STUDIES ON THE POST-FLOWERING DEVELOPMENT OF MAIZE (ZEA MAYS L.)

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CHAPTER 1

INTRODUCTION

1.1 General

Of the four major cereal crops - sorghum, millet, maize and rice - grown in Nigeria, maize (Zea mays L.) ranks third in importance both in terms of total production and utilization. The estimated annual production of maize is now about 1.6 million metric tons of dry grains from about 1.5 million hectares of small peasant holdings (Federal office of Statistics, 1972). This indicates a low average yield of about 1,000 kg/ha. Virtually all the grain produced is used for human consumption with a very small proportion used for livestock and poultry feeds. The traditional areas for maize grain production have been those approximately south of latitude 8°N, and maize is regarded as the most important staple cereal crop in the Western, Kwara, Lagos and to some extent in the Mid-Western and East Central States. In areas to the north of the main maize belt, sorghum and millet dominate the cereal crop acreage with the latter gaining more prominence as one goes still further north where the total rainfall and its distribution becomes inadequate for the long season traditional sorghum varieties. However, even north of the main maize growing areas short season varieties of maize adapted to the season and environment have been grown for centuries in relatively small plots in or near the homesteads to furnish ears that are often eaten green after boiling in the husk or roasting

without the husk.

Although research in agricultural and food sciences in Nigeria is about fifty years old, its increased tempo to meet the crucial challenge of increased food production to meet the need of Nigeria's fast growing population and provide the essential raw material to stimulate industrial growth is less than two decades old. Earlier research effort tended to emphasize export and industrial crops such as cotton, groundnuts, cocoa, rubber etc. much more than the food crops. A fairly balanced research approach, now pursued on all the major crops in Nigeria includes husbandry practices, plant breeding, crop protection, and maintenance and improvement of soil fertility.

Maize research in Nigeria has been the responsibility of the Federal Department of Agricultural Research with its headquarters at Ibadan in the Western State, Nigeria's most important traditional maize growing area. In the last decade, through cooperative and active participation of other research organizations such as the major cereals project of the Organization of African Unity(JP 26) and the Institute for Agricultural Research of Ahmadu Bello University, maize research programmes have expanded to cover both the southern and the Northern parts of Nigeria. Information gathered especially in the 1 st five years showed that the production potential of maize increases from south

to north up to 11°N in the northern guinea savanna where maize has its greatest grain yield potential (Kassam et al. 1974). Though two maize crops can be grown under the bimodal rainfall distribution in the south, on crop to crop basis, the higher potential in the north is attributed to larger solar energy for photosynthesis during grain filling. North of 11°N insufficient moisture during growth becomes a more important limiting factor to maize production than solar radiation.

Inspite of this great potential for maize as a grain crop in the north, agricultural extension services are finding it difficult to promote maize production at the expense of sorghum. The reason for this may be sociological, but it should be noted that maize, especially its high yielding varieties, does poorly and often fails completely when grown with little or no fertilizers under the conditions peasant farmers at present commonly grow their adapted long season sorghum varieties. It is hoped that this great potential for maize grain production in most of the northern parts of Nigeria will be exploited through intensive and extensive campaigns to get farmers to accept the use of fertilizers - an important prerequisite to successful maize production. At this juncture it is important to point at other characteristics that help to make maize an acceptable crop to farmers. In many areas of the north maize will

ripen at the end of the rainy season and dry down to a moisture level allowing safe storage while still on the field. Also the husks give some partial protection to the grains against birds, insects and from damage by rain during the ripening period.

The work reported in this thesis was an investigation of the growth performance of three maize genotypes with particular attention to their post flowering pattern of development in relation to production of dry matter and grain yield at Samaru ($11^{o}11'N$), in northern Nigeria, classified as having dry sub-humid climate according to Thornwaite's (1948) classification. In the first year of the study growth response to changes in plant density was investigated. Using the optimum plant density as determined from first year's investigation, response to date of sowing and top-dressing with nitrogen were investigated in the second year of the study. In addition, supplementary field experiments were carried out to study the source and sink relationships and pattern of translocation of assimilates in the plant after silking. It was hoped that the study would provide general agronomic information on maize husbandry for the Samaru area and areas with similar growing conditions, and would also elucidate some of the physiological bases for yield differences between the genotypes under the agronomic treatments included in the study. Also important is the

understanding of the relations ips of plant characters to yield so that the mode of inheritance of these characters could provide the basis for definite and constructive progress in plant breeding and agronomy.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Information which can be put to practical use in crop production consists essentially of relationship established between crop yield and variations which can be brought about by changing husbandry practices or by modifying plant character through plant breeding. These relationships between yield and environment only describe the connection between the end points of long and complex chain of inter-dependent processes in the environment and in the plant, the understanding of which broadly speaking form the object of agronomic and physiological research. For this understanding to be achieved plant growth must be identified in measurable terms and then growth reaction of the plant to these environmental factors must be determined. The problem of accounting for variation in terms of growth, development and yield of crop plants has been reviewed by Watson (1952). It involves the effects of external factors on all the physiological processes of the plant, the inter-relationships between the different processes of the plants and their dependence on the genetic make-up of the plant. Some of the major environmental factors which are themselves inter-dependent but which have direct or indirect effect on plant growth and development are temperature, rainfall, light intensity, day length and the growth medium of the plant. Other

factors, which are incidental to the environment, affecting growth of crop plants are insect pests and diseases. The growth reaction of the plant to environmental factors is also dependent on plant density, time of sowing, soil moisture and nutrient availability. Though considerable progress has been made since the time of Brooks (1902) who emphasized the need for integrating all factors which determined growth to the advantage of the farmer, there are today still many gaps to be filled towards a fuller understanding of the way in which different physical and physiological processes interact to determine plant growth.

2.2 Growth analysis

Early growth analysts such as Balls and Engledow (1934) measured morphological and numerical changes in plant organs which took place during growth but shed no light on the underlying physiological factors. Their technique did not succeed in defining easily measured plant characters which controlled yield and which the plant breeder could use as a basis for selection. The trouble was that the different yield attributes were not independent expressions of growth. Early investigators on growth also concentrated on one or few well known varieties of each species and emphasized comparisons among species rather than variability within species. Reviews of methods, terminology and results have

appeared many times in the literature (Watson, 1952; 1958, 1968; Wallace, 1958 and Hayashi, 1966). The growth analysis method is based on periodic sampling of a growing crop to determine total plant dry weight. The sampling may be over the whole or part of the life cycle of the plant or crop. In addition the analysis of growth may include division of plants into their components (e.g. leaves, stem).

Several expressions are commonly used to explain growth and morphological characteristics of an individual plant or a crop community. The review sources given above give most of the original references to these growth parameters. Blackman (1919) took the first step to develop a procedure for analysing growth in terms of dry weight changes. He regarded increase in dry weight as a process of continuous compound 'interest', the increment produced in any interval adding to captal growth in subsequent periods. Thus Blackman suggested the use of relative growth rate defined as the mean increase in dry weight, per unit dry weight per unit time as a measure of the rate of growth of plants. Heath and Gregory (1938) worked with a number of species in different environments and concluded that net assimilation rate, defined as the net increase in dry weight, per unit leaf area per unit time, was a relatively constant parameter for all plants; and that observed

differences were attributed to different environmental variables such as light. Briggs et al. (1920b) pointed out that the relative growth rate was equivalent to the product of net assimilation rate and leaf area ratio. Leaf area ratio was defined as the amount of leaf area present per unit dry weight of the whole plant.

Watson (1937) suggested another useful growth concept - the concept of crop growth rate which is defined as the net increase in dry weight per unit of ground area per unit time. Further he showed that the crop growth rate was equivalent to the product of net assimilation rate and leaf area index - leaf area per unit area of ground. The reviews by Williams (1946) and Watson (1947a) highlighted some of the limitations, inaccuracies and assumptions made in the use of net assimilation rate as a measure of photo-synthetic efficiency. One of its inherent limitations is that the net gain in the dry weight which is the net difference between gain from photo-synthesis and loss from respiration, is related to leaf area when in fact respiration occurs throughout the plant and not only in the leaves. Errors in estimating net assimilation rate are present when only the above-ground plant parts are measured to the exclusion of the roots. Inspite of these limitation net assimilation rate remains a convenient method of estimating mean rates of photosynthesis of field crops from successive extended periods of time.

2.3 Physiological bases of inter- and intra-specific differences in yield

This subject was reviewed by Watson (1952) who emphasized that differences in dry matter accumulation must be due to differences in either the size, or the net activity of the photosynthetic system or both. This again stresses the importance of growth analysis in studying field crops.

2.3.1 Leaf area difference

There is considerable information in the literature on the relationship between leaf area and crop yield. Watson (1958) showed that leaf area, the size of the assimilatory system, was generally more important than net assimilation rate in determining yield.

Leaf area index unlike leaf area per plant serves as a better indication for the surfaces available for light interception and absorption and provides a more common denominator for discussing the photosynthetic potential of a given crop. The early work of Nichiporovich (1954), Watson (1947a) and Brougham (1960) made immense contributions to the usage of leaf area concepts. Nichiporovich suggested that each economic crop has an optimum leaf area index. Such optimum leaf area is sufficient to intercept as much of the incoming radiation as possible allowing little or minimum parasitism by one part of the plant on the other. He considered this optimum to be between 2.5 and 5.0 pointing out that the leaf area index must

suit the conditions and purposes for which the crop is grown. Duvick and Noble (1970) showed that optimum leaf area index values may vary for different maize hybrids and environments. In their study these varied between 3.3 and 5.9. They also showed that environmental differences changed optimum leaf area index values of individual maize hybrids as much as two fold. Similar variations in optimum leaf area indices for different maize hybrids were reported by Eik and Hanway (1966); William et al. (1968); Humez and Kampath (1969); and Hunter et al. (1970). Tanaka et al. (1964) reported that optimum leaf area index of crops varied with plant types and light conditions during growth.

Watson (1958) found differences in leaf area indices and leaf area duration (the integrated leaf area for the growth cycle) of a range of field crops - the greater the leaf area the greater the dry matter accumulation. Van Eijanatten (1963) found that a difference in the rates of leaf area senescence (the duration of functional leaf surface) was responsible for a difference in grain yield between two maize varieties in Ibadan - southern part of Nigeria. Boonstra (1929b) found that oat varieties with longer duration of leaves had bigger grain yields.

It is evident that leaf area size, its duration and efficiency are affected by several environmental factors in addition to those inherent in the genetic

make-up of the species and varieties. Literature is generally consistent on the relationship between leaf area index and plant density. As plant density is increased the leaf area index also increases until it reaches its highest value at maximum plant density. However, the leaf area per plant decreases as plant density is increased. Maximum grain yields are generally not associated with maximum leaf area index values, eventhough no drastic reduction in grain yield is found associated with maximum leaf area index. Watson (1947b) reviewed evidence that showed the influence of mineral nutrition and leaf expansion on the size of leaf area. Gregory and Crowther (1928) found a difference in the response of barley varieties to nutrient application, and attributed this to differences in leaf area. Similar differences in the response of hybrid and inbred maize to nutrient applications have been recorded by Whaley (1950).

2.3 Differences in net assimilation rate

Heath and Gregory (1938) as mentioned earlier considered that net assimilation rates were relatively constant for a wide range of plant species, and that leaf area was the main factor determining dry matter accumulation. Watson (1952) however reported considerable variations in the net assimilation rates of several crop species - barley, wheat, potatoes and sugar beets. However, only limited variations were observed within species. Buttery (1970) found the

net assimilation rate in maize to be twice that in soyabeans.

Many workers (Loomis and Williams, 1963; Loomis et al. 1967; Duncan et al. 1967; Wit, 1959, 1965) reported a possible correlation between light intensity and net assimilation rate. Watson (1952) showed that increase in the leaf area of sugar beet reduced light intensity within the crop canopy with consequent reduction in net assimilation rate. These differences especially among varieties or strains within species have in recent years been understood to be attributed to differences in leaf disposition and the manner of light interception. Evidence is available to show that the chlorophyll concentration in leaves can affect net assimilation rate. Sprague and shive (1929) and Sprague and Curtis (1933) related 'leaf efficiency' and consequent grain yield to variations in the chlorophyll concentrations of maize leaves. Miller and Johnson (1938) however found no such relationship. Gabrielsen (1948) investigated the effect of chlorophyll concentration in different species and concluded that chlorophyll concentration was important only under poor light conditions. It would appear that the result of investigations on the relationship between chlorophyll concentration and net assimilation rate would depend much on the conditions under which the experiments

were carried out.

2.3.3 Translocation of stored assimilates to the grain

In the early decades of this century, it was generally believed that dry matter already present in the plant at the time of flowering made the greatest contribution to the final dry weight of the mature grain. Archbold (1942) working on barley and Barnell (1936) on rice, however, found that the amount of dry matter formed in the grain of these two crops represented more than twice the amount of dry matter lost from the shoot during the period of grain filling. Later investigations by Archbold and Mukerjee (1942) showed that dry matter lost from barley shoot during grain filling was equal to a maximum of 20% of the final dry weight of the ear while the dry weight lost from the root, most of which was considered to be mechanical, amounted to only 10% of the final ear weight. They concluded that at least 80% of the final dry weight accumulated in the grain of barley came from assimilation taking place after flowering or ear emergence. In further series of experiments with barley Archbold (1945) concluded that only concurrently assimilated carbohydrates are utilised for grain growth and that once the sugar is stored elsewhere in the plant, it is no longer available for translocation to the grain.

The conclusions of Archbold and her co-worker have been confirmed in more recent investigations with other cereals. Judging the relatively little changes in the weights of the different parts of the shoot compared with the large changes in the weight of grain between flowering and physiological maturity, it appears that in most cereals, carbohydrates present at flowering make at most only minor contributions to final grain weight. This general conclusion has been confirmed by several workers - Asama and Mani (1949, 1950); Kiesselbach (1948); Watson et al. (1959, 1961) Van Eijanatten (1963). Goldsworthy (1970) reached a similar conclusion with different varieties of sorghum at Samaru, Northern Nigeria.

Nevertheless, there were reports, few and inconclusive as they were, which have indicated movement at least under certain conditions of stored dry matter to the grain. Aldrich (1943) reported that mean kernel weight of maize increased by up to 20% within eight days after a pre-mature cutting of the stem. In recent investigations Daymond et al. (1973) and Adelana and Milbourne (1972) showed evidence that considerable remobilization of dry matter may occur from the stem of maize towards filling the ear up to two or three weeks after silking. They also suggested that dry matter continues to be stored in the stem during the first three weeks after silking due to inadequate ear sink.

2.3.4 Contributions of the various parts of the photosynthetic area to the production of dry matter after flowering

From the review in the previous sections it is apparent that most of the dry matter used for filling the grain of cereals is normally produced by assimilation taking place after flowering and during grain filling. A considerable number of studies had been carried out with a number of crops to determine the absolute and relative contributions which various parts of the photosynthetic organs of plants make to the final dry matter accumulated in the grains. Most workers have measured these contributions as a part of the difference in weight between control plants and plants in which the part was removed or shaded, or as an increase in weight when only the part in question was allowed to photosynthesize. The techniques of Doonstra (1929) and Smith (1933) working on wheat; those of Watson and Norman (1939) working with barley showed the prominent role of the ear in its own growth and development. In these plants the ear contributes between 30 - 50% of its own weight after emergence. Their studies showed the contributions made by the leaves, both laminae and sheaths, to be of similar magnitude to that of the ear. Doonstra reported that most of the contributions from the leaves came from the top four leaves present. It was also reported by Porter et al. (1950) that the contribution of the flag leaf to the ear weight of barley was of the same magnitude as that of the ear itself - each contributing about a third of the dry matter in the grain.

While for barley, wheat and rice there is evidence that up to about 60% of the ear weight is jointly contributed by the flag leaf and the ear itself, results of experiments with crops such as sorghum and maize suggest that leaf lamina is the chief source of dry matter for filling the grain. Complete leaf removal at about flowering has led to severe decreases in the grain yields of sorghum (Li and Liu, 1935; and Stickler and Pauli, 1961).

