EFFECT OF PLANTING DATE AND PLANT POPULATION DENSITY ON GRAIN YIELD OF TWO VARIETIES OF MUNGBEANS (*Vigna radiata* (L.)Wilckzek)

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Thesis submitted to the Graduate School of the University of Zambia, in partial fulfilment of the requirements for the Degree of Master of Science in Agronomy.

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DECLARATION

I, **EDAH MWEKWA NAWALE,** declare that this thesis represents my own work and that it has not previously been submitted for a degree at this or another University.

Signature..Date. 20/8/01

APPROVAL

This thesis of **Ms. Nawale Edah Mwekwa,** is approved as a partial fulfillment of the requirements for the award of the degree of Master of Science in Agronomy (Crop Science) by the University of Zambia.

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ABSTRACT

The objective of the study was to investigate the effect of planting date and plant population density on grain yield of two varieties of mungbean (*Vigna radiata* (L) Wilczek). It was carried out at the Natural Resources Development College Farm (Lusaka) during the 1995/96 rainy season.

A split-split plot design with whole units arranged as Randomized Complete Block Design (RCBD) was used. There were three treatments i.e. varieties, planting date and plant population density: two varieties, Kenya 1 and Accession 183407 were assigned to the main plots, three planting dates, 5/1/96, 19/1/96 and 2/2/96 were assigned to the sub plots; and four plant population densities 30cm x 10cm (666,667 plants per hectare), 60cm x 20cm (200,000 plants per hectare), 50cm x 10cm (400,000 plants per hectare), and 60cm x 10cm (333,333 plants per hectare) were assigned to the sub-sub plots. The main plot size was 281.35m^2, the sub plot size was 80.49m$_2$, while the sub-sub plot size was 9.60m^2. The parameters measured included: days to 50% flowering, days to physiological maturity, plant height, number of pods per plant, pod length, number of seeds per pod, 100 seed weight, grain yield (kg/ha) and grain protein content(%).

The study revealed that all the three factors, variety, planting date and plant population density contributed significantly to grain yield. Accession 183407 yielded more (526.4 kg/ha),was earlier in maturity (65 DAP), and had a higher protein content (21.8%) than K-1, which yielded 284.4 kg/ha, matured later (70 DAP) and had a lower protein content (18.4%). Second planting date (19/1/96) gave the highest yield (543.0 kg/ha) across the varieties and plant population. The plant population of 666,667 plants per hectare gave the highest yield of 481.5 kg/ha across variety and planting date.

The results lead to the following preliminary conclusions; the optimum planting date is mid-January (19/1/96), while the optimum plant population is 666,667 plants per hectare. However, the study needs to be repeated in order to arrive at more conclusive results.

DEDICATION

For my 'day' daughter Auredetsi and my 'sun' son Anthony

[You just have to go all the way]

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ABBREVIATIONS

DAP	Days after planting
m	meter
^oC	Degree Celsius
≥	greater than or equal to
≤	less than or equal to
%	percentage
kg	kilogram
AVRDC	Asian Vegetable Research and Development Centre
TPI	Tropical Plant Institute
NRDC	Natural Resources Development College

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CHAPTER ONE

INTRODUCTION

Legumes in general and grain legumes in particular, are among the world's most important crops, second only to cereals. The grain legumes are a major source of protein for both man and livestock. They form an important source of food, largely because of the fact that they have high protein content. Their amino acids compliment those of cereals in man's diet especially in areas where cereals form the main food base. Among the potentially important food legume is mungbean (*Vigna radiata* L. Wilckzec). In countries where it is cultivated, rich and varied, delicious and nutritious mungbean products are prepared, e.g. sprouts, vermicelli, sheet jelly and pastries; mungbean noodles, candy, porridge and soups with distinct flavors. Mungbean liquor and drinks are also believed to have medicinal properties (Thirumaran and Seralathan, 1985; Chen *et al.*, 1986). Other uses of mungbean other than food include, assistance in rational use of land, sunlight, heat and water resources, increased cash income, enrichment of the soil through nitrogen fixation and formation of a good ecological environment on the land. Mungbean is rich in digestible protein (17.5% to 24.0%), however, it lacks the essential sulphur containing amino acids, methionine and cysteine, thereby limiting the protein quality (Xianghuai *et al.*, 1989). This, limitation not withstanding, the crop is a good protein source.

Mungbean, is an early maturity (60 to 70 days) crops which is one of the candidates for crop diversification. It is however, characterized by low yield potential, poor yield stability, susceptibility to insect pests, disease and also susceptible to abiotic stresses (Fernandez and Shanmuganundrum, 1987).

In Zambia, some serious production constraints of food legumes include low yielding potential of the local landraces, unstable yields due to proneness to heavy yield losses caused by insect pests, diseases, inadequate and untimely agronomic management, the latter caused by greater attention being paid to the maize crop (Mulila and Javaheri, 1994). The potential for the production of mungbean in

Zambia has been and is still being investigated and encouraging results have been reported (Hill, 1980).

Research on grain legumes in Zambia, dates back to the sixties (Agricultural Research Branch, 1968-1980). Initially, a number of legume crops were worked on, and these included groundnuts (*Arachis hypogeae* L.), field beans (*Phaseolus vulgaris* L.), cowpeas (*Vigna unguiculata* (L) Walp) , Bambara groundnuts (*Vigna subterranea* (L) Verdic.), dwarf lima bean *(Phaseolus lunatis* (L), winged bean *(Psophocarpus tetragonolobu* (L), and mungbean (*Vigna radiata* (L.) Wilckzec). By 1980, due to scarcity of financial support, research on food legumes concentrated on field beans, cowpea, groundnuts and Bambara groundnuts. Other legumes like winged beans and mungbeans were only grown as collection or rejuvenation plots (Hill, 1980). The research on legume crops in the late sixties and seventies, did not produce technological packages appropriate to small holder or traditional farmers (Mulila and Javaheri, 1994).

Intensive research work on food legumes was initiated in 1978 for groundnut breeding with UNDP/FAO assistance, and in 1982, for beans, cowpeas and groundnut agronomy with IBRD/IFAD loan assistance. From 1988 to date, the Food Legumes Research Team, has a national mandate for research into improved productivity and production of food legume crops (groundnuts, field beans, cowpeas, Bambara groundnuts, pigeon peas and chick peas, and more recently lentils, and mungbeans). This is being undertaken with the assistance of UNDP/FAO (Mulila and Javaheri, 1994).

Earlier studies by Hill (1976) in different areas showed yields of 675 kg/ha at Sesheke, 80 kg/ha at Kaoma and 272 kg/ha at Lusitu. The early research results showed that the potential for the crop was good. This confirmed the results obtained as early as 1972, when yields of 650 kg/ha at Mansa (Laupula Province), and 1140 kg/ha at Sesheke (Southern Province) were recorded (Agricultural Research Branch, 1974).

During the 1977/78 season the First International Mungbean Nursery was planted at Lusitu and Kaoma to screen 30 mungbean introductions from Asia Vegetable Research and Development Centre (AVRDC), Taiwan. Only 18 lines survived, with a yield range of 15 kg/ha to 475 kg/ha. This nursery was repeated the following season at Magoye, with a local check. Accession V2007 yielded the highest with 1402 kg/ha against the local genotype with yielded 508 kg/ha. Hill (1980) reported various trials of mungbeans in other parts of Zambia. The trial at Mansa yielded an average of 125 kg/ha. The occurence of higher incidence of `damping-off' disease in wetter areas led to the conclusion that mungbean was suited to the drier parts of the country, more especially the Zambezi Valley.

