/ha increased the stem dry weight but this response did not attain statistical significance; however, a significant response was observed at 83 kg/ha. Combined analysis of the data from the three experiments showed that 41.5 kg K/ha significantly increased stem dry weight. This is not unexpected considering that the soils are generally low in K. However higher rates had no significant effect.

Table 25 Stem dry weight of tobacco plants as influenced by magnesium and potassium application

Treatment	Stem dry weight (g)			Average
	Maigana upland	Maigana lowland	Kano	
Mg kg/ha				
0	108.52	103.76	68.30	93.53
24	144.63	101.33	74.02	106.66
48	158.13	111.50	61.04	110.19
72	134.24	109.18	75.71	106.38
L.S.D.	22.02**	N.S.	N.S.	N.S.
K kg/ha				
0	128.13	95.55	56.32	93.33
41.5	160.18	118.35	70.65	116.39
83.0	120.76	105.44	83.33	102.84
L.S.D.	19.07**	10.64**	19.37*	16.02*

a.4) Leaf yield:

The total leaf production of a tobacco crop constitutes the most important parameter for measuring the success or failure of the crop. The effect of most fertility treatments are therefore usually measured in terms of their effect on leaf yield and quality.

In the preeent investigation 24 kg/ha of applied Mg significantly increased total leaf production at two sites (Maigana upland and Maigana lowland) and there was no significant response attained beyond the first rate of applied Mg. At these two sites application of 72 kg/ha Mg depressed yield (Table 26). This depression attaining statistical significance at site I, (Maigana upland). Based on the soil test values, the available Mg levels at the three sites may be regarded low to medium (ranging from 0.42 meq/100g to 0.69 meq/100g). Critical levels of Mg of about 0.2 meq/100g to 0.42 meq/100g have been given by many workers (Brycott and Durrant, 1971 : Doll and Lucas, 1973 and Krstic et al., (1981). However, higher value of 0.6 meq/100g was given by Sato et al., (1958) for tree crops and 0.5 meq/100g was suggested by Seo (1957). Yamasaki et al., (1956) reported that plants growing on soils having 0.5 to 1.0 meq of exchangeable Mg per 100g of soil showed Mg deficiency symptoms when available K was excessive.

Table 26 Yield of tobacco leaves as influenced by magnesium and potassium fertilizer

Treatment	Yield of leaves (kg/ha)			Average
	Maigana upland	Maigana lowland	Kano	
Mg kg/ha				
0	2434	2721	1710	2288
24	3644	3506	1825	2992
48	3945	3693	1590	3076
72	3223	3446	2117	2929
L.S.D.	496**	380**	N.S.	460**
K kg/ha				
0	2799	3072	1403	2424
41.5	3686	3467	1816	2989
83.0	3451	3483	2212	3049
L.S.D.	429.0**	329**	424**	398**

Compared with the above values at which Mg response is generally expected, the greatest probability of response would have been at site III (Kano) with 0.42 meq/100g exchangeable Mg. But paradoxically, this was the site at which no response to Mg was obtained. It would seem therefore that there must be some other factor accounting for the response attained other than the soil Mg level per se. The high rate of growth and the tremendous increase in the leaf area observed in sites I and II (Maigana upland and lowland respectively) compared with that of the third site, may lend some support to the view, that the plant uptake in these two sites was higher than what the soil could release. As a result a noticeable response was evident at the first rate of applied Mg in these two sites. The soils of site I and II were silty loam with high percentage of clay + silt (50.8 and 54.8% respectively) compared with the sandy loam soil (24.8% clay + silt) of the third site. These differences in soil texture may have contributed to changes in the plant uptake and thus the leaf yield responses in the first two sites.

Significant yield response was obtained to K at all three sites but beyond 41.5 kg K/ha, further yield increase was not significant. Based on the results obtained in this study, it would appear that the soils included in the study are generally deficient in K at

least for tobacco (Table 22). Further work is needed to verify this but it seems reasonable to speculate that potash deficiency may become a limiting factor for tobacco production in northern Nigeria in no distant future. Potash response has been reported in cotton (Lombin and Mustafa, 1981) and groundnuts 1983) in several areas of northern Nigeria.

Though the leaf yield was apparently influenced by Mg and K applications, the two elements acted independently.

(b) EFFECT OF MAGNESIUM AND POTASSIUM ON THE CHEMICAL COMPOSITION AND QUALITY OF TOBACCO LEAVES

b.1) Magnesium

The survey conducted in the farmers' tobacco farms showed that leaf Mg content of the tobacco grown in the area under investigation was low (0.26%). A normal tobacco plant contains 0.66% Mg in the leaves and when the Mg content is less than 0.24% deficiency symptoms are expected (Garner, 1951).

In this investigation Mg application consistently increased Mg concentration of plant tissue, the increase attaining statistical significance with the upper leaves in experiment I (Maigana upland) and the lower leaves in experiment III (Kano). However this trend was not clear in experiment II (Table 27). The increase in leaf Mg concentration in the third experiment was significant in the lower leaves while that of the upper leaves was not. This was probably associated with the retardation of growth which discouraged the movement of the absorbed element to the younger leaves.

Normally the lower leaves contain higher concentration of Mg than the upper leaves. As a mobile element in the plant, magnesium migrates from the old leaves (provided that they have not entered the maturity stage) to younger leaves to meet the high demand

Table 27 Magnesium content of tobacco leaves as influenced by magnesium and potassium application

Treatments	Maigana upland			Maigana lowland			Kano		
	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean
				M A G N E S I U M %					
Mg (kg/ha)									
0	0.380	0.238	0.309	0.380	0.266	0.323	0.767	0.420	0.594
24	0.349	0.254	0.302	0.354	0.284	0.319	0.863	0.406	0.635
48	0.454	0.335	0.395	0.350	0.270	0.310	1.019	0.438	0.729
72	0.407	0.418	0.413	0.360	0.262	0.311	0.931	0.422	0.677
L.S.D.	N.S.	0.084^{++}	0.049^{++}	N.S.	N.S.	N.S.	0.166^{++}	N.S.	0.079^{++}
K (kg/ha)									
0	0.310	0.331	0.320	0.346	0.267	0.307	0.915	0.450	0.683
41.5	0.421	0.262	0.342	0.374	0.277	0.326	0.890	0.405	0.648
83.0	0.460	0.342	0.401	0.362	0.267	0.315	0.880	0.410	0.645
L.S.D.	0.091^{++}	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.026^{++}	N.S.

associated with the greater physiological activity of the younger tissue most especially when the rate of growth is high or when the soil is low in Mg. These probably explain the increase in Mg content of the upper leaves in the first experiment.

The amount of Mg taken up by tobacco generally increased with the application of Mg (Table 28), the apparent lack of changes in Mg concentration in the leaves in some cases could be attributed to the dilution effect.

The effect of magnesium content of tobacco leaves on their quality seems to be a controversial issue. Garner et al., (1923) reported that quality of tobacco leaf was affected badly by Mg deficiency as the leaf lacked weight, body, colour and elasticity. The ash from such leaf was dark coloured. Breland and Fritchet (1956) reported that an increase in the amount of magnesium in the leaf decreased the rate of burn of cigar tobacco. Tanconge and Chouteau (1979) reported that application of Mg increased tobacco Mg content and improved the combustibility. On the contrary, Elliot and Birch (1958) reported that leaf Mg has a negative relationship to tobacco quality and there was no direct evidence that this element has any influence on quality. Evaluation of leaf quality of tobacco in most parts of the world depends mainly on chance classification which is not normally related to the internal

Table 28. Estimated amounts of magnesium in the tobacco leaves in kg/ha

Treatment	Magnesium (K/ha)		
	Maigana upland	Maigana lowland	Kano
Mg (kg/ha)			
0	7.50	8.79	10.15
24	10.96	11.19	11.58
48	15.57	11.45	11.58
72	13.30	10.71	14.32

S.D. = 2.21

content but mainly to physical properties of the leaf. But with the introduction of high-yielding, disease resistant varieties and new cultural practices coupled with the advancement in analytical techniques, the evaluation of tobacco leaf quality can no longer rely on the external characteristics of the leaves which lack objective principles and are still preserved only within the professional caste. Various ratios of chemical constituents are being proposed from time to time as indices of leaf quality but none of them has proved to be standard since the behaviour of tobacco leaf is the result of numerous interactions between a large number of compounds and picking out a small number to express their relationship as a general quality index is only likely to be of limited local usefulness. Chemical analysis could be useful only when acceptable standards are established on correlation between the available empirical knowledge with the chemical, physical and physiological behaviour of tobacco as a plant. Once these standards are established for an area any deviations from them may be detected and steps be taken to effect improvements through altered growing techniques (Akehurst 1971). In the absence of such acceptable standards, investigators' hands are tied to only the description of the influence of a treatment or treatments on the chemical composition on the leaf as a stage of more intensive research to be followed in that

line. The influence of magnesium application on the magnesium content of tobacco leaves described above is a step in this direction. The survey carried out in this study showed that tobacco grown plants were generally low in Mg and so Mg fertilization may be viewed as a way of improving the tobacco leaf quality.