Duncan (1930, 1942) found that removing maize laminae soon after flowering caused severe reduction in grain yield suggesting that laminae supplied most of the dry matter to fill the grain. In maize as in sorghum, studies by Kurbator and Dovnar (1960), Prime (1960), Hoyt and Bradfield (1962) and Rottray (1962) showed that the upper leaves make substantially greater contribution to dry matter production of grain than lower leaves, eventhough Loomis (1935) found that the contribution to dry matter and grain yield of a given area of lower leaves was equal to that of upper leaves at equal illumination. In many studies such as the one by Van Dijnatten (1963) on maize it was shown that contributions made by leaf sheath and ear compared to that made by laminae were small.

2.3.5 Sink-source relationships

In the previous sections the importance of the assimilatory system to yield was reviewed. It was shown that yield may be limited by the source of the photosynthates. In more recent postulates, it was shown that the yield may also be limited by the size of the economic sink (e.g. head, ear) in which assimilates are stored. Most experiments on

the effects of defoliation showed that the reduction in the size of the photosynthetic system at silking resulted in less than proportionate decrease in the grain yield of maize. This suggests that the photosynthetic efficiency of the remaining assimilatory surface is increased after partial defoliation, and the increase in efficiency may be due partly to increased light to the remaining leaves. Just as the efficiency of the photosynthetic system is increased by reducing its size, studies have shown that the efficiency of the sink is increased when its size is decreased relative to the size of the source of photosynthates. Mc Allister and Krober (1958) reported the ability of two soybeans varieties to compensate for pod losses of 22% and 17% by an increase in seed weight of the remaining seeds. Singh and Colville (1962) reduced the size of heads in sorghum and noticed an increase in the test weight of the seeds. They reported only 13% reduction in grain yield when sorghum head size was reduced by half during booting and heading stages. Devit (1959) showed that when the sink capacity of potato plants was reduced by removing tubers, the photosynthetic rate was also reduced. Goldsworthy and Tayler (1970) showed that the lack of yield response to better crop husbandry by the tall local sorghum varieties in northern Nigeria was principally due to the limited capacity of the heads to store assimilates. Results of experiments by Allison and Watson (1966) showed that movement of carbohydrates into the grains of maize was determined by the capacity of the grains to accept it.

Moss (1962) showed that when grain formation is prevented the assimilates in maize accumulate in the leaves resulting in slowed photosynthetic activity. Adelana and Milbourne (1972) reported that after removing 30% ears of two maize varieties, grain yield was reduced by only 19% and 3% respectively. They found that the storage sink and the capacity of the ear responded by increase in the weight of grain.

The various investigations on sink-source relationships considered that the distribution of metabolities between the source and the sink is controlled by the gradient between them (Tanaka et al., 1966). The rapidity of assimilate movement towards a given sink was determined by the steepness of the gradient and the gradient is made steeper by the unloading or removal process at the sink. Investigators have however found it difficult to decide whether it is the source of assimilate or the storage capacity that is restricting the yield in any given situation. Reevers (1969), and Tanaka (1972) agreed that in source-sink relationships there is a complex interaction in which the photosynthetic rate of the source appears to be very closely related and regulated by the demand of the sink.

2.3.6 Pattern of metabolites translocation

Defoliation and shading techniques have for many decades been used to measure the contributions of the various parts of the assimilatory system to yield of economic plants especially cereals. Techniques using

radioactive carbon-^{14}C, have been added and used to study pattern and efficiency of translocation of assimilates in plants. Some investigations have so far shown that after flowering the upper leaves of maize exported carbon principally to the ear (Palmer, 1969, Tanaka 1972). Other studies (Palmer et al. 1973, and Tripathy et al. (1972) have shown that even though ultimately the principal sink of assimilated carbon after flowering is the ear, the position of the leaf relative to the developing ear strongly influenced the rate of translocation. The use of ^{14}C technique has also shed some additional light to the understanding of the source-sink theory. The study of Palmer et al. (1973) showed that maize plants which had partly fertilized ears accumulated larger quantities of ^{14}C in the stem and roots than plants which had completely fertilized ears.

2.3.7 Effect of plant density on dry matter production

Enormous literature on the effect of plant density on dry matter production and distribution in many economic crops has been published. Investigations in this area are concerned not only with fundamental information on growth and development of an individual plant within a crop community but also with the equally important aspect of growth and development of the crop community as a whole. This is because in practice farmers are more concerned with the behaviour and performance of a group rather than with individual plants. Results of these investigations are variable and many times contradictory depending

on the crop species, and genotypes within species or varieties, and the environmental factors which include level of fertility, moisture availability and solar energy.

Several investigators (Bond et al., 1964; Colville and McGill, 1962; Carmer and Jacobs, 1965; Stickler, 1964) have reported decreases in yield both of grain and stover per plant as the number of plants per unit area increased but the total dry matter produced per unit area may and generally did increase. For crops that are grown for their total dry matter the advantage of high plant density seems obvious. But many economic crops are grown for only a specific plant part, and for cereals such as wheat, rice, sorghum and maize, they are grown primarily for grain. Literature is generally consistent that the density for maximum dry matter production of cereals is generally higher than the optimum density for grain yield.

Sielinger (1926) investigated the effect of plant density on grain yield of tillering and non-tillering varieties of sorghum. He reported different optimum plant densities at which the two types gave their best grain yields. Tillering types yielded better at low densities while the non-tillering varieties had greater yields at relatively high densities. Karper (1929) reported similar results to Sielinger's from experiments with various sorghum varieties over a ten year period. He pointed out that the different varieties of sorghum may require different plant densities to produce optimum yields. He also attributed the differences in optimum plant densities of sorghum varieties to differences in their tillering capacities. Goldsworthy and Tayler (1972) studied the

effect of plant spacing on grain yield of tall and dwarf sorghums at Samaru, northern Nigeria. In both varieties the grain yield per plant was two to three times larger at 24,000 plants/ha than at 135,000 and 247,000 plants/ha. This yield advantage was due to more grain per plant at the lower population. Ikeda and Nakagama (1971) studied the interaction between plant density and nitrogen on the yield of twelve American sorghum cultivars. They reported optimum grain yield at 49,000 plants/ha. In another study Atkins et al. (1968) reported that short (4-dwarf) grain sorghum hybrids yielded 11% more in 76 centimeter rows compared to 102 centimeter row spacing; but in both row spacings a plant population of 215,000 plants/ha produced the highest grain yield. From this review on sorghum, it is clear that optimum plant densities vary with genotype from as low as 24,000 plants/ha for the tall long season varieties such as reported by Goldsworthy and Tayler (1972) to as high as 215,000 plants/ha for double dwarf sorghum hybrids in the United States of America.

Duncan (1958) found that grain yield of maize plants decreased not only with increasing plant density but due to other factors such as soil fertility, soil moisture and genotype. He carried out a series of experiments on widely different soil types and with various levels of fertilizers in the corn belt of the United States. He reported yield differences resulting from increasing plant density from 19,000 plants/ha to 59,000 plants/ha ranging from a loss of 1425 kg/ha on low fertility to a gain of 4066 kg/ha on high fertility. He also found

that the late-maturing hybrids out-yielded the medium-maturing hybrids up to 39,000 plants/ha beyond which there was no significant difference between the late-and medium-maturing hybrids. Lang et al. (1956) found that initially as yield/ha was increased due to increase in plant density, there was gradual though less proportionate reduction in the weight of ears per plant up to the density corresponding to maximum grain yield per hectare. Beyond this population there is a sharp decline in the grain yield per plant.

Termude et al. (1963) studied the effects of population on yield and maturity of corn hybrids in the Northern Great Plains of the United States. They reported optimum plant population ranging from 28,000 to 39,000 plants/ha. Wooley, Bracco and Russel (1962) found that growth attributes were influenced more by plant population per se than by pattern of sowing.

2.4 Effect of sowing date

Investigations on date of sowing cereals particularly millet, sorghum and maize in Nigeria and other countries have been reported (Curtis, 1967; Andrews, 1973; Allan and Musianga, 1973; Cooper, 1972). It has been observed that in many tropical regions these important cereal crops give higher grain yields when sown with the early establishment of the rainy season than say successive later sowings. In areas with short growing seasons this decline in yield is obviously caused to a great extent by deficit of moisture at the end of the growing period. However even in areas with long rainfall seasons where late sown crops do not

suffer such water deficits, similar decline in yields have been caused by delayed sowing. Allan and Musianga (1973) found that in the long rainfall season areas of western Kenya these declines have been as much as 70 - 80 kg/ha for every day's delay in sowing maize after the establishment of the rains. Grays (1972) reported similar trends as with maize in south west Kenya where he showed that the decrease in yield due to delay in sowing was prevented by top-dressing with nitrogen. In the northern part of Nigeria with its distinctive dry and wet seasons, and where all of Nigeria's millet and sorghum are produced, similar phenomenon of reduced yield due to late sowing was reported by Curtis (1967) and Andrews (1973) both of whom worked with sorghum. Kassam and Andrews (1974) reported a loss of 380 kg/ha. of grain in sorghum for every week's delay in sowing at Samaru after May 26. Although literature and observations on the advantages of early sowing of cereals is considerable, there has been relatively little information on the fundamental reasons why this is usually so. In northern Nigeria part of the explanation for reduced yields of late sown sorghum is sue to loss of sorghum stands as a result of attack by the shoot fly (Atherigona spp.). This is in addition to the water deficit during grain filling after flowering which coincides with the end of normal rainy seasons.

Inconclusive and rather inconsistent experimental evidence suggests other possible causes of reduced yields

when sowing is delayed. Experiments (Cooper, 1970) which relate the characteristics of maize plant to the climatic and soil conditions at the beginning of the growing season suggest that under tropical conditions maize sown at the start of the rains is put into moist, well aerated, warm soil, and grows through the most critical first five to six weeks under the most favourable conditions. Maize planted later on is put into wet, poorly aerated, cooler soils and therefore experiences unfavourable conditions during this critical stage of growth. This may cause a severe check on early growth from which the plant never fully recovers. In the long rainfall season areas of Kenya the decline in yields due to late sowing was reported to be due to poor soil aeration in the early stages of growth of late sown maize. In the short rainfall season areas late planted maize can suffer from this effect as well as from water deficit later in the season. More recent work by Kowal and Kassam (1974) suggested that the causes in yield variation for both early and late sown cereals could be further complicated by the sensitivity of the various phases of plant development to water stresses which may occur regardless of whether rains per se were late or early in the season.

Stockinger and Jones (1973) attributed reduced maize yields with lateness in sowing to shortage of nitrogen during the grain filling phase which occurs as a result of leaching between sowing and flowering.

CHAPTER 3

MATERIALS AND METHODS

The experiments were conducted at the Samaru station ($11^{o}11'N$ and $7^{o}40'E$) of the Institute for Agricultural Research of Ahmadu Bello University in northern Nigeria. The 45 year mean annual rainfall at Samaru is 1093 mm of which about 90% falls between the months of May and October. Average annual minimum and maximum temperatures at Samaru are $69.3^{o}F$ and $87.1^{o}F$ respectively and remain relatively steady during the growing season - between May and October (Kowal and Knabe, 1972). The vegetation is of northern guinea savanna which has been described by Keay (1953). Soils are generally of aeolian deposit overlaying the basement complex (Pullan, 1968).

3.1 1972 Season

3.1.1 Experiment 1 - Genotype x population

Maize Bulk $_{3-096}$ synthetic variety, Biu Yellow x C_{10} hybrid, and improved local variety - Bomo Local - were planted on the 17th of May, 1972 on a portion of agronomy farm which had been under grass-legume ley for about fifteen years. The field was ploughed and 896 kg/ha of 21-14-14 compound fertilizer, equivalent to 188, 125 and 125 kg/ha of N, P_2O_5 and K_2O, respectively, were broadcast and disked in. Sowing was by hand on the flat. The experiment was a split-plot design with the genotypes in the main plot

and plant populations completely randomised in the sub-plots. A uniform plot size of 7.3 x 10.1 m was used. Two row spacings - 91 and 61 cm; and three within-row spacings - 56, 28 and 20 cm were used to give populations of 19, 570; 38, 140; 57, 710; and 78, 280 plants/ha after thinning to one seedling per stand two weeks after emergence. About the fourth week after emergence some plants showed apparent symptoms of zinc deficiency. Zinc sulphate solution was sprayed on the whole experiment at the rate of 11kg of zinc/ha. Plots were clean weeded by hand hoeing three times between sowing and tasseling.

3.1.2 Measurements and records

3.1.2a Dry matter accumulation and its distribution

From the time of 75% silking and thereafter at two weeks interval until physiological maturity (black layer formation at the placental region of the cob), five plants from each plot, randomly selected from rows other than the guard and two centre rows, were cut at ground level and taken to the field laboratory for growth analysis. Because of the relatively small proportions of sampled to total number of plants in the plots, the random nature of the samples, and the stage of development at the time of the first sample, it was reasonable to assume that the growing conditions, especially light distribution in the canopy of the crop, were not materially altered by the sampling to significantly affect the parameters measured in this

growth analysis study. Each plant was separated into leaves, stem (including leaf-sheaths and tassel), top ear and bottom ear. Third ear which occurred occasionally was bulked with the stem. Similar plant parts from the five plants of each plot were bulked to record the total fresh weight. Sub-samples (about 10% of the fresh weight) of the leaves, stems and ears were dried in a forced draught oven until there were no changes in weight. It was necessary to chop the stems before sub-samples for drying were taken. The date of 75% silking which marked the first sample date was different for the three genotypes; so varietal comparisons in post flowering development were between equivalent stages of post-flowering development of the genotypes which did not necessarily occur at the same time.

3.1.2b Folliage area measurement

(i) Leaf area

Leaf area was determined from the leaf dimensions of length and maximum width. The relationship between lamina area and lamina dimensions is of the form:-

Area = length x maximum breadth x k

where k is a correction factor. A seperate k was estamated for each variety using samples of laminae from plants taken in all plots at the time of silking. The sampled laminae were phototraced on light sensitive paper and their actual area was determined with a hand

planimeter. Regression analyses were run between the products of length and breadth and actual lamina area. It was found that for the hybrid and the synthetic variety the estimates for k were virtually identical at 0.77. The k value for the local variety was 0.80. In this study it was not necessary to further relate actual area with dimension measurements after silking because the leaves were already fully expanded.

For the leaf area estimation per plant, five intact plants randomly selected from the two centre rows of each plot were used, and the length and width of laminae on each plant were recorded. At subsequent fortnightly intervals the number of live and dead leaves were recorded until physiological maturity. A leaf was regarded as being dead when it had lost more than 50% of its green surface.

(ii) Sheath area

Leaf sheath area was calculated from the measurements of the circumferences of the bottom-most and top-most sheath and the length of stem between the two sheaths. The product of the average circumference of the plant and the length of stem is the estimate of sheath area of the plant. Plants used for foliage measurement were used.

3.1.2c Leaf number

At silking individual green leaves on each of the five randomly selected plants from each plot were counted.

3.1.2d Plant height

Plant heights of the five plants used for lamina area measurements were recorded. It was measured from the ground level to the tip of the tassel.

3.1.2e Ear height

Ear height was recorded from the five plants used for leaf area measurements. It was measured from the ground level to the node at which the top-most ear was attached.

3.1.2f Lodging counts

On the day of harvest the number of lodged plants in each plot was counted. A plant was regarded as lodged if the angle between the stem and ground was less than 45^{o} or if the stem was broken below the ear.

3.1.2g Grain yield

Ears from plants in the two centre rows of each plot were harvested after lodging count was taken. Top and bottom ears were kept separate. After removing the husks, the ears were air dried to about 20% moisture. At this stage the ears were weighed. Shelling percentage was determined from sub-samples of about 5kg while exact moisture content was determined from oven dried samples. Final grain weight was adjusted to 12% moisture.

The number of grains per ear and per 100 gm weight was determined.

3.1.2h Analysis of major nutrients

Sub-samples dried for dry matter measurement were

ground to pass a 40 mesh sieve for nitrogen analysis. Total percent N was obtained by kjeldhal method.

3.2. 1973 Season

In 1973 the same maize genotypes as the ones described under experiment 1 in 1972 were used.