The research on mungbean to-date has been mainly exploratory and has therefore, not produced any production packages. The need for the promotion of mungbean is in line with the country's efforts to diversify the crop production base, especially in view of changing environmental conditions. In Zambia, the Food Legumes Research Team addresses the research issued pertaining to improvement and production of food legumes. Mungbean referred to as a 'minor legume', in comparison to groundnuts, cowpeas, beans and soybeans, is one of the newly introduced food legumes under the mandate of the team. This study augers well within the objectives of the research on food legumes.

The objectives of the study, therefore, were:

(i) to determine the optimum planting date, and

(ii) to determine the optimum plant population density of two mungbean varieties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and names of mungbean

Mungbean originated in South East Asia and is an important pulse crop throughout southern Asia especially India, Burma, Thailand, Indonesia and the Philippines (AVRDC, 1985). It is now being grown to a lesser extent in may parts of Africa and the Americas. In addition, it is also being grown on small scale in Australia (TPI, 1979). Common names other than mungbean are green or golden gram. Different cultures have varied local names for mungbean, but it is known as 'Kanyense' in Soli (Lusaka rural) or 'Kankhoma' in Chewa (Eastern Province), Zambia.

Mungbean is botanically described as *Vigna radiata* (L) Wilczek, syn. *Phaseolus aureus* Roxb., *Phaseolus radiata* L., and belongs to the *Leguminosea* family (TPI, 1979).The wild form is found in Madagascar as *Vigna perririana* (R) Vig. and on the Indian Ocean shores of East Africa.

2.2 Adaptation and distribution

Mungbean is well adapted to altitudes of zero to 1,800 meters above sea level. Mungbean thrives well in areas with average temperatures of between 30°C and 36°C, and the crop is sensitive to frost. For optimum results, a well distributed rainfall of 750 -900 mm/annum is required, although reasonable yields can be obtained in areas with only 650 mm/annum. Mungbean is fairly tolerant to drought. Prolonged rainfall is very detrimental to yield (TPI, 1979).

With respect to soil requirements, the crop can be grown on a wide range of soil types, provided that the soils are well drained, since it cannot tolerate water-logging (Singh and Yadav, 1976). For optimum results, a deep loamy soil is required, but mungbean is well adapted to clay soils. In soils where the pH is below 5, one ton per hectare of agricultural lime is recommended to be incorporated just before the final discing (Kassim et al., 1976). Mungbean grows well on poor soils without supplemental nitrogen, which is an added advantage to subsistence agriculture (Baudoin et al., 1987; Anishetty and Moss, 1988).

Mungbean shows wide distribution in the tropics and subtropics, i.e. Asia, Australia and Oceania, adapted to a wide range of agro-climatic conditions.

2.3 Growth habit of mungbean

The growth habit of mungbean can be dwarf, erect, determinate and non-branching or indeterminate and semi-prostrate to tendrilious and profusely branching (Paroda and Thomas, 1986). The leaves are trifoliolate with large, ovate, entire or rarely lobed, membranous leaflets. The yellow or greenish yellow flowers are crowded in clusters (10-20), on axillary or terminal raceme. Flowers are self pollinated.

The seed pods are sub-cylindrical, 5-10 cm long and 4-6 mm wide, straight or slightly curved and normally containing 10-20 small seeds. When unripe, the pods are of various shades of green, but when mature, turn brown to buff. The seeds are oblong, often green, but may be yellow, brown or speckled with black. The seed size varies from 1.2 to 77.3 gm/100 seeds (AVRDC, 1985). Two types of mungbean are usually recognised: (i) *aureua,* yellow or golden gram, which has yellow seeds, is generally low in seed production, has a tendency for the pod to shatter and is often grown for forage or green manure, (ii) *typica,* green gram, which has dark or bright green seeds, is more prolific, ripens more uniformly, has less tendency to shatter and is more popular as a grain legume (TPI), 1978; Fernandez and Shanmuganudram, 1987; Sandhu et al., 1988).

Plants with medium stature, erect growth habit, short internodes and more effective flowering nodes, are thought to be able to utilize solar energy more efficiently compared to the taller vinyl trailing types (Sandhu et al., 1987)

Singh and Singh (1987), reported positive correlation of plant height with days to flowering, days to maturity, number of branches, clusters per plant, pods per plant, pod length and number of seeds per pod. This may suggest that early flowering and early maturing varieties are shorter, while late maturing and late flowering varieties are taller. In general, early maturing varieties may possess larger seeds compared to late maturing varieties based on 100 seed weight in correlation with pod length (Singh and Singh, 1987).

Podding in mungbean is usually restricted to the upper most fourth and fifth nodes of the stem and branches (AVRDC, 1985). Prolonged vegetative growth (as maybe the case with later flowering cultivars), therefore, may result in the accumulation of lower sterile nodes, without an appreciable increase in the yield of a plant (Paroda and Thomas, 1985). The number of effective flowering nodes and effective flowers per node may be the real determinants of the yield potential of a mungbean plant. In fact, pods per plant is the best indicator of yield per plant (Sandhu et al., 1987; Xianghuai et al., 1988).

Considerable work on the improvement of mungbean has been undertaken in recent years mainly in India, Taiwan and America, resulting in short duration types suitable for multiple cropping programmes. Recently, a high yielding, quick maturing, non shattering cultivar has been developed in U.S.A., which produces semi-glossy, large seeds, particularly suitable for the production of bean sprouts (AVRDC, 1994).

2.4 Mungbean productivity in relation to time of planting

Time of planting has been described as the most important non-monetary factor for obtaining potential yield in mungbeans (Digra and Sekhon, 1987). This factor ensures the complete harmony between vegetative and reproductive phases on the one hand and the climatic rhythm on the other.

Timely planting not only aids in obtaining maximum returns, but the very success of the crop may depend on time of planting. In mungbean, planting date is determined by the photosensitive nature and availability of soil moisture at planting (Summerfield and Lawn, 1979). Variation of planting date has proved to be a simple and effective means of investigating phenological development of several grain legume species in the tropics. e.g. in soybeans , pigeon pea (Akinola and Whiteman, 1974). Serial plantings at a location enable cultivar response to be observed in the field in relation to environmental factors such as temperature, rainfall, with minimum variation in other factors (e.g. edaphic), which may be of major adaptive significance

Plant growth and development are sensitive to low temperatures. Raison and Chapman (1976) tested one blackgram genotype and described it as `chilling sensitive' with critical temperature of 15°C, below which growth rate is substantially reduced. Aggarwal and Poelhman (1977) reported that in general cooler temperatures (18°C) delayed flowering compared with 23°C and 28°C for a wide range of mungbean genotypes.

Time of planting trials have been conducted by researchers in a number of mungbean growing areas, mainly the Far East, India and Australia (Radjit and Adisarwanto. 1988; Aziz et al. 1974; Bharat, 1974; Beech and Wood, 1975 and Lawn, 1978). In most of Asia, up to three crops of mungbean can be grown per year. In Thailand for example, first planting coincides with the first monsoon rain fall and harvested before the onset of heavy rains; second planting is practiced near the end of the rainy season (September to October), but only in the upland regions. In fact about two thirds of the country's production comes from the second planting (Nalampang, 1976). The third planting is done in the paddy fields after rice harvesting in January and February; the residual moisture is sufficient to produce a full crop, though in some areas supplemental irrigation may be necessary.

