CHAPTER 1

INTRODUCTION

Paprika (*Capsicum annuum* L.) belongs to the Solanaceae family and is closely related to potato (*Solanum tuberosum* L.), tomato (*Lycopersicon esculentum* Mill.) and tobacco (*Nicotiana tabacum* L.) (Ware and McCollum, 1980). This crop belongs to the sweet pepper group from whose fruit a concentrated spice product, oleoresin, is extracted and used as an ingredient in industrial food processing (Mvere, 1996). Paprika is generally used as a culinary colouring agent, as a flavouring vegetable or as a seasoning in cooking, in cheese, in processed meats, in goulash or eaten raw in salads (Peirce, 1987). It is now widely used to replace artificial food colourants that are believed to be carcinogenic in humans (Paprika Zimbabwe, 2000).

Paprika, an important high value cash crop, has the potential to boost Zimbabwe's foreign exchange earnings since the entire production is exported, specifically to Europe. Its production will also improve the livelihood of the smallholder (SH) farmers through increased incomes. The production of paprika in Zimbabwe is relatively recent and major production dates back to 1992 (Agrikor, 2000). Zimbabwe has been the largest producer of paprika in Southern Africa since 1997, and has in fact replaced Morocco as the largest African supplier of raw materials to international markets (Agrikor, 2000).

As a high value cash crop, paprika guarantees communal farmers a reliable income. The produce is exported and there is a ready market created by companies such as Hyveld Seed, Paprika Zimbabwe, CTE Paprika and others. In most communal parts of Zimbabwe where paprika is grown it is fiercely competing with, and fast replacing tobacco as a cash crop (Agritex, 2000). Also, the none – to – low viability of growing maize due to low prices and high input costs, has necessitated introduction of alternative cash crops in the SH sector.

Although paprika production in the smallholder-farming sector in Zimbabwe is fast gaining momentum it has so far received very little research attention. Research on paprika has been done for the commercial sector by private individuals and companies and their results are confidential, thus not made available to the general public, which may otherwise make use of such vital information. This has greatly limited the availability of, and access to information by SH farmers. Also, the high input recommendations being given to SH farmers by both extension and paprika contracting companies are specific for commercial producers, who have precision equipment and heavy capital outlays at their disposal. For example, farmers are recommended to use basal fertilizer rates of 700 – 1 000 kg/ha, 200 – 300 kg/ha ammonium nitrate (AN) and 350 – 400 kg/ha of potassium chloride. The majority of communal farmers cannot even afford these high fertilizer rates. Farmers have indicated difficulty in sourcing the recommended compound “L”. This is because agro-dealers do not supply it, mainly because farming in CRA is maize based and the fertilizer used for maize is compound “D”. Consequently, farmers use the readily available fertilisers for maize such as compound “D” and ammonium nitrate (AN) as well as manure to grow paprika. However, the response of paprika to these types of fertilisers has not been reported. Successful production of any crop can best be achieved with locally available resources. Compound “L” is recommended for paprika because it contains boron which enhances fruit formation and has fairly high P_2O_5 (17%) which ensures availability of phosphorus throughout the long growing season required for paprika (about seven months).

Most of the information used for paprika production, particularly in the smallholder sector, is being extrapolated from other crops related to paprika such as tobacco, and other types of pepper. These recommendations were developed for irrigated commercial crops in which the levels of fertilizer, chemical and water use are very high whereas these inputs are limiting under dryland conditions in the SH sector. Although there are some similarities, bell pepper production cultural practices like fertilization regimes, irrigation and time of harvesting are different from those for paprika (Kahn, Cooksey and Motes, 1997). Bell pepper is harvested whilst still green and succulent while paprika is harvested when dry and red in colour. Recommendations for closely related crops may not necessarily be the best for paprika production and as such, it is important that recommendations that are specific for paprika be developed. The plant architecture for tobacco is different from that of paprika and also, for tobacco, the leaf is the economically important plant part whereas for paprika the fruit is utilized. This means that management practices for tobacco are aimed at enhancing leaf growth yet for paprika the aim is to have increased number of high quality fruits. The foregoing would suggest that seedbed practices for tobacco are likely to be inappropriate for paprika because the plant parts utilized are different. Hardening may lead to vigorous leaf growth after transplanting for tobacco but its effect on paprika fruit growth has not been reported for dryland paprika. Paprika research recommendations from tobacco culture or other parts of the world can only be of limited use as they may not be suited to the local farmers' situation in view of climatic and soil differences.

Use of inappropriate agronomic practices is the probable cause of many of the problems encountered when growing paprika in smallholder areas of Zimbabwe. Some of the major agronomic problems in dryland paprika production identified to date include poor field establishment, with its attendant serious weed and disease infestation. Poor paprika transplant establishment in the field arising from high transplant mortality can result in sub-optimal plant population, and serious weed challenge even to the extent of wiping the whole crop, culminating in low yields as reported by Agritex (2000) that farmers in Chinyika East and West obtain yields of between 0.4 to 0.6 tonnes per hectare, compared to yields of above 6 tonnes per hectare obtained in the commercial sector (Mande, 1998). Besides poor field establishment some other reasons that have been cited for the low yields include unfavourable soil conditions of pH, low fertility, moisture stress, weeds and diseases (Mukaro, 1997).

Some of the problems that have been highlighted include those expressed by communal farmers during the 1999 review workshop of the Integrated Crop Management Research (ICMR) project based in the Chinyika Resettlement Area (CRA) in Makoni North, Manicaland Province. (Chivinge and Mariga, 2000). Informal interviews, field visits and observations indicated that seedling densities in the seedbeds were very high and the seedlings were tall and thin. It was also observed that some farmers do not bother to harden their seedlings in nurseries prior to transplanting. There is need therefore, for appropriate research and development strategies to be put in place to address these various paprika production problems hence this present study.

Study Objectives

The main objective of the study was, therefore, to assess the effects of changing the current nursery practices on seedling vigour and field establishment, and of agronomic field practices on fruit yield and quality of paprika in the smallholder-farming sector. The specific objectives were to:

- assess the effects of seedling density in the nursery on field establishment and final yield and quality of paprika;
- determine the effects of period of seedling hardening on final stand establishment in paprika;
- assess the response of different paprika cultivars to hardening treatments
- study the effects of different field level plant populations and spatial arrangements on yield and quality of paprika; and
- assess the effects of different basal fertilisers and combination of basal and top dressing on paprika yield and quality.

Hypotheses

- reducing seedling density from 1500 to 450 seedlings m^{-2} in the nursery increases the quality of paprika seedlings
- increased period of hardening off leads to higher quality seedlings resulting in improved field establishment of paprika
- different paprika cultivars respond differently to various hardening treatments
- increasing plant density and number of rows per ridge in the field leads to an increase in yield of paprika
- type of basal fertiliser and timing of nitrogen top dressing affect yield and quality of paprika

CHAPTER 2

LITERATURE REVIEW

2.1 **Field Establishment Methods for Paprika**

Paprika transplanting is done in areas where the growing season is limited, especially under dryland conditions in the SH sector. The aim of seedbed production is to obtain healthy, strong seedlings that can survive the stress of transplanting. Direct drilling of seed is a method that is being recommended currently in Zimbabwe for paprika production. According to Paprika Zimbabwe, (2000) this method offers a number of advantages. Suggested advantages are that lodging is considerably reduced, it is possible to sow far higher populations are possible than is the case with transplanted seedlings, plants are more upright, with fruits being held well clear of the ground. This limits disease spread by soil splash, plants seem far less susceptible to water logging and a number of nutrient related leaf diseases and labour input are reduced. However, direct seeding is currently very expensive and can only be done on small acreages on commercial farms, as it requires precision planting equipment and overhead irrigation for early planting.

Leskover, Cantliffe and Stoffella (1989) compared directly seeded with transplanted hot pepper, raised in pots in a nursery, and found that transplanted plants exhibited a faster initial root growth and an increased fruit growth and production. Several workers have reported that total fruit yields from bell pepper (Leskovar and Cantliffe, 1992) and Tabasco pepper (Sundstrom *et al.*., 1984) plants established by transplanting usually are equal to or greater than yields from plants established by direct seeding. According to Schultheis, Cantliffe, Bryan and Stoffella (1988) transplanted tomato (*Lycopersicon esculentum* Mill.) and pepper crops matured earlier than seeded crops and out-yielded them when grown under conditions of environmental stress. However, under more optimal conditions yields improved with direct seeding.

Seed trays are also used to raise seedlings. These are portable and compact miniature seedbeds that are in the form of trays. They are also known as speedling trays or flats. They are made from very light materials like polystyrene, styrofoam or kaylite and are rectangular in shape. Each tray has several individual cells in which the seed is sown. Seed trays are very expensive (Schultheis *et al.*, 1988) but have less wastage thus saving on the cost of seed especially when using F_1 seed, which is very expensive. Seedling roots are not damaged during transplanting when seedlings are raised in trays (Schultheis *et al.*, 1988). The use of seed trays under SH conditions has not been documented but they are extensively used in commercial agriculture in Zimbabwe. The widely used method of establishing paprika seedlings in the SH is using nurseries.

2.2 **Effect of nursery practices on seedling vigour, crop establishment and yield of paprika.**

All of the paprika grown in the smallholder-farming sector in Zimbabwe is raised in the nursery (Agritex, 2000). The various nursery practices like seed spacing, watering, hardening, disease and pest management, transplanting techniques, and fertility management affect the quality of seedlings and their rate of recovery after transplanting (Aloni, Pashkar, and Karni, 1991a). Some of the identified practices that could lead to poor crop establishment are use of very high seedling density in the seedbed, inadequate hardening, inappropriate plant spatial arrangement in the field and application of inadequate fertiliser.

2.2.1 **Seedling density in the nursery**

Spacing has an effect upon the growth and development of plants in the nursery. Plants, either in the seedbed or trays must be spaced far enough apart so that they can grow in an unrestricted manner (Davidson, Mecklenburg and Peterson, 1988). Bar-Tal, Bar-Yosef and Kafkafi (1993), working with pepper seedlings in speedling trays, concluded that high seedling densities in the nursery led to small seedlings and poorly developed root systems. Increasing seedling density from 6 to 13 and 40 per 100 cm^2 decreased shoot dry weight from 0.3 g to 0.2 and 0.08 g per seedling respectively (Bar-Tal *et al.*, 1993).

Informal interviews with smallholder farmers and our own observations in CRA revealed that extension staff from both Agritex and companies dealing in paprika have recommended row spacing of 5 cm with about 100 seeds equally spaced per metre row giving a seedling density of about 1500 plants m^{-2}. This was thought to be a very high and undesirable seedling density as it led to the production of visibly weak seedlings that cannot withstand stress thereby resulting in high mortality in the field. Since paprika is a relatively new crop even extension workers do not have much information on its production practices that would have enabled them to advise farmers accordingly (J. Kwaramba[1], 2000 - *personal communication*). The possible solution to this problem is thought to be reducing seedling density in the nursery.

2.2.2 **Hardening treatment**

In many parts of the world, pepper seedlings are established in the field by transplanting.

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Transplanting shock occurs because field conditions are often more stressful than those of the nursery. To reduce the impact of transplanting shock on the final yield and harvest maturity, seedlings are hardened by withholding nutrients or drought stress, which inhibits excessive growth and increase seedling uniformity (Aloni, Daie and Karni, 1991b). Hardening is a process whereby seedlings are introduced to harsh environmental conditions so that they can withstand stress on transplanting. Seedlings are subjected, after transplanting, to periods of dehydration in the open field, particularly under conditions of high evapotranspiration. Under such conditions seedlings have reduced growth rates (transplant shock) (Aloni *et al.*, 1991b). In tobacco production in Zimbabwe, hardening is done for at least two weeks prior to transplanting. Watering is stopped completely and only started when seedlings show signs of wilting before 10 a.m. A single watering of two to three times the daily requirement is then applied before the hardening process is repeated. This hardening process results in thicker stemmed seedlings with increased levels of stem carbohydrate. Increased carbohydrate levels are important for early root development and growth (Tobacco Handbook, 2000).

In communal area nurseries, hardening essentially involves the withholding of water (Mande, 1998; Agritex, 2000). Garmany and Bates (1957), working with tobacco, pointed out that cutting water off too early leads to the production of too tough seedlings which are slow to start growing again. Water stress during seedling growth affects bell pepper root growth as reported by Leskover and Cantliffe (1992) and Jaimez, Rada and Garcia-Nunez (1999). Their studies showed that continuous watering increased root dry weight, basal root count and diameter compared with alternate watering which caused a decrease in these parameters. Seedlings which have more root dry weight and thicker diameters have greater chances of success after transplanting.

Pretransplant nutritional conditioning (PNC) can also be used to harden seedlings. In this method, nutrients are withdrawn from seedlings to slow growth until transplanting (Aloni *et al.,* 1991a; Dufault and Schultheis, 1994). This method has been successfully used for bell pepper seedlings. The method is usually used in seedling production systems in which high amounts of fertilizers are used in the seedbed and is, therefore, not likely to be of importance in the SH sector where farmers use little or no fertilizers in the nursery.

2.3 **Fertility in the seedbed and after transplanting**.

Nutrient supply, particularly nitrogen (N), influences dry matter partitioning between roots and shoots (Leskover *et al.* 1989). Most of the N studies in pepper have been related to the above ground plant parts (Locascio, Fiskell and Martin, 1981). Leskovar *et al.* (1989) reported that nitrogen stimulated root and shoot growth in five pepper cultivars. Increased nitrogen levels led to increases in shoot and root (tap, basal and lateral) components. Studies by Aloni *et al.* (1991a) showed that nitrogen deficiency induced slow shoot growth but increased root growth. According to these studies, under N stress roots are more competitive sinks for assimilates than are young leaves and meristems.

Post-transplant recovery of N-deficient seedlings was shown to be slow even when sufficient N was supplied after transplanting. Application of optimal N concentrations (100 mg N/liter) to pepper seedlings before transplanting may ensure their rapid reestablishment, recovery and growth in the field (Aloni *et al.* 1991a). Daie, Seeley and Campbell (1979) reported that N-deficient tomato seedling leaves had high abscisic acid concentrations causing leaf fall during the post-transplanting recovery period.

Nitrogen also influences pepper flower and fruit growth and development (Payero and Bhangoo, 1990). Maximum fruit production in "Anaheim chilli" pepper was achieved with N applications as low as 70 kg/ha (O'Sullivan; 1979), 112 kg/ha for Tabasco pepper (Sundstrom *et al.*, 1984) to as high as 224 kg/ha for bell pepper (Locascio *et al.,* 1981). Total and red fruit production in "Anaheim chilli" peppers appeared to be affected more by timing and frequency of N applications than by total seasonal applied N (Locascio *et al.*, 1981; Sundstrom *et al.*, 1984). Total fruit yield was maximised at 240 kg N/ha, while red fruit yield decreased with increasing N for bell pepper (Locascio *et al.*, 1981). Similar results were reported by McCullough, Motes and Kahn (1995) who found that paprika needed 90 kg N/ha for maximum yield compared with 135 kg N/ha in Chile pepper.

Johnson and Decoteau (1996) determined the influence of N and K rates in Hoaglands nutrient solution on jalapeno pepper plant growth and fruit production in sand culture. Biomass and fruit production per plant responded curvilinearly to N rate in both experiments. Biomass, fruit count and fruit weight per plant increased linearly with increased K rate in the first experiment and curvilinearly with K in the second experiment. The plants that received higher nitrogen rates were larger, easier to harvest and withstood multiple harvests. This finding contrasts with the results of Mills and Jones (1979) with bell pepper, Stroehlein and Oebker (1979) with chilli pepper and those of Russo (1996) with jalapeno and banana peppers, which suggested that excessive N stimulated vegetative growth while it reduced flowering. Nitrogen affects fruit pungency in jalapeno peppers. Dihydrocapsaisin levels in the fruit increased as N fertility rate increased. These findings are in contradiction with the suggestion that pungency increases in response to low N (poor soils) (Johnson and Decoteau, 1996).

Babu, Lokeshwar, Rao and Rao (1988) reported that as phosphorus (P) increased from 0 kg P_2O_5 to 65 kg P_2O_5/ha pepper plant height, shoot dry weight and fruit yield increased significantly. Increased calcium applications significantly increased bell pepper fruit yield and reduced sunscald (Alexander and Clough, 1998). Calcium reduces the incidence of blossom end rot (BER) in bell peppers (Alexander and Clough, 1998; Karni, Aloni, Batal, Moreshet, Keinan and Yao, 2000). BER is a physiological disorder linked to localised low Ca levels in fruit tissues.

In a study by Aliyu (2000), application of farmyard or poultry manure at 5 t/ha each, supplemented with 50kg N/ha resulted in significantly higher pepper fruit yield compared with mineral fertilizers. However, high rates of combined organic and mineral fertilisers significantly reduced crop establishment and caused excessive vegetative growth. In another study comparing poultry manure, guano and farmyard manure, Aliyu and Kuchinda (2002) reported that poultry manure and guano were significantly comparable in pepper dry fruit yield and higher than farmyard manure. Chemical composition of fruits was not affected by manure source. Most of these studies were conducted with bell peppers under conditions of adequate moisture. The effects of these same plant nutrients on dryland paprika need to be studied so that appropriate fertilization regimes suitable for the SH sector are developed.

2.4 **Plant spatial arrangement and density in the field**

Several authors have reported that peppers produced fewer fruit per plant but more fruits per hectare as plant density in the field increased whereas fruit size was unaffected. In field experiments conducted in Canada by Jollife and Gaye (1995), bell pepper fruit yield per land area increased with increasing plant population density. Growth and reproductive potential of individual plants were reduced at high population densities but larger plant numbers overcame this. There was no reduction in average weight per fruit at high population densities, perhaps because fruits were collected throughout the study at approximately the same stage of maturity. Increased yield was due to increased number of nodes which itself was due to increased number of plants (Jollife and Gaye, 1995). Similar results were reported for Tabasco pepper (Sundstrom *et al.*, 1984) cayenne pepper (Decoteau and Graham, 1994) and pepperoncini pepper (Motsenbocker, 1996). No related studies have been documented for dryland paprika. Currently, farmers in CRA use various planting arrangements and spacing. Some farmers use the standard inter-row spacing for maize (0.9 m) with either single or double rows per ridge with intra-row spacing ranging between 20 to 30 cm as for maize. Other farmers use the standard inter-row spacing for tobacco (1.2 m) with either single or double rows per ridge with intra-row plant spacing ranging from 54 –64 cm as for tobacco. This means that plant populations for paprika in the CRA range from as low as 14 000 plants/ha to as high as 110 000 plants/ha. The standard planting configuration in the commercial sector is two rows per ridge with ridges spaced at 1.2 m apart and rows on the same ridge spaced either 30 or 40 cm apart. Intra-row plant spacing varies according to target population (Mande, 1998).

CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1 Site selection

A basic prerequisite for a field or site was that it should not have been under crops related to paprika, such as, tobacco or tomatoes, for at least three years prior to the season in which the experiment was to be conducted. This was done to avoid carry-over of disease and pest problems from previous related crops.

3.2 **Planting Materials**

All PapriKing seed was sourced from Paprika Zimbabwe Pvt Ltd, a paprika processing company. Red Tsar was sourced from Hyveld Seed Company. All paprika seed used in this experiment was F_2 seed. PapriKing is a strong well-framed plant, which can be grown under adverse windy conditions and is especially adapted to growing conditions in the northern tropical parts of Southern Africa. The fruit produced by PapriKing is about 15 cm long and has a very low to no pungency. It can be grown in most areas of Zimbabwe and requires rainfall of between 600 – 1250 mm and can perform adequately under rainfed conditions provided that there are no more than two weeks of continuous dry spell. It requires a temperature range of 24 – 30 ^{o}C and temperatures should not exceed 34 ^{o}C during anthesis (Paprika Zimbabwe, 1999). PapriKing is the most popularly grown variety in Zimbabwe and is easily available to farmers in CRA. Red Tsar produces thick walled fruits of about 15 cm long. The variety has no pungency and has been found to give consistent high yields. It combines earliness with uniform and high yields. Yield is improved by multiple pod setting over a long period.

3.3 **Nursery establishment and management**

Beds were dug using hoes and the soil was worked to a fine tilth. To simulate the farmers' practice, brushwood was piled on the beds and burnt to sterilise the soil. Charcoal and ash were raked off and Compound "S" fertiliser (7 N:27 P_2O_5:7 K_2O) at a rate of 1000 kg/ha was evenly broadcast on the beds and incorporated using a hoe. Each row received approximately 100 equally spaced seeds. The distance between rows was 10 cm, where seedling density was not a treatment. Seedlings were thinned to 750 seedlings m^{-2} by physically counting the number of seedling and pulling out the excess. After sowing beds were mulched with seedless grass and watered with a fine rosed can. Beds were kept moist and weed free. Bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*) and powdery mildew (*Leveillula taurica*) were noticed at Chinyudze nursery in 2000/1 and controlled using a mixture of 30g copper oxychloride (a.i copper oxychloride, 850 g/kg) and 30g Dithane M45 (85%WP a.i mancozeb (800 g/kg)) per 15 litres of water.

