CHAPTER 1

INTRODUCTION

1.Background and justification

Paprika (*Capsicum annuum*) is a high value crop that began to be commercially produced in Zimbabwe in the last decade (2000-1990) (AGRITEX, 2000). It has the potential to be a major foreign currency earner, which is a great economic advantage, especially now that the tobacco market is very unpredictable in Zimbabwe. Globally there are some strong anti smoking campaigns. The world demand for paprika is estimated at between 50 000 tonnes and 60 000 tonnes per annum (AGRIKOR, 2000). In Zimbabwe, it is grown as a summer crop and requires 7 to 9-months from nursery establishment to harvesting. A food colourant called oleoresin is extracted from paprika fruit and is the major economic product from paprika. Despite the fact that Zimbabwe is still relatively new in paprika production and trade, it has built an international reputation of producing a high quality crop with high oleoresin content that competes favourably on the world market. In recent years, Zimbabwe and South Africa have produced between them the equivalent of one third of the world production and more than 85% of the Southern Hemisphere production (AGRIKOR, 2000).

Paprika in Zimbabwe is produced from an annual average of 6 610 hectares, from which a total annual overall production of 10 810 tonnes is harvested (AGRITEX, 2000). Within the past 5 years many smallholder farmers have started producing paprika and are becoming major producers. In the CRA for

example, farmers started to produce paprika on a large scale in 1996 (J. Kwaramba[1], *personal communication*). It is therefore no coincidence that the CRA is the heartland for paprika production by smallholder farmers (I. K. Mariga[2], *personal communication*). The yields obtained vary from less than one tonne per hectare in the communal areas to around six tonnes per hectare in the commercial farming sector (Hyveld Seed, 1996). These low yield figures recorded in the smallholder sector have been attributed to major problems associated with the production of paprika. Regardless of paprika's potential to boost the country's foreign exchange earning, it has received very little research attention, mostly by the private sector. There is limited availability and restricted access to paprika production information (AGRITEX, 2000). This has prevented smallholder producers from taking full advantage of the large paprika market.

The total annual production of paprika in Zimbabwe is far below the annual demand for processing and export to the international market (AGRITEX, 2000). Thus if Zimbabwe has to maintain or improve the paprika production volume and quality, the smallholder farmers' must be equipped with the relevant paprika production knowledge.

Major problems in paprika smallholder production highlighted during the workshop on Integrated Crop Management Research in 1998 in Chinyika include poor paprika field establishment and lack of disease and weed management information (Chivinge and Mariga, 2000). The effective control

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of diseases and weeds in the field is just one of the effective ways of ensuring the production of a high quality crop and has a great impact on yield of paprika. Santin (2001) reported that growth and fruit yield of both tomato and pepper were very sensitive to the presence of *Datura stramonium*. Light and nitrogen were the decisive competition factors in tomato and pepper fields against the weed *Datura* spp (Santin, 2001). Greater weed competition was also observed when paprika was directly sown rather than transplanted (Santin, 2001).

Disease control, especially in the nursery, is very important because healthy seedlings produced in the nursery will stand a greater chance of survival when transplanted onto the field (Fisher, 1991). Most paprika handbooks in Zimbabwe recommend fungicide spraying intervals ranging from seven to fourteen days. Although fungicide application maybe the most effective method of disease management, it is not financially sustainable for most smallholder paprika farmers. Residues of organic (synthetic) pesticides create food safety concerns and mounting pressure from various groups, environmentalists, and others to reduce the use of pesticides are creating a serious dilemma for the food processing industry (Bolkan and Ranert, 1994). Fungicides residues increases health risks for the consumer, export chemical residue limits and the cost of fungicides makes it imperative therefore to come up with a cost-effective and environmental friendly fungicide-spraying regime for smallholder paprika production in Zimbabwe.

1.1 Objectives

The main objective of this study was to develop cost effective crop protection practices in the nursery and field for paprika production in the smallholder sector of Zimbabwe.

1.1.1. Specific objectives

- To assess diseases occurring in the smallholder farmers' fields and the farmers' existing knowledge on paprika diseases, weeds, their identification and control.
- To compare seedbed sterilisation methods and their effect on disease and weed incidence in paprika nursery beds.
- To assess the effect of a reduced fungicide spray programme on disease incidence, severity and final yield of paprika.
- To assess the impact of selected weed management strategies on weed density, disease incidence, severity and final yield of paprika.

1.2 Hypotheses

- Chinyika Resettlement Area (CRA) smallholder farmers have limited knowledge of paprika diseases, weeds, their identification and control.
- Solarisation, burning of cowdung, brushwood or maizecobs as seedbed sterilisation methods are less effective than methyl bromide.
- Disease incidence and severity can be reduced and the final fruit yield of paprika enhanced by a regime of reduced fungicide sprays to the same levels as achieved by weekly fungicide applications.

- Oxidiazon (Ronstar) and Alachor (Lasso) will provide higher levels of weed control and reduce disease incidence, severity and increase final yield when compared to hand weeding in paprika.

1.3 Background of study area

1.3.1 Location

CRA is located in the Makoni District of Manicaland province. It lies between lat 18^{o} 02' and 18 ^{o} 17' S and 32 ^{o} 09' and 32 ^{o} 24' E with an altitude ranging from 700 - 1200 metres above sea level. CRA is 140km north east of Harare and 7 km from Headlands, which is the nearest service centre. It is divided into Chinyika East and West and was initiated by the government's programme to resettle people in 1982 after the attainment of Zimbabwe's independence in 1980. It is one of the first resettlement areas in Zimbabwe, with each family allocated an average of 6ha. The major crops grown in CRA are maize, tobacco, field beans and the recently fast-adopted paprika.

1.3.2 Climate

CRA spans three Natural Regions II, III and IV (Appendix 1), which relate to climate, soils and topography (Vincent and Thomas, 1961). A subtropical climate is experienced in CRA with three distinct seasons, namely, a dry winter from April - August with temperatures ranging from 7-21 ^{o}C, dry hot season starting in mid-September - November when temperatures are up to 30 ^{o}C and a rainy season normally starting in mid November and ends in late March to early April. In CRA paprika production is under dry land system.

1.3.3 Justification for working in CRA

- ✓ Individual land ownership of 6 ha per family provides an opportunity for farmers to diversify into cash crops such as paprika.
- ✓ Smallholder farmers requested for paprika production research as it is a relatively new crop in CRA and they would wish to make the most out of the economic empowerment growing the crop will offer.
- ✓ The area covers three ecological regions zones, hence the results from this work can be extrapolated to other areas and be used to boost paprika yields nationally and regionally.

CHAPTER 2

LITERATURE REVIEW

2.1 Background to the paprika crop

Paprika (*Capsicum annuum L.*) is a herbaceous perennial crop that is a member of the Solanaceae family and is closely related with Spanish pepper, bell pepper, cherry pepper, chilli pepper, pimento green pepper potato, tomato and tobacco (Rice, Rice and Tindall, 1987; Agrikor, 2000). It produces fruits that are longish, slender, thick pointed and slightly curved (AGRITEX, 2000). Paprika is grown for its pods, which have a smooth skin and thick flesh. Pods turn to the usable red crimson colour from which “oleoresin” is extracted (AGRITEX, 2000). In Zimbabwe, there are mainly three cultivars grown for commercial production, namely, UF 15, Papri King and Papri Queen. Paprika is grown as a rainfed annual crop in areas with 600 - 1250mm of annual in the smallholder sector (Mukaro, 1997). Paprika can be either sown directly, transplanted from seed trays or transplanted from seedbeds, however, seedbed production produces healthy and strong seedlings (Mukaro, 1997; AGRITEX, 2000). The production of healthy, hardy seedlings is the first step in ensuring that a good and high yielding crop is obtained. Comparison of directly seeded sweet pepper in the field with plants raised in pots in a nursery and then transplanted revealed that transplanted plants exhibited a faster initial root growth and increased fruit growth (Leskovar, Cantliffe and Stofella, 1990). There is therefore justification for adopting the more common method of raising paprika seedlings in a nursery bed and then transplanting these

onto the field. All of the paprika grown in the smallholder-farming sector of Zimbabwe is first raised in a nursery (AGRITEX, 2000).

Sterilisation of seedbeds is a common practice in the production of Solanaceous crops such as tobacco, tomatoes, eggplant and paprika. Generally, fields for pepper-transplant production are not fumigated and weeds and soil borne plant pathogens sometimes cause major losses. It is difficult to effectively control weeds even with recommended herbicides, when paprika is planted repeatedly on the same field (Jaworski, McCarter and Glaze, 1980). To date, effective seedbed sterilisation in the nursery has been achieved through the use of methyl bromide. However, with the impending ban of methyl bromide in the year 2015 under the Montreal Protocol (Noling and Gilreath, 2000 as cited by South Florida Research and Education Centre Homepage, 2000), suitable alternatives have to be found within the shortest possible time.

2.2. Diseases of economic importance in paprika production in Zimbabwe

There are several diseases that have been identified in paprika production in Zimbabwe. These can be arranged in descending order of economic importance as follows; powdery mildew (*Leveilulla taurica* (Lev)), bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*), anthracnose (*Colletotrichum* spp), blossom end rot (physiological), damping off (*Pythium* spp and *Rhizoctonia* spp) and seedling root rots, wilt disease (*Sclerotium rolfsi),* Cercospora leaf spot (*Cercospora unamunoi (Cast.)*), Stemphylium leaf

spot (*Stemphylium solani*), Phytophthora blight (*Phytophthora* spp), bacterial soft rot (*Erwinia* spp), alternaria rot (*Alternaria* spp) and viral infection (Potato Y and Tobacco Mosaic virus) (Hyveld Seed, 1996).

2.2.1 Fungal diseases

Powdery mildew is caused by *Leveilulla taurica (Lev)* (Masuka, Cole and Mguni, 1998). It is usually observed on the older parts of plants and is rarely seen on young plants. The first evidence of the disease is observed in January, when, a mid-season drought is usually experienced in Zimbabwe (Hyveld Seed, 1996). Powdery mildew represents one of the biggest constraints to paprika production in Zimbabwe and this *L. taurica* pathogen has a very large host range (Hyveld Seed, 1996).

Anthracnose is caused by *Colletotrichum piperatum* and *Colletotrichum parasitica.* It is usually observed late in the season as it mainly affects the paprika pods or observed as a post harvest disease. *Sclerotium rolfsii* is a soil borne pathogen that causes a wilt disease (Masuka *et al*., 1998) of economic importance in Zimbabwe.

Cercospora leaf spot or frogeye is caused by the fungus *Cercospora unamunoi (Cast.)* (Masuka *et al*., 1998). In Zimbabwe, the disease has not been of any significance as it has only been observed in isolated instances (Hyveld Seed, 1996). *Stemphylium solani (Weber)* causes Stemphylium leaf spot. On peppers, it causes minute light brown spots on young leaves, which expand, developing red brown margins with distinct white centres as the

leaves mature (Ellis and Gibson, 1975). Stemphylium leaf spot is a disease of virtually no economic significance in Zimbabwe to-date (Hyveld Seed, 1996).

The two causative agents of Phytophthora blight disease are *Phytopthora capsici (Leonian)* and *Phytophthora infestans (Mont)*. *P. capsici* causes stem and fruit rots on older plants. *Phytophthora infestans (Mont)* causes late blight in solanaceous crops and affects the leaves, stems and fruits. The disease was observed in one isolated incident in Zimbabwe, but it is of major economic significance in New Mexico, probably due to continual production over a number of years and due to the practice of poor rotation (Hyveld Seed, 1996).

Alternaria blight, also known as early blight, is caused by *Alternaria solani*. Early blight affects leaves, stems and the fruits. The leaf symptoms observed are circular, brown spots with concentric rings, which appear on the older leaves first and then progress up the plant (Hyveld Seed, 1996).

2.2.2. Bacterial diseases

Bacterial spot on paprika is caused by the bacterium *Xanthomonas campestris* pv. *vesicatoria.* This bacterium has a narrow host range and may infect other solanaceous plants, such as tomato, potato, *Datura stramonium* and *Physalis* sp. It is seed-borne (Higgins, 1922, Stapleton, 1996). Disease spread is favoured by long periods of high relative humidity such as those experienced under the summer rainfall conditions in Zimbabwe (Hyveld Seed, 1996). Bacterial soft rot is caused by the bacterium *Erwinia carotovora*

(Masuka *et al*., 1998). Bacterial soft rot can be distinguished from other pod rots by the classical foul bacterial smell that it produces (Hyveld Seed, 1996).

2.2.3. Viral diseases

There are a number of viruses that attack paprika, but those that are present in Zimbabwe are Alfalfa Mosaic Virus, Cucumber Mosaic Virus, Potato Y Virus, Tobacco Mosaic Virus and Tomato Spotted Wilt Virus (Hyveld Seed, 1996). Older paprika plants survive tobacco mosaic virus better than younger ones (Igwegbe and Ogungbade, 1985).

2. 2.4 Disease management

Control of the fungal and bacterial disease is being achieved mainly by the use of fungicides. At present there is pressure from environmentalists and consumer groups to reduce the use of pesticides. Implementation of integrated pest management among growers as a biologically and environmentally sound approach to pest control is supported and promoted as a means to significantly reduce the amount of pesticides applied to a crop (Bolkan and Ranert, 1994). Fungicides and pesticides in paprika production constitute about 30% of the total production cost per hectare (Mukaro, 1997). Under such economic and social conditions, methods of disease control that are environmentally and economically sustainable must be found to meet the needs of the farmer and the society.