In Australia, work done by Lawn,1974 showed that planting time is very closely related to moisture availability. Trials included comparison of irrigated and rain fed mungbean crops. Yields in the range of 200 to 800 kg/ha (rain fed crop) and 760 to 1300 kg/ha (irrigated crop) were obtained (AVRDC Annual Report, 1978). Tsuing (1974), summarized five years of work on planting date of mungbean in Malaysia and observed that irrespective of the month of planting, the phenology was similar; i.e. flowering, ripening of pods and maturity occurred within the genotypic potential, although considerable differences were observed in plant growth. Not only climatic data could explain this difference in growth, but observations in terms of diseases and insect pests which tend to adversely affect leaf area hence the plant's ability to photosynthesize, need to be considered.

In India experiments conducted on dates of planting showed that the highest yields (0.89 t/ha) were obtained from mungbean crops planted between 20th March and 20th April for the summer crop. The monsoon rains begin from late June to early July. This implies that a crop planted later than 20th April matured between 28th June and 30th June (65-70 day varieties) faced a high risk of being caught in the monsoon rains. Yields from later planted crops were as low as 0.59 t/ha. In the monsoon season, the best time for planting mungbean was found to be from the end of June to the first week of July (1.2 t/ha). There was a drastic reduction in yield (0.56 t/ha) when planting was delayed to the end of July. The yield loss was greatly reduced due to the photosensitivity nature of the genotypes (Dingra and Sekhon, 1986).

2.5 Mungbean productivity in relation to plant population

Lawn, (1974), reported conclusively that under ideal growing conditions, optimum planting density is that which allows full light interception to be achieved prior to pod production, but that which avoids excessive vegetative growth. This is influenced by the physiology of the crop. Both the rate and extent of dry matter production of a crop are determined by the amount of photosynthetic active radiation and the crop's efficient use of light energy in dry matter production. Economic yield (seed yield for mungbean) is determined both by the amount of dry matter produced and by the way that dry matter is partitioned amongst the various parts of the plant.

In India Dingra and Sekhnon, (1986), reported that plant population and spatial arrangement of mungbean vary under different seasons. In summer, plant growth is limited by high temperatures, low humidity and shorter growth duration. It is thus possible to use higher plant populations in summer than during the monsoon season. Mean yield increases (1.08 – 1.38 t/ha in summer; 0.83 – 0.97 t/ha in monsoon) consistently in summer with increase in seed rate from 15 kg/ha to 25 kg/ha. There was no significant increase above these seed rates. Row spacing of 22.5 and intra-row spacing of 5 cm produced the highest yield (1.96 t/ha) during summer; while the monsoon at 30 cm inter-row and 10 cm intra-row spacing produced the highest yield (1.03 t/ha).

Yield responses to planting density are basically consequences of intra- and inter-plant competition for water and nutrient and of above ground competition particularly for light. These responses are affected by planting date, light duration and intensity, temperature, soil structure and nutrient status, moisture availability, species or genotype and insect pest and disease control (Akinola and Whiteman, 1974).

Willey and Heath (1969) reported that yield per unit area is dependent not only on the number of plants per unit area (plant density) but also on the spatial arrangement of those plants (plant rectangularity). The latter is defined as the ratio of the distance between plants within the row to the distance between rows. This plant rectangularity produces unevenness of competition. Competition may be too intense between some plants and insufficiently intense between others. The extent to which rectangularity may affect the yield of a crop is clearly dependent on the plasticity of the individual plant, which in turn must be dependent on the plant species. In general, as rectangularity increases, either by increasing seed rate or increasing row width, yield per unit area gradually declines. In other words, a change in density may not only change the space available to a plant, but might also bring about some change in the environment, e.g. an effect of rooting depth.

Plant population density and spatial requirements if mungbean vary depending on season and soil type. Yield per hectare is a function of plant population and yield per plant (Singh et al., 1988). Most legumes like grams, lentils, show higher yield potential when sown closely.

Budi and Adisarwanto (1987), reported the highest yields when mungbeans were planted at a spacing of 30 cm between rows and 10 cm within rows, i.e., 666,6667 plants per hectare. However, as population increases, the number of flowers per plant and pod setting decrease much more in mungbean than in soybean (McKenzie et al., 1975).

Poelhman (1978), reported the highest experimental yield of mungbean, i.e., 6.9 tones per hectare. Adequate irrigation, high light intensity, slightly cooler temperatures due to high elevation, and minimum disease damage contributed to this high yield. Of interest was the row spacing of 90 cm which produced large plants with high biomass before anthesis.

Kuo et al. (1977), reported that the potential yield of mungbean is limited by the source rather than the sink, although the yield is directly determined during the post anthesis period. Mungbean sink capacity depends on the number of pods per unit area, the number of seeds per pod and the individual seed size (AVRDC, 1974). Some varieties achieve high yield through high pod number, others through seed numbers and seed weight and still others through a harmonious combination of these characteristics (Verma and Sandhu, 1988).

The yield of mungbean is generally decided by its capacity to grow vigorously and accumulate as much dry matter as possible before anthesis (Sadasiran et al., 1987). Slow rate of dry matter accumulation during the period of pod development and low partitioning efficiency of assimilates to the grain, are major physiological constraints to yield increase (Mitra et al., 1987). Maximum seed yield depends on the duration of seed filling, which in turn depends upon the availability of nutrients especially nitrogen.

2.6 Mungbean production in relation to other factors

2.6.1 Drought stress

Moisture stress at all stages of growth reduces yield in mungbean (Sadavisan et al., 1987). However, stress during the vegetative phase (from germination to flowering) causes the maximum reduction in yield of up to 21.6%. Stress during this phase irreversibly reduces plant height, root growth, leaf area, number of clusters, number of pods and dry matter accumulation.

Stress during flowering reduces yield only by 1.3%, while stress during pod development reduces yield by 17.6%. Mungbean has been reported to suffer 40% to 60% grain yield reduction due to water stress especially during vegetative and pod development phases (Kuo et al., 1978). Mungbean lacks rapid growth during the basic vegetative stage which is essential to obtain optimum leaf area index and early ground cover (Yoshida, 1981).

2.6.2 Diseases

Mungbean is host to disease organisms such as fungi, viruses and nematodes (Orton et al., 1982). Several diseases especially cercospora leafspots (*Cercospora canenses, Cercospora cruenta*), powdery mildew (*Erysiphe polygoni*), mungbean yellow mosaic virus transmitted by white flies, and a complex of fungal root diseases, reniform nematodes and root knot nematodes (*Rotylenchulus reniformis, Meloidogyne* species), may cause serious yield losses.

2.6.3 Insect pests

Mungbean is prone to insect attack from the seedling stage to maturity, resulting in severe yield losses. Most common insects are Agromyzid beanfly (*Ophiomyia phaseoli, Ophiomyis centosemantitis, Melanagromyze sojae*), pod borers and feeders (*Maruca testularis, Heliothis armigera*), piercing and sucking insects, whitefly (*Bemisia tabaci*), aphids (*Aphis craccivora*), and storage pests, bruchids (*Cellosobruchus chinensis*) (Sehgal and Ujari, 1987); Fernandezi and Shanmungasundram, 1987). A warm humid climate favours rapid insecticidal degradation and enhances pest population build up.

2.6.4 Nutrition

Urea, as an exogenous source of nitrogen increases nitrogen supply during flowering and pod filling, retards leaf senescence and improves photosynthate and nitrogen availability for seed biomass. In fact Pawar and Bhatia (1980), reported that mungbean responds well to application of 20 kg N/ha, 20 kg P/ha and 42 kg K/ha. The need to inoculate with an appropriate strain of rhizobium or brady-rhizobium arises when mungbean has not been grown for a long time (Busby, 1987). In general, members of the genus *Vigna*, are effectively nodulated by brady-rhizobium, from a wide range of legumes and many soils already contain natural populations of rhizobia (Miller and Fernandez, 1987).