3.4 **Land Preparation and transplanting**

Fields at all sites were ploughed and ridged using ox-drawn plough. Ridges were 0.9 m apart, 0.15 m high, and 30 cm wide. A basal fertiliser of Compound "L" (5 N;17 P_2O_5;10 K_2O) was banded 10 cm below the ridge at a rate of 1 000 kg per hectare. Transplanting was done at least 8 weeks after sowing (WAS) on receiving adequate rains. Where plant population was not a treatment within ridge spacing was 0.2 m, giving a theoretical plant population of 55 555 plants ha^{-1}.

3.5 **Harvesting and Post harvest handling**

Fruits were picked in a once off harvest in the 2000/1 season. All fruits (red and dry, red and succulent, and green and immature) were picked. In the 2001/2 season fruits were picked twice. In the first picking red and dry fruits were picked. In the second and final picking all fruit types were picked and no fruits were left on the plant. Harvested fruits were dried by placing them directly in the sun (farmer practice) until they attained a moisture content of approximately 10 percent. After drying, calyxes were removed from the fruits and the fruits were graded as marketable and non-marketable and weighed. Grading is done according to visual assessment. Three grades were: A consisting of unblemished, ripe pods of a deep red/purple colour; B consisting of deep orange to red pods. Grade or grade C consisted of pale fruits diseased or pest damaged and mouldy or rotting fruit and this constituted unmarketable fruit.

3.6 **Data Analysis**

Data collected were subjected to two-way analysis of variance to test for significant treatment effects (Snedecor and Cochran, 1980). Where the F-tests were significant the various treatment means were separated using the Least Significant Difference test. Data from the nursery experiment on hardening X seedling density was combined across seasons. Data from the other experiments was not combined across sites or seasons because the variances were not homogenous according to Bartlett's homogeneity of variance test.

3.7 **Rainfall Data**

Rainfall data were collected at Mhiripiri in Chinyika East (Figure 3.1) and Chinyudze in Chinyika

West (Figure 3.2). Rainfall data could not be collected for every site due to lack of reliable personnel and was collected only at Mhiripiri in Chinyika East and Chinyudze in Chinyika West. For sites in Chinyika West the mean rainfall used is that collected at Mhiripiri and for sites in Chinyika East rainfall data collected for Chinyudze are used. During 2000/1 and 2001/2 for both Mhiripiri and Chinyudze, rainfall increased from October to December and decreased in January. Total rainfall at Mhiripiri was 420 mm and 508 mm for 2000/1 and 2001/2 respectively. At Chinyudze, total rainfall was 875 mm, 475 mm, and 556 mm for 2000/1, 2001/2 and 2002/3 respectively.

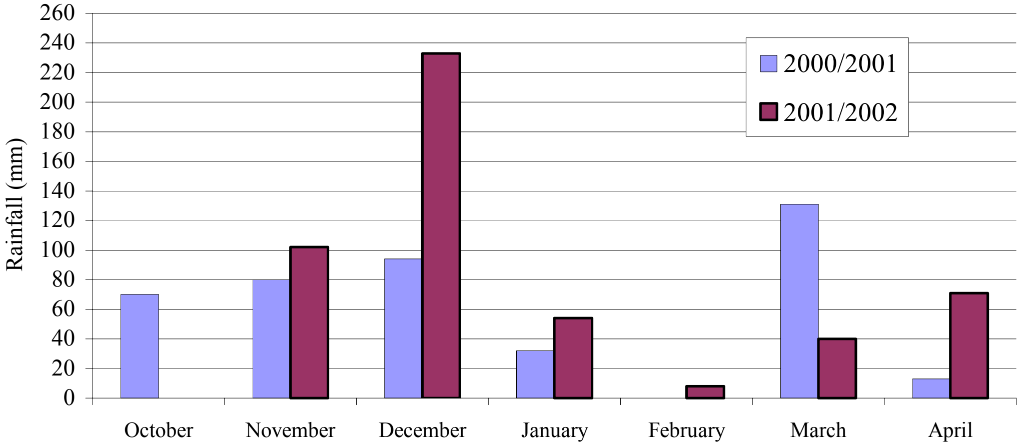


Figure 3.1 Monthly rainfall for the period October to April 2000/1 and 2001/2 at Mhiripiri in Chinyika East Resettlement Area

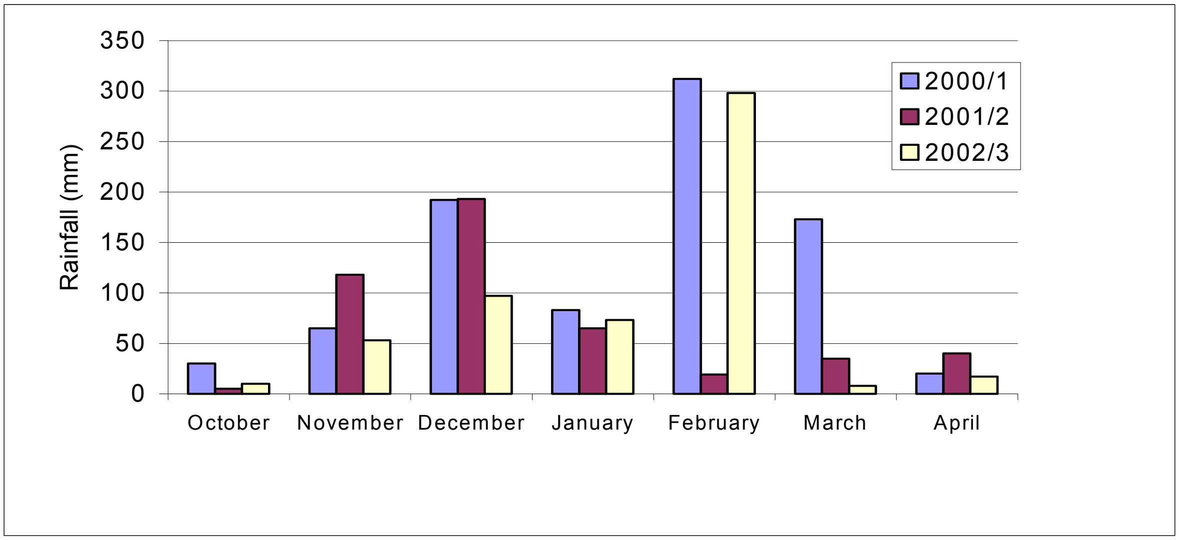


Figure 3.2 Monthly rainfall for the period October to April at Chinyudze in Chinyika West Resettlement Area from 2000 to 2003.

CHAPTER 4

EFFECTS OF SEEDLING DENSITY AND HARDENING TREATMENT ON VIGOUR AND SUCCESS OF FIELD ESTABLISHMENT OF PAPRIKA TRANSPLANTS.

4.1 **Introduction**

Paprika is a horticultural crop that is being grown under dryland conditions in Zimbabwe's SH farming sector. Paprika field establishment rates have been observed to be very low, presumably due to low and unreliable rainfall, the main cause of poor stand establishment in the semi-arid areas of the world (Pae`z, Gonzalez, Yrausquin, Salazaz and Casanova, 1995). In order to minimize the post-transplanting mortality, farmers in the SH sector of Zimbabwe establish their paprika crops using transplants that are raised in nurseries (Agritex, 2000). Nursery practices during the production of transplants have major effects on the quality of seedlings and their rate of recovery after transplanting (Aloni *et al*., 1991b). In the Chinyika Resettlement Area (CRA) poor stand establishment has substantially contributed to low paprika yields. Studies on pepper by Bar-Tal *et al*., (1993) concluded that high seedling density (40 seedlings/100 cm^2) in the nursery led to small seedlings with poorly developed root systems. Presently there are no standard seed spacing recommendations for seedling production in the SH sector. Consequently farmers use high seeding rates similar to those for brassicas and other vegetables. For paprika, the observed seedling density averaged 1500 seedlings m^{-2}. This density seemed to be too high, as the observed seedlings were thin and chlorotic, possibly due to competition for nutrients and light.

After transplanting, seedlings are subjected to periods of dehydration in the open field, and this represents a major stress factor for the transplants. Under such conditions, seedlings have reduced growth rates (Aloni *et al.*, 1991b). Pepper is known to be sensitive to transplanting shock. Transplanting shock occurs because field conditions are often more stressful than nursery conditions. To reduce the impact of transplanting shock seedlings can be hardened by nutritional deficiencies or by drought stress (Aloni *et al.*, 1991b; Dufault and Schultheis, 1994). In the CRA, farmers harden their seedlings by drought stress, that is, by withholding water for about two weeks prior to transplanting. However, it was observed that due to water shortages some farmers commenced hardening much earlier than recommended while other farmers did not harden their seedlings, as the season commenced before the hardening process started. The effect of these variations in management on seedling vigour and success of establishment are not known.

The objective of this experiment was, therefore, to study the impact of seedling density and different hardening methods on seedling vigour and field establishment ability of paprika transplants.

4.2 **Materials and Methods**

Land preparation was done as described in sections 3.3 and 3.4. The nursery experiment evaluated two factors, each at three levels. Three densities were established by varying the distance between furrows as: 5 cm, 10 cm and 15 cm. Seedlings were then thinned by physically counting the number of seedlings and pulling out the excess to densities of 450, 750, and 1500 plants m^{-2} for inter-row spacing of 5 cm, 10 cm, and 15 cm respectively. The three hardening methods were as follows; a) (H0) no hardening: seedlings were watered until date of transplanting, b) (H1) watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely, and c) (H2) water was gradually withheld at the beginning of the fifth week by skipping a day during the fifth week, skipping two days during the sixth and completely withholding water beginning of week seven. Watering was only done when plants showed signs of wilting by 10:00am. The experiment in the nursery was a randomised complete block design with treatments arranged as a split plot with hardening as the main plot factor for ease of management. In the field, the trial was arranged as a split plot with four replications with hardening method as the main plot factor and seedling density as the subplot factor. Each field plot had 6 rows of paprika, 7 m long and each net plot had 4 rows, 6 m long.

Data on seedling vigour were collected on 10 seedlings per plot in the nursery 8 weeks after sowing (WAS) and this consisted of seedling shoot dry mass, seedling height and number of leaves. Ten seedlings were randomly selected per plot. Plant height and number of leaves data were collected on standing seedlings and height was measured from ground level to the tip of the uppermost leaf. The seedlings were then cut at ground level and dried in an oven at 70 ^{o}C until they attained a constant mass. They were then weighed and the mass of one seedling was obtained by dividing by ten. Leaf number and height data were also averaged for the ten seedlings.

Field data were collected on plant height, plants per square metre, total and marketable yield and these were collected on the day of final harvest for each site. Fruits were harvested from the net plot area when ripe, graded into marketable and non-marketable fruits before allowing to air-dry.

4.3 **Results**

4.3.1 **Seedling vigour**

The data collected for the two seasons on seedling vigour indices at Chinyudze site are presented in

Table 4.1. The data were pooled over seasons so as to have the minimum number of residual degrees of freedom and also because the variances were homogenous according to Bartlett's homogeneity of variances test. While seedling density significantly ($p<0.01$) affected seedling vigour indices, hardening treatment influenced only seedling height. Hardening treatments had no significant effect on both seedling dry mass and leaf number but significantly influenced seedling height. Watering of seedlings up to transplanting (no hardening) and gradual withdrawal of watering at beginning of the 5th week by skipping a day during that week resulted in greater height of seedlings. Both treatments achieved similar seedling height. Seedlings that were hardened by withholding water for two weeks prior to transplanting were significantly shorter than those that received the two other hardening treatments (Table 4.1). Seedlings were shorter by about 15.0 to 19.5 percent.

Seedling density significantly influenced all the three parameters in that each of them was significantly depressed as seedling density was increased from 450 through 1500 seedlings m^{-2}. Seedling vigour indices were seriously depressed under a very high seedling density such as 1500 seedlings m^{-2}. Such affected seedlings were weak and spindly. Compared to the lowest seedling density, the highest density caused 55.5, 33.3 and 30.8 percent depressions in seedling dry mass, leaf number and height respectively.

Table 4.1. Main effects of hardening and seedling density on paprika seedling vigour 8 weeks after sowing (WAS) at Chinyudze during the 2000/1 and 2001/2 seasons.

Treatment	Dry mass/seedling^{++} (g)	No of^{++} leaves/seedling	Height^{++} (cm)

Hardening			
H0[#]	0.612	8.0	23.9a
H1	0.588	9.0	20.1b
H2	0.591	8.8	23.0a
Significance	ns	ns	**
LSD$_{(0.05)}$	-	-	1.6
Seedling density (seedlings m^{-2})			
450	0.867a	10.2a	26.9a
750	0.539b	8.8b	21.5 b
1500	0.386c	6.8c	18.6c
Significance	**	**	**
LSD$_{(0.05)}$	0.06	0.2	1.7
CV%	15.9	8.2	10.9

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$.

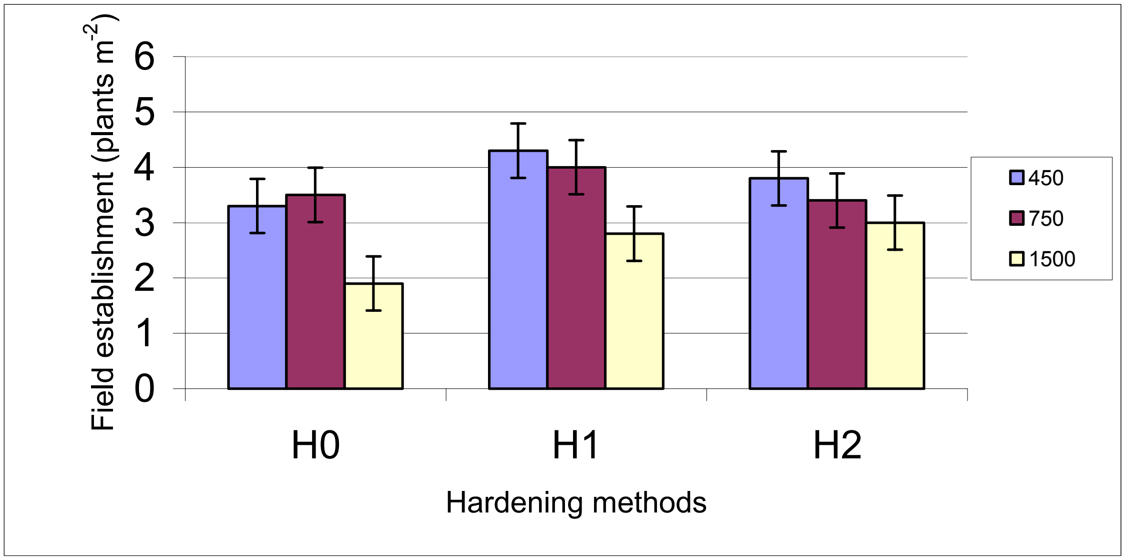
[++] Data pooled for two seasons – 2000/1 and 2001/2

[#] H0 - seedlings well-watered until transplanting, H1- watering stopped two weeks prior to transplanting, H2 - water was gradually withdrawn at beginning of fifth week by skipping a day during the fifth week, two days during the sixth week and completely withdrawing water beginning of week seven.

The three seedling densities were significantly ($p<0.05$) different in their effect on the seedling vigour indices. Seedling density of 450 plants m^{-2} resulted in the highest seedling dry mass, highest number of leaves per plant and the tallest seedlings at the two sites. Seedling density of 1500 plants m^{-2} produced seedlings with significantly ($p<0.01$) low dry mass, shorter plants and least number of leaves. Seedling shoot dry mass, seedling height and number of leaves were strongly negatively correlated with seedling density (r= -0.905; -0.896; -0.866: $p<0.01$ respectively).

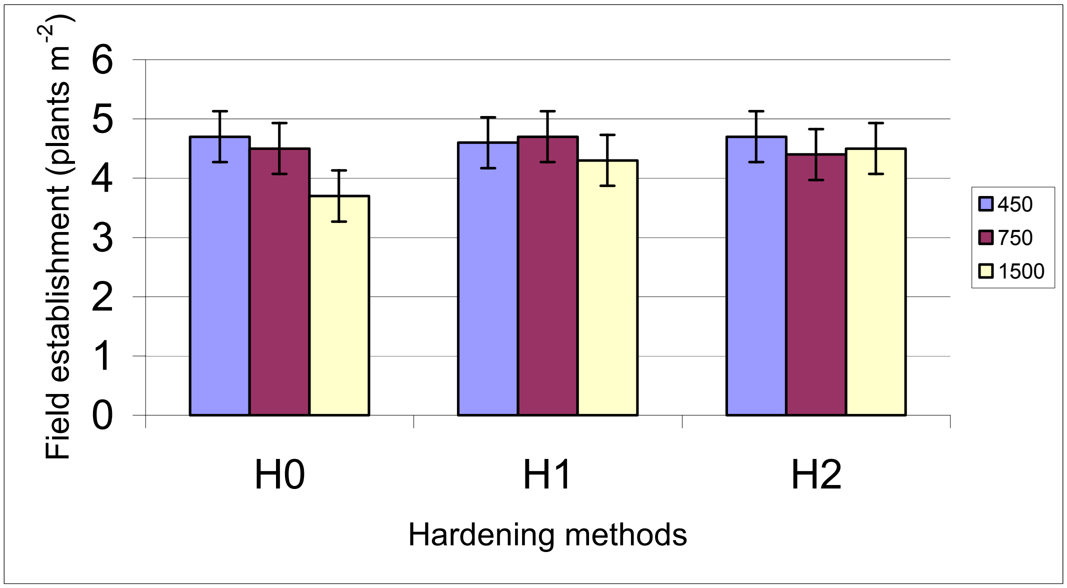
4.3.2 **Field establishment**

Seedling density and hardening treatment interacted significantly ($p<0.05$) to influence field establishment at Chinyudze in 2000/1 (Figure 4.1) and at Dengedza during 2001/2 (Figure 4.2).



H0 - seedlings well-watered until transplanting, H1- watering stopped two weeks prior to transplanting, H2 - water was gradually withdrawn at beginning of fifth week by skipping a day during the fifth week, two days during the sixth week and completely withdrawing water beginning of week seven.

Figure 4.1 Interaction effect of seedling density and hardening treatment on field establishment of paprika at Chinyudze during the 2000/1 season.



H0 - seedlings well-watered until transplanting, H1- watering stopped two weeks prior to transplanting, H2 - water was gradually withdrawn at beginning of fifth week by skipping a day during the fifth week, two days during the sixth week and completely withdrawing water beginning of week seven.

Figure 4.2 Interaction effect of seedling density and hardening treatment on field establishment at Dengedza in 2001/2

At Chinyudze, field establishment was lowest with the no hardening treatment H0 and increased with H1 but declined at H2 for the three seedling densities (Figure 4.1). At Dengedza, field establishment increased consistently from H0 to H2 for 1500 seedlings m^{-2} and was maintained at a high level for all hardening methods for 450 seedlings m^{-2} and increased with H1. It however slightly declined with H2 for the 750 seedlings m^{-2} treatment (Figure 4.2).

4.3.3 **Yield and yield-related parameters**

Nursery seedling density significantly ($p<0.01$) influenced total and marketable yields at Chinyudze only in 2000/1 and at Dengedza in both seasons. Hardening main factor affected yield at Chinyudze only (Table 4.2). At Dengedza, seedling density affected total and marketable yield in both seasons. The highest total and marketable yields were obtained with the lowest nursery seedling density at both sites in both seasons (Table 4.2). The lowest total and marketable yields of paprika fruits came from plants grown under the highest seedling density of 1500 seedlings m^{-2}. Total and marketable yields were negatively correlated ($p<0.01$) with nursery seedling density ($r= -0.578$; -0.543 respectively), thus, high seedling densities were associated with low fruit yields. The hardening main factor influenced both total and marketable yield at Chinyudze with the highest yield being obtained with H1. The lowest yields were obtained with the no hardening treatment (H0). Hardening treatments did not influence paprika yields at Dengedza (Table 4.2).

Table 4.2. Main effects of seedling density and hardening treatment on yield of paprika at

Chinyudze and Dengedza during the 2000/1 and 2001/2 season.

	Chinyudze		Dengedza			
	Total yield (kg ha^{-1})	Marketable yield (kg ha^{-1})	Total yield (kg ha^{-1})		Marketable yield (kg ha^{-1})	
Treatment	2000/1	2000/1	2000/1	2001/2	2000/1	2001/2
Seedling density (seedlings m^{-2})						
450	637a	385a	513a	318a	301a	188a
750	601a	323a	310b	298a	181b	177a
1500	398b	241b	240b	249b	152b	149b
Siginificance	**	**	**	**	**	**
LSD$_{(0.05)}$	115	72	121	72	47	34
Hardening method						
H0$^{\#}$	387b	232b	334a	255a	201	156
H1	662a	416a	381a	294a	218	171
H2	587a	301b	348a	316a	216	186
Significance	**	**	ns	ns	ns	ns
LSD$_{(0.05)}$	102	46	-	-	-	-
CV%	24.6	26.4	39.9	19.0	39.7	23.2

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$.