3.2.1 Experiment 2 - genotype x sowing date x nitrogen

The optimum plant density obtained from the 1972 trial - 38,570 plants/ha - was used to examine the effects of date of sowing and top dressing with nitrogen at tasseling on the post flowering development of the three maize genotypes. The first sowing was on 13th June. The second and third sowings were on 27th June and 11th July respectively. Sowing, was by hand and on the flat. All plots received a blanket application of 896 kg/ha of 21-14-14 compound fertilizer at sowing. At tasseling half of each plot received an additional 56kg/ha N applied as Nitrochalk (Calcium Ammonium Nitrate, 26%N). The additional N was placed on the surface as near the plant as possible. The design of the experiment was a split-split-plot with date of the sowing in the main plots, genotypes in the sub-plots and top-dressing with nitrogen in the sub-sub-plots. The treatments were replicated three times. Plot size was 7.3 x 10.1m. Measurements for dry matter, foliage area, plant height, ear height, grain yield and nutrient content of the plants were as described under experiment 1 in 1972.

3.2.2 Experiment 3; Sink-source relationships

3.2.2a Leaf and ear clipping study

In another split-plot layout treatments were applied to investigate the relationships between the major source of photosynthesis - the leaf lamina - and the major sink for these assimilates - the ear. Sowing was on the flat and by hand on 13th June. The plots received 896 kg/ha of 21-14-14 compund fertilizer at sowing. The maize genotypes were in the main plot and the following treatments were randomised in the sub-plots about one week after 100% silking:-

Treatment

A - Intact plants - control

B - Ears were removed

C - All laminae removed

D - About 50% reduction in a lamina area.
All leaves were clipped to half size.

E - About 50% reduction in lamina area.
Alternate laminae were removed.

F - About 50% reduction in ear size.
The top half of the fertilized ear was carefully excised and extracted from the husk leaving the bottom half. After removing the top half, the husks were closed back and celltaped to protect the remaining half of the ear from pathogens and insects.

At the time of treatment five plants were sampled from each of the four control plots of each variety to

determine total dry matter of plant parts and its distribution between stem (including leaf sheaths and tassel), ears and leaves. Leaf area, number of leaves per plant and plant height were measured. No more samples were taken in this experiment until physiological maturity when a twenty plant sample was taken from treated and control plots to determine grain yield and dry matter of plant parts.

3.2.2b Translocation of ^{14}C study

Plants in the control plots of the experiment were selected for feeding with $^{14}CO_2$ on two dates. The first feeding at about 75% silk and the second three weeks later. At first feeding the index leaf (the leaf sub-tending the top ear) of each of the eight plants selected was allowed to assimilate $^{14}CO_2$ for 4 hours. The $^{14}CO_2$ (20 uCi) was generated in an assimilation chamber by adding in hydrochloric acid in excess to an acqueous solution of $Na_2\ ^{14}CO_3$ as illustrated in fig. 1. The chamber which was 40 x 8 cm and cylindrical in shape was constructed from 'Melinex' polyester film (50 microns thickness). One end of the chamber was closed and the open end was lined with 0.6cm thick strip of polyuerethrane foam to improve the seal. A small glass tube was fixed inside the assimilation chamber such that its open end was towards and about 2cm below the closed end of the chamber. At the time of feeding about half the length of the leaf was introduced into the assimilation chamber and the open end of the chamber was tightly closed using two

aluminium strips which could be screwed together. The $Na_2{}^{14}CO_3$ solution was introduced into the small glass tube by piercing the sealed end of the chamber with a hypodermic needle fixed to an 'Agla' micrometer syringe. Another syringe and needle was used to introduce the excess acid to the carbonate after which the needle hole was immediately closed with a strip of cellotape. All feeding was done between 1000 and 1200 hr. local time. At the second feeding the same procedure as in the first feeding was used except that eighteen plants were chosen and divided into two groups of 9 plants each. In one group the top-most leaf (flag leaf) was fed and in the second group the index leaf was fed.

Twenty-four hours after feeding, the treated plants were harvested at ground level and were seperated into the following parts for the ^{14}C determinations:-

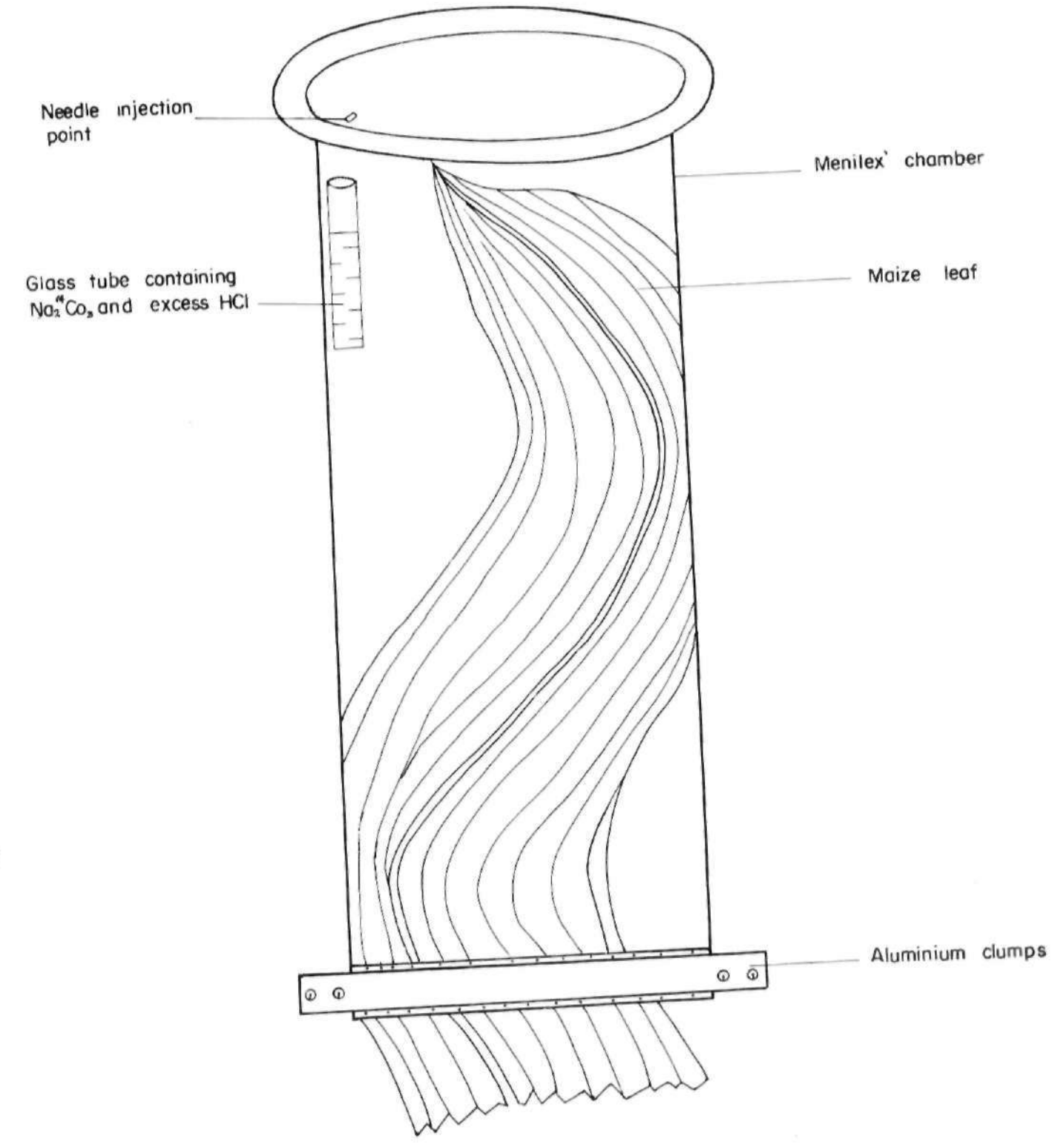
1. Index leaf (IL)
2. Flad leaf (FL)
3. Top ear (TE)
4. Bottom ear (where one was found) - (BE)
5. Leaves above the top ear (TLS)
6. Leaves below the top ear (BLS)
7. Top portion of the stem above the node of the top ear. (TC)
8. Bottom portion of the stem below the node of the top ear (BS)

The plant parts were oven dried until there was no change in weight. The dried samples were weighed and finely ground with Wiley mill to pass through a 40 - mesh sieve.

Radioactivity of dried tissue was assayed by counting technique using a thin end window Geiger tube (2B2) and a panax autoscaler P7603A. In all cases the background count was taken and subtracted from the gross count of each sample to obtain net activity. The count per milligram per minute (Specific activity) was calculated. The specific activity multiplied by the total dry weight of the sample in milligram gave the total count. The relative distribution of ^{14}C in each part of the plant was expressed as the percentage of the total radioactivity in the whole plant.

FIG·I

ILLUSTRATION OF $^{14}Co_2$ ASSIMILATION CHAMBER USED IN ^{14}C ASSIMILATION STUDY



G·S·N· 1988a

3.3 Growing condition - Climate

Total rainfall and its distribution, for the two years of the experiments are presented in table 1 and illustrated in fig. 2. In both years total rainfall was below the 45 year average. Early establishment of rainfall in 1972 made early sowing possible on 17th May. In 1973 rainfall was established in the second week of June and the first planting was only possible around the middle of June - about 4 weeks later than 1972 sowing. However in 1972 rainfall cessation was early, and evaporation was greater than rainfall in the first decade of September rather than the third decade of the same month in a normal growing season.

In addition to those used to describe the defoliation treatments (section 3.2.2b above) the following codes were used throughout this thesis to describe the various other treatments in this study:-

Plant Population (1972)

Code	
P1	19,570 plants per hectare
P2	39,140 " "
P3	58,710 " "
P4	78,280 " "

Varieties

V1	Improved Bomo Local
V2	Biu Yellow x C10 hybrid
V3	Bulk 3-096 Synthetic variety

Code	Sampling Date
S1	First Sample at silking
S2	Second Sample 14 days after the first
S3	Third Sample 28 days after the first

	Planting Date (1973)
D1	First Planting - 13th June, 1973
D2	Second Planting - 27th June, 1973
D3	Third Planting - 11th July, 1973

Table 1 Rainfall Distribution Pattern for 1972 and 1973

Compared with 45 - Year mean (mm)

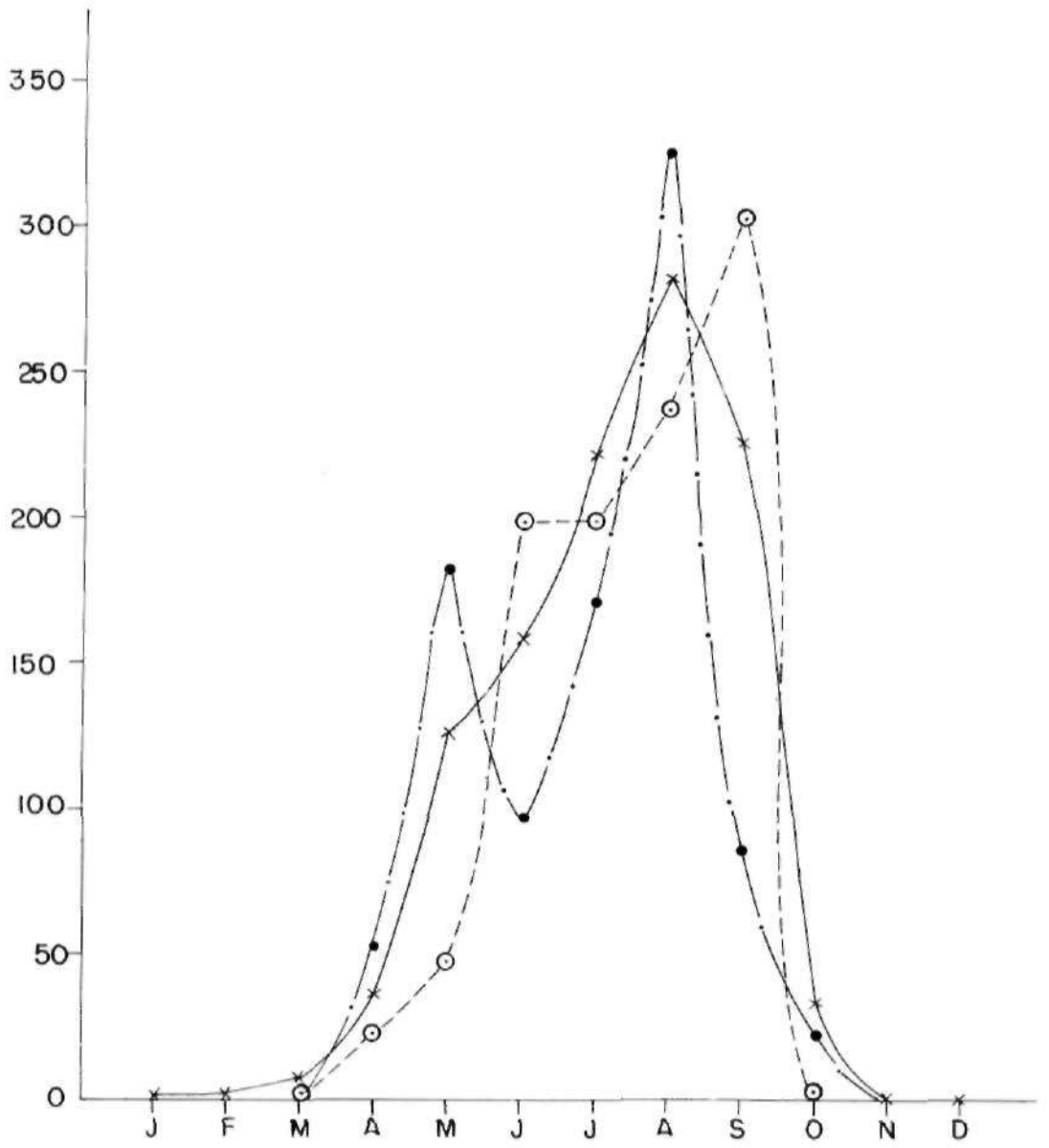
	Period	Rainfall		45-Year mean
		1972	1973	
Jan.	1 - 10	-	-	
	11 - 20	-	-	
	21 - 31	-	-	0.2
Feb.	1 - 10	-	-	0.2
	11 - 20	-	-	0.5
	21 - 28	-	-	0.8
March	1 - 10	-	-	0.5
	11 - 20	0.2	-	4.1
	21 - 31		0.5	2.5
April	1 - 10	9.4	-	6.9
	11 - 20	25.9	22.4	9.4
	21 - 30	16.0	-	19.3
May	1 - 10	46.2	5.0	32.3
	21 - 31	99.6	37.2	58.7
June	1 - 10	30.5	110.6	44.4
	11 - 20	18.0	0.3	56.9
	21 - 30	47.2	68.4	58.2
July	1 - 10	65.0	62.0	57.7
	11 - 20	38.6	47.3	70.6
	21 - 31	68.3	90.0	93.2
August	1 - 10	124.5	83.4	85.1
	11 - 20	91.2	84.0	87.4
	21 - 31	109.5	69.2	110.0

	Period	Rainfall		45-Year mean
		1972	1973	
Sept.	1 - 10	11.2	222.8	93.0
	11 - 20	21.8	44.9	30.5
	21 - 30	52.3	36.4	51.6
Oct.	1 - 10	19.1	1.6	21.6
	11 - 20	5.1	-	9.7
	21 - 31	-	-	3.3
Annual Total		934.4	1012.6	1093.1

FIG·2

MONTHLY RAINFALL DISTRIBUTION AT ZAMARU RESEARCH STATION IN 1972 & 1973 AND THE 45 YEAR — MONTHLY MEAN (m,m)

Scale 1cm ≡ 25mm



1972 represented by —·—

1973 " " – – – –

45 year-mean " " ——

G·S·N·1988b

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Grain yield and dry matter production - Experiment 1

Grain yields per hectare from experiment 1 were based on plants harvested from the two centre rows of each of the experimental plots. These are summarised in Table 2. Analysis of variance showed significant yield differences among genotypes and between plant populations. There was no significant interaction effect between genotype and population on grain yield. Increase in plant population from P_1 to P_2 increased the grain yield of the three genotypes significantly. Further increases in plant population to P_3 and P_4 produced grain yields which were not significantly different from those obtained at P_2 in all the three genotypes. At the lowest plant population the yields of the Biu Yellow x C_{10} hybrid and B_3-096 synthetic variety were not statistically different; but both genotypes gave significantly higher grain yield than Bomo Local variety. In P_2, P_3 and P_4 the genotypes gave grain yields which were significantly different among themselves. The highest grain yield was from Biu Yellow x C_{10} hybrid followed by the synthetic B_3-096 and Bomo Local varieties in that order. The effects of genotype and population on grain yield components are summarised in Tables 3 and 4. The number of seeds per cob in Bomo Local and B_3-096

varieties were not significantly different. Biu Yellow x C_{10} showed significantly greater number of seeds per cob than either the Bomo Local or the B_3-096 synthetic variety. The number of seeds per cob was 420.3, 549.8 and 426.5 for Bomo Local, the Biu Yellow x C_{10} hybrid and the B_3-096 synthetic variety respectively. This means that the average number of seeds per cob in the hybrid was 30.8% and 28.9% greater than in the Bomo Local and B_3-096 synthetic varieties respectively. The number of seeds per 100g. were 390.3, 339.6 and 302.7 for the local, synthetic and hybrid maize types respectively, and these were significantly different from each other. These yield components showed that the superiority in the average grain yield of the hybrid over the other two varieties was significantly due both to its greater number of seeds per cob and its heavier seeds in 1972. The superiority of B_3-096 synthetic variety over the Bomo local variety was attributed to its heavier seeds rather than by greater number of seeds per cob. The number of seeds per cob and the number of seeds per 100g. were not different between P_1 and P_2 each of which showed significantly greater number of seeds per cob than either P_3 or P_4 which were themselves not different in respect

of these yield components. This being the case the increase in grain yield resulting from increasing plant population from P_1 to P_2 was primarily due to increasing the number of ears per unit land area without reducing the number and weight of the grains produced by the ears of the individual plants. Failure to attain increased grain yield per unit land area by increasing plant population beyond P_2 as earlier reported (Table 2) was because of the significant reduction in the number and weight of grains produced per plant due to increased competition.