2.6.5. Weeding

Weeding is an important cultural practice to reduce unnecessary competition for nutrients, water and light. Weeding at least twice during the growing season is ideal. The first weeding is done 20 days after planting. When plants are closely spaced, weeding during flowering should be avoided. This reduces incidence of flowers dropping (Adisorwanto and Radjit, 1982).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted during the 1995/96 rainy season at two sites i.e. Natural Resources Development College (NRDC) Farm in Lusaka and Mochipapa Research Station in Choma, Southern Province. Soil nutrient status at N.R.D.C. and Choma was 0.04%N and 0.03% respectively, while soil pH was 6.22 and 3.94 respectively. The field at N.R.D.C. had been fallow the previous two seasons, while the field and Choma had been fallow the preious three seasons.

3.2 Weather

Zambia is divided into three (3) agro-ecological regions: Region I has a rainfall range of 600-800 mm; Region II has a range of 800-1 000 mm, while Region III has a rainfall avarage of over 1 000 mm per annum. Climatic data collected at NRDC farm, Lusaka and Mochipapa, Choma is presented in Appendix 1 and 2, respectively. The parameters include temperature, rainfall and number of rainy days during the growing season.

3.3 Experimental design and treatments

In a split-split plot design with whole units arranged as completely randomized block (RCB) (Appendix 3). Two varieties (genotypes) were assigned to the main plots. Three planting dates were assigned to the sub-plots while the four plant populations were assigned to the sub-sub-plots. The main plot size was 281.35m^2, the sub-plot size was 80.49m^2, while the sub-sub plot was 9.60m^2.

3.3.1 Varieties

The two genotypes under study were both introductions into the breeding programme. Kenya-1 (K-1), is determinate, maturing within 75 days after planting (DAP). Accession 183407, an introduction from Asia Vegetable Research Development Centre in Thailand, is determinate, maturing within 65 days. 30 genotypes or lines were revieved in the germplasm colletion during 1994/95 season. The yields obtained from the single row non replicated observation plots grown at Golden Valley Farm (Chisamba, Kabwe) were very low and only these two genotypes i.e., K-1 and Accession 183407 had enough seed to meet the requirement for the trial. A local check could not be obtained with sufficient seed for inclusion into the experiment.

3.3.2 Planting dates

Planting dates at the two sites were as follows:-

	Mochipapa	NRDC
1	28/12/95	5/1/96
2	11/1/96	19/1/96
3	28/1/96	2/2/96

The planting dates were chosen on the basis of the dates recommended for the other food legumes grown in the country. According to the Food Legumes Bulletin (1991), groundnuts (*Arachis hypogeae* L.) soyabean (*Glycin max* L.*)*,and Bambara groundnuts(*Voandezia subtteranea)* are recommended to be planted soon after the cash crop at about mid-December to late December, late December; field beans (*Phaseolus vulgaris* L.) and cowpeas (*Vigna unguiculata* L.), early to mid January; depending on the agro-ecological zone. Region I recommendations are earlier than those of Regions II and III respectively. Based on the close relationship of mungbean to cowpea, the planting dates of two weeks on either side of the recommended practices for cowpeas were chosen.

3.3.3 Plant populations

The four plant populations were as follows:

1 30cm x 10cm(666,667 plants per hectare)
2 60cm x 20cm(200,000 plants per hectare)
3 50cm x 10cm(400,000 plants per hectare)
4 60cm x 10cm(333,333 plants per hectare)

Selection of plant population was based on the recommendations made for the food legumes grown in the country. AVRDC recommends 666,667 plants per hectare, while 200,000, 333,333 and 400,000 plants per hectare are recommendations for runner type groundnuts, bunch type groundnuts, soybean, Bambara groundnuts and cowpeas (Agricultural Research Branch, 1993).

The required plant population was achieved by planting all plots at higher density (50 to 60 seeds per row), then thinning to a predetermined density at two weeks after planting.

Planting was done on flat after the field had been ploughed, disced and hand levelled. No inoculum was used. Compound `D' (10,20,10,5), representing N, P_2O_5, K_2O and S, respectively) was applied as a basal dressing at planting time at the rate of 200 kg/ha. One hand hoe weeding and three times of hand pulling of weedings was done. To control aphids, an insecticide Fenitrothion 40% EC at 1.5 litres per hectare was applied. Dithane M 45 a fungicide, was applied at the rate of 5 kg per hectare to control leaf spots.

3.4 Data collected: Ten plants were randomly selected per plot for obtaining measurements of plant height, number of branches, number of pods, pod length and number of seeds per pod. In addition to these data, the following phenological yield and yield components data were collected.

i. **Planting date**: When the crop was planted.

ii. **Days to 50% flowering**: The number of days from planting to when 50% the plants in the plot are in bloom.

iii. **Plant height (cm):** This parameter was recorded at 50% flowering. Vegetative growth of the stem usually ceases after flowering (Lawn,1976; Poelhmann, 1976). This implies that there will be no more height increase. Plant height is used as a measure of yield component associated with number of nodes on the main stem. The measure was from ground level to the upper most node.

iv. **Number of branches/plant**: Number of branches on the plant from the base.

v. **Days to physiological maturity**: Physiological maturity was determined when 95% of the pods turned black

(AVRDC,report, 1972). Only the ripe pods were harvested at any one time and up to three harvests were done.

vi. **Number of pods/plant:** Number of pods on a plant prior to harvesting.

vii. Pod length (cm): Length of the pods from the base to the tip of 100 randomly selected pods.

viii. **Number of seeds/pod:** Average count of number of seeds in a pod from 100 randomly selected pods.

ix. **Pod weight (gm/plot):** Weight of the dry pods before shelling or threshing. After harvest, the pods were sun dried for one week and re-weighed.

x. Grain weight (gm/plot): Two weeks after harvesting, the dry pods were put in bags, then beaten with sticks to loosen the seeds, which were then winnowed to remove trash. The weight of the clean grains was then recorded.

xi. **Grain yield (kg/ha):** This was calculated based on the following mathematical formula:

kg/ha = plot yield x $10,000m^2 \div$ plot size.

xii. **100 seed weight (gm):** Determined by physically counting 100 seeds at random and weighed.

xiii. **Shelling percentage:** Grain weight (gm/plot) x 100 $\div$ pod weight (gm/plot).

xiv. Grain protein content and soil pH and nitrogen status: as per laboratory procedures in 3.5.1 and 3.5.2 respectively.

3.5 Soil samples for pH

Two composite soil samples of the top (10-15 cm) and sub soil (15-30 cm) were analysed for pH and N prior to planting. The standard procedure of obtaining soil suspension with $CaCl_2$ electrolyte was carried out. pH was measured potentiometrically by using glass calomel electrodes connected to a pH meter.

3.6 Grain and soil samples for N determination

Nitrogen was analysed by use of the modified Kjeldah procedure. A 1.0 gm sample of either sieved soil (2 mm seive size) or ground plant material (in this case grain), and digested in 98% H_2SO4 with a mixed catalyst (i.e. mix 100g K_2SO_4, 10g $CUSO_4.5H_2O$ and 1g selenium powder) for at least one hour onto a digestion block set at 410°C. After cooling, the digest was diluted with distilled water up to 100 ml.