In a test of 10 fungicides against paprika disease caused by *P*. *nicotianae* var *nicotianae*, six sprays of copper oxychloride (0.3%) at 10-day intervals proved

the most effective in checking infection and increasing yield (Bhardwaj and Sharma, 1985). Mancozeb and 0.3% Blitox at 0.25% and 200 p.p.m respectively reduced bacterial leaf spot and fruit rot diseases of chilli caused by *Xanthomonas campestris* pv. *vesicatora* and *Colletotrichum capsici (Syd)* (Raju and Rao, 1984). Application of mancozeb and 0.3% Blitox at 5, 10, 15 or 20 days interval revealed that although yield rose with decreasing spray interval, the net profit was highest with 15-day interval (Raju and Rao, 1984). Application of *Trichoderma harzianum* to soil or by coating tomato fruits reduced *Rhizoctonia solani* fruit rot by up to 43% and 85%, respectively, under laboratory and field conditions (Strashnov, Elad, Sivan, Rudich and Chet, 1985). Spraying fungicides only after scouting could probably reduce the frequency of fungicide spraying and consequently spray volume per hectare; thereby the cost of disease management is reduced. Vos and Duriat (1995) reported a 72% yield reduction in unsprayed plots as compared to sprayed plots in Indonesia yield.

Much has been documented on the incidence of viral disease in paprika. One major recommendation on viral disease management has been to adhere to recommended planting times, crop rotations and proper field sanitation (Hyveld, 1996)

Disease control, especially in the nursery, is very important because healthy seedlings produced in the nursery will stand a greater chance of survival when transplanted onto the field (Fisher, 1991). There are different ways to achieve the nursery sterilisation.

2.3. Seedbed sterilisation

A seedling grown in an area that is disease and pest-free and where there is no competition from weeds has a better chance of growing into a strong and high yielding plant (Way, 1991). Traditionally in the commercial sector, seedbeds are usually sterilised using methyl bromide as a fumigant but other alternatives are now being tested, so that methyl bromide can be replaced.

2.3.1 Methyl bromide

Methyl bromide is a very effective fumigant, which controls disease pathogens, nematodes and weeds and it is a difficult task to find alternative chemicals that will match its efficacy (Flower, Cole, Cottrell, Thomas, Way and Maposa, 2000). The use of methyl bromide as a seedbed fumigant in the smallholder sector never became popular, even for the tobacco growers, due to the high cost of the chemical and the lack of technical know-how on how to effectively apply the chemical (J. Kwaramba, *personal communication*). Methyl bromide is to be phased out due to its adverse effect on the environment, particularly its deleterious effect on the ozone layer (MBTOC, 1994).

2.3.2 Sterilisation using dry heat

The burning of wood (dry heat) is not a new technique as it has been used in the past for the sterilisation of tobacco seedbed (Akehurst, 1981). In CRA, some communal farmers burn maize cobs and cow dung as fuel for dry heat treatment in tobacco and paprika seedbed sterilisation. Burning is more effective when the soil is slightly damp and the weather is calm (Garmany and

Bates, 1957). Garner (1951) reported that burning was effective in killing weed seeds in the upper soil layer but it did not adequately control soil-borne diseases and was therefore not suitable for use in the permanent tobacco seedbeds used at the time. Burning of 45 to 60 cm layer of brushwood or a 15 cm layer of maize cobs, followed by scraping off the surplus ash, produced excellent seedlings with absence of weed growth (Akehurst, 1981). However, care must be taken to remove most of the ash from the surface of the beds, failure of which may result in poor and uneven seedlings, due to excess alkalinity and soluble salts (Garmany and Bates, 1957). A draw back is that this method is not environmentally friendly, particularly in areas of high human population.

2.3.2 Biological methods of soil sterilisation

Biological control agents are generally highly specific, but some control a wide range of pathogens. *Trichoderma* species, for example, are used to control *Rhizoctonia* in tobacco seedbeds (MBTOC, 1994). Biological control of *Rhizoctonia solani* and *Fusarium solani* infections in tobacco transplants was achieved by adding *Trichoderma harzianum* to methyl-bromide-fumigated seedbed before seed was sown (Cole and Zvenyika, 1988). Tobacco seedlings from seedbeds treated with *Trichoderma* resulted in greater growth uniformity in the field as indicated by the number of plants topped at first topping, than in a block planted with seedlings from an untreated seedbed (Cole, 1991). Biological control plays an important role in Integrated Pest Management (IPM) approaches, but used alone it does not meet the requirements of intensive production systems (MBTOC, 1994; Rodriguez-

Kabana and Martinez-Ochoa, 1995, Miller, 1996, as cited by U.S.E.P.A, 2002).

2.3.3. Soil solarisation

Solarisation is a method of soil treatment using trapped solar radiation, in which the soil is covered with plastic for four to eight weeks in order to raise temperature sufficiently to suppress or eliminate soil-borne pests, weeds and pathogens (Stapleton, 1996; P.A.N.N.A., 2000). It can raise temperature by 2-15 ^{O}C above the ambient soil (U.S.E. P. A., 1996). Solarisation also causes complex changes in the biological, physical and chemical properties of the soil that improve plant development, growth, quality and yield for up to several years (Devay, Stapleton and Elmore, 1990; Stapleton, 1996; U.S.E. P. A., 1996). The success of soil solarisation is based on the fact that most plant pathogens and pests are mesophilic or unable to survive for long periods at temperatures above 37^{O}C (U.S.E. P.A., 1996). Pathogens may be killed either directly by the heat or are weakened by sub-lethal heat to the extent that they are unable to damage crops (U.S.E. P. A, 1996; DeVay, Stapleton, Elmore, 1990). Solarisation is a viable soil sterilisation method for smallholder farmers as it is a simple method that does not require expensive equipment and a lot of technical knowledge. Solarisation leaves no toxic residues in the soil and is therefore environmentally friendly. Concern, however, has been raised over the environmental impact of the plastics used.

2.3.4. Chemical methods of soil sterilisation

Not only non chemical alternatives to methyl bromide for fumigation of seedbeds are being sought, other chemicals with equal efficacy to methyl bromide but which do not affect the ozone layer are being investigated.

2.3.4.1. Burn and Ethyl-Dibromide (EDB)

Burning brushwood or maize cobs and followed by applying Ethyl-Dibromide at a rate of 35ml/m^2 has potential as an alternative to methyl bromide (Flower *et al.*, 2000). However, the burn and EDB treatment is unlikely to be recommended as an alternative because of environmental implications of burning (Flower *et al*., 2000).

2.3.4.2. EDB/Metham sodium (Vapam^R)

Metham sodium is supplied in a liquid form that can be applied as a drench using a watering can to small areas and then EDB is applied at its recommended rates on the same day, immediately after applying metham sodium. The combination of metham sodium and EDB was highly effective (Flower *et al.*, 2000). It is likely to be recommended, however further work is still being done to determine the best application rates for the chemicals.

2.3.4.3. 1, 3-dichloropropene (1, 3-D) (Telonell^R) and chloropicrin (C-35)

A mixture of 1, 3-D/C-35 is more difficult to handle than EDB or 1, 3-D on their own due to the presence of the eye and nose irritant chloropicrin (Flower *et al*., 2000). The mixture of 1, 3-D/C-35 has some herbicidal control on grasses (Flower *et al*., 2000). Combination of 1, 3-dichloropropene with a herbicide

and chloropicrin has been found to provide efficacy approaching or equal to that of methyl bromide (Vick, Caulkins and Zapp, 2000). Its major drawbacks are its requirement for complete protective clothing (moon suits) and full face respirators while fumigation is in progress and a 90-metres buffer zone (untreated area) between the treated area and any occupied dwellings (Vick *et al*., 2000). There is no effective herbicide registered to partner with 1, 3 dichloropropene/Chloropicrin for peppers in U.S.A (Vick *et al*., 2000). TeloneII® chemical is also suspected to be a human carcinogen (MBTOC, 1994).

2.3.4.4. Methyl iodide

Methyl iodide works in the same way as methyl bromide (Stepanovich, 1988). It was equal to or better than methyl bromide in tomatoes on the control of soil-borne fungi, nematodes and weeds (Ohr, Sims, Grech, Becker and Mc Giffen, 1996). Pest organisms that are equally or better controlled with methyl iodide than methyl bromide include *Phytopthora critical, Phytopthora cinnamoni, Phytopthora parasitica, Rhizoctonia solani,* the nematode *Heteordera schachtii* and the weeds *Cyperus rotundus, Poa annua, Portulaca oleracea* and *Sisymbrium irio* (MBTOC, 1994). Methyl iodide was 2.7 times more efficacious than methyl bromide in controlling fungi (Hutchinson, Mc Giffen, Ohr, Sims and Becker, 2000). Presently fumigation of paprika nursery using methyl iodide controls fungi such as *Phytopthora cinnamoni*, *P. parasitica* and *Rhizoctonia solani* (Ohr *et al*., 1996). The only drawback of methyl iodide is that it is more expensive than methyl bromide (Stepanovich, 1998).

2.3.4.5. Dazomet (Basamid^{R}) and Methyl Isothiocyanate

Methyl isothiocyanate had little control of the bacterial wilt disease in tomatoes (Murakoshi and Takahashi, 1984). Dazomet is being recommended for use in Zimbabwe on crops such as paprika and tobacco (Flower *et al.*, 2000).

Although a number of chemicals are being tested, none of them seems to offer the broad-spectrum disinfestation features of methyl bromide (MBTOC, 1994). Metham sodium and 1, 3-D and are suspected or proven carcinogenic or teratogenic compounds and so pose similar threats to human health and the agro-ecosystem as methyl bromide (MBTOC, 1994).

2.4. Weed management

Several studies have found that pepper (*Capsicum annuum*) is a poor competitor against weeds (Frank, Schwartz and Bourke, 1998; Lagoke Adejonwo, Nongu, Uwannah and Lawal, 1998). Eshel, Katan and Palevitch (1973) found that weed competition during one month after pepper emergence caused a 70% yield reduction. Yield losses from unrestricted weed growth can be serious in paprika. In Israel, losses of about 36-56% in pepper fruit were reported by Eshel *et al*. (1973), when weeds were allowed to compete with the crop for thirty days following transplanting. Weed control increased marketable transplant yield by 81% over unweeded seedbeds (Jaworski, McCarter and Glaze, 1980). Weed infested conditions reduced yield of tomatoes by 57-60% when compared with weed free conditions. Even though some chemicals such as diphenamid are generally used, weed control

is difficult because paprika seed germinates slowly (Taylorson, 1965). Weeds are not only primary pests themselves but can reduce the efficacy of other alternative strategies such as crop rotation and fallow for the management of plant parasitic nematodes (Noling and Gilneath, 2000 as cited by South Florida Research and Education Centre Homepage, 2000).

Weeds compete with the crop for water, nutrients and sunlight and also serve as hosts to many pests and diseases (Labrada and Paredes, 1983 as cited in Lagoke et al 1998). In Sudan, yield losses due to weeds are estimated at 65 - 93% for cotton, 85% for sorghum, 60% for maize and 63 - 88% for groundnuts (Deat, 1984). There is no documented evidence that yield losses caused by weeds to paprika have been determined in Zimbabwe.

In drier seasons, hand hoe weeding was more economic than applying herbicides in maize (Chivinge, Musambasi and Mariga, 1999). Hand hoe weeding done once in addition to a herbicide application significantly increased yield of tomato (Singh, Bhan and Tripathi, 1984). However, the use of hand hoe weeding has sometimes proved ineffective, resulting in the abandonment of crop fields to weeds by farmers, as they are unable to cope with the extent of weeding required (A.B.Mashingaidze[3], *personal communication*).

Research has shown that transplanted pepper should be kept weed-free for the first 60 days after planting to achieve maximum yield (Labrada and

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Paredes, 1983 as cited in Lagoke et al 1998). This can effectively be done using herbicides that have been recommended for use in paprika such as Alachlor and Oxidiazon for the control of grass weeds (Hyveld Seed, 1996). Pre-emergence application of metribuzin, alachlor and nitrofen produced significantly more paprika yield than non-treated plots (Singh *et al*., 1984).

CHAPTER 3

GENERAL MATERIALS AND METHODS

All the trials were carried out in CRA located in Manicaland province. CRA is mainly divided into West and East, it spans over Natural Regions IIa, IIb and IIIa. The major centres are Chinyudze (NRIIIa) in CRA West and Bingaguru (NRIIb) in the East. In this study each field experiment had two sites one in the East and the West of CRA in both 2000/2001 and 2001/2002 rainy season. All the field trials were under dryland systems.

In all experiments the variety Papri King certified seed was used.

3.1 Site selection

All sites both nursery and field were selected fundamentally on the basis of the field having not grown paprika or any other crop belonging to the Solanaceae family in past three years. This was so in order to avoid the risk of disease carry-over, from soil-inhabiting pathogens. Sites with the same name over two seasons means they were hosted by the same farmer over the two seasons but on a different piece of land each season.

3.2 Land preparation and management

Land preparation was done using an ox-drawn plough. The land was harrowed to a fine tilth after ploughing and then ridges of 90 cm apart were made.