$^{\#}$H0 - seedlings well-watered until transplanting, H1- watering stopped two weeks prior to transplanting, H2 - water was gradually withdrawn at beginning of fifth week by skipping a day during the fifth week, two days during the sixth week and completely withdrawing water beginning of week seven.

4.4 Discussion

According to the vigour indices that were used in this study, stockier and more vigorous seedlings were produced as seedling density was reduced from 1500 to 450 seedlings m^{-2}. Intra-specific competition, which prevailed under a high seedling density, resulted in significant loss in seedling vigour, which was much more pronounced in the case of seedlings that were raised at a density of 1500 plants m^{-2}. Similarly, field establishment also increased significantly as nursery seedling density decreased from 1500 to 450 seedlings m^{-2}. Thus the high seedling density produced weak seedlings that subsequently had high mortality when transplanted hence very low establishment rates. It is noteworthy that although there were significant differences in field establishment due to seedling density, the highest establishment for Dengedza in 2000/1 was much lower than for 2001/2. This could be attributed to low and unevenly distributed rainfall that prevailed that season. Transplanting was delayed for two weeks due to inadequate soil moisture for transplanting and consequently seedlings became overgrown. Large and old seedlings have been reported to lose more roots at transplanting and have also been shown to have low root replacement rates after transplanting (Loomis, 1925). Such seedlings have a much lower potential to withstand transplanting shock in the field.

In the 2000/1 season transplanting was done after only 4 mm of rain in expectation of more rain. However, there was no follow up rain for five days after transplanting when only 10mm of rain fell. Until the day of assessment of field establishment (4 weeks after transplanting (WAT)) rain had fallen on six other occasions and was very little in amounts. From the foregoing, it can be seen that the weather was not very favourable such that field establishment was very low due to high mortality caused by moisture stress after transplanting. Plants that are transplanted under unfavourable conditions of humidity and soil moisture are subject to a rapid wilting which may prove fatal. Those plants which escape death by wilting will be subjected to a slower drying until the new root system becomes established (Loomis, 1925).

The significant interactions suggest that the effects of hardening treatment, although not apparent in the hardening main factor, were present and of a permanent nature as suggested by Delfine, Loreto and Alvino (2001). Also, the observed significant seedling density x hardening interactions for field establishment suggest that different seedling densities might require different hardening techniques. Generally, stand establishment and total yield were least with no hardening treatment and were highest with hardening method H1 for all seedling densities. According to Squire (1990) the intercellular moisture necessary to maintain life is less strongly held in plants which are not hardened, and with the great reduction in water supply following transplanting the older leaves and in some cases the entire plant might be killed by drying.

There are several explanations that can be given for the non-significance of the hardening main effect on seedling vigour and agronomic parameters such as yield at Dengedza. The administration of the drought stress regimes only began in the fifth week after sowing. Prior to that, all nursery treatments were subjected to the same management. All seedlings were raised in an open nursery exposed to direct sunlight. It is possible that these seedlings were hardened by exposure to high temperature even though they may have been well-watered. The seedbeds were established during September and October, which incidentally are very hot months. By the time the hardening regimes commenced all the seedlings were already well hardened and the withholding of water may have been just additional hardening. Also, the nurseries were farmer managed for the first five weeks after sowing and due to water shortages the farmers could not provide adequate water to the seedlings thus causing moisture stress. It was observed that even after watering in the morning, evaporation was very high such that a few hours after watering the seedbeds were dry and the plants already wilting. The nurseries were only watered once a day, usually not to field capacity, and on other days were not watered. It is thus most likely that by the time the hardening regimes commenced, all the seedlings in all treatments had gone through some degree of hardening. The continuous watering for the no hardening treatment and the alternate watering and drought stress treatments after five weeks may not have been able to reverse the effects of temperature and drought stress hardening already imparted to the seedlings by previous management. Severe drought stress may impair many plant functions but the main effect is reduction of carbon fixation. This, in turn, may differentially affect plant growth and production depending on many variables such as the length of the stress and the vegetative status of the crop (Delfine, Loreto and Alvino, 2001).

In their study, Delfine *et al.* (2001) suggested that mild drought stress over the first part of the vegetative cycle of bell pepper does not impair plant growth and may even be useful to improve yield of early fruit. Fruit dry weight was even higher in rain-fed plants compared to irrigated plants until drought stress and photosynthesis became permanent. The reduction in photosynthesis due to drought stress became permanent as the bell pepper plants aged. These findings suggest that under field conditions the photosynthetic apparatus of bell pepper plants is resistant to drought stress episodes at least during the first phase of growth when photosynthesis inhibition is overcome. In older plants, photosynthesis limitations become permanent. Photosynthesis limitations reduce plant growth but may not necessarily decrease fruit yield if the stress is transient or occurred much earlier in the life of the plant. In this present study, paprika plants were subjected to drought, light and temperature stresses from the seedbed stage up to the field. It is possible that under such conditions photosynthesis limitations became permanent and therefore the yield potential of paprika was reduced as had been suggested by Delfine *et al.,* (2001). In another study, Katerji, Mastrorilli and Hamdy (1993) investigated the effects of water stress occurring at various stages during the growth cycle of peppers under greenhouse conditions. The water stress was applied to four phenological stages: vegetative growth, flowering, fruit setting and fruit formation. They reported that the early fruit setting stage was the most sensitive to drought stress.

4.5 **Conclusions and Recommendations**

1. As seedling density in the seedbed increases from 450 to 1500 seedlings m^{-2} seedling shoot dry mass, height, and number of leaves decreased significantly, that is, seedling vigour is greatly reduced at high nursery densities. Increasing seedling density from 450 to 1500 m^{-2} leads to drastic reduction in paprika transplant establishment capability. This study has shown that 1500 seedlings m^{-2} is not a desirable density in view of the weak seedlings produced whereas 750 seedlings m^{-2} appears to be a good density and it is recommended that SH farmers adopt it.

2 Seedling density and hardening treatment interact to influence establishment ability of paprika. Even at the highest density, field establishment increased with increased exposure to drought stress in the seedbed. Thus seedling vigour can be increased by exposure to drought stress. However, moderate hardening (H1) appeared to be the best method for all seedling densities. This is the method currently being used by farmers and it is recommended that they continue using this method.

CHAPTER 5

EFFECTS OF HARDENING METHOD ON FIELD ESTABLISHMENT AND YIELD OF TWO PAPRIKA CULTIVARS

5.1 **Introduction**

Hardening is the process whereby seedlings are introduced to stressful conditions during their production so that they will be able to withstand post transplanting shock. In paprika production in Zimbabwe, hardening is achieved through drought stress. The recommended practice is to continuously harden seedlings by withholding water in the last two weeks prior to transplanting (7th and 8th weeks). It was gathered through informal surveys that most farmers do not adhere to this hardening regime, but instead subject their seedlings to alternate watering and hardening. Research on the response of different paprika cultivars to alternate watering and hardening treatment has not been done in Zimbabwe. The objective of this study therefore, was to compare the response of two paprika cultivars to alternate watering and hardening regimes compared with continuous hardening prior to transplanting.

5.2 **Materials and Methods**

During the 2000/1 season a field trial was conducted at the University of Zimbabwe research farm. Prior to field establishment, paprika seedlings were raised in flat trays in a greenhouse, with sowing being done on 7 November 2000. Compound “S” (7 N:27 P_2O_5:7 K_2O) fertiliser was applied to the trays at a rate of 1kg 10 m^{-2}. Two paprika cultivars, namely, PapriKing and Red Tsar were used. The six hardening methods that were compared are as follows:

H0 – Seedlings well watered until the day of transplanting.

H1 – watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely.

H2 – Water gradually withheld at the beginning of the 5th week by skipping a day during the 5th week, skipping 2 days during the 6th week and then completely withhold watering beginning of the 7th week. Watering was only done when plants showed signs of wilting by 10:00 a.m.

H3 – No watering in the 5th and 7th and watering resumed in the 8th week until transplanting

H4 – No watering in the 6th and 7th week only.

H5 – Water withheld from the fifth week until transplanting and only applied when seedlings showed signs of wilting by 10:00 a.m.

Where transplanting could not be done exactly at the end of the 8th week after sowing, the treatment administered to the seedlings during the 8th week was continued until transplanting could be eventually done. After field preparation, transplanting of seedlings onto the field was done on 22 January 2001, i.e. 10 weeks after sowing (WAS). Treatments were factorial combinations of two paprika cultivars and six hardening methods laid out in randomised complete block design with three replications. Transplanting was done when the soil was moist, on ridges that were 0.9 m apart and intra-row spacing was 0.2 m. A top dressing of potassium chloride (60%) K_2O at a rate of 350 kg/ha was applied at 31 days after transplanting (DAT) but no ammonium nitrate was applied because it was not available. The trial was sprayed with a mixture of 30g copper oxychloride (a.i copper oxychloride, 850 g/kg) and 30g Dithane H45 (85%WP a.i mancozeb (800 g/kg)) per 15 litres of water at 30 and 64 DAT to control bacterial leaf spot *(Xanthomonas campestris* pv *vesicatoria*). The trial was hoe-weeded twice, at 17 and 33 DAT. Plant establishment was assessed 4 WAT by counting the number of plants per net plot. Average fruit length was determined by sampling 5 representative fruits per plot.

In the 2001/2 season the trial was conducted at Mukada farm in Chinyika West. Sowing was done on 17 September 2001 and transplanting was done on 6 December 2001 (11 WAS). Weeding was done twice at 21 and 38 DAT. Ammonium nitrate and potassium chloride were applied 42 DAT each at a rate of 350 kg per hectare. No spraying against pests and diseases was done. Harvesting was done once on 31 March 2002 for the University of Zimbabwe experiment and twice at 150 and 197 DAT for the Mukada experiment. During the first harvest only red and dried fruits were picked. During the second and final harvest all fruit types (red and dry, red and succulent and green and unripe) were picked. Harvested paprika fruits were processed by allowing them to air-dry and then graded and classified into categories of marketable and non-marketable fruit before weighing.

5.3 **Results**

5.3.1 **Field establishment**

Hardening and cultivar treatments did not influence field establishment in both seasons (Tables 5.1 and 5.2).

Table 5.1. Main effects of hardening method and cultivar on yield and field establishment

at the University of Zimbabwe farm in 2000/1 season.

Treatment	Total yield kg/ha	Marketable yield kg/ha	Field establishment plants m^{-2}
Hardening method			
H0[#]	1561	1058	3.3
H1	1668	1099	3.9
H2	1460	970	3.5
H3	1460	949	3.3
H4	1383	878	3.3
H5	1507	938	3.4
Significance	ns	ns	ns
Cultivar			
PapriKing	1477	920	3.3
Red Tsar	1536	1043	3.5
Significance	ns	ns	ns
CV%	33.2	38.6	27.8

ns = difference between means not significant at $p<0.05$

[#] H0 – Seedlings well watered until the day of transplanting, H1 – watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely, H2 – Water gradually withheld at the beginning of the 5th week by skipping a day during the 5th week, skipping 2 days during the 6th week and then completely withhold watering beginning of the 7th week. Watering was only done when plants showed signs of wilting by 10:00 a.m, H3 – No watering in the 5th and 7th and watering resumed in the 8th week until transplanting, H4 – No watering in the 6th and 7th week only, H5 – Withhold water from the fifth week until transplanting and only applied when seedlings showed signs of wilting by 10:00 a.m.

Table 5.2. Main effects of hardening method and cultivar on paprika yield and field

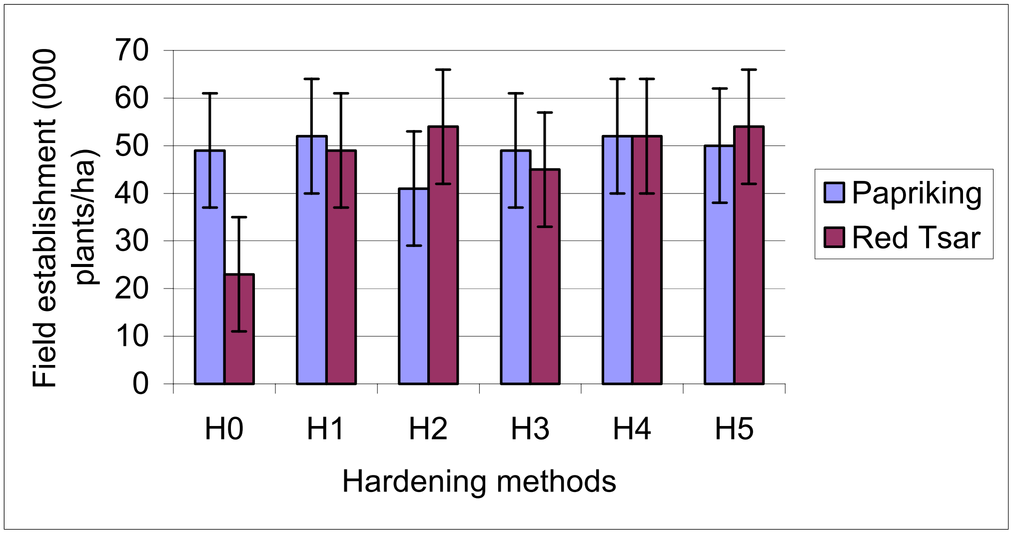
establishment at Mukada farm in 2001/2 season.

Treatment	Total yield kg/ha	Marketable yield kg/ha	Field establishment plants m^{-2}
Hardening method			
H0[#]	420	277	2.5
H1	489	267	3.5
H2	559	307	3.4
H3	485	371	3.3
H4	636	390	3.7
H5	671	367	3.7
Significance	ns	ns	ns
Cultivar			
PapriKing	553	331	3.4
Red Tsar	534	329	3.3
Significance	ns	ns	ns
CV%	28.0	28.8	20.6

ns = difference between means not significant at $p<0.05$

[#] H0 – Seedlings well watered until the day of transplanting, H1 – watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely, H2 – Water gradually withheld at the beginning of the 5th week by skipping a day during the 5th week, skipping 2 days during the 6th week and then completely withhold watering beginning of the 7th week. Watering was only done when plants showed signs of wilting by 10:00 a.m, H3 – No watering in the 5th and 7th and watering resumed in the 8th week until transplanting, H4 – No watering in the 6th and 7th week only, H5 – Withhold water from the fifth week until transplanting and only applied when seedlings showed signs of wilting by 10:00 a.m.

However, there were significant interactions of cultivar x hardening methods in the 2001/2 trial that was conducted at Mukada in CRA (Figure 5.1). Cultivar Red Tsar was far more susceptible to lack of hardening with respect to field establishment of paprika, which was only slightly above 20 000 plants per hectare. Cultivar PapriKing was able to maintain a good field establishment even in the absence of seedling hardening. While not watering of seedlings in the 5th and 7th weeks was somewhat detrimental to field establishment in PapriKing, that hardening treatment was actually of benefit to Red Tsar. The other hardening methods seemed to have performed equally well for both cultivars with respect to their effects on field establishment.

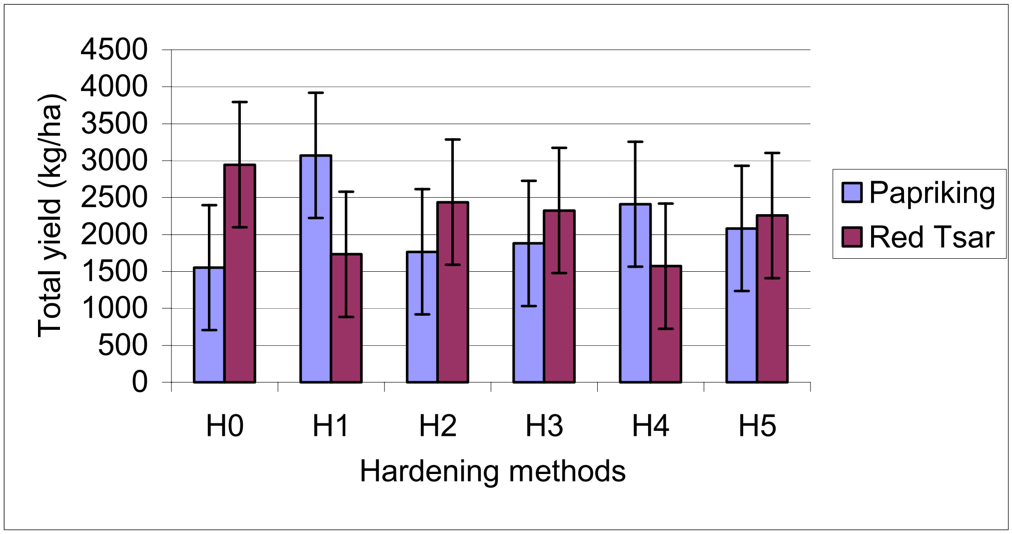


H0 – Seedlings well watered until the day of transplanting, H1 – watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely, H2 – Water gradually withheld at the beginning of the 5th week by skipping a day during the 5th week, skipping 2 days during the 6th week and then completely withhold watering beginning of the 7th week. Watering was only done when plants showed signs of wilting by 10:00 a.m, H3 – No watering in the 5th and 7th and watering resumed in the 8th week until transplanting, H4 – No watering in the 6th and 7th week only, H5 – Withhold water from the fifth week until transplanting and only applied when seedlings showed signs of wilting by 10:00 a.m.

Figure 5.1. Interaction effect of hardening method and cultivar on paprika field establishment at Mukada during the 2001/2 cropping season.

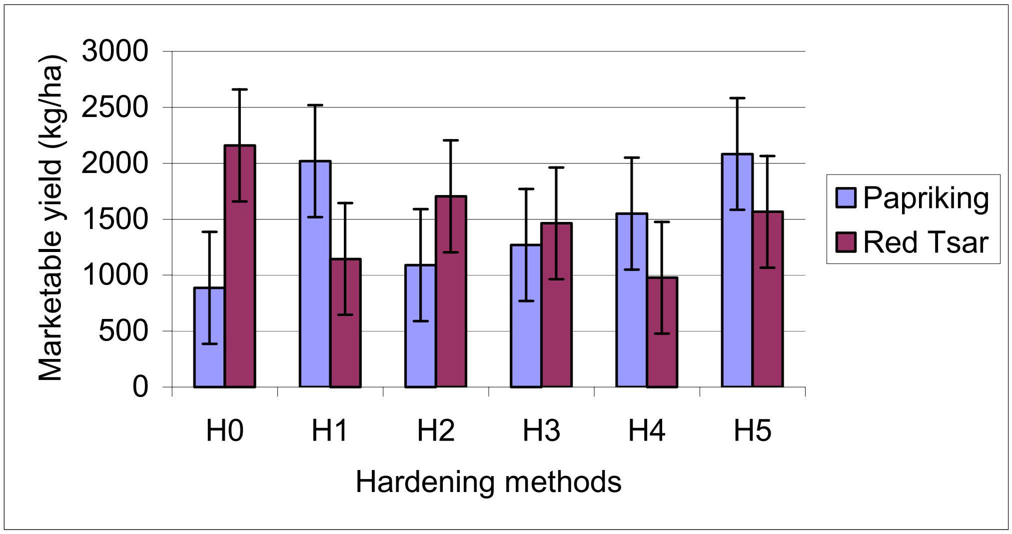
5.3.2 **Yield and yield-related parameters**

Although there were no significant yield differences due to hardening and cultivar main effects, there were significant interactions ($p<0.05$) between hardening and cultivar on both total (Figure 5.2) and marketable yield (Figure 5.3).



H0 – Seedlings well watered until the day of transplanting, H1 – watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely, H2 – Water gradually withheld at the beginning of the 5th week by skipping a day during the 5th week, skipping 2 days during the 6th week and then completely withhold watering beginning of the 7th week. Watering was only done when plants showed signs of wilting by 10:00 a.m, H3 – No watering in the 5th and 7th and watering resumed in the 8th week until transplanting, H4 – No watering in the 6th and 7th week only, H5 – Withhold water from the fifth week until transplanting and only applied when seedlings showed signs of wilting by 10:00 a.m.

Figure 5.2. Interaction between hardening treatment and cultivar on total pod yield of paprika at the University Farm in 2000/1



H0 – Seedlings well watered until the day of transplanting, H1 – watering of seedlings was stopped two weeks prior to transplanting. They were only given survival irrigation when they wilted severely, H2 – Water gradually withheld at the beginning of the 5th week by skipping a day during the 5th week, skipping 2 days during the 6th week and then completely withhold watering beginning of the 7th week. Watering was only done when plants showed signs of wilting by 10:00 a.m, H3 – No watering in the 5th and 7th and watering resumed in the 8th week until transplanting, H4 – No watering in the 6th and 7th week only, H5 – Withhold water from the fifth week until transplanting and only applied when seedlings showed signs of wilting by 10:00 a.m.

Figure 5.3. Interaction between hardening treatment and cultivar on marketable yield of paprika at University farm in 2000/1.