The magnesium content of the leaves of the plant as a whole was not significantly affected by the application of potassium (Table 27). However, in the third experiment where the crop appeared to have suffered some moisture stress during the growing season, the application of potassium significantly decreased the magnesium content of the upper leaves. This finding agreed with the negative response reported by Hutcheson et al., (1959) between the potassium supply and the accumulation of Mg in the upper leaves of tobacco. There was insignificant effect of potassium application on Mg content of the lower leaves; however, there was a trend of decrease with successive application of potassium. This result suggests some antagonistic relationship between these two elements in the light textured soil of this site under a moisture stress condition. This may explain the lack of yield response to Mg application in this experiment which was explained earlier.

In summary, there was generally a trend of increase in leaf Mg content due to the application of Mg. Changes in Mg content of upper and lower leaves due to Mg application did not follow any specific or regular pattern which is believed to be as a result of the effect of other factors that normally control the migration and accumulation of nutrients in different parts of the plant, one of such factors being the rate and pattern of plant growth.

Since the Mg content of tobacco leaves in the area under investigation was generally low (averaging 0.26%). and the application of Mg tended to increase its content in plant tissues it would seem that Mg application on these soils may increase the plant tissue Mg content and subseqnently improve the leaf quality of tobacco. A certain percentage of Mg in the leaf appeared to be essential for satisfactory combustion. For example, in cigar, the optimum is nearly 2%. More than 2% Mg decreased combustibility and made burning less uniform (Tso, 1972). Considering this along with the evidence that Mg also increased the leaf yield it would rather suggest that application of Mg could possibly increase the yield and improve the leaf quality of tobacco in these soils.=

b.2) Calcium

Application of Mg did not affect the leaf Ca content of the plant as a whole. The soils are generally low in both Ca and Mg. Reith (1963), reported that crops grew satisfactorily when exchangeable Mg and Ca were both small but became Mg deficient when Ca was increased by liming. There was also no significant effect of K on the Ca content of the leaves (Table 29).

Changes in Ca content in upper or lower leaves with the application of Mg or K which were noticed in some cases in Table 29 could not be attributed to any antagonism or association between any of these two elements on one hand and Ca on the other. Calcium is known to be an immobile element in the plant and these changes in the plant tissue may be due to physiological disorder in the plant rather than the application of Mg and or K to these soils. A similar view was reported by Salmon (1963). Combined analysis of the data also did not show any interaction effect between both Mg and K on the concentration of Ca in the plant leaves. It would, therefore, be stated that under the conditions of these experiments, Mg and K application had no significant effect on the Ca content of tobacco leaves. It has been reported that deficiency systems manifest themselves when Ca content of the tobacco leaves fall below 0.21 - 0.21% (I.C.T.A., 1960). The leaf Ca content in this

Table 29 Calcium content of tobacco leaves as influenced by magnesium and potassium application

Treatment	Maigandi Upland			Maigana lowland			Kano		
	Lower leaves	Upper leaves	Mean	Lower Leaves	Upper Leaves	Mean	Lower leaves	Upper leaves	Mean
				Calcium %					
Mg (kg/ha)									
0	1.474	0.490	0.982	0.994	0.532	0.763	2.985	1.091	2.038
24	1.037	0.563	0.800	0.891	0.592	0.742	3.154	0.872	2.013
48	1.435	0.688	1.062	0.939	0.555	0.747	2.976	1.129	2.053
72	0.974	0.653	0.814	0.995	0.513	0.754	3.159	1.075	2.117
L.S.D.	0.433^{+}	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.14^{++}	N.S.
K (kg/ha)									
0	0.875	0.654	0.765	0.895	0.519	0.707	2.947	1.127	2.037
41.5	1.247	0.505	0.876	0.990	0.576	0.783	2.991	1.043	2.017
83.0	1.568	0.636	1.102	0.979	0.549	0.764	3.268	0.955	2.112
L.S.D.	0.375^{++}	N.S.	N.S.	N.S.	N.S.	0.053^{+}	N.S.	0.122	N.S.

study ranged from 0.74 to 2.12%.

b.3) Potassium

Application of magnesium did not significantly affect the potassium content of the tobacco leaves (Table 30). These findings are not in full agreement with those of Tanconge and Chouteau, (1979) who reported that Mg application slightly decreased the potassium content of tobacco leaves. Only in the third experiment where the soil was light lextured did the application of Mg decrease the K content of the leaves significantly. It appears, however, that Mg does not seem to have any strong antagonistic effect on potassium. Potassium is taken up actively, that is, enters the plant cells by facilitated diffusion that favours its uptake when compared with divalent cations.

Potassium application significantly increased the K content of tobacco leaves. The soils are generally low in K (0.14 - 0.27 meq/100g). An application of K to a soil so low in K would be expected to increase K content in the leaves. The apparent lack of effect of K application on the concentration of tobacco leaves in the first experiment may not necessarily mean the plant uptake of that element was not affected, rather, it was probably a result of the vigorous plant growth which tended to reduce the percentage of K content of the leaves.

Table 30: Potassium content of tobacco leaves as influenced by magnesium and potassium application

Treatments	Maigana upland			Maigana lowland			Kano		
	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean
Mg (kg/ha)				Potassium %					
0	3.748	3.797	3.773	1.358	1.567	1.463	2.548	3.947	3.248
24	3.629	3.865	3.747	1.469	1.614	1.542	2.578	4.166	3.372
48	3.340	4.156	3.748	1.497	1.593	1.345	1.594	3.759	2.677
72	3.698	4.025	3.862	1.427	1.582	1.505	2.038	2.838	2.939
L.S.D.	N.S..	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	0.495^{+}
K (kg/ha)									
0	3.342	3.936	3.639	1.303	1.515	1.409	1.074	3.723	2.399
41.5	3.861	3.977	3.919	1.535	1.671	1.603	2.422	3.816	3.119
83.0	3.608	3.970	3.789	1.474	1.581	1.528	3.072	4.244	3.658
L.S.D.	N.S.	N.S.	N.S.	0.147^{++}	0.116^{+}	0.094^{++}	0.840^{++}	0.356^{++}	3.429^{++}

Takahashi and Yoshida (1958), found that by increasing the supply of potassium in the culture solution, the content of the element increased in the tobacco plants but magnesium content decreased.

Tobacco leaves containing as much as 8% potassium on the dry weight basis have been reported to show symptoms of potassium deficiency when the content falls below 3%. Potassium is preferentially transported to young meristematic tissues. Data presented in table 30, illustrate that tendency. Where the plants were deficient in K the highest concentration of this nutrient was in the upper leaves and where the plants were sufficiently supplied with K, the highest concentration was in the lower leaves.

Published data suggest that tobacco quality may continue to improve as a result of additional rates of potassium beyond those needed for maximum growth (McCants and Woltz, 1967). Other workers have shown that tobacco leaf quality depends on the balance of the nutrients in the leaf (Nessler, 1867; Attoe, 1942; Johsnon and Attoe, 1944; and Sastry and Karup, 1957) and the most important and very noticeable K effect on tobacco quality is its positive influence on burning

capacity. Tobacco leaf from which potassium has been leached will not burn. Furthermore, it has the ability to counteract the deleterious effect on burning of some other elements notably chlorine (Akehurst, 1971).

Analysis of data did not show any interaction of Mg and K on the content of tobacco leaves. This indicates that each element acted independently.

(4) Nicotine

The effect of magnesium on the nicotine contents of tobacco leaves was generally not significant (Table 31). Nicotine is produced only on the growing root tip and its production is closely related to the rate of root growth (Wolf and Bates, 1964). This relationship partly explains the influence of dry weather, that stimulate the root growth, in increasing plant nicotine. Data in Table 31 show also that the nicotine content of both upper and lower leaves were also not affected by the application of potassium. The interaction of Mg and K on the nicotine of tobacco leaves was also not significant.

It may be concluded that no desirable changes in the nicotine content of the tobacco leaves are likely to be achieved by the application of either magnesium or potassium.

Table 31: Nicotine content of tobacco leaves as influenced by magnesium and potassium application

Treatments	Maigana upland			Maigana lowland			Kano		
	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean
Mg (kg/ha)				Nicotine %					
0	2.078	1.300	1.689	2.017	1.122	1.570	2.990	0.833	1.912
24	1.763	1.050	1.400	1.910	0.977	1.444	2.460	0.738	1.599
48	2.073	1.163	1.618	1.898	1.062	1.480	2.620	0.853	1.737
72	1.832	1.088	1.470	2.050	1.120	1.585	2.520	0.678	1.599
L.S.D.	0.243+	-	-	-	-	-	-	-	-
K (kg/ha)									
0	1.850	1.086	1.468	1.969	1.153	1.561	2.890	0.830	1.860
41.5	1.953	1.004	1.479	1.823	1.004	1.414	2.675	0.800	1.738
83.0	2.024	1.361	1.693	2.115	1.054	1.585	2.380	0.700	1.540
L.S.D.	-	-	-	-	-	-	-	-	-

The nicotine content of tobacco grown in these experiments ranged from 1.4 to 1.91% (Table 31), which may be considered moderate compared with the level reported in other places in the world. For example Indian General Tobacco Committee (1960) working in India reported a nicotine content of 1.0 - 2.0% in cigarette tobacco and 1.75% in American flue-cured tobacco. The desirable nicotine content of a variety performing under average conditions was given as around 2.25% in the cured leaf (Akehurst, 1971). However, nicotine content differs with the type of tobacco and varied with figures as low as 1.05% in Turkish tobacco to 1.27; 1.93; and 2.91% in Maryland, American flue-cured and air-cured tobacco (Burley) respectively (Akehurst, 1971). Nicotine content is also influenced to a large extent by agricultural practices and the supply of nitrogen. With increased supply of nitrogen in the soil by manuring, the nicotine content increased to over 8% in some cases (I.C.T.C., 1960).