4.2 Growth of main shoot and component parts including leaf area changes

Change in total dry weight per plant between silking and physiological maturity are summarised in Tables 5 and 6. Changes in the weights of stem, ear and leaves are presented in Tables 7 to 14. The effects of plant density on total dry matter production per hectare are given in Tables 15 and 16. Total dry weight per plant decreased significantly with increase in plant population and this decrease is reflected by the decrease in the weight per plant of stem, ear and leaves as a result of inter plant competition when the plant population was increased. The results however showed significant increase in total dry matter produced per hectare when plant population was increased (Table 15). The total dry matter per plant or per hectare increased by about 52.5% between silking and physiological maturity. This increase was primarily due to the dry matter which was assimilated and stored in the grain after silking. Of secondary importance especially at the lower two plant populations was the significant

continued increase in the weight of stem in the first two weeks after silking. There was an initial increase in foliage dry weight soon after silking which showed a decline at physiological maturity. This ultimate decline in leaf dry weight was attributed more to mechanical rather than other causes when the leaves were dead. The results showed that at silking the proportions of stem, leaves and ears were 61.6%, 26.6% and 11.8% of the total dry weight respectively. At harvest the corresponding percentages were 33.2% 11.8% and 55.0% for stem, leaves and ears respectively.

The results so far generally concurred with earlier reports (Bond et al., 1964; Colvilie and McGill, 1962; Carmer and Jacobs, 1965; Stickler, 1964) on dry matter accumulation and its distribution in the maize plant after flowering; and the effect of planting density on the accumulation and distribution on the dry matter. It was shown that increased plant population caused significant reduction in the total dry weight per plant arising from reduction in dry weight of its component parts. The results also showed that total dry matter production per hectare was increased significantly by increasing plant density. This means that the loss in plant weight due to plant competition was more than compensated for by the total increase in dry weight arising from increased number of plants per

unit area of land. Dry matter assimilated after silking was diverted primarily to the developing grain. The weight of the ear at silking was for practical purposes considered to have consisted entirely of husk and ear sheaths since, from observation and the dry matter distribution data obtained in this experiment, the fertilized ovules had accumulated no measurable dry matter compared with the dry matter which was subsequently accumulated in the following six weeks.

Plant leaf areas and canopy leaf area indices for the four plant populations and the three genotypes are presented in Tables 17 - 20. Leaf area per plant attained at silking was reduced significantly by the increased plant density up to P_3, but plant leaf areas for P_3 and P_4 were not significantly different. Leaf area indices, however, increased with increased plant density. At silking LAIs for plant populations P_1, P_2, P_3, and P_4 were 1.99, 3.70, 4.99 and 6.53 respectively; and these were significantly different from one another. Between silking and maturity, as expected, the leaf area per plant and consequently the leaf area indices showed a gradual decline as the leaves aged and senesced. The rate of the decline during this period of grain filling was faster in higher than in lower plant densities. The higher rate of decline in leaf

area in high plant population was probably due to increased shading of the lower by the upper leaves as plant populations increased. Thus the relative duration of the leaf area per plant was greatest at lowest plant populations and vice-versa. But because the leaf area duration per plant did not decrease in the same proportion with increase in plant density, the total leaf area per unit land area increased asympotically with increase in plant density (Table 21). Given that the final dry matter accumulated in the grain is a function of the LAI and LAD, it could be expected that the highest grain yield should be produced at the highest planting density. As it turned out the yield of grain was not significantly increased by increasing plant density beyond a leaf area index of 3.70 at silking with a leaf area duration of 123.5. This could imply that beyond a LAI of 3.70, there was an under utilization of sunlight by the foliage at the lower part of the canopy profile which apparently remained functional at the expense of the upper portion of the plant profile. Thus visual estimation of the functionality of the leaf, as was the case in this study, had probably resulted in over-estimating the apparent duration of the leaves in respect of their positive contribution to dry matter stored in the grain.

There were significant differences among the genotypes in their leaf area indices at various stages of grain filling in 1972. At silking the tall B_3-096 synthetic variety which had the greatest number of leaves per plant, gave the greatest total leaf area per plant and of course the largest leaf area index. This variety was followed by the Biu Yellow x C_{10} hybrid and the improved local variety in that order. Although leaf area per plant and leaf area index at silking were higher in the synthetic variety than in the hybrid, the hybrid, ultimately at harvest, had greater leaf area per plant and leaf area index. Because of the faster decline in the leaf area of the synthetic variety it ultimately had the same leaf area duration with the hybrid. The superior yield of the hybrid over the synthetic variety must have been due to other factors such as the differential efficiency of the foliage or the ability of the grain (the sink) to accept assimilated dry matter. In fact the latter is more likely to be the important reason for the higher grain yield of the hybrid because the total stover weight of the synthetic variety was greater than that of the hybrid.

Table 2

1972: Interaction of population and genotype on yield of grain (kg/ha)

Plant pop./ha	Bomo Local	Biu Yellow x C_{10}	B_3-096	Aver.
19,570	2968	4657	4765	4130
38,140	4480	7740	6151	6124
57,710	4227	7430	6171	5943
78,280	4980	7328	5668	5992

LSD 0.05 = 520

Table 3

1972: Effect of genotype on seed weight and seed number/cob

	Seeds/cob	Seeds/100 g.wt
Bomo Local	420.3	390.3
Biu Yellow x C_{10}	549.8	302.7
B_3-096	426.5	339.6
s.e.	16.7	8.1

Table 4

1972: Effect of population on seed weight and number of seeds/cob

Population (Plants/ha)	Seeds/cob	Seeds/100 g.wt.
19,570	486.9	331.2
38,140	491.4	325.9
57,710	446.6	363.5
78,280	437.2	356.1
s.e.	16.8	8.8

Table 5

1972: Effect of variety on changes in total dry weight/plant over sampling period (gm)

Sample Date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	142.9	176.3	229.4	6.3
S_2	234.8	258.9	310.6	18.2
S_3	339.6	366.7	386.0	23.0
S_4	322.6	421.6	440.1	22.7

Table 6

1972: Effect of population on changes in total dry weight/plant over sampling period

	Plant population (plants/ha)				
Sample date	19,570	38,140	57,710	78,280	s.e.
S_1	235.1	195.9	165.7	134.7	10.5
S_2	355.1	310.9	218.4	187.9	17.6
S_3	497.7	414.5	282.9	235.4	19.7
S_4	556.2	426.6	316.9	269.4	21.4

Table 7

	Plant population /ha				
Sample date	19,570	38,140	57,710	78,280	s.e.
S_1	142.8	122.2	103.7	81.7	6.2
S_2	172.5	149.3	107.3	99.0	6.7
S_3	184.2	155.0	111.9	100.0	6.8
S_4	180.3	143.1	104.2	92.9	4.7
s.e.	8.1	7.1	3.4	4.3	

Table 8

1972: Effect of genotype on mean weight of stem per plant at different sample dates

Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	87.6	106.6	143.5	3.1
S_2	112.2	125.2	158.4	8.2
S_3	117.7	125.0	170.6	5.6
S_4	93.5	137.4	159.5	4.4

Table 9

1972: Effect of genotype on mean weight of leaves per plant at different sample dates

Sample date	Boro Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	37.7	47.3	58.9	2.1
S_2	43.9	49.0	59.1	1.6
S_3	45.3	51.9	62.2	1.5
S_4	35.3	47.4	52.7	1.2

Table 10

1972: Effect of population on mean weight (gm) of leaves/plant at different sample dates

	Plant population /ha				
Sample date	19570	38,140	57,710	78,280	s.e.
S_1	56.8	49.3	45.9	39.9	1.4
S_2	60.2	55.6	45.6	41.3	1.8
S_3	64.0	58.8	46.5	43.6	1.7
S_4	56.3	48.6	40.9	34.7	1.4
s.e.	1.9	1.4	1.0	0.9	

Table 11

1972: Effect of population on mean weight (gm) of top ear/plant at different sample dates

	Plant population /ha				
Sample date	19,570	38,140	57,710	78,280	s.e.
S_1	27.8	19.6	12.3	10.7	2.3
S_2	87.5	86.7	60.1	45.3	4.9
S_3	189.0	175.5	123.7	103.7	8.4
S_4	254.6	212.9	160.9	135.9	7.7
s.e.	8.9	5.8	3.7	4.2	

Table 12

1972: Effect of genotype on mean weight of top ear/plant at different sample dates

Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	13.9	18.6	20.3	1.6
S_2	63.5	75.2	70.9	3.0
S_3	135.3	175.6	133.0	14.3
S_4	173.9	224.0	175.0	8.7

Table 13

1972: Effect of genotype on mean weight of bottom ear per plant at different sample dates

Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	3.5	3.7	7.4	0.7
S_2	15.1	9.4	23.9	2.7
S_3	21.2	14.3	41.1	5.5
S_4	19.7	13.0	53.3	6.6

Table 14

1972: Effect of population on mean weight (gm) of bottom ear/plant at different sample dates

	Population /ha				
Sample date	19,570	38,140	57,710	78,280	s.e.
S_1	8.9	4.4	3.8	2.4	1.1
S_2	34.9	20.1	5.7	3.9	3.2
S_3	60.7	25.5	9.7	6.3	4.8
S_4	74.9	23.6	10.9	5.2	8.1
s.e.	7.1	5.1	2.1	1.5	

Table 15

Experiment 1: Effect of plant population on total dry matter production (metric tons/ha) between silking and physiological maturity

	Population /ha			
Sample date	19,570	38,140	57,710	78,280
S_1	5.07	8.44	10.71	11.98
S_2	7.65	13.40	14.12	16.71
S_3	10.73	17.87	18.29	20.93
S_4	12.20	18.39	20.49	23.95

Table 16

Experiment 1: Effect of plant population on the total and relative weights (tons/ha) of stem leaf and ear at silking and harvest

Sample date	Population (plants/ha)							
	19,570		38,140		57,710		78,28	
	Total Wt. (ton/ha)	% of Total Wt.	Total Wt. (ton/ha)	% of Total Wt.	Total Wt. (ton/ha)	% of Total Wt.	Total (ton/	
				Stem				
S_1	3.08	60.7	5.27	62.4	6.71	62.7	7.26	
S_4	3.89	31.9	6.17	33.6	6.74	32.9	8.26	
				Leaves				
S_1	1.22	24.1	2.13	25.2	2.97	27.3	3.55	
S_4	1.21	9.9	2.09	11.4	2.64	12.9	3.09	
				Ears				
S_1	0.79	15.6	1.03	12.2	1.04	9.7	1.16	
S_4	7.10	58.2	10.19	55.4	11.11	54.2	12.54	

Table 17

1972: Effect of genotype on leaf area index at different Sample dates

Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	3.91	4.35	4.65	0.14
S_2	3.19	3.61	3.78	0.14
S_3	3.06	3.39	3.46	0.09
S_4	1.74	2.46	2.21	0.20

Table 18

1972: Effect of population on leaf area index at different sample dates

	Plant Population /ha				
Sample date	19,570	38,140	57,710	78,280	s.e.
S_1	1.99	3.70	4.99	6.53	0.13
S_2	1.67	3.13	4.01	5.28	0.13
S_3	1.63	2.90	3.84	4.85	0.11
S_4	1.29	2.04	2.17	3.04	0.20

Table 19

1972: Effect of genetype on leaf area per plant (sq.cm) at Different dates of sample

Sample date	Bomo Local	Biu Yellow x C_{10}	B_{3-096}	s.e.
S_1	8113	9178	9873	273
S_2	6671	7606	8121	260
S_3	6361	6545	7576	203
S_4	3694	5714	5209	372

Table 20

1972: Effect of population on leaf area per plant at different dates of sample

	Plant population /ha				
Sample date	19,570	38,140	57,710	78,280	s.e.
S_1	10,202	9,437	8,502	8,072	232
S_2	8,513	7,983	6,833	6,535	225
S_3	8,289	7,386	6,545	6,001	229
S_4	6,604	5,209	3,915	3,764	441

Table 21

1972: Effects of plant population and genotypes on mean leaf area Duration (LAD) between silking and physiological maturity

	Genotype			Plant population /ha			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	19,570	38,140	57,710	78,280
LAD	125.2	144.9	148.3	69.3	125.5	157.5	207.1
s.e.				25.6			

4.3 Net assimilation rate and crop growth rate

Effects of plant population and genotype on net assimilation rate and crop growth rate in the 1972 growing season are summarised in Tables 22 and 23 respectively. Net assimilation rate which is dependent on leaf area index declined with increase in plant population. This is most probably because at higher populations the leaves especially at the lower profile were more shaded than at the lower plant densities. The higher net assimilation rates in lower plant densities did not however compensate for the bigger leaf area indices in the higher plant densities and consequently as has been shown in Table 23 the crop growth rates were bigger at higher than at lower plant densities. There was a sharp decline in the net assimilation rates and crop growth rates in the two weeks before the end of the grain filling period which was a reflection of the corresponding decline in the leaf area indices of the crop populations during the same period.

The differences between the net assimilation rates and the crop growth rates of the varieties after flowering is only partially accounted for by differences in their leaf area indices during the same period. For example the synthetic variety which had higher average leaf index during grain filling than either the hybrid or the local variety showed lower net assimilation rates and crop growth rates than the hybrid. This would mean that other factors and parameters beside, simple relationships

between net assimilation rates, crop growth rates and leaf area index are probably as important if not more important in explaining the differences in total dry matter production in maize varieties after flowering. It is suggested that the efficiency with which the canopy assimilates are more important determinants of the variability in the net assimilation rates and crop growth rates among maize varieties during the period of grain filling than the leaf area index.

Table 22: Experiment 1: Effect of Plant density and genotype on net assimilation rate during grain filling (g.sq.m/week)

Genotypes	Intervals between dates of sampling			
	S1-S2	S2-S3	S3-S4	Aver.
Bomo Local	59.1	60.8	1.7	40.5
Biu Yellow x C_{10}	47.8	74.0	40.1	53.9
B_3-096	44.0	59.5	15.4	39.9
Aver.	50.3	64.8	19.1	
Plant Population /ha				
19,570	63.9	85.3	40.0	63.1
38,140	67.9	57.6	14.5	46.7
57,710	35.2	66.3	11.1	37.5
78,280	34.2	49.9	10.6	31.6
Aver.	50.3	64.8	19.1	

Table 23: Experiment 1: Effect of population and genotype on crop growth rate during grain filling (g.sq.m/week)

Genotypes	S1-S2	S2-S3	S3-S4	Aver.
Bomo Local	209.8	190.3	4.2	127.9
Biu Yellow x C_{10}	190.2	259.0	87.4	169.5
B_3-096	185.7	215.4	43.7	119.2
Aver.	175.4	174.7	66.9	
Plant population /ha				
19,570	116.9	40.7	58.4	107.8
38,140	232.2	174.0	35.8	151.7
57,710	257.4	260.5	33.4	116.6
78,280	202.1	252.9	41.9	179.4
Aver.	175.4	174.7	66.5	

4.4. Grain yield and dry matter production - Experiment 2

Effects of date of sowing, genotype and top dressing with N on grain yield are summarized in Tables 24, 25 and 26 respectively. The grain yields of the first and the second dates of sowing were not significantly different between themselves but were each significantly higher than grain yield obtained from the third date of sowing. The decline in grain yield btween the first and the second, and between second and third dates of sowing were 10.0 and 75.7 kg/ha per day respectively. The average loss in the yield of grain between the first date of sowing (13th June) and the third sowing date (10th July) 1973 was 42.9 kg/ha per day. Average grain yields of the genotypes over the three dates of sowing showed that the grain yields of the hybrid, although substantially greater, was not significantly different from the yield of the synthetic variety. Both the hybrid, and the synthetic each had given grain yield statistically greater than that obtained from the local variety. Top dressing with N increased the average yield of grain from 2479 to 2638 kg/ha, but the increase was not significant.

