A STUDY OF THE EFFECTS OF ROW SPACING AND SOWING RATE ON GROWTH, SEED YIELD AND SEED QUALITY OF SAFFLOWER. (**Carthamus tinctorius** L)

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SUMMARY

In this study on safflower production, the experimental data showed that the square planting treatment produced the highest seed yield per unit area. As row width increased, a steady decline in seed yield per unit area resulted. However, by increasing the sowing rate eight fold, the seed yield was more than doubled (2699 to 6200 Kg/Ha).

The significantly high seed yield per unit area obtained from the square planting treatment and the highest sowing rate treatment was largely due to the total number of seed heads produced. This was confirmed by the high and positive correlation between seed yield and the number of plants and number of seed heads per unit area. However, on a per plant basis, seed yield appeared to depend on the number of heads per plant, head weight, number of seeds per head and seed weight.

From data obtained in this study, both row spacing and sowing rate affected the growth and development of safflower. At the same sowing rate, it appeared that narrow row spacing and square planting resulted in bigger plants with a greater number of leaves and branches and also earlier flowering. Wide row spacing (72 cm) showed only one positive trend in plant character, viz. an increase in height.

The main effect of increasing the sowing rate was the reduction in plant size, its associated features (i.e. fewer branches and leaves), and the delay in flowering.

Growth analysis revealed that RGR, NAR and LAR showed

a rapid initial increase during the first 7 weeks before starting to decline with time. This trend in safflower growth curves may be attributed to its peculiar growth pattern which includes the rosette stage, after emergence. In this study, the seedlings remained in this rosette stage for approximately 5 to 6 weeks with little evidence of growth activity. The CGR of safflower was in fact found to be similar to that of soybean but greatly accelerated after the rosette stage. Harvest index (HI) values were high and corresponded to the high seed yield obtained in this study.

Evidence from growth components i.e. RGR, NAR, LAI and LAR showed little support in their relationship with the high seed yield as far as row spacing treatments were concerned. However, in sowing rate treatments, the relationship between LAI and high seed yield was evident but other growth components showed no such relationship.

Neither plant spacing nor sowing rate had any significant effect on seed moisture and seed viability. Seed oil content, which ranged from 26 - 28%, was also not significantly affected by the different treatments.

From the evidence of this study, it appeared that plant competition had been the major factor affecting safflower growth and development. It is concluded therefore, that this agronomic aspect of safflower needs further research under controlled environment conditions.

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INTRODUCTION

Major interest in the potential of oil seed crop in New Zealand agriculture has been shown over the past few years. Through extensive research, soybean has been successfully established as a crop in local agriculture. This is evident by the substantial increase in soybean acreage (2000 - 3000) in the Gisborne area this year. In the South Island, oil seed crop such as sunflower has also been grown successfully.

The main interest in oilseed crop production is the oil and its composition. Vegetable oils which contain high level of polyunsaturated fatty acids are highly sought after because of their low cholesterol property. In the past, this type of oil has been used mainly for making low cholesterol content margarine and cooking. However, the recent interest in easy-spread butter and the discovery by research scientists of the C.S.I.R.O. in Australia that feeding stock with vegetable oils containing poly-unsaturated fatty acids reduces cholesterol levels in both meat and milk have increased interest in oilseed crop in this country.

Safflower is one of the oilseed crops known to produce oil containing very high polyunsaturated fatty acids (73-80%). However, lack of agronomic information in New Zealand may well hamper the possible large scale production of this crop. Thus, the present study is an attempt to gather some information regarding the growth of safflower under local conditions. Planting pattern and sowing rate are two of the major considerations in its successful development and an early understanding of these agronomic factors is regarded as important for the rapid expansion of a potential oilseed crop industry in New Zealand.

CHAPTER ONE

1.1 SAFFLOWER - DESCRIPTIVE

1.11 HISTORY

Safflower (Carthamus tinctorius L), one of the world's oldest crop, is thought to have originated either from Carthamus lanatus L (saffron thistle) or Carthamus oxyacantha Bieb (wild safflower) (Knowles 1958), in two primary centres of origin viz. the mountainous regions of Abyssinia and Afghanistan (Knowles 1955 and 1958; Weiss 1971). For centuries its culture was confined to regions of India and other areas of Asia, Africa and Europe, where the flowers were used a source of dye for clothing and food (Cobley 1957; Knowles 1955 and 1958; Knowles and Miller 1965; Weiss 1971). In recent times safflower has been introduced to the United States and South America (Beech 1969; Knowles 1955), South Africa and Australia (Anon. 1963; Horowitz and Kleinig 1958; Knowles 1955 and Weiss 1971).

1.12 BOTANY

Several investigators have recorded the botanical characteristics of safflower (Anon. 1961; Beech 1969; Classen 1949 and 1950; Cobley 1957; Knowles 1955 and 1958; Know les and Miller 1965; McGregor and Hay 1952; and Weiss 1971). Taxonomically safflower belongs to the compositae subfamily Cynareae. The plant is a much branched, herbaceous, thistle-like annual varying in height from 30 - 150 cm. It has a deep tap root with numerous thin laterals and a strong stem w hich is stiff, solid, circular in section, thick at the base and tapering with height. All branches are terminated by individual flowering head consisting of 20 - 150 tubular hermaphrodite florets and the extent of branching varies with environment, variety and plant spacing. The leaves are simple, usually dark green and short spines may or may not be present depending on the variety. The flower heads or capitulum are protected by several series of involucral bracts. The inner involucral bracts are imbricated in several layers around the head and completely enclose the unopened florets.

Flowering begins in the head that terminates the main axis (primary head) of the plant and proceeds basipetally with the upper branches flowering first and the lower branches last. The flowers of an individual head open over a period of 3 to 6 days. Those at the margin of the head open first and flowering proceeds centripetally. Flower colour varies with varieties from red through orange and yellow to white. Each floret may produce one seed, an achene, with a white hull (pericarp) and the pappus normally absent. New varieties have grayish, brown or striped seed. The seed is oleaginous and exalbuminous.

1.13 VARIETIES

Safflower varieties differ in flower colour, degree of spininess, diameter of seed heads, oil content, resistence to disease, and ease of harvest.

Most widely grown varieties were known as N-10 and Pacific 1 and other commercially important varieties are US-10 and GILA (Anon. 1961; Knowles and Miller 1965). Recent work on safflower selection and hybridization has produce varieties with higher oil content (Ashri and Knowles

1960; Ebert and Knowles 1966 and 1968; Urie and Zimmer 1970a and 1970b). These new varieties include the thin-hull and strip-seed character (Ebert and Knowles 1966 and 1968; Knowles and Miller 1965) and the reduced -hull seed character (Urie and Zimmer 1970b).

The new variety is referred to as striped because the hull of the seed has alternating white and brown stripes. The other type is termed thin-hull because it has paper thin hulls, grayish or brownish in colour (Knowles and Miller 1965). The thin-hull type cannot be used directly in commercial production because of the pleiotrophic manifestations of the <u>th</u> gene giving weak stems and structures and male sterility (Ebert and Knowles 1966).

The latest release is the reduced-hull character resulting from a reduction of outer sclerenchyma layers of pericarp. Studies have shown that reduced-hull lines significantly outyield US-10, a standard check variety (Urie and Zimmer 1970a). Hull reduction is of practical importance in view of the negative correlation between oil content and hull percentage (Beech 1969; Classen et al 1950; Pawlowski 1961; Yermanos and Francois 1963; Yermanos et al 1967). According to Knowles and Miller (1965), with less hull, the whole seed oil content is above 40% and the protein content increases from 12 - 15% up to as high as 21%.

Another variety of safflower has been discovered which gives a completely different type of oil from the normal type of safflower. This variety, UC-1, has a high percentage of oleic and low linoleic acid, the reverse of the normal type (Knowles 1965). The original line was found in Australia (Horowitz and Winter 1957). The change in the proportion of oleic and linoleic acid makes the oil from this variety chemically similar to olive oil. The variety UC-1 has an average oil content of 36% and iodine value of 90.

The variability in the composition of the oil is the most interesting aspect for future beeding work. Knowles and Hill (1964) in their investigation found that selections from an introduction from the Azerbaijan area of Iran have an oil with an iodine value ranging from 109 to 123, depending on environment. Apparently one allele is responsible for the fatty acid composition. This compares with the 'normal' iodine value of around 140. The oil composition also varies in having a linoleic acid content averaging 48% and oleic acid content of some 43%.

1.14 Climate

The cultivated safflower shows a fairly wide adaptability within certain geographical limits (Weiss 1971), but does not favour extremes either of heat or cold (Beech 1960 and 1969; Beech and Norman 1963; Phillis 1961 and Knowles 1958). Large scale safflower production is usually confined to areas below 900 metres because the low temperatures in the higher altitudes limits growth and restricts seed yield. Weiss (1971) reported that in the United States and Russia, safflower is grown commercially between 30° and 45°N and in Australia between 15° and 35°S, usually under irrigation, or with supplementary water available should the rainfall be insufficient.

1.141 Temperature

Frost-resistance depends mainly on variety and the stage of development of the safflower plant (Beech 1969; Classen and Hoffman 1950; Knowles 1955 and 1958; Knowles and Miller 1965; and Weiss 1971). In the United States, at seedling stage, most safflower varieties will tolerate temperatures down to -7°C (Classen and Hoffman 1950). At elongation stage, safflower plants appear to be more susceptible to frost injury. Klarges (1954) observed that young plants had a varying degree of frost damage at a temperature of -2.2°C. In Canada, safflower was reported to be uninjured by frost which damaged maize (McGregor and Hay 1952). At flowering and seed-maturation stage, the crop must be frost-free because frost can reduce the quality and yield of seed (Classen and Hoffman 1950; Harbison 1968; Klarges 1954).

Seed germination takes place when soil temperatures are above 40°F (Classen and Hoffman 1950; Dennis and Rubis 1966; Knowles 1955; and Weiss 1971), and the rate of germination increases as temperatures increase up to 60°F (Classen and Hoffman 1950; Klarges 1954; Knowles 1955; and Weiss 1971). Warm temperature during early growth reduces the period spent in the rosette stage, and the transition can be rapid when there is no cool period after emergence.

High temperature at flowering appears to have a detrimental effect on safflower. According to Phillis (1961), high temperatures tend to reduce the success of floret fertilization and thus subsequently reduces the seed yield. Other investigators (Knowles 1955; Knowles and Miller 1960 and 1965) have indicated that safflower tends to give higher yields when daytime temperatures at flowering and seed development are moderate, in the range of 24 - 32°C.

However, Cavin (1965) found that high temperatures up to 26.5°C during seed development did not affect seed oil content or the fatty acid composition of the oil.

1.142 Rainfall

Although safflower is considered to be drought-resistant (Beech 1969; Classen and Hoffman 1950; Knowles 1955 and 1958; Palti and Hizani 1953; and Weiss 1971), adequate soil moisture is essential to see the crop through to maturity (Knowles 1955; Knowles and Miller 1960 and 1965; and Weiss 1971). With adequate preplanting soil moisture and the absence of hot dry winds, 300 mm of rain prior to flowering will produce good yields (Weiss 1971). Safflower becomes more susceptible to hail damage during the stem-elongation stage (Beech 1969; Knowles 1955; and Weiss 1971), and heavy rain during flowering can seriously affect pollination (Beech 1969 and Knowles 1955). Rain after flowering may discolour the seed and adversely affect its development and oil content. Also prolonged rain and warm temperature after the crop is mature causes the seed to germinate in the head (Knowles 1955 and Weiss 1971).

At all stages of growth, excessive rainfall or humidity favours fungal diseases such as leaf spot, rust, root rot and head rot (Davis 1965; Dennis and Rubis 1966; Harbison 1968; Knowles 1955 and 1958; Knowles and Miller 1965).

Prolonged rain or waterlogging due to poor drainage is detrimental to safflower. Damage to the crop is accentuated with high temperature (Knowles 1955; and Weiss 1971).

1.143 Wind

The mature plant is extremely wind resistant, and even after seeds are mature there are few losses from lodging or shattering (Weiss 1971). Knowles and Miller (1965) reported that in California, winds of 24 km per hour caused no damage to the crop. However, etiolated plants due to very close spacing may be damaged by wind (Weiss 1971).

1.2 General Growth Pattern

The growth pattern of safflower has been recorded by a number of workers. Of these, studies by Stern and Beech (1965) in Australia, and Knowles and Miller (1965) in U.S.A., give a good account of the general growth and development of safflower. Germination and development of safflower is very slow at minimum temperatures. During cold weather, time taken for seedlings to emerge may be up to three weeks. Seedlings emerge rapidly (3-4 days after planting) when soil temperature rises. After emergence, the seedlings remain close to the ground (rosette stage) and produce numerous leaves. The plants stay at the rosette stage for about 5-6 weeks before the stem begins to elongate. Rapid elongation occurs between 48 - 55 days after planting, and after 76 days branching and flowering begin. Seed formation takes place between 104 and 11 days from sowing and the seed matures in about 25 days after flowering. Within a head, the flowering and maturing of individual florets and seed may range up to 7 days. On the average, a field is ready for harvesting about 35 to 40 days after flowering.

Various factors such as temperature, availability of soil moisture, variety, weeds and disease infestations can modify the general growth pattern of this crop. (Beech

1960, Beech and Norman 1966, Knowles 1955 and Knowles and Miller 1965 and Weiss 1971).

1.3 Growth Analysis

In this section, the procedure of growth analysis is reveiwed. Various investigators have been involved in growth analysis of a number of crops but to date complete growth analysis of safflower is not available.

Before proceeding, growth analysis parameters and components are defined.

W = mean total accumulated dry weights.

A = mean total leaf area per plant.

RHO = the number of plants per unit area.

Relative growth rate (RGR) - dry weight accumulated per unit of plant dry weight per unit of time.

Net assimilation rate (NAR) - dry weight accumulated per unit of leaf area per unit of time.

Leaf area ratio (LAR) - leaf area per unit of plant dry weight.

Leaf area index (LAI) - leaf area per unit of land area.

Leaf area duration (LAD) - leaf area intergrated over time.

Crop growth rate (CGR) - dry weight accumulated per unit of land area per unit of time.

Harvest index (HI) - economic yield divided by total plant dry weight x 100.

Growth analysis have been reviewed by Eagles 1971; Radford 1967; Wallace et al 1972 and Watson 1952. With growth analysis, mean total accumulated plant weights (W), mean leaf areas (A), and mean dry weight of the different plant organs including weights of economically important organ (economic yield) are obtained at the beginning and end of a time period of plant growth. These parameters are used to calculate the various components of growth analysis such as RGR, NAR, LAR, LAI, LAD, CGR and HI and other measures of capacity and efficiency of growth and yield. The LAR indicates the relative a mount of A supporting a unit of W i.e. the photosynthetic capacity per unit of respiring and growing tissue. The function of LAR is further indicated in that LAR and NAR are physiological components of RGR. (RGR = NAR x LAR).

Buttery (1969) illustrated the effects of planting density and fertilizer treatments on various growth components of soy bean. NAR decreased with increasing planting density and declined in all treatments throughout the growing season. RGR declined linearly with time and the lower values of RGR were clearly associated with higher densities. The application of fertilizer however tended to slow the decline in RGR. LAR declined with declining density in the early stages but toward the end of the growing season the situation was reversed. There was in increase in CGR for the first 60 - 70 days but it declined quite sharply after that period. Higher densities generally resulted in higher value of CGR. Under conditions of low illumination (i.e. high population density) high LAR value would be expected (Buttery 1969). Stern and Beech (1965) reported that the LAI of safflower rose rapidly to a peak of 4.5 at 62 days from planting and declined to almost nil by the final harvest.

During the peak growth, there were approximately 100 leaves per plant. They also found that the low HI values were possibly due to the direct effect of high temperature during flowering and ripening.

1.4 Growth and Development

In this section, the various factors affecting the crop establishment, vegetative and reproductive growth and development of safflower will be reviewed. Greater emphasis is placed on the following factors, i.e. population density, seeding rate, plant spacing and planting pattern since they are most relevant to the subject of this thesis. A brief account of the other factors is also included.

1.41 Factors Affecting Growth and Development

Safflower can be successfully grown on a wide range of soil types (Knowles 1955; Weiss 1971), but does very well on fertile, fairly deep and well drained soil of neutral reaction. (Classen and Hoffman 1950; Kapusta et al 1962; Knowles 1955; Peterson 1965; Shaw and Joppa 1963; and Weiss 1971). For good crop establishment, the seed bed should be well prepared with firm subsoil, a surface tilth free from large clods and moist at 1 in. below the soil surface (Anon 1961; and Weiss 1971).

About 300 mm of rain is essential for a good crop (Knowles 1955; and Weiss 1971). In irrigated crops, depending on variety and location, safflower requires about 2 - 3.5 feet of water. (Beech 1960; Knowles 1955; Knowles and Miller 1965; Luebs et al 1965; Stern 1965; and Weiss 1971).

Safflower responds to fertilizer application, N in particular, where adequate soil moisture is available. (Beech and Norman 1968; Jones and Tucker 1968; Knowles and Miller 1960 and 1965). The crop requirements depend on the soil fertility, the previous cropping history and the available moisture (Anon. 1963; Beech 1960; Dennis and Rubis 1966; and Weiss 1971).

The growth habit of safflower makes it extremely susceptible to weed competition in the early growth stages. (Knowles and Miller 1960 and 1965; Weiss 1971). Heavy infestations later in the growing season tend to interfere with mechanical harvesting (Knowles and Miller 1960 and 1965; and Weiss 1971). Both these factors tend to reduce safflower yields thus weed control is essential. Under dry land conditions weed control is achieved by harrowing, (Classen and Hoffman 1950; Klages 1954; Knowles 1955; Shaw and Joppa 1963; Tongren 1964; and Weiss 1971), and inter-row cultivation is practiced when the crop is grown in beds or under irrigation (Anon. 1961; Classen and Hoffman 1950; Knowles 1955; and Tongren 1964). Recently, selective herbicides have become available for use in safflower (Knowles and Miller 1960 and 1965; Tongren 1964; Van Rijn 1962 and Weiss 1971). Investigators have shown that pre-emergence herbicides such as EPTC, trifluvalin and diuron are superior to those of post-emergence which appear to depress seed yield and injure safflower (Knowles 1955; Tongren 1964; Van Rijn 1962; and Weiss 1971).

Extensive literature on diseases of safflower have been published by Klisiewicz (1962, 1963, 1965, 1966, 1967 and 1970), Thomas (1952, 1956, 1960 and 1963), Zimmer (1961, 1962, 1963, 1965, 1967 and 1968) and Zimmer and Urie (1967, 1967a, 1969, 1969a and 1970). The most common diseases are rust, root rot, leaf spot, bud rot and verticillium wilt (Anon. 1961; Ashri 1961; Dennis and Rubis 1966; Knowles and Miller 1960 and 1965; Thomas 1952; and Thomas et al 1963). The severity of these diseases depends on climatic conditions, cultural practices and variety (Anon. 1961; Dennis and Rubis 1966; Knowles 1955 and Weiss 1971). Recently, virus diseases associated with safflower have also been discovered. (Klissiewicz 1966 and Klissiewicz and Thomas 1970).

Although safflower can be attacked by many insect pests, only a few are of economic importance. (Knowles 1955 and Weiss 1971). The major pests are safflower fly (Acanthiophilus helianthi), cluster caterpillar (Spodoptera litura), thrips and larvae of Heliothis spp. (Anon. 1961; Beech 1964; Carlson 1964 and 1966; Knowles 1955 and 1958; Knowles and Miller 1960 and 1965; and Weiss 1971). During the early seedling stage, wireworms, aphids and thrips are the main ones to watch (Anon. 1961; Knowles 1955; and Knowles and Miller 1965).

Safflower is also susceptible to a number of root knot nematodes particularly at high soil temperature (Lear et al 1966 and Weiss 1971).

1.411 Seeding Rates

Plant population is one of the important factors in determining crop yields. With sunflower, plant spacing significantly affected seed yield, weight of seed per head, seed size and head and stem diameters (Massey 1971). With other oil seed crops such as soy bean, by increasing planting density, the plant weights, the weights and numbers of most plant parts were depressed (Buttery 1969 and 1970; Hanson and Hinson 1961 and 1962; Lehman a nd Lambert 1960; Shibles and Weber 1965). The effects of high density were more obvious with later samples, indicating that competitive stress increased with the growth of plants (Buttery 1969).

Methods of achieving the optimum plant population for safflower production have been studied by Beech (1960 and 1963); Beech and Norman (1965 and 1966) in Australia and in U.S.A., Hoag et al (1968); Peterson (1965); Weiss (1971) and Williams (1962). Seeding rate of safflower depends on several factors, namely method of production i.e. non-irrigated or irrigated; time of planting; row width and method of sowing and variety (Beech 1969; Classen and Hoffman 1950; Knowles 1955; Knowles and Miller 1965; McGregor and Hay 1952; and Weiss 1971). The major factor in determining plant populations under non-irrigated conditions is available moisture. In the U.S.A., for the same row spacing, the irrigated crop is generally sown with 25% more seed than the non-irrigated crop. In Queensland for non-irrigated crop, the sowing rates vary from 10 to 55 lb per acre and the row spacing from 7 to 21 inches. (Anon. 1963; and Harbison 1968). With similar growing conditions in U.S.A. seeding rates of 20 - 40 lb per acre are commonly used in close-drilled crops and 15 - 20 lb per acre for wide-spaced crops. In other countries such as India, Hungary and Israel, the sowing rates range from 40 - 80 lb per acre for close drilled crops (7 - 10 inches spaced rows) and 20 - 25 lb per acre for wide-spaced crop (Anon. 1961; Beech 1960; Classen and Hoffman 1950; Knowles and Miller 1960; and Shaw and Joppa 1963). The higher seeding rates provide good weed control, but lower rates may be necessary where there is a lack of moisture (Classen and Hoffman 1950 and Knowles 1955).

At Kimberly in Australia, maximum seed yield was obtained at a density of 247,000 plants per acre. Assuming that there is 100% emergence and based on 10,000 seeds per pound, a seeding rate of approximately 25 lb per acre would achieve this plant population. However, a population density of less than 120,000 plants an acre gave reduced yields at 3 foot row spacing (Stern and Beech 1965). Later, Beech and Norman (1966) reported that a drilled crop of 593,000 plants per acre yielded less than the optimum row-crop density of 114,000 plants to an acre. They concluded that under Kimberly conditions, the optimum population density for safflower is approximately $\frac{1}{4}$ million plants and $\frac{1}{8}$ million plants per acre for drilled crop and row crop respectively.

1.412 The Effect of Population Density and Spacing on Growth and Development

Stern and Beech (1965) carried out a plant density trial with populations of 25, 50, 100, 520 and 1120 plants per square meter and showed that the first three levels of population were not significantly different in the number of plants at harvest. At the 520 and 1120 levels, numbers fell by over 40% in the first six weeks after emergence. The population gained equilibrium at about 100 days after emergence.

The main effect of increasing plant density was to reduce plant size. Plants too close together tended to have thinner tems or a more superficial root system, becoming susceptible to wind and storm damage (Weiss 1971).

The dry weight of tops per plant fell steadily with increasing density (Beech and Norman 1965 and 1966). Williams (1962) found that plants in wider plant spacings produced many more secondary and tertiary branches. In the 1-inch plant spacing, there were only a few secondary heads and frequently no tertiary flowers. In a row spacing study, Hoag et al (1968) observed that narrow row spacing (15 cm) resulted in advanced plant development compared to those in 53 - or 91 - cm spaced rows. However, plants in 91 -cm spaced rows were taller than plants in 15 or 53 cm spaced rows at the bud stage. At maturity, there was very little difference in plant height from all three row spacing treatments.

Plant density has a major effect on the size and number of leaves per plant. Beech and Stern (1965) illustrated the effect of five population densities (25, 50, 100, 520 and 1120 plants per square meter) on the number of leaves per plant. At the early stage, the effect of density on leaf numbers was already apparent, the highest plant population having half the leaves per plant of the lowest. The number of leaves rose quickly between five and ten weeks after sowing, reaching a maximum at thirteen weeks and then falling sharply. The degree and number of branches was directly related to the total number of leaves. Plants with the lowest total leaf number were those from the highest population, which also had the least branching.

Plants in narrow rows appear to bloom significantly earlier than those in wider spaced rows (Hoag et al 1968). Beech and Norman (1966) observed that with increasing plant density the span of time over which flowers bloomed decreased. Williams (1962) however, indicated that increasing plant spacing did not influence the mean date of flowering.

With respect to yield attributes, Beech and Norman (1966) found that number of heads, number of seeds and seed yield on per unit area basis increased up to 114,000 plants per acre and then fell sharply. But on per plant basis these attributes fell steadily with increasing density. Plants in wide-spaced rows produced more heads per plant, more seed per head and heavier seeds than plants in narrow rows (Hoag et al 1968). Similar results were obtained by Williams (1962) in his plant spacing study.

Evidence from various studies on the effect of plant population and spacings on oil content appear to be inconsistent. The oil content in the seed decreases when the unit area per plant increased (Hoag et al 1968 and Williams 1962). Peterson (1965) stated that increasing the distance between rows did not influence the oil content of the seed. However, the oil content of the seed decreased when plant population was increased in the 7-inch row. But Beech and Norman (1966) in their trial in Australia, found that oil content of the seed showed little change with increasing density. The relationship between plant spacing and oil quality is not clear but Hoag et al (1968) concluded that iodine value of oil increased as the unit area decreased.

1.5 Seed

Safflower is grown primarily for oil which is obtained from the seed. Thus the seed yield is an important aspect of safflower production

1.51 Yield

Under irrigation, safflower grown in the Great Plains of the U.S.A. produces 1750 - 2750 lb seed per acre, with a maximum yield of 4000 lb/acre (Classen & Hoffman 1950; Knowles 1955 and Purdy et al 1959). Similar seed yields are obtained in California, but with a maximum of 4800 lb/acre. In Western Australia, safflower seed yields have been reported to be in the vicinity of 3000 lb/acre (Beech 1960 and Beech and Norman 1963).

Safflower grown under non-irrigated areas tends to yield far less than the irrigated crop. The seed yields range from 350 to 1500 lb/acre (Beech 1969). The average annual yields in Queensland range from 380 to 630 lb/acre, with 1000 lb in the better areas (Harbinson 1968, Horowitz and Kleinig 1958). In India, similar yields are obtained (Chavan 1961). In the States, a reasonable seed yield of 750 - 1200 lb/acre can be expected on fallow land, but when grown after a cereal crop, seed yield is reduced to 350 - 750 lb/acre.