b.5) Nitrogen Content

Magnesium and potassium application did not significantly affect nitrogen concentration in plant tissue (Table 32). The leaf nitrogen concentration averaged 2.46 and 2.20% at Maigana upland and lowland sites respectively which fall within the normal range of 2.00 to 5.00% considered adequate for normal plant growth (Garner, 1951). Values of 1 - 2% N in tobacco

Table 32 Total nitrogen content of tobacco leaves as influences by magnesium and potassium application

Treatments	Maigana upland			Maigana lowland		
	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean
			Total nitrogen %			
Mg (kg/ha)						
0	1.642	3.389	2.515	0.962	4.027	2.495
24	1.402	3.465	2.433	0.957	3.222	2.090
48	1.500	3.232	2.366	0.908	3.733	2.321
72	1.373	3.673	2.523	0.700	3.060	1.880
L.S.D.	N.S.	N.S.	N.S.	N.S.	N.S.	0.499+
K (kg/ha)						
0	1.436	3.548	2.493	0.951	3.139	2.045
41.5	1.383	3.813	2.598	0.925	3.575	2.250
83.0	1.618	2.959	2.289	0.769	3.818	2.294
L.S.D.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

leaves are considered low (I.C.T.C., 1960 , Akehurst, 1971).

As with K, nitrogen content of the upper leaves was much higher than that of the lower leaves, suggesting that most of its is concentrated in the actively growing tissue. Nitrogen is vital for leaf and plant development but an excess can ruin quality. It is a constituent of nicotine which gives tobacco its strength.

The interaction effect of magnesium and potassium on leaf nitrogen content was also not significant in these experiments.

b.6) Reducing sugar

Carbohydrates are the most reactive organic constituent of tobacco. Reducing sugars form an important part of the reserve of carbohydrates that enter into cell metabolism. The sugar:nicotine ratio is frequently used as a basis for evaluation relating to strength or smoothness of tobacco. (Tso, 1972). However, this ratio depends on the type of tobacco. The cigarette types are rich in carbohydrates and poor in nitrogenous constituents while the reverse is true in cigar tobacco. In tobacco the reducing sugars consist chiefly of glucose and fructose. Their concentration in the leaves vary between fairly wide limits in response to weather conditions, age of leaf and its position on the stalk. The data in Table 33 indicate that the effect of Mg on reducing sugar content is inconsistent although

Table 33 Reducing sugar content of tobacco leaves as influenced by magnesium and potassium application

	Maigana upland			Maigana lowland			Kano		
Treatments	Lower leaves	Upper leaves	Mean	Lower leaves	Upper leaves	Mean	Lower Leaves	Upper Leaves	Mean
Mg (Kg/ha)				Reducing sugar %					
0	1.233	4.233	2.733	2.300	1.500	1.900	0.817	0.900	0.859
24	1.250	4.100	2.675	2.267	1.433	1.850	0.750	0.880	0.815
48	1.333	3.067	2.200	2.100	1.433	1.767	0.817	0.970	0.894
72	1.217	2.7500	1.983	2.217	1.217	1.717	0.767	0.780	0.774
L.S.D.	N.S.	1.068^{+}	0.556^{+}	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
K (kg/ha)									
0	1.538	3.412	2.475	2.150	1.568	1.859	0.962	0.790	0.876
41.5	1.188	3.337	2.263	2.100	1.425	1.763	0.737	0.860	0.799
83.0	1.050	3.862	2.456	2.413	1.2000	1.806	0.662	1.000	0.831
L.S.D.	0.197^{++}	N.S.	N.S.	N.S.	N.S.	N.S.	0.1302^{++}	N.S.	N.S.

there was a slight decrease with increasing rate of Mg application. Similarly, the application of K did not affect the leaf content of reducing sugars significantly. However, there was also a trend of a slight idecrease with increasing rate of applied potassium. The slight decrease in the reducing sugar content with increasing rates of Mg may be attributed to increased plant growth which probably resulted in greater use of reducing sugar.

The sugar contents of tobacco leaves ranged from 0.78 to 4.23 per cent (Table 33). These are relatively low compared with the range of 5 to 16 per cent reported by I.C.T.C. (1960) for Indian Tobacco. Further investigations are probably required on how to improve the sugar content level of the tobacco grown in this area since reducing sugar is considered to be one of the quality promoting substances for all types of tobacco. A high level of reducing sugar is considered desirable provided it does not exceed 22% (Tso, 1972).

The effect of Mg and K and their interaction on agronomic performance, chemical composition and quality of tobacco leaves could be summarized as follows:

Growth of tobacco plants in these soils was greatly improved by Mg application which significantly increased the plant height, and the leaf area with a trend of increase of the stem dry weight. As a result

leaf yield was significantly increased. It was apparent that the highest response was associated with the application of 24 kg Mg/ha and further application did not make any appreciable change.

There was a trend of increase in Mg leaf content which was more pronounced in the light textured soils. Total Mg uptake of tobacco plants was significantly increased with the application of Mg. This increase in leaf Mg content is very desirable, since the leaf Mg content of tobacco grown in the area under investigation is considered to be low. Such increase is essential for the improvement of the leaf quality of the tobacco grown in this area. The tobacco leaf contents of calcium, potassium, nicotine and nitrogen were not significantly affected by Mg application. Magnesium application did not significantly affect the reducing sugar content of tobacco leaves but there was a slight trend of decrease with increasing rates of Mg application.

Potassium application increased the potassium content of the tobacco leaves significantly but did not significantly affect the leaf content of magnesium, calcium, nicotine, reducing sugar and total nitrogen.

There was generally no interactive effect of Mg and K on any of the chemical component of tobacco leaves consid-

CONCLUSIONS

One of the most important tools in modern agriculture is effective use of dependable soil test methods. In the west African savannah region, concerted effort is now being directed towards involving reliable soil test procedures to help in evaluating the productive potential of the soils.

As part of the present study, six soil analytical procedures for plant available Mg (repeated and single extraction with NH_4OAc; 0.01M $CaCl_2$ and 0.05M $CaCl_2$) were evaluated using greenhouse cropping. The results showed that the various methods extracted significantly differing amounts of soil Mg. Increasing the extraction time and the concentration of the extractants tended to extract more Mg than shaking once for a shorter time. From the correlation coefficients between the Mg taken up by plant and that extracted by each method, all methods appeared satisfactory. However, considering other related factors such as laboratory convenience, availability of equipment and chemicals, time saving factor, and above all, the degree of accuracy required, repeated extraction and single shaking with ammonium acetate were considered equally suitable and recommendable. However, single extraction with ammonium acetate was the method used in assessing the Mg status of some selected soils in northern Nigeria.

The mean value of exchangeable Mg of the Sudan Savannah soils (essentially Inceptisols derived from aeolian deposits) was 0.54 meq/100g. Based on the critical level of 0.42 meq/100g reported in the literature, about 52% of the locations within this zone may be considered low in Mg. For the northern Guinea savannah soils (predominantly Alfisols with a small proportion of Ultisols), the mean exchangeable Mg value was 0.96 meq/100g while that of the southern Guinea savannah soils (predominantly Ultisols and Oxisols) was 0.56 meq/100g. The lower Mg contents of the Sudan and southern Guinea savannah were probably connected with the lower content of soil organic matter at the former and the pronounced high leaching at the latter. The relatively higher Mg content of northern Guinea savannah zone soils may be attributed to a combined effect of relatively high level of organic matter and lower leaching intensity.

A detailed soil profile examination of Mg status and distribution showed evidence of Mg leaching from the top soil and its accumulation mainly at the 20 - 60cm depths. It would seem that in northern Nigeria the onset of Mg deficiency would first show up in the shallow rooted crops such as groundnut while the deep rooted crops like cotton may be able to benefit from the subsoil Mg and would therefore show such deficiency symptoms much later.

Clay and organic matter are shown to have been the principal factors influencing Mg contents in these soils and since the content of clay in the soil cannot be altered, then the fertility management efforts must be directed at conserving soil organic matter in these soils. Use of crop residue, animal manure under good management practices would help towards maintaining the soil organic matter at satisfactory levels.

The Mg content of tobacco samples taken from farmers' fields averaged 0.26%. The absence of significant correlation between plant and soil Mg contents further confirms the widely held view that the Mg status of the soil may not necessarily be the only factor controlling Mg uptake by crops under field condition. However Mg uptake was found to be largely dependent upon the soil Mg status under greenhouse cropping with a limited volume of soil.