Total nitrogen was determined by Markham still distillation of an aliquot (with six drops of mixed indicator i.e., 0.1g bromocresol green and 0.07g methyl red in 100 ml of ethanol) of the digest made alkaline by adding 45% NaOH. The ammonia was trapped in saturated boric acid solution then titrated with .01N HCl for soil samples and .1N HCl for the grain sample.

The nitrogen content of each sample was calculated as follows:-

$$\%N = \frac{(Vs-Vb) \times N\ HCl \times 14}{1000 \times m} \times 100$$

where:

where:	Vs	=	Volume of sample
	Vb	=	Volume of blank
	N HCl	=	Normality of HCl
	14	=	Atomic weight of nitrogen

To convert %N into proteins, the standard formula was used, i.e.,

Protein content = %N x 6.24

3.7 Statistical analysis

Analysis of variance (ANOVA), to test treatment significance, LSD for mean separation of significant F tests, and correlation of data, was analysed using standard procedures through the M-stat computer package (Panse and Sikhame, 1978; Steel and Torrie, 1980). The statistical model in the analysis of data is as presented in Appendix 4.

CHAPTER FOUR

RESULTS

4.1 Weather

At both sites, weather was characterised by normal precipitation. Choma received 809 mm total rainfall between November and May distributed over 65 rainy days, while NRDC received 801 mm over 65 days. The 30 year period rainfall averages, as compiled by the Meteorological Department (Muchindu, 1985), show that the normal rainfall for Choma is 809 mm over 67 days ; while that of Lusaka (NRDC) is 744 over 67 days. Temperatures averaged 26.7 °C maximum and 15.2°C minimum for Choma; while the corresponding figures for NRDC were 25.2°C and 18.0°C,for maximum and minimum, respectively (Appendices 1 and 3).

4.2 Plant establishment

Germination of the two varieties was excellent at both sites. Within a period of two weeks after emergence, `damping-off' disease killed about 75% of seedlings, forcing the abandonment of the trial at Mochipapa, Choma. The results reported herein, therefore, are based on the trial site at the Natural Resources Development College, Lusaka. At this site, the actual plant stand after thinning was 320, 160, 80 and 200 plants per plot; corresponding to 666,667, 333,333, 200,000 and 400,000 plants per hectare, respectively.

4.3 Yield and yield components

4.3.1 Grain yield (kg/ha)

Significant differences were observed between varieties ($P \leq 0.01$), among the planting dates ($P \leq 0.05$) and among plant densities ($P \leq 0.01$) for grain yield (Table 1). The second planting date had the highest grain yield of 543.9 kg/ha, while the third planting date yielded the least 235.9 kg/ha on average. Plant population of 666,667 plants per hectare ranked first, yielding 481.5 kg/ha, while the plant population of 200,000 plants per hectare yielded least 293.0 kg/ha. Plant populations of 400,000 and 333,333 plants per hectare were not significantly different from each other, yielding 471.0 kg/ha and 375.7 kg/ha, respectively. Of the two varieties, Accession 183407 out yielded ($P \leq 0.01$) Kenya 1 with a yield of 526.4 kg/ha, compared to a yield of 284.4 kg/ha for Kenya 1.

4.3.2 Number of branches per plant

Non of the factors had any significant effect on number of branches.

4.3.3 Number of pods per plant

There were no significant varietal differences in number of pods per plant. However, planting date and plant population significantly effected on number of pods per plant ($P \leq 0.05$). The means of 24.8 pods/plant for population density 666,667 plants/hectare and 26.1 pods/plant for 333,333 plants/hectare were not significant from each other; while means 29.4 pods/plant for population density 200,000 plants/hectare and 32.2 pods/plant for population density 400,000 plantd/hectare were also not significantly different from each other. However, means for pods per plant for population density 400,000 and 200,000 plants/hectare were significantly different from those for population density 666,667 and 333,333 plants per hectare .

4.4.4 Pod length

Planting date and plant population affected pod length, while variety and the interactions had no significant effect ($P \leq 0.01$). Accession 183407 had longer pods (8.3 cm) while Kenya 1 had an average of 6.5 cm pod length. The first planting date had relatively longer pods (7.7 cm), while second and third planting dates were not significantly different from each other (7.2 cm and 7.2 cm, respectively).

4.3.5 Number of seeds per pod and 100 seed weight

There were significant differences among varieties in the two yield components, i.e., number of seeds per plant ($P \leq 0.05$) and 100 seed weight ($P \leq 0.01$). Plant population and planting date had no significant effects on the two yield components. Interaction effects were not significant. Accession 183407 had more seeds per pod and higher seed weight than Kenya 1 (Table 2).

4.3.6 Plant height (cm)

Planting height was not significantly affected by variety and plant population. On the other hand, planting date significantly affected plant height ($P \leq 0.01$). The second planting date had relatively taller plants for both varieties (43.7 cm) while the first and third planting dates had shorter plants (36.6 cm and 30.4 cm, respectively).

4.3.7 Plant stand at harvest

Variety significantly affected plant stand at harvest ($P \leq 0.01$). Planting date had no significant effect on stand, while population density had a significant effect on plant stand ($P \leq 0.01$). The population density of 666,667 plants per hectare ranked highest with 161.2 plants per plot at harvest, reflecting 50.3% of the stand at emergence of 320 plants per plot; while population densities of 400,000, 333,333, and 200,000 had 65.8, 104.6 and 48.6 plants per plot , respectively. This reduction in stand was a result of pests and diseases. Non of the interactions had any significant effects.

4.3.8 Days to 50% flowering (DAP)

Variety and planting date had significant effects on the duration to flower ($P \leq 0.05$ and $P \leq 0.01$, respectively); while plant population showed no significant effect. None of the interactions showed significant effects. However, Accession 183407 flowered much earlier (46 DAP) than K-1 which flowered later (50 DAP). There were significant differences between planting dates. The first planting date showed late flowering (55 DAP for K-1, and 49 DAP for Accession 183407), while the second and third plantings were not significantly different from each other at 48 DAP for K-1 and 44 DAP for Accession 183407.

Table 1: Analysis of variance for grain yield (kg/ha).

Source	df	MS	F	Prob
Rep	2	200458.8	28.6ns	.033
Var.	1	1053962.4	150.3**	.006
Error	2	7010.4		
Pl date	2	583933.6	5.9*	.030
Pl x var	2	47857.8	0.4ns	
Error	8	104727.2		
Pop	3	142105.6	5.8**	.002
Var x pop	3	14819.9	0.6ns	
Pl x pop	6	41751.3	1.7ns	
Var x Pl x Pop	6	9364.8	0.4ns	
Error	36	24277.6		

C.V. (%) 38.43
* significant at 5%
** significant at 1%
ns non significant

Tables 2: Means of grain yield and yield components of two varieties of mungbeans grown at NRDC during 1995/96 growing season

Variety	Yield (kg/ha)	Plant height (cm)	Pods per plant (no.)	Pod length (cm)	Seeds per pod (no.)	100 seed weight (gm)
K-1	284.4[b]	36.8[a]	27.3[a]	6.5[b]	10.1[b]	3.1[b]
Acc. 183407	526.5[a]	36.5[a]	27.8[a]	8.3[a]	11.8[a]	4.2[a]
S.E.	91.4	0.8	1.3	1.1	0.3	0.1
C.V. (%)	22.4	4.8	2.2	1.5	2.8	2.3
Sign.	**	NS	NS	**	**	*

* significant at 5%
** significant at 1%
NS non significant

Table 3: Means of grain yield and yield components of two varieties of mungbeans grown at three planting dates at NRDC during 1995/96 growing season