When no hardening was done, Red Tsar produced about twice the total and marketable yields of PapriKing. However, with hardening method H1 (withholding water during the last two weeks prior to transplanting), which is the presently recommended practice, PapriKing produced about double the total and marketable yield of Red Tsar (Figures 5.2 and 5.3). With hardening methods H2 and H3 Red Tsar produced slightly higher total and marketable yields than PapriKing whilst PapriKing produced more marketable yields with hardening methods H4 and H5.

5.4 **Discussion**

The two main factors in this study, that is hardening method and cultivar, did not reflect any significant differences in terms of field establishment. Since transplanting causes the interruption of soil-root contact, root injury and post transplant shock, PapriKing and Red Tsar seedlings could have been similarly affected. It is also a common observation that after transplanting, the transplants are affected by transplanting shock. The length of time until the resumption of rapid growth depends on environmental conditions but is also an inherited feature of each crop (Aloni *et al*., 1991b). It appears that different crops have different capabilities to recover from transplanting shock and this is highly dependent on their ability to withstand root disturbance (Loomis, 1925). Trends in the current study suggest that interactions between the two cultivars and the hardening methods may be more important than the main effect with respect to field establishment. When seedlings were well-watered up to transplanting time, PapriKing, the widely available cultivar in Zimbabwe, performed much better than Red Tsar. Field establishment of PapriKing was more than twice that of Red Tsar. However, the two cultivars performed similarly with respect to field establishment when subjected to the other five moisture stress regimes. This result suggests that Red Tsar field establishment is enhanced under moisture stress. On the other hand, PapriKing is a stable cultivar, which does not drastically respond to changes in management techniques during the production of seedlings.

The almost consistent performance of the two cultivars when subjected to some form of hardening (mild or extreme) makes both of them useful to smallholder (SH) farmers where water is constraint during the production of seedlings. In the SH sector, seedlings are invariably subjected to temperature and moisture stress during the production period. Paprika cultivars that would positively respond to stress or those cultivars whose performance remains stable after being stressed would be most ideal for the SH farmers.

Besides the pre-transplant moisture stress regimes administered in the nursery, the two cultivars could also have been subjected to reasonably high temperature in the seedbed and both temperature and moisture stress in the field after transplanting, especially during the 2001/2 season at Mukada, where there was no supplementary irrigation. This continued stress could explain the drastic reduction in total and marketable yields at Mukada in 2001/2 when compared with the University of Zimbabwe trial, which was supplemented with irrigation.

5.5 Conclusions and Recommendations

1. Red Tsar is more susceptible to post-transplant stress and has higher mortality when the seedlings are not hardened.
2. Farmers need to moderately harden paprika seedlings by withholding water in the last two weeks to impart some resistance to drought stress.
3. PapriKing is recommended in the event that the farmer has no time to harden his/her seedlings.

CHAPTER 6

EFFECTS OF PLANT POPULATIONS AND PLANT SPATIAL ARRANGEMENTS ON

PAPRIKA YIELD PERFORMANCE

6.1 Introduction

Knowledge of crop response to population density is useful for management decisions and it provides the basis for assessing the effects of intraspecific competition. Elsewhere, plant density is known to influence fruit yield in paprika. In experiments conducted and reported by Jolliffe and Gaye (1995), high population densities in the range 150 000 to 200 000 plants/ha enhanced total fruit yield in bell pepper. Fruit yield per land area increased with increasing population density. Reports by Motsenbocker (1996) indicated that high plant densities led to increased pepperoncini pepper yield per land area although fruit yield per plant declined. Growth and reproductive potential of individual plants were reduced at high population densities but large plant numbers overcame this as also reported by Decoteau and Graham (1994).

Also, plant spatial arrangement influences pepper yield and quality of some pepper types. The study by Decoteau and Graham (1994) showed that plant density and plant arrangement (number of rows per ridge) influenced cayenne pepper plant dry weight, stem diameter and plant width. The highest plant dry weight and thickest stems were produced on plants in the widest in-row spacing (0.85 m X 0.45 m) and one row of plants per ridge.

The number of rows per bed and in-row plant spacing affected red fruit and total fruit yields. As in-row plant spacing increased from 15 to 60 cm, red, green and total fruit yield per plant increased linearly. Red, green and total fruit production per hectare decreased as in-row plant spacing decreased. As number of rows per bed increased from one to two rows, red and total yield per plant decreased.

However, in Zimbabwe SH farmers, as reported by CRA farmers, grow their paprika in either single or double rows on ridges. The two rows per ridge arrangement was developed for mechanically harvested pepper in which the distance between ridges is 1.2 m to facilitate the use of tractors and other machinery for spraying and harvesting operations. It is not clear whether this two-ridge planting arrangement is of any benefit to SH farmers with respect to paprika yield and quality. The objective of this experiment was to compare performance of paprika at different plant densities with either the one or double row per ridge arrangement under dryland conditions.

6.2 **Materials and Methods**

The experiment had two factors: plant arrangement with two levels (one or two rows per ridge) and plant population with four levels (35 000, 50 000, 65 000 and 80 000 plants/ha) which made up the treatments in factorial combinations in randomised complete block design, replicated four times. Plants were arranged either as one row per ridge or as two rows per ridge according to treatments. There were four plant populations obtained by varying the in-row plant spacing as follows:

1) 35000 plants per hectare (31.7 cm and 63.4 cm in-row for single row and two rows per ridge respectively)
2) 50000 plants per hectare (22.2 cm and 44.4 cm in-row for single row and two rows per ridge respectively)
3) 65000 plants per hectare (17 cm and 34 cm in-row for single row and two rows per ridge

respectively)

4) 80000 plants per hectare (13.8 cm and 27.6 cm in-row for single and two rows per ridge respectively)

Spacing between ridges was constant at 0.9 m. Where there were two rows per ridge, the rows were 0.1 m apart.

The experiment was conducted over three seasons, 2000/1, 2001/2 and 2002/3, at two sites each season. During the 2000/1 season it was conducted at Masunda site in Chinyika East and Mugadza School in Chinyika West. However, at Masunda cattle and baboons destroyed the experiment before records were taken so no results are available for this site. Transplanting was done on 28 December 2000 at both sites but almost all the transplants died due to drought stress. Re-transplanting was done on 31 January 2001. Weeding was done at 16 and 46 days after transplanting (DAT). Ammonium nitrate was applied at a rate of 350 kg/ha as a single dose. No disease control was done in 2000/1. Harvesting of fruits was done on 10 May 2001 and all fruits, that is, ripe and unripe, were harvested at once. The seed used in all the trials was that of cultivar PapriKing.

During the 2001/2 season, the experiment was conducted at two sites, namely, Mugadza in Chinyika West and Chikodzo in Chinyika East. At Mugadza transplanting was done on 23 November 2001. Weeding was done twice, at 34 and 57 DAT. A mixture of 30g copper oxychloride (a.i copper oxychloride, 850 g/kg) and 30g Dithane M45 (85 %WP a.i mancozeb (800 g/kg)) per 15 litres of water was sprayed as a curative spray to control bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*) in all plots. Harvesting was done twice on 1 March 2002 and finally on 29 March 2002.

Apart from fruit yield data, the other records taken were number of fruits per plant, plant height and number of plants per net plot. At Chikodzo transplanting was done 18 December 2001. Weeding was done only once, at 30 DAT. No disease and pest control measures were applied on the trial. Harvesting was done on 30 March 2002.

In the 2002/3 season transplanting was done on 12 December 2002 at Kunyongana and 15 December 2002 at Sanhi. AN top dressing was applied on 5 February 2003 at a rate of 350 kg/ha. First harvesting was done on 27 March 2003 and the final one on 17 April 2003. The harvested fruits in all cases were allowed to air-dry and then graded into marketable and non-marketable categories before weighing. Other parameters recorded were total and marketable yield per plant, number of fruits per plant, plant height and mean fruit mass.

6.3 **Results**

For all three seasons, the results for only one site per season are presented here. This is because cattle destroyed the trial in the second site (Masunda) for 2000/1 by grazing the crop before harvest data could be collected. The second sites for 2001/2 (Chikodzo) and for 2002/3 (Sanhi) were affected by drought and there was severe mortality and no meaningful data could be collected either.

Variations in plant population significantly influenced total fruit yield per hectare at Mugadza in the 2000/1 and 2001/2 seasons (Tables 6.1 and 6.2). As plant population was increased from 35 000 plants per hectare total fruit yield per hectare increased significantly up to 65 000 plants per hectare but declined as plant population was increased to 80 000 plants per hectare in the 2000/1 season.

Table 6.1. Main effects of plant population and number of rows per ridge on paprika yield at Mugadza in the 2000/1 season

Treatment	Fruit Yield (kg/ha) Total	Fruit Yield (kg/ha) Marketable	Total fruit yield (g/plant)	Number of Fruits/plant
Plant population (plants/ha)				

35 000	578c	265	12.4ab	6.9c
50 000	703b	357	13.1ab	8.3bc
65 000	952a	393	14.7a	10.0a
80 000	726b	311	9.7b	9.0ab
Significance	*	ns	*	**
$LSD_{(0.05)}$	222	-	3.3	1.5
Number of rows per ridge				
single-row	642b	312	12.1	7.6b
double-row	838a	350	12.9	9.4a
Significance	*	ns	ns	**
$LSD_{(0.05)}$	157	-	-	1.1
CV%	28.8	33.2	25.2	17.1

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$.

Significant response to plant population increase was up to the highest plant population, that is, 80 000 plants per hectare in the 2001/2 season (Table 6.2). The percent total yield difference between 35 000 and 65 000 plants per hectare in 2000/1 season was 64.8% increase. The percent increase in total yield between 35 000 and 80 000 plants per hectare in 2001/2 season was even higher, 82.2%. Marketable yield responded more to plant population increase in the 2000/1 season than in the season following that. In the 2000/1 season, marketable yield increased by 48.1% when plant population was increased from 35 000 plants per hectare to 65 000 plants per hectare.

Total yield per plant and pods per plant responded significantly ($p<0.05$) to variations in plant population in 2000/1 season (Table 6.1). The two parameters responded significantly to increase in plant population up to 65 000 plants per hectare in 2000/1. Any increase in plant population beyond 65 000 plants per hectare caused a decline in yield per plant and plant height. In the case of the 2001/2 season, number of fruits per plant and plant height did not respond to variations in plant population (Table 6.2). There was a significant correlation between plant population and total and marketable yield at Mugadza in 2001/2 season ($r=0.6;p<0.05$, $r=0.5;p<0.05$ respectively).

Table 6.2. Main effects of plant population and number of rows per ridge on yield and number of fruits per plant at Mugadza in the 2001/2 season

	Fruit Yield (kg/ha)		
Treatment	Total	Marketable	Number of Fruits/plant
Plant population (plants/ha)			

35 000	286c	162	6.4
50 000	343bc	193	5.9
65 000	409b	210	4.9
80 000	521a	272	4.1
Significance	**	ns	ns
LSD$_{(0.05)}$	109	-	-
Number of rows per ridge			
single-row	392	201	5.1
double-row	386	218	5.5
Significance	ns	ns	ns
LSD(0.05)	-	-	-
CV%	26.9	31.6	35.8

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0$.

Plant arrangement significantly influenced total yield per hectare in 2000/1-season and plant height in the 2001/2 season. The double-row plant arrangement outyielded the single-row by some 30.5%. Plants were slightly, though significantly, taller under the single-row arrangement in the 2001/2 season.

There was a significant ($p<0.05$) interaction between plant population and plant arrangement for plant height at Mugadza site in 2000/1 (Figure 6.1).

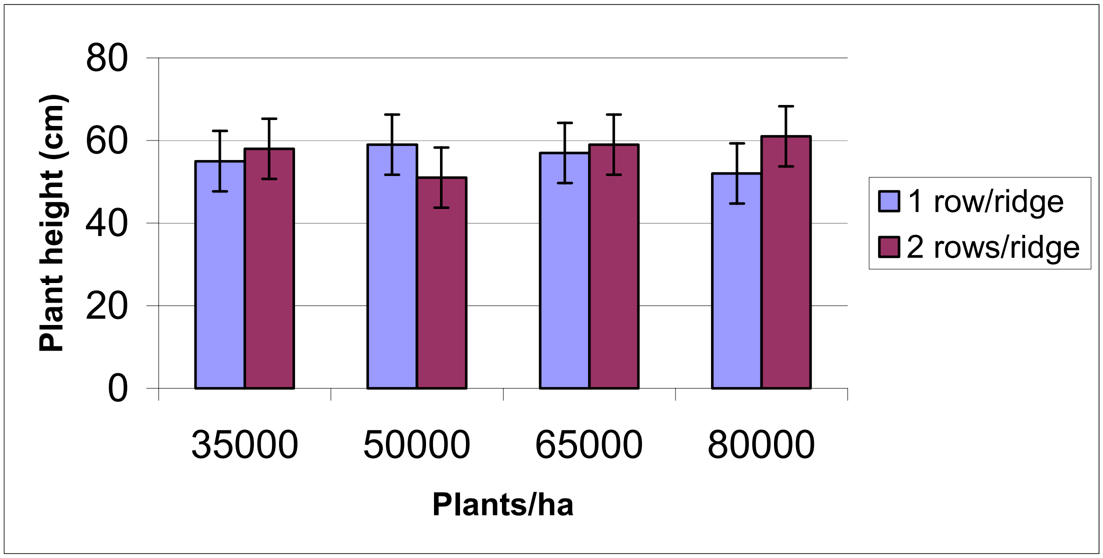


Figure 6.1. Interaction effect of plant population and plant spatial arrangement on paprika plant height at Mugadza in the 2000/1 season

With 2 rows per ridge, plant height decreased with 50000 plants per hectare but increased as plant population was increased to 65000 and 80000 plants per hectare. With single row per ridge plant height increased slightly at 50000 plants per hectare but then decreased when plant population was increased further to 65000 and 80000 plants per hectare.

None of the various parameters measured at Kunyongana site in 2002/3 responded significantly either to plant population or plant arrangement (Table 6.3). Those parameters include total and marketable yield per hectare, plant height, number of fruits per plant and per plot, mean fruit mass and plant height. Upon analysis of the data, there were indications that the treatments had similar number of plants per plot, indicating that mortality had reduced number of plants in plots with the higher plant population treatments (Table 6.3).

Table 6.3. Main effects of plant population and number of rows per ridge on paprika yield, number of fruits per plant at Kunyongana in the 2002/3 season

Treatment	Fruit Yield (kg/ha) Total	Fruit Yield (kg/ha) Marketable	Plant height (cm)	Fruits per plant	Mean fruit mass (g)
Plant population (plants/ha)					

35 000	513	318	63.3	9.4	4.0
50 000	564	348	60.9	9.5	3.8
65 000	564	341	64.1	8.8	3.6
80 000	560	368	63.8	9.3	3.5
Significance	ns	ns	ns	ns	ns
Number of rows per ridge					
Single-row	557	340	63.4	9.6	3.6
Double-row	563	348	62.7	8.9	3.8
Significance	ns	ns	ns	ns	ns
CV%	38.0	45.0	9.3	27.8	19.7

ns = no differences between means at $p<0.05$.

6.4 **Discussion**

The reduction of total and marketable yields at Mugadza for the 80000 plant population level in 2000/1 can be attributed to competition arising from high plant growth rate due to high fertiliser rate (1000 kg/ha) and rainfall. Under optimum conditions of rainfall and fertiliser, closely spaced plants compete for light and grow tall (vegetative growth) at the expense of reproduction. Fruits on tall plants were located higher up the plant canopy whilst for the shorter and sturdier plants, fruits were found at the lower strata to the apex of the plant canopy. The significant ($p<0.05$) increase in yield observed for 80000 plants in 2001/2 can be attributed mainly to higher plant number since population did not affect fruit number per plant in that particular season. Plant growth was greatly reduced by moisture stress and probably there was less competition between plants as they were stunted in growth.

These results suggest that the yield increase under a higher population in 2000/1 is attributable both to a higher a plant population and higher fruit production per plant rather than fruit size. Whereas paprika yield increase in 2001/2 season is attributable solely to higher number of plants per hectare as there were no significant differences in number of fruits per plant. The yield depression that occurred under high plant densities in 2002/3 was directly due to reduced plant numbers caused by high plant mortality. The high plant mortality was itself due to a combination of drought stress and soluble salt injury from the high rate of basal fertiliser (1 000 kg/ha) under dryland conditions. It is also possible that evapotranspiration was higher under a situation where there were more plants.

The results of the present study, that is, increase in yield with increasing plant population, are similar to those reported for once-harvested cayenne pepper (Decoteau and Graham, 1994); single machine harvested Tabasco pepper (Sundstrom *et al.*, 1984); multiple harvested bell pepper (Stoffella and Bryan, 1988; Everett and Subramanya, 1983); Pepperoncini pepper (Motsenbocker, 1996); bell peppers (Joliffe and Gaye, 1995) and paprika peppers (Kahn, Cooksey and Motes, 1997). In contrast, Cavero, Ortega and Gutierrez (2001) reported that paprika fruit number per plant decreased as plant density increased from 13333 to >500 000 plants per hectare. Their finding may have been due to the fact that they used much higher plant populations than used in the present study. Locascio and Stall (1994) reported that in-row plant spacing affected bell pepper yield per plant (yield per plant was inversely related to plant population). Total yield was higher with row arrangements under higher rather than lower plant populations. Batal and Smittle (1981) concluded that total plant population was a more important factor affecting bell pepper yield than plant arrangement while Sundstrom *et al.* (1984) noted that close spacing appeared to substantially reduce stem breakage. Their data suggested that adjacent plants in closely spaced treatments supported each other and avoided lodging. Reports about the effect of plant density on yield do not agree on an optimum plant density because this is influenced by the growing system, including the method of establishment (transplanting or direct seeding), the number of rows per bed and the in row plant spacing, as well as other factors such as fertility or cultivar traits (Cavero *et al.*, 2001).

Several non-experimental factors affected this study. Weather conditions were very variable after transplanting as excessive dry and wet periods and high temperatures caused stress conditions during and after stand establishment. In 2000/1 the two sites (Mugadza and Masunda) were affected by drought, as there was no rain after transplanting resulting in seedlings dying due to drought stress. They were retransplanted with overgrown seedlings. At Masunda there was no follow up rain after retransplanting and establishment rates were very low. The trial was subsequently abandoned after cattle and baboons destroyed the remaining plants before harvest data could be collected. The main reason for the destruction was that the trial was established late, well after farmers had established their own crops. Surrounding farmers had completed their own harvesting well before the crop in the trial was mature. The trial, being the remaining crop, was therefore a target of stray livestock that had been released to graze on stover left in the field. It is therefore essential for researchers to establish their trials at the same time with farmers so that they can harvest at the same time before livestock is released to feed on crop stover *in situ* in the offseason. Abandonment of paprika fields due to reduced plant stand (>90% reduction) was a common occurrence among farmers during the period of study. This was mainly caused by drought stress. The study shows the difficulties of conducting plant population studies with transplanted crops under dryland conditions in seasons or environments with unreliable rainfall.

6.5 **Conclusions and Recommendations**

1. Increasing plant population from the present 55 000 plants per hectare to above 65000 results in significant increase in total fruit yield. There is need however for the upper limit to be determined, particularly on the basis of economic viability.
2. Arranging plants in two rows per ridge can give higher yields per hectare and increased yield per plant. However, there is need for more studies as this occurred only once at Mugadza in 2000/1.

CHAPTER 7

PRELIMINARY STUDIES ON THE RESPONSE OF PAPRIKA (*Capsicum annuum* L.) TO TYPE OF BASAL FERTILISER AND TIMING OF TOP DRESSING

7.1 **Introduction**

According to what is available in the literature, most studies on pepper and paprika plant nutrition have focused mainly on nitrogen and to a lesser extent phosphorus and other mineral elements. The major mineral nutrients, namely, N, P and K are known to affect growth and yield of the capsicums, which include bell, sweet, chilli and paprika peppers. It is well established that N influences the growth and development of pepper grown for its fruit. The overall effect would depend on the available N in the soil, in addition to the amount of nitrogen that is applied (Payero and Bhangoo, 1990). In studies by Johnson and Decoteau (1996), macronutrients were shown to affect Jalapeno pepper plant growth, fruit yield and pungency. As N concentration increased from 1 mM to 22.5 mM, leaf number and weight, number of fruits per plant and dry fruit weight increased. Biomass and fruit production per plant increased linearly with increasing K rate. Stroehlein and Oebker (1979) reported that N applications on chilli peppers showed a significant increase on plant growth characteristics, colour, and nutrient content of leaves and yield. In their study, moderate rates of N tended to produce a more desirable type of plant and generally highest yields. In studies by Babu *et al.* (1988), increasing calcium and phosphorus levels increased pepper yields. Alexander and Clough (1998) were able to show that total pepper fruit yield increased linearly as calcium rate increased although marketable yield was not affected. They also observed that yield of fruit affected by sunscald at the first harvest decreased linearly as supplemental calcium rate increased.