Three field experiments in two cropping seasons were carried out to study the response of tobacco to Mg application and the possible interaction by Mg and K on the crop. Growth of tobacco plants in these soils was greatly improved by Mg application which significantly increased plant height and leaf area while stem dry weight was only slightly increased. As a result leaf yield was significantly increased. The highest response was associated with 24 kg/ha applied Mg and further

application would not effect any noticeable change. There was a tendency for Mg leaf content to increase especially in light textured soil with the application of magnesium. This increase is desirable since the Mg leaf content of tobacco grown in this area is considered to be low. The calcium, potassium, nicotine, nitrogen and reducing sugar of tobacco leaves were not significantly affected while reducing sugar tended to decrease with the application of Mg. Magnesium-potassium interactive effects were not evident on any of the chemical component of tobacco leaves considered. It would seem from the distribition of Mg in the soil profile, that under intensive cropping system coupled with the introduction of high grade fertilizers Mg deficiencies may occur in no distant future.

The above results must be evaluated with caution considering that the field work involved only three sites spread over two seasons. Obviously it will require further field work to permit a firm conclusion to be drawn regarding the nature of response of tobacco to Mg applications in these soils. The present study has however some fundamental information on which future studies can be based.

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APPENDIX TABLES

Appendix Table 1: Some Physical and chemical properties of the surface soils of selected sites of northern Nigeria

Sample No.	Zone	pH		Organic matter %	CEC	K	Ca	Mg	Silt	Clay	Mg:K	Mg:Ca	$\frac{Mg+Ca}{K}$	Mg:CEC
		Water	$CaCl_2$		Meq/100g				%					
1.	Sudan													
1.	Savannah	5.2	6.0	0.33	1.40	0.05	0.53	0.15	5.6	3.6	3.0	0.28	13.60	0.11
2.	"	3.9	4.6	0.24	2.40	0.03	0.20	0.03	5.6	7.6	1.0	0.15	7.67	0.01
3.	"	5.2	6.1	0.64	5.36	0.07	3.25	1.32	3.60	11.6	18.86	0.41	65.29	0.25
4.	"	4.9	5.8	0.29	2.08	0.17	1.23	0.38	11.60	7.6	2.24	0.31	9.47	0.18
5.	"	5.3	5.9	0.56	2.68	0.18	1.32	0.43	11.60	7.6	2.3	0.33	9.72	0.16
6.	"	5.2	6.2	0.33	4.00	0.11	1.00	0.41	13.60	5.6	3.7	0.41	12.82	0.10
7.	"	4.5	5.2	0.17	2.88	0.03	0.25	0.10	7.6	5.6	3.3	0.40	11.67	0.03
8.	"	4.8	6.4	0.22	1.24	0.07	0.58	0.16	1.6	3.6	2.2	0.28	10.57	0.13
9.	"	5.0	5.8	0.22	1.88	0.07	1.44	0.34	7.6	5.6	4.8	0.24	25.43	0.18
10.	"	5.1	5.3	0.24	2.36	0.05	1.08	0.17	5.6	5.6	3.4	0.16	25.00	0.07
11.	"	5.4	5.9	0.34	2.20	0.10	1.28	0.36	13.6	7.6	3.6	0.28	16.40	0.16
12.	"	3.5	4.7	0.49	2.85	0.16	1.00	0.48	6.4	10.4	3.0	0.48	9.25	0.17
13.	"	4.0	5.2	0.74	4.58	0.12	1.80	0.57	38.4	18.4	4.7	0.32	19.75	0.12
14.	"	4.2	4.5	0.80	7.33	0.09	3.45	1.03	34.4	20.4	11.4	0.30	49.78	0.14
15.	"	5.3	6.0	1.15	6.86	0.79	3.65	1.14	42.4	14.4	1.4	0.31	6.06	0.17
16.	"	4.3	4.7	0.20	3.44	0.27	1.30	0.42	14.4	10.4	1.5	0.32	6.37	0.12
17.	"	4.3	4.7	0.19	4.02	0.27	1.30	0.43	14.4	10.4	1.5	0.33	6.41	0.11
18.	"	4.2	5.2	0.40	4.78	0.19	0.75	0.40	7.40	12.4	2.1	0.53	6.05	0.08
19.	"	3.1	3.6	1.71	16.40	0.38	5.15	2.00	20.40	60.4	5.2	0.39	18.82	0.12
20.	Northern Savannah	5.0	5.4	0.55	4.16	0.42	2.07	0.65	41.6	9.6	2.9	0.31	12.36	0.16
21.	"	4.3	4.9	0.83	6.76	0.24	4.10	1.43	37.6	35.6	5.9	0.35	23.04	0.21

Appendix Table 1 (Cont'd)

Sample No.	Zone	pH Water	pH $CaCl_2$	Organic Matter %	CEC Meq/100g	K Meq/100g	Ca Meq/100g	Mg Meq/100g	Silt %	Clay %	Mg:K	Mg:Ca	Mg:Ca / K	Mg:CEC
	Northern													
22.	Savannah	4.6	5.6	0.76	4.60	0.16	1.55	0.58	29.6	13.6	3.6	0.37	13.31	0.13
23.	"	5.3	6.1	0.91	6.64	0.15	3.95	0.93	31.6	15.6	6.2	0.24	35.53	0.14
24.	"	5.2	5.7	1.09	5.68	0.11	1.78	0.58	13.6	11.6	5.2	0.33	21.45	0.10
25.	"	5.9	7.0	0.98	5.58	0.13	1.69	0.87	18.4	20.4	6.9	0.51	19.69	0.16
26.	"	4.0	4.6	0.30	6.58	0.13	1.69	0.87	24.4	20.4	6.6	0.51	19.59	0.13
27.	"	4.0	4.9	0.75	5.71	0.12	2.70	0.99	35.4	31.4	8.2	0.37	30.75	0.17
28.	"	4.6	5.6	0.61	8.09	0.10	2.02	1.00	28.4	34.4	10.00	0.56	30.20	0.12
29.	"	5.3	4.9	0.49	7.19	0.19	3.36	1.02	30.4	23.4	5.37	0.30	23.05	0.14
30.	"	3.9	3.5	0.42	6.50	0.10	1.70	0.77	30.4	30.4	7.70	0.45	24.70	0.12
31	"	4.4	3.3	0.58	3.06	0.14	1.06	0.55	38.4	18.4	3.93	0.52	11.50	0.14
32.	"	4.6	4.0	0.65	7.30	0.15	3.95	1.53	10.6	16.4	10.20	0.39	36.53	0.21
33.	"	4.5	4.0	0.71	6.37	0.21	2.00	1.86	34.4	16.4	8.86	0.93	18.38	0.29
34.	"	6.0	4.7	0.75	7.72	0.15	4.20	1.04	22.4	33.4	6.93	0.25	34.93	0.13
35.	"	4.5	3.8	0.71	7.80	0.14	2.40	0.73	26.4	23.4	5.21	0.30	22.36	0.09
36.	"	5.7	5.0	0.75	7.69	0.36	2.72	0.80	18.4	27.4	2.20	0.29	9.78	0.10
37.	"	4.5	3.8	0.70	8.62	0.11	5.10	1.37	18.4	20.4	12.45	0.27	58.82	0.16
38.	"	5.4	4.9	0.62	7.43	0.21	5.92	1.35	14.4	23.4	6.43	0.23	34.62	0.18
39.	"	5.1	4.1	0.52	4.47	0.09	1.60	0.43	26.4	13.4	4.78	0.27	22.56	0.10
40.	"	4.5	4.0	0.72	6.13	0.21	2.04	0.87	36.4	18.4	4.14	0.43	13.86	0.14
	Southern													
41.	Savannah	5.9	5.4	1.12	3.44	0.07	1.82	0.40	9.60	7.60	5.71	0.22	31.71	0.12
42	"	5.8	5.2	1.34	4.80	0.17	1.89	0.54	11.60	9.60	3.18	0.25	14.29	0.10
43.	"	5.4	4.8	1.86	6.88	0.16	2.00	1.00	15.60	23.60	6.25	0.50	18.75	0.15

Aprendix Table 1 (Cont'd)

Sample	Zone	pH water	pH $CaCl_2$	Organic matter %	CEC	K	Ca	Mg	Silt %	Clay %	Mg:K	Mg:Ca	Mg:Ca / K	Mg:CEC
					Meq. 100g									
44.	Southern savannah	4.7	4.6	1.48	9.08	0.40	2.49	1.27	41.60	29.60	3.18	0.51	9.50	0.14
45.	"	5.7	5.0	0.60	2.72	0.08	0.88	0.29	7.60	9.60	3.63	0.33	14.63	0.11
46.	"	5.9	5.0	1.29	3.44	0.05	1.00	0.34	5.60	7.60	6.80	0.34	26.80	0.10
47.	"	5.6	5.0	0.95	2.72	0.10	1.00	0.43	9.60	9.60	4.30	0.25	21.30	0.16
48.	"	5.1	5.2	0.93	4.28	0.10	1.74	0.63	15.60	11.60	6.30	0.36	23.70	0.15
49.	"	5.1	4.3	0.81	1.56	0.07	0.50	0.12	13.60	7.60	1.71	0.24	8.86	0.08

Appendix Table 3: Magnesium taken up by maize grown in greenhouse in different soils