Variety	Planting date	Yield kg/ha	Plant height (cm)	Pods per plant (no.)	Pod length (cm)	Seeds per pod (no.)	100 seed (gm)
K-1	5/1/96	367[ab]	37.9[a]	32.1[a]	6.9[b]	9.8[a]	3.1[a]
	19/1/96	389[a]	43.5[a]	32.7[a]	6.3[c]	11.1[a]	3.2[a]
	2/2/96	97[c]	28.5[a]	17.1[b]	6.3[c]	9.6[a]	3.1[a]
Acc. 183407	5/1/96	508[a]	38.3[a]	35.1[a]	8.4[a]	12.1[a]	3.9[a]
	19/1/96	697[a]	43.9[a]	30.2[a]	8.1[a]	10.8[a]	4.5[a]
	2/2/96	375[a]	33.1[a]	18.3[b]	8.2[a]	10.7[a]	4.3[a]
LSD (0.05)		215.4		5.7	0.4		
C.V. (%)		38.4	23.3	13.2	5.3	10.4	6.6
Significance		*	NS	**	*	NS	NS

* significant at 5%
** significant at 1%
NS non significant
(means within a colomn followed by a common letter are not significantly different)

Table 4: Means of yield and yield components of two varieties of mungbeans grown at four population densities at NRDC during 1995/96 growing season

Variety	Plant pop per hectare	Yield kg/ha	Plant height (cm)	Pods per plant (no.)	Pod length (cm)	Seeds per plant (no.)	100 seed (gm)
K-1	200 000	180^{d}	33.4^{b}	28.9^{a}	6.6^{a}	10.4^{a}	3.1^{a}
	333 333	311^{d}	35.2^{ab}	24.9^{a}	6.5^{a}	9.9^{a}	3.2^{a}
	400 000	283^{d}	40.2^{a}	30.6^{a}	6.6^{a}	10.1^{a}	3.2^{a}
	666 667	364^{cd}	37.8^{a}	24.8^{a}	6.3^{a}	10.2^{a}	2.9^{a}
Acc. 183407	200 000	406^{c}	37.8^{ab}	29.6^{a}	8.2^{a}	10.6^{a}	4.3^{a}
	333 333	532^{a}	39.7^{a}	27.2^{a}	8.4^{a}	11.6^{a}	4.4^{a}
	400 000	468^{ab}	38.2^{a}	29.7^{a}	8.2^{a}	10.9^{a}	4.1^{a}
	666 667	599^{a}	38.1^{a}	24.9^{a}	8.3^{a}	11.7^{a}	4.2^{a}
LSD (0.05)		105.3	4.3				
C.V. (%)		38.4	23.0	13.8	5.32	10.2	6.6
Significance		**	*	NS	NS	NS	NS

* significant at 5%
** significant at 1%
NS non significant
(means within a column followed by a common letter are not significantly different)

CHAPTER FIVE

DISCUSSION

5.1 General

During the first month of crop establishment, the stand counts in all plots at both sites were 666,667, 333,333, 200,00,and 400,000 plants per hectare respectively. However, stands were drastically reduced between the period of three weeks after emergence and 50% flowering after which plant stand stabilized till harvest. The reasons for the mortality were identified as follows:-

5.1.1. Diseases

The trial suffered a set back due to problems associated with insect pests and diseases. Soon after emergence, the high incidence of seedling mortality caused by `damping-off' diseases. This is a collective term for diseases of germinating seed and seedlings characterised by seedlings dying back in the early seedling stage (Agrios, 1969)). This led to the abandonment of the Mochipapa, Choma site.

According to Mehroha (1989) the causal organisms of `damping-off' disease are *Rhizoctonia* species, *Fusarium* species and *Pythium* species of fungi which are soil borne. AVRDC (1974), has identified *Rhizoctonia solani* and *Pythium aphanidematon,* as the causal organisms of `damping-off' disease of mungbean seedlings. At two to three weeks after emergence, the post-emergence `damping-off' disease was observed. This is characterized by death of newly emerged seedlings at ground level, causing the plants to collapse. Another symptom observed was the sudden death of large number of seedlings within a localized area. These fungi live saprophytically in the soil, on organic matter and have a wide range of hosts. The development of these fungi is favoured by soil temperatures of around 30^{o}C and above, soil moisture of 15 to 20% and alluvial or sandy soils (Agrios, 1969). *Pythium* induced `damping-off' is most severe in wet soils at high pH, while the *Rhizoctonia* induced disease is most severe in wet soils at low pH.

In order to establish the cause of the seedling mortality at Mochipapa, Choma, a field survey and collection of infected plant material and soil samples were collected from mungbean fields in Choma, Siatwinda and Livingstone. Unfortunately, the samples were tampered with (through mixing of samples and lables; some samples were thrown away from the laboratory for lack of identification) before a comprehensive laboratory study could be made. However, the coloured pictures from AVRDC on mungbean disease identification and a pathologist's expertise helped in identifying the disease and ascertain the causal organism.

The five Choma soils are characterised by light sandy loams and had a pH in the range of 3.8 to 4.2. These five fields showed the above mentioned symptoms. An attempt was made to replant the trial, but similar disease symptoms were observed. Soil samples collected from Siatwinda and Livingstone mungbean fields had a pH of 5.8 to 6.0 and silt clay loam soil texture. The plants from these sites were healthy and showed no signs of the disease. NRDC trial sites had a pH of 6.2, with heavy clay loam. The plants showed some disease occurence but less severe.

Cercospora leaf spot (*Cercospora canescens*) and leaf blight (*Thanatophorus cucumeris*) were the other disease problems at the NRDC, Lusaka trial site. Scores of 8 and 9 at 50% flowering were recorded (based on the 1-9 scale for disease scoring; where 1 is no disease and 9 is heavy disease infestation). Dithane M45, (a fungicide) was used to control these leaf diseases. Pandler (1979) reported the seriousness of both cercospora leaf spots caused by *Cercospora canensis* and leaf blight, which result in heavy yield losses. Yield reduction is proportionate to the reduction in leaf area as low leaf area translates to reduced photosynthates being translocated to the sink. In some instances, the leaf may be lost completely.

A deliberate stand count for plants that showed symptoms of mungbean yellow mosaic virus (MYMV), which is transmitted by white flies (*Bemisia tabaci*) revealed that Accesion 183407 was more susceptible than Kenya 1.

Observation also showed that, the second planting date had a higher incidence of the characteristic yellow mottling of the leaf than the first and third plantings. A possible explanation for this would be the fact that the control measure taken when aphids were observed in the first planted crop just before 50% flowering, the second planted crop then three weeks old, also benefitted. This may also have controlled the whiteflies from the first planted crop which could then have infested the second and third planted crops, respectively.

Seed yield has a close relationship with duration and rate of photosynthesis. This implies that shading or reduction in leaf area during the period after anthesis reduces yield substantially. AVRDC (1974; 1976) reported that the most limiting mungbean grain yield physiological processes have been identified as photosynthesis (the source), translocation and the sink capacity. In fact, according to Kuo et al. (1974), in mungbean, optimum leaf area index which is an important determination of dry matter production and hence yield, is attained very slowly until the beginning of flowering. In this study, the high incidence of leaf spots and leaf blight, which resulted in substantial loss of photosynthetic area considerably affected the final grain yield.

5.1.2 Insect pests

As earlier mentioned, the incidence of aphids (*Aphis craccivora*) was not serious and control was by use of Fenitrothion 40% EC. During peak flowering, blister beetles (*Mylabris* species) which feed on flowers and young tender pods were observed in large numbers. These were controlled by hand picking, because the blister beetle are difficult to control chemically. Termites (*Macrotermes, Microtermes and Odontotermes* species) only appeared very late in the season and had no detrimental effect on the crop.