With sufficient soil moisture, factors affecting seed yield are date of sowing, which is largely a reflection of soil temperature (Beech 1960; Beech and Norman 1963; Knowles 1955; Luebs et al 1965 and Yermanos et al 1967), variety (Beech and Norman 1963; Nelson 1964; Rubis and Black 1958), plant population (Beech and Norman 1966; Nelson 1964;

Peterson 1965; Stern and Beech 1965), insect infestation and disease (Beech 1964; Carlson 1964; Thomas 1956), soil fertility (Beech and Norman 1967; Kapusta et al 1962; Stern and Beech 1965), soil salinity (Francois and Bernstein 1964 and Werkhoven et al 1961), and climate (Davis 1965 and Phillis 1961).

1.52 Composition

Commercially grown seeds have an average composition of oil 36 - 43%, kernel 55 - 65% and hull 33 - 45%. Experimental varieties may have a composition of oil 40 - 50%, kernel 66 - 81% and hull 18 - 30% (Rubis 1963). The present commercial varieties are far superior in their percentage oil content compared with the earlier varieties containing an average of 27 - 28% oil (Classen and Hoffman 1952; McGregor and Hay 1952 and Purdy et al 1955). The major proportion of the oil comes from the kernel and the rest from the hull. In the variety Gila for example, the p roportions of the oil are 60.0 - 61.7% and 12.6 - 13.8% for kernel and hull respectively (Beech and Norman 1963).

A number of workers have given the breakdown of the components of safflower oil (Knowles 1955 and 1965; Rubis and Black 1958; Yermanos 1967 and Weiss 1971). The major fatty acid acids are linoleic and oleic (Table 1).

Table 1 Fatty acid composition of safflower oil

Palmitic	Stearic	Oleic	Linoleic	Mis.	Non.Sapon.
6.4-7.0	2.4-2.8	9.7-18.1	76.9-80.5	0.2-0.8	0.9-1.6

Although protein is not a consideration of this study, it is interesting to note that protein is one of the main components of safflower seed. In commercial varieties, the protein component of the seed is in the range of 15.4 - 19.4% and 20.3 - 22.5% for experimental lines (Guggolz 1967).

The oil content of a particular variety of safflower is influenced by such factors as sowing date (Beech 1960; Beech and Norman 1963 and 1967; Lueb et al 1965; Nelson 1964 and Peterson 1865); soil salinity (Werkhoven et al 1966 and Yermanos et al 1964); plant population (Beech and Norman 1966; Hoag et al 1968; Peterson 1965 and Williams 1962); seed size (El Saeed 1966; and Hoag et al 1968); fertilizer treatment (Hoag et al 1968; and Yermanos et al 1964); disease (Classen and Hoffman 1950; and Thomas 1956), and insect damage (Beech 1964; Classen and Hoffman 1950; and Knowles 1955). Reports on the effect of sowing date on oil content is variable. In some cases, delay in sowing reduces oil content and in others increases. This is possibly caused by above-optimum temperatures for grain yields in the former case (Beech and Norman 1963); and below optimum temperatures in the latter (Knowles 1955; Luebs et al 1965 and Yermanos et al 1967). Canvin (1965) working with temperature range of 10°C to 26.5°C established that temperature had no effect on oil content and oil composition in terms of saturated fatty acids but the protein content increased with increasing temperature. Thus the importance of sowing date is in its relation to soil temperature and temperature at flowering. Moderate temperatures of 24 - 32°C at flowering improves seed yield while higher temperature above this level tend to lower seed yield and decrease oil content (Knowles and Miller 1965; and Weiss 1971).

Under conditions of high soil salinity, crop yield become uneconomic due to a combination of lower oil content and lower seed weight. On per unit area basis, oil yield may be reduced as much as 60% depending on variety. Gila for example, is more susceptible to saline conditions than N-10 or US10. It is possible to establish the correlation between rate of reduction of seed oil % and increasing salinity. For each millimhos per centimeter increase in soil salinity (ECe), the average oil percentage decreases by about 0.4%. Although soil salinity does not affect the chemical composition of oil, it does depress the protein content (Werkhoven et al 1966 and Yermanos et al 1964).

Fertilizer applications appear to give conflicting results in that some trials show a decrease in oil content while others show no change (Hoag et al 1968; Werkhoven 1968; and Werkhoven and Massentini 1967). Also the iodine value of the oil is not affected by fertilizers (Werkhoven 1968).

1.53 Viability

In general, seed becomes viable four days after flowering and reaches maximum viability in 14 - 16 days after flowering (Leininger and Urie 1964). At harvest, the viability of safflower seed is 95% or higher, and to maintain this viability in storage, the seed moisture content should be between 5 to 8% (James et al 1967). In U.S.A., for both registered and certified safflower seed, the minimum viability requirement is 90% (Knowles and Miller 1965).

1.54 Utilization

Safflower is grown primarily for oil. The oil is used in industries as a drying oil for paints, varnishes and alkyd resins for its rapid drying, non-yellowing and colour-retaining properties. It is also used as a high quality cooking oil and for margarine, mayonnaise and salad oil manufacture (Knowles and Miller 1960 and Weiss 1971).

Safflower meal can be prepared in two ways, viz one undecorticated meal with protein content of 19% and the other is the decorticated meal containing 36% protein. (Baker et al 1951 and 1959 and Knowles 1955). Undecorticated meal is a useful animal feed for cattle, but less suitable for poultry and pig owing to its fibre content (Baker et al 1951 and 1959; Dennis and Rubis 1966; Heineman 1953; Peterson et al 1957). Decorticated meal is suitable for ruminants, and poultry provided lysine and methionine are included (Young and Halloran 1962, and Zablan et al 1963).

CHAPTER TWO

2.1 INTRODUCTION

The experimental area was located on the Massey University Campus, Palmerston North. This area had previously been in mixed pasture species for grazing and also in crop trials for several years. The soil is a silt loam of Ohakea series.

After seed-bed preparation, including the application of 30% potassic superphosphate and nitro lime each at a rate of 628 KG per hectare, the area was hand raked and laid out in five blocks with provision for plots of 4 row spacings of 18, 36, 72 centimeters and square planting and 4 seeding rates of 5.6, 11.2, 22.4, 44.8 KG per hectare corresponding to ⅛, ¼, ½, and 1 million plants per hectare.

The experiment was laid out in a split-plot design with row spacing as a main plot and seeding rate as the sub-plot (Appendix 1). Both the main plot and sub-plot were randomised within each replication. Initially there were five replications, however owing to poor seeding establishment in the fifth replication, only the first four were used in subsequent samplings.

Seed was obtained from Dr. J.M. McEwan of the Crop Research Division of the D.S.I.R. 022 Safflower seed was used in this experiment. This line was selected by a series of accessions at Crop Research Division, Lincoln, who originally obtained them from Davis Campus of University of California. 022 proved to have the best disease resistance in local trials (Pers. Comm. Dr. J.M. McEwan).

However, special precautions were taken to prevent any possible incidence of safflower rust and pre-emergence damping off. One of these was a hot water treatment of the seed and the other was dusting of seed with Drisan and Benlate each at the rate of 57 grams per bushel.

Seed was hand planted in 3.6 meter rows and string grids were used to obtain the desired plant spacing and population density. Seed was sown on 3/11, 4/11, 5/11 6/11 and 7/11/71. Thinning and transplanting were carried out three weeks after sowing. Sufficient number of plants for 10 samplings were planted plus a minimum of two guard rows in each plot.

The first sampling was made 35 days from sowing, with the others following at intervals of 14 days except for the third and seventh samplings. The third sampling was made 10 days after the second and the seventh 4 weeks after the sixth sampling. The crop was harvested for final seed yield and component measurements 161 days from sowing.

Herbicide, namely Diuron, was incorporated into the experimental plots one week before sowing, at the rate of 0.84 KG per hectare. Over the course of the experiment weed control had to be maintained by hand cultivation since the herbicide was not fully effective. For aphid control, Disyston at the rate of 0.84 KG per hectare was broadcast one week after sowing. Benlate was sprayed at flowering time as a precaution against Botrytis blight. Rate of application was 127 gm a.i. per hectare for 1000 litres spray.

A hive of bees were placed at the southern edge of the experimental plot during the flowering period to aid pollination.

The climatic conditions were favourable over the experimental period such that no irrigation was necessary for the crop. Rainfall and insolation are summarized in Appendix 2.

2.2 Experimental Methods

2.2.1 Sampling Procedures

At each sampling, 6 plants were taken from each sub-plot. Plants were cut at the base and placed in a plastic bag. 3 plants were randomly selected from the 6 plants sampled, for dry weight measurements.

With the first sampling, only dry weights and leaf area measurements were recorded. Plant height was included as from sample 2. Data on number of different categories of branching were collected as from sample 3 onwards. Records of number of seed heads, number of seeds and seed moisture were included in sample 8.

The 3 plants chosen for dry weight data were weighed fresh then placed in a container and dried in the oven at 82°C for 24 hours.

Leaf area was determined by using an automatic area meter, model AAM-5 (Hayashi Denko). To minimise error, care was taken to see that leaves were spread properly before measurement took place. Leaf area and leaf number were recorded on per plant basis. Light penetration into the canopy was determined at approximately 2.5cm above ground on two occasions in all treatments using an omnidirectional photometer.

Plant height and number of branches were recorded from the 6 plants chosen at each sampling. Plant height was taken as from the base of the plant to the tip of the primary head. The branches were classified into primary, secondary and tertiary head depending on their position on the plant.

From the final sampling taken on the 13th April, 2 plants were randomly selected for yield attributes and a further 15 plants were also randomly selected for seed yield, seed moisture and seed viability. These 15 plants were machine threshed with the use of a cereal threshing machine from the Crop Research Division of D.S.I.R. From the two plants chosen, the following yield attributes were recorded: number and weight of primary, secondary and tertiary heads and seed yield on per plant basis, and number of seed per head. Final seed yield was calculated on the basis of 17 plants per plot. Yield was recorded on per plant basis, per unit area and per 1000 seed weight.

2.2.2 Seed Measurements

Machine threshed seeds were sampled for moisture and germination tests. A duplicate sample was used for moisture content determination. Seed moisture content was determined by placing seeds in an air oven at 105°C for 16 hours. (ISTA Regulations 1966).

For germination tests, duplicate samples of 100 seeds each were taken. Seeds were placed between moist blotters in lots of 100 and placed in a germination chamber with a temperature of 25°C. An interim count was taken after 4 days and the final count after 14 days. Seedling evaluations were based on ISTA germination regulations.

2.2.3 Oil Extraction

Seeds obtained from the two plants in the final harvest were used for oil extraction. Owing to a large number of treatments, seed samples were reduced to two replications by bulking replications 1 and 2 and also replications 3 and 4. For each treatment duplicate samples were used.

The seed samples were oven dried at 105°C for 16 hours. After cooling the seed in a dessicator, the seed samples were ground using a coffee grinder. 1 - 1½ minutes of grinding was sufficient to give a finely ground material for oil extraction. The ground seed was kept in airtight bottles until it was required for extraction.

Solvent extraction method using Sohxlet extraction apparatus was used in extracting oil from the seed. The method used was that described by Kennedy and Urau (1949).

2.2.4 Estimation of Fatty-Acid Composition by Gas Liquid Chromatography (G.L.C.)

G.L.C. was used to determine the fatty acid composition and also the proportion of fatty acids in the safflower oil. The G.L.C. analysis was done in the BiOchemistry Department in co-operation with Dr. J.C. Hawke. The procedure to estimate the fatty acid composition of safflower using G.L.C. was as reported by Van Wijngaarden (1967).

2.3 Growth Analysis

There are two methods of calculating the growth analysis of crops. One is the regression method and the other is the classical method. The main difficulty of the regression method is finding an equation which adequatley describes the growth of a plant, (i.e. change in weight or area with time). With this method, some true effects brought about by changes in the environment may be lost. This is because regression equations tend to smooth these irregularities in the sampling values. In view of this and the nature of the data collected, the classical method was found preferable.

The classical method of growth analysis involves the calculation of various mean rates from changes in plant weights (W_2 and W_1) and leaf area (A_2 and A_1) observed at two sampling periods (t_2 and t_1), as follows:

Mean net assimilation rate (NAR)

$$\overline{NAR} = (W_2 - W_1)(\log_e A_2 - \log_e A_1)/(t_2 - t_1)(A_2 - A_1)$$

Mean relative growth rate (RGR)

$$\overline{RGR} = (\log_e W_2 - \log_e W_1)/(t_2 - t_1)$$

Mean relative leaf growth rate (RLGR)

$$\overline{RLGR} = (\log_e A_2 - \log_e A_1)/(t_2 - t_1)$$

where W = dry weight per plant (gms)

A = leaf area per plant (cm^2)

t = time in days.

In addition, the following are included.

Mean crop growth rate (CGR)

$$\overline{CGR} = (W_2 - W_1)/(t_2 - t_1)$$

Mean leaf area index (LAI)

$$\overline{LAI} = (L_2 + L_1)/2 \quad \text{Or}$$

$$= (\log_e L_2 - \log_e L_1)/(L_2 - L_1)$$

where W and L represent the plant weight and leaf area per unit area of ground respectively.

2.4 Statistical Analysis

The analysis of variance of data was done using the 1130 computer at the Massey Computer Centre. The 1130 statistical system performs major statistical functions such as analysis of variance using the set programme called ANOVA. The general procedure may be described as follows:

From the experimental observations on a variable x, this programme will compute an analysis of variance for a complete factorial design for a maximum of 4 factors. This method is particularly useful since it can be extended to accomodate several experimental designs including split plot. The extension to other experimental designs is accomplished by utilizing a special report generator (i.e. a specially punched card) which chooses the appropriate components to pool in forming the error term or terms to accomodate the design.

The sum of squares was computed as follows:

Let Ai = Sum of all the observations at level ai.
na = Number of observations summed to obtain Ai.
ABij = Sum of all observations at level abij.
nab = Number of observations summed to obtain ABij.
ABCijk = Sum of all observations at level abcijk.
nabc = Number of observations summed to obtain ABCijk.

Thus a general formula for the main effect due to factor A is

1. $SSa = \sum A^2i/na - G^2/ng$

where G = the grand total of all observations, and ng is the number of observations summed to obtain G. The main effect due to factor B has the form

2. $SSb = \Sigma B^2 i/nb - G^2/ng$

The general computational formula for variation due to AB interaction is

3. $SSab = \Sigma (ABij)^2/nab - G^2/ng - (SSa + SSb)$

The general computational formula for variation due to ABC interaction is

4. $SSabc = \Sigma (ABCijk)^2/nabc - G^2/ng - (SSa+SSb+SSc+SSab+SSac+SSbc)$

The following table shows the layout of the complete table of analysis of variance of a split plot (A x B x C). In this case, let A = main treatments (row spacings); B = sub treatments (sowing rates), and C = blocks or replications. Then, appropriate error terms were calculated as follows:

(a) SS error = SSac

(b) SS error = SSbc + SSabc

The ANOVA table becomes:

Table 2

Main treatment (row spacing)	A	SSa
Blocks (replications)	C	SSc
Error (a)		SSac
Sub treatment (sowing rate)	B	SSb
Interaction	A x B	SSab
Error		SSbc+SSabc
Total		SS total

The main effects and interactions were tested for significance by dividing the mean square (MS) for the particular effect or interaction by the appropriate error term. Thus the F - ratios for this design are as follows:

A : MSa/MSac

B : MSb/MSbc + MSabc

AB : MSab/MSbc + MSabc

Least significant difference (LSD) was calculated based on the procedure described by Cochran and Cox (1957).

CHAPTER THREE

RESULTS

3.1 Seed Yield

Seed yield calculated on per unit area basis ranged from 2150 Kg/Ha to 8627 Kg/Ha according to treatments (Fig. 1). The highest yield was obtained in the square planting pattern at a seeding rate of 44.8 Kg/Ha and the lowest yield in 72 cm row spacing at 5.6 Kg/Ha. The effects of both row spacing and seeding rate were highly significant. Mean seed yield of the different spacing treatments showed that the square planting pattern gave a significantly higher yield than row planting, with no significant difference being recorded between the different row spacings. Seed yield increased significantly with increasing seeding rate. There was also a significant interaction between row spacing and sowing rate, with the superiority of the square planting being more evident at the higher seeding rates.

3.2 Plant Dry Weight

The effects of row spacings and sowing rates on dry weight per plant at different samplings are shown in Fig.2. Initially, dry matter accumulation was slow as shown in the first two samplings but from the third sampling onwards there was a rapid accumulation of dry matter reaching a maximum by the seventh sampling. Dry weight per plant dropped by the final sampling. Row width had no significant effect on the dry weight per plant up to the fifth sampling. From the sixth sampling onwards, row width appeared to have a significant effect on the plant dry weight. Plants from the 72cm row width had lower dry weight compared with those from 18 and 36cm row width and the square planting. Sowing rate tended to influence plant dry matter accumulation as early as the third sampling (63 days after sowing), with dry weight per plant being inversely related to sowing rate (Fig. 2).

Figure 1. Mean Seed Yield

Identification of row spacings:

—●——●— 18 cm.

-·-●-·-●-·- 36 cm.

—▲——▲— 72 cm.

-·-▲-·-▲-·- Square Planting

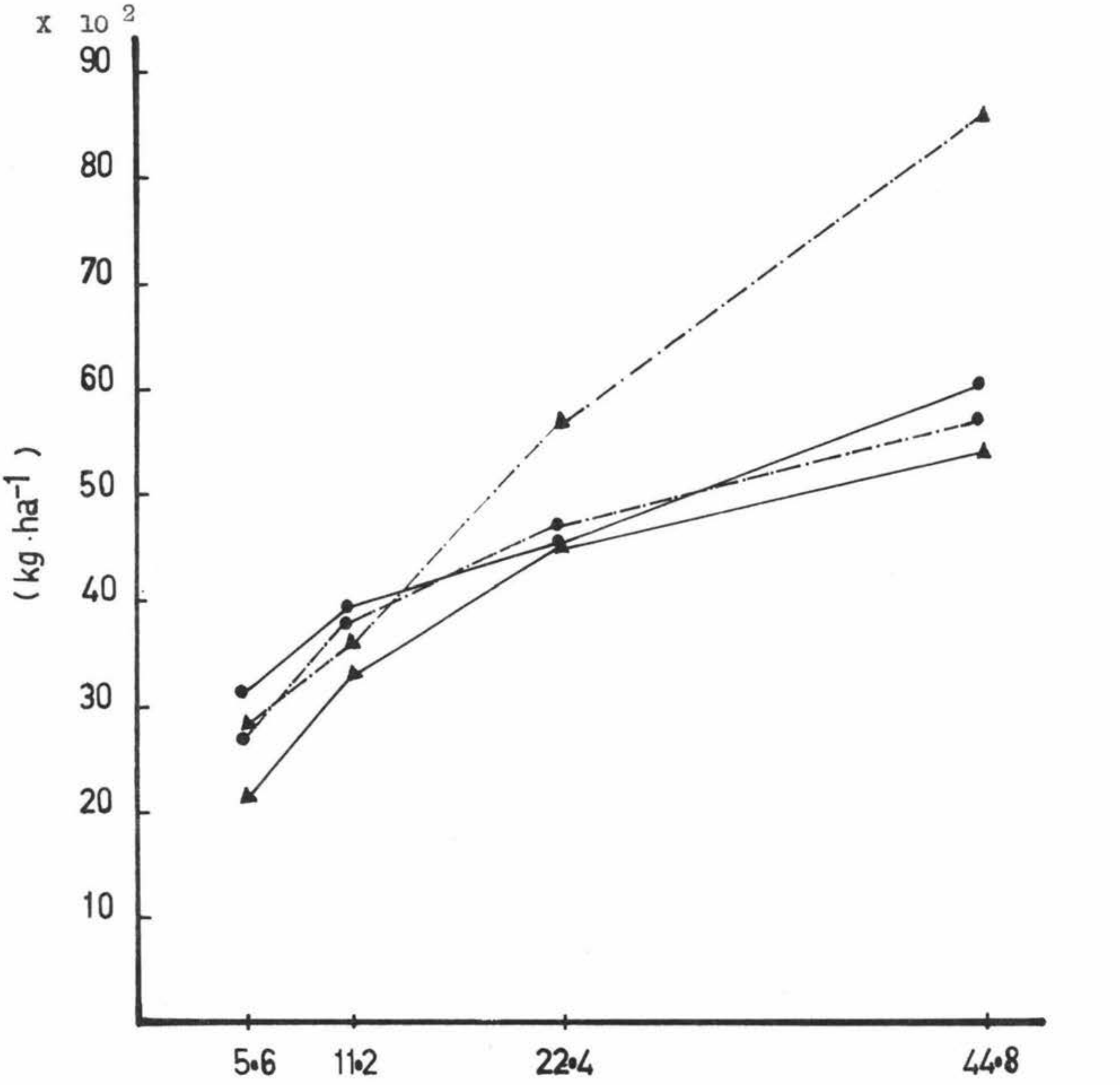

x 10 2
90
80
70
60
50
40
30
20
10
(kg·ha-1)
5·6
11·2
22·4
44·8
Sowing Rate (kg·ha-1)

Figure 2. Mean Dry Weight Per Plant

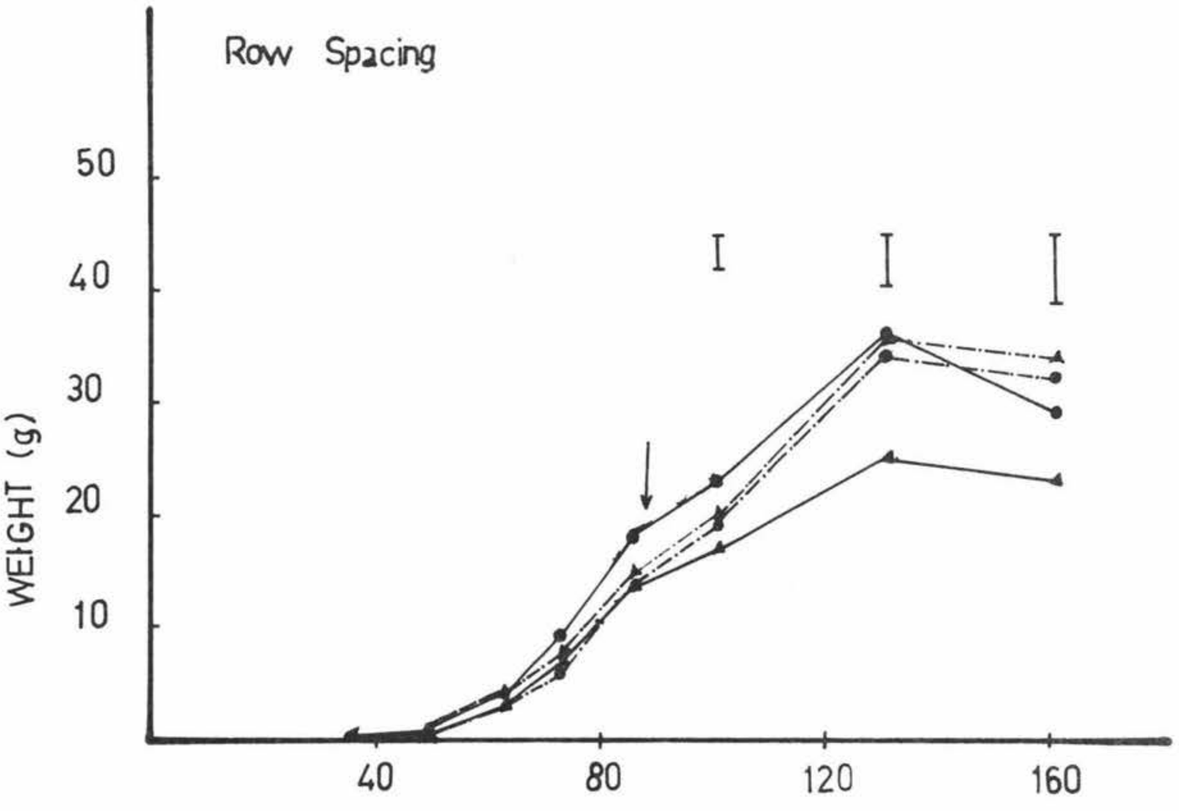
Identification of row spacings:

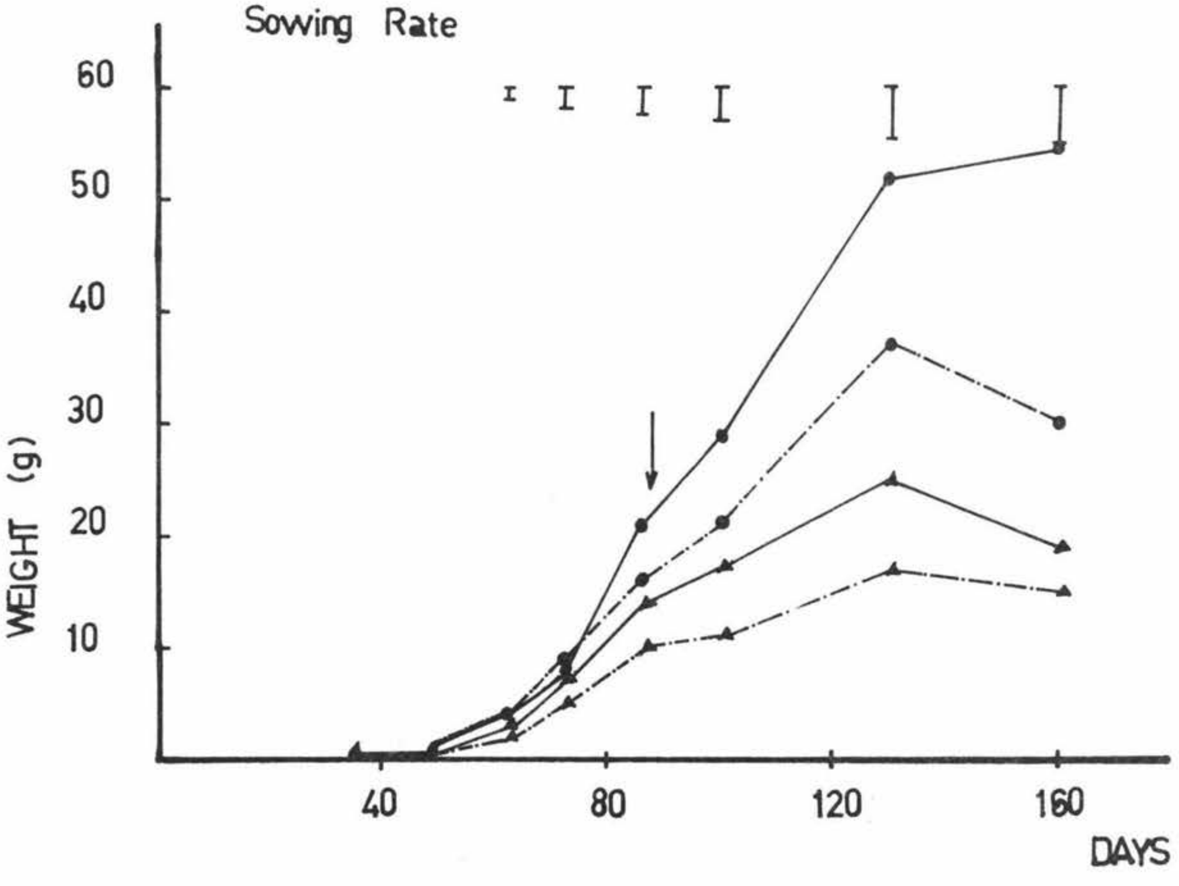
——●——●—— 18 cm.
-·-·-●-·-·-●-·- 36 cm.
——▲——▲—— 72 cm.
-·-·-▲-·-·-▲-·- Square Planting

Identification of sowing rates:

———————— 5.6 KG/Ha.
- - - - - - - - 11.2 KG/Ha.
———————— 22.4 KG/Ha.
- - - - - - - - 44.8 KG/Ha.