Soil No.	First Crop Uptake mg/kg soil	Second Crop Uptake mg/kg soil	Third Crop Uptake mg/kg soil	Total Uptake mg/kg soil
1	36.10	24.38	9.60	70.08
2	8.42	13.69	7.22	29.33
3	13.93	6.07	5.49	25.49
4	30.05	14.85	6.04	50.74
5	4.95	4.46	2.69	12.10
6	17.42	5.70	5.69	28.81
7	15.19	7.02	6.75	28.96
8	2.53	8.13	3.71	14.37
9	12.50	4.21	3.67	20.38
10	11.59	16.21	6.39	45.19
11	37.51	14.40	10.11	62.02
12	24.01	16.61	4.55	45.17
13	11.77	4.40	4.34	20.51
14	30.02	25.07	9.36	64.45
15	29.07	32.44	16.58	78.09
16	27.59	15.57	6.23	49.09
17	26.11	12.10	7.06	45.27
18	27.22	23.58	7.05	57.85
19	4.19	-	2.94	7.13
20	1.57	-	2.70	4.27
21	3.41	-	5.19	8.60
22	14.28	6.52	4.74	25.54
23	2.87	6.33	4.18	13.38
24	26.17	16.83	4.91	47.91
25	17.55	18.99	14.49	51.03

Appendix Table 4: Analysis of Tobacco samples taken from farmers' fields

Site	Location	Mg %		K%		Ca%	
		Upper leaves	Lower leaves	Upper leaves	Lower leaves	Upper leaves	Lower leaves
1	Hawsare	0.153	0.308	0.407	2.087	1.75	1.30
2	Maigana	0.197	0.097	2.175	0.625	0.075	0.350
3	Rahama	0.170	0.115	2.050	0.600	0.375	0.425
4	Ikara	0.233	0.425	1.788	1.788	0.363	1.050
5	Shinkafi	0.230	0.20	2.125	2.150	0.300	0.400
6	Bambigwa	0.175	0.195	2.300	1.500	0.412	0.725
7	Ungowa Danala	0.193	0.343	2.250	1.675	0.313	0.800
8	Sahel Namida	0.237	0.450	1.925	2.375	0.350	0.975
9	Danmosa	0.173	0.390	1.787	1.500	0.25	0.875
10	Zambuc	0.210	0.210	1.712	1.650	0.45	0.70
11	Danja	0.208	0.190	2.00	2.30	0.455	0.763
12	Gombe	0.250	0.300	2.05	1.337	0.475	0.763
13	Shagari	0.153	0.335	2.038	2.175	0.295	1.276
14	Arguwani Goji	0.135	0.142	4.688	5.313	1.225	1.350
15	Kaayarda	0.205	0.258	2.500	1.362	0.400	0.913
16	Sabon Berni	0.240	0.143	2.150	1.675	0.350	0.450
17	Namida	0.260	0.450	2.125	2.350	0.800	1.450
18	Yargoji	0.188	0.245	1.500	1.083	0.313	0.975
19	Sabon Layin	0.215	0.215	0.700	1.900	0.800	0.450
20	Sanyinawal	0.215	0.500	1.787	2.075	0.413	1.475
21	Magazo	0.183	0.478	1.538	0.388	0.405	2.115
22	Maigana	0.265	0.325	3.712	3.481	0.606	1.494
23	Wanka	0.274	0.389	1.540	1.184	0.517	0.985
24	Kano	0.459	0.792	3.830	1.100	1.235	2.816

Appendix Table 5: Some physical and chemical properties of profile samples of tobacco growing areas

Site No.	Depth (cm)	pH $CaCl_2$	pH H_2O	OM %	CEC meq/100g	Mg meq/100g	K meq/100g	Ca meq/100g	Mg:K	Mg:Ca	Mg+Ca / K	Mg / CEC	Sand %	Silt %	Clay %
1	0-20	5.9	7.0	0.98	5.58	0.87	0.13	1.69	6.96	0.51	19.69	0.16	61.2	18.4	20.4
	20-40	5.8	6.5	0.49	6.71	1.27	0.17	1.72	7.47	0.74	17.59	0.19	71.2	10.4	18.4
	40-60	5.7	6.5	0.44	7.78	1.94	0.16	3.40	12.13	0.57	33.38	0.25	62.2	14.4	23.4
	60-80	5.6	6.5	0.52	7.17	1.71	0.14	2.80	12.21	0.61	32.21	0.24	54.2	18.4	27.4
2	0-20	4.9	5.3	0.49	7.19	1.02	0.19	3.36	5.37	0.30	23.05	0.14	45.2	30.4	23.4
	20-40	4.8	5.3	0.39	8.82	1.02	0.09	4.40	13.56	0.28	62.44	0.14	42.2	22.4	35.4
	40-60	4.5	5.1	0.22	8.37	1.37	0.17	3.92	8.06	0.35	31.12	0.16	39.2	22.4	38.4
	60-80	3.8	4.5	0.16	6.96	1.26	0.21	3.20	6.00	0.39	21.24	0.18	52.2	22.4	25.4
3.	0-20	4.0	4.5	0.71	6.37	1.86	0.21	2.00	8.86	0.93	18.38	0.29	42.2	34.4	16.4
	20-40	3.7	4.8	0.50	7.67	1.33	0.26	3.40	5.12	0.39	18.19	0.17	39.2	26.4	34.4
	40-60	3.7	4.8	0.28	8.21	1.60	0.27	3.70	5.93	0.43	19.63	0.19	31.2	30.4	38.4
	60-80	3.8	4.8	0.35	8.82	1.60	0.23	3.50	6.96	0.46	22.17	0.18	35.2	26.4	38.4
4	0-20	4.0	4.6	0.65	7.30	1.53	0.15	3.95	10.20	0.39	36.53	0.21	73.2	10.4	16.4
	20-40	4.0	4.7	0.65	9.73	2.45	0.15	5.00	16.33	0.49	49.67	0.25	53.2	18.4	28.4
	40-60	4.0	5.0	0.50	10.17	3.37	0.21	6.30	16.05	0.53	46.04	0.33	49.2	14.4	36.4
	60-80	4.0	4.8	0.34	10.87	3.33	0.24	6.00	13.88	0.56	38.88	0.31	50.2	14.4	35.4

Appendix Table 5: (Cont'd)

Site No.	Depth (cm)	pH $CaCl_2$	pH H_2O	OM %	CEC meq/100g	Mg meq/100g	K meq/100g	Ca meq/100g	Mg:K	Mg:Ca	$\frac{Mg+Ca}{K}$	$\frac{Mg}{CEC}$	Sand %	Silt %	Clay %
5	0-20	4.0	4.6	0.30	6.58	0.87	0.13	1.69	6.69	0.51	19.69	0.13	55.2	24.4	20.4
	20-40	3.2	4.8	0.30	6.71	1.27	0.17	1.72	7.47	0.74	17.59	0.19	44.2	24.4	32.4
	40-60	3.9	4.5	0.14	7.78	1.94	0.16	3.40	12.13	0.57	33.37	0.25	39.2	18.4	42.4
	60-80	3.8	4.7	0.12	7.17	1.71	0.14	2.80	12.21	0.61	32.21	0.24	35.2	22.4	42.4
6	0-20	4.7	6.0	0.75	7.72	1.04	0.15	4.20	6.93	0.25	34.93	0.13	46.2	22.4	33.4
	20-40	4.3	5.6	0.65	7.54	1.23	0.15	4.31	8.20	0.29	36.93	0.16	38.2	24.4	37.4
	40-60	4.2	5.2	0.49	8.30	1.38	0.15	4.58	9.20	0.30	39.73	0.17	31.2	26.4	42.4
	60-80	3.5	4.6	0.22	8.30	1.32	0.16	3.90	8.25	0.34	32.63	0.16	31.2	26.4	42.4
7	0-20	4.0	4.9	0.75	5.71	0.99	0.12	2.70	8.25	0.37	30.75	0.17	33.2	35.4	31.4
	20-40	3.8	4.5	0.49	7.12	1.31	0.13	3.60	10.08	0.36	37.77	0.18	27.2	22.4	50.4
	40-60	3.5	4.6	0.30	6.81	1.81	0.16	2.35	11.31	0.77	26.00	0.27	27.2	22.4	50.4
	60-80	3.7	4.7	0.26	6.02	1.63	0.26	3.40	6.27	0.50	19.36	0.27	25.2	22.4	52.4
8	0-20	4.2	5.2	0.40	4.78	0.40	0.19	0.75	2.11	0.53	6.05	0.08	80.2	7.4	12.4
	20-40	4.5	5.3	0.28	5.10	0.58	0.25	1.00	2.32	0.58	6.32	0.11	79.2	6.4	14.4
	40-60	4.5	5.8	0.18	5.00	0.51	0.21	1.10	2.43	0.46	7.67	10.20	75.2	6.4	18.4
	60-80	4.5	5.6	0.18	4.12	0.40	0.21	1.10	1.90	0.36	7.14	0.10	79.2	6.4	14.4

Appendix Table 5: (Cont'd)