The results confirm earlier findings (Curtis, 1967, Andrews, 1973; Allan, 1971; Kassam and Andrews, 1974) that in many tropical areas, especially in those areas with distinct dry and rainy seasons, maize like millet and sorghum generally give their best grain yields when sown soon after the rains are properly established,

rather than in later sowings. The results showed no significant interaction effects between date of sowing and top dressing with N on grain yield. Hence it is suggested that increased moisture shortage rather than shortage of available nitrogen after silking was a more important factor which adversely affected the vegetative and the post-flowering development of the crop resulting in reduced grain yield of later sowings. Tables 27 and 28 summarise the effects of sowing date and genotype on two major grain yield components - grain weight and number of grains per cob. In each date of planting differences in the grain yield of the genotypes can be explained by the differences in their grain weight and number of grains per cob. The hybrid, as in 1972 season, had heavier grains than the synthetic variety though the difference was not significant in 1973. Both the hybrid and the synthetic variety had significantly heavier grains than the local variety. Similarly the number of grains per cob was not different between the hybrid and the synthetic variety but they each had greater number of grains per cob than the local variety. The effects of date of sowing averaged over genotype showed no significant difference between the grain weight of the first and second dates of sowing. The grain weight however declined significantly in the third sowing date. The effects of genotype averaged over sowing dates showed no significant difference in the grain weights of the hybrid and the synthetic

variety both of which had significantly higher grain weight than the local variety.

Table 24

1973: Effect of sowing date on the average grain yield of three maize genotypes

Sowing date (1973)	Grain yield (kg/ha)
13th June	3006
27th June	2865
11th July	1805
s.e.	220

Table 25

1973: Effect of genotype on grain yield averaged over date of sowing

Genotype	Grain yield (kg/ha)
Bomo Local	1656
Biu Yellow x C_{10}	3241
B_3-096	2780
s.e.	215

Table 26

1973: Effect of top dressing with N at tasseling on grain yield

Level of N	Grain yield (kg/ha)
N_1	2479
N_2	2638
s.e.	147

Table 27

The effects of sowing date and genotype on the average number of grains/100g. weight (1973)

	Sowing dates					
	13th June		27th June		11th July	
	N_1	N_2	N_1	N_2	N_1	N_2
Bomo Local	466	396	587	563	685	627
Biu Yellow x C_{10}	359	348	333	348	442	417
B_3-096	378	353	369	399	515	452
s.e.	6.5		7.1		8.2	

4.5 Growth of main shoot including changes in leaf area

Changes in the total dry weight and of the component parts of the maize shoot as affected by variety, date of sowing and top dressings with N are summarised in Tables 29 - 43. At silking 57.0%, 21.0% and 22.0% of the total dry matter was in the stem, ear and leaf respectively. At harvest the corresponding distribution of the total dry matter in the plant was 38.0%, 48.0% and 14% in the stem, ear and leaves respectively. The study showed in-consistent and insignificant changes in the dry weights of the stem and leaves between silking and physiological maturity. As expected however the total dry weight increase observed after silking must have been as a result of the increase in the weight of the ear, the grain of which received the assimilated dry matter produced by the leaves during the grain filling phase.

The total dry matter produced, more than its distribution within a given sowing date, was significantly influenced by the date of sowing (Table 29). The first two dates of sowing showed no significant differences in their total dry matter production and not in its distribution among the main component parts of the shoot including the grain yield as reported above. The first two dates of sowing each statistically produced more dry matter per plant and per unit area of land than the third date of sowing. Since the relative distribution of the total dry matter produced within a sowing date was similar for all dates of sowing, the two earlier dates of sowing

produced significantly greater economic yield in the form of grains. The smaller dry matter produced in the component parts of the latest sown crop is reflected in the smaller plants which were produced due to delayed planting and the fact that the effective growing season of the crop in terms of rainfall was greatly reduced by delayed sowing.

Varieties differred significantly in their total dry matter and its distribution within the plant. Although the grain yield difference between the hybrid and the synthetic variety was not significant in 1973, the stover weight of the synthetic variety was significantly greater than that of the hybrid. Thus the grain yields of the hybrid and the synthetic variety were similar, but the synthetic variety had a lower harvest index than the hybrid. The synthetic variety grew much taller and had greater number of leaves per plant than either the hybrid or the improved local variety. The stover weight of the local variety as well as its grain weight were significantly lower than those of the hybrid and the synthetic variety.

Top dressing with nitrogen, did not significantly increase the total and component dry weights of the shoot. Since the grain yield was not significantly increased it means that the harvest index or the efficiency of grain production was not improved through top dressing with N.

Grain yields and total dry matter production for the first date of sowing in 1973 could be compared with those from P_2 in Experiment 1 in 1972 in order to bring

out differences between the two cropping seasons. It should be noted that in 1973 the total dry matter and grain yields were significantly less than those from comparable population of these genotypes in 1972. These differences were apparently attributed to the differences in growing conditions in the two seasons. Total rainfall received in both seasons were not significantly different, but the rains were established much earlier (by as much as 4 weeks) in 1972.

The effect of sowing date, genotype and top dressing with N on plant leaf area and leaf area index are summarised in Table 44 to 47. Plant leaf area and leaf area index were not significantly different between the first and second dates of sowing at silking either of which, however, had significantly higher leaf area index and plant leaf area than the third date of sowing at the silking stage. After silking the decline in plant leaf area, mainly due to leaf senescence and death, was fastest in the third date of sowing and slowest in the first sowing date. The significantly smaller leaf area per plant and leaf area index in the third sowing date at silking and the subsequent stages between silking and physiological maturity was as a result of smaller plants and relatively shorter favourable grain filling period arising from delay in sowing. The average effects of genotype over dates of sowing showed that at silking the synthetic variety had significantly higher plant leaf area and leaf area index than the hybrid

Table 29 Effect of Sowing date on total dry matter and Percent ear Weight during grain filling

Sowing date	Sample date	Total Dry matter/plant (gm)	Ear Weight (gm)	Percent Ear weight (HI)
	S_1	244.2	59.1	24.2
	S_2	334.4	141.9	42.4
13th June				
	S_3	414.7	237.4	57.2
	S_4	388.9	230.7	59.3
	S_1	271.2	75.0	27.7
	S_2	314.3	145.5	46.3
27th June				
	S_3	397.9	219.8	55.2
	S_4	355.3	186.5	52.5
	S_1	226.9	61.9	27.3
	S_2	255.2	107.4	42.1
11th July				
	S_3	268.8	137.9	51.3
	S_4	246.1	134.8	54.8

Table 30 Effect of genotype on total dry matter and percent ear weight during grain filling

Genotype	Sample date	Total Dry matter/plant (mg)	Ear weight (mg)	Percent Ear weight (HI)
	S_1	203.9	50.9	25.0
	S_2	263.3	114.5	43.4
Bomo Local	S_3	271.6	145.9	53.7
	S_4	272.0	149.3	54.9
	S_1	254.1	73.2	28.8
	S_2	313.2	142.7	45.6
Biu Yellow x C_{10}	S_3	389.0	216.7	55.7
	S_4	379.1	223.7	59.0
	S_1	285.5	73.0	25.6
	S_2	326.6	136.7	41.9
B_3-096				
	S_3	417.7	229.5	54.9
	S_4	413.6	242.5	58.6

Table 31 Effect of top-dressing with N on total matter and Percent ear weight during grain filling

Levels of Nigrogen	Sample date	Total dry matter/plant (gm)	Ear weight (gm)	Percent ear weight (HI)
	S_1	242.0	63.6	26.3
	S_2	300.8	132.0	43.9
N_1				
	S_3	363.1	203.5	56.0
	S_4	337.9	177.1	52.4
	S_1	253.1	67.2	26.6
	S_2	301.5	130.8	43.4
N_2				
	S_3	354.0	189.5	53.5
	S_4	343.9	192.4	55.9

Table 32

1973: Effect of sowing date on dry weight of stem/plant at different dates of sampling

Sample date	Sowing date 13th June	27th June	11th Jyly	s.e.
S_1	134.2	145.5	115.8	8.8
S_2	142.8	123.3	105.1	7.0
S_3	127.4	133.1	90.8	4.4
S_4	112.4	124.6	90.0	5.6

Table 33

1973: Effect of genotype on dry weight of stem/plant at different dates of sampling

Sample date	Genotype Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	110.2	130.0	155.3	6.4
S_2	107.4	122.7	141.1	6.5
S_3	91.3	123.1	136.8	5.8
S_4	90.4	109.9	126.7	6.1

Table 34

1973: Effect of top dressing with N at tasseling on stem weight at different dates of sampling

	Levels of Nitrogen		
Sample date	N_1	N_2	s.e.
S_1	127.7	136.0	5.3
S_2	122.5	125.0	5.7
S_3	116.1	118.0	6.2
S_4	116.8	117.3	6.3

Table 35

1973: Effect of genotype on top ear weight/plant at different sampling dates

	Genotype			
Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	39.3	53.8	49.0	4.2
S_2	85.3	110.2	99.5	7.1
S_3	108.7	178.3	158.9	7.2
S_4	134.9	164.4	148.4	6.9

Table 36

1973: Effect of date of sowing on top ear weight/plant at different sampling dates

Sample date	Sowing date			
	13th June	27th June	11th July	s.e.
S_1	42.3	53.8	45.9	5.9
S_2	103.5	107.1	84.4	9.3
S_3	165.1	165.0	115.8	6.8
S_4	169.9	156.2	121.6	8.1

Table 37

1973: Effects of top dressing with N on top ear weight/plant at different sampling dates

Sample date	Levels of nitrogen		
	N_1	N_2	s.e.
S_1	45.1	49.6	2.4
S_2	100.6	96.0	4.1
S_3	148.7	148.5	6.6
S_4	149.0	159.4	6.9

Table 38

1973: Effect of genotype on leaf weight/plant at different dates of sampling

Sample date	Genotypes			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	42.8	50.9	57.2	2.0
S_2	41.4	47.8	48.8	1.6
S_3	34.4	49.2	51.4	3.4
S_4	32.3	45.5	44.4	2.9

Table 39

1973: Effect of sowing date on leaf weight/plant at different dates of sampling

Sample date	Sowing date			
	13th June	27th June	11th July	s.e.
S_1	50.9	50.7	49.2	1.9
S_2	49.7	45.5	42.7	2.0
S_3	49.9	45.0	40.1	2.0
S_4	45.8	44.2	32.3	2.3

Table 40

1973: Effect of top dressing with N on leaf weight/plant at different dates of sampling

Sample date	Levels of nitrogen		
	N_1	N_2	s.e
S_1	50.7	49.9	1.4
S_2	46.3	45.7	1.4
S_3	43.5	46.5	1.9
S_4	44.0	44.2	2.0

Table 41

1973: Effect of genotype on the weight of bottom ear/plant at different sampling dates

	Genotype			
Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	S.e.
S_1	11.6	19.4	24.0	1.4
S_2	29.2	32.5	37.2	3.1
S_3	37.2	38.4	70.6	3.8
S_4	14.4	59.3	94.1	6.2

Table 42

1973: Effect of sowing date on the weight of bottom ear/plant at different sampling dates

Sample date	Sowing date			
	13th June	27th June	11th July	s.e.
S_1	16.8	21.2	16.0	1.4
S_2	38.4	38.4	23.0	3.6
S_3	72.3	54.8	22.1	7.9
S_4	60.8	30.3	3.2	7.3

Table 43

1973: Effect of top dressing with N on the weight of bottom ear/plant at different sampling dates

Sample date	Levels of nitrogen		
	N_1	N_2	s.e.
S_1	18.5	17.6	0.06
S_2	31.4	34.8	0.14
S_3	54.8	41.0	0.85
S_4	28.1	23.0	0.61

which in turn and at the same stage had higher plant leaf area and leaf area index than the Local variety. The rate of plant leaf area decline was such that by the end of the first two weeks after silking, there was no difference between plant leaf areas of the hybrid and the synthetic variety either of which, however, had maintained significantly higher plant leaf area than the local variety. From the fourth week after silking plant leaf area of the hybrid was significantly higher than either the synthetic or the local variety up to the point of physiological maturity. The results showed that top-dressing with N increased plant leaf area although the increase was not significant at any time between silking and maturity. The results on leaf area per plant provide an additional physiological basis for explaining the causes for the grain yield and dry matter production differences reported in this study among the genotypes and the differences between dates of sowing. The differences, though not significant, in the grain yields of the first and the second dates of sowing could be explained by both the small differences in their total foliage at silking, and only slightly earlier senescence and death of leaves in the second date of sowing. The large grain yield differences between the two earlier and the third dates of sowing could most probably be due to the significantly smaller foliage of the plant at silking, and even more important to the more rapid decline of the

photosynthetic apparatus of the latest sown crop. Four to five weeks after silking the functional foliage on the latest sown crop was virtually non-existent in all the genotypes. Thus the decline in grain yield resulting from delayed sowing reported in this study was due to two principal factors - first, delayed sowing caused a reduction in the total photosynthetic apparatus attained by the crop at the beginning of the grain filling phase of its development, and secondly, after silking the time needed to fill the grain was shortened by the earlier senescence and death of leaves of the late sown crop. The relatively small foliage produced at silking when sowing was delayed may have been due to the slightly earlier flowering of the later sown crop which in turn may have been induced by poor moisture conditions to which the plant had to adjust to complete its reproductive cycle before the end of the growing season.

Table 44

1973: Effect of sowing date on leaf area/plant (sq. cm) at Different sample dates

	Sowing date			
Sample date	13th June	27th June	11th July	s.e.
S_1	9413	9356	8116	406
S_2	7691	7098	5465	366
S_3	6235	6553	894	112
S_4	655	77	66	98

Table 45

1973: Effect of genotype on leaf area/plant (sq.cm) at different sample dates

	Genotypes			
Sample date	Bomo Local	Biu Yellow x C_{10}	B_3-096	s.e.
S_1	7898	9215	9772	220
S_2	5349	7552	7353	283
S_3	1183	5203	2938	113
S_4	48	778	56	112

Table 46

1973: Effect of top dressing with N on average leaf area/plant (sq.cm) at different sample dates

Sample date	Level of nitrogen		
	N_1	N_2	s.e.
S_1	8879	9045	146
S_2	6734	6769	231
S_3	2725	3025	122
S_4	166	237	70

Table 47

1973: Effect of sowing date on leaf area index at different dates of sampling

Sampling date	Sowing date		
	13th June	27th June	11th July
S_1	3.50	3.48	3.02
S_2	2.86	2.64	2.03
S_3	2.68	1.77	1.02
S_4	0.71	0.30	0.28
	Genotypes		
	Bomo Local	Biu Yellow x C_{10}	B_3-096
S_1	2.94	3.42	3.63
S_2	1.99	2.81	2.73
S_3	1.17	2.46	1.84
S_4	0.23	0.95	0.24
	Levels of nitrogen		
	N_1	N_2	
S_1	3.30	3.36	
S_2	2.50	2.30	
S_3	1.78	1.87	
S_4	0.41	0.52	

4.6 Plant and ear heights, leaf number per plant, leaf width length, lodging and date of flowering

Table 48 shows a summary of the dates of flowering from the dates of sowing as influenced by plant population, genotype, date of sowing and top dressing with N. Of the three genotypes included in this study, Bomo improved local variety had the shortest total growth cycle followed by the hybrid and the synthetic variety in that order. It was clear that the differences in the total growth cycle of these genotypes was largely due to differences in their dates of tasseling from sowing as all of them, when planted early in the season, had similar grain filling period of about six weeks after silking. Increasing plant density did not significantly affect the flowering date and thus the physiological maturity of the genotypes. Although the relative flowering dates of the genotypes was significantly shortened by delayed sowing, the relative maturity dates of the genotypes as indicated by date of flowering was not altered by delay in sowing.