Day of 50% flowering


Row Spacing
WEIGHT (g)
50
40
30
20
10
40
80
120
160


Sowing Rate
WEIGHT (g)
60
50
40
30
20
10
40
80
120
160
DAYS

3.3 Plant Height

Plant height increased rapidly after the second sampling (49 days after sowing). The increase in plant height slowed down after the 4th sampling, gradually reaching the maximum height by the seventh harvest. There was then little change in plant height up till the final harvest. Plant spacing seemed to have little affect on plant height although there was a tendency for plants of the square planting treatment to be shorter than those of the other treatments, this difference reaching significance only at the seventh harvest (Fig. 3). Increasing sowing rate appeared to increase plant height in most instances, this trend reaching statistical significance at the 2nd, 7th and 8th samplings (Fig. 3).

3.4 Leaf

3.41 Leaf Number

Leaf number increased rapidly reaching its maximum by the fifth sampling in plant spacing treatment, then it gradually decreased and by the final harvest there were no green leaves left. Plants in the 18 cm row spacing appeared to have the highest leaf number, those in the 72 cm spacing generally had the lowest number, with the other two spacing treatments being intermediate in this respect. Differences between treatments reached significance over the mid period of the experiment (Fig. 4).

In the sowing rate treatments, leaf number per plant showed no significant difference at the first four samplings but thereafter differences were statistically significant. Here too, leaf number followed similar trend as before in that it reached its maximum at the 5th sampling,

Figure 3. Plant Height

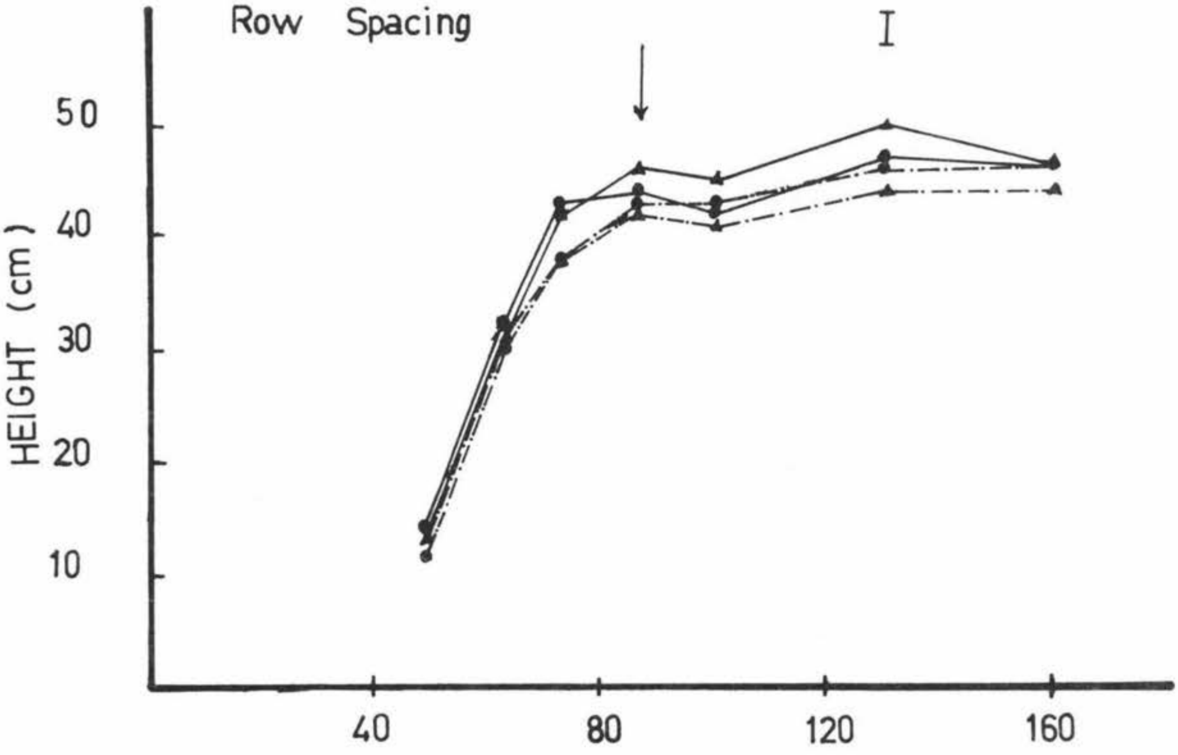
Identification of row spacings:

—●——●— 18 cm.
-·-●-·-●-·- 36 cm.
—▲——▲— 72 cm.
-·-▲-·-▲-·- Square Planting

Identification of sowing rates:

—●——●— 5.6 KG/Ha.
-·-●-·-●-·- 11.2 KG/Ha.
—▲——▲— 22.4 KG/Ha.
-·-▲-·-▲-·- 44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
HEIGHT (cm)
50
40
30
20
10
40
80
120
160

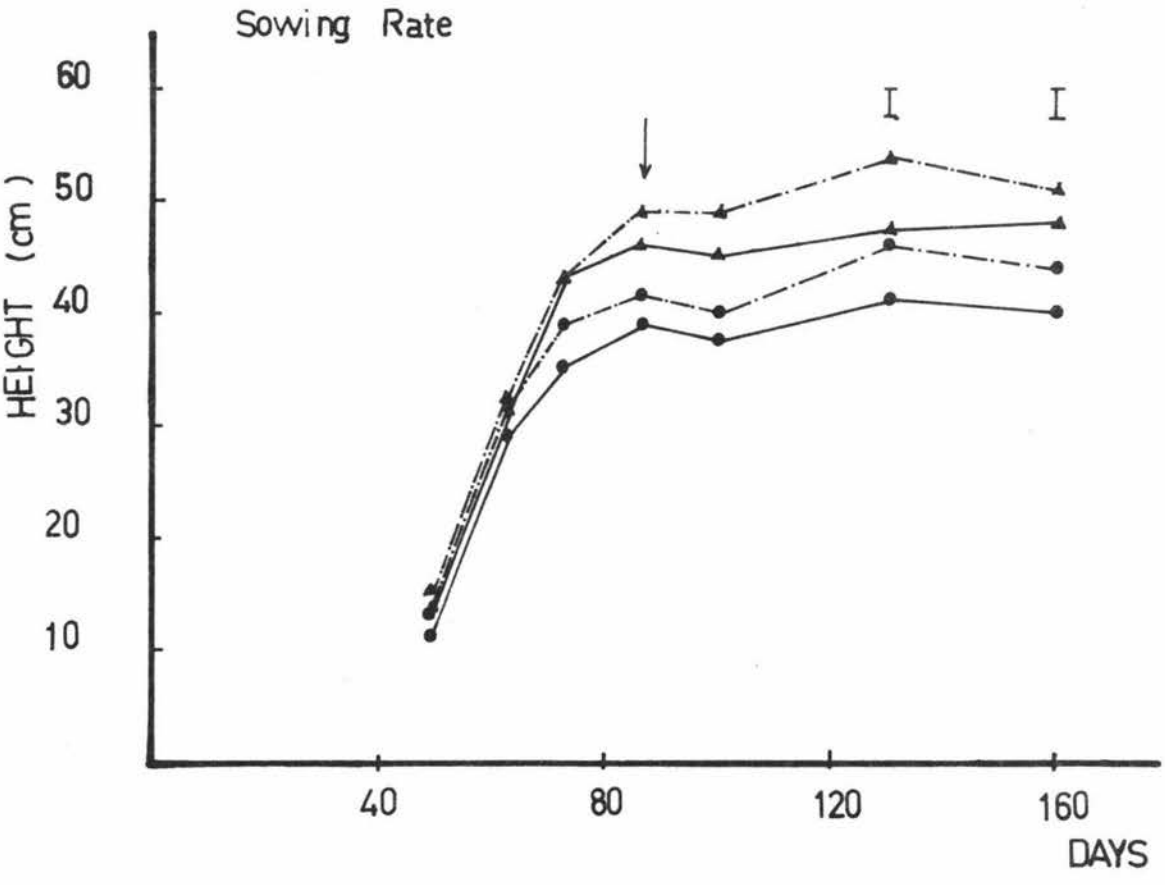

Sowing Rate
HEIGHT (cm)
60
50
40
30
20
10
40
80
120
160
DAYS

Figure 4. Mean Leaf Number Per Plant

Identification of row spacings:

—●——●— 18 cm.

-·-●-·-●-· 36 cm.

—▲——▲— 72 cm.

-·-▲-·-▲-· Square Planting

Identification of sowing rates:

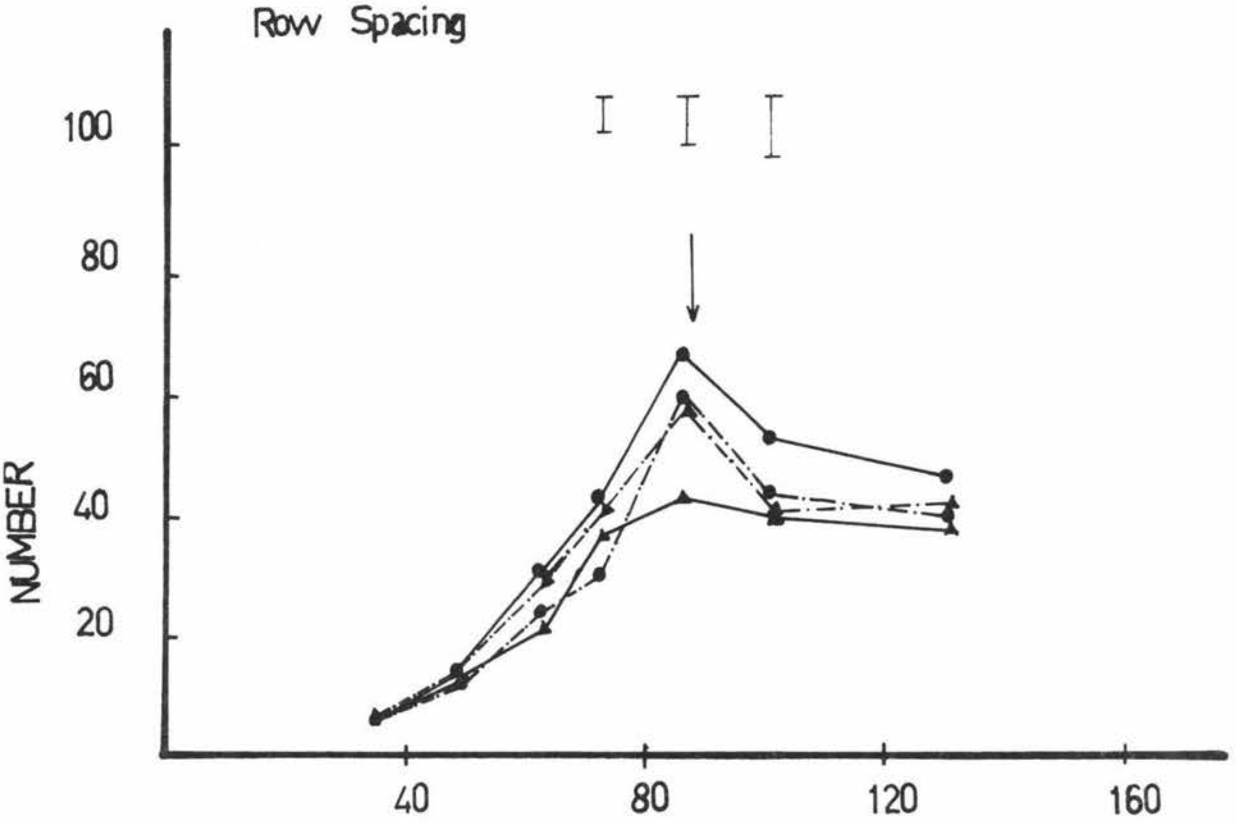
—●——●— 5.6 KG/Ha.

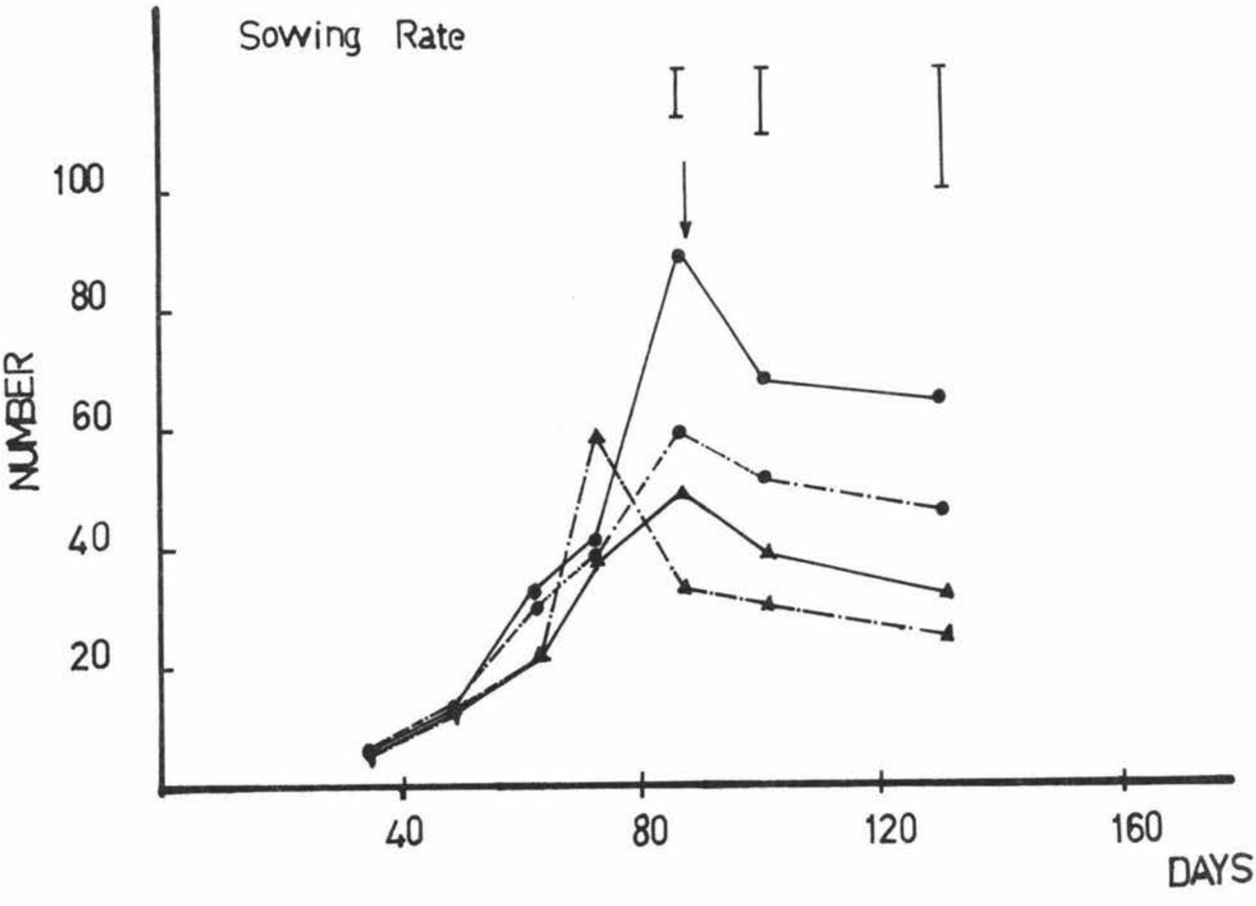
-·-●-·-●-· 11.2 KG/Ha.

—▲——▲— 22.4 KG/Ha.

-·-▲-·-▲-· 44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
NUMBER
100
80
60
40
20
40
80
120
160


Sowing Rate
NUMBER
100
80
60
40
20
40
80
120
160
DAYS

with the exception of the highest sowing rate treatment (44.8 Kg/Ha). In this treatment, maximum leaf number was reached a fortnight earlier than the other sowing rates (i.e. 4th sampling). It is interesting to note that as from the 5th sampling onwards leaf number per plant appeared to decrease with increasing sowing rates (Fig. 4).

3.42 Leaf Area

Leaf area per plant appeared to have a similar trend as the leaf number per plant in plant spacing treatments. Leaf area increased rapidly reaching its maximum at the fifth sampling. Thereafter it gradually decreased to zero in terms of green leaf at the final harvest (161 days after sowing). Generally, the 18 cm spacing appeared to have the highest leaf area per plant followed by the square planting, 36 cm and 72 cm plant spacing respectively (Fig. 5).

In general, increasing sowing rate showed a decreasing trend in leaf area per plant. At the first three sowing rates, maximum leaf area was achieved at the 5th sampling and there was a rapid decrease thereafter. However, at the highest seeding rate, maximum leaf area was reached at the 4th sampling, and the decline of leaf area appeared to be less rapid than the other three sowing rate treatments. Leaf area difference was found to be statistically significant at the 5th, 6th and 7th samplings but not in the earlier samplings (Fig. 5).

3.43 Leaf Area Index

With increasing row spacing, there was a tendency for the LAI to decrease. In general, the 18 cm plant spacing

Figure 5. Mean Leaf Area Per Plant

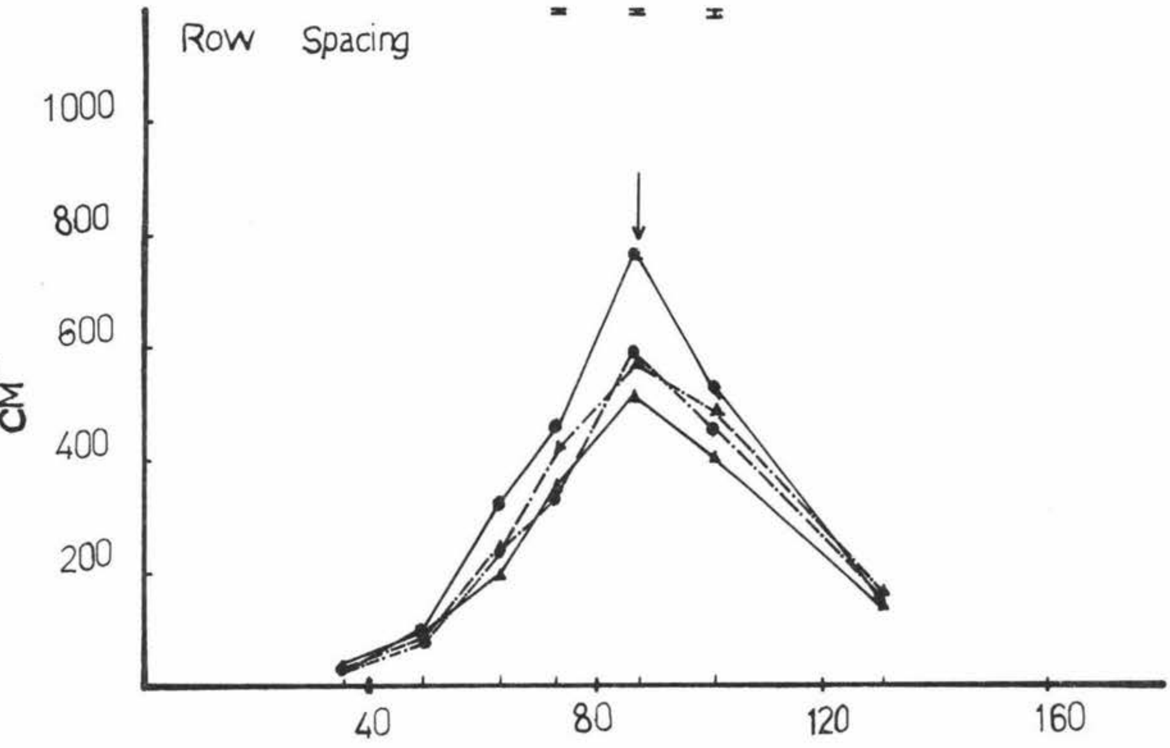
Identification of row spacings:

—●—●—	18 cm.
-·-●-·-●-·	36 cm.
—▲—▲—	72 cm.
-·-▲-·-▲-·	Square Planting

Identification of sowing rates:

—●—●—	5.6 KG/Ha.
-·-●-·-●-·	11.2 KG/Ha.
—▲—▲—	22.4 KG/Ha.
-·-▲-·-▲-·	44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
CM^2
1000
800
600
400
200
40
80
120
160

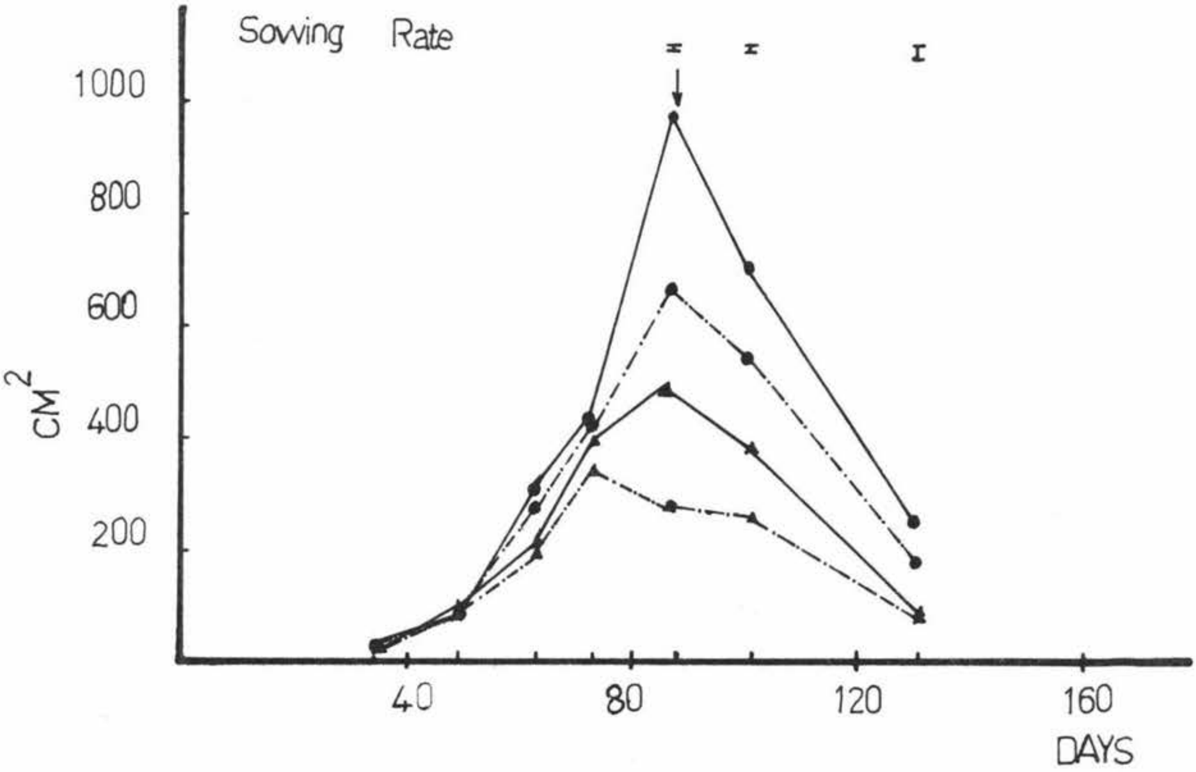

Sowing Rate
CM^2
1000
800
600
400
200
40
80
120
160
DAYS

Figure 6. Leaf Area Index

Identification of row spacings:

——●——●—— 18 cm.

-·-●-·-●-·- 36 cm.

——▲——▲—— 72 cm.