3.3 Nursery establishment and management

For the fungicide and herbicide trials, paprika seeds were sown on seedbeds five days after dry heat sterilisation with brushwood. Compound S (7%N: 27%P_2O_5; 7%K_2O) was incorporated in the seedbed at a rate of 1kg/m^2. Rows spaced at 5 cm were marked across the seedbed length. The seedbeds were sown by hand drilling 100 seeds/m. Seedbeds were grass mulched soon after sowing and mulch removed soon after seedling emergence. Watering was done three times a day at 0800hrs, 1200hrs and 1700hrs until the seedling emergence with a watering can fitted with a fine sprayer. After emergence the seedbeds were watered twice a day at 0800hrs and 1700hrs. Hardening, by withholding of water and watering when seedlings began to show signs of wilting was carried out from 5 to 10 weeks after sowing.

3.4 Field trials

Paprika was transplanted onto the ploughed and ridged fields between 25 November and 15 December of each season depending on the onset of the first effective rains. The seedlings had spent 10 – 13 weeks in the nursery and were 15-20cm long.

A basal dressing of compound L (5%N: 17%P_2O_5; 10%KCl) was applied at a rate of 1000 kg/ha before transplanting onto ridges. In all field trials inter and intra row spacings of 90 cm and 20 cm respectively were used. One paprika seedling was transplanted per planting station and gap filling was done within the first 2 weeks to guarantee attainment of the desired plant population. This resulted in a theoretical plant population of 55 555 plants per hectare. Each

plot had five rows each 5 m long. This resulted in a gross plot size of 22.5 m^2. Of the gross plot, two outer paprika rows i.e. one from either side, plus 0.6 m on both sides of the plot length were discarded, thus giving a net plot size of 10.26 m^2 (57 plants) from which all records were collected. The crop was top dressed with Ammonium nitrate (34.5%N) in 2 splits at a rate of 350 kg/ha, half of which was applied at 4 weeks after transplanting (WAT) and the other half at 8 WAT. In addition, Potassium chloride (60% KCl) at 350kg/ha was applied two equal splits at 4 WAT and 8 WAT.

3.5 Data collection

3.5.1 Disease severity score

General disease scouting was done at weekly intervals starting one week after transplanting up to a week before harvesting. Disease severity was scored using the following scale on randomly selected five plants from a total of 57 plants in the net plot, a differently randomly selected plants was used each time: Using the following subjective scoring scale (overall infection) data on disease severity was recorded:

0 – no disease

1 – very low severity

2 – low severity

3 – moderate severity

4 – high severity

5 – very high severity/ plant dead

The above scale was used in the first season (2000/2001). After the first season, it was determined that the scale was not adequately reflecting the

observable differences in disease severity, hence it was modified to two separate scales: one scoring for leaf and stem spots and the other for overall percentage of disease symptoms covering the whole plant.

Leaf and stem spots:

0 – no leaves and stems with spots

1 – 5 leaves with leaf spots and stem spot

2 – 6-10 leaves with leaf spots and stem spots

3 – 11-15 leaves with leaf spots and stem spots

4 – 16 and above leaves with leaf spots and stem spots

5 – plant dead

Percentage disease coverage (percentage infection) on the plant:

1- 0%

2- 1-20%

3- 21-40%

4- 41-60%

5- 61-80%

6- 81-100%

The original scale used in 2000/2001 season was not totally discarded in the second season, rather it was used alongside the modified scales. Disease severity assessments were done on five randomly chosen plants from a total of 57 plants in the net plot.

3.5.2 Disease incidence

Disease incidence data were obtained by randomly assessing the presence of disease symptoms such as leaf spots only and/or wilt and powdery mildew on 20 randomly chosen plants in the net plot. The number of plants showing symptoms was expressed as a percentage of the 20 plants.

Disease incidence data was calculated by using the formula below:

$$\text{Disease incidence} = \frac{n}{N} \times 100\ \%$$

Where n =number of plants infected by a disease

N= total number of plants assessed (20 plants)

3.5.3 Weed density

Weed data were collected from the area defined by a 0.3 x 0.3 m quadrant. The quadrants were thrown randomly three times in the gross plot. Using identification aids, weeds were identified to species level. The weeds within the quadrant were then uprooted and dried to measure biomass. Weeds biomass data was collected in the gross plot. Weed density and biomass data was Log (x+1) transformed before analysis of variance.

3.5.4 Disease and Pathogen Identification

Diseases were identified by the use of coloured visual aids showing diseases and symptoms on paprika (Paprika Zimbabwe, 1998). Diseased plant samples were collected from the field and taken to the Plant Pathology laboratory at the University of Zimbabwe where identification and confirmation through laboratory tests was carried out. Potato Dextrose Agar (PDA)

(Appendix 3) for fungi and Nutrient agar (Appendix 4) for bacteria were prepared, sterilised and poured into 9cm and 5cm clear plastic Petri dishes respectively. Before plating, the infected paprika plant tissues were cut into very small pieces and surface sterilised using 70% dilution of 3.5% sodium hypochlorite solution and then plated in both PDA and NA plates. The plates were then incubated at 24-28^{0}C for a minimum of 48 hours after which bacterial or fungal growths were examined under different magnifications of a stereoscopic microscope. Fungi associated with the plant tissue were carefully examined and identified on the basis of habit characters or by preparing a slide of fruiting structures. Slides were examined at higher magnifications of a compound microscope. To confirm their identity, references were made to the (International Mycological Institute (IMI)) descriptions. In the case of bacteria, the growth was first tested for Gram reaction (Appendix 5), all Gram-negative cultures were isolated by sub culturing and colony characteristics were also used for identification (Lelliot and Stead, 1987). For *Xanthomonas* spp, further tests namely oxidase reaction and nitrate reduction were done to confirm its presence (Appendix 6 and 7).

3.5.5 Rainfall data

The rainfall was measured by the use of a rain gauge for both sites, Bingaguru and Chinyudze, for the 2000/2001 and 2001/2002 seasons and are shown in Figure 3.1 and 3.2 below. Bingaguru sites received a total annual rainfall of 418.5mm and 507mm in 2000/2001 and 2001/2002 rainy seasons

respectively. Chinyudze sites received 855mm in 2000/2001 and 475.5mm in 2001/2002 rainy seasons.

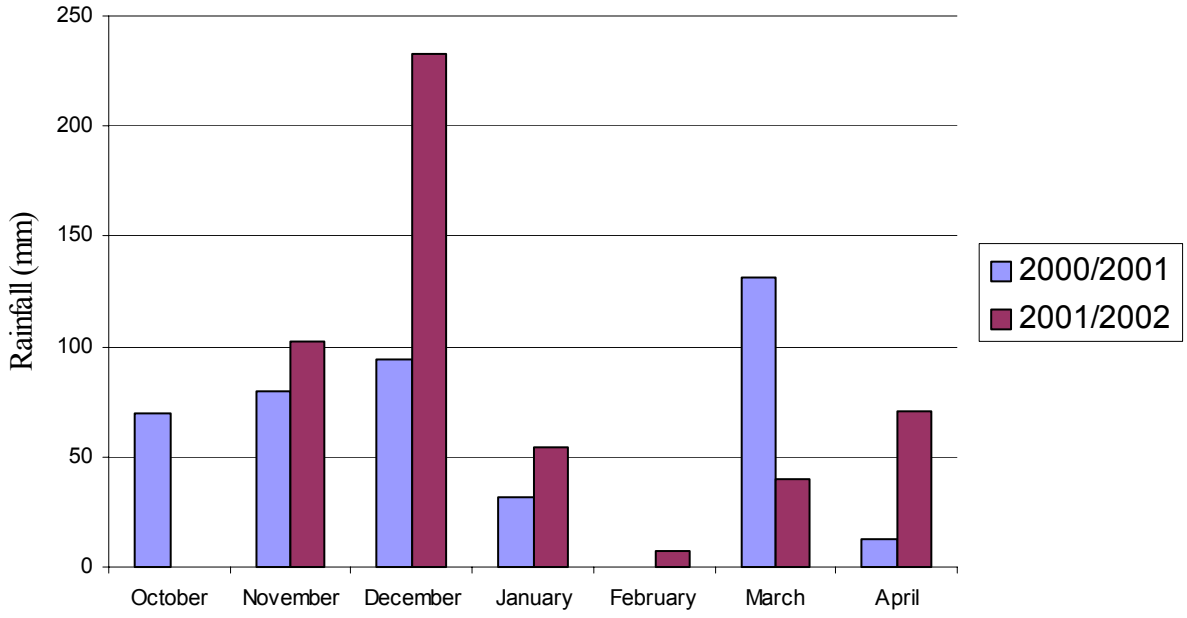


Figure 3.1 Rainfall distribution in Bingaguru (CRA East) in the 2000/2001 and 2001/2002 rainy seasons

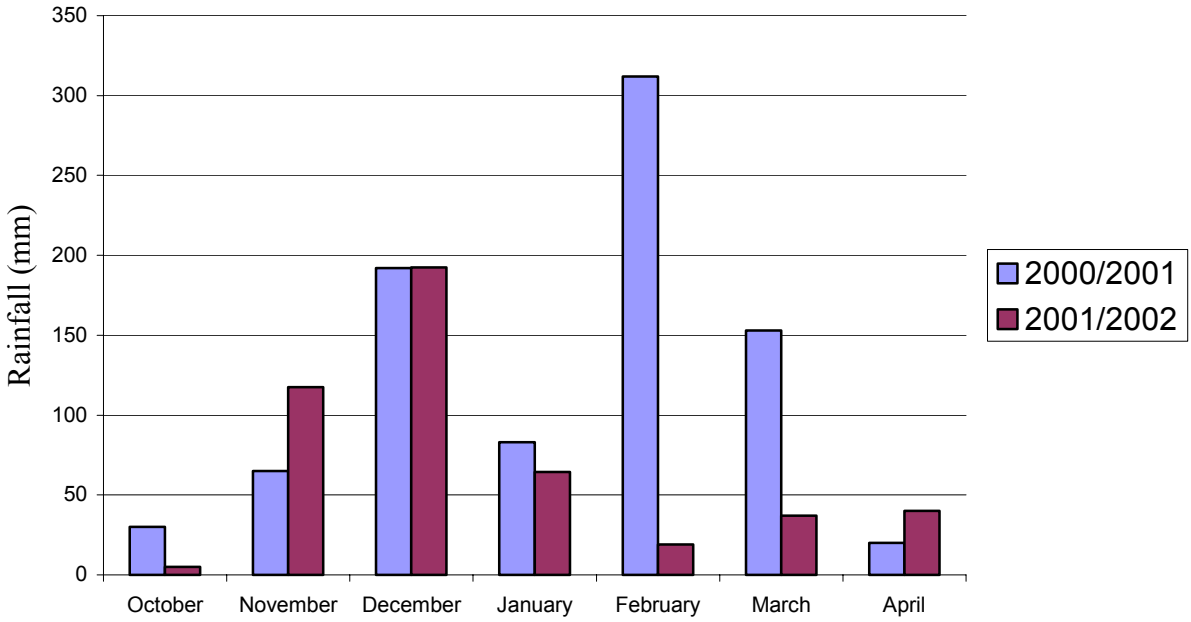


Figure 3.2 Rainfall distribution in Chinyudze (CRA West) in 2000/2001 and 2001/2002 seasons.

3.6 Experimental Design

All trials were laid out in Randomised Complete Block Design (RCBD) with each treatment having three replications.

3.7 Harvesting

Harvesting was done when the pods were deep red and could be wrapped around the finger without breaking. They were later spread under shade to enable them to air dry before weighing. The paprika was graded into marketable and non-marketable yield.

3.8 Data analysis

The data collected were subjected to analysis of variance to test for significance of treatment effects (Snedecor and Cochran, 1980) using MSTATC statistical package. Where the F tests were significant, the treatment means were separated using the Duncan's Multiple Range Test.

To deduce the effectiveness of the various fungicides, disease progress curves were drawn using disease measurements from overall disease severity scale and the areas under the disease progress curve (AUDPC) were compared. Area under disease progress curves (AUDPC) (Shanner and Finney, 1977) were calculated before the analysis of variance using formula:

$$AUDPC = \sum^{n}_{i=1}[(Y_{i+1} + Y_i)/2][X_{i+1} - X_i]$$

where Yi = disease severity score at time i, and Xi = time of scoring (weeks).

AUDPC and was achieved by using a Sigma Plot 2000 computer package. From the overall infection scores, overall AUDPC was generated, percentage infection scores resulted in percentage infection AUDPC, leaf and stem spots

resulted in leaf spots AUDPC, disease incidence resulted in AUDPC disease incidence. For the purposes of comparison over two different seasons overall AUDPC was used as it had been used in both seasons where as percentage infection AUDPC and leaf spot AUDPC came into use only after the modification of the overall disease severity in the second season.

An economic analysis was carried out to compare the profitability of treatments according to the procedure described by CIMMYT (1988) and the modified method of Ward, Darroch, Laing, Cairns and Dicks (1997). In each season, different operation costs were used due to price changes over the season (Appendix 8). Overall AUDPC was used in economic analysis as it was measured in the two seasons. Standardised Area under disease progress curve (SAUDP) is the area under disease progress curve, standardised by dividing AUDPC by the time duration (weeks) of the disease epidemic.

CHAPTER 4

SURVEY: ASSESSMENT OF DISEASES OCCURRING ON THE FARMERS' FIELDS, THE EXISTING LEVELS OF KNOWLEDGE ON PAPRIKA DISEASES, IDENTIFICATION AND CONTROL IN THE CRA.