The effects of genotype, population, sowing date and top dressing with N on some morphological characteristics of the plant both in 1972 and 1973 are summarised in Tables 49, 50 and 51. These figures which are averages from twenty plants in each treatment (five plants from each of the four replication) may be considered as fairly representive of the expression of the populations and genotypes under the growing conditions

in each season. Within each genotype ear and plant heights were not significantly affected by plant population. However plant and ear heights were significantly influenced by genotype both in 1972 and 1973 seasons. B_3-096 synthetic variety was the tallest variety and also had the heighest point of ear attachment; followed by Biu Yellow x C_{10} hybrid and Bomo Local variety in that order. These results are at variance with the findings of Colville and McGill (1962), Francis (1970) who, working in temperate regions, had reported significantly taller plants in more dense populations. Differences in radiation between tropical and temperate growing conditions might be responsible for the differences in the height response of plants growing in different plant densities in the two regions. Plant and ear heights were however influenced by date of sowing in 1973. Both of these morphological characteristics were not different between the first and second dates of sowing, but they declined significantly in the third sowing date. Plant and ear heights were not significantly affected by top dressing with nitrogen at tasseling. Tables 52 and 53 summarise the effect of plant density sowing date, genotype and top dressing with N on lodging. Stem and root lodging increased with increased plant density in all the genotypes which were themselves different in their root and stem lodging in both 1972 and 1973 seasons. Increased lodging with increased plant density was attributed to the smaller and weaker stems and

density. This decline was significant with each increase in population up to P_3 beyond which the decline was insignificant. This partially explained the significant decline in plant leaf area as plant density increased. That these growth parameters did not decline in proportion to the increase in plant density explained why the leaf area index increased with increase in plant density. The result showed significant variation among the genotypes in the number of leaves per plant, leaf length and leaf width. Both the hybrid and the synthetic variety had leaves which were similar in length and width, but the synthetic variety had significantly greater number per plant at silking than had the hybrid. This means that the greater leaf area of P_3-096 at silking was due more to its greater number of leaves per plant than to the width or length of its leaves. The Poro Local variety had similar number of leaves per plant at silking as the hybrid, but the leaves were significantly shorter and narrower than those of the hybrid. In this study the lateness in sowing had no effect on leaf length, but leaf width and number of leaves per plant showed a significant decline in the third date of sowing. This explained the difference in plant leaf area index as affected by sowing date. The number of leaves per plant, leaf length and leaf width were not influenced by top dressing with nitrogen.

Table 48 Effect of Plant density, genotype and sowing date on the date of 50% tasseling of Maize (days)

1972

Genotypes

Plant pop./ha	Bomo Local	Biu Yellow x C_{10}	B_3-096
19,570	53	62	71
38,140	53	61	70
57,710	52	62	71
78,280	53	62	71
s.e.		2.1	

1973

Genotype	Sowing date		
	13th June	27th June	11th July
Bomo Local	54	52	50
Biu Yellow x C_{10}	61	57	56
B_3-096	70	68	62
s.e.		2.4	

Table 49

1972: Effect of genotype on some morphological plant characteristic: at silking

Genotype	Plant Height (cm)	Ear Height (cm)	Leaf Length (cm)	Leaf Width (cm)	Leaf Number/Plant
Bomo Local	227.9	101.3	68.3	8.20	14.80
Biu Yellow x C_{10}	265.0	117.8	72.4	9.20	14.70
B_3-096	287.5	154.6	73.0	9.70	16.30
s.e.	4.6	3.8	0.76	0.24	0.24

Table 50

1972: Effect of population on some morphological plant characteristics at 50% silking

Plant pop./ha	Plant Height (cm)	Ear Height (cm)	Leaf Length (cm)	Leaf Width (cm)	Leaf Number
19,570	258.1	119.5	76.9	10.2	16.4
38,140	265.0	128.1	72.0	9.1	15.9
57,710	262.6	128.4	68.5	8.5	15.2
78,280	254.9	122.3	67.4	8.4	14.8
s.e.	6.7	4.4	1.6	0.25	0.27

Table 51

1973: Effect of genotype sowing date and top dressing with N on some morphological plant characteristics at

Genotype	Plant Height (cm)	Ear Height (cm)	Leaf Length (cm)	Leaf Width (cm)	Leaf Number/plant
Bomo Local	218.9	100.4	71.3	8.7	13.1
Biu Yellow x C_{10}	260.0	118.9	73.8	9.8	13.7
B_3-096	289.8	158.2	82.7	8.9	14.4
s.e.	4.4	3.7	0.97	0.16	0.20
Sowing date					
13th June	258.6	126.0	75.5	9.1	14.7
27th June	261.0	126.2	76.9	9.3	13.5
11th July	209.5	97.1	75.3	8.8	13.0
s.e.	7.2	4.9	2.24	0.24	0.30
Levels of nitrogen					
N_1	245.2	118.1	76.6	9.2	13.8
N_2	239.1	115.0	75.3	9.0	13.7
s.e.	2.60	2.10	1.27	0.13	0.18

Table 52

1972: Effects of plant density and genotype on lodging percentage

Plant Population/ha	Genotypes		
	Bomo Local	Biu Yellow x C_{10}	B_3-096
19,570	17.5	7.0	28.7
38,140	22.9	12.4	42.3
57,710	48.5	27.0	64.5
78,280	49.1	32.1	70.9

s.e. 4.9

Table 53

1973: Effects of date of sowing, genotype and top dressing with N on lodging

Sowing date			
13th June	27th June	11th July	s.e.
30.4	26.5	21.6	2.8
Genotype			
Bomo Local	Biu Yellow x C_{10}	B_3-096	
20.5	19.1	39.1	3.6
Levels of nitrogen			
N_1	N_2		s.e.
25.7	26.6		1.8

4.7 Nutrienal study - N uptake

In Tables 54 to 57 the effects of population, genotype, sowing date and top-dressing with N on the nitrogen uptake of stems, leaves and ears at silking and at harvest are summarised. The results showed that at silking N content of stems was not affected significantly by differences in plant population. The N content of stem was also not affected by plant population at harvest although there was a significant decline in N content of stems from silking to harvest. The N content of stem decreased by 31% at harvest compared to that at silking stage. The average N content in the stem at silking and at harvest was 0.95% and 0.66%

respectively. The N content of leaves both at silking and at harvest was significantly affected by plant population. There was a significant decline in the N content of leaves when plant population was increased from P_1 up to P_3 beyond which the decline was not significant. The average N content of leaves at silking was 2.39% but this declined to 1.14% at harvest. Percentage nitrogen in the ear at silking and, at harvest was statistically the same and in each case its level was not significantly affected by plant population. The average N content of the ear

Table 54

1972: Effect of population on percent N in different parts of the plant at silking and at harvest

Plant pop. per ha	Stem		Leaves		Ears	
	Silk	Harvest	Silk	Harvest	Silk	Harvest
19,570	1.05	0.62	2.55	1.33	1.49	1.39
38,140	0.87	0.66	2.47	1.20	1.42	1.47
57,710	0.98	0.70	2.33	0.98	1.14	1.30
78,280	0.89	0.64	2.21	1.03	1.48	1.33
s.e.	0.09	0.08	0.06	0.08	0.10	0.06

Table 55

1972: Effect of genotype on percent N in different parts of the plant at silking and at harvest

Genotype	Stem		Leaves		Ears	
	Silk	Harvest	Silk	Harvest	Silk	Harvest
Bomo Local	0.92	0.77	2.44	1.22	1.15	1.36
Biu Yellow x C_{10}	0.95	0.53	2.37	0.94	1.39	1.36
B_3-096	0.98	0.67	2.36	1.25	1.60	1.41
s.e.	0.07	0.09	0.04	0.10	0.08	0.05

Table 56

1972: The effect of plant population on total uptake of nitrogen/ha at harvest and silking (kg/ha) - 1972

Sample date	Stem	Leaf	Ear	Total	% uptake after silking
			19,570 plants/ha		
S_1	29.3	28.2	10.7	68.2	
					45.9
S_4	21.9	14.6	89.5	126.0	
			38,140 plants/ha		
S_1	41.6	47.7	13.3	102.6	
					47.6
S_4	36.9	22.7	135.9	195.5	
			57,710 plants/ha		
S_1	59.6	62.8	10.8	122.2	
					38.1
S_4	42.8	23.5	131.0	197.3	
			78,280 plants/ha		
S_1	58.6	71.2	15.6	145.4	
					36.2
S_4	47.9	28.9	151.3	228.1	

Table 57

1973: Effects of date of sowing genotype and top-dressing with N on percent N in the different parts of maize at harvest and silking

	Leaves		Stem		Ear	
	Silking	Harvest	Silking	Harvest	Silking	Harvest
13th June	2.68	1.46	1.02	0.69	1.41	1.47
27th June	2.41	1.37	1.45	0.73	1.50	1.46
11th July	2.28	1.42	0.98	0.73	1.39	1.39
s.e.	0.09	0.13	0.30	0.06	0.05	0.07
Bomo Local	2.38	1.38	0.98	0.74	1.52	1.45
Biu Yellow x C_{10}	2.48	1.58	1.03	0.68	1.37	1.41
B_3-096	2.51	1.29	1.43	0.73	1.42	1.46
s.e.	0.08	0.08	0.38	0.05	0.07	0.05
N_1	2.35	1.40	0.98	0.67	1.43	1.48
N_2	2.56	1.43	1.31	0.77	1.44	1.39
s.e.	0.08	0.07	0.32	0.04	0.06	0.05

which includes the grain, the cob and the ear sheaths was 1.38% and 1.37% at the silk and harvest stages respectively.

The results showed that the leaves had a higher percent N at silking than the ear in which the N content was higher than that found in the stem. This was not surprising in view of the active photosynthetic activity taking place in the leaves at this stage of plant development. The higher N content of the ear than in the stem might also be because the N containing substances which were being synthesized in the leaves were being translocated principally to the developing ear. The decline shown in the N content of the leaves and the stem at harvest was due both to reduced or ceased photosynthetic activity of the leaves as well as the translocation of N containing substances such as proteins and amino acids from the leaves and the stem to the developing grains.

The effects of genotype on N content of the stems, leaves and ear both at silking and harvest showed that percent N in the stems and leaves at silking did not differ significantly for the three genotypes. But the N content of the ears differed significantly at the silking stage. It was lowest in the local variety and highest in the synthetic variety. At harvest the stems and leaves of the hybrid showed N content which was significantly lower than either that of the local or the synthetic variety. This suggests greater or more efficient translocation of N from the leaves and the stems of the

hybrid to the grain than was the case in the local or in the synthetic variety.

The effects of plant population on total uptake of N per hectare and the relative distribution of N among the major plant components at silking and at final harvest showed that the total N up take at silking was significantly increased with each increase in plant population. The N up-take was 68.2, 102.6, 122.2 and 145.4 kg/ha for the corresponding populations of 19, 570, 39, 140; 58, 710 and 78, 280 plants/ha. A similar trend in total N uptake, at harvest was observed except that for the same corresponding plant populations greater levels of N-126.0, 195.5, 197.3 and 228.1 kg/ha respectively were taken up. It was shown earlier that total dry matter production per hectare was increased significantly with increasing plant population. As N is needed to produce dry matter, it was not surprising that the total N taken up per hectare showed a similar increase with increase in plant population. The results also showed that a considerable proportion of the total N was taken up by the plant after silking during grain filling. The proportion of N taken up after silking was almost 50% for P_1 and P_2 and was a little over one-third of the total N taken up in P_3 and P_4. The results showed that all the N taken up by the plant after silking went to the developing ear, and that the N loss shown by the leaves and stem at harvest was obvicusly remobilised to the ear during grain filling. The effects of date of

sowing, top dressing with N and genotype on the N content of the major parts of the maize shoot in 1973 showed that the levels of N in the leaves, the stem and the whole ear both at silking and at harvest had similar variations as in 1972. Also the genotypes behaved as in 1972 in their uptake of N. Delayed sowing by four weeks in 1973 led to a significant decline in the N content of the leaves, stem and whole ear at the silk stage. However the N levels for the corresponding parts of the plant were not different for all sowing dates at the harvest stage. The levels of N in the leaves, stem, and whole ear were not significantly affected by top dressing with N. This means as already reported above that top-dressing with N did not infact significantly increase total dry matter or grain yield.

Besides the universally recognised importance of N to growth and high yield of maize, these results have other significant agronomic implications. That a considerable proportion of the total N (up to 40%) is taken up by the maize plant after silking and during grain filling means that shortage of available N at this stage of development could seriously reduce grain yields. This then emphasizes the need for adequate fertilization of the maize crop such that N is not in short supply before or after silking. Adequate N before silking would ensure rapid development of the vegetative phase so that the plant may attain its optimum leaf area for photosynthesis. In this

investigation a total of 188 kg/ha N was applied at sowing. Making allowance for unrecorded loss due to leaching, total plant uptake in populations 2, 3 and 4 exceeded the amount of N supplied in fertilizer form, with the difference increasing with increased population. It is however believed that plants even in the high populations did not suffer shortage of N throughout the growing period because the relatively small short-fall must have been more than made good by the natural supply from the soil which was under ley for the previous fifteen years.

4.8 Sink-source relationships

The effects of reducing the sizes of leaf area and ear on grain yield of twenty sampled plants are summarised in Table 58. When all the laminae were removed at silk, mean grain yield of the three genotypes was significantly reduced by 80% compared with yield of intact plants. Reducing the leaf area to about one half by clipping the tip half of all laminae and by removing alternate laminae reduced grain yield by 12% and 13% respectively. When the size of the ear was reduced by one half the average grain yield was reduced by 37.3%. These results showed that up to 80% of the dry matter in the grain may have been contributed by the laminae after flowering. This is in agreement with what has extensively been reported in the literature that the dry matter used for filling the grain in cereals is normally produced by assimilation taking place after flowering and during grain filling. The results also agreed with many others such as those obtained by Li and Liu (1935) and Stickler and Pauli (1961b) on sorghum; and Dungan (1930, 1934) on maize that complete removal of leaf at about flowering has led to severe reduction in the grain yield of the two crops, suggesting that laminae supplied most of the dry matter to fill the grain. In this study it was shown that 20% of the grain dry matter was either assimilated by the leaf sheaths or it was the result of both assimilation by the sheaths and the translocation

of already stored dry matter from the stem to the grain. Earlier investigations in the southern part of Nigeria by Van Eijinatten (1963) estimated that the leaf sheath area, being approximately one-fifth of the total assimilatory area of the maize plant, contributed about one fifth of the total dry matter in the grain. If, as found in this investigation, the leaf blades and the leaf sheaths contributed 80% and 20% respectively of the total dry matter in the grain; it would be expected that when the leaf blade area is reduced uniformly throughout the canopy profile to about one half, grain yield should be about 60% of the normal if the reduction in grain yield was proportional to the reduction in the assimilatory surface area. In this study reducing the leaf blade area to about one half through clipping of the tip half of each lamina and by removing alternate leaf blades resulted in grain yields which were 88% and 87% of the normal respectively. This suggests, as reported in many plant species especially cereal crops, that when the size of the assimilatory surface is reduced there is less than proportionate decrease in grain yield. This is also in agreement with earlier reports in the literature that reduction in yield of grains of cereal crops was not directly proportional to the degree of defoliation because the photosynthetic efficiency of the remaining leaves was increased (Duvick and Noble, 1970; Eik and Hanway, 1966; Mc Allister and Krober, 1958; Singh and Colville, 1962).

The effects of reducing the sizes of leaf area and of the ear on the harvest dry weights of stem and leaves per plant are summarised in Table 59. When all leaf laminae were removed the stem dry weight was significantly reduced to 62% of the normal plant. When the leaf area was reduced by one half through clipping and by removing alternate laminae the stem dry weight was also significantly reduced to 85% and 81% of the normal plant respectively. When the ear was completely removed the stem weight increased significantly by 30%. The increase in stem weight was only 9% when the ear size was reduced by one half and was not significant. The significant loss in stem when leaf area was drastically reduced could have been due to either respirational losses or to stimulated translocation of dry matter from the stem to the grain. If however the contribution to the dry matter in the grain from the leaf sheaths, which remained green and visually functional for a long time after defoliation, was assumed to be about one-fifth of the total assimilatory surface; then the measured losses in the dry weight of defoliated stem must have been as result of tissue respiration. The results further suggest that in partially defoliated plants there was greater diversion of assimilates to the grain and the respirational needs of the stem have therefore to be met by the dry matter already present in

the stem at the time of defoliation. The greater the degree of defoliation the greater the loss of dry matter in the stem due to respiration.