Plant survival and growth after this disease and pest stress as well as water logging problems due to too much rainfall affected grain yield. This fact is evident in the plant stand count at harvest, which reflects nearly 50 to 60% of the original stand at germination and thinning. Agrios (1969), reported that plants not killed by the `damping-off' disease have their growth retarded considerably and their yields reduced drastically.

There was an influx of snails which at first sight seemed harmless. Snails are known to suck sap from the tender stems and leaves thereby leaving the plants vulnerable to inversion by rots. Sodium chloride (common table salt)and heavy rainfall controlled the snails.

5.2 Effect of Variety

The two varieties under study were genetically different as evidenced by the results (Table 1). Acc. 183407 is earlier in maturity (65 DAP) and yielded (526.4 kg/ha). This yield was based on plant height of 37.8cm, pod length of 8.12cm and 100 seed weight of 4.4gm (Table 2). The protein content was 21.8%. Kenya 1 was later in maturity (70 DAP), yielding 284.4 kg/ha with a plant height of 33.4cm, pod length of 6.26cm and 100 seed weight of 3.1gm while protein content was 18.4%. The higher yield of Acc. 183407 was more a result of longer pods, more seeds per pod and larger seeds than those of Kenya 1. These results agree with the findings of Rachie and Roberts, 1974; Singh, 1988; Sandhu et al. 1987 and Gupta and Singh, 1969 who reported that yield of mungbean depends primarily on pods/plant, number of seeds /pod and seed weight. These authors also reported that yield is a complex and quantitative inherent character which is influenced by environmental fluctuations and also determined by several interacting components. However, according to AVRDC, 1990, grain yield in mungbean is a function of plant population and yield per plant.

5.3 Effect of planting date

There was a significant effect (Table 3) of planting date on grain yield of mungbean ($P \leq 0.05$). A delay in planting date results in yield loss. This yield loss was more a result of a reduction in the number of pods per plant. This may be due to a shortened growth period, as planting date was delayed. Lower yield could also have been due to the attack of blister beetle contributed to the reduction of flowers and consequently, number of pods.

The second planted crop yielded highest, while the first and third plantings yielded second and third, respectively. The first planted crop suffered a short spell of moisture stress prior to flowering, while the third planted crop yielded lower due to dwindling rainfall, increased incidence of pests and diseases.

5.4 Effect of plant population

Less densely planted mungbean tends to be stronger, shorter, with larger leaves and a lower grain yield; whereas at a higher plant population, plants tend to be taller, with smaller leaves and a higher grain yield. In this study, it was observed that plant population had no significant effect on plant height (Table 4).

It is also true that as plant population increases, there is more competition among plants for nutrients, light and water; plants then tend to grow taller in order to expose more leaf area to incoming radiation. The response of plant height to plant population was not significant probably due to non achievement of desired stands.

Plant population affected grain yield ($P \leq 0.01$), through number of plants per unit area (Table 4). These results agree with Poelhmann (1976) and McKenzie et al. (1975), who reported that as plant population increases, the number of flowers per plant decreases. The increase in plant number results in net increase of vegetative growth and hence further dry matter production in the stem and leaves without parallel increase in seed yield. This was also reported by AVRDC (1983).

In this study, higher grain yield was obtained from the highest plant population (Figure 19), as a result of the higher number of contributing plants. This agrees with the findings of Gupta and Singh (1969), who reported a significant yield increase of mungbean as plant population increased from 250,000 to 666,667 plants per hectare; while variety and plant population had no effect on the number of pods per plant and number of branches per plant.

CHAPTER SIX

CONCLUSIONS

The results of the trial whose aim was to determine the optimum planting date and optimum plant population of two varieties of mungbean have led to the following conclusions:

(i) The optimum planting date was the second date (19th January, 1996). The later the crop is planted beyond mid-January, the more the loss in yield.

(ii) The optimum plant population was 666,667 plants per hectare at a configuration of 30cm between plant rows and 10cm between plants while maintaining 2 plants per station. This was true for both varieties.

RECOMMENDATION

The short comings which were observed during the trial execution included:- the reduction and non achievement of target plant population due to disease pressure, and the loss of the whole trial at one site. In view of the above, the following consideration can be made for future research studies:-

(i) The trial should be repeated with slight modification, to include more mungbean genotypes, in order to exploit the genetic variability.

(ii) Although the plant population of 666,667 (30 cm x 10 cm), resulted in the highest yield, hand hoe weeding was not an easy task and even walking through the field during spraying disturbed the plants. A different configuration should be looked at, e.g., 50 cm x 5 cm

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Appendix 1: Statistical model:

$$Y_{ijkl} = \mu + \propto_i + B_j + \propto\beta_{ij} + \sigma_k + \propto\sigma_{ik} + \beta\sigma_{jk} + \tau_l + \propto\tau_{il} + \beta\tau_{jl} + \propto\tau_{kl} + \propto\beta\sigma\tau_{ijkl}$$

Where:

Y_{ijkl} = i^{th} population density at the k^{th} planting date of the j^{th} variety and i^{th} replicate
μ = overall population mean

Main plot effects:

$\propto_i$ = effect of the i^{th} replicate or block
β^j = effect of the j^{th} variety
$\propto\beta_{ij}$ = main plot error

Sub plot effects:

σ_k = effect of the k^{th} planting date
$\beta\sigma_{jk}$ = interaction of the j^{th} variety and the k^{th} planting date
$\propto\beta\sigma_{ijk}$ = sub plot error

Sub - sub plot error:

τ_l = effect of the l^{th} population density
$\propto\tau_{il}$ = interaction of the i^{th} replicate and l^{th} population density
$\beta\tau_{jl}$ = interaction of the j^{th} variety and l^{th} population density
$\beta\sigma\tau_{jkl}$ = three way interaction of the j^{th} variety, k^{th} planting date and l^{th} population density
$\propto\beta\sigma\tau_{ijkl}$ = sub-sub plot error

Appendix 2: Field plan and randomization

V1 IA2	V1 IA4	V1 IA1	V1 IA3	V1 IB1	V1 IB3	V1 IB2	V1 IB4	V1 IC2	V1 IC1	V1 IC4	V1 IC3
V2 IA2	V2 IA4	V2 IA1	V2 IA3	V2 IB1	V2 IB3	V2 IB2	V2 IB4	V2 IC2	V2 IC1	V2 IC4	V2 IC3
V2 IIC1	V2 IIC3	V2 IIC4	V2 IIC2	V2 IIA4	V2 IIA2	V2 IIA1	V2 IIA3	V2 IIB4	V2 IIB3	V2 IIB1	V2 IIB2
V1 IIC1	V1 IIC3	V1 IIC4	V1 IIC2	V1 IIA4	V1 IIA2	V1 IIA1	V1 IIA3	V1 11B4	V1 IIB3	V1 IIB1	V1 IIB2
V2 IIIB 4	V2 IIIB1	V2 IIIB3	V2 IIIB2	V2 IIIC3	V2 IIIC1	V2 IIIC4	V2 IIIC2	V2 IIIA4	V2 IIIA2	V2 IIIA3	V2 IIIA4
V1 IIIB4	V1 IIIB1	V1 IIIB3	V1 IIIB2	V1 IIIC3	V1 IIIC4	V1 IIIC4	V1 IIIC2	V1 IIIA4	V1 IIIA2	V1 IIIA3	V1 IIIA

Key:

Replicate	Variety	Planting date	Plant population
I	V1 K-1	A 5/1/96	1 666,667 plants/ha
II	V2 Acc. 183407	B 19/1/96	2 200,000 plants/ha
III		C 2/2/96	3 400,000 plants/ha
			4 333,333 plants/ha

Appendix 3: Temperature and rainfall data for the 1995/96 growing season at NRDC, Lusaka.