4.1 Introduction

Paprika is a relatively new crop in the smallholder farming sector of Zimbabwe. The farmers' ability to identify paprika diseases and control them has a lot to do with his/her level of knowledge about the diseases. Smallholder farmers usually operate in a resource-poor environment and have little access to inputs such as pesticides and fertilisers. The technical resource base available to both extension services and farmers is limited, with inadequacies being present in a very wide range of areas, including horticultural technical expertise (Sibanda, Dobson, Cooper, Manyangarirwa and Chiimba, 2000)

Agronomic information relating to cultivar and seed choice, soil fertility, water management and pest management using cultural, biological and chemical methods is also lacking (Sithole and Chikwenhere, 1995a). Many of these farmers are relatively new to intensive paprika production so are unable to recognise and identify pests and disease organisms on their crops. The losses incurred due to pests and diseases are a major constraint faced by smallholder horticultural farmers in Zimbabwe (Sithole and Chikwenhere, 1995b). Pesticide selection is made on the basis of availability and various sources of informal advice such as neighbours and retailers with occasional

assistance from extension staff. The tank concentrations were mostly between 20 and 60% of the recommended dosage as farmers attempt to reduce the cost of expensive pesticide (Sibanda *et al.*, 2000). The aim of the survey was to assess the existing level of farmers' knowledge on paprika diseases, focusing mainly on disease identification and disease control. Additionally an assessment of prevalence of specific disease on paprika in fields owned by farmers who participated in the survey.

4.2 Materials and Methods

A survey was conducted in Bingaguru in CRA East and Chinyudze in CRA West in the middle of the 2001/2002 rainy season. The study involved 20 randomly selected farmers from a numbered village lists provided by area government extension offices at each of the two sites. Random selection of farmers involved picking numbered tags from a hat with a total of 35 paprika producing household names. A structured questionnaire (Appendix 1) was prepared and administered using the 20 selected farmers in each of the sites. A total of 40 farmers participated in the survey.

4.2.1 Plant Samples

Plant samples were collected from the farmers' fields for disease diagnosis. For, each field, size and crop condition were noted, plants sampled were collected by making a specified number of equally spaced paces (depending on the size of the field) following an inverted 'V' pattern This was done randomly in any direction. Having made the pre-set number of paces, the nearest plant to the right foot was sampled. For each field, ten plants were

randomly sampled, symptoms (if any) were recorded. A sub-sample of three leaves from each plant was selected from the upper, middle and lower canopy layers of the main stem, yielding a total of thirty leaves per field. Leaves with disease symptoms were given preference to leaves not showing symptoms. Symptoms were verified by culturing diseases tissues on Nutrient and Potato Dextrose agar. Powdery mildew infected plant sample were observed under the compound microscope and identified with reference to the International Mycological Institute (IMI) descriptions, at the University of Zimbabwe Plant Pathology Laboratory and handled as described in Chapter 3. Additionally, coloured pictorial aids of paprika diseases were used to assess farmers' knowledge of the diseases. This was achieved by showing farmers coloured paprika disease pictures from which they indicated which disease they had experienced in their fields.

4.2.2 Questionnaire

The questionnaire (Appendix 1) was completed by the interviewer during a guided discussion with the farmers. SPSS computer package was used to analyse data collected from the survey.

4.3 Results

4.3.1 Background and Training

Figure 4.1 shows an increase in the number of farmers growing paprika every season in CRA.

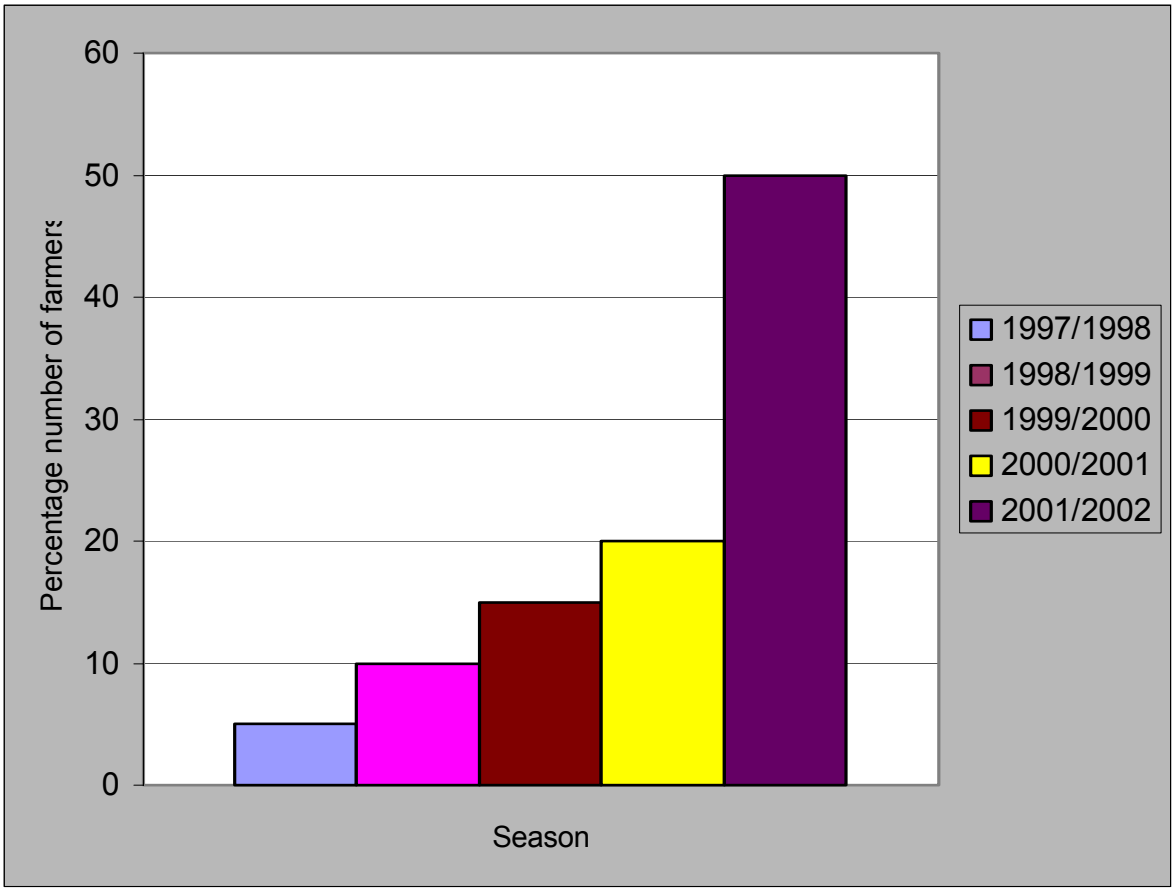


Figure 4.1 Percentage of new farmers entering into paprika production from the season 1997/1998-2001/2002

In CRA, 50% of the farmers were new paprika growers during the 2001/2002 season. Twenty percent of the total farmers interviewed were producing paprika for the second time (1998/1999 season), 15% for the third time (1999/2000), 10% fourth time (2000/2001) and 5% the fifth time (2001/2002) (Figure 4.1). The majority of the paprika farmers in CRA did not receive any formal paprika production or disease management training. Only 15% and 10% of in Chinyika East and West respectively received some training on

paprika production or disease management information.

4.3.2 Diseases

4.3.2.1 Farmer perception

Ninety percent of the farmers indicated they could not identify any paprika diseases. Forty-five percent of the total farmers mentioned that they usually attempt to identify paprika diseases by themselves. The majority of farmers from both Chinyika East and West were of the opinion that bacterial leaf spot was a major paprika disease (Table 4.1). Twenty percent of the farmers considered anthracnose as the second major paprika disease.

Table 4.1 Diseases/condition perceived as major by the farmer

Diseases/condition perceived as major by the farmer	East %	West %	Mean %
Bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*)	22.5	25	23.75
Anthracnose (*Colletotrichum capsici (Syd)*)	20	20	20
Cercospora leaf spot (*Cercospora unamunoi (Cast.)*)	12.5	20	16.25
Grey leaf spot (*Stemphylium solani (Weber)*)	5	15	10
Powdery mildew (*Leveillula taurica (Lev)*)	15	5	10
Wilt disease	5	10	7.5
Blossom end rot	15	0	7.5
Alternaria (*Alternaria solani*)	5	5	5

Paprika farmers in CRA consider wilt diseases and leaf spots caused by *Alternaria* as the least major diseases.

4.3.2.2 Cultural Practices

Table 4.2 Cropping practices of paprika producers in CRA .

CHARACTERISTICS	CHINYIKA EAST	CHINYIKA WEST	MEAN
1.Variety grown			
Red Tsar	0	15	7.5
Papriking	100	85	92.5
2.Seedbed Sterilisation			
Brushwood	15	40	27.5
Maize cobs	35	25	30
Maize cobs + Brushwood	25	20	22.5
Brushwood + Maize cobs + Cow dung	5	0	2.5
None	15	5	10
Other*	5	10	7.5
3.Disease control method			
Biological	0	0	0
Chemical	70	50	60
None	30	50	40
4.Method of chemical Spray			
Knapsack sprayer	50	45	47.5
Broom	20	5	12.5
None	30	50	40
5.Frequency of fungicide spraying			
When necessary	5	5	5
Once per every week	5	0	2.5
Once per every two weeks	5	0	2.5
Once per season	20	15	17.5
Twice per season	25	25	25
Three times per season	10	5	7.5
6.Weed Management			
Hand hoe weeding on the ridge	75	75	75
Re-ridging	10	0	5
Ox-drawn+Hand hoe weeding	15	25	20
7.Weeding frequency per season			
Once	10	10	10
Twice	25	25	25
Three times	45	45	45
Four times	20	20	20

* Other; in some cases farmers used chemicals not meant for fumigation and would not remember the names of the chemicals.

Most farmers in CRA cultivate variety Papriking. On average, 92.5% of the farmers in CRA East grow Papriking as compared to 7.5% that grow Red Tsar (Table 4.2).

The most popular sterilisation method is the use of maize cobs for seedbed heat sterilisation in CRA. Farmers also combine maize cobs and brushwood. However, 10% of the farmers did not sterilise seedbeds.

Most farmers in CRA East apply fungicides often either as preventive or curative measures. This was especially practised in CRA East. On average, 10% of the farmers in CRA did not apply pesticides at all. Use of a knapsack sprayer was the most common practice whilst the traditional method of using a broom accounted for 12.5% in the study area (Table 4.2).

The majority of the farmers in CRA use fungicides once per season followed by those applying twice per season. Five percent in both CRA East and West apply fungicides only when necessary.

Hand-hoe weeding is practised by 75% of the farmers in CRA. Ox-drawn implements and hand-hoe weeding combination accounted for 15 and 25% in CRA East and West respectively. Most farmers weed three times during the cropping the season. Ten percent of farmers in CRA weed only once. None of the farmers failed to weed at all in CRA (Table 4.2).

4.3.3.3 Disease Direct observation and laboratory tests

As confirmed by direct observation, coloured visual aids and laboratory tests, the major paprika disease in CRA in the 2000/2001 season was powdery mildew (*Leveillula spp*) (35.6% incidence) followed by bacterial leaf spot (*Xanthomonas spp*) (24.4% incidence) (Table 4.3). The least occurring paprika diseases in the same season were anthracnose (*Colletotrichum spp*) (1.9% incidence) and bacterial soft rot *(Erwinia spp)* (0.6% incidence).

Bacterial leaf spot and powdery mildew were the major diseases in Chinyika East followed by grey leaf spot. According to Table 4.3, Chinyika West powdery mildew (41.5% incidence) was the major disease followed by Cercospora leaf spot (22.2% incidence) and bacterial leaf spot (19.2% incidence).

Table 4.3 Incidence of paprika diseases from CRA samples confirmed by laboratory tests

Diseases identified in the laboratory	**East%**	**West %**	**Mean%**
Powdery mildew (*Leveillula spp*)	29.6	41.5	35.6
Bacterial leaf spot (*Xanthomonas spp*)	29.6	19.2	24.4
Grey leaf spot (*Stemphylium spp*)	27.0	9.2	18.1
Cercospora leaf spot (*Cercospora spp*)	5.0	22.5	13.8
Alternaria (*Alternaria spp*)	7.5	3.8	5.6
Anthracnose (*Colletotrichum spp*)	1.3	2.5	1.9
Bacterial soft rot (*Erwinia spp*)	0	1.3	0.6

4.4 Discussion

The survey showed a general lack of knowledge on paprika disease identification in the smallholder farming sector of CRA. This is attributed to the fact that paprika is a relatively new crop and also the government and the private sector have not placed much emphasis in paprika production training as compared to other cash crops as cotton and tobacco. The number of

paprika growing farmers in the CRA has increased each season mainly because of the economic benefits associated with paprika production. Sibanda *et al*. (2000) reported that many farmers are relatively new to intensive vegetable production and as such unable to identify pest and disease organisms on their crop in the smallholder vegetable farms of Zimbabwe. The 12.5% of farmers recorded in CRA to have received some formal training have mainly been taught by government extension agencies on how to raise healthy seedlings in the nursery through field demonstrations conducted when the crop was first introduced 8-9 years ago. Pesticide selection is made on the basis of availability and various sources of informal advice such as from neighbours and retailers with occasional assistance from extension staff (Sibanda *et al*., 2000).