-·-▲-·-▲-·- Square Planting

Identification of sowing rates:

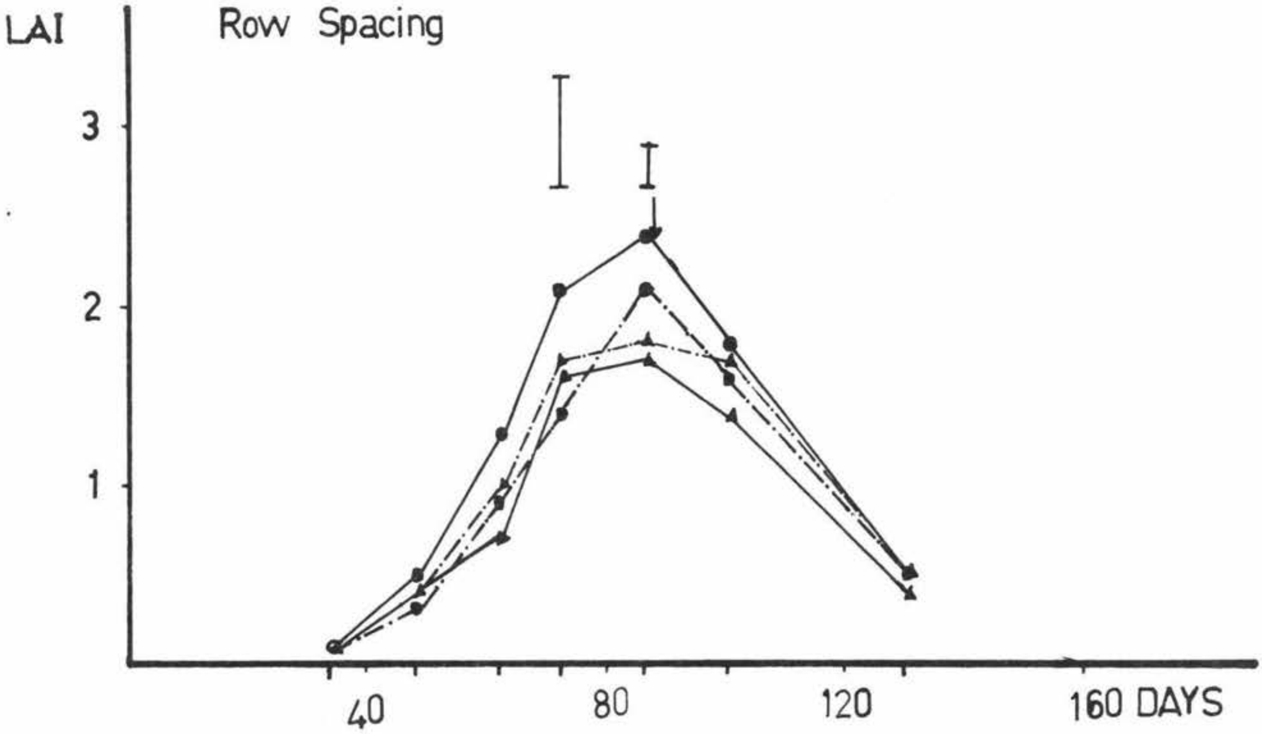
——●——●—— 5.6 KG/Ha

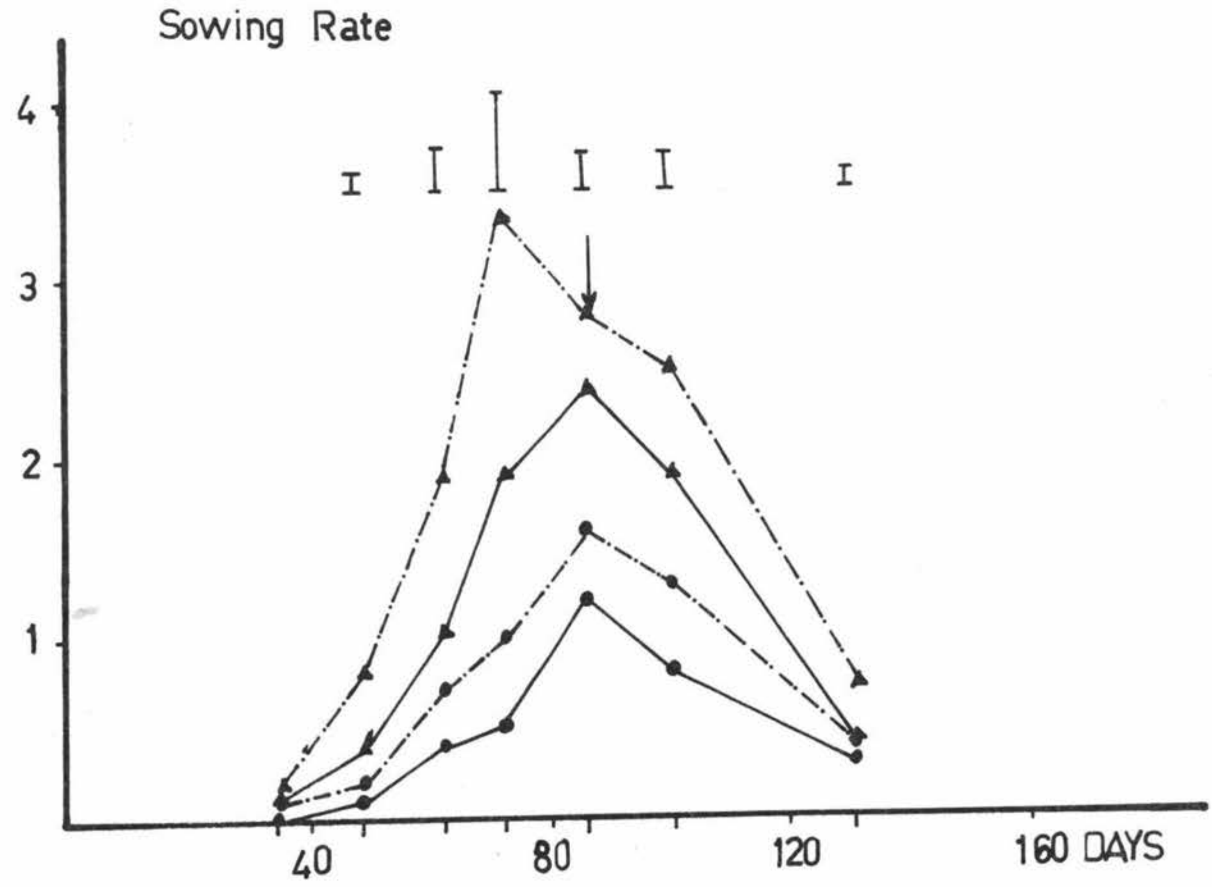
-·-●-·-●-·- 11.2 KG/Ha.

——▲——▲—— 22.4 KG/Ha.

-·-▲-·-▲-·- 44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing


Sowing Rate

had the highest value of LAI followed by the square planting, 36 cm and 72 cm plant spacing. LAI increased rapidly in the first four samplings reaching its peak at the 5th and then gradually declined (Fig. 6).

LAI appeared to increase with increasing sowing rate. The peak value for the highest sowing rate (44.8 Kg/Ha) was reached about a fortnight earlier than the other treatments.

3.44 Light Interception

Light measurements midway between rows were made at floral initiation and full bloom. In plant spacing treatments, light interception by the plant canopy increased with narrowed rows to a maximum of approximately 70% at full bloom in the 18 cm spacing. Square planting also trapped a large percentage of insolation, approximately 66% (Table 3a).

Higher sowing rates resulted in a greater percentage of light interception. At 5.6 Kg/Ha, light interception was only 6% at floral initiation but there was a substantial increase to 33% at full bloom. Similar increase was noted in the 11.2 Kg/Ha sowing rate at full bloom. However in the remaining two sowing rate treatments there was no further increase in light interception at full bloom compared to the earlier measurement (Table 3b).

Table 3a Effect of row spacing on light interception (%) at two growth stages

Row width cm	Growth Stages	
	Floral initiation	Full bloom
18	60	70
36	44	53
72	5	11
Square	52	66

Figure 7. Crop Growth Rate

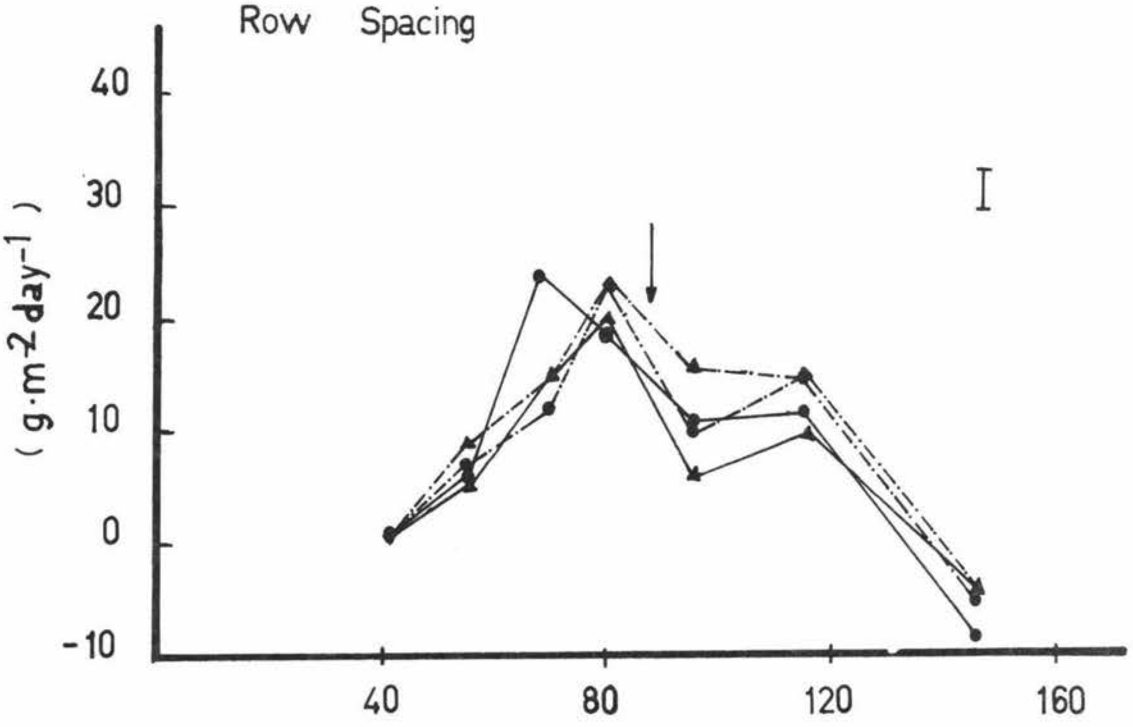
Identification of row spacings:

—●——●— 18 cm.
-·-●-·-●-·- 36 cm.
—▲——▲— 72 cm.
-·-▲-·-▲-·- Square Planting

Identification of sowing rates:

—●——●— 5.6 KG/Ha.
-·-●-·-●-·- 11.2 KG/Ha.
—▲——▲— 22.4 KG/Ha
-·-▲-·-▲-·- 44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
(g·m-2 day-1)
40
30
20
10
0
-10
40
80
120
160

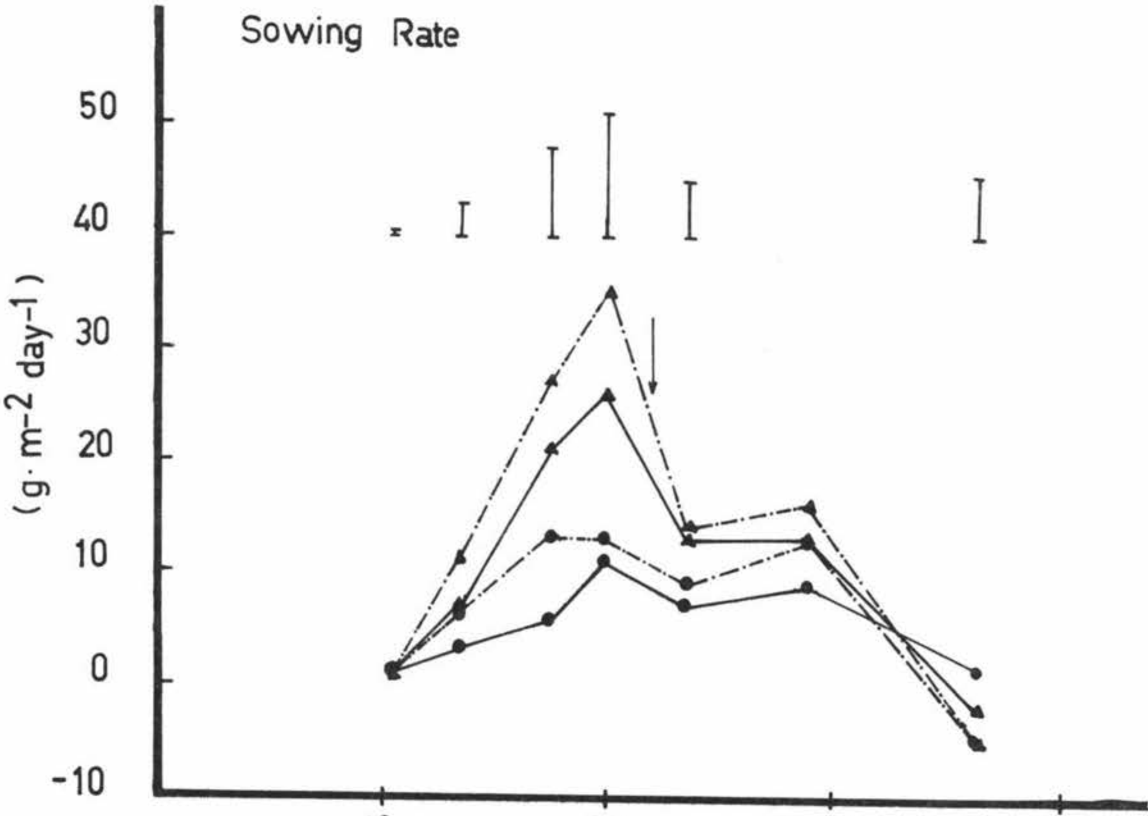

Sowing Rate
(g·m-2 day-1)
50
40
30
20
10
0
-10
40
80
120
160
DAYS

Table 3b Effect of sowing rate on light interception (%) at two growth stages

Sowing rate $KgHa^{-1}$	Growth Stages	
	Floral initiation	Full bloom
5.6	6	33
11.2	26	45
22.4	57	51
44.8	71	70

3.5 Growth Analysis

3.51 Crop Growth Rate (CGR)

There was a rapid increase in CGR in all treatments with time reaching peak value after approximately 80 days in 36 cm, 72 cm spacing and square planting but earlier in 18 cm spacing. Square planting appeared to maintain a relatively high value of CGR throughout the second half of experimental period. In spacing treatments, CGR values were significantly different only in the 7th sampling (Fig. 7).

CGR also increased with increasing plant density reaching a peak value after approximately 80 days (Fig. 7). The lowest sowing rate treatment also appeared to retain a significantly lower level of CGR than those of the highest sowing rate in all samplings except the 6th sampling.

3.52 Relative Growth Rate (RGR)

Relative growth rate reached a peak value in all treatments at approximately 8 weeks from sowing then rapidly declined to harvest. Highest value was recorded in the 18 cm and square planting treatments but declined more rapidly than the other treatments in the following 10 to 12

Figure 8. Relative Growth Rate

Identification of row spacings:

—●——●— 18 cm.

-·-●-·-●-·- 36 cm.

—▲——▲— 72 cm.

-·-▲-·-▲-·- Square Planting

Identification of sowing rates:

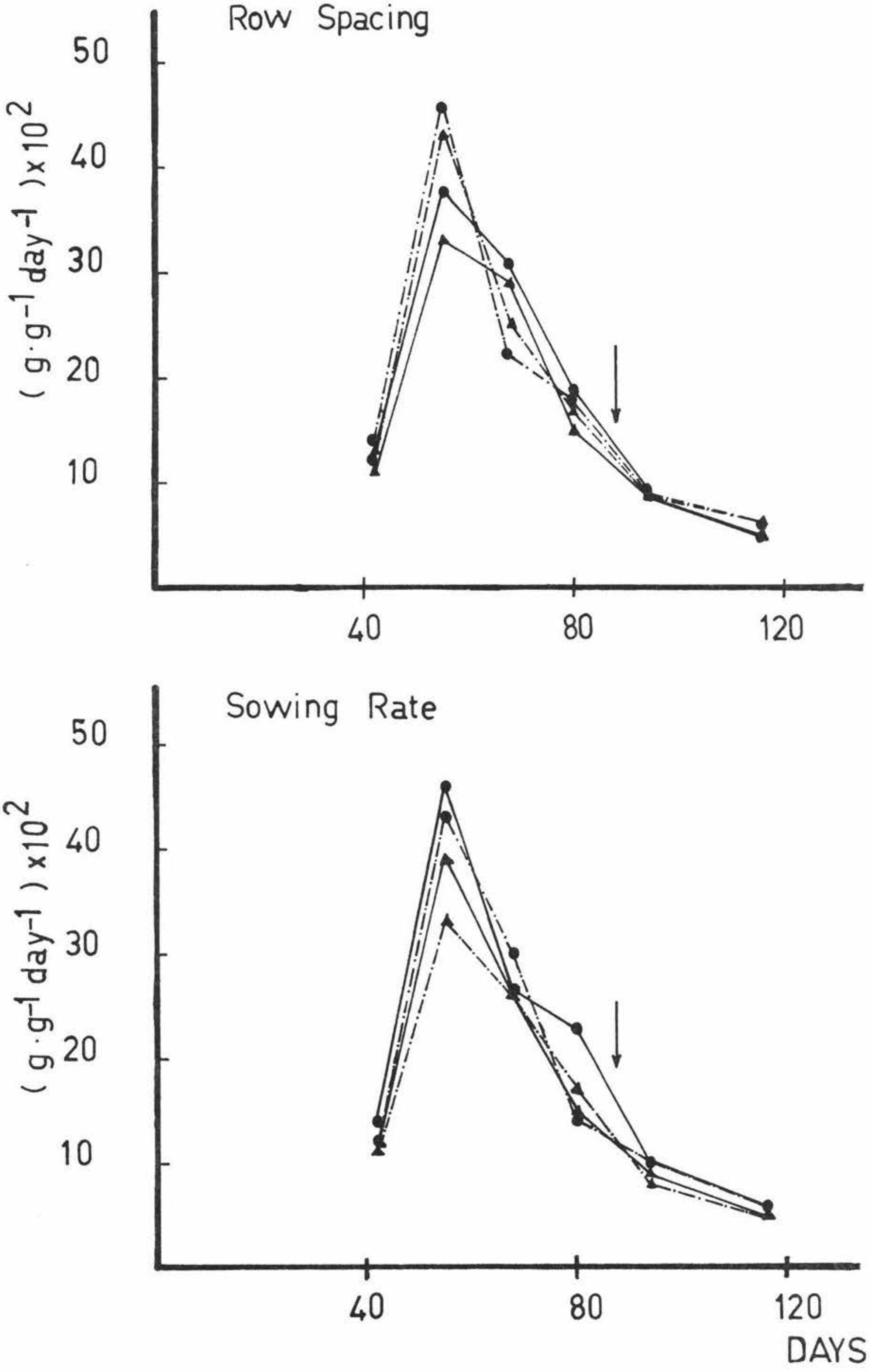
—●——●— 5.6 KG/Ha.

-·-●-·-●-·- 11.2 KG/Ha.

—▲——▲— 22.4 KG/Ha.

-·-▲-·-▲-·- 44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
50
40
30
20
10
(g·g⁻¹ day⁻¹) x 10²
40
80
120
Sowing Rate
50
40
30
20
10
(g·g⁻¹ day⁻¹) x 10²
40
80
120
DAYS

days (Fig. 8).

The increase in relative growth rate was inversely related to sowing rates during the first 8 weeks, then showed a similar relationship as it declined to harvest. CGR values in both row spacing and sowing rate treatments were found to be statistically non-significant.

3.53 Net Assimilation Rate (NAR)

In all treatments net assimilation rate conformed a general pattern of a sharp increase in value reaching a peak, followed by a decline till harvest. In the spacing treatments, 72 cm and 36 cm tended to show a higher NAR than those of the other spacing treatments over the early period of growth, i.e. up to 12 weeks after sowing. However, during the later period of growth the square planting treatment was clearly superior in NAR. It is also interesting to note that the square planting recorded its peak NAR approximately 2 weeks earlier than the other treatments, i.e. 8 weeks after sowing. In the 72, 36 and 18 cm spacing treatments NAR started to decline quite sharply after approximately 10 or 11 weeks of growth, while in the square planting treatment, NAR showed a more gradual decline through to harvest. Row spacing treatment differences were statistically significant only in the 3rd and 4th harvest (Fig. 9).

In all sowing rate treatments, NAR tended to follow a similar trend except that the lower sowing rates (5.6 and 11.2 $KgHa^{-1}$) reached peak levels 14 days earlier than did the higher sowing rates (22.4 and 44.8 $KgHa^{-1}$). The highest NAR was recorded in the lowest seeding rate treatment. NAR values from harvest 3, 4 and 5 showed significant treatment differences (Fig. 9).

Figure 9. Net Assimilation Rate

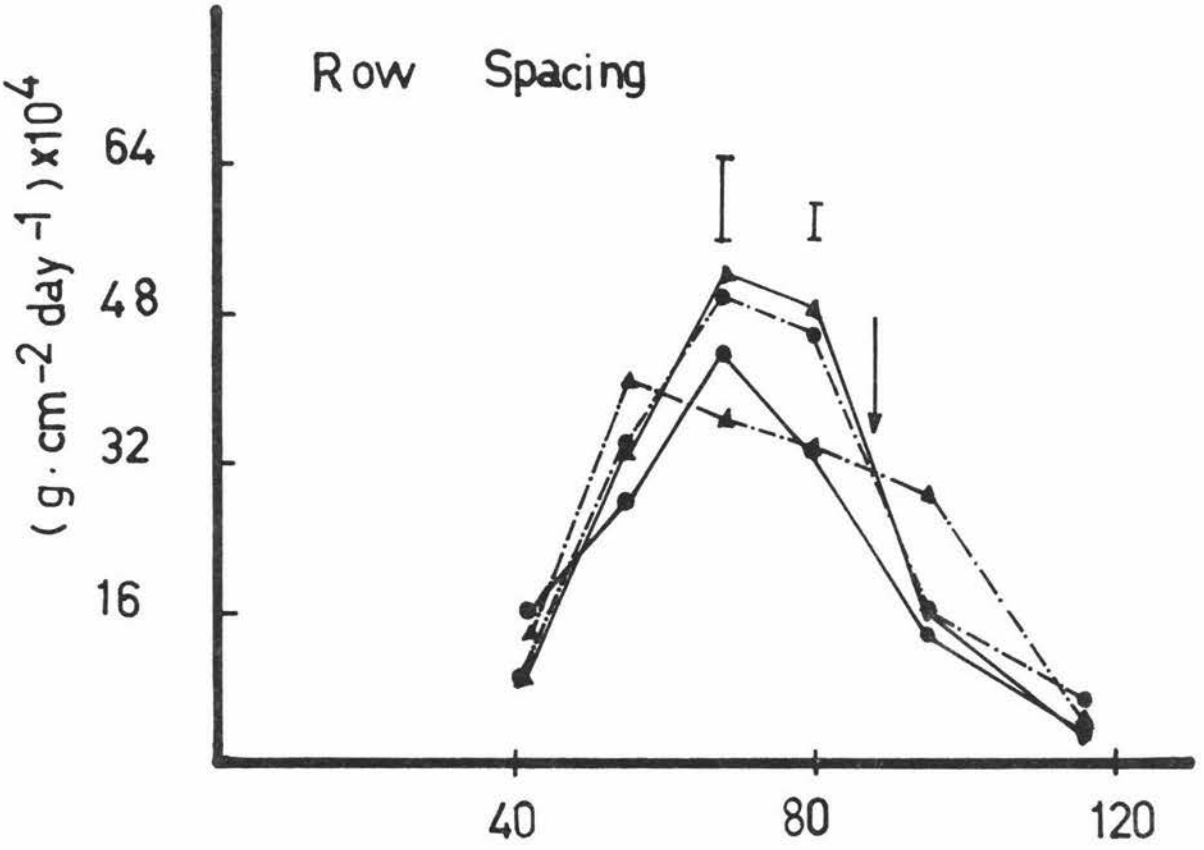
Identification of row spacings:

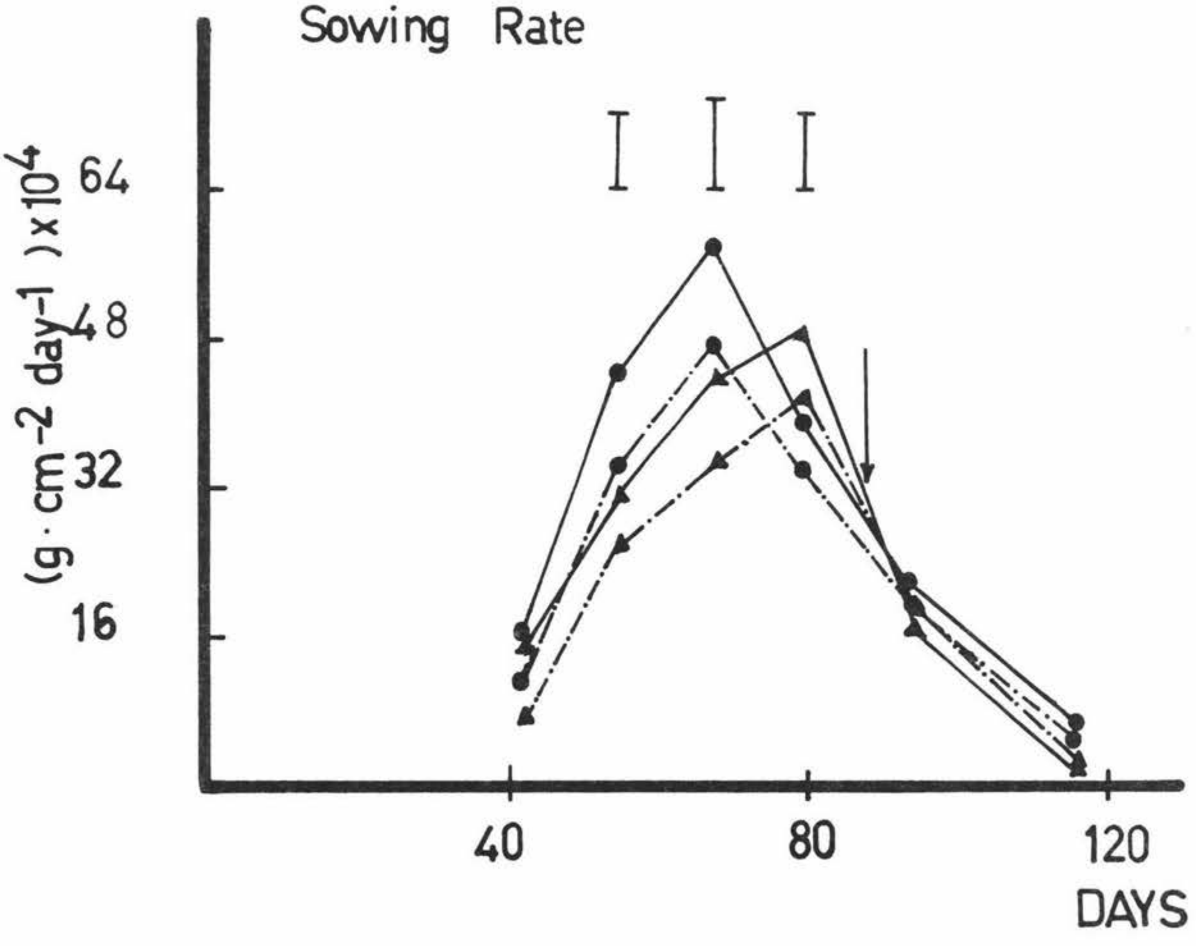
——●——●——	18 cm.
—·—●—·—●—·—	36 cm.
——▲——▲——	72 cm.
—·—▲—·—▲—·—	Square Planting

Identification of sowing rates:

——●——●——	5.6 KG/Ha.
—·—●—·—●—·—	11.2 KG/Ha.
——▲——▲——	22.4 KG/Ha.
—·—▲—·—▲—·—	44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
(g · cm⁻² day⁻¹) x10⁴
64
48
32
16
40
80
120


Sowing Rate
(g · cm⁻² day⁻¹) x10⁴
64
48
32
16
40
80
120
DAYS

3.54 Leaf Area Ratio (LAR)

LAR increased rapidly from the first sampling to reach its peak at the 2nd sampling in all spacing treatments. Thereafter LAR showed a rapid decline in all treatments. LAR showed little difference between treatments except in the 2nd and 3rd samplings. Fig. 10 shows that row spacing treatment differences were not statistically significant in all samplings.

A similar LAR trend with time appeared in the sowing rate treatments, with the highest sowing rate generally showing the highest LAR throughout the first 11 to 12 weeks of growth i.e. to the 4th harvest. Statistically significant treatment differences were recorded in the 4th, 5th and 7th harvests (Fig. 10).

3.6 Flowering

3.61 Days to 50% Flowering

Plants at the narrower spacings (18 cm and 36 cm) reached 50% flowering approximately 1 day earlier than those in the wider spacing (72 cm) and the square planting. Lower seeding rates (5.6 and 11.2 KgHa^{-1}) also tended to result in earlier flowering than did the higher sowing rates (22.4 and 44.8 KgHa^{-1}). However, the difference was not significant (Table 4).