The results showed clearly that the largest sink for assimilated dry matter after flowering of maize was the grain. When the ear was removed the stem showed a 30% increase in its weight suggesting that in the absence of the grain, the stem assumes a greater role as a major sink for assimilates from the leaves. Similarly the dry weight of leaves increased, though to a lesser degree than the stem, when the ear was removed or reduced in size. The increase was most likely due to the fact that the leaf, in the absence of the ear, retained a greater than normal proportion of the dry matter it assimilated. The reduction in the leaf dry weight due to half defoliation of the plants was expected but this reduction in the leaf weight was slightly by less than half of the leaf dry weight of the normal plant. This may be a reflection of the increased photosynthetic efficiency of the remaining leaves, and in the case of laminae which had their tip halves removed, the greater proportion by weight of the mid-ribs was left in the remaining halves. This probably explains the greater loss in the leaf weight per plant when alternate whole laminae were removed. The The reduction in ear size to one half reduced grain yield to 63% the yield of intact ears. In Table 60 grain yield components are summarised. From the results it can be seen

that reducing the ear size by one half before grain filling caused, as expected a proportional reduction in number of seeds per cob. However the weight of grain from reduced ear size was 25% greater than the seed weight from normal plant. This result showed that like the source of assimilate (the assimilatory surface) the efficiency of the sink (the grain) was increased relative to the assimilatory surface through increased size of the grain. Increased grain weight as a compensationary adjustment has been reported in several crops. Mc Alister and Krober (1958) reported that a 17 - 22% loss in number of pods in soyabeans was compensated by an increase in the weight of the remaining seeds. Singh and Colville (1962) showed only 13% reduction in grain yield after clipping the tip half of heads in sorghum. Tufail (1971) showed that when the number of seeds in shorghum heads was reduced to one half of its expected number, an increase of 62.3% in the seed weight occurred. Such phenomenal increase in seed size as a result of reduced number of seeds allowed to be set in maize ear was reported by Allison (1966). The effects of manupulating leaf area as the major source of dry matter assimilation and the size of the ear as the major sink for these assimilates on grain yield of maize emphasizes the importance of the sink-source relationships. In this study the reduction of assimilatory surface to about one half caused an

Table 58

1973: The effect of defoliation and reduction of ear size on grain yield (gm) of 20 sampled plants

	Genotype			
	Bono Local	Biu Yellow x C_{10}	B_3-096	Aver.
A	2008	3188	2164	2453
B	-	-	-	-
C	518	498	466	494
D	1659	2728	2103	2163
E	1841	2909	1623	2124
F	1213	1978	1423	1538
	s.e. =	166		96

Table 59

1973: Effects of reducing leaf area and ear size on harvest weight/plant of stem and leaves

Treatment	Stem	Leaves
A	112.1	26.6
B	145.2	33.5
C	69.7	-
D	95.2	19.4
E	91.1	17.2
F	122.1	29.4
s.e.	6.0	2.1

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Table 60

The effects of defoliation and reduction of ear size on the number of grains per cob and grain weight (wt/100 grains)

Genotypes

Treatment	Bomo Local		Biu Yellow x C_{10}		B_3-096	
	Seed No.	Seed Wt.	Seed No.	Seed Wt.	Seed No.	Seed Wt.
A	396	25.1	522	19.1	381	262
B	-	-	-	-	-	-
C	102	9.8	182	12.1	81	13.1
D	328	27.2	446	22.2	370	27.6
E	364	27.0	476	21.4	386	35.0
F	202	50.0	272	37.1	200	50.0
s.e.	20.6	6.1	26.1	5.9	16.2	7.9

Treatment

A - Intact plants - control

B. - Ears were removed

C - All laminae removed

D - About 50% reduction in a lamina area. All leaves were clipped to half size.

E - About 50% reduction in lamina area. Alternate laminae were removed.

F - About 50% reduction in ear size. The top half of the fertilized ear was carefully excised and extracted from the husk leaving the bottom half. After removing the top half, the husks were closed back and cellotaped to protect the remaining half of the ear from the pathogens and insects.

average reduction in grain yield of only about 12.5%. On the other hand when the ear size vis-a-vis the number of seeds per cob was reduced to one half the reduction in grain yield was 37.0%. This suggests that, proportions of sink and source being equal, the sink is a more important factor limiting the potential yield of the maize crop at the moment. For all the genotypes included in this investigation, a breeding programme designed to increase both the number and individual seed size would achieve greater success in boosting yield than one which seeks to increase the relative size of the assimilatory system.

4.9 The distribution of assimilated ^{14}C

The pattern of distribution of ^{14}C in the plant after assimilating $^{14}CO_2$ at silking is summarised in Table 61. Twenty-four hours after feeding the leaf with $^{14}CO_2$ at silking, the index leaf exported between 38.46 and 48.93 percent of assimilated ^{14}C. The index leaf of Biu Yellow x C_{10} hybrid retained 61.54 percent of the total ^{14}C twenty-four hours after it assimilated $^{14}CO_2$. The index leaves of the Bomo Local and the synthetic B_3-096 varieties retained 53.60 and 51.02 percent of the total assimilated ^{14}C respectively. Twenty-four hours after $^{14}CO_2$ assimilation at silking the index leaves of the hybrid, the Bomo Local variety and the Bulk 3-096 synthetic variety exported respectively to the growing ears 30.0, 24.2 and 38.5 percent of the total ^{14}C assimilated. They also exported 7.0, 19.6 and 8.6 percent of the total assimilated ^{14}C to the stem, respectively. The export to the leaves, excluding the leaf which assimilated the $^{14}CO_2$, was 0.7, 1.3 and 0.9 percent of the total ^{14}C assimilated by the hybrid, the Bomo Local and the synthetic varieties respectively. Mean ^{14}C percent content of the treated index leaf of the three genotypes twenty-four hours after assimilating $^{14}CO_2$ at silking was 55.4. For the same period mean percent ^{14}C content in the ears of the genotypes was 33.2. The untreated leaves and the stem contained 1.94 and 11.7 percent of the total assimilated ^{14}C

respectively.

Table 62 summarises the pattern of ^{14}C distribution within the plant when the index leaf assimilated $^{14}CO_2$ about three weeks after silking. At this stage of grain filling the index leaves of the Biu Yellow x C_{10} hybrid, the Bomo Local and the B_3-096 synthetic varieties retained 24.0, 42.2 and 72.2 percent respectively of the total ^{14}C twenty-four hours after $^{14}CO_2$ assimilation. They exported, respectively 35.2, 35.3 and 12.0 percent of the assimilated ^{14}C to their ears; 26.2, 16.2 and 11.8 percent to the stem; and 14.4, 5.8 and 3.9 percent to their untreated leaves. For the three genotypes the index leaves, the ears, the stems and the leaves the mean $^{14}CO_2$ assimilation were 46.3, 26.5, 18.2 and 8.0 respectively.

Table 63 shows a summary of ^{14}C assimilation and distribution within the maize plant when, three weeks after silking, the flag leaf was fed with $^{14}CO_2$. The flag leaf of the hybrid, the local and synthetic varieties retained respectively 24.0, 42.2, 72.2 percent of the total assimilated ^{14}C twenty four hours after feeding the flag leaf with $^{14}CO_2$. Mean ^{14}C retention in the flag leaf of the three genotypes was 41.0 percent. Exports to the developing ear were 30.0, 54.4 and 24.5 percent for the hybrid, Bomo Local and the synthetic varieties respectively. Percent ^{14}C content in the stem were 26.3, 16.2 and 11.8; and in the leaves 14.4, 5.8 and 3.9 for the hybrid, the local and synthetic varieties

respectively. Mean ^{14}C content of the three genotypes were 36.3, 15.2 and 7.3 percent in the ear, stem and untreated leaves respectively.

Tables 64 and 65 show the summary of the total ^{14}C recovered from the various plant parts twenty-four hours after assimilation of $^{14}CO_2$ at silking and three weeks after silking respectively. The percentage distribution of ^{14}C reported in Tables 61, 62 and 63 were obtained from these values. These figures are given merely to point out differences in absolute radioactivity in the whole plant eventhough the plants were fed similar quantities of $^{14}CO_2$.

The trend in ^{14}C distribution among the major plant parts - treated leaf, ears, stem and untreated leaves - showed a fairly consistent pattern which merit emphasis. The results showed that at silking and twenty-four hours after assimilating $^{14}CO_2$, 55.4 percent of the total ^{14}C assimilated was retained by the treated index leaf while the remaining 44.6 percent was exported to the other parts of the plant. The result showed considerable variation in the distribution of the exported ^{14}C among similar organs of the plant in the three genotypes. But the patterns of distribution clearly revealed that the developing ear was the largest sink for ^{14}C assimilated by the index leaf at silking. Twenty-four hours after labelling 27.2 percent was recovered from the stem while only 6.9 percent was recovered from untreated leaves. At about

three weeks after silking the pattern of label assimilation and export from the index leaf was very much similar to the pattern at silking except that on the average the index leaf at three weeks after silking retained a smaller percentage of the label (46.5%) than that (55.4%) retained at silking twenty-four hours after $^{14}CO_2$ assimilation. Again at this stage the ear received the largest fraction of the exported label followed by the stem and leaves. When the flag leaf assimilated $^{14}CO_2$ three weeks after silking, it retained on the average 41.0 percent of the total recovered label. It exported to the growing ear 36.3 percent of the total ^{14}C assimilated. The next largest sink for the label was the stem followed by the untreated leaves.

These results showed that the largest sink for ^{14}C assimilated in these two leaf positions was the developing ear followed by the stem and then the untreated leaves. This is consistent with and fits the general developmental phases of maize plant after flowering. After flowering the greatest point of dry matter accumulation is the grain. The large amounts of label recovered from the stem and the amounts recovered from untreated leaves within twenty-four hours of assimilation suggest that while assimilates may be translocated from point of assimilation directly to its final destination, it appeared that

a large proportion of assimilates are first circulated to all parts of the plant from where they are retranslocated to their final sink. This study was not however designed to provide information on the precise pattern of this retranslocation of assimilates between different organs within the plant.

These results which showed that the high percentage of the label retained by treated leaf after twenty-four hours of $^{14}CO_2$ assimilation agreed with the findings of Oritsejafor (1974) and Labbo (1973) who worked on ^{14}C translocation in maize under Samaru climatic conditions. However the results are at variance with the results obtained by Palmer et al. (1973) which showed that twenty-four hours after labelling the leaf, about 60 to 70% of the recovered label was already in the ear and only 8 to 11% remained in the labelled blade.

It was found that while the relative distribution of assimilated ^{14}C between the major organs within the plant followed a consistent pattern within and among the genotypes, absolute total radioactivity (summarised in Tables 64 and 65) was highly variable among the genotypes, where leaves in similar positions and equivalent state of development were exposed to the same amount of $^{14}CO_2$.

The variation in total radioactive carbon recovered from the plants of different genotypes, which were at equivalent stages of development at the time of

treatment, could have been caused by a number of reasons associated with the photosynthetic conditions for the plants during the four hours of $^{14}CO_2$ assimilation by the leaf. Although plants were treated at equivalent stages, they were treated at different dates during the growing season because the three genotypes were different in their dates of maturity. Although radiation and temperature measurements during and after assimilation were not recorded, it was observed that the solar radiation and temperature conditions varied considerably during the hours of assimilation and afterwards. This fluctuation in photosynthetic conditions is suggested to have been an important factor responsible for differential total assimilation and possibly the rate of ^{14}C translocation to the various parts of the plants. It should be noted that there was no facility to measure residual unassimilated $^{14}CO_2$ after the expiration of the four hour period of leaf exposure.

Table 61

The percentage distribution of the total ^{14}C recovered from treated and untreated parts of the plant twenty-four hours after the first feeding with $^{14}CO_2$ (at silking)

	Genotypes			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	Aver.
IL	53.60	61.54	51.02	55.39
TB	10.72	37.32	33.98	27.51
BB	13.49	0.63	4.55	6.22
TLS	0.71	-	0.93	0.55
BLS	1.82	0.01	0.89	0.91
TS	10.94	0.00	3.22	4.72
BS	8.72	0.00	5.41	4.71

Table 62

The percentage distribution of the total ^{14}C recovered from treated and untreated parts of the plant twenty-four hours after second feeding with $^{14}CO_2$

	Genotypes			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	Aver.
IL	42.22	24.04	72.20	46.15
TB	34.77	21.77	8.20	21.65
BB	0.64	13.46	3.63	5.91
TLS	5.68	4.37	0.30	3.45
BLS	0.13	10.09	3.63	4.62
TS	13.10	13.50	1.42	9.34
BS	3.15	12.77	10.42	8.78

Table 63

The percentage distribution of the total ^{14}C recovered from treated and untreated parts of the plant twenty-four hours after feeding with $^{14}CO_2$

	Genotype			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	Aver.
FL	36.23	61.23	25.60	41.02
TE	54.35	29.20	14.35	32.63
BE	0.13	0.38	10.16	3.72
TLS	0.81	0.81	6.35	2.65
BLS	0.33	0.56	12.72	4.70
TS	1.94	2.55	12.02	5.50
BS	5.71	4.77	18.80	9.76

Table 64

Total ^{14}C recovered from various parts of the plant 24 hours after the first feeding of index leaf with $^{14}CO_2$

	Genotype			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	Aver.
IL	260,473	76,757	118,394	151,875
TE	173,473	15,355	72,557	87,128
BE	23,215	19,314	1,207	14,579
TLS	4,738	1,020	-	1,919
BLS	4,538	2,592	222	2,451
TS	16,455	15,668	-	10,708
BS	27,621	12,486	-	13,369
Total	510,513	143,192	192,380	

Table 65

Total ^{14}C recovered from various parts of the plant 24 hours after assimilating $^{14}CO_2$ three weeks after silking

Treatment	Genotypes			
	Bomo Local	Biu Yellow x C_{10}	B_3-096	Aver.
IL	108,470	150,335	265,000	174,602
TE	89,321	136,149	30,845	85,438
BE	1,653	84,175	13,328	33,052
TLS	14,585	27,351	1,114	14,350
BLS	728	63,117	13,328	25,724
TS	33,652	84,458	5,180	41,097
BS	8,563	79,814	38,265	42,214
Total	256,972	625,399	367,060	
FL	216,438	197,825	72,577	162,280
TE	324,722	2,624	40,676	122,674
BE	784	2,850	28,790	10,808
TLS	4,830	1,818	17,988	8,212
BLS	4,933	8,235	36,089	16,419
TS	11,585	15,413	34,063	20,354
BS	34,135	94,338	53,305	60,593
Total	597,427	323,103	283,489	

Treatment

IL Index leaf

FL Flad leaf

TE Top ear

BE Bottom ear (where one was found)

TLS Leaves above the top ear

BLS Leaves below the top ear

TS Top portion of the stem above the node of the top ear

BS Bottom portion of the stem below the node of the top ear

SUMMARY

Field and laboratory experiments were conducted, using the methods of growth and chemical analyses, to study the effects of genotypic differences, plant density, sowing date and the effect of top dressing with nitrogen on growth, dry matter accumulation and distribution between silking and physiological maturity of maize (Zea, mays) at Samaru ($11^{o}11'N$) in the northern guinea savanna zone of Nigeria.

The study showed that for a given date of sowing and regardless of plant density, the date of flowering was earliest for the local variety - Bomo Local - followed by Biu Yellow x C_{10} hybrid; and Bulk 3-096 synthetic variety was the latest maturing. The earlier the date of flowering the smaller the dry weight and leaf area per plant when the vegetative phase of development ceased at flowering. Thus the later the flowering date the higher the leaf area index for a given plant density at silking which influenced the leaf area duration between silking and grain maturity. There was no difference between the genotypes in the length of the grain filling period when sowing was done soon after the rains were well established. Differences in the length of the grain filling period were however found among the genotypes as the sowing date was progressively delayed. The relative rates of the leaf area decline after silking

were different among the genotypes.