Site No.	Depth (cm)	pH $CaCl_2$	pH H_2O	OM %	CEC meq/100g	Mg meq/100g	K meq/100g	Ca meq/100g	Mg:K	Mg:Ca	$\frac{Mg+Ca}{K}$	$\frac{Mg}{CEC}$	Sand %	Silt %	Clay %
9	0-20	4.2	4.5	0.80	7.33	1.03	0.09	3.45	11.44	0.30	49.78	0.14	45.2	34.4	20.4
	20-40	4.3	4.9	0.35	6.42	0.90	0.07	2.73	12.86	0.33	51.86	0.14	55.2	26.4	18.4
	40-60	4.5	5.5	0.26	3.85	0.68	0.05	2.00	13.60	0.34	53.60	0.18	71.2	18.4	10.4
	60-80	4.5	5.7	0.19	3.62	0.66	0.05	1.99	13.20	0.33	53.00	0.16	75.2	14.4	10.4
10	0-20	3.8	4.5	0.70	8.62	1.37	0.11	5.10	12.45	0.27	58.82	0.16	61.2	18.4	20.4
	20-40	3.4	4.2	0.49	10.71	1.52	0.13	5.40	11.69	0.23	53.23	0.14	58.2	14.4	27.4
	40-60	3.0	4.6	0.37	11.07	1.76	0.16	6.91	11.00	0.25	54.19	0.16	50.2	18.4	31.4
	60-80	3.0	3.8	0.26	11.57	2.00	0.19	6.78	10.53	0.29	46.21	0.17	49.2	14.4	36.4
11	0-20	5.3	6.0	1.15	6.86	1.14	0.79	3.65	1.44	0.31	6.06	0.17	43.2	42.4	14.4
	20-40	5.58	6.6	0.79	8.11	1.12	1.49	3.62	0.75	0.31	3.18	0.14	39.2	38.4	22.4
	40-60	5.2	6.6	0.47	7.93	0.82	1.36	2.80	0.60	0.29	2.66	0.10	43.2	34.4	22.4
	60-80	5.3	5.7	0.30	5.98	0.67	0.92	2.84	0.73	0.24	3.82	0.11	47.2	30.4	22.4
12	0-20	4.9	5.4	0.62	7.43	1.35	0.21	5.92	6.43	0.23	34.62	0.18	62.2	14.4	23.4
	20-40	4.5	5.9	0.32	11.87	1.93	0.14	7.59	13.79	0.25	68.00	0.16	50.2	14.4	35.4
	40-60	5.2	5.2	0.28	14.92	2.10	0.23	9.70	9.13	0.22	51.30	0.14	35.2	14.4	50.4
	60-80	4.2	5.1	0.30	13.89	1.03	0.25	9.95	4.12	0.10	43.92	0.07	31.2	22.4	46.4

Appendix Table 5: (Cont'd)

Site No.	Depth (cm)	pH $CaCl_2$	pH H_2O	OM %	CEC meq/100g	Mg meq/100g	K meq/100g	Ca meq/100g	Mg:K	Mg:Ca	Mg+Ca / K	Mg / CEC	Sand %	Silt %	Clay %
13	0-20	3.1	3.6	1.71	16.50	2.00	0.38	5.15	5.26	0.31	18.82	0.12	19.2	20.4	60.4
	20-40	3.1	4.0	1.16	15.60	2.08	0.27	3.75	7.70	0.55	21.59	0.13	25.2	18.4	56.4
	40-60	3.2	4.1	0.58	11.60	2.10	0.14	4.60	15.00	0.46	47.55	0.18	41.2	18.4	40.4
	60-80	3.7	4.1	0.41	10.11	2.10	0.11	4.25	19.09	0.49	57.73	0.21	49.2	18.4	32.4
14	0-20	3.8	4.5	0.71	7.80	0.73	0.14	2.40	5.21	0.30	22.36	0.09	50.2	28.4	23.4
	20-40	4.2	5.0	0.31	8.50	1.33	0.26	3.16	5.12	0.42	17.27	0.16	34.2	22.4	43.4
	40-60	4.5	4.9	0.18	8.97	1.37	0.28	3.00	4.89	0.46	15.61	0.15	34.2	22.4	43.4
	60-80	4.5	4.8	0.16	9.95	1.47	0.30	3.20	4.90	0.46	15.57	0.15	34.2	22.4	43.4
15	0-20	5.0	5.7	0.75	7.69	0.80	0.36	2.72	2.22	0.29	9.78	0.10	54.2	18.4	27.4
	20-40	5.0	4.5	0.39	8.46	0.88	0.24	2.25	3.69	0.39	13.04	0.10	38.2	22.4	39.4
	40-60	3.9	4.9	0.19	8.46	0.72	0.19	2.14	3.79	0.34	15.05	0.09	34.2	22.4	43.4
	60-80	3.8	4.7	0.17	6.82	0.62	0.25	1.88	2.48	0.33	10.00	0.09	34.2	22.4	43.4
16	0-20	3.5	3.9	0.42	6.50	0.77	0.10	1.70	7.70	0.45	24.70	0.12	39.2	30.4	30.4
	20-40	3.6	4.7	0.17	7.22	0.87	0.13	1.64	6.69	0.53	19.31	0.12	39.2	18.4	42.4
	40-60	3.5	4.1	0.14	7.40	1.23	0.18	2.60	6.83	0.47	21.28	0.17	27.2	22.4	50.4
	60-80	3.5	4.1	0.10	6.90	1.13	0.17	2.35	6.65	0.48	20.47	0.16	31.2	22.4	46.4

Appendix Table 5: (Cont'd)

Site No.	Depth (cm)	pH $CaCl_2$	pH H_2O	OM %	CEC meq/100g	Mg meq/100g	K meq/100g	Ca meq/100g	Mg:K	Mg:Ca	$\frac{Mg+Ca}{K}$	$\frac{Mg}{CEC}$	Sand %	Silt %	Clay %
17	0-20	4.3	4.7	0.19	4.02	0.43	0.27	1.30	1.59	0.33	6.41	0.11	75.2	14.4	10.4
	20-40	4.3	5.1	0.19	5.96	0.73	0.26	2.10	2.81	0.35	10.88	0.12	67.2	10.4	22.4
	40-60	4.2	4.8	0.17	5.41	0.96	0.15	2.50	6.40	0.38	23.07	0.18	71.2	10.4	18.4
	60-80	3.7	4.9	0.17	4.93	0.62	0.08	1.57	7.75	0.39	27.38	0.13	71.2	10.4	18.4
18	0-20	4.1	5.1	0.52	4.47	0.43	0.09	1.60	4.78	0.27	22.56	0.10	60.2	26.4	13.4
	20-40	4.4	5.3	0.45	6.87	0.55	0.06	2.96	9.17	0.19	58.50	0.08	51.2	26.4	22.4
	40-60	4.7	5.5	0.35	6.87	0.60	0.07	3.11	8.57	0.19	53.00	0.09	51.2	26.4	22.4
	60-80	4.7	5.4	0.23	6.04	0.75	0.08	2.60	9.38	0.29	41.88	0.12	59.2	22.4	18.4
19	0-20	4.6	5.6	0.61	8.09	1.00	0.10	2.02	10.00	0.50	30.20	0.12	37.2	28.4	34.4
	20-40	3.4	4.0	0.32	8.22	1.01	0.09	1.28	11.22	0.79	25.44	0.12	26.2	28.4	48.4
	40-60	3.6	4.6	0.23	6.90	0.73	0.09	0.44	8.11	1.66	13.00	0.11	26.2	28.4	45.4
	60-80	3.1	4.5	0.23	5.02	0.67	0.14	0.40	4.79	1.68	7.64	0.13	30.2	24.4	45.4
20	0-20	3.5	4.7	0.49	2.85	0.48	0.16	1.00	3.00	0.48	9.25	0.17	83.2	6.4	10.4
	20-40	4.1	4.6	0.31	3.18	0.44	0.11	1.28	4.00	0.34	15.64	0.14	59.2	26.4	14.4
	40-60	4.5	5.0	0.19	3.18	0.30	0.12	0.80	2.50	0.38	9.17	0.09	75.2	10.4	14.4
	60-80	4.3	4.5	0.10	1.95	0.20	0.07	0.50	2.86	0.40	10.00	0.10	83.2	2.4	14.4

Appendix Table 5 (Cont'd)

Site No.	Depth (cm)	pH $CaCl_2$	pH H_2O	OM %	CEC	Mg	K	Ca	Mg:K	Mg:Ca	$\frac{Mg+Ca}{K}$	$\frac{Mg}{CEC}$	Sand %	Silt %	Clay %
					meq/100g										
21	0-20	4.0	5.2	0.74	4.58	0.57	0.12	1.80	4.75	0.32	19.75	0.12	43.2	38.4	18.4
	20-40	3.5	4.8	0.37	5.01	0.53	0.07	1.62	7.57	0.33	30.71	0.11	51.2	22.4	26.4
	40-60	3.9	4.8	0.31	5.24	0.57	0.07	2.00	8.14	0.29	36.71	0.11	43.2	26.4	30.4
	60-80	3.8	5.0	0.34	5.74	0.68	0.07	2.28	9.71	0.30	42.29	0.12	43.2	26.4	30.4
22	0-20	3.3	4.4	0.58	3.86	0.55	0.14	1.06	3.93	0.52	11.50	0.14	43.2	38.4	18.4
	20-40	3.7	4.5	0.52	6.98	1.17	0.14	2.04	0.08	0.57	22.93	0.17	31.2	22.4	48.4
	40-60	3.8	5.1	0.39	7.40	1.90	0.26	3.46	7.31	0.55	20.62	0.26	31.2	22.4	46.4
	60-80	4.3	5.1	0.27	7.65	1.90	0.26	3.50	7.31	0.54	20.77	0.25	35.2	22.4	42.4
23	0-20	4.0	4.5	0.72	6.13	0.87	0.21	2.04	4.14	0.43	13.86	0.14	45.2	36.4	18.4
	20-40	3.7	4.4	0.54	8.87	1.36	0.26	3.45	5.23	0.39	18.50	0.15	33.2	28.4	38.4
	40-60	3.7	4.8	0.30	8.22	1.60	0.27	3.75	5.93	0.43	19.81	0.19	25.2	32.4	42.4
	60-80	3.9	4.8	0.30	7.28	1.60	0.24	3.53	6.67	0.45	21.38	0.22	31.2	26.4	42.4
24	0-20	4.3	4.7	0.20	3.44	0.42	0.27	1.30	1.56	0.32	6.37	0.12	75.2	14.4	10.4
	20-40	4.3	5.1	0.19	6.88	0.72	0.26	2.10	2.77	0.34	10.85	0.10	67.2	10.4	22.4
	40-60	4.2	4.8	0.17	5.96	0.94	0.16	2.45	5.88	0.38	21.19	0.16	72.2	10.4	19.4
	60-80	3.7	4.9	0.17	4.30	0.61	0.08	1.56	7.63	0.39	27.13	0.14	72.2	10.4	19.4