Table 4 Days to 50% flowering

Row width cm	Sowing rates Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	88	86	86	88	87
36	85	86	89	89	87
72	85	86	90	90	88
Square	89	88	88	87	88
Sowing rate mean	87	87	88	89	LSD: 1
	Interaction LSD: 2				

Figure 10. Leaf Area Ratio

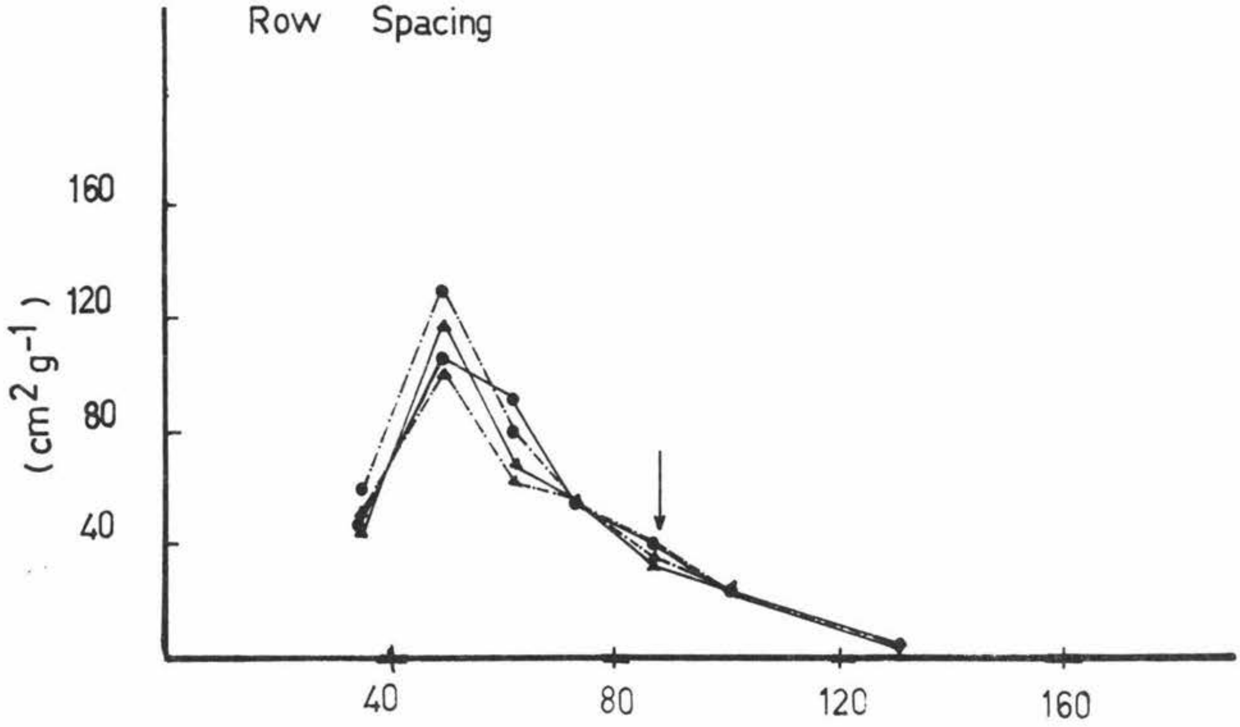
Identification of row spacings:

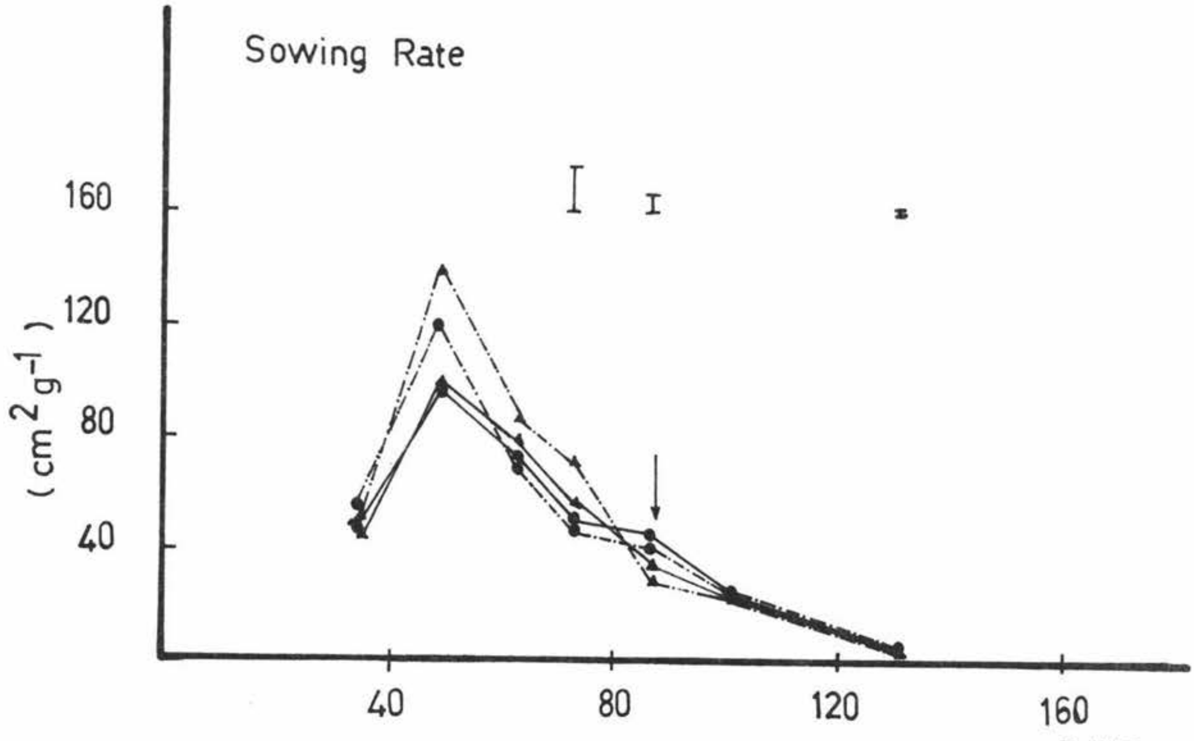
——●——●——	18 cm.
-·-●-·-●-·-	36 cm.
——▲——▲——	72 cm,
-·-▲-·-▲-·-	Square Planting

Identification of sowing rates:

——●——●——	5.6 KG/Ha.
-·-●-·-●-·-	11.2 KG/Ha.
——▲——▲——	22.4 KG/Ha.
-·-▲-·-▲-·-	44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
(cm^{2}g^{-1})
160
120
80
40
40
80
120
160


Sowing Rate
(cm^{2}g^{-1})
160
120
80
40
40
80
120
160
DAYS

3.62 Days to 90% Flowering

Differences between the number of days to 90% flowering between treatments increased compared with the earlier measurement. 90% flowering was achieved earliest in the narrowest spacing (18cm) followed by square planting, 36 cm and 72 cm spacing in that order and over a period of 4 days. The differences were significant between all spacing treatments.

So far as sowing rates were concerned, the trend was similar to that of 50% flowering and the differences were statistically significant, i.e. the two lower sowing rates reached 90% flowering earlier than the two higher sowing rate treatments.

The interaction between row spacing and sowing rate was also significant due to the greater delay in flowering in the more widely spaced rows as seeding rate increased (Table 5).

Table 5 Days to 90% flowering

Row width cm	Sowing rates Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	92	94	94	94	93
36	96	96	97	96	96
72	96	95	100	101	98
Square	94	95	95	95	95
Sowing rate mean	94	95	96	96	LSD: 1
	LSD: 1	Interaction LSD: 2			

3.7 Branching

The amount of branching per plant was measured

Figure 11. Mean Number Of Branches Per Plant

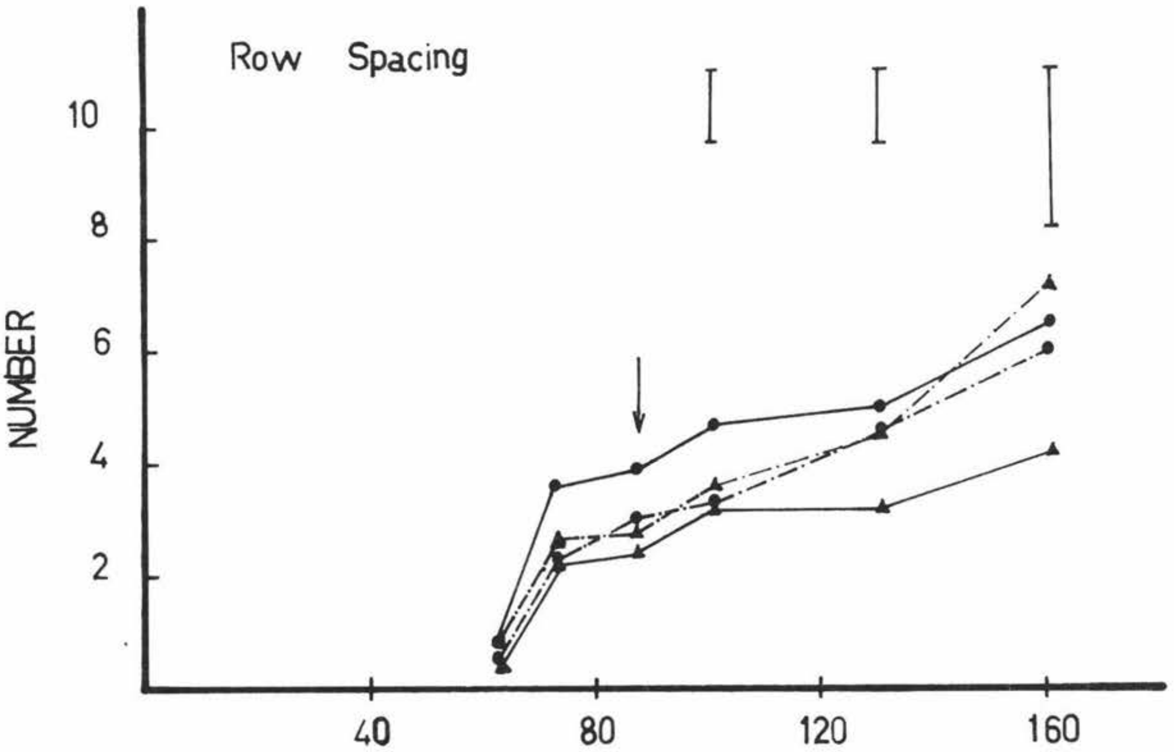
Identification of row spacings:

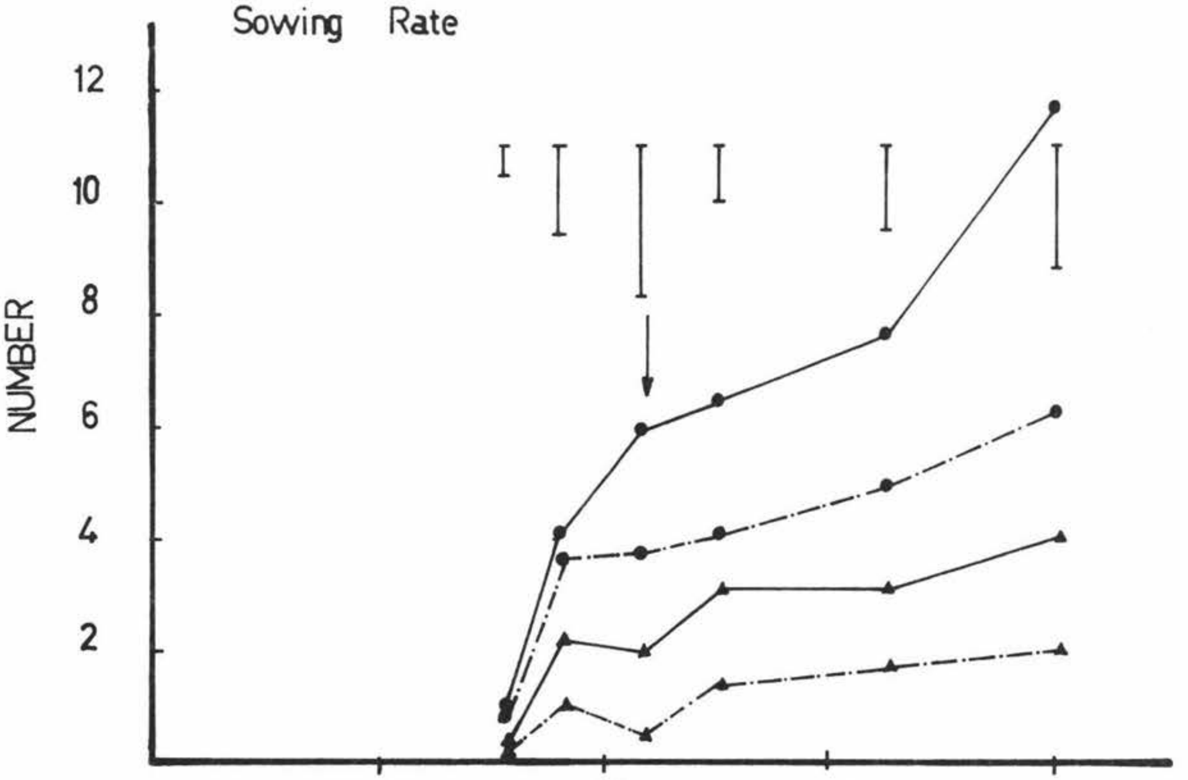
——●——●—— 18 cm.
-·-·-●-·-·-●-·- 36 cm.
——▲——▲—— 72 cm.
-·-·-▲-·-·-▲-·- Square Planting

Identification of sowing rates:

——●——●—— 5.6 KG/Ha.
-·-·-●-·-·-●-·- 11.2 KG/Ha.
——▲——▲—— 22.4 KG/Ha.
-·-·-▲-·-·-▲-·- 44.8 KG/Ha.

↓ Day of 50% flowering


Row Spacing
10
8
6
4
2
NUMBER
40
80
120
160


Sowing Rate
12
10
8
6
4
2
NUMBER
40
80
120
160
DAYS

from the 3rd sampling (9 weeks after sowing) onwards. As shown in Fig. 11 there was a rapid increase in branching between the 3rd and 4th samplings in all treatments, followed by a gradual increase thereafter. The 72 cm spacing seemed to have the least number of branches with the 18 cm treatment generally having the highest number. However, in the final harvest, square planting showed a greater degree of branching than all other spacing treatments. These differences were significant as from the 6th sampling onwards.

Lower sowing rates appeared to encourage branching (Fig. 11) with the superiority of the lowest seeding rate (5.6 $KgHa^{-1}$) being clearly displayed right through to the final sampling at harvest. Treatment differences were statistically significant as early as the 3rd sampling and right through to the final sampling at harvest.

3.8 Seed Yield Per Plant

Seed yield per plant ranged from 5.80 gms to 27.45 gms according to treatments. The lowest yield was obtained in the 72 cm spacing at 44.8 $KgHa^{-1}$ and the highest yield in the 18 cm spacing at 5.6 $KgHa^{-1}$. Increasing row width and therefore more plants within the row, appeared to decrease yield per plant, with square planting showing an intermediate yield. Once again it was interesting to note the apparent superiority of square planting as seeding rate increased. As might be expected, an increase in sowing rate led to a significant and progressive decrease in yield per plant (Table 6).

Table 6 Seed yield per plant (grams)

Row width cms	Sowing rates Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	27.4	16.7	7.8	6.6	14.6
36	23.3	16.7	10.2	6.1	14.1
72	18.7	14.1	9.3	5.8	12.0
Square	24.1	15.7	12.3	9.2	15.0
Sowing rate mean	23.4 LSD:2.6	15.8	10.4 Interaction: NS	6.9	LSD:2.2

3.9 Components of Seed Yield

The components of seed yields included seed heads per plant and per unit area, number and weight of seeds per head and 1000 seed weight. Also included in this section is the number of secondary and tertiary heads, weight and number of seeds from these heads and their 1000 seed weight. The number of primary head per plant is not included in this section because each plant obviously has only one primary head. However other aspects of the primary head such as number and weight of seed per head and 1000 seed weight are included.

3.91 Seed heads per plant

Total number of seed heads per plant ranged from 6 to 22 with the lowest number recorded in the 72 cm spacing at 44.8 $KgHa^{-1}$ and the highest in the 18 cm spacing at 5.6 $KgHa^{-1}$. The effect of spacing resulted in the square planting having a greater number of heads compared with 18 cm, 36 cm and 72 cm spacing. It appeared that with an increase in row width there was a decrease in the number of seed heads.

Thus the 72 cm spacing had the lowest number of seed heads in relation to the other treatments (Table 7).

As for the secondary heads, row spacing appeared to have little effect on this component although the narrowest row width tended to support slightly more secondary heads per plant (Table 8).

Table 9 shows that the number of tertiary heads per plant was found to be variable depending on treatments, ranging from 1 to 13. However, the mean number of tertiary heads in the different row spacing treatments showed that the square planting treatment had a slight advantage over 18 and 36 cm spacing treatments but a considerable advantage over 72 cm spacing treatment.

Increasing sowing rates appeared to depress the total number of seed heads per plant. As a result, the lowest sowing rate had 20 seed heads per plant while the highest sowing rate had only 8. Both the secondary and tertiary heads per plant were similarly affected by sowing rate, i.e. increasing the sowing rate caused a consequent reduction of these components. For example, Table 9 shows that by increasing the sowing rate 8 fold, the number of tertiary heads was reduced to 1/6th. In all three categories of seed heads, treatment differences were significant.

Table 7 **Total number of heads per plant**

Row width cms	Sowing rate Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	22	14	11	7	13
36	18	13	10	8	12
72	17	11	7	6	10
Square	23	14	11	8	13
Sowing rate mean	20 LSD:2	13 Interaction: NS	10	7	LSD: 2

Table 8 **Number of 2^{0} heads per plant**

Row width cms	Sowing rate Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	8	6	5	4	6
36	6	6	5	4	5
72	7	5	4	4	5
Square	7	6	5	4	5
Sowing rate mean	7 LSD:NS	6 Interaction: NS	5	4	LSD:NS

Table 9 **Number of 3^{0} heads per plant**

Row width cms	Sowing rate Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	13	7	5	1	6
36	11	6	4	3	6
72	9	5	2	1	4
Square	14	7	5	3	7
Sowing rate mean	12 LSD:2	6 Interaction: NS	4	2	LSD:NS

3.92 Number of seed heads per unit area (meter square)

Total number of seed heads per meter square ranged from 212 to 825 depending on treatments (Appendix 4). The effect of row spacing on the number of seed heads per unit area showed that the square planting had the highest number while the lowest number was from the widest row spacing (72 cm). Similar trend was also displayed by the tertiary heads but not in the secondary heads where the differences were not statistically significant. In both the total and the tertiary heads, the row spacing differences were significant only between that of the widest row spacing and the remaining row spacing treatments. Figures 12A and C show the distribution of the different seed heads and their percentage contribution.

The effect of sowing rate on the total number of heads, secondary and tertiary heads per unit area is shown in Fig. 12B. Both the total and the number of secondary heads per unit area increased correspondingly with increasing sowing rate. However, in the case of tertiary heads, it is interesting to note that this component reached a maximum at sowing rate of 22.4 $KgHa^{-1}$ but declined at the highest sowing rate (44.8 Kg/Ha^{-1}). Figure 12D shows that increasing the sowing rate resulted in the increased percentage contribution of the primary and secondary heads but there was a corresponding decrease in the percentage of tertiary heads. Treatment differences were significant in the total number of seed heads and the number of secondary heads per meter square but not in that of tertiary heads.

3.93 Weight of seed head

Mean weight of seed heads per plant in the

Figure 12: Number and Percent of Primary, Secondary and Tertiary Heads Per Meter Square.

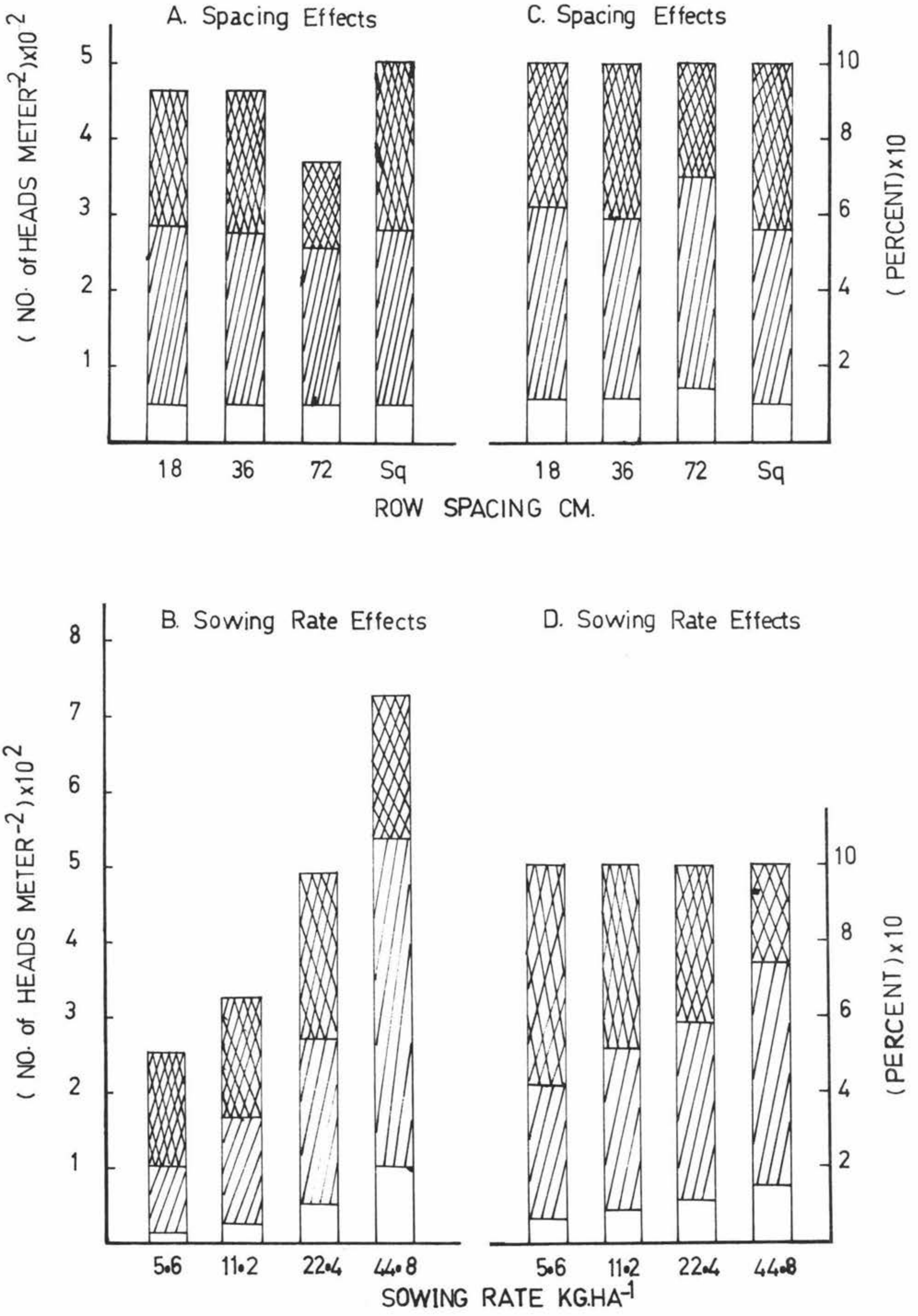
A. Number of Heads as affected by Row Spacings.

B. Number of Heads as affected by Sowing Rates.

C. Percent of Heads as affected by Row Spacings.

D. Percent of Heads as affected by Sowing Rates.

☐	Primary Heads
▨	Secondary Heads
▩	Tertiary Heads


A. Spacing Effects
C. Spacing Effects
(NO. of HEADS METER^{-2})x10^{-2}
5
4
3
2
1
10
8
6
4
2
(PERCENT) x10
18
36
72
Sq
18
36
72
Sq
ROW SPACING CM.
B. Sowing Rate Effects
D. Sowing Rate Effects
(NO. of HEADS METER^{-2}) x10^{2}
8
7
6
5
4
3
2
1
10
8
6
4
2
(PERCENT) x10
5•6
11•2
22•4
44•8
5•6
11•2
22•4
44•8
SOWING RATE KG.HA^{-1}

different spacing treatments showed little variations, with the square planting treatment indicating a slight superiority over the other treatments (Table 10). Similar trends were also displayed in the weight per primary, secondary and tertiary head (Tables 11, 12 and 13). However, treatment differences were not significant in all cases.

Increasing the sowing rate appeared to depress the total weight of seed heads per plant. This trend was also demonstrated by seed head weight per primary and tertiary head but not so in the case of secondary head. It appeared that the secondary head from the 11.2 $KgHa^{-1}$ had a slight weight advantage over that of 5.6 $KgHa^{-1}$, followed by those of 22.4 and 44.8 $KgHa^{-1}$ in that order. In the case of the total weight of seed heads per plant, all treatment differences were significant but in the case of separate head weight only certain treatment differences were significant.

Table 10 Weight of heads per plant (grams)

Row width cms	Sowing rate Kg/ha				Row width mean
	5.6	11.2	22.4	44.8	
18	50.3	29.7	18.5	12.9	27.8
36	41.3	29.3	17.5	12.0	25.0
72	41.0	23.8	14.1	9.7	22.1
Square	46.1	27.8	23.0	15.3	28.0
Sowing rate mean	44.7	27.6	18.3	12.5	LSD:NS
	LSD:6.9		Interaction: NS		

Table 11 Weight per primary head (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	3.19	2.93	2.69	2.48	2.82
36	2.99	3.16	2.63	2.24	2.75
72	3.57	3.02	2.51	2.18	2.82
Square	3.01	3.10	3.00	2.63	2.92
Sowing rate mean	3.19	3.05	2.71	2.38	LSD:NS
	LSD:0.32		Interaction: NS		

Table 12 Weight per secondary head (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	2.50	2.72	2.06	2.00	2.32
36	2.61	2.66	2.10	1.66	2.26
72	2.68	2.69	2.24	1.59	2.29
Square	2.56	2.44	2.47	2.08	2.39
Sowing rate mean	2.59	2.61	2.22	1.84	LSD:NS
	LSD:0.24		Interaction: NS		

Table 13 Weight per tertiary head (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	1.89	1.53	1.07	0.88	1.34
36	1.92	1.57	1.09	0.97	1.39
72	2.07	1.51	1.27	1.00	1.46
Square	1.73	1.50	1.45	1.24	1.48
Sowing rate mean	1.90	1.53	1.22	1.02	LSD:NS
	LSD:0.26		Interaction: NS		

3.94 Number of seed per head

This data was obtained by dividing the number of seed obtained from a plant with the total number of seed heads irrespective of their locations. The breakdown into the different categories is also included in this section.