Published research work on paprika mineral nutrition in Zimbabwe is not available. Current production recommendations are from other parts of the world and because of differences in climate, agro-ecological zones and management techniques it is inappropriate to adopt these for dryland paprika. There is no known information on critical nutrient levels for paprika plant parts. This, therefore, makes it impossible to determine whether paprika is deficient in nutrients in the absence of defined standards or threshold levels. Rational fertilization schedules require information on season long growth trends and on changes in nutrient concentrations or nutrient demand over time (O'sullivan, 1979). SH farmers in CRA have indicated difficulty in sourcing the recommended compound "L" and some use the readily available fertiliser for maize such as compound "D" and ammonium nitrate (AN) as well as manure. The response of paprika to these types of fertilisers is not known. Also, the recommended rates of fertilizer application (700 – 1000 kg/ha compound "L") may not be economical in the SH farming sector in view of the short growing season experienced. Compound "L" is recommended because it has boron and also because of a fairly high (17%) phosphate content which ensures a continuous supply of phosphorus throughout the long growing season required by paprika under irrigation. However, there is need for studies on the response of rainfed paprika to compound "D" which is easily and cheaply available in the SH sector.

Mineral nutrition is thought to influence the chemical composition of paprika plant parts, especially fruit quality. Adequate nutrition has been reported to increase the ASTA units, a measure of quality in paprika fruits (Paprika Zimbabwe Pvt. Ltd., 1999).

This experiment was, therefore, carried out to compare the effect of the recommended compound "L" fertilizer with locally available basal fertilizers (organic and inorganic) with and without supplementary nitrogen (either as split or single dose) on growth, yield and chemical composition and quality of paprika.

7.2 **Materials and Methods**

the experiment was conducted at Mhiripiri in Chinyika East and at Sanhi in Chinyika West. There were two factors, basal fertiliser and top dressing. There were four basal fertiliser levels as follows: no basal fertiliser (control), cattle manure (5 000 kg/ha), Compound "L" (5 N; 17 P_2O_5; 10 K_2O) (200 kg/ha), and Compound "D" (7 N;14 P_2O_5;7 K_2O) (200 kg/ha) banded in the centre of the ridge as preplant. Ammonium nitrate (34.5%N) (AN) top dressing had three levels: no top dressing (control), 350 kg/ha AN applied either as a single application 4 weeks after transplanting (WAT) or as a 50:50 split at 4 and 8 WAT. The two factors were arranged in factorial combinations in a randomised complete block design with 3 replications. Cattle manure was obtained locally from the host farmer's kraal.

During the 2000/1 season transplanting was done on 29 December 2000. However, all the transplants died due to severe drought stress and retransplanting was done on 31 January 2001. All plots were retransplanted. Mhiripiri site was subsequently abandoned after most of the retransplanted seedlings died due to absence of follow up rainfall. Weeding was done once on 19 March 2001. Ammonium nitrate (AN) top dressing was applied on 19 February and 13 April according to described treatments. Harvesting was done once off on 11 May 2001 and all fruits were harvested.

In the 2001/2 season transplanting was done on 28 November at the Sanhi site and 5 December at the Mhiripiri site. A mixture of 30 g copper oxychloride and 30 g Dithane M45 (85%WP) per 15 litres of water was applied on 19 December 2001 to all plots as a curative spray to control bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*) at Sanhi. Weeding was done once on 24 December at Sanhi and on 27 December at Mhiripiri. Ammonium nitrate was applied on 14 March and 16 April at Sanhi and on 16 March and 17 April 2002 at Mhiripiri according to treatments. Harvesting was done once off on 23 April 2002 at both sites. Whole plant samples (4 plants per plot) were randomly collected on the day of harvest from both sites for the purpose of nutrient analysis. In the 2002/3 season transplanting was done on 12 December at both sites (Kunyongana and Sanhi). AN was applied at 4 and 8 WAT. Harvesting was done on 17 April 2003. Whole plant samples were also collected from both sites at final harvest but only samples from one site (Kunyongana) were analysed due to cost implications. Data were collected on total and marketable yield, plant height, shoot dry mass, mean fruit mass, fruits per plant and nutrient content of plant parts.

7.2.1 **Method of Plant Sampling**

Four plants in the border rows were randomly selected per plot. Each plant was cut at ground level using a sharp knife. The whole plants from the same plot were composited, weighed and the fresh weights recorded. Plants were dissected into fruits, leaves and petioles, before being dried in an oven at 70°C until they attained a constant mass. The dried samples were then subjected to chemical analysis in the analytical laboratory.

7.2.2 **Methods of Plant Analysis**

Dried plant samples were ground with a Wiley mill to pass through a 40-mesh screen before subjecting them to chemical analysis. Total nitrogen was determined by micro-kjeldahl method after digestion of plant sample with concentrated sulphuric acid (Bremner, 1965). Phosphorus concentration was determined by the Vanadomolybdate yellow method (Olsen and Sommer, 1982) after digestion with 2.4N perchloric acid. Extraction of exchangeable bases was done using 25% hydrochloric acid and 55% nitric acid. Concentrations of exchangeable bases in plant tissue were determined by Atomic Absorption (AA) except K concentration which was determined using Flame Emission.

7.2.3 **Methods of Manure Analysis**

Nitrogen, potassium, calcium, magnesium and phosphorus contents of manure were analysed as for plant analysis. Sand and organic carbon were determined by loss on ignition.

7.2.4 **Methods of Colour Content Analysis**

Colour content (ASTA) analysis was done for fruits from Sanhi in 2001/2 in the Hyveld Seed Company laboratory. Paprika fruits were sun-dried, de-stemmed and then graded according to visual assessment. The various grades per plot were bulked before a sample of about 50g was taken and submitted for analysis. Analysis of fruits for colour content was conducted in accordance with the American Spice Traders Association (ASTA) method 20.1. ASTA units according to method 20.1 refer to ASTA integral. This means that the laboratory analysis is done on a complete sample, including seeds and in some cases including peduncles (calyxes). The colour content is tested in a laboratory where a spectrographic meter is used to determine the absorption of red light through an extraction (sample of paprika dissolved in acetone) (Agrikor, 2000). The result is then calculated to ASTA units. The term ASTA refers to the international standard for measuring the extractable colour units in paprika fruits and powder as set out by the American Spice Traders Association (ASTA). The quality of paprika is determined by its taste, texture and mostly by the colour content it holds. The colour content is tested in a laboratory where a spectrographic meter is used to determine the absorption of red light through an extraction (sample of paprika dissolved in acetone) (Agrikor, 2000). The result is then calculated to ASTA units and this value is the most important factor that determines the value of the final product. Another method used for determining paprika fruit quality is visual grading. Visual grading classifies into three quality grades depending on the intensity of the red colour. Fruits with a very deep red to maroon colour would be the highest grade while those with light red to yellow colour comprise the lowest grade (Agrikor, 2000).

7.2.5 **Methods of Soil Sampling**

Soil samples were taken systematically in a zigzag manner at 10 points in each experimental block. The samples were taken using an auger to a depth of 30 cm before the field was ploughed. The soil samples from each field were composited and thoroughly mixed. They were then air-dried and ground before subjecting to physico-chemical analysis by standard procedures (Black, 1965).

7.2.6 **Methods of Soil Analysis**

Nitrogen (N) was determined by micro-kjeldahl method. Phosphorus (P) was extracted using the resin method (Cooke and Hislop, 1963). P concentration was determined by the ascorbic acid method (Watanabe and Olsen, 1965) and soil pH was measured in 0.01M calcium chloride as recommended by Schofield and Taylor, (1955). Exchangeable cations (K, Ca, Mg) were extracted using the ammonium acetate (pH 7) method (Thomas, 1982). Concentrations of Mg and Ca were determined by atomic absorption and K concentration was determined by Flame Emission.

7.3 **Results**

7.3.1 **Paprika Yield and Yield-Related Parameters**

Paprika fruit yield was sorted into two categories namely, marketable and non-marketable fruit mass. Total yield included calyxes, immature and blemished fruits. Analysis of variance was carried out on the yield categories (total and marketable yields).

For the 2000/1 season results presented are for one site (Sanhi). The second site (Mhiripiri) was abandoned after most of the transplants died due to drought stress. During this season application of basal fertiliser significantly affected ($p<0.05$) all yield categories, yield components and plant height (Table 7.1). The lowest values for total and marketable yields were obtained with the no basal fertiliser treatment. The basal fertilisers were not statistically different with respect to total and marketable yields, fruit number per plant, fruit length, fruit mass and plant height. Ammonium nitrate (AN) top dressing significantly ($p<0.05$) affected total and marketable yield. Significantly higher yields were obtained by applying AN either as a single dose or as an equal split compared with the no AN treatment (Table 7.1). Both categories of fruit yields were extremely depressed in the absence of AN top dressing. The observed high coefficients of variation were due plant mortality in some replications due to either waterlogging or drought stress.

Table 7.1. Main effects of type of basal fertiliser and ammonium nitrate (AN) top dressing on yield (kg/ha), fruit number, fruit length and height of paprika at Sanhi farm during the 2000/1 season.

Treatment	Fruit Yield (kg/ha) Total	Marketable	Fruit no/plant	Fruit length(cm)	Plant height(cm)
Basal fertiliser					
No basal fertiliser	17.4b	6.3b	0.4b	8.9b	35.8b
Cattle manure	64.9a	24.4a	0.9a	12.3a	43.9a

Compound "L"	74.4a	32.4a	1.1a	11.4a	41.4ab
Compound "D"	59.6a	20.4a	1.0a	11.0a	43.9a
Significance	*	*	**	*	*
LSD$_{(0.05)}$	35.3	14.7	0.4	2.1	5.9
Top dressing					
No AN	15.1b	5.0c	0.5b	8.4b	39.2
Single dose[+]	88.4a	35.5a	1.2a	12.9a	42.8
2-split AN[++]	58.7a	22.6b	0.9a	11.5a	41.8
LSD$_{(0.05)}$	30.5	12.6	0.3	1.8	-
Significance	**	**	**	**	ns
CV%	66.7	70.9	41.9	19.2	14.7

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$

[+] 350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)

[++] 350 kg/ha AN applied as two equal splits at 4WAT and 8WAT

Fruit number per plant and fruit length were significantly affected by both basal fertiliser and top dressing. Lack of AN top dressing resulted in depression in the yield components although the single dose and 2-split applications did not differ from each other in their effects. AN top dressing did not influence plant height.

There was a significant interaction between basal fertiliser and top-dressing for fruit mass (Figure 7.1). When no AN top dressing was done, cattle manure was the best of the three sources of basal dressing.

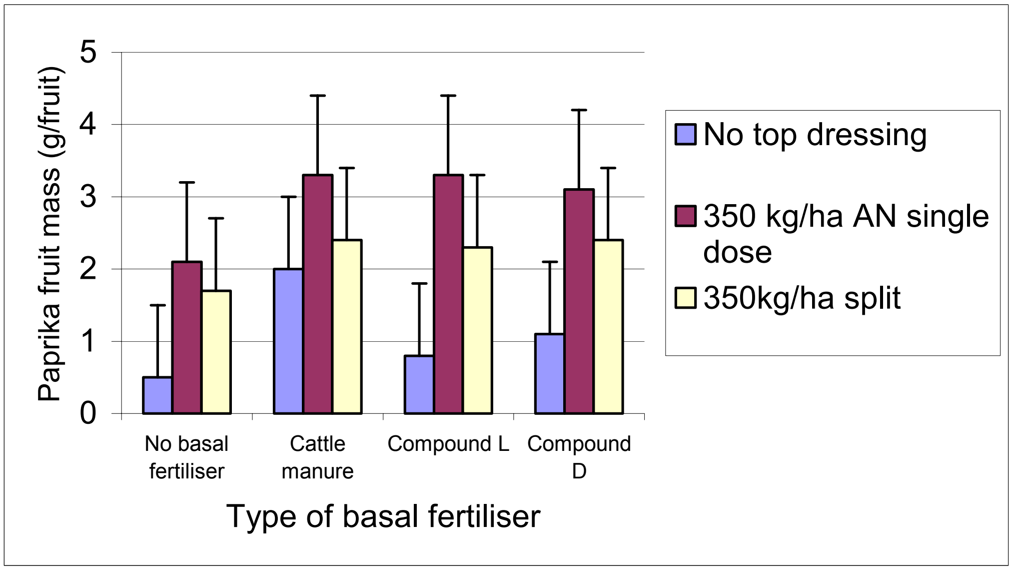


Figure 7.1. Interaction effect of basal fertiliser type and ammonium nitrate top dressing on paprika fruit mass at Sanhi farm in the 2000/1 season.

In the second season (2000/1) basal fertiliser application significantly ($p<0.05$) affected yield at both sites (Table 7.2). At Sanhi the lowest total and marketable yields were obtained where there was no basal fertiliser and this was significantly different from yields that were obtained with the three basal fertilisers. There were no significant differences in yield among the three basal fertilisers.

At Mhiripiri the least total yield was obtained with the manure treatment and this was not significantly different from the no basal fertiliser treatment. There were no significant differences in yield between Compound "L" and Compound "D" but these two differed significantly from the manure and no basal fertiliser treatments, which were not statistically significant (Table 7.2).

Table 7.2. Main effect of type of basal fertiliser on yield (kg/ha) at Sanhi and Mhiripiri in the 2001/2 season

	Sanhi		Mhiripiri		
Treatment	Total yield (kg/ha)	Marketable yield (kg/ha)	Total yield (kg/ha)	Marketable yield (kg/ha)	Fruits/ plant
No basal fertiliser	388b	202b	65 b	38b	2.1b
Manure	566a	300a	45b	24c	1.4c
Compound “L”	625a	308a	91a	58b	2.3b
Compound “D”	663a	371a	130a	64a	3.7a
Significance	**	*	**	*	**
LSD$_{(0.05)}$	134	96	42	30	1.3
CV%	24.5	33.3	52.0	65.4	44.9

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$

Compound “L” and Compound “D” fertilisers were superior to manure for basal dressing at Mhiripiri. Total and marketable yields were much lower at Mhiripiri than at Sanhi. The type of basal fertiliser affected the number of plants per hectare at final harvest in the 2001/2 season. At both sites, the number of plants per hectare for the manure treatment was significantly ($p<0.05$) lower than plant populations in the other two basal fertiliser treatments (Table 7.3). The no basal dressing treatment produced the least values for plant height, total and marketable yields at Sanhi.

Table 7.3. Main effect of type of basal fertiliser on final plant population and yield at Sanhi and Mhiripiri farms in the 2001/2 season

	Density ('000 plants/ha)		Plant height(cm)	Fruit Yield/plant(g)			
	Sanhi	Mhiripiri	Sanhi	Sanhi		Mhiripiri	
Treatment				Total	Marketable	Total	Marketable
No basal fertiliser	45.4a	37.0a	51.2b	7.1b	3.8c	1.4b	1.0
Cattle manure	40.2b	20.8b	61.7a	11.2a	6.3a	1.8ab	1.2
Compound "L"	44.1a	31.3a	54.7a	11.8a	5.8b	2.4a	1.9
Compound "D"	43.9a	37.6a	59.1a	12.6a	7.0a	2.9a	1.7
Significance	**	**	**	**	**	**	ns
$LSD_{(0.05)}$	2.4	6.5	5.0	2.5	1.8	0.8	-
CV%	5.8	20.9	9.1	23.4	32.3	40.3	53.9

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$

In the third season (2002/3), basal fertiliser did not affect the measured parameters, that is, plant height, shoot dry mass, fruit number per plant, total and marketable yields at both Kunyongana and Sanhi (Tables 7.4 and 7.5). However, at Sanhi, plant density responded to basal fertiliser. Plant density was significantly ($p<0.05$) reduced for all the three basal fertilisers (Table 7.5). It was highest for the no basal fertiliser treatment. At Kunyongana, application of AN top dressing whether as a split or as a single dose significantly increased plant height, shoot dry mass, fruits per plant, total and marketable yields (Table 7.4). At Sanhi, only fruits per plant and, total and marketable yields significantly responded to AN top dressing. (Table 7.5)

Table 7.4. Main effect of type of basal fertilizer and ammonium nitrate (AN) top dressing on height, plants m^{-2}, shoot dry mass, fruit number per plant, and yield at Kunyongana farm site during 2002/3 season.

Treatment	Plant height (cm)	Shoot dry mass (g)	Fruits/ plant	Plants m^{-2}	Fruit Yield (kg/ha)	
					Total	Marketable
Basal fertiliser						
No basal	62.4	196.4	9.7	4.8	1198	776
Manure	59.8	212.1	8.9	4.7	1085	707
Compound “L”	64.4	223.3	9.8	4.7	1086	712

Compound “D”	63.4	233.7	11.2	4.5	1063	779
Significance	ns	ns	ns	ns	ns	ns
Ammonium nitrate						
No AN	53.7b	105.0b	4.2b	4.6	499b	325b
Single dose AN^{+}	67.0a	264.6a	13.0a	4.7	1407a	934a
2- split AN^{++}	66.9a	279.5a	12.4a	4.7	1417a	972a
Significance	**	**	**	ns	**	**
LSD$_{(0.05)}$	3.6	37.3	1.4	-	227	109
CV%	6.9	20.3	17.2	7.2	24.2	17.3

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$

$^{+}$350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)
$^{++}$350 kg/ha AN applied as a split at 4WAT and 8WAT

Table 7.5. Main effects of basal fertiliser and ammonium nitrate (AN) top dressing on plant height, plants m^{-2}, fruit number per plant and yield at Sanhi farm site during 2002/3 season.

	Plant	Fruits/	Plants/	Fruit Yield (kg/ha)	
Treatment	height (cm)	plant	m^{-2}	Total	Marketable
Basal fertiliser					
No basal	54.3	5.0	5.3a	781	545
Manure	54.9	5.9	4.4b	789	483
Compound “L”	55.4	5.9	4.6b	789	462
Compound “D”	56.2	6.3	4.6b	808	482

Significance	ns	ns	**	ns	ns
$LSD_{(0.05)}$	-	-	0.5	-	-
<u>Ammonium nitrate</u>					
No AN	53.5	4.6b	4.7	581b	355b
Single dose AN[+]	55.4	6.3a	4.6	871a	557a
2- split[++]	56.8	6.4a	4.9	923a	567a
Significance	ns	*	ns	**	**
$LSD_{(0.05)}$	-	1.5	-	184	132
CV%	7.6	30.3	10.6	27.4	31.7

ns, *, ** not significant, significant at $p<0.05$ and $p<0.01$ respectively. Means within the same category in a column and have different letters are significantly different at $p<0.05$

[+] 350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)
[++] 350 kg/ha AN applied as a split at 4WAT and 8WAT

7.3.2 **Soil Analysis**

At Sanhi site the field used in the 2000/1 season had strongly acid soils (pH 4.7) on the calcium chloride scale and the field used in the 2001/2 season had medium acid soil (pH 5.2). At Mhiripiri farm the field used in the 2001/2 season had strongly acid soil. The field used at Sanhi in 2001/2 had higher N (48 ppm), P (22 ppm), and K (0.31 ME/100g) levels than the field used in the preceding season, which had N, P, and K levels of 13 ppm, 1 ppm and 0.21 ME/100 g respectively (Appendix Table 36).

7.3.3 **Manure Analysis**

Cattle manure was analysed for the 2001/2 season and the chemical composition is presented in Appendix Table 37. The mineral and organic matter content of the manure differed for the two sites. The manure at Mhiripiri contained higher levels of nitrogen, phosphorus and organic matter.

7.3.4 **Plant Analysis**

Chemical analysis was done for the macronutrients (N, P, K, Mg and Ca) and micronutrients Zn, Cu, Mn, and Fe. For the 2001/2 season all macronutrients: N, P, K, Ca and Mg in fruits were not affected by both basal fertilizer and nitrogen top dressing at both sites (Tables7.6 and 7.7).