Appendix Table 6: Different measurements of the first experiment (Maigana upland)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
1	0	0	1	0.220	0.270	3.650	3.500	0.375	1.175	93.9	85.0	2056	13680
	0	0	2	0.110	0.326	3.900	3.500	0.225	1.875	110.9	100.0	1817	15200
	0	0	3	0.350	0.500	4.000	3.426	0.875	1.675	77.9	102.0	1168	16650
	0	0	4	0.380	0.205	3.300	3.500	0.950	1.250	88.3	100.0	2670	21700
2	0	41.5	1	0.175	0.220	3.850	3.300	0.300	0.600	156.6	117.0	3375	16420
	0	41.5	2	0.090	0.445	3.800	3.226	0.400	1.475	125.8	105.0	1927	16300
	0	41.5	3	0.200	0.385	2.876	4.750	0.400	1.000	105.2	105.0	2225	19255
	0	41.5	4	0.400	0.275	4.300	4.000	0.575	0.775	111.1	111.0	2762	22640
3	0	83.0	1	0.240	0.458	3.390	3.600	0.450	1.725	98.0	70.0	3389	16920
	0	83.0	2	0.255	0.400	4.150	5.000	0.400	1.375	131.9	108.0	2540	22100
	0	83.0	3	0.150	0.482	4.350	3.926	0.325	1.960	98.7	109.0	2483	21850
	0	83.0	4	0.290	0.560	4.000	3.250	0.600	2.800	103.9	113.0	2805	23100
4	24	0	1	0.405	0.165	3.200	3.050	0.725	0.300	165.9	110.0	2298	16900
	24	0	2	0.225	0,185	4.400	3.300	0.500	0.500	140.1	111.0	2596	22930
	24	0	3	0.290	0.192	3.926	3.500	0.935	0.575	184.4	120.0	4001	26010
	24	0	4	0.235	0.160	3.850	3.300	0.200	0.240	111.7	120.0	3374	28750

Appendix Table 6: (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
5	24	41.5	1	0.090	0.180	4.250	4.000	0.475	0.425	194.8	120.0	3874	21150
	24	41.5	2	0.170	0.245	3.600	3.600	0.650	0.800	125.9	113.0	2771	24710
	24	41.5	3	0.120	0.600	2.500	4.250	0.200	2.000	225.9	119.0	4710	28720
	24	41.5	4	0.415	0.660	4.150	5.000	0.725	2.100	167.6	132.0	4357	30120
6	24	83.0	1	0.380	0.600	4.450	3.200	0.675	1.900	113.9	110.0	3627	22176
	24	83.0	2	0.088	0.415	4.000	3.300	0.550	1.250	119.9	118.0	2927	26300
	24	83.0	3	0.300	0.365	4.250	3.000	0.675	1.400	102.5	105.0	4891	28970
	24	83.0	4	0.325	0.415	3.800	4.050	0.1[illegible]	0.950	142.9	130.0	4306	30050
7	48	0	1	0.225	0.330	3.900	4.200	0.550	0.925	158.9	120.0	3523	19460
	48	0	2	0.225	0.285	4.300	4.400	0.625	0.650	158.9	112.0	2114	18210
	48	0	3	0.430	0.485	4.350	2.300	0.900	1.800	128.6	110.0	4283	27840
	48	0	4	0.355	0.213	4.400	2.000	0.900	0.900	154.5	123.0	4023	28000
8	48	41.5	1	0.200	0.270	4.750	3.800	0.200	0.525	199.8	120.0	3708	22500
	48	41.5	2	0.280	0.685	4.450	3.500	0.700	2.175	223.3	132.0	5655	29550
	48	41.5	3	0.315	0.635	4.300	3.500	0.400	1.980	209.1	140.0	4876	29070
	48	41.5	4	0.195	0.665	4.050	3.226	0.350	1.850	174.0	134.0	5192	31200

Append. Table 6 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
9	48	83.0	1	0.555	0.225	3.900	3.552	1.025	1.400	119.9	100.0	3616	20160
	48	83.0	2	0.380	0.470	3.850	3.176	0.750	1.800	152.9	119.0	3059	27590
	48	83.0	3	0.375	0.630	3.876	3.076	0.650	1.850	103.9	118.0	2951	26990
	48	83.0	4	0.484	0.555	3.750	3.350	1.200	1.450	106.5	124.0	4351	29400
10	72	0	1	0.725	0.215	3.900	2.500	1.000	0.450	135.9	119.0	3245	19000
	72	0	2	0.415	0.516	3.500	0.800	0.540	0.540	154.6	111.0	2627	23280
	72	0	3	0.325	0.540	4.000	3.500	0.280	0.750	129.9	135.0	1992	19870
	72	0	4	0.375	0.375	4.400	4.000	0.625	0.400	115.6	128.0	3003	25050
11	72	41.5	1	0.400	0.345	4.100	4.500	0.650	1.100	99.9	100.0	3594	19458
	72	41.5	2	0.384	0.360	4.000	3.500	0.680	0.750	194.4	129.0	3986	28990
	72	41.5	3	0.380	0.250	3.900	3.600	0.750	0.885	103.9	103.0	2132	21330
	72	41.5	4	0.370	0.320	4.750	4.026	0.625	1.550	145.5	130.0	3832	28290

Appendix Table 6 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
12	72	83.0	1	0.435	0.295	4.000	4.000	0.700	0.725	129.9	112.0	3454	21168
	72	83.0	2	0.400	0.355	3.800	3.400	1.000	0.750	184.4	117.0	3671	27100
	72	83.0	3	0.414	0.600	3.800	3.600	0.225	2.125	106.5	110.0	3371	24400
	72	83.0	4	0.378	0.510	4.150	4.250	0.500	1.625	110.4	129.0	3780	28010

V_1 = Mg content of upper leaves (%)
V_2 = Mg content of lower leaves (%)
V_3 = K content of upper leaves (%)
V_4 = K content of lower leaves (%)
V_5 = Ca content of upper leaves %
V_6 = Ca content of lower leaves (%)
V_7 = Stem dry weight (gram/plant)
V_8 = Plant height (cm)
V_9 = Yield (kg/ha)
V_{10} = Leaf area (cm^2/plant)

Appendix Table 7: Different measurements of the second experiment (Maigana lowland)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{1}
1	0	0	1	0.270	0.445	1.675	1.075	0.475	1.018	63.9	70.0	2013	1600
	0	0	2	0.265	0.350	1.568	1.275	0.450	1.025	89.9	77.0	2532	1720
	0	0	3	0.245	0.317	1.295	1.138	0.468	0.825	105.9	90.0	2032	1848
	0	0	4	0.314	0.447	1.625	1.250	0.475	1.070	110.5	95.0	2437	1890
2	0	41.5	1	0.273	0.360	2.000	1.560	0.438	0.868	73.9	70.0	2100	1760
	0	41.5	2	0.300	0.340	1.570	1.537	0.608	1.000	111.9	90.0	3207	1760
	0	41.5	3	0.260	0.414	1.688	1.645	0.605	1.250	147.8	100.0	3607	2700
	0	41.5	4	0.255	0.290	1.418	1.405	0.580	0.870	133.8	105.0	2407	2185
3	0	83.0	1	0.293	0.490	1.438	1.000	0.620	1.160	87.9	89.0	2244	1860
	0	83.0	2	0.250	0.450	1.620	1.208	0.640	0.990	69.9	78.0	3259	2060
	0	83.0	3	0.245	0.342	1.500	2.000	0.550	1.055	129.8	105.0	3790	2800
	0	83.0	4	0.223	0.315	1.413	1.200	0.475	0.795	119.9	95.0	3030	2200
4	24	0	1	0.272	0.368	1.875	1.275	0.670	1,005	65.9	83.0	2778	1760
	24	0	2	0.292	0.375	1.425	1.050	0.583	0.816	69.0	80.0	3263	2400
	24	0	3	0.295	0.330	1.625	1.500	0.500	0.825	137.8	120.0	3285	2700
	24	0	4	0.290	0.301	1.563	1.545	0.560	0.740	83.9	100.0	3548	2100