The farmers' perception that bacterial leaf spot is the major paprika disease in both CRA East and West regions agrees with observations by Paprika Zimbabwe (1998), which ranks bacterial leaf spot as a disease of major economic importance in Zimbabwe. Farmers identified anthracnose as the second major disease of economic importance probably because this disease's appearance on pods resembles blossom end rot symptoms . The farmers' perception of anthracnose was neither backed by direct observation nor laboratory tests. In addition, no documented record ranks this diseases so highly on its economic importance in Zimbabwe. There was a tendency by farmers to mix up the descriptions of anthracnose and blossom end rot because of their symptomatic characteristic black colour. The perceived

occurrence percentage was 20% the actual percentage recorded from laboratory analysed samples of 1.9%.

The use of the paprika variety Papriking by most farmers (85%) in CRA was not based on information on characteristics of the variety but rather a mere coincidence arising from its relative abundance and preferred supply by most seed suppliers. Most farmers indicated during discussion that they would not worry themselves on which variety they need but rather on whether or not the paprika seed is treated. It would seem farmers consider all treated seed as good seed as indicated by the fact that all farmers who participated in the survey had planted treated certified paprika seed.

Most farmers in CRA do sterilise their seedbeds and the most popular method of seedbed sterilisation is the burning of maize cobs. Their appreciation of the need of seedbed sterilisation is probably borne out of their understanding on the importance of producing and transplanting healthy seedlings which has a bearing of the final yield of paprika in the field. The use of maize cobs as fuel for seedbed sterilisation is predominant in CRA East region probably due to the fact that this region produces a lot of maize. Maize cobs are therefore available in abundance.

Disease incidence and severity in the field are subject to the farmers' management practices in the nursery and field. Since 40% of the paprika farmers in CRA do not spray their paprika crop, there is therefore need to encourage farmers to adopt some chemical disease management so as to

reduce disease pressure and improve the quality and quantity of their marketable produce.

The practice of not spraying is more prevalent in Chinyika West region, where very low and erratic rainfall has characterised the past two to four seasons, coinciding with the period when most farmers started producing paprika. This rain pattern has been associated with low disease incidence. Most farmers (47.5%) in CRA use a knapsack sprayer for pesticide application. This is expected as the majority of the farmers that produce paprika in CRA have been producing tobacco or still do. Even though the use of a broom in application of pesticide is regarded as an old fashioned practice, 12.5% of the paprika producing farmers in CRA still uses this method. Similar results were observed by Sibanda *et al.* (2000) in Mutoko where most of the farmers apply pesticides using knapsack sprayers, with only one farmer using a bucket to mix the pesticide and a broom to splash the mixture onto the crop.

Most paprika production manuals in Zimbabwe recommend a weekly fungicide spraying interval, yet in CRA only 2.5% spray at that interval. The most popular (25%) spraying interval is spraying of fungicide twice a season in CRA and it confirms the findings by Sibanda *et al.* (2000) in Mutoko that most farmers using fungicide often applied these weekly or fortnightly, either as preventive and curative treatments in vegetable production. However, most of these farmers' tank concentrations in Mutoko are generally between 20 and 60% of the correct value, reportedly due to the farmer trying to economise on the quantity of the pesticide.

There is also a close relationship between disease incidence and occurrence of some weeds (Hyveld 1996). It is therefore vital to ensure that proper weed management practices are adapted. Hand hoe weeding on the ridge accounts for 75% of the farmers' weed management practices in CRA. However, this method is laborious hence 20% of the farmers use an ox-drawn plough and then hand hoe on the ridge.

Most farmers in CRA conduct more weedings than fungicide spraying, for instance 40% of the farmers in CRA do not spray fungicides yet all weed at least once. This is so mainly because farmers have observed or experienced the threat of weeds on paprika fields and have in some instances abandoned their paprika fields. The absence of farmers who use herbicides in paprika can be explained by the perceived prohibitive costs of herbicides and also lack of proper promotion of herbicides. Sibanda *et al.* (2000) reported that none of the farmers who were interviewed in Mutoko used herbicides in vegetable production.

Weeding three times per season is practiced by 45% of the paprika producing farmers in CRA. In Chinyika West this is so because of the high level of infestation of *Datura stramonium*, which not only reduce yield due to its competitiveness for light and nutrients but also because of its close relationship with the occurrence of powdery mildew. In Chinyika East this weeding frequency is as a result of prevailing moisture content which results in the conditions favourable for weed seed germination and growth almost throughout the season.

4.5 Conclusion

Bacterial leaf spot, Cercospora leaf spot and powdery mildew are ranked as major diseases of economic importance whereas anthracnose and bacterial soft rot are the minor disease of economic importance in CRA. Papriking is the most grown variety in CRA but is not necessarily because of agronomic importance alone but it is the seed that most paprika processors supply them with. Most paprika farmers use maize cobs burning as a method of sterilising their seedbeds. Even though applying fungicides by knapsack is the most popular method for the majority of the farmers, they cannot afford the weekly pesticide spraying interval.

Most farmers rank weeds as a threat higher than diseases as deduced from their cultural practices. The survey revealed limited farmers' knowledge on paprika diseases, their identification and control. The major probable cause of the limited knowledge in the smallholder paprika farmers is the absence of proper paprika production training by experts in both the public and private sectors. This lack of training can be one of the major reasons why most smallholder farmers in CRA achieve very low quality and quantity paprika per hectare as compared to the commercial farmers.

CHAPTER 5

NURSERY TRIAL: ASSESSMENT OF AN EFFECTIVE METHOD OF SOIL STERILISATION IN PAPRIKA SEEDBEDS.

5.1 Introduction

Paprika requires the production of healthy and vigorous seedlings for transplanting, and these can be achieved by effective soil sterilisation of the seedbeds to control weeds and reduce soil-borne pathogens. Sterilisation can be achieved through the use of methyl bromide, however the pending ban of methyl bromide has created a challenge to researchers to find a replacement. Methyl bromide production and use will be phased out in 2005 in developed countries and 2015 in developing countries because it depletes the protective ozone layer in the stratosphere (Csinos, Dowler, Johnson, Johnson, McPherson, Summer, 2000).

Since methyl bromide has a wide spectrum of biological activity and is relatively inexpensive, it has become the standard to manage soil problems for transplant production (Koch 1951, Martin, Jorn, Cop*,* 1955., Todd and Lucus, 1956). No other single pesticide is available that has such a wide spectrum of activity and as cost effective and easy to use as methyl bromide. For the smallholder paprika farmers the challenge is beyond finding an alternative for methyl bromide as whatever alternative may be found, its cost and user friendliness need to be considered. Therefore, there is need for an alternative method preferably non-chemical.

Paprika farmers, particularly in the smallholder sector, were being encouraged to burn materials such as brushwood on their paprika seedbeds for dry heat sterilisation. In addition to emphasising sterilisation methods, the smallholder farmers have been using, promising practices such as solarisation must be investigated under smallholder farming conditions. Soil solarisation is a hydrothermal method of soil disinfestation using solar heat trapped and conserved through a polythene mulch (Sharma and Nene 1990). The hydro-thermal process of soil solarisation causes complex changes in soil that are deleterious to many plant pests and pathogens while stimulating activity of soil biota beneficial to crop growth (Stapleton and DeVay, 1986).

For any thermal seedbed sterilisation, the temperature has to be equal to or above lethal for the most heat–tolerant pest existing in the soil (Katan, 1981). Too high temperatures also eliminate some beneficial microorganisms in the soil. A drastic reduction in soil microbial activity may result in rapid reinfestation of the sterilized soil by a contaminating inoculum, ultimately leading to disease incidence which could be even higher than that in the non treated soil due to a “biological vacuum” (Baker, 1962). There is a need to evaluate various methods of soil sterilisation both not being used or currently used by the farmers. The effectiveness of the sterilisation method should be mainly based on its effectiveness in reducing soil pathogens and weeds in the seedbed. In addition sterilisation material residues must not deter the growth of paprika transplants in the nursery.

The objective of this study was to assess an effective method of soil sterilisation in paprika seedbeds by comparing the effectiveness of the following treatments: solarisation, methyl bromide, burning of cowdung, maize cobs and brushwood (farmer practice) under smallholder farming conditions.

5.2 Materials and Methods

On-farm trials were established at Bingaguru and Chinyudze areas during the 2001/2002 and 2002/2003 rainy seasons. In Chinyudze area the sites were Chinyudze centre in 2001/2002 and Nare in 2002/2003.In Bingaguru area the trials were hosted at Homestead site in both seasons. Seedbeds, measuring 1m X 5.25m, were prepared. The experiment was laid out in a RCBD with 3 replications for each treatment.

The following seedbed sterilisation methods were tested in the paprika nursery:

1. Non-treated soil (Control).
2. Burning cow dung on the seedbeds at 12kg/m^2.
3. Burning brushwood on the seedbeds at 7kg/m^2 (farmer's practice).
4. Burning maize cobs 8kg/m^2.
5. Solarisation for 10 weeks using black plastic.
6. Applying methyl bromide at 30g/m^2 (Standard).

5.2.1 Methyl bromide

The seedbeds to which methyl bromide was applied were irrigated a week before application. The seedbeds were then fumigated with the methyl bromide for 48 hours under a polythene sheet and then allowed a week of

aeration before the seeds were sown.

5.2.2 Measurements of soil temperatures for the burning treatments

The temperatures reached 30, 60 and 90 minutes after the flame died away at 5, 10 and 15cm soil depth were recorded using a T350 Thermocouple temperature probe at three different points namely the first third, second third and last third of the seedbed for each record. From the three equal subdivisions, measurements at 5, 10 and 15cm soil depth were taken at each point at 30, 60 and 90 minutes interval after the flame died away.

Temperatures from the same soil depth within each seedbed were then combined and the mean was used for data presentation.

5.2.3 Soil solarisation

A 3 micrometre thick black polythene plastic was used to cover for 10 weeks seedbeds that had been watered to field capacity 48 hours prior to treatment. Temperatures were measured by a T350 thermocouple temperature probe daily beginning two days after covering the seedbeds at between 1300hrs and 1400hrs. The seedbeds were divided into three equal parts from which measurements at 5, 10 and 15cm soil depth were taken at each point. The data was compared as means of solarised and unsolarised seedbeds, no ANOVA was perfomed on this data as the factors had no acceptable degrees of freedom.

5.2.4 Burning

The amounts of cow dung, brushwood and maize cobs per seedbed were determined by asking five different farmers to lay out the sterilisation materials

independently and then finding the mean weight. This was done at 3 different sites in each CRA East and West, the means were found to be in the same range. The means were then used as the rates during the two seasons. After the even distribution of brushwood, cow dung and maize cobs in their respective seedbeds they were set alight. The seedbeds were then allowed to cool for two days after which ash was thoroughly removed before sowing.

5.2.5 Measurements of soil microbial populations

Fungal and bacterial soil populations were estimated after soil sterilisation treatments and a non-sterilized sample was used as a control. Soils were taken immediately after sterilisation of seedbeds. Approximately 200g of soil were collected from three randomly selected points in each seedbed in three blocks from a depth of 5, 10 and 15cm. The soils for each point and from the same depth level in seedbed were combined and stored in a khaki paper bag to constitute one sample. One gramme of soil was air dried from each sample and suspended in 95ml of sterile water (H_2O) and dilution series made of the resulting suspension to obtain dilutions of 10^{-1} to 10^{-5}.

From each of the dilutions, 10^{-3}, 10^{-4} and 10^{-5} for bacteria and 10^{-2}, 10^{-3} and 10^{-4} for fungi, 0.5ml were pipetted onto Nutrient Agar (NA) and Potato Dextrose Agar (PDA) respectively, then spread evenly with a glass rod. Each dilution was replicated three times. Controls were set up by plating 0.5ml of sterile water onto the PDA and NA plates three times for each medium and dilution. The plates were incubated at 25^0C, for three days, before counting numbers of fungal and bacterial colonies on each plate. For each sample,

estimates of colony forming units (CFU) in 1g dry soil were made. The microbial colony number data were square root transformed (Csinos, 1998).

5.2.6 Disease incidence and seedling mortality

Disease incidence was assessed in the nursery seedbeds beginning 4 weeks after sowing (WAS) up to 8WAS. Seedling mortality was assessed by counting the number of seedlings dying after germination and expressing it as a percentage of seedlings that had germinated two weeks after sowing.

5.2.7 Height, dry weight of seedlings and weed density

At 10 WAS when seedlings were ready for transplanting, ten randomly selected seedlings were uprooted, their height measured, oven dried for 24 hours at 30^{o}C and the dry weight obtained. The mean height and weight of the seedlings was used for data analysis.

Weed density was measured as described in Chapter 3 at 2, 4 and 8WAS.

All the data obtained were subjected to ANOVA with the exception of temperatures data achieved by solarisation (insufficient degrees of freedom for ANOVA) whose means were used instead for comparison

5.3 Results

5.3.1. Soil Temperatures (achieved) by solarisation

In 2001/2002 at both sites Chinyudze and Homestead there was a general increase in temperatures achieved in solarised than in unsolarised seedbeds (Table 5.1 and 5.2).

Table 5.1 The mean soil temperatures recorded between 1300 and 1400hrs daily for 10 weeks in the solarised and unsolarised paprika seedbeds in 2001/2002 season at Homestead and Chinyudze sites

Soil depth (cm)	Soil temperature (^{0}C)			
	Homestead		Chinyudze	
	Solarised	Unsolarised	Solarised	Unsolarised
5	36.1	30.5	37.1	30.0
10	34.4	28.2	31.1	27.4
15	29	25.8	26.8	25.3
Mean	31.2	28.2	31.2	27.6

The highest mean temperature achieved by solarisation was 39.4 ^{0}C at 5 cm soil depth, 35.9 ^{0}C at 10cm soil depth and 31.7 ^{0}C at 15cm in 2002/2003 season.