Table 7.6. Chemical composition of paprika fruits in response to type of basal fertiliser and ammonium nitrate top dressing at Sanhi and Mhiripiri in 2001/2

	SANHI					MHIRIPIRI				
	Concentration (%)					Concentration (%)				
Treatment	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Basal fertiliser										
No fertiliser	2.59	0.38	2.78	0.75	0.23	2.52	0.34	2.49	0.75	0.23

Manure	2.68	0.37	2.90	0.68	0.23	2.71	0.35	2.67	0.76	0.27
Compound "L"	2.62	0.35	2.85	0.62	0.22	2.53	0.29	2.39	0.75	0.22
Compound "D"	2.67	0.37	2.84	0.61	0.21	2.54	0.35	2.47	0.95	0.24
AN top dressing										
No AN	2.56	0.38	2.89	0.66	0.21	2.62	0.34	2.50	0.79	0.24
AN single dose[+]	2.68	0.36	2.90	0.68	0.23	2.65	0.32	2.53	0.83	0.25
AN split[++]	2.69	0.37	2.79	0.66	0.22	2.45	0.33	2.49	0.79	0.23
CV%	6.9	8.5	4.1	12.5	9.7	10.1	8.6	4.9	26.4	11.7

Means within the same category in a column and have different letters are significantly different at $p<0.05$

[+] 350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)
[++] 350 kg/ha AN applied as a split at 4WAT and 8WAT

Table 7.7. Chemical composition of paprika leaves in response to type of basal fertiliser and ammonium nitrate top dressing at Sanhi and Mhiripiri in 2001/2

	SANHI					MHIRIPIRI				
	Concentration (%)					Concentration (%)				
Treatment	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Basal fertiliser										
No fertiliser	4.11	0.38	4.12	1.70	0.37	4.12	0.33	3.69	1.92	0.53

Manure	4.31	0.37	4.27	1.58	0.40	3.78	0.29	3.77	2.08	0.74
Compound "L"	4.37	0.38	4.43	1.62	0.36	3.75	0.29	3.39	2.09	0.61
Compound "D"	4.14	0.37	4.34	1.86	0.40	4.20	0.29	3.79	2.19	0.62
AN top dressing										
No AN	3.97	0.41	4.10	1.72	0.38	4.02	0.32	3.61	2.17	0.69
AN single dose[+]	4.36	0.36	4.30	1.70	0.39	3.85	0.28	3.73	2.01	0.59
AN split[++]	4.37	0.36	4.46	1.65	0.37	4.02	0.31	3.65	2.03	0.60
CV%	5.5	5.7	7.0	19.3	8.8	7.3	8.8	12.1	9.5	18.5

Means within the same category in a column and have different letters are significantly different at $p<0.05$

[+] 350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)
[++] 350 kg/ha AN applied as a split at 4WAT and 8WAT

Chemical analysis was done for Kunyongana site only for the 2002/3 season. Leaf micronutrient composition did not respond to either basal or top dressing fertiliser (Table 7.8) while the major nutrient status of the stems was not affected by basal fertiliser (Table 7.9).

Table 7.8. Chemical composition of paprika leaves in response to type of basal fertiliser and ammonium nitrate top dressing at Kunyongana in 2002/3 season.

	Concentration (%)					Concentration (ppm)			
Treatment	N	P	K	Ca	Mg	Zn	Cu	Mn	Fe
Basal fertiliser									
No basal	3.8	0.49	3.67	2.10	0.09	61	113	176	1249
Manure	4.2	0.48	3.12	1.86	0.08	57	116	219	956

Compound “L”	4.0	0.55	3.54	2.10	0.09	57	127	231	819
Compound “D”	3.8	0.53	3.80	2.38	0.10	63	126	246	922
AN top dressing									
No top dressing	3.6	0.67	4.28	2.04	0.09	63	120	194	867
AN single dose[+]	4.1	0.44	3.19	2.29	0.10	62	126	248	907
AN split[++]	4.3	0.43	3.12	2.00	0.09	54	118	213	1183
CV%	9.8	14.9	15.3	18.5	22.4	22.0	20.1	22.0	31.0

Means within the same category in a column and have different letters are significantly different at $p<0.05$

[+] 350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)
[++] 350 kg/ha AN applied as a split at 4WAT and 8WAT

Table 7.9. Chemical composition of paprika stems in response to type of basal fertiliser and ammonium nitrate top dressing at Kunyongana in 2002/3 season.

	Concentration (%)					Concentration (ppm)			
Treatment	N	P	K	Ca	Mg	Zn	Cu	Mn	Fe
Basal fertiliser									
No basal	1.7	0.31	1.98	0.52	0.06	31	18	66	423
Manure	1.8	0.25	1.80	0.35	0.05	28	18	49	440

Compound “L”	1.6	0.34	2.26	0.47	0.06	36	29	83	460
Compound “D”	1.7	0.29	1.85	0.38	0.05	28	17	51	412
AN top dressing									
No top dressing	1.5	0.37	2.21	0.40	1.5	33	34	83	503
AN single+	1.9	0.29	1.93	0.47	1.9	30	17	52	326
AN split++	1.7	0.24	1.77	0.43	1.7	29	10	51	470
CV%	11.8	45.0	23.5	53.0	19.2	20.4	83.8	60.8	27.5

Means within the same category in a column and have different letters are significantly different at $p<0.05$

+350kg/ha AN applied as single dose at 4 weeks after transplanting (WAT)
++350 kg/ha AN applied as a split at 4WAT and 8WAT

7.3.5 **Fruit Analysis for ASTA content**

ASTA analysis was done for one site only (Sanhi) due to prohibitive costs. There were no significant differences in ASTA levels among all treatments. All the ASTA values were above the minimum (250 units) required for international marketing of paprika (Figure 7.2).

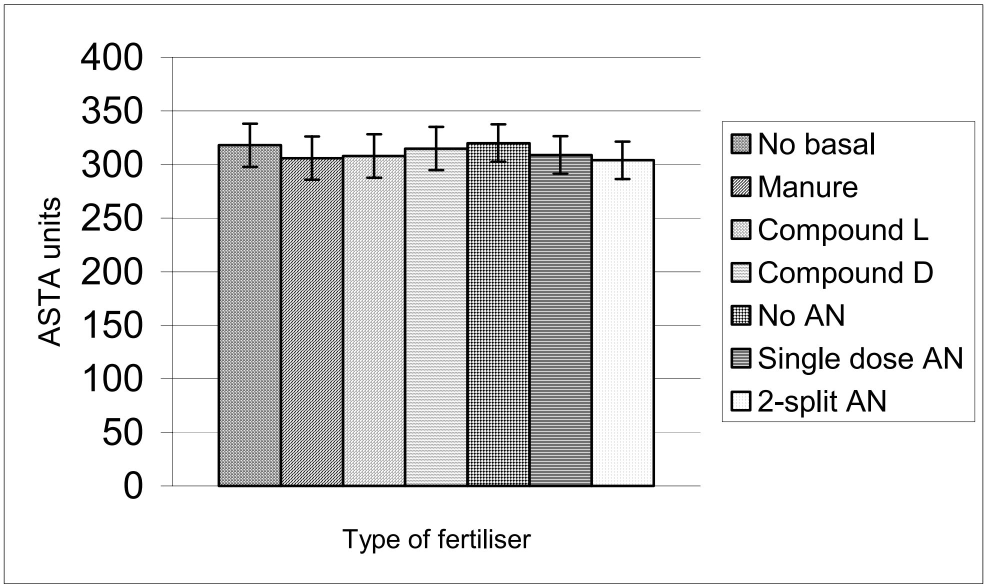


Figure 7.1. Main effects of basal fertiliser type and ammonium nitrate top dressing on paprika fruit ASTA content at Sanhi farm in the 2001/2 season.

7.4 **Discussion**

Mhiripiri site was abandoned due to severe drought in 2000/1. At Sanhi there was follow up rainfall and establishment was good. However the rains were so persistent that the soils were waterlogged and this retarded plant growth. As a result leaves of plants in all treatments and plots turned chlorotic and most leaves and flowers dropped prematurely. The waterlogging thus reduced the yield components such as number of fruits per plant, fruit size, total and marketable yield. This explains the rather deplorable yields that were recorded on the trial, almost amounting to failure of the crop. That situation invariably was responsible for the extremely low values for number of fruits per plant and plant dry mass. It would be difficult for the paprika plants to efficiently take up the mineral elements that were present in the soil under conditions of poor soil aeration caused by waterlogging. Many plants died due to waterlogging so the final plant stand was greatly reduced and far below optimum at final harvest. In studies on bell pepper, Sundstrom and Pezeshki (1988) reported that soil flooding adversely affect bell pepper. In their study, peppers responded to soil flooding by a reduction of their photosynthetic rate. Also, during this period of slow growth, soluble nutrients are subject to leaching (Locascio *et al.*, 1981). The soils of CRA are light and highly leached and are likely to predispose applied mineral nutrients to serious leaching when soils are waterlogged.

The lack of significant differences between compound "L" manure and compound "D has important implications for smallholder paprika growing farmers. Compound "L" is not readily available and is also much more expensive than compound "D", which is easily available in communal and resettlement areas and is relatively cheaper. Farmers can therefore use compound "D" and manure in place of compound "L". Nutrient source has been shown to affect marketable yield of bell pepper. Locascio *et al.* (1981) showed that N source, N rate and method of fertiliser placement interacted to affect marketable yield. With broadcast placement of AN, marketable yield increased as N was increased from 140 to 224 kg/ha. A further increase to 308 kg/ha N reduced yield sharply, probably due to soluble salt injury to the pepper plants. The basal fertilisers used in the present study were different in that they vary in their compositions of N, P and K. In other words, the same amounts of these different fertilisers would not supply the same amounts of N, P and K to the plants.

Use of split fertiliser application is done to minimize nutrient leaching and to extend the period of nutrient availability to the crop. It should therefore be beneficial to plants under favourable conditions of soil moisture. The result from the present study could have been caused by the fact that the second split of AN was applied rather late in the life of the crop, just a month before final harvest. Plants may not have had enough time to respond to this nitrogen supply, particularly that there was moisture stress during that part of the season. The suggested explanation for the failure of paprika yield and yield parameters to respond to nitrogen top dressing in 2001/2 is severe moisture stress.

Pepper yield is known to be affected by nitrogen rate and timing of application. In studies by Johnson and Decoteau (1996), increasing nitrogen from 0 mM to 22.5 mM led to a linear increase in dry weight of Jalapeno pepper. The plants were larger and able to withstand multiple harvests. There was a direct correlation between plant growth and fruit production. This finding contrasts with results of Stroehlein and Oebker (1979) on chilli peppers and Mills and Jones (1979) on Jalapeno pepper that indicated excessive N treatments stimulated vegetative growth and reduced flowering. In the study by Stroehlein and Oebker (1979) the high N rate either failed to increase yields above that of the medium N rate or tended to decrease yield and produced excessive foliage instead. This would suggest that in the SH farming sector where the cropping season is normally short, farmers should avoid recommendations with excessive N application. Application of excessive N levels would not be only economically wasteful, it can be detrimental to the paprika crop as well. Reports by Jaworski, Kays and Smittle (1978); Miller, McCollum and Claimon, (1979; Batal and Smittle (1981) and Bar-Tal *et al.* (1990), suggested that bell peppers deficient in N were stunted and pale green. In this current study, significantly shorter ($p<0.05$) plants were obtained with no fertiliser (0 kg/ha N) at Sanhi in the first two seasons and at Kunyongana in the 2002/3 season. Total yield per plant increased with application of basal fertiliser.

The very low marketable yield percentages in the first two seasons were mainly due to poor quality fruits at final harvest, possibly caused by moisture stress or by late application of N that produced a late flush of fruits towards the end of the season. Such late-formed fruits did not have adequate time with which to fully develop, mature and ripen before the end of the cropping season.

Use of plant N concentration provides a means to evaluate the N nutrient status and effectiveness of applied N in relationship to that available in the soil (Payero and Bhangoo, 1990). Several accounts relate plant tissue N concentration in pepper to plant growth, development, and fruit maturity. These reports are difficult to compare because different plant parts are sampled at different stages of ontogeny. Thus Thomas and Heilman (1964) reported that under greenhouse conditions the critical N level of leaf at the inititiation of flowering was approximately 4% while according to O'sullivan (1979) petiole nitrate N content at early fruit set reflected the rate of N applied. Payero and Bhangoo (1990) suggested that stem-petiole nitrate contents were more closely related to the magnitude of N treatments. In a study by Knavel (1977) the optimum level of leaf N for six-week-old transplants was approximately 3.7% dry weight. In a study by Miller (1961), cited by Miller *et al.* (1979), sufficiency levels of N, P, K, Ca and Mg in mature vegetative tissue of bell pepper plants were found to be 1.56, 0.30, 3.34 1.53 and 0.6% respectively and 1.75, 0.38, 2.90, 0.16 and 0.22% correspondingly, in fruit tissue.

Quality analysis (ASTA) which was done on fruits harvested from Sanhi farm in 2001/2 indicated that there were no significant differences in fruit quality based on ASTA values across all the treatments. The lowest ASTA value of 283 is above the lowest limit (250) required by international standards for paprika marketing (Agrikor, 2000). Quality analysis was done for only one site due to prohibitive high costs of ASTA testing. The foregoing therefore means that farmers can grow paprika using the locally available compound “D” and manure since produce quality is not likely to be compromised. The processing procedures of removing calyxes and grading paprika according to colour ensures that any marketed paprika from the SH farmers has a high ASTA content.

When rainfall was erratic and low as was the case for both sites in 2000/1 there was a significant ($p<0.05$) reduction in plant stand in manure plots. This was observed to be due to the presence of termites, which fed on plant roots in all plots that had manure. In a similar study by Aliyu (2000) in a semi-arid part of Nigeria, a combination of 5 tonnes farmyard manure and 5 tonnes poultry manure caused a significant reduction in plant stand but the reason for the reduction was not given. However, in the same study application of organic manure supplemented with 50 kg N/ha resulted in good stand establishment, plant growth and superior yield. This was attributed to the favourable effect of manure on soil physical and chemical properties.

The reasons for the observed low yields both seasons could be reduced plant growth rate and reduced period of growth due initially to drought stress and later to water logging for 2000/1 and due to drought stress only for 2001/2. For both years season length was also reduced due to delayed transplanting. Retransplanting in 2000/1 was done on 31 January 2001 and harvesting was done on 11 May. Thus the crop was in the field for just 4 months, a period that is less than satisfactory in length. The recommended latest transplanting time is mid-December. Field establishment of the 2000/1 crop, was therefore done one and a half months later than is recommended. Delayed sowing is known to greatly reduce yields in crops like wheat, barley and maize (Seed Co-op, 1996).

7.5 **Conclusions and Recommendations**

1. The application of basal fertiliser (manure, compound "D" or Compound "L") results in significant increase in paprika fruit yield when compared with no basal fertilizer application. Growing paprika without basal fertiliser results in very low yields although quality may not be impaired.
3 Application of AN top dressing with or without basal fertiliser results in increased paprika yields. Splitting of top dressing results in increased paprika yields if soil moisture is adequate at the time of application.

CHAPTER 8

GENERAL DISCUSSION

The manipulation of factors such as nursery seedling density and hardening treatment can be used to produce good quality seedlings, which have good establishment capability. This would ensure a good plant stand and increased yields. Results have indicated that optimum nursery seedling density and mild hardening lead to increased seedling vigour and improved establishment capability. Generally, reducing seedling density from 1500 seedlings m^{-2} to 750 seedlings m^{-2} and mild hardening produced vigorous seedlings with improved field establishment capability. Poor field establishment is a major constraint to paprika production in CRA. The current recommended practice of withholding water in the last two weeks prior to transplanting was found to be the best method for hardening of paprika seedlings and farmers should continue with it. The reduction in field plant stand due to seedling mortality translated into reduced fruit yields.

Results from the plant density experiment confirmed that high paprika yields are due to increased number of plants per hectare, which compensated for the low fruit yield per plant. However, it is unlikely that hardening of seedlings *per se* will make much difference to transplant mortalities in seasons of extremely low rainfall and hot conditions. It is necessary to develop drought tolerant varieties as well as moisture conservation techniques to enhance dryland paprika production. Farmers should therefore adopt management practices that ensure the production of good seedlings and also increase the plant population from the current 50 000 plants per hectare to
65 000 plants per hectare.

Prior to the administration of treatments for nursery experiments and prior to transplanting for field experiments, nurseries were farmer managed. The time of seedling production for dryland paprika coincides with the driest and hottest months of the year (September and October) in

Zimbabwe. This affected our study in that farmers could not water the seedbeds as thoroughly as was necessary after the wells could not yield adequate water. Thus seedling quality was reduced as seedling growth rates were reduced and over-hardened seedlings were produced. It may be worthwhile to test the effect of hardening seedlings grown under a sunscreen compared to those in the open.

The start of the rainy season at all sites during the first two seasons was quite varied and unreliable. This resulted in a prolonged transplanting period with variations of up to 3 weeks between sites hosting the same experiment. This may require farmers to have staggered seedlings of one-week intervals to avoid re-transplanting with overgrown seedlings or transplanting overgrown seedlings when rains delay. Usually, the first rains were light drizzle, which was intermittent and not adequate to moisten the soil for ploughing and transplanting to be done. Consequently, seedlings had to remain in the nursery for periods longer than 8 weeks. Although the light drizzle could not give adequate moisture for transplanting to be done, it nevertheless stimulated fast seedling growth and elongation. This resulted in tall and overgrown seedlings and where hardening had been done, this probably reversed the benefits of hardening. Overgrown seedlings have been reported to have reduced rooting ability. According to Villela and Junior (1996), older seedlings have more developed root systems, which are extensively damaged at transplanting, hence greater mortality of overgrown seedlings. It was also observed that the overgrown transplants had very few branches and these were located at the apex of the plant. Transplants that were not overgrown had many strata of branches from the plant base to the apex. Since fruits are borne on branches, this means that all overgrown seedlings had reduced yield potential due to reduced number of branches.

Even after successful field establishment, the soil moisture supply was not adequate for optimal plant growth. This inevitably reduced yields as plants could go for more than four weeks without receiving rainfall. According to Paprika Zimbabwe Pvt. Ltd, (1999) the cultivar PapriKing will drastically reduce in yield potential if it has a continuous period of two weeks or more without receiving rain or irrigation. Because rainfall could be absent for more than a month in all seasons, the trials which had PapriKing as the cultivar were badly affected, hence the reported yields were below the potential yield. Prolonged periods of drought stress and the accompanying high temperatures are also known to interfere with anthesis and this could have resulted in reduced fruit set.

The late commencement of the season, mid-season droughts and early termination of the rains led to reduction in season length. Therefore, paprika plants did not have sufficient time to grow to its full potential and consequently yields were reduced. Paprika is expected to remain in the field for at least seven months after transplanting yet during the present study, the season length was barely four months long in any given season.

There are many constraints, which presently confront the smallholder farmer growing paprika under dryland conditions. Given these constraints and the positive results from the present study, it is quite clear that there is scope for increasing paprika field establishment and yields under dryland conditions. This present 3-year study could not completely address all the problems being faced by dryland paprika farmers as time was limited. Nevertheless, the smallholder farmers are being encouraged to adopt the preliminary recommendations that have been given as a result of this study.

The major conclusions from this study are:

1) withholding water in the last two weeks prior to transplanting leads to production of seedlings that can withstand post-transplant stress
2) reducing nursery seedling density from 1500 seedlings m^{-2} to 750 seedlings m^{-2} and below leads to the production of vigorous seedlings that have high rates of survival when transplanted
3) paprika fruit yield increases as plant population is increased from 35 000 to 65 000 plants/ha
4) application of basal fertilizer and AN top dressing increases paprika fruit yield.

It is suggested that further research is undertaken in the same areas that were studied and new areas of study that have arisen as a result of this present study. The suggested areas of research are as follows:

1) A paprika-breeding programme is urgently needed. The cultivars that are presently being grown in Zimbabwe are introductions. There is no local paprika-breeding programme. For other crops, it is well known that breeding for adaptability always produces cultivars that perform better under local conditions than introductions. A local breeding programme would look at drought tolerance. Also, as paprika is grown more and more in Zimbabwe, pests and diseases would begin to emerge and accumulate, and because mainly use one cultivar (PapriKing) is used, there is the risk of emergence of devastating

pests and diseases, which can overwhelm the crop and wipe it. This lack of breeding for disease resistance is what caused the drastic reduction in paprika production in Spain (Agrikor, 2000).

2) An investigation to determine an optimum nursery seedling density between 750 and 1500 seedlings m^{-2}. If farmers can raise good seedlings at a density more than 750 but less than 1500 seedlings m^{-2} then they can reduce the size of their nursery and reduce the amount of water and labour they require.
3) An investigation into the effect of seedbed fertility on seedling vigour. Farmers do not always have access to the recommended Compound "S" fertiliser so there is need to evaluate manure and locally available fertilisers for use as basal dressing in the nursery. Also, a nursery period of 8 weeks appeared to be too long in view of the fact that transplanting is invariably delayed because rains do not always commence exactly after 8 weeks. Seedlings consequently become overgrown. Maybe seedlings between the age of 5 and 6 weeks after sowing may have better establishment capability. There is need to study the effect of seedling age on field establishment capability.

REFERENCES

Agrikor S.A (PTY) LTD. 2000. Paprika. *Updates and Latest News*. 6pp.

Agricultural Technical and Extension Services. 2000, Paprika. *Ministry of Agriculture and Rural Resettlement, Harare, Zimbabwe*. 7pp

Alexander, E.S and Clough, G.H. 1998. Spunbonded rowcover and calcium fertilization improve quality and yield in pepper. *HortScience* **33** (7): 1150-1152.

Aliyu, L. 2000Main effectsof organic and mineral fertiliser on growth, yield and composition of pepper (*Capsicum annuum* L.). *Biological Agriculture and Horticulture* **18**: 29 – 36.

Aliyu, L. and Kuchinda, N.C. 2002. Analysis of the chemical composition of some organic manures and their effect on the yield and composition of pepper. *Crop Research*. **23** (2): 362 –368.

Aloni, B., Pashkar, T. and Karni, L. 1991a. Nitrogen supply influences carbohydrate partitioning of pepper seedlings and transplant development. *Journal of the American Society for Horticultural Science*. **116** (6): 995-999.

Aloni, B., Daie, J. and Karni, L. 1991b. Water relations, photosynthesis and assimilate partitioning in leaves of pepper (*Capsicum annuum*) transplants: Effect of water stress after transplanting. *Journal of Horticultural Science* **66** (1): 75-80.