Leaf area per plant decreased while leaf area index increased with increase in plant density. Similarly dry weight per plant declined while total dry matter per hectare increased as plant density increased also. Both the highest leaf area index and the greatest total dry matter production per hectare were attained at the highest plant density. The optimum plant population for grain production in all the three genotypes was 39,000 plants/ha. At this population, however, the optimum leaf area index attained at silking varied among the genotypes. Differences in their grain yield were attributed more to the potential differences in the size of their sink relative to their photosynthetic surface available during the grain filling period. Biu Yellow x C_{10} hybrid had its grain yield superiority over the other two genotypes in 1972 because of its greatest number and heaviest grains per ear. The grain yield superiority of the synthetic B_3-096 variety over the local variety was due to its greater number of seeds per ear rather than to heavier grains. Average net assimilation rate during the grain filling period was highest in the hybrid which, unlike the local and synthetic varieties, had maintained a high net assimilation rate in the last two weeks preceding the attainment of maximum dry matter production. The net assimilation generally decreased with increase in plant density and with the aging and

death of leaves during the period of grain filling. As the net assimilation rate, the average crop growth rate during the grain filling period was highest for the hybrid mainly because of its high net assimilation rate in the two weeks before physiological maturity. However unlike the net assimilation rate crop growth rate increased significantly at plant densities greater than 39,000 plants/ha. Mean leaf area duration was similar for the hybrid and the synthetic variety each of which had significantly higher leaf area duration than the local variety. Mean leaf area duration increased significantly with each increase in plant density.

Delayed sowing led to reduced plant size, reduced photosynthetic surface at silking when the grain filling was about to begin, and the shortening of the grain filling phase all of which contributed to the observed decline in grain yield when sowing was progressively delayed. The reduced photosynthetic area of the crop at silking as a result of delayed sowing was due to relatively earlier flowering induced by conditions associated with delayed sowing. The shortening of the grain filling period after silking was attributed to the progressively poor soil moisture conditions which must have occurred at the latter part of the growth - cycle for the later sown crop.

The study showed that almost all the dry matter assimilated after silking went to the grain. Defoliation

study revealed that about 80% of the dry matter accumulated in the ear was contributed by the laminae. When the laminae area was reduced by one half either by removing alternate blades or clipping the tip half of each lamina on the plant, grain yield was reduced by only about 12.5% suggesting that the remaining leaf area was more efficient in dry matter assimilation than the complete canopy. It also suggested the limited nature of the plant 'sink' to store the assimilates which a complete canopy is potentially capable of assimilating. In the absence of the fertilized ear which was the major sink for assimilates after silking, the stem stored a greater proportion of the dry matter than it did when the ear was present. Reducing the ear size to one half caused a significant reduction in grain yield which was however not proportional to the proportion of the ear removed. Grain yield was 67.5% of that from the normal plant. This means that the loss in the number of grains was partially compensated by the increase in the weight of the remaining grains.

Radioactive ^{14}C recovered from the various parts of the plant twenty-four hours after the plant had assimilated $^{14}CO_2$ showed that in the first three weeks after silking the greatest proportion of ^{14}C exported from the point of assimilation was recovered from the growing ear, followed by the stem and leaf in that order.

Top dressing with nitrogen at tasseling had no significant effect on grain yield because of its insignificant influence on plant growth characteristics' such as leaf area per plant, leaf area duration, crop growth rate or net assimilation rate. Total nitrogen up-take by crop per hectare showed that the maize crop took up between one third to one half of its N after silking, and that about one third of the N already taken up at silking was later remobilised to the growing grain.

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R E F E R E N C E S

Allan, A.Y. 1971. The influence of agronomic factors on maize yield in Western Kenya with special reference to time of planting. Ph.D. Thesis in the University of East Africa.

Andrews, D.J. 1973. Inter cropping with sorghum in Nigeria. Samaru Research Bulletin, pp 13.

Asana, R.D. and V.S. Mani, 1950. Physiol. Plant. 3: 22 - 39

Atkins, R.E., V.H. Reick and J.J. Kern, 1968. Performance of short stature grain sorghum hybrids at different row and plant spacings. Agron. J. 60: 515 - 518.

Barnell, H.R. 1936. New Phytol. 35: 329 - 66.

Beevers, H. 1969. Metabolic sinks. In Physiological Aspects of crop yield. J.D. Eastin, F.A. Huskins, C.V. Sullivan and C.H.M. van Bavel, ed. A.S.A., Madison, Wisconsin pp. 169 - 180.

Blackman, V.H. 1919. The compound interest law and plant growth. Ann. Bot. 33: 353 - 360.

Boonstra, A.E.H. R. 1929b. Differences in vitality of the leaves of four varieties of oats as connected with yield. Quoted by Watson (1947a)

Briggs, G.E., F. Kidd, and C. West 1920b. A quantitative analysis of plant growth. Part II. Ann. Appl. Biol. 7: 202 - 223.

Brougham, R.W. 1960. The relationship between the critical leaf area, total chlorophyll content and growth rate of some posture and crop plants. Ann. Bot. N.S. 24: 557 - 559.

Carmer, S.G. and J.... Jacobs. 1965. An exponential model for predicting optimum plant density and maximum corn yield. Agron. J. 57: 214 - 44.

Colville, W.L. and D.O. McGill. 1962. Effect of rate and method of planting on several plant characters and yield of irrigated corn. Agron. J. 54: 235 - 238.

Cooper, G.C. Agricultural research in Tropical Africa. 1970. Nairobi, East African Lit. Bureau, pp. 211.

Curtis, D.L. The relationship between yield and date of heading of Nigerian Sorghums. Samaru Res. Bull. 93: 18.

Daynard, T.B. and W.G. Duncan. 1969. The black layer and grain maturity in corn. Crop Sci. 9: 473 - 76

DeWit, C.T. 1959. Potential photosynthesis of crop surfaces. Neth. J. Agr. Sci. 7: 141 - 49.

Donald, C.M. and W.R. Stern. 1961. Relationship of radiation, leaf area index and crop growth rate. Nature, Lond. 189: 597 - 598.

Duncan, W.G., R.S. Loomis, W.A. Williams and R. Hanau. 1967. A model for simulating photosynthesis in plant communities. Hilgardic 38: 181 - 205.

Dungan, G.H. 1930. Relation of blade injury to the yielding ability of corn plants. Journ. Amer. Soc. Agron. 22: 164 - 70.

Dungan, G.H. 1934. Losses to corn crop caused by leaf injury. Plant Phys. 4: 749 - 766.

Dungan, G.H. 1942. III. Acad. Sci. Trans. 35: 42 - 44.

Dungan, G.H., A.L. Lang and J.N. Pendleton, 1958. Corn Plant population in relation to soil productivity. Advanc. Agron. 10: 435 - 473.

Duvick, D.N. and S.W. Noble, 1970. Relationship between yield and leaf area index of several corn hybrids and inbreds. Agron. Abstr. 149.

Eik, K. and J.J. Hanway, 1966. Leaf area in relation to yield of corn grain. Agron. J. 58: 16 - 18.

Engledow, F.L. and B.P. Pal. 1934. Investigations on yield of cereals. VIII. Hybrid vigour in wheat. J. Agr. Sci. 24: 390 - 409.

Francis, C.A. 1970. Physiology in the improvement of maize. Ph.D. Thesis Cornell.

Gabrielson, E.K. 1948. Effects of different chlorophyll concentrations on photosynthesis in foliage leaves. Physiol. Plant. 1: 5 - 37.

Goldsworthy, P.R. and R.S. Tayler. 1970. The effect of plant spacing on grain yield of tall and short sorghum in Nigeria. J. Agric. Sci. Camb. 74: 1 - 10.

Gregory, F.G. and F. Crowther, 1928. A physiological study of varietal differences in plants. I. A study of the comparative yields of barley varieties with different manurings. Ann. Bot. Lond. 42: 757 - 770.

Heath, O.V.S. and F.G. Gregory. 1938. The constancy of net assimilation rate and its ecological importance. Ann. Bot. Lond. N.S. 2: 811 - 818.

Holliday, R. 1960a. Plant population and crop yield. Part 1. Field Crop Abstr. 13: 159 - 167.

Holliday, R. 1960b. Plant population and crop yield. Part II. Field Crop Abstr. 13: 247 - 254.

Hoyt, P. and R. Bradfield. 1962. Effect of varying leaf area by partial defoliation and plant density on dry matter production in corn. Agron. J. 54: 523 - 525.

Houter, R.B., L.M. Kennenberg and E.E. Gamble. 1970. Performance of five maize hybrids in varying plant populations and row width. Agron. J. 62: 255 - 56.

Ikeda, M. and A. Nakagana. 1971. Yield abilities in dwarf grain sorghum in relation to varieties and planting densities. Field Crop Abstr. 24: 383.

Karpe, R.E. 1929. The contrast in response of Kafir and milo to variation in spacing. J. Amer. Soc. Agron. 21: 344 - 354.

Kassam, A.H. and J.M. Kowal. 1973. Productivity of crops in the savannah and rainforest zones in Nigeria. Samaru Res. Bull. 202: 4.

Kassam, A.H., J.M. Kowal, M. Dagg and K. Harrison. 1974. Maize in West Africa. Its potential in Savannah areas. Unpublished.

Keay, R.W.J. 1953. An outline of Nigerian vegetation. Third Edit. Lagos. Fed. Govt. Printer 1959: 46.

Kiesselbach, T.A. 1948. Endosperm type as a physiological factor in corn yields. J. Amer. Soc. Agron. 40: 216 - 236.

Kowal, J.M. and D.J. Andrews. 1973. Pattern of water availability and water requirements for grain sorghum production at Samaru; Nigeria. Samaru Res. Bull. 188. 15.

Kowal, J.M. and D.T. Knabe, 1972. An Agroclimatological atlas of the Northern States of Nigeria, with explanatory notes, Zaria. Ahmadu Bello University Press, pp. III. 16 maps

Kurbator, I.M. and V.S. Dornar. 1960. Field Crop Abstr. 14: 648.

Labbo, A. 1973. The effect of Zn, Mg and Fe on the movement of ^{14}C- products in two contrasting varieties of Zea mays L. B.Sc. thesis,

Ahmadu Bello University, Zaria.

Lang, A.L., J.W. Pendleton and G.H. Dungan. 1956. Influence of population and nitrogen levels on yield and protein and oil content of nine corn hybrids. Agron. J. 48: 284 - 289.

Li, H.W. and T.N. Liu. 1935. Defolation experiment with Kaoliang (Andropogan sorghum) J. Amer. Soc. Agron. 27: 486 - 491.

Loomis, R.S., and W.A. Williams. 1963. Maximum crop productivity: an estimate. Crop Sci. 3: 67 - 72.

Loomis, R.S., W.A. Williams, W.G. Duncan, A. Dovrat and F.F. Nunez. 1968. Quantitative description of foliage display and light absorption in field communities of corn plants. Crop Sci. 8: 352 - 356.

Mc Allister, D.F. and D.A. Krober. 1958. Response to pod and leaf removal. Agron. J. 50: 67 - 677.

Moss, D.N. 1959. Photosynthesis of corn under field conditions. Ph.D. Thesis Cornell University Itheca, N.Y.

Moss, D.N. and H.T. Stinson. 1961. Differential response of corn hybride to shade. Crop Sci. 1: 416 - 418.

Moss, D.N. 1964. Optimum lighting of leaves. Crop Sci. 4: 131-136.

Murata, Y. 1961. Studies on the photosynthesis of the rice plant its culture significance. Bull. Nat. Inst. Agr. Sci. Ser. 2 Mishigahara. Tokyo, Japan.

Nichiporovich, A.A. 1960. Photosynthesis and the theory of obtaining high crop yields. An abstract with commentary by J.N. Black and D.J. Watson. Field Crop Abstr. 13: 169 - 175.

Nunez, R. and E. Kampath. 1969. Relationship between N response, plant population and row width on growth and yield of corn. Agron. J. 61: 279 - 282.

Oritsejafor, J. 1974. The movement of C^{14}- products from a single leaf at different developmental stages in Zea mays L. B.Sc. thesis, Ahmadu Bello University, Zaria.

Palmer, A.F.E., G.H. Heichel and R.B. Musgrave. 1973. Patterns of translocation of ^{14}C in maize labelled after flowering. Crop Sci. 13: 371 - 375.

Porter, K.B., M.E. Jensen and J.H. Slatten. 1960. The effect of row spacing, fertilizer and planting rate on the yield and water use of irrigated grain sorghum. Agron. J. 52: 431 - 434.

Pullan, A.A. 1968. A morphological classification of lateratic iron stones and ferruginised rocks in Northern Nigeria. Samaru Res. Bull. 87: 26.

Rattray, A.G.H. 1960. Maize populations and spacings. Rhod. agric J.57: 192 - 194.

Sielinger, J.D. 1926. The spacing of grain sorghum J. Amer. Soc. Agron. 18: 525.

Singh, J.J. and W.L. Colville. 1962. Effect of clipping on yield and certain agrononic characters of irrigated grain sorghum. Agron. J. 54: 484 - 486.

Sprague, H.B. and N. Curtis. 1933. Chlorophyll content as an index of the productive capacity of selfed lines of corn and their hybrids. J. Amer. Soc. Agron. 25: 709 - 724.

Sprague, H.B. and J.W. Shive. 1929. A study of the relations between chloroplast pigments and dry weights of tops in dent corn. Plant Physiol. 4: 165 - 192.

Stickler, F.C. 1964. Row width and plant population studies with corn. Agron. J. 56: 438 - 441.

Stickler, F.C. and A.W. Pauli. 1961b. Grain producing value of leaf sheaths in grain sorghum. Agron. J. 53: 352.

Stickler, F.C. and A.W. Pauli 1961a. Leaf removal in grain sorghum I. Effect of certain defoliation treatments on yield and components of yield. Agron. J. 53: 99 - 102.

Stockinger, K.R. and J.M. Jones. 1972. Maize experiments. Ann. Report Major Cereals in West Africa. O.A.U./STRC JP 26. Compiled by K.R. Stockinger. pp. 1 - 8.

Tanaka, A. 1972. The relative importance of the source and the sink as the yield limiting factors of rice. Tech. Bull. No.6 Food and Fertilizer Tech. Centre, Hokkaido University.

Tanaka, A. 1972. The relative importance of the source and the sink as the yield limiting factors of rice. Tech. Bull. No. 6 Food and Fertilizer Tech. Centre. Kokkaido University.

Tanaka, A., K. Kawano and J. Yanaguchi 1966. Photosynthesis, respiration and plant type of the tropical rice plant. IRRI Tech. Bull. No. 7.

Termunde, D.E., D.B. Shank, and V.A. Dirks. 1963. Effects of population levels on yield and maturity of maize hybrids grown on the northern Great Plains Agron. J. 55: 551 - 55.

Tufail, M. 1971. Studies on components of yield in relation to plant structure in sorghum Ph.D. Thesis University of Nebraska.

Van Eijanatten, C.L.M. 1963. A study of the development of two varieties of maize at Ibadan, Nigeria. J. Agric. Sci. 61: 65 - 72.

Wallace, D.H. 1958. The relationship of yielding ability to dry matter accumulation and its distribution for several varieties of dry bean (Phaseolus vulgaris L.) Ph.D. Thesis. Cornell University, Itheca, N.Y.

Whaley, W.G. 1950. The growth of inbred and hybrid maize. Growth 14: 123 - 154.

Watson, D.J. 1937. The estimation of leaf area of field crops. J. Agric. Sci. 27: 474 483.

Watson, D.J. 1947a. Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties and within and between years. Ann. Bot. Lond. N.S. 11: 41 - 76.

Watson, D.J. 1947b. Comparative physiological studies on the growth of field crops. II. The effect of varying nutrient supply on net assimilation rate and leaf area. Ann. Bot. Londo N.S. 11: 375 - 407.

Watson, D.J. 1952. A physiological basis of variation in yield. Advance. Agron. 4: 101 - 145.

Watson, D.J. 1958. The dependence of net assimilation rate on leaf area index. Ann. Bot. Lond. N.S. 22: 37 - 54.

Watson, D.J. 1968. A prospect of crop physiology. Ann. Appl. Biol. 62: 1 - 9

Watson, D.J., G.N. Thorne, and S.A.W. Fench, 1958. Physiological causes of the difference in grain yield.