Table 5.2 The mean soil temperatures recorded between 1300 and 1400hrs daily or 10 weeks in the solarised and unsolarised paprika seedbeds in 2002/2003 season at Homestead and Nare sites

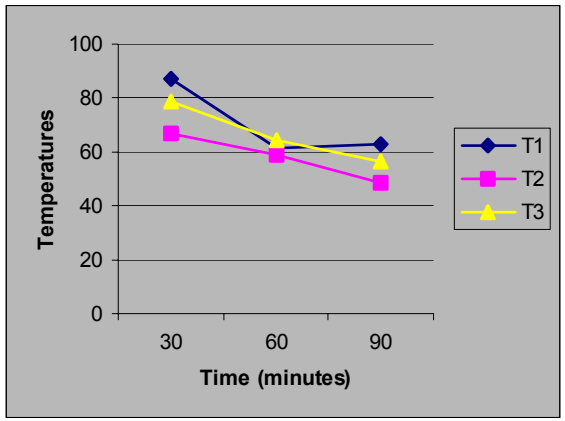
Soil depth (cm)	Solarised soil temperature (^{0}C)			
	Homestead		Nare	
	Solarised	Unsolarised	Solarised	Unsolarised
5	39.4	31.0	38.3	30.4
10	36.7	28.4	35.9	29.5
15	31.7	26.1	26.9	24.3
Mean	35.9	28.5	33.7	28.1

On average, higher temperatures were achieved in season 2002/2003, with the highest being at Homestead site, which had also the highest temperatures in the 2001/2002 season.

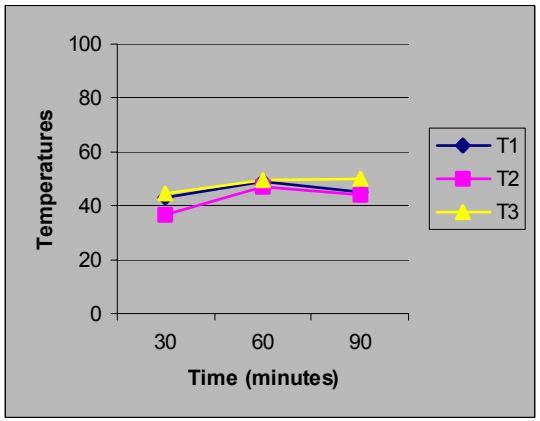
5.3.2. Soil temperatures achieved by burning cow dung, maize cobs and brushwood

Mean temperatures achieved by burning brushwood were significantly higher ($p<0.05$) than cow dung and maize cobs in 2001/2002 season at Chinyudze site and cow dung at Homestead site. There was a general increase in mean temperatures as the depth increased and time after the flame had died out increased with the exception of 5cm depth for both sites. Cow dung burning gave a significantly ($p<0.05$) higher temperature at Homestead site in 2002/2003 season. The lowest temperature was achieved by burning brushwood (52.2 ^{0}C). The maximum temperatures achieved by the various seedbed sterilisation heat decreased as the depth increased from 5, 10 to 15cm. Time after the fire died way had no significance effect on the heat levels achieved at Homestead site in the 2002/2003 season. There was an interaction between sterilisation methods, soil depth and time interval at Nare site in the 2002/2003 rainy season (Figures 5.1 - 5.12 below). There was a general decrease in temperature with an increase in depth in all treatments at Nare site.

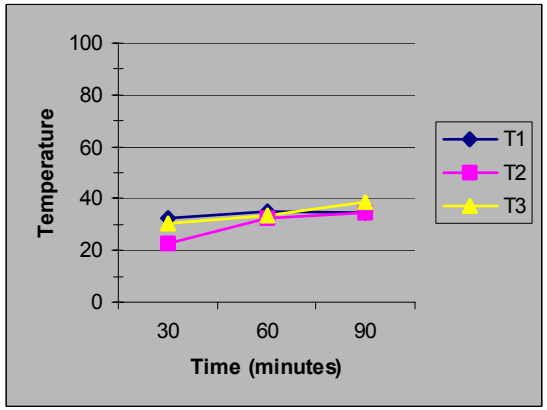
5cm



10cm

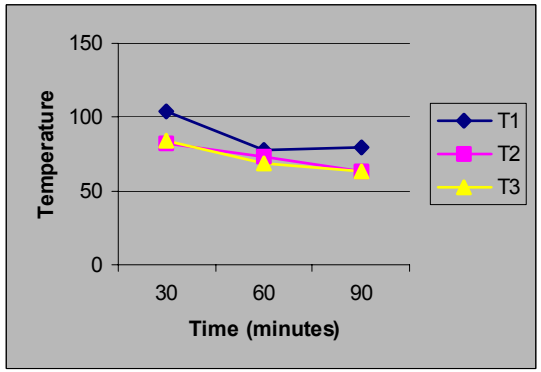


15cm

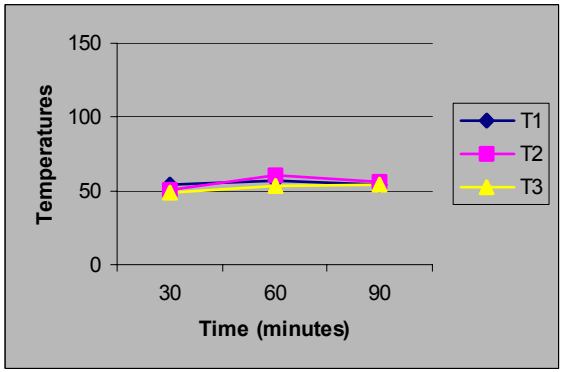


Figures **5.1-5.3** Temperatures achieved at 5, 10 and 15cm soil depth by burning of cow dung (T1), maize cobs (T2) and brushwood (T3) at Chinyudze site in 2001/2002

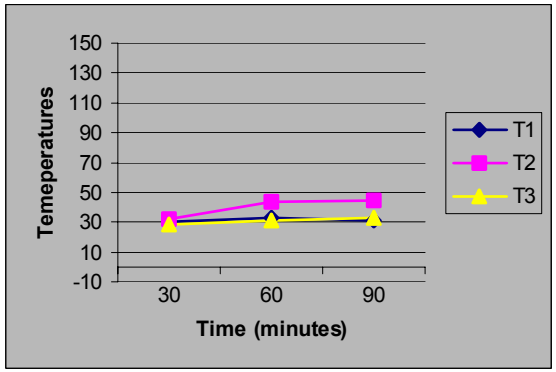
5cm



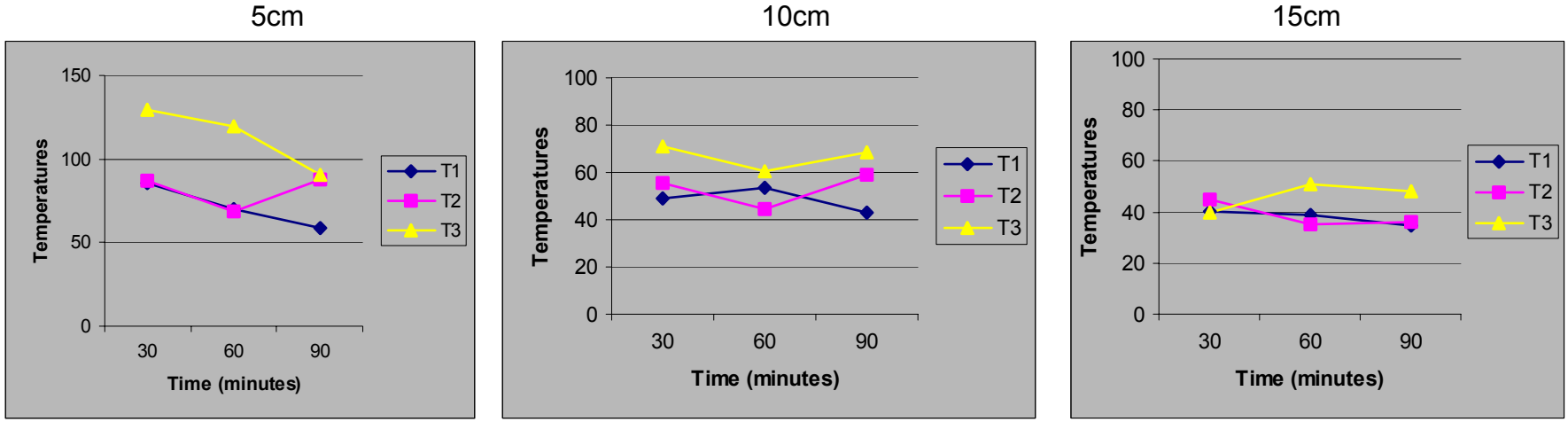
10cm



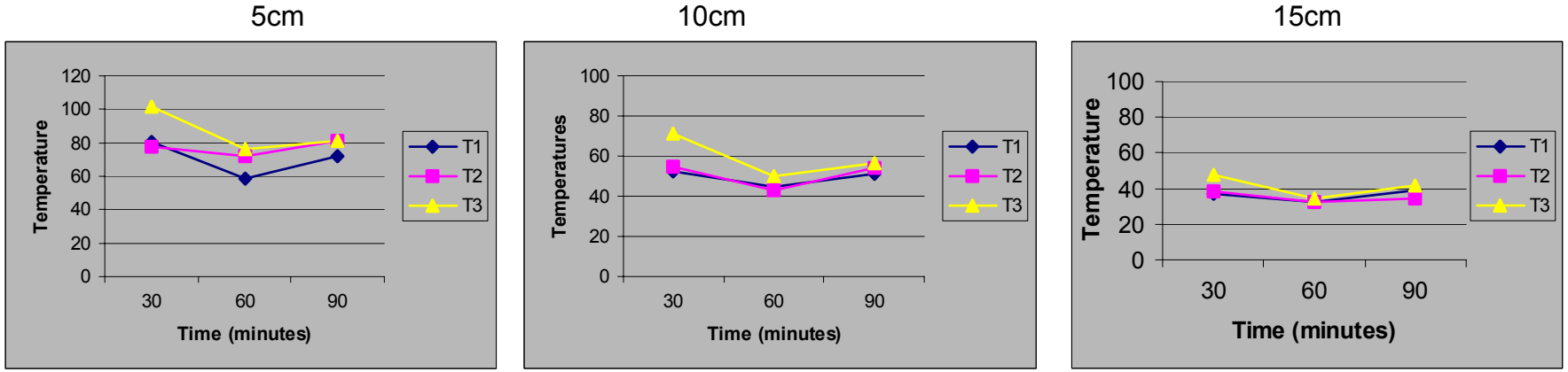
15cm



Figures **5.4-5.6** Temperatures achieved at 5, 10 and 15cm soil depth by burning of cow dung (T1), maize cobs (T2) and brushwood (T3) at Homestead site in 2001/2002



Figures **5.7-5.9** Temperatures achieved at 5, 10 and 15cm soil depth by burning of cow dung (T1), maize cobs (T2) and brushwood (T3) at Nare site in 2002/2003



Figures **5.10-5.12** Temperatures achieved at 5, 10 and 15cm soil depth by burning of cow dung (T1), maize cobs (T2) and brushwood (T3) at Homestead site in 2002/2003

5.3.3. Soil microbial population Assessment

5.3.3.1 Bacteria

At the Chinyudze site in the 2001/2002 season at 5 cm depth, brushwood had the greatest effect in reducing bacterial populations in the soil, whereas at 15 cm solarisation had the greatest efficacy in the reduction of bacterial population. These two treatments perfomed better than methyl bromide at all the three depths. At the Homestead site, significant ($p<0.05$) differences were observed in the 2001/2002 season (Table 5.3). The greatest bacterial reduction effect recorded was when maize cobs were used at 10 cm and solarisation were used at 15 cm soil depth.

Table 5.3 Number of bacterial colony forming units (CFUs) in 1g dry soil after different soil sterilisation methods at 5, 10 and 15 cm depths in 2001/2002 season at Homestead and Chinyudze sites

	Homestead*			Chinyudze		
SoilDepth (cm)	5	10	15	5	10	15
Treatment						
Non treated	5.43 (29.48)	3.92 (15.37)	6.55 (42.90)	6.40 (40.96)	6.17 (38.07)	6.45 (41.60)
Cow dung	6.43 (41.34)	6.39 (40.83)	6.51 (42.38)	6.16 (37.95)	6.23 (38.81)	5.85 (34.22)
Brushwood	6.64 (44.09)	6.42 (41.22)	6.41 (41.09)	0.72 (0.52)	2.49 (6.20)	2.44 (5.95)
Maize cobs	6.05 (36.60)	6.25 (39.06)	6.37 (40.58)	6.13 (37.58)	6.25 (39.06)	6.16 (37.95)
Solarisation	6.24 (38.94)	6.22 (38.69)	6.22 (38.69)	1.75 (3.06)	2.66 (7.08)	0.72 (0.52)
Methyl Bromide	6.70 (44.89)	6.54 (42.77)	6.52 (42.51)	6.21 (38.56)	6.42 (41.22)	6.44 (41.47)
CV%		16.2			22.8	
LSD		0.94			1.02	

*The figures outside and before the brackets represents square root transformed data of the figures in brackets.