The effect of spacing treatments on the number of seed per head, per primary, secondary and tertiary head showed no significant difference. However, it is interesting to note that the square planting treatment appeared to have a slight advantage in seed number in all the heads concerned (Tables 14, 15, 16 and 17).

Sowing rate treatments showed a definite trend of decreasing the number of seeds per head in all categories. Treatment differences were significant in all cases except that of primary head.

Table 14 Number of seeds per head (total)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	32	32	28	25	29
36	34	29	27	24	28
72	32	31	28	24	29
Square	32	33	31	27	30
Sowing rate mean	32	31	28	25	LSD:NS
	LSD:3		Interaction: NS		

Table 15 Number of seeds per primary head

Row width cms	Sowing rate Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	34	32	32	30	32
36	33	29	29	27	29
72	36	32	26	28	30
Square	34	35	34	28	32
Sowing rate mean	33	32	30	28	LSD:NS
	LSD:NS		Interaction: NS		

Table 16 Number of seeds per secondary head

Row width cms	Sowing rate Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	32	37	31	28	32
36	35	36	29	26	31
72	30	35	32	24	30
Square	33	35	34	31	33
Sowing rate mean	32	36	31	27	LSD:NS
	LSD:3		Interaction: NS		

Table 17 Number of seeds per tertiary head

Row width cms	Sowing rate Kg/Ha 5.6	11.2	22.4	44.8	Row width mean
18	30	27	22	16	24
36	34	23	21	20	25
72	30	26	27	18	25
Square	31	28	23	21	26
Sowing rate mean	31	26	23	19	LSD:NS
	LSD:4		Interaction: NS		

3.95 Weight of seed per head

This data was obtained by dividing the total weight of seed yielded per plant by the total number of seed heads irrespective of their locations. Weight of seed from the different heads (i.e. primary, secondary and tertiary) is also tabulated and discussed in this section.

As in the previous case (number of seed per head), the mean seed weight per head of all categories showed no significant spacing effect although the square planting treatment showed a slight superiority in seed weight per head in all instances (Tables 18, 19, 20 and 21).

The increase in sowing rate generally depressed seed weight of all heads. This effect of sowing rate on seed weight per head was statistically significant.

Table 18 Weight of seed per head (total) - (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	1.24	1.26	0.95	1.08	1.13
36	1.11	1.20	0.99	0.80	1.04
72	1.34	1.15	1.11	0.94	1.13
Square	1.24	1.12	1.13	1.07	1.14
Sowing rate mean	1.23 LSD:0.12	1.18	1.05 Interaction: NS	0.97	LSD:NS

Table 19 Weight of seed per primary head (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	2.05	1.87	1.72	1.60	1.81
36	1.88	1.96	1.67	1.34	1.71
72	2.32	1.92	1.54	1.41	1.79
Square	1.89	1.95	1.96	1.67	1.87
Sowing rate mean	2.05 LSD:0.26	1.92	1.72 Interaction LSD:NS	1.50	LSD:NS

Table 20 Weight of seed per secondary head (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	1.50	1.77	1.29	1.21	1.44
36	1.45	1.68	1.27	0.90	1.32
72	1.54	1.71	1.35	0.88	1.37
Square	1.55	1.47	1.55	1.29	1.46
Sowing rate mean	1.51 LSD:0.16	1.66	1.36 Interaction LSD:NS	1.07	LSD:NS

Table 21 Weight of seed per tertiary head (grams)

Row width cms	Sowing rate Kg/Ha				Row width mean
	5.6	11.2	22.4	44.8	
18	0.95	0.72	0.44	0.29	0.60
36	0.79	0.63	0.42	0.40	0.56
72	0.85	0.71	0.55	0.28	0.60
Square	0.86	0.70	0.61	0.52	0.67
Sowing rate mean	0.86 LSD:0.14	0.69	0.50 Interaction LSD:NS	0.37	LSD:NS

3.96 1000 Seed Weight

This data was obtained from seeds of the combined heads. The breakdown of this data into the different components is also included in this section.

The 1000 seed weight varied from 33.38 to 50.69 gms according to treatments. The lowest value was obtained at 18 cm spacing at 44.8 Kg/Ha^{-1} sowing treatment and the highest value at 72 cm spacing treatment in 5.6 KgHa^{-1}. Mean weight of seed in different spacing treatments showed little variations but increasing sowing rates appeared to depress seed weight (Table 22).

The effect of sowing rate on the seed weight of primary head was similar as the previous one although it tended to increase with wider row spacing (Table 23).

In the case of secondary head, row spacing treatments had no significant effect on 1000 seed weight but an increase in sowing rate appeared to depress this component (Table 24).

Table 25 shows that the 1000 seed weight of the tertiary head was substantially lower than that of the primary and secondary heads. As with the previous cases, spacing treatments did not show any significant effect although the same or similar trend was apparent. The effect of sowing rate on the 1000 seed weight of tertiary head was similar to that of primary and secondary heads.

Table 22 1000 seed weight - total (grams)

Row width cms	Sowing rate Kg/Ha^{-1}				Row width mean
	5.6	11.2	22.4	44.8	
18	46.28	45.09	39.11	33.38	40.96
36	41.49	46.27	41.97	35.62	41.34
72	50.69	46.03	40.51	36.16	43.35
Square	46.18	40.82	42.93	42.48	43.10
Sowing rate mean	46.16	44.55	41.13	36.91	LSD:NS
	LSD:4.56		Interaction: NS		

Table 23 1000 seed weight of primary head (grams)

Row width cms	Sowing rate Kg/Ha^{-1}				Row width mean
	5.6	11.2	22.4	44.8	
18	60.63	59.25	54.26	53.54	56.92
36	57.05	64.04	57.12	49.81	57.00
72	67.59	62.32	60.86	49.68	60.11
Square	64.35	57.07	57.48	51.04	59.44
Sowing rate mean	61.93	60.69	57.23	53.51	LSD:NS
	[illegible]:4.47		Interaction: NS		

Table 24 1000 seed weight of secondary head (grams)

Row width cms	Sowing rate Kg/Ha^{-1}				Row width mean
	5.6	11.2	22.4	44.8	
18	46.13	49.26	42.05	42.83	45.07
36	42.20	48.62	47.08	34.60	43.12
72	51.23	48.75	42.53	36.26	44.69
Square	47.84	41.93	44.80	41.78	44.24
Sowing rate mean	46.85	47.14	44.11	38.87	LSD:NS
	LSD:3.96		Interaction LSD:7.94 9.14		

Table 25 1000 seed weight of tertiary head (grams)

Row width cms	Sowing rate KgHa^{-1} 5.6	11.2	22.4	44.8	Row width mean
18	32.09	26.76	21.02	13.77	23.41
36	26.21	26.16	19.72	22.46	23.64
72	33.24	27.01	18.14	22.53	25.53
Square	28.12	24.46	26.82	24.61	26.00
Sowing rate mean	29.91	26.10	21.42	20.34	LSD:NS
	LSD 5.24		Interaction LSD:NS		

3.10 Seed moisture content

The seed moisture content varied only slightly across all treatments (Table 26). There was no significant effect due to either row spacing or sowing rates although the tendency for seed moisture content to decrease with increasing population density was apparent.

Table 26 Moisture content of seed (%)

Row width cms	Sowing rate KgHa 5.6	11.2	22.4	44.8	Row width mean
18	10.9	10.4	10.0	10.9	10.6
36	10.6	11.0	10.7	10.1	10.6
72	11.2	10.3	10.0	10.4	10.2
Square	11.1	10.2	10.0	9.7	10.2
Sowing rate mean	10.9	10.5	10.2	10.3	LSD:NS
	LSD:NS		Interaction LSD:NS		

3.11 Germination Percentage

Germination percentage ranged from 51% to 69% according to treatments. In terms of row width effect, the difference in percentage germination was very slight and non-significant (Table 27).

Although not statistically significant, the effect of sowing rate on germination was more evident and tended to increase with sowing rate.

Table 27 Seed germination (%)

Row width cms	Sowing rate Kg/ha				Row width mean
	5.6	11.2	22.4	44.8	
18	62	58	59	68	62
36	65	56	66	60	62
72	57	61	62	61	60
Square	57	65	63	69	62
Sowing rate mean	60	60	62	64	LSD:NS
	LSD:NS		Interaction LSD:NS		

3.12 Oil Percentage

The oil percentage varied from about 26 to 29% but there was no significant difference due to spacing or sowing rate treatments (Table 28). However, there was a slight tendency for oil percentage to increase with wider rows and higher sowing rates.

Table 28 Oil content of seed (%)

Row width cms	Sowing rate KgHa^{-1}				Row width mean
	5.6	11.2	22.4	44.8	
18	26.67	27.24	28.05	28.59	27.64
36	26.61	26.65	27.69	28.67	27.40
72	26.59	26.46	27.29	26.60	26.76
Square	27.11	26.89	27.62	28.07	27.42
Sowing rate mean	26.77	26.82	27.64	27.98	LSD:NS
	NS		Interaction : NS		

3.13 Oil Quality

The main fatty acid components of safflower oil are palmitic, stearic, oleic, and linoleic. The most desirable component, linoleic acid, formed the greatest proportion of these components ranging from 71.8 to 84.2% according to treatments. The remaining components were oleic acid (6.[illegible] - 13.5%), palmitic acid (6.4 - 11.2%) and stearic acid ([illegible] - 3.9%). (See Appendix 5).

The effect of row width on the composition of safflower oil was negligible and there was virtually no difference in the percentage of linoleic acid in the different row spacing treatments (Table 29). However, the square planting treatment did show a 2% to 3% rise in linoleic acid (81.9%) over the row treatments. As a result the oleic acid and palmitic acid levels tended to be lower in this treatment.

In the sowing rate treatments the 11.2 KgHa^{-1} had the highest % of linoleic acid (82.1), while the lowest percentage was 5.6 KgHa^{-1} (77.4). As noted above the highest linoleic acid level was associated with the lowest oleic acid level and vice versa (Table 30).

Table 29 Effect of row spacing on % composition of fatty acids in safflower oil

Row width cms	Fatty Acids			
	Palmitic	Stearic	Oleic	Linoleic
18	8.0	2.8	10.0	79.1
36	8.5	2.2	9.7	79.5
72	7.9	2.6	10.3	79.1
Square	7.1	2.3	8.7	81.9

Table 30 Effect of sowing rate on % composition of fatty acid in safflower oil

Sowing rate Kg/ha	Fatty Acid			
	Palmitic	Stearic	Oleic	Linoleic
5.6	8.6	2.8	11.2	77.4
11.2	7.0	2.0	8.9	82.1
22.4	7.6	2.5	9.7	80.1
44.8	8.3	2.5	9.0	80.2

CHAPTER FOUR DISCUSSION

4.1 Seed Yield

The highest seed yield per unit area was recorded in the square planting treatment followed by a steady decline as row width, and therefore as plant competition within the row, increased.

The highest seed yield per plant, however, was recorded in the narrowest row spacing treatment at the lowest seeding rate. As sowing rate increased yield per plant decreased although the depression was significantly less under the square planting than under row planting. This significant interaction meant that plants on the square were substantially superior in seed yield than the plants in rows at the high sowing rate, i.e. when competition was intense. As shown in Figure 1, by increasing sowing rate eight fold, the seed yield was more than doubled.

The relationship between sowing rates and yield had been investigated by several workers elsewhere. For example, orker et al (1965), demonstrated that by increasing sowing rate from 13 to 54 Kg/Ha at 35 cm row spacing, the seed yield increased from 3455 to 4376 Kg/ha^{-1}. In Australia, Beech and Norman (1966) and Stern and Beech (1965) noted that seed yield decreased when planting density exceeded the optimum level. They concluded that the optimum planting density for drilled crops was 618,000 plants per hectare (=30 Kg/ha^{-1}) and for row crops 309,000 plants per hectare (15 Kg/ha^{-1}). Peterson (1965), in Nebraska U.S.A. also noted the depressing effect on safflower seed yield when he doubled the planting rate from 13 to 26 seeds per meter row.

Similarly the relationship between row spacing and yield established in this study is in agreement with the findings of Beech (1969), Williams (1962) and Worker et al (1965), who observed that in general yields from wide row spacings had been lower than close-drilled sowings for the same seeding rate. In soybean too, the superiority of narrow row spacings had been demonstrated by Donovan et al (1963), Lehman and Lambert (1960) and Weber (1969).

Williams (1962), suggested that the reduction in safflower seed yield in the wide row spacing was attributed to greater intra-row and less inter-row plant competition. The superiority of square planting, as shown in the results presented, would indicate the importance of attempting to "equalize" and maximise the effecient use of the environmental factors. This competitive advantage of square planting is best demonstrated by seed yield from the two high sowing rates (22.4 and 44.8 Kg/ha^{-1}) (Figure 1). The increase in seed production per hectare over the highest alternative treatment was approximately 20% and 50% respectively. This large increase in seed yield was rather unexpected but Wiggans (1939) in his investigations with soybean had demonstrated that within a given population level, seed yield increased as inter-row and intra-row spacings approached a uniform (square) distribution pattern.

4.2 Yield Components

The components of yield presented in tables 31 and 32 show the sources of differences in seed yield between spacing treatments and between sowing rate studied.

The only component that was significantly related to the treatment differences recorded was the total number of heads per plant and per unit area. Nevertheless, many other components of seed yield also tended to contribute to the "spacing" effets, although such differences were not statistically significant (Table 31).

Thus the significantly high seed yield per unit area obtained from the square treatments was the result of the total number of seed heads produced. Table 31 shows that plants in the square planting treatments produced 503 seed heads per meter square and 13 heads per plant compared to 368 seed heads per meter square and 10 heads per plant from plants in the 72 cm row spacing - the lowest seed yield. This increase in the total number of seed heads in the square planting was the direct result of an increase in the number of tertiary heads. However, in row spacing treatments, the 72 cm treatment in particular, the increase in intra-row plant competition resulted in the decrease in the number of tertiary heads and thus affecting the total number of seed heads per unit area. Similar results have been recorded by Williams (1960).

In contrast to the "spacing" effects, many seed yield components contributed significantly to the sowing rate effects. Number and weight of heads, number and weight of seed per head and seed weight all showed a significant depression as sowing rate increased (Table 32).

Although seed yield per plant was superior in the lowest sowing rate, the reverse was the situation obtained on per unit area basis. As expected, plants from low sowing rate, due to lack of competition, produced significantly high number of seed heads. This lack of competition also influenced the other seed components showing a significant increase in the head weight, number and weight of seeds per head and also 1000 seed weight as mentioned earlier. Similar findings were reported by Beech and Norman (1963 and 1966), Knowles (1955, 1958), Yermanos and Francoise (1963) and Williams (1962).

The superiority of the highest sowing rate on seed yield per unit area was again largely due to an increse in the number of seed heads per unit area. Those seed yield components which favoured seed yield per plant at the lowest sowing rate were not sufficient to compensate for the gain on a unit area basis from an increased sowing rate.

TABLE 31 Yield and Yield Components as affected by Spacings

Mean values of yield components	Row Spacing (cms)				
	18	36	72	Square	LSD
Seed yield kg/ha^{-1}	4434	4256	3829	5199	727
No. of heads m^{-2} Total	465	465	368	503	72
No. of heads m^{-2} 20	238	225	207	232	NS
No. of heads m^{-2} 30	180	193	114	222	56
No. of heads plant^{-1} Total	13	12	10	13	NS
No. of heads plant^{-1} 20	6	5	5	5	NS
No. of heads plant^{-1} 30	6	6	4	7	NS
Wt. of head plant^{-1} (gms)	27.8	25.0	22.1	28.0	NS
Wt. head^{-1} 10	2.82	2.75	2.82	2.92	NS
Wt. head^{-1} 20	2.32	2.26	2.29	2.39	NS
Wt. head^{-1} 30	1.34	1.39	1.49	1.48	NS
No. of seeds head^{-1} Total	29	28	29	30	NS
No. of seeds head^{-1} 10	32	29	30	32	NS
No. of seeds head^{-1} 20	32	31	30	33	NS
No. of seeds head^{-1} 30	24	25	25	26	NS
Wt. of seed head^{-1} Total	1.13	1.34	1.13	1.14	NS
Wt. of seed head^{-1} 10	1.81	1.71	1.79	1.87	NS
Wt. of seed head^{-1} 20	1.44	1.32	1.37	1.32	NS
Wt. of seed head^{-1} 30	0.60	0.58	0.60	0.67	NS
1000 Seed weight Total	40.96	41.34	43.35	43.10	NS
1000 Seed weight 10	56.92	57.00	60.11	59.44	NS
1000 seed weight 20	45.07	43.12	44.69	44.24	NS
1000 Seed weight 30	23.41	23.62	25.53	26.00	NS

TABLE 32 Yield and Yield Components as affected by Sowing Rates

Mean values of yield components	Sowing rates $KgHa^{-1}$				
	5.6	11.2	22.4	44.8	LSD
Seed yield Kg/ha^{-1}	2699	3686	4677	6200	499
No. of heads m^{-2} Total	253	326	491	731	72
No. of heads m^{-2} 20	90	141	234	437	NS
No. of heads m^{-2} 30	150	161	209	194	NS
No. of heads $plant^{-1}$ Total	20	13	10	7	2
No. of heads $plant^{-1}$ 20	7	6	5	4	NS
No. of heads $plant^{-1}$ 30	12	6	4	2	2
Wt. of heads $plant^{-1}$ Total	44.7	27.6	18.3	12.5	6.9
Wt. $head^{-1}$ 10	3.19	3.05	2.71	2.18	0.32
Wt. $head^{-1}$ 20	2.59	2.61	2.22	1.84	0.24
Wt. $head^{-1}$ 30	1.90	1.53	1.22	1.02	0.26
No. of seeds $head^{-1}$ Total	32	31	28	25	3
No. of seeds $head^{-1}$ 10	33	32	30	28	NS
No. of seeds $head^{-1}$ 20	32	36	31	27	3
No. of seeds $head^{-1}$ 30	31	26	23	19	4
Wt. of seeds $head^{-1}$ Total	1.23	1.18	1.05	0.97	0.12
Wt. of seeds $head^{-1}$ 10	2.03	1.92	1.72	1.50	0.26
Wt. of seeds $head^{-1}$ 20	1.51	1.66	1.36	1.07	0.16
Wt. of seeds $head^{-1}$ 30	0.86	0.69	0.50	0.37	0.14
1000 Seed weight Total	46.16	44.55	41.13	36.91	4.56
1000 Seed weight 10	61.93	60.69	57.23	53.51	4.47
1000 Seed weight 20	46.85	47.14	44.11	38.87	3.06
1000 Seed weight 30	25.91	26.10	21.42	20.34	5.24

4.3 Correlation

Table 33 and Table 34 showed the relationship of the various yield components to seed yield per plant and seed yiled per unit area (per meter square).

As shown in Table 32, yield per plant showed a strong negative correlation with both the number of plants and number of seed heads per unit area. In other words, an increase in the number of plants per unit area resulted in smaller individual plants and reduced number of seed heads per plant. These characteristics would in turn reduce the seed yield per plant.

Seed yield components such as the number of seed heads per plant, head weight, weight and number of seeds per head and all 1000 seed weight were all positively correlated with seed yield per plant. Of these, the number of seed heads per plant showed the greatest correlation (r = +0.91). Thus by increasing the weight or number of any one of these components, particularly the number of seed heads per plant, would result in an increased seed yield per plant.

Yield per unit area was positively and most strongly correlated with number of plants and number of seed heads per unit area. In other words, the greater the number of plants and the number of heads produced per unit area, the greater the increase in seed yield. Also, the increased seed yield per unit area resulted in the reduction of several sources of yield, particularly in yield per plant, number of heads per plant and head weight. Other yield components (i.e. number and weight of seeds per head and 1000 seed weight) had little effect on the seed yield per unit area.

TABLE 33 Overall correlations of seed yield per plant and per unit area with their respective yield components

Yield components	Yield plant^{-1}	Yield meter^{-2}
Yield plant^{-1}	1.00**	- 0.48**
Plant m^{-2}	- 0.79**	+ 0.80**
Heads m^{-2}	- 0.61**	+ 0.83**
Heads plant^{-1}	+ 0.91**	- 0.52**
Weight head^{-1}	+ 0.71**	- 0.31*
Number of seed head^{-1}	+ 0.62**	-0.22 NS
Seed weight head^{-1}	+ 0.58**	- 0.12NS
1000 Seed weight	+ 0.54**	- 0.21NS

TABLE 34 Overall correlation and correlation coefficients between seed yield per meter square and its components at 2 sowing rates and 2 row spacings

Yield components	Overall correlation	Sowing rates KgHa^{-1}		Row spacings cm	
		5.6	44.8	36	Square
Yield meter^{-2}					
Yield plant^{-1}	-0.48**	+1.00**	+1.00**	-0.65**	-0.69**
Plant m^{-2}	+0.80**	0.00	0.00	+0.81**	+0.93**
Heads m^{-2}	+0.83**	+0.74**	+0.39NS	+0.84**	+0.90**
Heads plant^{-1}	-0.52**	+0.74**	+0.39NS	-0.60*	-0.67**
Weight head^{-1}	-0.31*	+0.28NS	+0.53*	-0.38NS	-0.25NS
No. of seeds head^{-1}	-0.22NS	+0.41NS	+0.43NS	-0.33NS	-0.15NS
Seed wt head^{-1}	-0.12NS	+0.50*	+0.44NS	-0.25NS	-0.03NS
1000 seed weight	-0.21NS	+0.17NS	+0.48NS	-0.26NS	-0.10NS

* significant at 5%   ** significant at 1%

As shown in Table 34, similar trends existed in the correlation coefficients of the square and 36 cm spacing treatments. Unlike that of the overall correlation, weight per head had no effect on seed yield per unit area in both these spacing treatments. Further, the square treatment appeared to have stronger correlation values in the various components compared to the 36 cm spacing.

At the lowest sowing rate (5.6 $KgHa^{-1}$), seed yield per unit area was largely affected by the number of seed heads per unit area and per plant and also the seed weight per head. Also, seed yield at both the highest and lowest sowing rate was strongly correlated to seed yield per plant. This is not surprising, since the number of plants per unit area was constant in both treatments. To a lesser degree, head weight had an influence in seed yield per unit area in the highest sowing rate where competition would be intense, but not at the low seeding rate. High number of plants per unit area resulted presumably in the production of fewer seed heads but heavier heads. Thus the heavier the seed heads, the higher would be the yield per unit area at very high seeding rates.

The correlation coefficients indicated that number of plants and number of seed heads per unit area were largely responsible for the total seed yield production in safflower. Thus, not only the optimum sowing rate (i.e. planting density) but also the planting pattern which results in a maximum number of seed heads per unit area is of utmost importance if maximum seed production is to be achieved.

4.4 Growth and Development

4.41 Plant Dry Weight

Plant dry weight increased very slowly over the first 7 - 8 weeks then increased rapidly during the following 10 weeks to reach a maximum at approximately 130 days from sowing (Fig. 3). The intense intra-row plant competition in the 72 cm row spacing treatment was reflected in the substantially lower dry weight of the plants. The reduction in plant dry weight in this spacing treatment was found to be statistically significant as from 100 days after sowing onwards. This trend was the result of increased intra-row plant competition in the later stage of growth.

In the first 8 weeks of the growing period, there was no significant change in dry weight of plants from 18 cm and square treatments. However, from approximately 10 weeks onwards, plants dry weight of the square treatment tended to be lower than that of 18 cm row spacing but reached a similar maximum dry weight at approximately 19 weeks. From then till the final harvest, plant dry weight in the square treatment superceded that in the other spacing treatments, possibly due to its competitive advantage.

The effect of increasing seeding rate and thereby increasing plant competition resulted in the reduction in plant dry weight. This effect was evident by the 9th week of growing period. The effect of seeding rate became more pronounced in the later stages of growth owing to greater plant competition. At the final harvest, it appeared that an eight fold increase in seeding rate had resulted in approximately two-third reduction in plant dry weight.

4.42 Plant Height

Plant height showed a similar trend to that of plant dry weight but reaching a near maximum earlier - about 90 days after sowing (Fig. 4). Plants in the 72 cm spacing treatment were significantly taller in the later stage of growth. This was attributed to the increased intra-row competition for light in this treatment. Plants from the square planting treatment were consistently lowest in height compared to the other spacing treatments. This feature in plant height suggests that uniform distribution of plants resulted in lessening the etiolation effects due to a restricted light regime.

Increasing sowing rate resulted in an increase in plant height. This response is expected since, the increased seeding rate would result in greater plant competition for light and consequently plants from high sowing rates would tend to be taller. Similar findings were recorded by Stern and Beech (1965).

4.43 Branching

Shortly after the commencement of elongation at about the 7th week, there was a rapid development of branches arising from the primary stem over the next 2 to 3 weeks. This was followed by a slower increase in branching which continued to final harvest. It is of interest to note that the increase in branching occurred to a much greater extent in those treatments with plants having less competition, e.g. lowest sowing rate and square planting (Fig. 11). A substantial increase in branching of plants from these two treatments was largely due to the greater number of tertiary branches produced (table 9).

4.44 Leaf Number

There was a steady increase in leaf number in the first 7 weeks of growth followed by a rapid leaf development reaching a maximum at approximately 12 weeks after sowing (Fig. 4). From this point there was a sharp drop in leaf number over the next 2 to 3 weeks followed by a more gradual decline. Again, plants in the 72 cm row spacing treatment reflected the effect of intense intra-row plant competition, consequently their leaf number was very much reduced.

The effect of increasing seeding rate was the reduction in leaf number. At the highest sowing rate ($44.8\ KgHa^{-1}$), leaf number per plant reached the maximum about 2 weeks earlier than those of other seeding rate treatments. Stern and Beech (1965) recorded a similar responce of leaf numbers per plant as affected by different planting density.

4.45 Flowering

Data on the number of days to 50% and 90% flowering are presented in Tables 4 and 5. The effect of increasing plant competition, either through spacing or seeding rate, was to delay flowering. Doubling the seeding rate appeared to delay flowering by approximately 1 day, but changing the row spacing and increasing intra-row plant competition delayed flowering by up to 5 days.

From data obtained in this study, both row spacing and sowing rate affected the growth and development of safflower. At the same sowing rate, it appeared that narrow row spacing and square planting resulted in bigger plants with a greater number of leaves and branches and also earlier flowering. As far as growth and development is concerned, the only positive trend in plant character from wide row spacing was the increase in height.

The main effect of increasing seeding rate (i.e. planting density), was the reduction in plant size, its associated features (i.e. fewer branches and leaves), and the delay in flowering.