Appendix Table 7 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
5	24	41.5	1	0.233	0.328	1.450	1.000	0.590	1.093	57.9	88.0	2535	19800
	24	41.5	2	0.251	0.515	1.700	1.375	0.538	1.020	106.9	90.0	3907	25100
	24	41.5	3	0.315	0.350	1.570	1.848	0.700	0.926	138.2	115.0	4398	25500
	24	41.5	4	0.260	0.300	1.500	1.438	0.525	0.773	127.8	100.0	3417	23900
6	24	83.0	1	0.283	0.318	1.355	1.700	0.483	0.800	29.9	83.0	3200	18500
	24	83.0	2	0.274	0.382	1.825	1.750	0.600	1.075	89.9	87.0	3565	25990
	24	83.0	3	0.380	0.328	1.750	1.500	0.820	0.775	137.9	115.0	4259	28030
	24	83.0	4	0.265	0.353	1.725	1.643	0.738	0.840	120.9	102.0	3907	26980
7	48	0	1	0.195	0.228	1.500	1.363	0.395	0.825	71.4	82.0	3050	16300
	48	0	2	0.268	0.320	1.450	1.375	0.420	0.968	75.9	78.0	3018	23000
	48	0	3	0.300	0.326	1.550	1.500	0.663	0.800	127.9	112.0	3865	24000
	48	0	4	0.288	0.290	1.613	1.412	0.900	0.860	111.9	100.0	3862	24000
8	48	41.5	1	0.288	0.362	1.698	1.558	0.470	0.838	129.8	100.0	3380	26000
	48	41.5	2	0.294	0.375	1.675	1.670	0.550	0.875	129.9	110.0	3657	27000
	48	41.5	3	0.263	0.429	1.695	1.770	0.550	1.075	126.9	105.0	4111	24000
	48	41.5	4	0.283	0.350	1.750	1.605	0.578	1.000	139.8	110.0	4050	26000

Appendix

Table 7 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
9	48	83.0	1	0.265	0.370	1.625	1.475	0.375	0.580	85.9	105.0	4491	26000
	48	83.0	2	0.260	0.395	1.525	1.560	0.675	1.000	84.9	98.0	3491	26000
	48	83.0	3	0.268	0.335	1.460	1.348	0.535	0.850	123.8	108.0	3037	26140
	48	83.0	4	0.285	0.425	1.575	1.325	0.545	1.325	129.9	107.0	4342	28000
10	72	0	1	0.263	0.308	1.228	1.100	0.463	1.050	71.2	80.0	2850	20000
	72	0	2	0.225	0.371	1.500	1.395	0.365	0.850	73.9	79.0	2959	17000
	72	0	3	0.248	0.339	1.387	1.475	0.485	0.845	151.8	115.0	3917	27000
	72	0	4	0.245	0.430	1.370	1.125	0.440	0.800	117.9	105.0	3768	24000
11	72	41.5	1	0.263	01500	1.595	1.000	0.533	1.115	67.9	84.0	3370	23000
	72	41.5	2	0.305	0.328	2.000	1.713	0.738	1.060	118.9	85.0	3186	20850
	72	41.5	3	0.301	0.339	1.670	1.750	0.590	1.100	163.8	120.0	4148	28000
	72	41.5	4	0.290	0.360	1.755	1.688	0.620	0.975	118.3	100.0	3957	25000

Appendix
Table 7 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
12	72	83.0	1	0.235	0.364	1.375	1.330	0.420	1.125	89.9	85.0	293	23500
	72	83.0	2	0.268	0.294	1.625	1.200	0.428	0.825	86.7	83.0	2411	21000
	72	83.0	3	0.259	0.325	1.553	1.675	0.475	1.275	129.9	114.0	3870	24000
	72	83.0	4	0.245	0.309	1.925	1.675	0.605	0.920	119.9	101.0	3891	24100

V_1 = Mg content of upper leaves (%)
V_2 = Mg content of lower leaves (%)
V_3 = K content of upper leaves (%)
V_4 = K content of lower leaves (%)
V_5 = Ca content of upper leaves
V_6 = Ca content of lower leaves (%)
V_7 = Stem dry weight (gram/plant)
V_8 = Plant height (cm)
V_9 = Yield (kg/ha)
V_{10} = Leaf area (cm^2/plant).

Appendix Table 8: Different measurements of the third experiment (Kano)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
1	0	0	1										
	0	0	2	0.440	0.730	3.500	1.170	1.120	2.000	41.7	55.6	1058	7911
	0	0	3	0.447	0.900	4.000	0.800	1.225	3.200	66.7	65.9	1260	9928
	0	0	4	0.490	0.743	4.000	1.330	1.360	3.250	65.0	56.8	1386	10504
2	0	41.5	1										
	0	41.5	2	0.367	0.848	3.930	2.700	0.985	3.230	58.3	61.0	2016	10452
	0	41.5	3	0.418	0.700	4.580	4.160	0.975	3.195	125.0	81.2	1928	16508
	0	41.5	4	0.408	0.690	3.970	2.300	1.105	2.390	40.0	62.0	1613	12078
3	0	83.0	1										
	0	83.0	2	0.429	0.760	3.000	3.470	1.050	3.150	60.0	62.6	2482	9840
	0	83.0	3	0.369	0.760	4.500	4.210	0.900	3.400	113.0	79.0	2785	15216
	0	83.0	4	0.415	0.800	4.040	2.790	1.000	3.050	45.0	52.2	882	9777

Appendix Table 8 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
4	24	0	1										
	24	0	2	0.455	0.852	3.890	0.930	0.955	3.380	50.0	61.0	1172	10227
	24	0	3	0.456	0.010	4.000	1.060	0.875	2.200	54.4	69.2	1247	13132
	24	0	4	0.454	1.010	3.780	0.820	1.035	3.460	50.0	60.9	1462	14672
5	24	41.5	1										
	24	41.5	2	0.375	0.836	3.890	4.600	0.835	3.200	53.4	65.8	1701	14895
	24	41.5	3	0.357	0.865	3.470	1.400	0.900	2.915	63.4	69.3	1512	14654
	24	41.5	4	0.380	1.000	3.800	2.000	0.900	3.300	83.3	62.5	1840	12740
6	24	83.0	1										
	24	83.0	2	0.405	0.782	4.800	2.550	0.815	3.525	56.7	57.9	1386	9360
	24	83.0	3	0.390	0.670	4.980	5.840	0.930	3.060	125.0	77.9	2961	16048
	24	83.0	4	0.380	0.743	4.880	4.000	0.600	3.350	130.0	84.7	3150	23028
7	48	0	1										
	48	0	2	0.400	0.900	4.260	1.000	1.020	2.750	55.0	59.4	932	9571
	48	0	3	0.465	0.960	3.310	1.000	1.085	3.200	71.7	71.1	1084	14872
	48	0	4	0.450	1.200	3.400	1.480	1.150	3.300	46.7	59.6	995	9078

Appendix Table 8 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
8	48	41.5	1										
	48	41.5	2	0.440	1.180	3.120	1.670	1.375	2.550	66.0	60.5	856	13302
	48	41.5	3	0.440	0.956	3.690	3.690	2.500	2.900	68.3	68.6	1323	14808
	48	41.5	4	0.503	1.010	4.390	1.430	1.360	2.950	60.0	66.2	814	13400
9	48	83.0	1										
	48	83.0	2	0.373	1.000	3.480	2.120	1.050	3.280	53.3	63.0	2381	14744
	48	83.0	3	0.465	0.890	4.180	1.350	1.170	2.400	68.4	74.9	1462	13160
	48	83.0	4	0.404	1.080	4.000	1.800	0.865	3.450	60.0	61.6	1865	14352
10	72	0	1										
	72	0	2	0.470	0.880	2.900	0.650	1.425	2.000	55.0	64.0	1833	10225
	72	0	3	0.395	1.010	3.380	1.000	0.975	3.670	66.7	62.3	1810	9628
	72	0	4	0.475	0.790	4.250	1.650	1.300	2.950	53.0	53.4	2016	9760
11	72	41.5	1										
	72	41.5	2	0.399	0.960	3.650	1.300	1.000	2.860	56.7	62.5	2028	10339
	72	41.5	3	0.405	1.024	3.700	1.690	1.050	3.650	56.7	62.3	2028	10320
	72	41.5	4	0.616	3.616	3.600	3.320	0.950	2.750	116.7	74.7	2142	17908

Appendix Table 8 (Cont'd)

Treatment	Mg rates (kg/ha)	K rates (kg/ha)	Block No.	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
12	72	83.0	1										
	72	83.0	2	0.458	1.160	3.680	1.460	1.075	3.250	63.3	63.6	2190	13852
	72	83.0	3	0.430	0.982	4.390	2.670	1.190	3.800	90.0	63.7	2089	11096
	72	83.0	4	0.400	0.960	5.000	4.600	0.710	3.500	123.3	71.1	2917	18756

V_1 = Mg content of upper leaves (%)
V_2 = Mg content of lower leaves (%)
V_3 = K content of upper leaves (%)
V_4 = K content of lower leaves (%)
V_5 = Ca content of upper leaves
V_6 = Ca content of lower leaves (%)
V_7 = Stem dry weight (gram/plant)
V_8 = Plant height (cm)
V_9 = Yield (kg/ha)
V_{10}= Leaf area (cm^2/plant).