The effect of different sterilisation methods used on the soil borne microbial population changed with soil depth at both Homestead and Nare site in 2002/2003 rainy season though the trend was not clearly defined (Table 5.4). There was a general decrease in bacterial populations from 5,10 to 15cm soil depth in the control. At 5cm depth, the best soil control was achieved by burning of maize cobs and brushwood only at Homestead. Solarisation and maizecobs gave the least bacterial colony forming units at 10 cm and 15 cm depth and was significantly lower than for methyl bromide treatment at Homestead, as well as at 15 cm soil depth at Nare site.

Table 5.4 Number of bacterial colony forming units (CFU) in 1g dry soil after different soil sterilisation method at 5, 10 and 15 cm depths in 2002/2003 season at Homestead and Nare sites

	Homestead*			Nare		
Soil Depth (cm)	5	10	15	5	10	15
Treatment						
Non treated	5.69 (32.38)	5.54 (30.69)	6.00 (36.00)	4.50 (20.25)	4.30 (18.49)	5.60 (31.36)
Cow dung	5.90 (34.81)	5.20 (27.04)	4.00 (16.00)	5.80 (33.64)	5.70 (32.49)	5.50 (30.25)
Brushwood	5.10 (26.01)	5.40 (29.16)	5.50 (30.25)	4.90 (24.01)	5.00 (25.00)	4.50 (20.25)
Maize cobs	5.00 (25.00)	3.80 (14.44)	3.30 (10.89)	5.10 (26.01)	5.90 (34.81)	5.50 (30.25)
Solarisation	5.50 (30.25)	3.40 (11.56)	3.10 (9.61)	4.90 (24.01)	5.20 (27.04)	3.10 (9.61)
Methyl Bromide	5.80 (33.64)	5.00 (25.00)	4.20 (17.64)	5.00 (25.00)	4.80 (23.04)	4.20 (17.64)
CV%		26.1			20.5	
LSD		2.05			1.66	

*The figures outside and before the brackets represents square root transformed data of the figures in brackets.

5.3.3.2 Fungi

There were no significant differences ($p>0.05$) between treatments for fungal populations at the Homestead site in the 2001/2002 season (Table 5.5). Brushwood treatment had the greatest fungal population reduction effect at the Chinyudze site in the 2001/2002 season. At Homestead site in 2002/2003, sterilisation methods responded differently with an increase in soil depth (Table 5.6).

Table 5.5 Number of fungal colony forming units (CFUs) in 1g dry soil after different soil sterilisation methods at 5, 10 and 15cm depths in 2001/2002 season at Homestead and Chinyudze sites

	Homestead *			Chinyudze		
Soil Depth (cm)	5	10	15	5	10	15
Treatment						
Non treated	5.55 (30.80)	4.89 (23.91)	4.68 (21.90)	5.20 (27.04)	5.14 (26.42)	5.08 (25.81)
Cow dung	5.21 (27.14)	5.26 (27.67)	5.49 (30.14)	5.16 (26.63)	5.01 (25.10)	4.87 (23.72)
Brushwood	5.56 (30.91)	5.22 (27.25)	4.73 (22.37)	1.47 (21.61)	3.17 (10.05)	2.37 (5.62)
Maize cobs	5.04 (25.40)	5.29 (27.98)	5.02 (25.20)	5.11 (26.11)	5.16 (26.63)	4.86 (23.62)
Solarisation	5.31 (28.20)	5.17 (26.73)	5.14 (26.42)	4.65 (21.62)	3.96 (15.68)	1.91 (3.65)
Methyl Bromide	5.60 (31.36)	5.15 (26.53)	5.13 (26.32)	5.26 (27.63)	5.27 (27.77)	5.37 (28.84)
CV%		14.3			17.9	
LSD		NS			0.73	

*The figures outside and before the brackets represents square root transformed data of the figures in brackets.

There was an interaction between sterilisation method and soil depth. The number of fungal forming units decreased with an increase in soil depth. There were no significant differences between treatments for fungal population at the Nare site in 2002/2003.

Table 5.6 Number of fungal colony forming units (CFUs) in 1g dry soil after different soil sterilisation method at 5, 10 and 15cm depths in 2002/2003 season at Homestead and Nare sites

	Homestead			Nare		
Soil Depth (cm)	5	10	15	5	10	15
Treatment						
Non treated	3.50 (12.25)	3.70 (13.69)	2.40 (5.76)	3.97 (15.76)	3.45 (11.90)	3.73 (13.91)
Cow dung	4.90 (24.01)	4.20 (17.64)	4.70 (22.09)	3.69 (13.62)	3.75 (14.06)	4.20 (17.64)
Brushwood	4.60 (21.16)	4.70 (22.09)	4.40 (19.36)	3.86 (14.90)	4.32 (18.66)	4.31 (18.58)
Maize cobs	4.50 (20.25)	4.50 (20.25)	4.90 (24.01)	4.94 (24.40)	5.01 (25.10)	4.20 (17.64)
Solarisation	4.40 (19.36)	3.80 (14.44)	3.80 (14.44)	3.89 (15.13)	4.53 (20.52)	4.43 (19.62)
Methyl Bromide	4.90 (24.01)	4.40 (19.36)	5.20 (27.04)	4.69 (22.00)	4.42 (1954)	3.94 (15.52)
CV%		16.4			23.6	
LSD		1.12			NS	

*The figures outside and before the brackets represents square root transformed data of the figures in brackets.

5.3.4. Seedling emergence

In seedbeds sterilised with methyl bromide and burning maize cobs, seedling emergence was significantly ($p<0.05$) higher, 61% and 57.3% respectively than from non sterilized seedbeds at Chinyudze site in the 2001/2002 season. There were no significant differences at the Homestead site in 2001/2002 for seedling emergence. There were no significant ($p<0.05$) differences in emergence

percentage as a result of the different sterilisation methods used at both sites in 2002/2003 (Table 5.7 and 5.8 below).

Table 5.7 Paprika seedling emergence percentage, height and dry weight of paprika seedlings at Chinyudze and Homestead sites in the 2001/2002 season as influenced by sterilisation methods

Sterilisation Method	Emergence (%)		Height (cm)		Dry weight (g)	
	Homestead*	Chinyudze	Homestead	Chinyudze	Homestead	Chinyudze
Non treated	53.8	31.4	21.3	18.2	0.61 (3.07)	0.60 (2.98)
Cow dung	64	35.9	25.7	18.4	0.54 (2.47)	0.54 (2.47)
Brushwood	63.9	43.1	20.5	23.7	0.71 (4.13)	0.71 (4.13)
Maize cob	71.7	57.3	17.3	25.7	1.01 (9.23)	1.01 (9.23)
Solarisation	62.4	42.8	13.7	18.5	0.45 (1.82)	0.45 (1.82)
Methyl bromide	50.0	61.0	17.7	30.0	1.07 (10.75)	1.07 (10.75)
CV (%)	15.3	23.8	20.9	11.5	41.3	41.3
LSD (5%)	NS	19.6	NS	4.7	NS	NS

*The figures outside and before the brackets represents Log (X+1) transformed data of the figures in brackets.

Table 5.8 Paprika seedling emergence percentage, height and dry weight of paprika seedlings at Nare and Homestead sites in the 2002/2003 season as influenced by sterilisation methods

Sterilisation Method	Emergence (%)		Height (cm)		Dry weight (g)	
	Homestead	Nare	Homestead	Nare	Homestead	Nare
Non treated	76.7	38.9	19.9	16.4	0.53 (2.38)	0.74 (4.50)
Cow dung	87.1	42.0	26.0	15.1	0.72 (4.25)	0.50 (2.16)
Brushwood	87.6	44.2	23.8	21.4	0.60 (2.98)	0.76 (4.75)
Maize cob	75.0	49.1	20.4	15.5	1.00 (9.00)	0.37 (1.34)
Solarisation	83.7	41.0	16.0	16.4	0.79 (5.17)	0.67 (3.68)
Methyl bromide	84.9	47.4	22.1	15.3	1.20 (14.85)	0.67 (3.68)
CV (%)	10.3	40.2	18.3	29.4	23.1	43.7
LSD (5%)	NS	NS	NS	NS	0.34	NS

*The figures outside and before the brackets represents Log (X+1) transformed data of the figures in brackets.

5.3.5. Seedling vigour

5.3.5.1 Seedling height

Significant differences ($p<0.05$) were observed for seedling height, with seedlings from the methyl bromide and burning maize cobs seedbeds giving the highest seedling height. At Chinyudze site in 2001/2002 there were no significant differences in seedling height between methyl bromide and maize cob treated seedbeds (Table 5.7). No significant differences ($p>0.05$) were observed for seedling emergence and height at the Homestead site in the 2001/2002 season. Different sterilisation methods did not result in significant ($p>0.05$) differences in seedling height at transplanting at both sites in 2002/2003 rainy season.

5.3.5.2 Seedling dry weight

Treatments did not influence mean seedling weight at both sites and seasons (Table 5.8) except at Homestead in 2002/2003 where methyl bromide, solarisation and maize cob treated seedbeds produced seedlings of significantly ($p<0.05$) higher seedling dry weight than seedlings from unsterilised seedbeds.

5.3.6. Seedling disease incidence

Table 5.9 The effect of seedbed sterilisation method on Area under disease progress curve (AUDPC) for disease incidence on paprika seedling at Homestead in 2001/2002 and 2002/2003

Sterilisation Method	Area Under Disease Progress (Disease Incidence)			
	2001/2002		2002/2003	
	Homestead	Chinyudze	Homestead	Nare
Non treated	1.50	1.50	2.00	4.33
Cow dung	0.50	1.00	0.67	2.00
Brushwood	1.17	0.83	2.00	1.50
Maize cob	1.00	2.50	1.67	3.70
Solarisation	0.17	1.00	0.83	3.70
Methyl bromide	0.17	0.50	0.67	2.50
CV (%)	93.5	41.8	89.4	35.5
LSD (5%)	NS	1.18	NS	1.65

A significantly ($p<0.05$) low AUDPC disease incidence at Chinyudze (2001/2002) and Nare (2002/2003) sites in both seasons was observed in brushwood, methyl bromide, cowdung and solarisation treated seedbeds (Table 5.9).

5.3.7. Weed management

5.3.7.1 Weed density

At 2, 4 and 8 WAS at the Homestead site, brushwood resulted in the best suppression effect on weed densities in the 2001/2002 season, whereas at the Chinyudze site methyl bromide had the least weed density for the same season (Table 5.10).

Table 5.10 The effect of seedbed sterilisation method weed density in paprika seedbeds at Homestead and Chinyudze sites in the 2001/2002 season

Sterilisation method	Weed density (number/m^2)			
	2 WAS*		4 WAS	
	Homestead	Chinyudze	Homestead	Chinyudze
Non Treated	1.66 (44.7)	1.48(29.2)	2.01(101.3)	2.06(113.8)
Cow dung	1.97 (92.3)	1.50 (30.6)	2.23(168.8)	1.80(62.1)
Brushwood	0.85 (6.1)	1.68 (46.9)	0.99(8.8)	2.46(287.4)
Maize cob	2.97(932.3)	2.55(353.8)	2.94(870.0)	2.90(793.3)
Solarisation	3.01(1022.3)	2.94(870.0)	2.90(793.3)	3.02(1046.1)
Methyl bromide	1.48(29.2)	0.72(4.2)	2.10(124.9)	1.70(49.1)
CV (%)	21.0	15.5	15.5	18.4
LSD (5%)	0.78	0.51	0.62	0.78

*The figures outside and before the brackets represents Log (X+1) transformed data of the figures in brackets.
WAS- Weeks after sowing

Table 5.11 The effect of seedbed sterilisation method weed density 8 weeks after sowing (WAS) paprika seedbeds at Homestead, Chinyudze and Nare sites in the 2001/2002 and 2002/2003 seasons

Sterilisation method	Weed density (number/m^2)			
	2001/2002		2002/2003	
	Homestead	Chinyudze	Homestead	Nare
Non Treated	2.43(268.2)	2.54(345.7)	0.74(4.5)	1.33(20.3)
Cow dung	2.71(511.9)	2.48(301.0)	0.82(5.6)	1.24(16.4)
Brushwood	1.48(29.2)	2.53(337.8)	0.76(4.6)	0.97(8.3)
Maize cob	2.89(775.2)	2.84(690.8)	1.06(11.5)	1.84(68.2)
Solarisation	3.01(1022.3)	2.84(690.8)	1.18(14.1)	1.87(73.1)
Methyl bromide	2.42(262.0)	1.94(86.1)	0.58(2.8)	1.30(19.0)
CV (%)	5.09	12.5	42.9	31.9
LSD (5%)	0.23	0.57	NS	NS

*The figures outside and before the brackets represents Log (X+1) transformed data of the figures in brackets.

Weed density was not significantly ($p>0.05$) different at 8 WAS at Nare site and 2,4 and 8 WAS at Homestead site in 2002/2003 season. Sterilisation methods

that resulted in the best weed suppression effect at 2 WAS in 2002/2003 season were cow dung, methyl bromide and maize cobs (Table 5.12).