Alvino, A., Centritto, M. and De Lorenzi, F. 1994. Photosynthesis response of sunlit and shade pepper (*Capsicum annuum*) leaves at different positions in the canopy under two water regimes. *Australian Journal of Plant Physiology* **21**:377 – 391.

Babu, S.H., Lokeshwar, D., Rao, N.S. and Rao, B.R.B. 1988. The response of chilli (*Capsicum annuum* L.) plants to early innoculation with mycorrhizal fungi at different levels of phosphorus. *Journal of Horticultural Science* **63** (2): 315-320.

Batal, K.M. and Smittle, D.A. 1981. Response of pepper to irrigation, nitrogen and plant population. *Journal of the American Society for Horticultural Science* **106** (3): 259 – 262.

Bar-Tal, A., Bar-Yosef, B. and Kafkafi, U. 1990. Pepper seedling response to steady and transient nitrogen and phosphorus supply. *Agronomy Journal* **82**: 600 – 606.

Bar-Tal, A., Bar-Yosef, B. and Kafkafi, U. 1993. Modeling pepper seedling growth and nutrient uptake as a function of cultural conditions. *Agronomy Journal* **85**: 718 - 724.

Black, C.A.(ed). 1965. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. 1572p. *American Society of Agronomy*, Madison, Wisconsin.

Bremner, J.M. 1965. Total Nitrogen, pp 1149-1178. In: Black, C.A.(ed). Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Madison, Wisconsin.

Cavero, J., Ortega, R.G. and Gutierrez, M. 2001. Plant density affects yield, yield components, and colour of direct seeded paprika pepper. *HortScience* **36** (1): 476 – 480.

Chivinge, O.A and Mariga, I.K., 2000. The integrated crop management research (ICMR) project-Chinyika Resettlement Area. Proceedings of the ICMR Review Workshop, Mutare, Zimbabwe. June 1998. 105 pp.

Cooke, I.J. and Hislop, J. 1963. Use of anion exchange resin for the assessment of available soil phosphate. *Soil Science* **96**: 308 –312.

Daie, J., Seely, S.D. and Campbell, W.F. 1979. Nitrogen deficiency influences abscisic acid in tomato. *Hortscience* **14**: 261-262.

Decoteau, D.R. and Graham, H.A.H. 1994. Plant spatial arrangement affects growth, yield, and fruit distribution of cayenne peppers. *HortScience* **29** (3): 149-151.

Davidson, H., Mecklenberg, R. and Peterson, C. 1988. *Nursery management - administration and culture*. 2nd ed. Prentice Hall, Eaglewood Cliffs, New Jersey. pp 275-287.

Delfine, S., Loreto, F. and Alvino, L. 2001. Drought stress effects on physiology, growth and biomass production of rainfed and irrigated bell pepper plants in the Mediterranean region. *Journal of the American Society for Horticultural Science* **126** (3): 297 – 304.

Doorenbos, J. and Kassam, A.H. 1986. Yield response to water. *Food and Agricultural Organisation (FAO) Irrigation and Drainage paper* 33.

Dufault, R.J. and Schultheis, J.R. 1994. Bell pepper seedling growth and yield following pretransplant nutrient conditioning. *Hortscience* **29** (9): 999-1001.

Everett, P.H. and Subramanya, R. 1983. Pepper production as influenced by plant spacing and nitrogen-potassium rates. *Proceedings of the Florida State Horticultural Society* **96**: 79 – 82.

Garmany, H.F.M and Bates, T.E. 1957. Factors in the production of healthy tobacco seedlings. *Tobacco Research Board of Rhodesia and Nyasaland, Bulletin 6*. 32pp.

Jaimez, E.R., Rada, F. and Garcia-Nunez, C. 1999. The effect of irrigation frequency on water and carbon relations in three cultivars of sweet pepper (*Capsicum chinense* Jacq.) in a tropical semiarid region. *Scientia Horticulturae* **81**: 301-308.

Jaworski, C.A., Kays, S.J. and Smittle, D.A. 1978. Effects of nitrogen and potassium fertilization in trickle irrigation on yield of pepper and polebean. *HortScience* **13**: 477 – 478.

Johnson, D.C. and Decoteau, D.R. 1996. Nitrogen and potassium fertility affects jalapeno pepper plant growth, fruit yield, and pungency. *HortScience* **31** (7): 1119-1123.

Jollife, P.A. and Gaye, M.M. 1995. Dynamics of Growth and Yield Component responses of bell peppers *(Capsicum annuum* L.) to row covers and population density. *Scientia Horticulturae* **62**: 153 - 164.

Kahn, B.A., Cooksey, J.R. and Motes, J.E. 1997. Within-row spacing effects on traits of importance to mechanical harvest in paprika-type peppers. *Scientia Horticulturae*. **69** : 31 - 39.

Katerji, N., Mastrorilli, M. and Hamdy, A. 1993. Effects of water stress at different growth stages on pepper yield. *Acta Horticulturae* **335**: 165 – 171.

Karni, L, Aloni, B., Bar-Tal, A., Moreshet, S., Keinan, M. and Yao, C. 2000. The effect of root restriction on the incidence of blossom-end rot in bell pepper (*Capsicum annuum* L.). *Journal of Horticultural Science and Biotechnology* **75** (3): 364-369.

Knavel, D.E. 1977. The influences of nitrogen on pepper transplant growth and yielding potential of plants grown with different levels of soil nitrogen. *Journal of the American Society for Horticultural Science* **102** (5): 533 – 535.

Loomis, W.E. 1925. Studies in the transplanting of vegetable plants. *Cornell Agricultural Experimental Station Memoir* **87**: 1 – 63.

Leskover, D.I., Cantliffe, D.J. and Stoffella, P.J. 1989. Pepper (*Capsicum annuum* L.) root growth and its relation to shoot growth in response to nitrogen. *Journal of Horticultural Science* **64** (6): 711-716.

Leskover, D.I. and Cantliffe, D.J. 1992. Pepper seedling growth response to drought stress and exogenous abscisic acid. *Journal of the American Society for Horticultural Science* **117** (3): 389-393.

Locascio, J.S., Fiskell, J.G.A. and Martin, F.G. 1981. Responses of bell pepper to nitrogen sources. *Journal of the American Society for Horticultural Science* **106** (5): 628-632.

Locascio, S.J. and Stall, W.M. 1994. Bell pepper yield as influenced by plant spacing and row arrangement. *Journal of the American Society for Horticultural Science* **119**: 899 – 902.

Lurie, S., Shapiro, B. and Ben-Yehoshua, S. 1986. Effects of water stress and degree of ripeness on rate of senescence of harvested bell pepper fruit. *Journal of the American Society for Horticultural Science* **111** (6): 880 – 885.

Mande, B. 1998. *Paprika Handbook*. Agrispice, P.O.Box WGT679, Westgate, Harare. 29pp.

McCullough, M.D., Motes, J.E. and Kahn, B.A. 1995. Soil bedding treatments improve pepper plant anchorage. *HortScience* **30** (6): 1202-1204

Miller, C.H., McCollum, R.E. and Claimon, S. 1979. Relationships between growth of bell peppers (Capsicum annuum L.) and nutrient accumulation during ontogeny in field environments. *Journal of the American Society for Horticultural Science* **104** (6): 852 – 857.

Mills, H.A. and Jones, J.B, Jr. 1979. Nutrient deficiencies and toxicities in plants: Nitrogen. *Journal of Plant Nutrition* **1**:101-122.

Motsenbocker, C.E. 1996. In-row plant spacing affects growth and of pepperoncini pepper. *HortScience* **31** (2): 198-200.

Mukaro, G. 1997. *Horticulture Handbook for Small Scale Growers*. Zimbabwe Farmers Union. pp 28 - 36.

Munguri, M.W. 1996. Inorganic fertilisers and cattle manure management for dryland maize production under low input conditions.Unpublished Mphil Thesis, University of Zimbabwe.

Mvere, B. 1996. Cultivating paprika. *Farming World* **22** (11): 13-15

Nyamapfene, K. 1991. Soils of Zimbabwe. Nehanda publishers, Harare.

Olsen, S.R. and Sommer, L.E. 1982. Methods of soil analysis: Part 2. *Agronomy No* **9**: 406 – 407. *American Society of Agronomy*, Madison, Wisconsin.

O'Sullivan, J. 1979. Response of pepper to irrigation and nitrogen. *Canadian Journal of Plant Science* **59**: 1085-1091.

Pae'z, A., Gonzalez, M.E., Yrausquin, X., Salazar, A. and Casanova, A. 1995. Water stress and clipping management on guineagrass:II. Photosynthesis and water relations. *Agronomy Journal* **87**: 760 – 771.

Paprika Zimbabwe (Pvt.) Ltd. 1999. Paprika Cultivation in Zimbabwe. A guide to the important aspects of cultivating paprika as a commercial crop. Department of Agronomy, Paprika Zimbabwe (Pvt). Ltd, P Bag AY4 Amby, Harare, Zimbabwe. Hill, Billy Graphics and Printers.

Paprika Zimbabwe (Pvt) Ltd. 2000. *Paprika handbook*. 11pp.

Payero, J.O. and Bhangoo, M.S. 1990. Nitrogen fertiliser management practices to enhance seed production by 'Anaheim Chili' peppers. *Journal of the American Society for Horticultural*

Science **115** (2): 245-251

Peirce, L.C. 1987. *Vegetables - Characteristics, Production and Marketing*. John Wiley and Sons. New York. pp 325 - 329.

Rupende, E. 1996. Weed management studies in maize (*Zea mays* L.) for the smallholder farming sector. Unpublished Mphil Thesis. University of Zimbabwe.

Russo, V.M. 1996. Planting date, fertiliser rate, and harvest timing affect yield of jalapeno and banana peppers. *HortScience* **31** (7): 1124-1125.

Seed co-op, 1996. *Grain Handbook*. Commercial Grain Producers Association.

Schofield, R.K. and Taylor, A.W. 1955. The measurement of soil pH. *Soil Science Society of America Proceedings* **19**: 164 – 167.

Schultheis, J.R., Cantliffe, D.J., Bryan, H.H. and Stoffella, P.J. 1988. Planting methods to improve stand establishment, uniformity, and earliness to flower in bell pepper. *Journal of the American Society for Horticultural Science* **113** (3): 331-335.

Snedecor, G.W. and Cochran, W.G. 1980. Statistical Methods. 7th edition. Iowa State University Press, Ames, Iowa.

Squire, G.R. 1990. *The physiology of tropical crop production*. C.A.B International Wallingford, UK. 236pp.

Stoffella, P.J. and Bryan, H.H. 1988. Plant population influences growth and yields of bell pepper. *Journal of the American Society for Horticultural Science* **113**: 835 – 839.

Stroehlein, J.L. and Oebker, N.F. 1979. Effects of nitrogen and phosphorus on yields and tissue analysis of chilli peppers. *Journal of the American Society for Horticultural Science* **114** (7) 559-563.

Sundstrom, F.J., Thomas, C.H., Edwards, R.L. and Baskin, G.R. 1984. Influence of N and plant spacing on mechanically harvested Tabasco pepper. *Journal of the American Society for Horticultural Science* **109** (5): 642-645.

Sundstrom, F.J. and Pezeshki, S.R. 1988. Reduction of *Capsicum annuum* L. growth and seed quality by soil flooding. *HortScience* **23** (3): 574 – 576.

Tobacco Handbook. 2000. *Flue cured tobacco recommendations*. Tobacco Research Board, Harare.

Thomas, G.W. 1982. Exchangeable cations. Methods of soil analysis. Part 2. Agronomy No 9. *American Society of Agronomy*, Madison, Wisconsin: 160 – 161.

Thomas, J.R. and Heilman, D. M. 1964. Nitrogen and phosphorus content in leaf tissue in relation to sweet pepper yields. *Proceedings of the American Society for Horticultural Science* **85**: 419 – 425.

Vincent, V. and Thomas, R.G. 1961. *An agricultural survey of Southern Rhodesia. Part 1 – Agro-ecological survey*. Government Printers, Salisbury.

Vos, J.G.M. and Nurtika, N. 1995. Transplant production techniques in integrated crop management of hot pepper (*Capsicum spp*) under tropical lowland conditions. *Crop Protection* **14** (6): 453-459.

Villela, O. and Junior, E.F. 1996. Seedling age effects on rice cultivar development. *Bragantia Campinas* 55 (2): 329-339.

Ware, G.W. and McCollum, J.P. 1980. *Producing Vegetable Crops*. 3rd ed. The Interstate Printers and Publishers Inc. Danville, Illinois. pp 391 - 402.

Watanabe, F.S. and Olsen, S.R. 1965. Test of ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Soil Science Society of America Proceeding* **29**: 677 – 678.

Yanez, C.E., Alvino, A., Magliulo, V. and Steduto, P. 1992. Pepper response to mild conditions of combined soil-water and salinity stress. *Advances in Horticultural Science* **6**: 3 –10.

APPENDICES

APPENDIX TABLES FOR CHAPTER 4

Appendix Table 1: Analysis of variance of seedling height (cm) for the effect of basal fertiliser and timing of top dressing at Chinyudze combined over the 2000/1 and 2001/2 seasons

SOURCE	DF	SS	MS	F	P
Season	1	3716.741	3716.741	661.2982	0.0000
Rep(Season)	4	5.037	1.259	0.2241	
Hardening	2	140.444	70.222	12.4942	0.0035
Season(Hardening)	2	144.148	72.074	12.8237	0.0032
Error	8	44.963	5.620		
Density	2	652.111	326.056	54.5953	0.0000
Season (density)	2	89.815	44.907	7.5194	0.0029
Hardening(density)	4	5.778	1.444	0.2419	
Sea*Hard*density	4	27.630	6.907	1.1566	0.3545
Error	24	143.333	5.972		
Total	53	4970.000			

Appendix Table 2: Analysis of variance of seedling dry mass (g) for the of seedling density and hardening treatment at Chinyudze combined over the 2000/1 and 2001/2 seasons

SOURCE	DF	SS	MS	F	P
Season	1	2.272	2.272	295.8370	0.0000
Rep(Season)	4	0.029	0.007	1.2446	0.3659
Hardening	2	0.006	0.003	0.5438	
Season(Hardening)	2	0.005	0.003	0.4772	
Error	8	0.046	0.006		
Density	2	2.182	1.091	121.4070	0.0000
Season (density)	2	0.334	0.167	18.5995	
Hardening(density)	4	0.008	0.002	0.2230	
Sea*Hard*density	4	0.060	0.015	1.6678	0.1902
Error	24	0.216	0.009		
Total	53	5.158			

Appendix Table 3: Analysis of variance of number leaves per seedling for the effect of seedling density and hardening treatment at Chinyudze during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Season	1	75.852	75.852	40.3547	0.0002
Rep(Season)	4	0.963	0.241	0.1281	

Hardening	2	9.926	4.963	2.6404	0.1317
Season(Hardening)	2	0.593	0.296	0.1576	
Error	8	15.037	1.880		
Density	2	107.704	53.852	107.7037	0.0000
Season (density)	2	16.593	8.296	16.5926	0.0000
Hardening(density)	4	9.074	2.269	4.5370	0.0072
Sea*Hard*density	4	5.296	1.324	2.6481	0.0581
Error	24	12.000	0.500		
Total	53	253.037			

Appendix Table 4: Analysis of variance of plant height (cm) for the effect of seedling density and hardening treatment at Chinyudze during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	175.333	58.444	9.6073	0.0104
Hardening	2	402.389	210.194	33.0731	0.0006
Error	6	36.500	6.083		
Density	2	907.389	453.694	42.6078	0.0000
H * D	4	510.278	127.569	11.9804	0.0001
Error	18	191.667	10.648		
Total	35	2223.556			

Appendix Table 5: Analysis of variance of total yield (kg/ha) for the effect of seedling density and hardening treatment at Chinyudze during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	98317.669	32772.556	3.1539	0.1075
Hardening	2	487234.840	243617.42	23.4444	0.0015
Error	6	62346.386	10391.064		
Density	2	399990.628	199995.314	11.1574	0.0007
H * D	4	191708.167	47927.042	2.6738	0.0655
Error	18	322648.721	17924.929		
Total	35	1562246.411			

Appendix Table 6: Analysis of variance of marketable yield (kg/ha) for the effect of seedling density and hardening treatment at Chinyudze during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	10058.980	3352.993	1.5643	0.2929

Hardening	2	208021.274	104010.637	48.5234	0.0002
Error	6	12861.082	2143.514		
Density	2	126301.928	63150.964	9.0223	0.0019
H * D	4	132233.493	33058.373	4.7230	0.0088
Error	18	12989.395	6999.411		
Total	35	615466.151			

Appendix Table 7: Analysis of variance of field establishment (plants m^{-2}) for the effect of seedling density and hardening treatment at Chinyudze during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	0.133	0.044	0.3220	
Hardening	2	3.538	1.769	12.8884	0.0067
Error	6	0.823	0.137		
Density	2	10.729	5.365	48.6999	0.0000
H * D	4	1.823	0.456	4.1376	0.0150
Error	18	1.983	0.110		
Total	35	19.029			

Appendix Table 8: Analysis of variance of field establishment (plants m^{-2}) for the effect of seedling density and hardening treatment at Chinyudze during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	3.504	1.168	2.1443	0.1959
Hardening	2	2.027	1.013	1.8601	0.2352
Error	6	3.269	0.545		
Density	2	7.204	3.602	10.1517	0.0011
H * D	4	0.661	0.165	0.4656	
Error	18	6.387	0.355		
Total	35	23.052			

Appendix Table 9: Analysis of variance of total yield (kg/ha) for the effect of seedling density and hardening treatment at Dengedza during the 2000/1 season

SOURCE	DF	SS	MS	F	P

Replication	3	122648.001	40882.667	1.1938	0.3888
Hardening	2	13783.223	6891.612	0.2012	
Error	6	205477.242	34246.207		
Density	2	481955.597	240977.798	12.0465	0.0005
H * D	4	154755.618	38688.904	1.9341	
Error	18	360070.363	20003.909		
Total	35	1338690.044			

Appendix Table 10: Analysis of variance of field establishment (plants m^{-2}) for the effect of seedling density and hardening treatment at Dengedza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	0.913	0.304	1.0986	0.4196
Hardening	2	0.143	0.071	0.2581	
Error	6	1.662	0.277		
Density	2	12.860	6.430	29.0490	0.0000
H * D	4	2.353	0.588	2.6581	0.0666
Error	18	3.984	0.221		
Total	35	21.916			

Appendix Table 11: Analysis of variance of mean fruit mass (g) for the effect of seedling density and hardening treatment at Dengedza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	4.478	1.493	1.6655	0.2721
Hardening	2	0.032	0.016	0.0177	
Error	6	5.377	0.896		
Density	2	2.045	1.023	1.3503	0.2842
H * D	4	10.098	2.525	3.3340	0.0329
Error	18	13.630	0.757		
Total	35	35.660			

Appendix Table 12: Analysis of variance of marketable yield (kg/ha) for the effect of seedling density and hardening treatment at Dengedza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	47768.520	15922.840	1.0836	0.4247
Hardening	2	2053.387	1026.693	0.0699	
Error	6	88167.404	14694.567		
Density	2	147657.511	73828.755	10.4469	0.0010
H * D	4	31939.925	7984.981	1.1299	0.3737
Error	18	127207.394	7067.077		
Total	35	444794.141			

Appendix Table 13: Analysis of variance of plant height (cm) for the effect of seedling density and hardening treatment at Dengedza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	48.556	16.185	2.0909	0.2029
Hardening	2	80.222	40.111	5.1818	0.0493
Error	6	46.444	7.741		
Density	2	156.222	78.111	3.5371	0.0506
H * D	4	172.444	43.236	1.9579	0.1444
Error	18	397.500	22.083		
Total	35	901.889			

Appendix Table 14: Analysis of variance of total yield (kg/ha) for the effect of seedling density and hardening treatment at Dengedza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	61287.864	20429.288	0.9059	
Hardening	2	22685.756	11342.878	0.5030	
Error	6	135303.011	22550.502		
Density	2	30435.101	15217.550	5.0759	0.0179
H * D	4	33480.253	8370.063	2.7919	0.0577
Error	18	53964.109	2998.006		
Total	35	337156.094			

Appendix Table 15: Analysis of variance of field establishment (plants m^{-2}) for the effect of seedling density and hardening treatment at Dengedza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	0.322	0.107	0.4680	
Hardening	2	0.443	0.222	0.9654	
Error	6	1.378	0.230		
Density	2	1.620	0.810	9.5976	0.0015
H * D	4	1.015	0.254	3.0074	0.0460
Error	18	1.519	0.084		
Total					

APPENDIX TABLES FOR CHAPTER 5

Appendix Table 16: Analysis of variance of total yield (kg/ha) for the effect of hardening treatment and cultivar at University farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	302809.722	151404.861	0.2913	
Hardening	5	604986.806	120997.361	0.2328	
Cultivar	1	65450.694	65450.694	0.1259	
H * C	5	7598820.278	1519764.028	2.9243	0.0358
Error	22	11433290.278	519695.013		
Total	35	20005357.639			