4.46 Leaf Area

Leaf area per plant accumulated rapidly over the early growth stage (i.e. from the 7th week onwards), reaching peak values at the same time as 50% flowering, approximately 85 - 90 days after sowing. This was then followed by a rapid decline in leaf area indicating the reduction of vegetative growth and also leaf senescence. Plants from the narrow row spacing had superior leaf area production and were significantly greater at the 4th, 5th and 6th samplings. However, towards the later part of growth, i.e. approximately 120 days after sowing, differences in leaf area between spacing treatments disappeared.

As expected, sowing differences in leaf area production were large, with plants in the lowest sowing rate treatment having almost four times as much leaf area as those of the highest sowing rate. Also, as observed in leaf numbers, plants in the highest sowing rate treatment attained their peak value about 2 weeks earlier than those of the remaining treatments.

4.47 Growth Analysis

Crop growth rates and photosynthetic rates reported in this discussion are based upon the weight of above ground parts and therefore underestimate the total plant reaction. For true rate, underground parts, i.e. roots, basal stem and precise methods for measuring gaseous exchange, light and temperature should be included in calculating these rates. Thus data presented here may only represent the gross values of these rates.

Crop growth rates (CGR) reached maximum

values at approximately one week before 50% flowering (approximately 12 weeks from sowing), except that of 18 cm row spacing treatment which attained its peak value earlier. However, CGR declined sharply by the time the crop reached 90% flowering, particularly those of high sowing rates and wide row spacings, where plant competition was severe. This was then followed by a relatively small increase in CGR values in all treatments and a further decline towards the later part of the growing period, i.e. approximately 145 days after sowing (Fig. 7).

The low values of CGR recorded in all treatments at 90% flowering (approximately 14 weeks), may have been due to the environmental conditions at the time. Around this period of growth there was little or no rainfall which might well have resulted in a moisture stress, and also a reduction in light intensity (Appendix 2) which may have affected the photosynthetic rates. As shown in the high sowing rate and wide row spacing treatments, where plant competition was intense, this reaction was accentuated.

The slight increase in CGR from this stage probably was indicative of a degree of plant recovery with improved moisture conditions. Further decline of CGR was expected because its components leaf area index (LAI) and net assimilation rates (NAR) also showed a decline. This trend was a reflection of the decline in the net photosynthesis activity resulting from reduced light intensity and temperature as the season progressed (Appendix 2), an increase in grain development and filling and the senescence of the leaves. Consequently CGR declined rather rapidly over the final 30 days to harvest.

There was no significant difference in CGR values of spacing treatments except in the last sampling. However, it is interesting to note the superior CGR values of the square planting during the important flowering and early grain development period (80 - 120 days). Both LAI and NAR values showed statistically significant difference between spacing treatments only at two samplings immediately prior to 50% flowering. Narrow row spacing showed higher values than the wider row spacing where there was intense intra-row competition. Nevertheless, it is of interest to note that values in the square planting showed a more gradual decline than the other spacing treatments (Figs. 6 and 9). The superior LAI level of the narrow row spacing was also supported by the relatively high light interception recorded in this treatment (Table 3).

Significant sowing rate differences in CGR values were recorded up to 90% flowering and at the final sampling. CGR of the highest sowing rate treatment was significantly greater for most of the growing season but in the later stage, CGR of thelowest sowing rate was clearly superior. This later trend was probably due to the lack of competition in the lowest sowing rate treatment, where plant growth was able to continue longer than those of other treatments. LAI showed rather similar trends as CGR but the reverse was seen in that of NAR - the highest sowing rate tended to have the lowest NAR compared to the other sowing rate treatments. The superior LAI recorded at the highest sowing rate was again clearly reflected in the high light interception measured in this treatment.

Growth response based upon relative growth rates (RGR) and its components show much the same effects as mentioned above. The trends in RGR were similar in both row spacing and sowing rate treatments. There was a sharp increase in RGR in the 6 to 7 weeks reaching its maximum values by the 8th week of growth. From then on RGR declined with time. The rates of decline in time were alike for spacing and sowing treatments (Fig. 8). Also, the differences in mean RGR for all treatments were not significant but it appeared that low RGR was associated with wide row spacing and high sowing rate (i.e. high planting density).

Leaf area ratio (LAR) showed similar trends to that of RGR. This trend was also alike for both spacing and sowing treatments. However, LAR values of sowing rate differences were statistically significant in samples 4, 5 and 7.

Work on growth analysis of this crop is not available and therefore it is difficult to compare the findings of this study with those of other workers. Since extensive literature on growth analysis of soybean is available, an attempt is made to compare some of the findings with those of soybean. RGR, NAR and LAR of soybean declined almost linearly with time (Buttery 1969, 1970). However, in this safflower study, these growth analysis components showed a rapid initial increase during the first 7 weeks before starting to decline with time (Figs. 7, 8 and 9). This trend in safflower growth curves may be attributed to its peculiar growth pattern. For example, after emergence, safflower seedlings tend to remain in the rosette stage for varying periods depending on the environmental conditions (Beech 1969), Knowles (1955, 1958), Stern and Beech (1965) and Weiss (1971), followed by a rapid elongation of the reproductive stem to flowering. In this study safflower seedlings remained in this rosette stage for approximately 5 to 6 weeks with little evidence of growth activity except in the relatively prostrate leaf development.

Thus, as illustrated in LAR, at this stage leaf area production was superior to the accumulation of dry matter. Consequently the values of RGR and NAR were also affected. However, as plants elongated and branching developed after the 7 to 8 weeks of growth, the response of RGR, NAR and LAR was much like those of soybean. For example, by comparing RGR and plant height (Figs. 8 and 9) it can be seen that RGR reached a peak (as did LAR) just as the plant was commencing to elongate. Thereafter these components of growth response showed a rapid decline with subsequent plant development as found in other crops.

CGR of safflower was similar to that of soybean but greatly accelerated after the rosette stage.

Harvest index (HI) was included in growth analysis discussion by some workers such as Donald (1962) HI for various treatments are shown in Table 35. These indices reflect the efficiency of plants to produce seeds. There appeared to be little affect of row spacing treatments on the efficiency of plants to produce seeds. However, in the sowing rate treatments, the two intermediate sowing rates appeared to have a significantly greater efficiency in seed production. The HI values in this study were high compared with those obtained by Stern and Beech (1965), i.e. 0.13 - 0.21. Nevertheless, these high HI values were reflected in the correspondingly high seed yield obtained in this study.

According to Beech and Norman (1963), HI values of safflower were susceptible to delayed planting and plant densities above optimal. It appeared that both these factors tend to reduce HI quite considerably.

Table 35 Effect of row spacings and sowing rates on Harvest Index (HI)

Row width (cm)	Sowing Rate $Kg\,Ha^{-1}$				Row width mean
	5.6	11.2	22.4	44.8	
18	0.51	0.52	0.51	0.44	0.50
36	0.38	0.48	0.53	0.41	0.45
72	0.42	0.60	0.67	0.40	0.52
Square	0.37	0.46	0.53	0.48	0.46
sowing rate mean	0.42	0.51	0.56	0.43	LSD:NS
LSD: 0.06	Interaction : LSD:NS				

Evidence from growth components i.e. RGR, NAR, LAI and LAR showed little support of their relationships with high seed yield as far as row spacing treatments were concerned. Presumably other factors were more important in achieving maximum seed yield e.g. number of heads per plant and per unit area.

Nevertheless, in sowing rate treatments, the relationship between LAI and high seed yield was evident but other growth components showed no such relationships. It seemed that other factors were also involved in achieving higher seed yield in these treatments. Sowing rate treatment with the highest seed yield was presumably due to the number of plants per unit area.

With regards to yield, it may be of interest to note the role of bees in assisting pollination. Safflower is basically self - not wind - pollinating, but bees and other insects are required for optimum fertilization and maximum yields. (Levin et al 1967; Levin and Butler 1966; Rubis 1966). In this experiment care was taken to ensure that an adequate population of bees was present by placing one hive immediately adjacent to the area. It is felt this may have been a major factor in achieving high fertilization and high seed yields.

4.5 SEED COMPONENTS

Neither plant spacing nor sowing rate had any significant effect on seed moisture and seed viability (Tables 26 and 27).

Obviously of major importance is the level of oil content in the seed. In this experiment oil percentage ranged from only 26 - 28% according to treatment but without significant differences being recorded (Table 28). The usual range of oil content is from 25 to 40% (Weiss 1971). Thus the oil content obtained appeared to be that of the lower level owing to the seed line used. Apparently these seed components were relatively independent and unaffected by the treatments imposed in spite of the very contrasting degrees of competition. Nevertheless, other workers had recorded the depressing effects of wider-spaced plants and high density on oil content (Williams 1962; Peterson 1965). In his investigation, Peterson (1965) obtained reduction of oil content from 37 to 33.5% as population increased from 71 to 318 plants per meter square. By comparison in the current investigation plant density from 12 to 100 plants per meter square.

The quality of oil obtained was shown to be high and in keeping with other reports on safflower (Applewhite 1966; Weiss 1971). Linoleic acid, the desired fraction, appeared to be little affected by plant competition. From the production standpoint it would therefore appear that the major consideration should be centred on achieving maximum seed yield per hectare and oil content rather than a concern for oil composition.

Plant competition had been the major factor affecting the various treatments but it is difficult to determine the exact nature of this competition either for nutrients, moisture or light. However, it appeared that light interception may have been a critical factor (Table 3) in this investigation. The effect of the other two factors, i.e. nutrients and moisture in plant competition was not clear although moisture stress appeared to have taken place at some stage of the plant growth (Appendix 2). This agronomic aspect of safflower obviously needs further research under controlled environmental conditions.

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BIBLIOGRAPHY

ANON. (1961). Growing safflower - an oilseed crop. Farmers' Bull. No. 2133, U.S.D.A. pp.16.

ANON. (1963). Safflower growing in Queensland. Qd. Agric. J. 89 (3), 148-52.

ANON. (1966). The germination test. Determination of moisture content. Proc. I.S.T.A. 31 (1), 49-91 and 128-134.

APPLEWHITE, T.H. (1966). The composition of safflower seed. J. Amer. Oil. Chem. Soc. 43 (6), 406-8.

ASHRI, A. (1961). The susceptibility of safflower varieties and species to several foliage diseases in Israel. Pl. Dis. Reptr. 45 (2), 146-50.

ASHRI, A. and KNOWLES, P.F. (1960). Cytogenetics of safflower (*Carthamus L.*) species and their hybrids. Agron. J. 52, (1), 11-17.

BAKER, M.L. *et al* (1951), Feeding safflower meal. Bull. 402. Neb. Agric. Expt. Stn. pp.11.

BAKER, M.L. *et al* (1959). Safflower meal as a protein supplement for wintering calves. Bull. 447, Neb. Agric. Expt. Stn. pp.15.

BASINSKI, J.J. BEECH, D.F. and LEE, L.C. (1961). Effect of time of planting on yields of safflower in Northern Australia. J. Aust. Inst. Agric. Sci. 27 (3), 156-8.

BEECH, D.F. (1960). Safflower. An oil crop for the Kimberelys. Bull. No. 2720. West Aust. Dept. of Agric., Perth.

BEECH, D.F. (1962). Irrigating dry season crops in the Ord River Valley. How to prepare land for sowing. J. Agric. W. Aust. 3 (12), 956-8.

BEECH, D.F. (1964). The effect of leaf removal on yield attributes of safflower. Aust. J. Expt. Agric. and Anim. Husb. 4 (14), 215-16.

BEECH, D.F. (1969). Safflower. Field Crop Abst. 22 (2), 107-17.

BEECH, D.F. and NORMAN, M.J.T. (1963). The effect of time of planting on yield attributes of varieties of safflower. Aust. J. Expt. Agric. and Anim. Husbd. 3 (9), 140-8.

BEECH, D.F. and NORMAN, M.J.T. (1966). The effect of plant density on the reproductive structure of safflower in the Ord River Valley. Aust. J. Expt. Agric. and Anim. Husbd. 6 (22), 255-60.

BEECH, D.F. and NORMAN, M.J.T. (1967). The effect of time of planting on the performance of irrigated winter crops in the Ord River Valley. J. Aust. Inst. Agric. Sci 33 (2), 77-84.

BEECH, D.F. and NORMAN, M.J.T. (1968). The effect of wet season land treatment and nitrogen fertilizer on safflower, linseed and wheat in the Ord River Valley. Aust. J. Expt. Agric. and Anim. Husbd. 8 (30), 66-71.

BRAUNS, P and RUDDER, T. (1963). Trying safflower as a grazing crop. Queensland Agric. J. 89 (10), 583-4.

BUTTERY, B.R. (1969). An analysis of growth of soybeans as affected by plant population and fertilizer. Can. J. Pl. Sci. 49, 675-84.

BUTTERY, B.R. (1970). Effects of variation in LAI on growth of maize and soybeans. Crop. Sci. 10 (1), 9-13.

CANVIN, D.T. (1965). The effect of temperature on oil content and fatty acid composition of the oils from several oilseed crops. Can. J. Bot. 43 (1), 63-69.

CARLSON, E.C. (1964). Damage to safflower plants by thrips and lygus bugs and a study of their control. J. Econ. Entom. 57 (1), 140-5.

CARLSON, E.C. (1966). Further studies of damage of safflower plants by thrips and lygus bugs J. Econ. Entom. 59 (1), 138-41.

CHAVAN, V.M. (1961). Niger and Safflower. Indian Central Oilseed Committee. Examiner Press, Bombay, India.

CLAASSEN, C.E. (1950). Natural and controlled crossing in safflower. Agron. J. 42 (8), 381-8.

CLAASSEN, C.E. *etal* (1950). The estimation of oil percentage in safflower seed and the association of oil percentage with hull and nitrogen percentage, seed size and degree of spininess of plant. Agron. J. 42 (10), 478-82.

CLAASSEN, C.E. and HOFFMAN, A. (1950). Safflower production in the western part of the northern Great Plains. Circ. 87 (rev.) Neb. Agric Expt. Stn. U.S.A.

COBLEY, L.S. (1957). An introduction to the botany of tropical crops. London: Logmans. Green and Co. 94-8.

COCHRON, W.G. and COX, G.N. (1957). Experimental Designs. Wiley International Edition, U.S.A.

DAVIS, A.M. (1965). Investigations with new crops. Rep. Ser. 139. Ark Agric. Expt. Stn. pp.12.

DENNIS, R.E. and RUBIS, D.D. (1966). Safflower Production in Arizona. Bull. A. 47. University of Arizona Agric. Expt. Stn. U.S.A.

EAGLES, C.F. (1971). Ann. Bot. (London) (N.S) 35, 63-74.

EBERT, W.W. and KNOWLES, P.F. (1966). Inheritance of Pericarp Types, sterility dwarfness in several safflower crosses. Crop Science 6 (6), 579-582.

EBERT, W.W. and KNOWLES, P.F. (1968). Development and anatomical characteristics of thin-hull mutants of *Carthamus* tinctorius). Am. J. Bot. 55 (4), 421-30.

EL SAEED, E.A.K., (1966). Effects of seed size on oil content and seedling, emergence in safflower (*Carthamus tinctorius*) grown in Sudan. Expt. Ag. 2 (4), 299-304.

FRANCOIS, L.E. and BERNSTEIN, L. (1964). Salt Tolerance of Safflower. Agron. J. 56 (1), 38-40.

GILBERT, N.W. and TUCKER, T.C. (1967). Growth, yield and yield components of safflower as affected by source, rate and time of application of nitrogen. Agron. J. 59 (1), 54-6.

GUGGOLZ, J. (1967). Composition of safflower seed. Proc. First Res. Conf. on utilisation of safflower, 31-36. Albany, California.

HARRISON, J. (1968). A place in Queensland for safflower. Queensland Agric. J. 94 (4), 203-11.

HEINEMANN, W.W. etal (1953). The feeding value of wood molasses, dehydrated alfalfa, dehydrated apple pomace and undecorticated safflower meal when fed to fattening cattle. Bull. 543. Washington Agric. Expt. Stn. pp.21.

HILL, A.B. and KNOWLES, P.F. (1968). Fatty acid composition of the oil developing seeds of different varieties of safflower. Crop. Sci. 8(3), 275-7.

HINSON, K. and HANSON, W.D. (1962). Competition studies in soybeans. Crop Sci. 2 (2), 117-23.

HOAG, B.K. etal (1968), Effect of fertilizer treatment and raw spacing on yield, quality and physiological response of safflower. Agron. J. 60 (2), 198-200.

HOROWITZ, B. and [illegible]INIG, C.R. (1958). Safflower trials in Australia. Tech. Pap.11. Div. Pl. Industry. CSIRO, pp.19.

HOROWITZ, B. and WINTER, G. (1957). A raw safflower oil with a low iodine value. Nature, Land 179 (4559), 582-3.

JAMES, E. etal (1967). Effects of variable and constant storage temperatures and subsequent room storage on the viability of certain seeds. Crop Sci. 7 (5), 495-6.

JONES, J.P. and TUCKER, T.C. (1968). Effect of nitrogen fertilizer on yield, nitrogen content and yield components of safflower. Agron. J. 60 (4), 363-4.

KAPUSTA, G. etal (1962). An oil seed crop: Safflower production in North Dakota. Bull. 22 North Dakota Agric. Expt. Stn. No.4, 4-11.

KENNEDY, W.K. and UNRAW, J. (1949). A rapid method for determining the oil content of Sunflower seeds. Agron. J. 41 (2), 93-5.

KLAGES, K.H.W. (1954). Safflower Production Bull. 222 Idaha Agric. Expt. Stn. pp.16.

KLISIEWICZ, J.M. (1963). Wilt-incited Fusarium Oxysporum f. present in seed from infected safflower. Phytopath. 53 (9), 1046-9.

KLISIEWICZ, J.M. (1965). Identity of viruses from safflower affected with necrosis. Pl. Dis. Rept. 49 (6), 541-5.

KLISIEWICZ, J.M. (1966). Reactions of safflower to lettuce mosaic virus. Phytopath. 56 (12), 1354-56.

KLISIEWICZ, J.M. (1967). Inheritance of reactions in safflower to lettuce mosaic virus. Phytopath. 57 (7), 789-90.

KLISIEWICZ, J.M. and THOMAS, C.A. (1970). Pathogenic races of Fusarium Oxysporum f. sp. Carthami. Phytopath. 60 (1), 83-4.

KNOWLES, P.F. (1955). Safflower. Production, processing and utilisation. Econ. Bot. 9 (3), 273-99.

KNOWLES, P.F. (1958). Safflower. Advances in agronomy 10 pp. 289-323.

KNOWLES, P.F. (1960). New crop establishment, Econ. Bot. 14 (4), 263-75.

KNOWLES, P.F. (1965). Variability in oleic and linoleic acid contents of safflower oil. Econ. Bot. 19 (1), 53-62.

KNOWLES, P.F. and HILL, A.B. (1964). Inheritance of low fatty acid content in the seed oil of a safflower introduction from Iran. Crop. Sci. 4 (4), 406-9.

KNOWLES, P.F. and MILLER, M.D. (1960). Safflower in California. Man. 26 Calif. Agric. Expt. Stn. pp. 23.

KNOWLES, P.F. and MILLER, M.D. (1965). Safflower. Circ. 532. Calif. Agric. Expt. Stn. Exten. Ser. Univ. of Calif. Davis, California, U.S.A.

LEAR, B. et al (1966). Susceptibility of safflower varieties to root-knot nematodes and to the sugar beet nematode. F.A.O. Pl. Prot. Bull. 14 (4), 69-71.

LEININGER, L.N. (1963). Evaluation of safflower lines with low iodine numbers. Crop. Sci. 3 (2), 181.

LEININGER, L.N. and URIE, A.L. (1964). Development of safflower seed from flowering to maturity. Crop Sci. 4 (1), 83-7.

LEVIN, M.D. et al (1967). Pollination of safflower by insects other than honey bees. J. Econ. Entom. 60 (5), 1481-2.

LEVIN, M.D. and BUTLER, G.D. (1966). Bees associated with safflower in south central Arizona. J. Econ. Entom. 59 (3), 654-7.

LEHMAN, W.F. and LAMBERT, J.W. (1960). Effects of spacing soybean plants between and within rows on yield components. Agron. J. 52, 84-86.

LUEBS, R.E. etal (1965). Effect of planting date on seed yield, oil content and water requirements of safflower. Agron. J. 57 (2), 162-4.

MASSEY, J.H. (1971). Effects of nitrogen and plant spacing on sunflower seed yields and other characteristics. Agron. J. 63 (1), 137-8.

McGREGOR, [illegible] and HAY, [illegible] (1952). Safflower: Canadian experiments. Sci. Agric. 32 (4), 204-14.

NELSON, C.E. (1964). An experiment with safflower under irrigation. Circ. 430, Wash. Agric. Expt Stn. Washington U.S.A.

PALTI, [illegible] and MIZANI, F. (1953). Safflower growing in Israel. World crops 5 (7), 266.

PAWLOWSKI, S. (1961), Estimation of oil in safflower seed. Nature, Land 189, (4766), 772-3.

PETERSON, [illegible] (1965). Safflower culture in the West-Central Plains. Agric. Inf. Bull. No. 300. Agric. Res. Serv. U.S.D.A. Washington, U.S.A.

PETERSON, W.F. et al (1957). The use of safflower oil meal in poultry rations. Poult. Sci. 36 (1), 3-8.

PHILLIS, E. (1961). Preliminary observations on the temperature requirements of safflower (Carthamus tictorius. L.). Memo. No. 61/21 C.S.I.R.O. Aust. Div. Land. Res. Serv. Tech. Canberra , Australia.

PURDY, R.H. et al (1959). Safflower, its development and utilisation. J. of. Am. Oil. Chem. Soc. 36 (9), 26-30.

RADFORD, P.J. (1967). Growth analysis formulae - their use and abuse. Crop Sci. 7, 171-175.

RUBIS, D.D. (1963) Proc. Saff. Planning Confer. Univ. of Arizona, Tucson, U.S.A.

RUBIS, D.D. and BLACK, D.S. (1958). Gila. A new safflower variety. Bull. 301. Agric. Expt. Stn. Univ. of Arizona, U.S.A.

SHAW, J.J. and JOPPA, L. (1963). Safflower and oil seed crop. Circ. 289. Montana Agric. Expt. Stn. pp.16.

SHIBLES, R.M. and WEBER, C.R. (1965). Leaf area, solar radiation interception, and dry matter production by soybeans. Crop. Sci. 5, 557-77.

STERN, W.R. (1965). Evapotranspiration of safflower at three densities of sowing. Aust. J. Agric. Res. 16 (6), 961-71.

STERN, W.R. and BEECH, D.F. (1965). The growth of safflower (Carthamus tinctorius. L.) in a low latitude environment. Aust.J.

THOMAS, C.A. (1952). Transmission of safflower rust on treated seed. Phytopath. 42 (2), 108-9.

THOMAS, C.A. (1956). The effect of rust on the yield and oil content of safflower. Phytopath 46 (1), 29.

THOMAS, C.A. et al (1960). Development of safflower varieties resistant to Phytophthora root rot. Phytopath. 50 (2), 129-30.

THOMAS, C.A. et al (1963). Safflower diseases. U.S.D.A. Agric. Res. Serv. Wash. ARS. 34-52.

TONGREH, T.S. (1964). Safflower weed control. Calif. Weed Conf. Proc. 16th A. Conf. 53-4.

URIE, A.L. et al (1967). Development of safflower seeds as influenced by windrowing varieties and seasons. Crop Sci. 7 (6), 584-7.

URIE, A.L. etal. Effects of degree of and time of defoliation on yield and related attributes of safflower. Crop Sci. 8 (6), 747-50.

VAN, RIJN, P.J. (1962). Weed problems in the Kimberleys. J. Agric. West. Aust. 3 (3), 211-4.

WALLACE, *et al* (1972). Physiological genetics of crop yield. Advances in Agron. 24, 97-142.

WEISS, E. . (1971). *Castor, Sesame and Safflower.* University Press Aberdeen, Great Britain. 529-724.

WATSON, D.J. (1952). The physiological basis for variation in yield. Adv. Agron. 4, 101-144.

WERKHOVEN, C.H. . *et al* (1968). Fertilizer trials with safflower in Sacramento Valley. Calif. Agric. 22 (1), 6-7.

WERKHOVEN, C.H.E. and MASSENTINI. F. (1967). Effects of Phosphorus and Nitrogen placement on safflower growth and phosphorus absorption. Agron. J. 59 (2), 169-71.

WIGGANS, R.G. (1939). The influence of spacing and arrangement on the production of soybean plants. Agron. J. 31, 314-21.

WILLIAMS, J.H. (1962). The influence of plant spacing and flower position on oil content of safflower. (*Carthamus tinctorius.* L.) Crop. Sci. 2 (6), 475-7.

WORKER, G.F. *et al* (1965). Summary of performance of safflower trials conducted at the Imperial Valley Field Station from 1957-64. Field crop Rep. 16.Univ. of Calif. Davis, California, U.S.A.

YERMANOS, D.M. and FRANCOIS. L.E. (1963). Differences among seed samples from primary, secondary and tertiary heads of safflower. Crop. Sci. 3 (6), 560-1.

YERMANOS, D.M. FRANSCOIS, L.E. and BERNSTEIN. L. (1964). Soil salinity of effects on the chemical composition of the oil and oil content of safflower seed. Agron. J. 56 (1), 35-7.

YERMANOS, D.M. HEMSTREET, S. and GARBER, M.J. (1967). Inheritencei of quality and quality of seed oil in safflower (*Carthamus* tinctorius.L) Crop Sci. 7 (5), 417-22.

YOUNG, R.D. and HALLORAN, H.R. (1962). Decorticated safflower meal in chicken rations. Poult. Sci. 41, 1696-7.

ZABLAN, T.A. *et al* (1963). Metabolizable energy of some oil seed meals and some unusual feed stuffs. Poult. Sci. 42 (3), 619-25.

ZIMMER, D.E. (1961). Powdery mildew of safflower. Pl. Dis. Reptr. 45 (2), 944.

ZIMMER, D.E. (1962). Hypocctyl reaction to rust infection as a measure of resistance of safflower. Phytopath. 52, 1177-80.

ZIMMER, D.E. (1963). Spore stages and life cycle of *Puccinia Carthami*. Phytopath. 53, 316-9.

ZIMMER, D.E. (1965). Rust infection and histological response of susceptible and resistant safflower. Phytopath. 55, 296-301.

ZIMMER, D.E. (1967). Response of non-cultivated safflower (*Carthamus*) species to rust and Verticillium wilt. PH. Dis. Reptr. 51, 589-90.

ZIMMER, D.E. *et al* (1968). The nature and inheritance of seedling rust resistance of Nebraslea 1-1-5 safflower. Phytopath. 58 (9) 1451-6.

ZIMMER, D.E. and URIE, A.L. (1967. a). Significance of seedling rust resistance of safflower and its relationship to foliage rust resistance. Phytopath. 57 (7), 772-6.