Month	Temperature (°C)			Total rainfall per month (mm)		Number of rain days (No.)	
	Max	Min	Mean				
November	28.4	21.3	24.8	57	(95)	9	(9)
December	24.1	19.9	22.0	76	(219)	14	(16)
January	26.8	19.6	23.2	181	(203)	16	(16)
February	25.0	18.2	21.6	329	(177)	16	(15)
March	23.7	17.6	20.6	142	(13)	4	(8)
April	24.5	18.1	21.3	10	(25)	3	(2)
May	23.7	18.3	21.0	6	(12)	3	(1)
Total				801	(744)	65	(67)

Source: NRDC meteorological office, Lusaka.
(The figures in brackets are representative of the data average over a 30 year period, Muchindu, 1985).

Appendix 4: Temperature and rainfall data for the 1995/96 growing season at Mochipapa, Choma.

Month	Temperature (°C) Max	Min	Mean	Total rainfall per month (mm)		Number of rain days (no.)	
November	28.8	17.5	23.2	46	(104)	3	(9)
December	27.1	18.6	22.8	158	(202)	14	(15)
January	26.8	17.3	22.1	275	(204)	16	(16)
February	26.4	16.7	21.5	194	(174)	16	(14)
March	26.5	15.3	20.9	105	(91)	12	(9)
April	25.8	11.5	18.6	6	(25)	1	(3)
May	24.8	9.6	17.2	25	(9)	3	(1)
Total				809	809	65	67

Source: Mochipapa Research Station Meteorology Station, Choma. (Figures in brackets represent a 30 year period average, Muchindu, 1985).

Appendix 5: Analysis of variance table for days to 50% flowering

Source	df	MS	F	Prob.
Rep	2	1.8	1.1^{ns}	.475
Var	1	378.1	232.7*	.004
Error	2	1.6		
Pl. date	2	271.1	47.32**	.000
Var x Pl.dt	2	11.3	1.97^{ns}	.201
Error	8	5.7		
Pop.	3	6.3	1.5^{ns}	.219
Var x Pop	3	4.9	1.2^{ns}	.323
Pl x Pop	6	1.3	0.3^{ns}	
Var x Pl x Pop	6	1.9	0.5^{ns}	
Error	36	4.1		

C.V. 4.2%
* significant at 5%
** significant at 1%
ns non significant

Appendix 6: Analysis of Variance for plant height (cm)

Source	df	MS	F	Prob
Rep	2	529.1	71.6*	.013
Var	1	58.9	7.9^{ns}	.105
Error	2	7.4		
Pl.date	2	1006.5	13.6**	.002
Var x pl	2	34.8	0.5^{ns}	
Error	8	73.9		
Pop.	3	40.9	1.5^{ns}	
Var x pop	3	46.2	1.7^{ns}	
Pl x pop	6	19.1	0.7^{ns}	
Var x pl x pop	6	20.2	0.7^{ns}	
Error	36	26.8		

C.V. 13.78%
* significant at 5%
** significant at 1%
ns non significant

Appendix 7: Analysis of Variance for number of branches per plant.

Source	df	MS	F	Prob.
Rep	2	4.5	21.1*	.045
Var	1	0.7	3.2^{ns}	.214
Error	2	0.2		
Pl. Date	2	3.1	1.9^{ns}	.211
Var x Pl	2	0.1	0.1^{ns}	
Error	8	1.6		
Pop	3	0.5	2.5^{ns}	.078
Var x pop	3	0.1	0.5^{ns}	
Pl x pop	6	0.2	1.3^{ns}	.295
Var x pl x pop	6	0.3	1.4	.230
Error	36	0.2		

C.V. 37.8%

* significant at 5%
** significant at 1%
ns non significant

Appendix 8: Analysis of Variance for stand count at harvest

Source	df	MS	F	Prob.
Rep	2	2543.7	76.8*	.012
Var	1	5066.9	151.7**	.006
Error	2	33.4		
Pl. date	2	17633.4	3.3^{ns}	.088
Var x pl	2	3639.1	0.7^{ns}	
Error	8	5291.4		
Pop	3	31646.2	28.9**	.000
Var x pop	3	546.9	0.5^{ns}	
Pl x pop	6	3002.6	2.7^{ns}	.026
Var x pl x pop	6	1581.4	1.5^{ns}	.223
Error	36	1092.3		

C.V. 15.5%

* significant at 5%

** significant at 1%

ns non significant

Appendix 9: Analysis of Variance for number of pods per plant

Source	df	MS	F	Prob
Rep	2	1603.4	76.5*	.012
Var	1	4.8	0.2ns	
Error	2	20.9		
Pl. date	2	1791.1	5.5*	.031
Var x pl	2	46.5	0.1ns	
Error	8	326.6		
Pop.	3	115.8	2.8*	.049
Var x pop	3	8.2	0.2ns	
Pl x pop	6	106.8	2.1ns	.031
Var x pl x pop	6	17.3	0.4ns	
Error	36	40.4		

C.V. 23.03%
* significant at 5%
** significant at 1%
ns non significant

Appendix 10: Analysis of Variance for pod length (cm)

Source	df	MS	F	Prob
Rep	2	0.3	2.8^{ns}	.355
Var	1	55.6	380.6**	.002
Error	2	0.2		
Pl. date	2	1.9	5.6*	.030
Var x pl	2	1.2	0.4^{ns}	
Error	8	0.3		
Pop	3	0.1	0.2^{ns}	
Var x pop	3	0.2	0.9^{ns}	
Pl x pop	6	0.2	0.9^{ns}	
Var x pl x pop	6	0.1	0.5^{ns}	
Error	36	0.2		

C.V. 5.32%
* significant at 5%
** significant at 1%
ns non significant

Appendix 11: Analysis of variance table for number of seeds per pod

Source	df	MS	F	Prob
Rep	2	7.1	6.6^{ns}	.132
Var	1	10.5	19.1*	.048
Error	2	1.1		
Pl. date	2	4.6	1.6^{ns}	.255
Var x pl	2	8.9	3.1^{ns}	.100
Error	8	2.9		
Pop.	3	0.8	0.7^{ns}	.177
Var x pop	3	2.1	1.7^{ns}	.326
Pl x pop	6	1.4	1.2^{ns}	
Var x pl x pop	6	0.6	0.5^{ns}	
Error	36	1.2		

C.V. 10.24%
* significant at 5%
** significant at 1%
ns non significant

Appendix 12: Analysis of Variance for 100 seed weight (gm)

Source	df	MS	F	Prob
Rep	2	0.8	8.6^{ns}	.103
Var	1	22.9	256.6**	.003
Error	2	0.1		
Pl. date	2	0.6	1.9^{ns}	.208
Var x Pl	2	0.2	0.7^{ns}	
Error	8	0.3		
Pop	3	0.2	2.6^{ns}	.065
Var x pop	3	0.1	2.4^{ns}	.083
Pl x pop	6	0.1	2.4^{ns}	
Var x pl x pop	6	0.1	1.4^{ns}	.242
Error	36	0.1		

C.V. 6.59%
* significant at 5%
** significant at 1%
ns non significant