Appendix Table 17: Analysis of variance of marketable yield (kg/ha) for the effect of hardening treatment and cultivar at University farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	357230.167	178615.083	0.6015	
Hardening	5	414637.667	82927.533	0.2793	
Cultivar	1	284089.000	284089.000	0.9567	
H * C	5	4695928.000	939185.600	3.1628	0.0267
Error	22	6532889.176	296949.508		
Total	35	12284774.000			

Appendix Table 18: Analysis of variance of total yield (kg/ha) for the effect of hardening treatment and cultivar at Mukada during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	94597.146	47298.573	0.9891	
Hardening	5	580420.177	116084.035	2.4276	0.0676
Cultivar	1	6864.124	6864.124	0.1435	
H * C	5	95069.045	19013.809	0.3976	
Error	22	1052005.623	47818.437		
Total	35	182895.115			

Appendix Table 19: Analysis of variance of marketable yield (kg/ha) for the effect of hardening treatment and cultivar at University farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	81936.698	40968.349	2.1855	0.1362
Hardening	5	172270.873	34454.175	1.8380	0.1469
Cultivar	1	98.671	98.671	0.0053	
H * C	5	60116.246	12023.249	0.6414	
Error	22	412405.466	18745.703		
Total	35	726827.953			

Appendix Table 20: Analysis of variance of field establishment (plants/m^{-2}) for the effect of hardening treatment and cultivar at University farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	398.167	199.083	2.0348	0.1546
Hardening	5	1168.583	233.717	2.3887	0.0711
Cultivar	1	38.028	38.028	0.3887	
H * C	5	1403.472	280.694	2.8689	0.0384
Error	22	2152.500	97.841		
Total	35	5160.750			

APPENDIX TABLES FOR CHAPTER 6

Appendix Table 21: Analysis of variance of total yield (kg/ha) for the effect of plant population and number of rows per ridge at Mugadza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	3540337.035	1180112.345	9.8800	0.0003
Plant population	3	1532103.477	510701.159	4.2756	0.0167
Rows per ridge	1	807180.411	807180.411	6.7578	0.0167
Plant pop x Rows	3	940366.786	313455.595	2.6243	0.0773
Error	21	2508344.283	119444.966		
Total	31	93238331.992			

Appendix Table 22: Analysis of variance of marketable yield (kg/ha) for the effect of plant population and number of rows per ridge at Mugadza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	985925.000	328641.667	10.3684	0.0002
Plant population	3	193473.438	64491.146	2.0346	0.1398
Rows per ridge	1	30628.125	30628.125	0.9663	
Plant pop x Rows	3	139079.688	46359.896	1.4626	0.2533
Error	21	665628.125	31696.577		
Total	31	2014734.375			

Appendix Table 23: Analysis of variance of total yield per plant (g) for the effect of plant population and number of rows per ridge at Mugadza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	158.074	52.691	5.3507	0.0068
Plant population	3	107.394	35.798	3.6353	0.0295
Rows per ridge	1	4.767	4.767	0.4841	
Plant pop x Rows	3	23.714	7.905	0.8027	
Error	21	206.797	9.847		
Total	31	500.747			

Appendix Table 24: Analysis of variance of number of fruits per plant for the effect of plant population and number of rows per ridge at Mugadza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	63.844	21.281	10.0640	0.0003
Plant population	3	41.594	13.865	6.5567	0.0027
Rows per ridge	1	22.781	22.781	10.7734	0.0036
Plant pop x Rows	3	11.344	3.781	1.7882	0.1803
Error	21	44.406	2.115		
Total	31	183.969			

Appendix Table 25: Analysis of variance of plant height for the effect of plant population and number of rows per ridge at Mugadza during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	3	1002.844	334.281	13.3864	0.000
Plant population	3	40.094	13.365	0.5352	
Rows per ridge	1	13.781	13.781	0.5519	
Plant pop x Rows	3	288.594	96.198	3.8523	0.0243
Error	21	524.406	24.972		
Total	31	1869.719			

Appendix Table 26: Analysis of variance of total yield (kg/ha) for the effect of plant population and number of rows per ridge at Mugadza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	100301.563	33433.854	1.1562	0.3499
Plant population	3	642348.171	214116.057	7.4043	0.0014
Rows per ridge	1	758.552	758.552	0.0262	
Plant pop x Rows	3	159770.910	53256.970	1.8417	0.1705
Error	21	607269.994	28917.619		
Total	31	1510449.189			

Appendix Table 27: Analysis of variance of marketable yield (kg/ha) for the effect of plant population and number of rows per ridge at Mugadza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	42083.201	14027.734	1.2212	0.3267
Plant population	3	135029.332	45009.777	3.9185	0.0229
Rows per ridge	1	6266.399	6266.399	0.5455	
Plant pop x Rows	3	81514.734	27171.578	2.3655	0.0999
Error	21	241216.903	11486.519		

Total	31	506110.568

Appendix Table 28: Analysis of variance of number of fruits per plant for the effect of plant population and number of rows per ridge at Mugadza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	40.125	13.375	3.7018	0.0278
Plant population	3	24.375	8.125	2.2488	0.1124
Rows per ridge	1	1.125	1.125	0.3114	
Plant pop x Rows	3	3.375	1.125	0.3114	
Error	21	75.875	3.613		
Total	31	144.857			

Appendix Table 29: Analysis of variance of plant height (cm) for the effect of plant population and number of rows per ridge at Mugadza during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	3	52.844	17.615	0.8736	
Plant population	3	23.344	7.781	0.3859	
Rows per ridge	1	101.531	101.531	5.0357	0.0357
Plant pop x Rows	3	26.094	8.698	0.4314	
Error	21	423.406	20.162		
Total	31	627.219			

Appendix Table 30: Analysis of variance of total yield (kg/ha) for the effect of plant population and number of rows per ridge at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	3	74423.547	24807.849	0.4644	
Plant population	3	35327.380	11775.793	0.2204	
Rows per ridge	1	301.352	301.352	0.0056	
Plant pop x Rows	3	72626.765	24208.922	0.4532	
Error	21	1121803.229	53419.201		
Total	31	1304482.272			

Appendix Table 31: Analysis of variance of marketable yield (kg/ha) for the effect of plant population and number of rows per ridge at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	3	70231.048	23410.349	0.8230	
Plant population	3	11913.166	3971.055	0.1396	
Rows per ridge	1	660.662	660.662	0.0232	
Plant pop x Rows	3	66757.034	22585.678	0.7940	

Error	21	597349.726	28445.225
Total	31	747911.636	

Appendix Table 32: Analysis of variance of plant height (cm) for the effect of plant population and number of rows per ridge at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	3	36.313	12.104	0.3539	
Plant population	3	48.378	16.126	0.4715	
Rows per ridge	1	3.713	3.713	0.1085	
Plant pop x Rows	3	219.658	73.219	2.1406	0.1255
Error	21	718.294	34.204		
Total	31	1026.357			

Appendix Table 33: Analysis of variance of mean fruit mass (g) for the effect of plant population and number of rows per ridge at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	3	1.705	0.568	1.0529	0.3900
Plant population	3	1.132	0.377	0.6994	
Rows per ridge	1	0.361	0.361	0.6693	
Plant pop x Rows	3	0.326	0.109	0.2013	
Error	21	11.335	0.540		
Total	31	14.860			

Appendix Table 34: Analysis of variance of number of fruits per plant for the effect of plant population and number of rows per ridge at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	3	49.229	16.410	2.4911	0.0882
Plant population	3	2.203	0.734	0.1115	
Rows per ridge	1	3.569	3.569	0.5418	
Plant pop x Rows	3	33.842	11.281	1.7124	0.1951
Error	21	138.337	6.587		
Total	31	227.181			

Appendix Table 35: Analysis of variance of final plant density (plants m^{-2}) for the effect of plant population and number of rows per ridge at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	3	365.844	121.948	0.8808	
Plant population	3	152.094	50.698	0.3662	

Rows per ridge	1	11.281	11.281	0.0815	
Plant pop x Rows	3	610.844	203.615	1.4707	0.2512
Error	21	2907.406	138.448		
Total	31	4047.469			

APPENDIX TABLES FOR CHAPTER 7

Appendix Table 36. Soil analysis results for Sanhi and Mhiripiri sites in 2000/1 and 2001/2

Site	Colour	Texture	pH	Mineral N (ppm)		Available P2O5 (ppm)	Exchangeable cations (ME/100g)		
				Initial	After Incubation			K	Ca
Mg Sanhi									
2000/01	P/B	MG/S	4.7	13	30	1	0.21	1.86	0.83
2001/02	P/B	MG/S	5.2	48	69	22	0.31	1.98	0.60
Mhiripiri									
2001/02	P/B	MG/S	4.0	19	42	5	0.17	1.39	0.57

Key

P/B - pale brown

MG/S - medium grained sand

ME/100g - milliequivalents per 100g

Calcium chloride pH values

below 4.5	very strongly acidic	5.5 – 6.0	slightly acid
4.5 – 5.0	strongly acidic	6.0 – 6.5	neutral
5.0 – 5.5	medium acid	7.5 – 7.0	mildly alkaline

Appendix Table 37: Chemical content of cattle manure from Sanhi and Mhiripiri sites for 2001/2 season

Site	Total N	Total P	K%	Organic matter (%)
Sanhi	2.29	2.36	0.97	34.74
Mhiripiri	2.48	2.84	0.96	63.05

Appendix Table 38: Analysis of variance of plant height (cm) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	818.000	409.000	11.109	0.0005
Basal fertiliser	3	395.194	131.731	3.578	0.0302
Top dressing	2	83.167	41.583	1.129	0.3413
Basal*Top	6	68.389	11.398	0.310	
Error	22	810.000	36.818		
Total	35	2174.750			

Appendix Table 39: Analysis of variance of total yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	9636.418	4818.209	3.7109	0.0409
Basal fertiliser	3	17134.934	5711.645	4.3991	0.0144
Top dressing	2	32639.124	16319.562	12.5692	0.0002
Basal*Top	6	11147.322	1857.887	1.4309	0.2477
Error	22	28564.329	1298.379		
Total	35	99122.128			

Appendix Table 40: Analysis of variance of marketable yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	2035.831	1017.915	4.5321	0.0225
Basal fertiliser	3	3235.224	1078.408	4.8015	0.0101
Top dressing	2	5464.509	2732.254	12.1650	0.0003
Basal*Top	6	2649.910	441.652	1.9664	0.1145
Error	22	4941.192	224.600		
Total	35	18326.666			

Appendix Table 41: Analysis of variance of number of fruits per plant for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	0.534	0.276	2.118	0.1441
Basal fertiliser	3	2.230	0.743	5.897	0.0041

Top dressing	2	3.096	1.548	12.281	0.0003
Basal*Top	6	1.038	0.173	1.372	0.2692
Error	22	2.773	0.126		
Total	35	9.670			

Appendix Table 42: Analysis of variance of fruit length (cm) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	14.597	7.299	1.657	0.2136
Basal fertiliser	3	55.632	18.544	4.210	0.0170
Top dressing	2	129.597	64.799	14.711	0.0001
Basal*Top	6	37.347	6.225	1.413	0.2540
Error	22	96.903	4.405		
Total	35	334.076			

Appendix Table 43: Analysis of variance of mean fruit mass (g) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2000/1 season

SOURCE	DF	SS	MS	F	P
Replication	2	3.767	1.884	4.482	0.0233
Basal fertiliser	3	6.437	2.146	5.105	0.0078
Top dressing	2	20.217	10.109	24.052	0.0000
Basal*Top	6	1.812	0.302	0.7184	
Error	22	9.246	0.420		
Total	35	41.479			

Appendix Table 44: Analysis of variance of plant height (cm) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	468.222	234.111	8.873	0.0015
Basal fertiliser	3	587.667	195.889	7.425	0.0013
Top dressing	2	6.056	3.028	0.1148	
Basal*Top	6	74.833	12.472	0.4727	
Error	22	580.444	26.384		
Total	35	1717.222			

Appendix Table 45: Analysis of variance of total yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P

Replication	2	11628.132	58109.066	3.0847	0.0659
Basal fertiliser	3	401854.019	133951.340	7.1107	0.0016
Top dressing	2	17696.405	8848.202	0.4697	
Basal*Top	6	110689.620	18448.270	0.9793	
Error	22	414435.735	18837.988		
Total	35	1060893.911			

Appendix Table 46: Analysis of variance of marketable yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	31883.482	15941.741	1.6493	0.2151
Basal fertiliser	3	131462.791	43820.930	4.5336	0.0128
Top dressing	2	20818.927	10409.464	1.0769	0.3579
Basal*Top	6	62156.099	10359.350	1.0718	0.4089
Error	22	212646.775	9665.763		
Total					

Appendix Table 47: Analysis of variance of number of final plant density (plants/m^{-2}) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	742.056	371.028	12.7685	0.0002
Basal fertiliser	3	642.889	214.296	7.3748	0.0013
Top dressing	2	72.056	36.028	1.2399	0.3089
Basal*Top	6	127.944	21.324	0.7338	
Error	22	639.278	29.058		
Total	35	2224.223			

Appendix Table 48: Analysis of variance of total yield per plant (g) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	32.933	16.467	2.5801	0.0985
Basal fertiliser	3	171.591	57.197	8.9621	0.0005
Top dressing	2	2.574	1.287	0.2017	
Basal*Top	6	41.451	6.908	1.0825	0.4030
Error	22	140.407	6.382		
Total	35	388.956			

Appendix Table 49: Analysis of variance of marketable yield per plant (g) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P

Replication	2	18.754	9.377	2.7390	0.0867
Basal fertiliser	3	52.135	17.378	5.0761	0.0080
Top dressing	2	6.102	3.051	0.8912	
Basal*Top	6	19.581	3.263	0.9533	
Error	22	75.318	3.424		
Total	35	171.891			

Appendix Table 50: Analysis of variance of total yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Mhiripiri farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	3170.397	1585.198	0.8615	
Basal fertiliser	3	36467.999	12156.000	6.6065	0.0024
Top dressing	2	452.948	226.474	0.1231	
Basal*Top	6	14346.948	2391.158	1.2995	0.2985
Error	22	40480.083	1840.004		
Total	35	94918.376			

Appendix Table 51: Analysis of variance of marketable yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Mhiripiri during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	2002.770	1001.385	1.0947	0.3522
Basal fertiliser	3	9207.756	3069.252	3.3551	0.0373
Top dressing	2	136.170	68.085	0.0744	
Basal*Top	6	5344.900	890.817	0.9738	
Error	22	20125.569	914.799		
Total	35	36817.165			

Appendix Table 52: Analysis of variance of plant height (cm) for the effect of basal fertiliser and timing of top dressing at Mhiripiri farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	4.389	2.194	0.1533	
Basal fertiliser	3	65.444	21.815	1.5238	
Top dressing	2	28.389	14.194	0.9915	
Basal*Top	6	74.056	12.343	0.8622	
Error	22	314.944	14.316		
Total	35	487.222			

Appendix Table 53: Analysis of variance of number of fruits per plant for the effect of basal fertiliser and timing of top dressing at Mhiripiri farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	2.722	1.361	1.1846	0.3246
Basal fertiliser	3	23.444	7.815	6.8015	0.0021
Top dressing	2	0.389	0.194	0.1692	
Basal*Top	6	2.722	0.454	0.3949	
Error	22	25.278	1.149		
Total	35	54.556			

Appendix Table 54: Analysis of variance of final plant density (plants/m^{-2}) for the effect of basal fertiliser and timing of top dressing at Mhiripiri farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	22.167	11.083	0.0540	
Basal fertiliser	3	7601.444	2533.815	12.3459	0.0001
Top dressing	2	38.000	19.000	0.0926	
Basal*Top	6	304.222	50.704	0.2471	
Error	22	4515.167	205.235		
Total	35	12481.000			

Appendix Table 55: Analysis of variance of total yield per plant (g) for the effect of basal fertiliser and timing of top dressing at Mhiripiri farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	2.332	1.166	1.6163	0.2213
Basal fertiliser	3	12.317	4.106	5.6911	0.0048
Top dressing	2	0.040	0.020	0.0277	
Basal*Top	6	6.697	1.116	1.5472	0.2096
Error	22	15.871	0.721		
Total	35	37.258			

Appendix Table 56: Analysis of variance of marketable yield per plant (g) for the effect of basal fertiliser and timing of top dressing at Mhiripiri farm during the 2001/2 season

SOURCE	DF	SS	MS	F	P
Replication	2	1.400	0.700	1.7394	0.1989
Basal fertiliser	3	3.512	1.171	2.9081	0.0574
Top dressing	2	0.010	0.005	0.0124	
Basal*Top	6	2.311	0.385	0.9567	
Error	22	8.856	0.403		
Total	35	16.089			

Appendix Table 57: Analysis of variance of plant height for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	23.722	11.861	0.6721	
Basal fertiliser	3	17.556	5.852	0.3316	
Top dressing	2	64.056	32.028	1.8147	0.1864
Basal*Top	6	90.611	15.102	0.8557	
Error	22	388.278	17.649		
Total	35	584.222			

Appendix Table 58: Analysis of variance of fruits per plant for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	7.722	3.861	1.2564	0.3043
Basal fertiliser	3	8.444	2.815	0.9159	
Top dressing	2	25.722	12.861	4.1849	0.0288
Basal*Top	6	10.722	1.787	0.5815	
Error	22	67.611	3.072		
Total	35	119.221			

Appendix Table 59: Analysis of variance of final plant density (plants/m^{-2}) for the effect of basal fertiliser and timing of top dressing at Sanhi farm during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	523.389	262.694	8.9655	0.0014
Basal fertiliser	3	499.417	166.472	5.6815	0.0049
Top dressing	2	67.389	33.694	1.1500	0.3350
Basal*Top	6	99.500	16.583	0.5660	
Error	22	644.611	29.301		
Total	35	1836.306			

Appendix Table 60: Analysis of variance of total yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Sanhi during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	154663.349	77331.675	1.6400	0.2168
Basal fertiliser	3	3452.770	1150.923	0.0244	
Top dressing	2	818359.045	409179.523	8.6774	0.0017
Basal*Top	6	171908.064	28651.344	0.6076	
Error	22	1037373.747	47153.352		
Total	35	2185756.974			

Appendix Table 61: Analysis of variance of marketable yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	48001.597	24000.799	0.9855	
Basal fertiliser	3	34608.430	11536.143	0.4737	
Top dressing	2	342219.963	171109.982	7.0260	0.0440
Basal*Top	6	20908.894	3484.816	0.1431	
Error	22	535783.973	24353.817		
Total	35	981522.857			

Appendix Table 62: Analysis of variance of plant height (cm) for the for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	24.889	12.444	0.6758	
Basal fertiliser	3	108.750	36.250	1.9686	0.1482
Top dressing	2	1413.389	706.694	38.778	0.0000
Basal*Top	6	410.833	68.472	3.7185	0.0105
Error	22	405.111	18.414		
Total	35	2362.972			

Appendix Table 63: Analysis of variance of fruits per plant for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	5.056	2.528	0.8742	
Basal fertiliser	3	25.861	8.620	2.9814	0.0534
Top dressing	2	585.722	292.861	101.2865	0.0000
Basal*Top	6	24.056	4.009	1.3866	0.2638
Error	22	63.611	2.891		
Total	35	704.306			

Appendix Table 64: Analysis of variance of shoot dry mass for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	9240.277	4620.138	2.3847	0.1155
Basal fertiliser	3	6909.462	2303.254	1.1888	0.3369
Top dressing	2	224567.363	112283.682	57.9566	0.0000
Basal*Top	6	19705.561	3284.260	1.6952	0.1694
Error	22	42622.221	1937.374		
Total	35	303044.884			

Appendix Table 65: Analysis of variance of final plant density (plants m^{-2}) for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	23.389	11.694	0.8873	
Basal fertiliser	3	84.444	28.148	2.1358	0.1246
Top dressing	2	6.056	3.028	0.2297	
Basal*Top	6	53.056	8.843	0.6709	
Error	22	289.944	13.179		
Total	35	456.889			

Appendix Table 66: Analysis of variance of total yield (kg/ha) for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	69751.529	34875.765	0.4847	
Basal fertiliser	3	101286.906	33762.302	0.4692	
Top dressing	2	6673587.387	3336793.694	46.3700	0.0000
Basal*Top	6	669438.296	111573.049	1.5505	0.2087
Error	22	1583124.418	71960.201		
Total	35	9097188.537			

Appendix Table 67: Analysis of variance of marketable yield for the effect of basal fertiliser and timing of top dressing at Kunyongana during the 2002/3 season

SOURCE	DF	SS	MS	F	P
Replication	2	101443.167	50721.584	3.0634	0.0670
Basal fertiliser	3	41500.353	13833.451	0.8355	
Top dressing	2	3162852.507	1581426.254	95.5109	0.0000
Basal*Top	6	193328.175	32221.362	1.94360	0.1179
Error	22	364256.893	16557.541		
Total	35	3863381.095			