ZIMMER, D.E. and URIE, A.L. (1967. b.). Influence of irrigation and soil infestation with strains of *Phytophthora* dreschsleri on root rot resistance of safflower. Phytopath. 57, 1056-9.

ZIMMER, D.E. and URIE A.L. (1969. a.). Inheritance of rust resistance in crosses between cultivated safflower. Phytopath. 59 (1), 16-17.

ZIMMER, D.E. and URIE, A.L. (1969.b.). Inheritance of rust resistance in safflower. Crop Sci. 9 (4), 491-4.

ZIMMER, D.E. and URIE, A.L. (1970). Inheritance of rust resistance in safflower. Plt. Dis. Reptr. 54 (5), 364-7.

Appendix 1. Experimental Layout

(a) Split-plot Design

Main plot: Row spacing

Sub-plot: Sowing rate

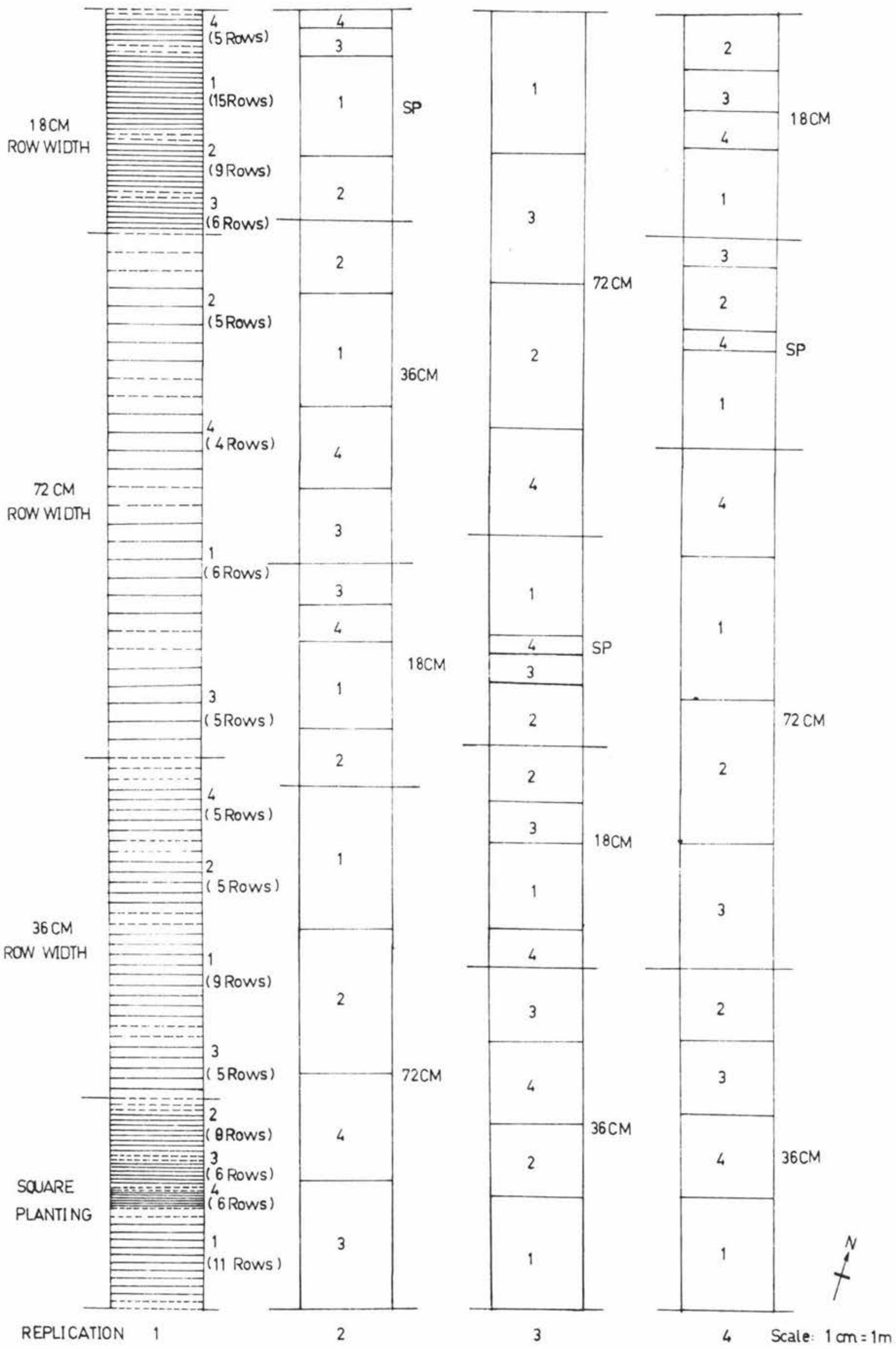
Four row spacings are 18, 36, 72 cm. square planting. (SQ).

Four sowing rates are 1, 2, 3, 4 corresponding to 5.6, 11.2, 22.4, 44.8 Kg Ha^{-1} respectively.

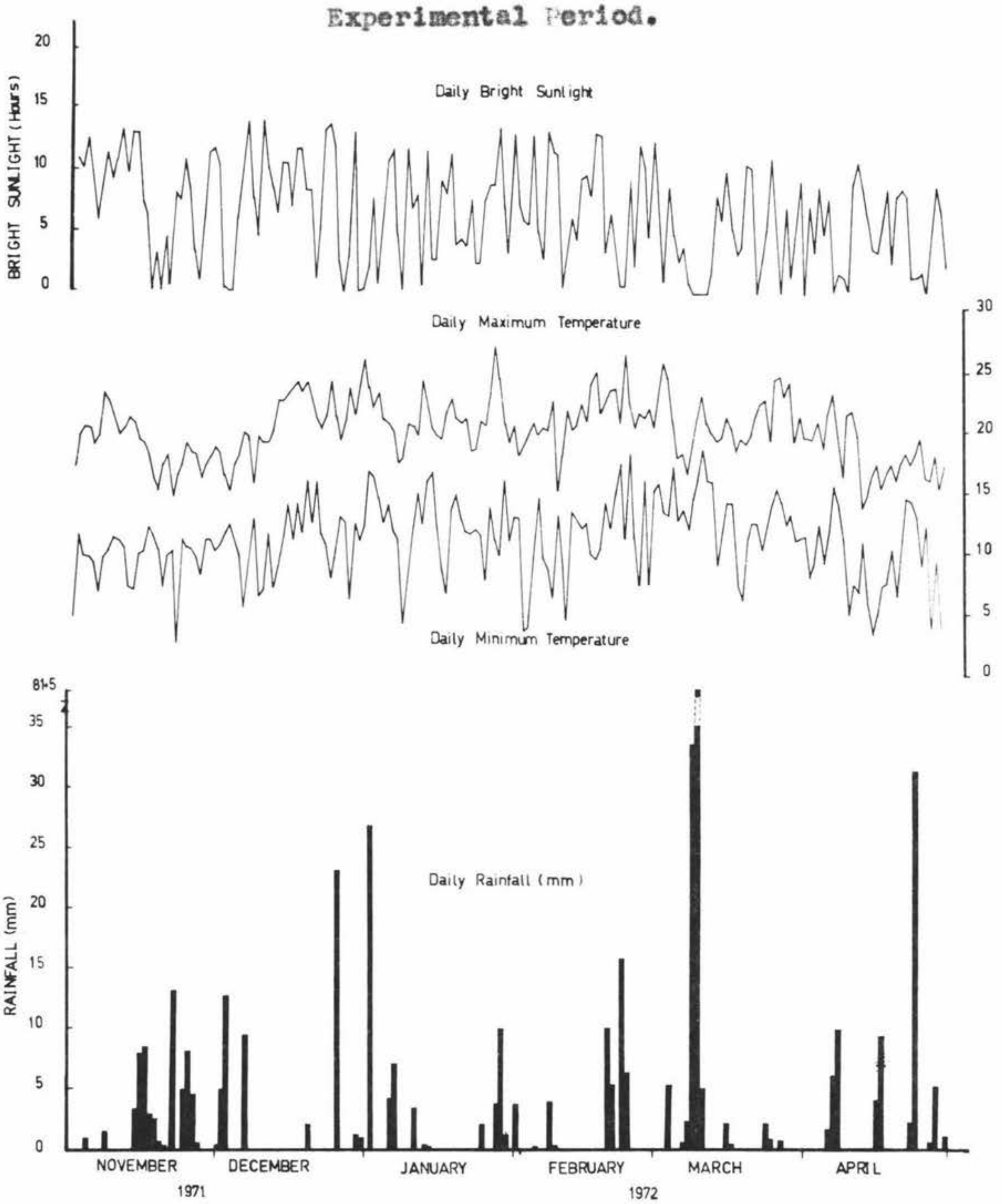
(b) Intra-row plant spacing at different sowing rates. (cm).

Row Spacing (cm)	Sowing Rates 1	2	3	4
18	45.7	22.8	11.4	5.7
36	22.8	11.4	5.7	2.8
72	11.4	5.7	2.8	1.4
SQ	28.5	20.2	14.2	10.1

PLAN OF EXPERIMENT



Appendix 2. Weather Data Recorded During the Experimental Period.



Daily bright sunlight hours, maximum and minimum temperatures, and rainfall measured with standard meteorological instruments at Massey University, Palmerston North.

Appendix 3.

Seed Yield Kg ha^{-1}

Row Spacing (cm) Sowing rate (Kg ha^{-1})	18	36	72	SP	Mean
5.6	3154	2741	2150	2792	2699
11.2	3963	3838	3271	3653	3686
22.4	4566	4719	4500	5723	4877
44.8	6055	5725	5394	8627	6200
LSD. 727	4434	4526	3829	5199	LSD. 499

Interaction LSD. 882

Appendix 4.

Table A: Total Number of Heads per m^2

Row Width	Sowing Rate	Kg/ha			RW - Mean
(cms)	5.6	11.2	22.4	44.8	
18	284	350	550	675	465
36	231	331	500	800	465
72	212	275	362	625	368
SQ	284	350	552	825	503
SR-Mean	253	326	491	731	LSD:72
LSD:72			Interaction:NS		

Table B: Number of Secondary Heads per m^2

	5.6	11.2	22.4	44.8	
18	103	150	250	450	238
36	81	144	250	425	225
72	84	119	200	425	207
SQ	93	150	237	450	232
SR-Mean	90	141	234	437	LSD:NS
LSD:50			Interaction NS		

Table C: Number of Tertiary Heads per m^2

	5.6	11.2	22.4	44.8	
18	169	175	250	125	180
36	137	162	200	275	193
72	115	131	112	100	114
SQ	178	175	275	275	222
SR-Mean	150	161	209	194	LSD:56
LSD:NS			Interaction:NS		

Appendix 5.

Safflower Oil

Fatty Acids Composition.

		Palmitic	Stearic	Oleic	Linoleic
18-cm	1	10.5	3.9	13.5	72.1
	2	7.6	2.1	9.6	80.7
	3	7.2	2.9	9.0	80.9
	4	6.8	2.5	8.0	82.7
36-cm	1	6.5	2.0	9.8	81.7
	2	7.7	1.9	9.6	80.8
	3	10.3	3.2	13.1	73.4
	4	9.7	1.6	6.4	82.3
72-cm	1	11.2	3.5	13.5	71.8
	2	6.5	2.1	8.8	82.6
	3	6.2	1.9	8.6	83.3
	4	7.6	2.8	10.5	78.8
SQ.	1	6.4	1.9	7.9	83.9
	2	6.4	1.9	7.5	84.2
	3	6.9	2.2	8.2	82.7
	4	8.7	3.1	11.1	77.1

Appendix 6: Analysis of Variance of Total Dry Weight Per Plant

		Mean Square							
Source	df	Harvests 1	2	3	4	5	6	7	8
Main plots:									
Row Width (A)	3	0.15 NS	0.42 NS	4.89 NS	18.73 NS	79.73 NS	122.93**	403.81**	382.11*
Replications	3	0.65	1.59	2.19	8.39	0.52	64.73	18.77	317.60
Main plot error	9	0.07	0.30	15.50	21.51	32.10	15.72	32.76	56.14
Total	15								
Sub-plots:									
Sowing rate (B)	3	0.04 NS	0.17 NS	14.32*	58.83**	302.95**	965.78**	3716.64**	491.55**
A x B	9	0.15 NS	0.16 NS	2.19 NS	4.06 NS	26.19 NS	21.98 NS	77.68*	58.68 NS
Sub-plot error	36	0.09	0.13	3.37	10.12	13.62	20.08	32.35	46.97
Grand total	63								

Appendix 7. Analysis of Variance of Plant Height

Source	df	Harvests 2	3	4	5	6	7	8
		Mean Square						
Main plots:								
Row width (A)	3	18.38 NS	16.37 NS	126.30 NS	1691.80 NS	1044.17 NS	76.04*	21.21 NS
Replications	3	159.49	157.86	1463.02	2045.98 NS	1251.68	211.29	178.51
Main plot error	9	27.68	52.85	370.41	1060.65	854.10	16.44	38.71
Total	15							
Sub-plots:								
Sowing rate (B)	3	36.58*	41.94 NS	421.32 NS	712.34 NS	1588.05 NS	439.12*	364.26*
A x B	9	16.67 NS	20.73 NS	205.80 NS	1288.19 NS	636.38 NS	17.42 NS	18.95 NS
Sub-plot error	36	11.21	21.08	230.71	1316.44	700.55	11.61	11.69
Grand total	63							

Appendix 8

Analysis of Variance of Leaf Number Per Plant

		Mean Square						
Source	df	Harvests 1	2	3	4	5	6	7
Main plots:								
Row Width (A)	3	2.85 NS	10.12 NS	942.29 NS	545.05**	1447.04**	615.43*	722.43 NS
Replications	3	3.18	53.12	11.87	21.80	192.04	1576.14	581.89
Main plot error	9	1.09	10.16	651.83	54.09	96.47	150.26	451.00
Total	15							
Sub-plots:								
Sowing rate (B)	3	1.27 NS	9.66 NS	297.70 NS	136.76 NS	6508.87**	4225.55**	5177.59**
A x B	9	0.72 NS	11.87 NS	373.44 NS	163.77 NS	997.47**	231.57 NS	906.09 NS
Sub-plot error	36	0.99	6.18	373.47	82.52	123.35	233.79	782.90
Grand total	63							

Appendix 9   Analysis of Variance of Leaf Area

Source	df Harvests	Mean square 1	2	3	4	5	6	7
Main plot:								
Row Width (A)	3	$0.14x10^{3}$NS	$1.51x10^{3}$NS	$53.42x10^{3}$NS	$56.81x10^{3}$NS	$23.69x10^{4}$**	$14.21x10^{4}$NS	$1.48x10^{3}$*
Replications	3	$0.61x10^{3}$	$1.29x10^{3}$	$17.98x10^{3}$	$94.47x10^{3}$	$2.14x10^{3}$	$56.78x10^{4}$	$2.39x10^{3}$
Main plot error	9	$0.21x10^{3}$	$1.44x10^{3}$	$16.20x10^{3}$	$57.99x10^{3}$	1[illegible]$x10^{3}$	$37.45x10^{4}$	$0.36x10^{3}$
Total	15							
Sub-plot:								
Sowing rate (B)	3	$0.22x10^{3}$NS	$1.84x10^{3}$NS	$24.00x10^{3}$NS	$116.87x10^{3}$NS	1[illegible]$x10^{5}$**	$49.95x10^{4}$NS	$11.06x10^{4}$**
A x B	9	$0.06x10^{3}$NS	$2.12x10^{3}$NS	$13.77x10^{3}$NS	$65.21x10^{3}$NS	1[illegible]$.37x10^{4}$**	$53.47x10^{3}$	$0.23x10^{3}$NS
Sub plot error	36	$0.15x10^{3}$	$1.09x10^{3}$	$10.65x10^{3}$	$49.60x10^{3}$	$10.$[illegible]$x10^{3}$	$32.17x10^{4}$	$0.56x10^{3}$
Grand total	63							

Appendix 10 **Analysis of Variance of Leaf Area Index (LAI)**

		Mean Square						
Source	df	Harvests 1	2	3	4	5	6	7
Main plot:								
Row width (A)	3	0.21 NS	0.04 NS	0.87 NS	3.89*	1.69**	0.37 NS	0.03 NS
Replications	3	0.18	0.38	0.51	2.80	0.06	0.83	0.04
Main plot error	9	0.21	0.03	0.30	0.70	0.07	0.19	0.00
Total	15							
Sub-plot:								
Sowing rate (B)	3	0.07 NS	1.59**	6.91**	24.57**	8.18**	8.44**	0.56**
A x B	9	0.30 NS	0.03 NS	0.32 NS	1.32 NS	0.50**	0.19 NS	0.01 NS
Sub-plot error	36	0.30	0.04	0.26	1.54	0.10	0.12	0.01
Grand total	63							

Appendix 11

Analysis of Variance of Crop Growth Rate (CGR)

		Mean Square						
Source	df Harvests	1/2	2/3	3/4	4/5	5/6	6/7	7/8
Main plot:								
Row width (A)	3	1.28 NS	[illegible] NS	361.24 NS	51.67 NS	129.49 NS	51.64 NS	128.30*
Replications	3	1.64	21.90	135.79	325.6[illegible]	136.22	274.14	253.70
Main plot error	9	1.04	10.76	133.38	357.[illegible]	84.56	52.02	20.64
Total	15							
Sub-plot:								
Sowing rate (B)	3	5.19**	187.54**	1110.40**	1923.20**	343.21**	315.23 NS	485.65**
A x B	9	1.34*	12.04 NS	124.63 NS	163.00 NS	110.73 NS	28.60 NS	51.14
Sub-plot error	36	0.58	19.48	147.64	223.00	53.67	151.80	92.94
Grand total	63							

Appendix 12. Analysis of Variance of Relative Growth Rate (RGR)

		Mean Square					
Source	df	Harvests 1/2	2/3	3/4	4/5	5/6	6/7
Main plot:							
Row width (A)	3	19.12 NS	499.10 NS	227.76 NS	44.93 NS	2.45 NS	2.43 NS
Replications	3	131.01	1465.02	113.51	141.64	20.33	5.68
Main plot error	9	85.23	825.06	253.34	108.19	14.76	1.56
Total	15						
Sub-plot:							
Sowing rate (B)	3	23.18 NS	537.60 NS	76.01 NS	220.18 NS	10.12 NS	2.72 NS
A x B	9	60.51 NS	263.81 NS	264.96 NS	154.23 NS	6.11 NS	0.77 NS
Sub-plot error	36	57.98	759.14	258.37	92.64	4.92	2.82
Grand total	63						

Appendix 13

Analysis of Variance of Net Assimilation Rate (NAR)

		Mean Square					
Source	df	Harvests 1/2	2/3	3/4	4/5	5/6	6/5
Main plot:							
Row width (A)	3	29.01 NS	837.60**	230.76**	170.80*	22.64 NS	12.34 NS
Replications	3	141.23	546.02	123.50	140.46	41.21	14.86
Main plot error	9	95.40	225.60	74.51	61.20	35.11	11.03
Total	15						
Sub-plot:							
Sowing rate (B)	3	33.91 NS	947.01 NS	483.71**	322.81**	31.03 NS	12.83 NS
A x B	9	71.51 NS	463.81 NS	205.38 NS	160.23 NS	16.11 NS	7.03 NS
Sub-plot error	36	67.80	895.41	110.66	80.45	15.03	12.48
Grand total	63						

Appendix 14 Analysis of Variance of Leaf Area Ratio (LAR)

Source	df Harvests	Mean square 1	2	3	4	5	6	7
Main plot:								
Row width (A)	3	0.77x10^3NS	1.12x10^3NS	34.03x10^3NS	0.41x10^3NS	0.49 x10^3NS	0.008x10^3NS	0.006x10^3NS
Replications	3	[illegible]x10^3	2.56x10^3	25.96x10^3	1.94x10^3	0.007x10^3	0.09 x10^3	0.008x10^3
Main plot error	9	[illegible]x10^3	3.51x10^3	21.26x10^3	1.71x10^3	0.20 x10^3	0.02 x10^3	0.002x10^3
Total	15							
Sub-plot								
Sowing rate (B)	3	[illegible]x10^3NS	5.62x10^3NS	36.04x10^3NS	2.20x10^3*	0.85x10^3**	0.02 x10^3NS	0.008x10^3**
A x B	9	0.46x10^3NS	1.43x10^3	31.38x10^3NS	0.92x10^3NS	0.38x10^3**	0.02 x10^3NS	0.002x10^3NS
Sub-plot error	36	0.27x10^3	2.91x10^3	24.96x10^3	0.55x10^3	0.08x10^3	0.03 x10^3	0.001x10^3
Grand total	63							

Appendix 15   Analysis of Variance of Harvest Index (HI) and Mean Seed Yield Per Plant

Source	df	Mean Square	
		(a) Harvest Index	(b) Seed Yield Per Plant (gm)
Main plot:			
Row width (A)	3	0.01 NS	36.37*
Replications	3	0.05	3.18
Main plot error	9	0.01	7.89
Total	15		
Sub-plot:			
Sowing rate (B)	3	0.06**	817.57**
A x B	9	0.01 NS	12.67 NS
Sub-plot error	36	0.01	12.64
Grand total	63		

Appendix 16 Analysis of Variance of Branching Per Plant

		Mean Square					
Source	df	Harvests 3	4	5	6	7	8
Main plot:							
Row width (A)	3	7.10 NS	12.45 NS	23.34 NS	10.93*	21.51**	43.54**
Replications	3	3.10	2.00	47.05	2.68	1.30	3.79
Main plot error	9	1.97	7.26	54.04	2.52	2.59	5.16
Total	15						
Sub-plot:							
Sowing rate (B)	3	32.85**	81.79**	271.39**	130.89**	177.76**	501.95**
A x B	9	1.78 NS	3.00 NS	55.48 NS	2.84 NS	4.33 NS	5.50 NS
Sub-plot error	36	2.12	5.23	57.36	2.02	4.41	9.47
Grand total	63						

Appendix 17: Analysis of Variance of the Total Number of Heads Secondary and Tertiary Heads Per Plant

Source	df	Mean Square Total	 Secondary	 Tertiary
Main plot:				
Row width (A)	3	42.05**	21.09 NS	25.18*
Replications	3	3.80	12.55	2.43
Main plot error	9	5.21	11.62	2.34
Total	15			
Sub-plot:				
Sowing rate (B)	3	502.26**	24.80 NS	295.35**
A x B	9	5.55 NS	13.76 NS	3.70 NS
Sub-plot error	36	9.48	15.08	5.75
Grand total	63			

Appendix 18

Analysis Variance of Total Number of Heads Secondary and Tertiary Heads on Per Meter Square Basis

Source	df		Mean Square	
		Total	Secondary	Tertiary
Main plot:				
Row width (A)	3	54078.80*	738023.25 NS	34745.73**
Replications	3	6025.39	661377.12	5114.72
Main plot error	9	8222.54	664675.50	4858.56
Total	15			
Sub-plot:				
Sowing rate (B)	3	720564.12**	681834.12 NS	12358.60 NS
A x B	9	9090.61 NS	676135.25 NS	8818.99 NS
Sub-plot error	36	10103.40	697214.83	5744.11
Grand total	63			

Appendix 19 Analysis of Variance of Total Head Weight Per Plant and Weight of Primary, Secondary and Tertiary Head

		Mean Square			
Source	df	Total	Primary	Secondary	Tertiary
Main plot:					
Row width (A)	3	212.24 NS	0.09 NS	0.04 NS	0.10 NS
Replications	3	41.29	0.46	0.15	0.07
Main plot error	9	64.98	0.29	0.16	0.12
Total	15				
Sub-plot:					
Sowing rate (B)	3	2868.91**	2.05**	2.29**	3.23**
A x B	9	26.99 NS	0.19 NS	0.15 NS	0.17 NS
Sub-plot error	36	91.93	0.22	0.11	0.13
Grand total	63				

Appendix 20

Analysis of Variance of Seed Number Per Primary, Secondary and Tertiary Head

Source	df	Mean Square Primary	Secondary	Tertiary
Main plot:				
Row width (A)	3	23.75 NS	24.15 NS	29.37 NS
Replications	3	46.79	34.66	45.07
Main plot error	9	68.40	25.87	11.66
Total	15			
Sub-plot:				
Sowing rate (B)	3	64.30 NS	214.47**	633.20**
A x B	9	22.38 NS	16.20 NS	50.74 NS
Sub-plot error	36	58.93	22.43	39.83
Grand total	63			

Appendix 21: Analysis of Variance of Seed Weight per Primary, Secondary and Tertiary Head

		Mean Square		
Source	DF	Primary	Secondary	Tertiary
Main plot:				
Row width (A)	3	0.06 NS	0.05 NS	0.04 NS
Replications	3	0.26	0.06	0.01
Main plot error	9	0.17	0.09	0.03
Total	15			
Sub-plot:				
Sowing rate (B)	3	0.87**	1.02**	0.87**
A x B	9	0.10 NS	0.08 NS	0.04 NS
Sub-plot error	36	0.15	0.06	0.04
Grand total	63			

Appendix 22: Analysis of Variance of 1000 Seed Weight from Primary, Secondary and Tertiary Heads

Source	df	Mean Square		
		Primary	Secondary	Tertiary
Main plots:				
Row width ([illegible])	3	46.32 NS	3.46 NS	44.19 NS
Replications	3	27.06	13.79	22.35
Main plot error	9	71.62	53.76	64.75
Total	15			
Sub-plots:				
Sowing rate (B)	3	215.12**	298.20**	492.06**
A x B	9	77.28 NS	13.79 NS	94.02 NS
Sub-plot error	36	[illegible]8.75	30.66	53.48
Grand total	63			

Appendix 23: Analysis of Variance of Days to 50% and 90% Flowering

Source	df	Mean Square 50% Flowering	 90% Flowering
Main plot			
Row width (A)	3	10.70*	54.80**
Replications	3	5.20	67.22
Main plot error	9	2.41	1.82
Total	15		
Sub-plot			
Sowing rate (B)	3	1.87 NS	19.55**
A x B	9	3.63*	8.15**
Sub-plot error	36	1.47	1.46
Grand total	63		

Appendix 2 **Analysis of Variance of Transformed % of Seed Germination, Seed Moisture Content and Seed Oil Content**

Source	df	Mean Square Seed germination%	 Seed moisture content%	 Seed oil content%
Main plot:				
Row width (A)	3	523.82 NS	19.35 NS	245.23 NS
Replications	3	469.57	15.65	3145.03
Main plot error	9	468.79	13.47	3093.10
Total	15			
Sub-plot:				
Sowing rate (B)	3	249.07 NS	3.44 NS	327.51 NS
A x B	9	493.01 NS	17.21 NS	231.27 NS
Sub-plot error	36	418.65	17.90	3060.00
Grand total	63			