Table 5.12 The effect of seedbed sterilisation method weed density at 2 and 4 weeks after sowing (WAS) of paprika seedlings at Homestead and Nare sites in the 2002/2003 season

Sterilisation method	Weed density (number / m^2)			
	2WAS		4WAS	
	Homestead	Nare	Homestead	Nare
Non treated	0.48 (2.0)	0.64 (3.4)	0.96(8.1)	1.26(17.2)
Cow dung	0.37 (1.3)	0.90 (8.9)	0.70(4.0)	1.36(22.9)
Brushwood	0.18 (0.5)	0.76 (4.8)	0.35(1.2)	0.89(6.8)
Maize cob	1.12 (12.2)	1.67(45.8)	1.48(29.2)	1.95(88.1)
Solarisation	0.84 (5.9)	1.93 (84.1)	1.23(16.0)	1.98(94.5)
Methyl bromide	0.36 (1.5)	0.86 (6.2)	0.59(2.9)	1.19(14.5)
CV (%)	36.6	49.1	28.7	34.3
LSD (5%)	0.37	NS	0.46	NS

*The figures outside and before the brackets represents Log (X+1) transformed data of the figures in brackets.

At 4 WAS the best weed suppression method was brushwood, which was not significantly different from cow dung and methyl bromide at Homestead site in 2002/2003 (Table 5.12).

5.3.8. Seedling Mortality

Seedbed sterilisation method did not influence seedling mortality in 2001/2002 and 2002/2003 seasons at both sites.

5.4 Discussion

It was envisaged that the heat generated by such methods as solarisation, burning of maize cobs, brushwood and cow dung would eliminate both weeds and the microbe population which is probably made up of pathogenic and non pathogenic microbes. Brushwood was effective in microbe and weed

management. Temperatures of 70 ^{0}C for 30-60 minutes is sufficient to eradicate most soil borne pathogens (Newhall, 1955; Runia, 1983; Bollen, 1985).

Bacterial and fungal microbes in the soil in 2001/2002 at Chinyudze site were greatly reduced mainly because the temperatures achieved by burning of brushwood at 5 cm soil depth were too high for most bacterial and fungal microbes to survive. At greater soil depth, heat from burning brushwood was not enough and microbial counts were higher. Solarisation had the best microbe reduction effect as soil depth increased. Soil temperatures in plots mulched with black plastic were lower than those mulched with clear plastic. Black plastic has been reported to be less effective in transmitting solar radiation (Katan, 1981). The black plastic was however used in CRA mainly because it is cheaper, multi-purpose and widely available. The use of black rather than clear plastic for soil mulching was more effective in controlling weed growth, probably due to the exclusion of light which would otherwise facilitate growth of thermo tolerant weeds (Coates-Bedeford, Cohen, Prendergast and Riley, 1997 as cited by Yucel, 2000).

In this study however solarisation was not effective in weed suppression mainly because it was initiated at the end of July so as to meet the required 8 weeks of solarisation before paprika sowing in September. In July, temperatures in Zimbabwe are still very low thus not very high temperatures were reached by solarisation. In Zimbabwe, Tobacco Research Board has reported poor results

with solarisation, especially with regards to weed control (Farming World, July 1997).The temperatures obtained with solarisation in this study were 9-7 ^{0}C lower than the work done by Yucel (2000). However soil temperatures obtained in solarised plots were 3-8 ^{0}C higher than unsolarised plots, similar to the findings of Smith, Pullman and Garber (1980) and Cebolla, Busto, Barreda, Martinez and Cases (1989). When solarisation was tested in Zimbabwe the soil temperature did not go above 45^{0}C and weed control was poor (Mashingaidze, Chivinge and Mtetwa, 1996).

Brushwood was effective in reducing the microbial populations as indicated by the significantly low AUDPC recorded in 2001/2002. However, it was inconsistent in its effect on the weed population

At Homestead site most factors tested were not significantly different from each other probably due to the high temperatures achieved at this site. The high temperatures achieved were because of the gravely nature of the soil.

Farmers's choice of sterilisation method will be based on treatment that ensures that weed management is effective and pathogen reduction ensures a healthy seedling. In addition a sterilisation method that is effective but expensive or laborious may not be best for smallholder farmers.

5.5 Conclusions and Recommendations

Brushwood may have proved effective for seedbed sterilisation, and solarisation was promising. However, the methods resulted in some inconsistencies particularly on microbe and weed management in the nursery. It may therefore be recommended that, for their efficacy to be improved they be combined with other sterilising agents such as chloropicrin, methyl iodide and dazomet, if they have to match the efficacy of methyl bromide treatment.

CHAPTER 6

DETERMINATION OF AN EFFECTIVE REDUCED FUNGICIDE SPRAY PROGRAMME

6.1. Introduction

Paprika yields obtained in Zimbabwe vary from less than one tonne per hectare in the smallholder farming sector to around six tonnes per hectare in the commercial farming sector (Hyveld Seed, 1996). These low yield figures recorded in the smallholder sector have been attributed to a number of production-related problems, which include poor disease and weed management. Diseases of economic importance in Zimbabwe on paprika are powdery mildew, bacterial leaf spot, anthracnose, Cercospora leaf spot, damping off, stemphylium leaf spot, phytophthora blight, altenaria rot, and wilt (*Sclerotium rolfsii*) and bacterial soft rot (Paprika Zimbabwe, 1998). Management of these diseases has been a problem in the smallholder-farming sector due to the prohibitive cost of pesticides. Therefore, as a result of the high cost of pesticides and the campaign for limited Maximum Residual Level (M.R.L) in paprika, a viable management option that involves minimum fungicide input needs to be developed. Integrated pest management among growers must be supported and promoted as a means of significantly reducing the amount of synthetic pesticides applied to a crop (Bolkan and Ranert, 1994).

In a test involving 10 fungicides against the paprika disease caused by *Phytophthora nicotiane* var. *nicotiane*, six sprays of copper oxychloride (0.3%) at 10-day interval proved to be the most effective in checking infection and increasing yield (Bhardwaj and Sharma, 1985). Mancozeb and 0.3% Blitox at 0.25% and 200 ppm respectively reduced bacterial leaf spot and fruit rot diseases of chilli caused by *Xanthomonas campestris* pv *vesicatora* and *Colletotrichum capsici (Syd)* (Raju and Rao, 1984). Application of Mancozeb and 0.3% Blitox at 5, 10, 15 or 20 days interval revealed that although yield rose with the decreasing spray interval, the net profit was highest with 15-day interval (Raju and Rao, 1984). Acibenzolar-S-methyl (Bion) is a novel plant protection product that mimics the pathogen – host interaction and results in systemic acquired resistance in plants (Cole, 1999). It protected tobacco plants against several diseases (Cole, 1999). It is with this background that Bion could be vital in paprika disease management as it also belongs to the Solanaceae family as tobacco.

Resistant cultivars are not yet available and farmers rely on pesticides for crop protection (Vos, Nurtika and Surmarni, 1994). The negative impacts of reliance on pesticides for maintenance of crop health is manifold with residues of chemicals such as monocrotophos (0.2-7.5 ppm) and chlorpyrifos (1.4 ppm) detected in freshly harvested pepper fruits (Asandhi, 1983 as cited by Bolkan and Ranert, 1984). Vos and Duriat (1995) recommended that the reduction of the intensive use of pesticides must be included as an important issue within the

future crop management programmers for pepper production. In order to reduce pesticide usage, which can be extremely high, alternative and more sustainable methods of crop protection should be investigated (Vos, Uhan and Sutarya, 1995). The objective of this investigation was to assess the effect of reduced fungicide spray programme on disease incidence, severity and final yield of paprika.

6.2. Materials and Methods

On-farm trials were established at Bingaguru and Chinyudze sites during the 2000/2001 and 2001/2002 rainy seasons. The farm sites in Bingaguru were Mhiripiri in 2000/2001 and Mukada in 2001/2002. In Chinyudze the farm sites were Dengedza and Mugadza in 2000/2001 and 2001/2002 rainy seasons respectively. The seedlings were transplanted onto ridges in fields prepared as described in Chapter 3. The treatments tested were as follows:

1. Spraying when necessary after scouting (a threshold of an overall severity score of 3 on at least 25% of the total plants was required for the plot to be sprayed). (Sulphur (320g active ingredient (a.i)) at 3 weeks after crop transplant (WAT)) and copper oxychloride (255g a.i/ha) – mancozeb (120g a.i/ha) mixture at 13 WAT in 2000/2001 and Copper oxychloride (255g a.i/ha) – mancozeb (120g a.i/ha) mixture at 3 WAT, 11 WAT and Sulphur (320g a.i/ha) at 15 and 17 WAT in 2001/2002).
2. Fungicide weekly recommended spraying programme (Sulphur (320g a.i/ha) at 3, 5, 7,9,11 and 15 WAT, mancozeb (240g a.i/ha) at 4, 8, and 12

WAT and copper oxychloride (255g a.i /ha)-mancozeb (120g a.i/ha) mixture at 6,10,13,14 and 16 WAT).

3. Applying Sulphur (320g a.i/ha) 2 weeks after transplanting and a mixture of copper oxychloride (255g a.i/ha) and mancozeb (120g a.i/ha) 4 WAT. This was repeated at 6 WAT and 8 WAT.
4. Alternate Sulphur (320g a.i/ha) and the mixture of copper oxychloride (255g a.i/ha)-mancozeb (120g a.i/ha) once every 2 weeks.
5. Spraying acibenzolar-S-methyl (2.5g a.i/ha) (Bion) 10 days after transplanting then every 14 days. Spraying will be done 5 times. (10 days after transplanting, 5, 7, 9 and 11 WAT)
6. No spraying. (Control)

Fungicide application was done according to treatments. Experimental design, plot size, agronomic practices and disease assessment and identification were carried out as earlier described in Chapter 3. Yield data and AUDPC data generated from the disease severity and incidence records were subjected to ANOVA.

6.2.1 Economic analysis

All operations were timed and costed, the data were then used to perform an economic analysis for seasons which had treatments showing significant differences ($p<0.05$). All timed operations and fungicides were costed using the price rates in that season (Appendix 8).

The gain in marketable yield (G) due to fungicide treatment is the difference between yield with fungicide treatment (Yc) and yield of the non-sprayed treatment (Yo), as shown in equation (i):

G=Yc-Yo……. (i)

The added profit attributable to fungicide treatment (Pa) was calculated from the gain in yield (G) multiplied by the paprika price per tonne (R) less the costs of fungicide (F), fungicide application (A) and the extra cost of harvesting the gain in yield (H), as shown in equation (ii):

Pa=(GxR)-(F+A+H)…… ……..……(ii)

Added profit (Pa) reflects the estimated economic benefits of fungicide use as it shows the extra income less increased costs associated with fungicide treatment.

6.3 Results

6.3.1 Disease assessments

Major diseases identified and confirmed in the laboratory in the two seasons were Bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*), Cercospora leaf spot (*Cercospora unamunoi (Cast.)*), Grey leaf spot (*Stemphylium solani*), bacterial soft rot (*Erwinia* spp), Powdery mildew (*Leveillula taurica (Lev)*), Alternaria leaf spots (*Alternaria alternata*) and Anthracnose (*Colletotrichum capsici (Syd)*) for all sites.

6.3.1.1 Disease severity

6.3.1.1.1 Overall AUDPC

There were no significant differences among the various treatments with respect to overall AUDPC at the Mhiripiri and Mukada sites in the 2000/2001 and 2001/2002 seasons. At the Mugadza site, the control and the treatment involving spraying when necessary had the highest disease (Figures 6.1-6.4). Regardless of the treatment, disease severity increased as the season progressed at Mhiripiri in 2000/2001 season. In case of Dengedza site, disease severity fluctuated across the 2000/2001 season.

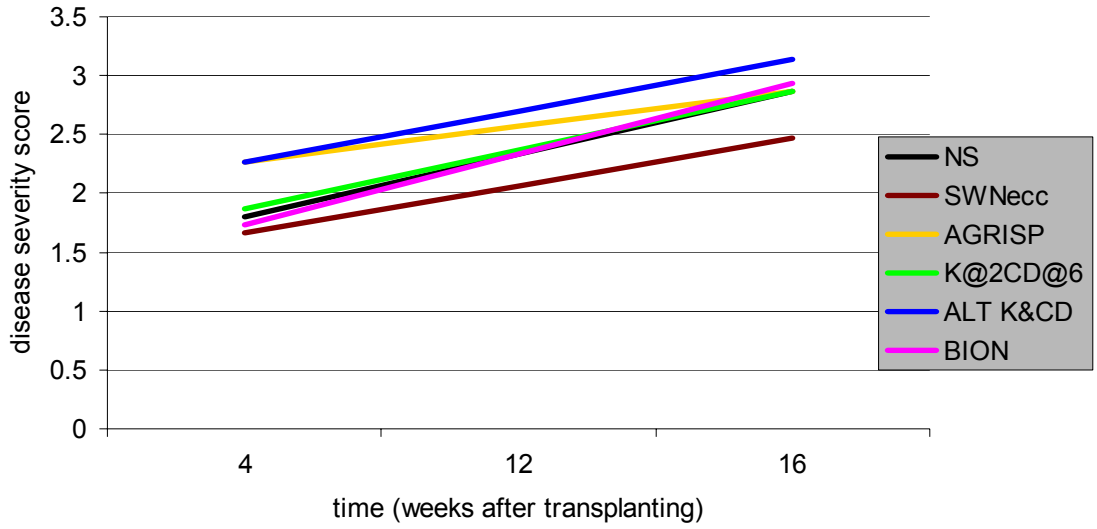


Figure 6.1 Disease Progress Curves for Mhiripiri site in the 2000/2001 rainy season

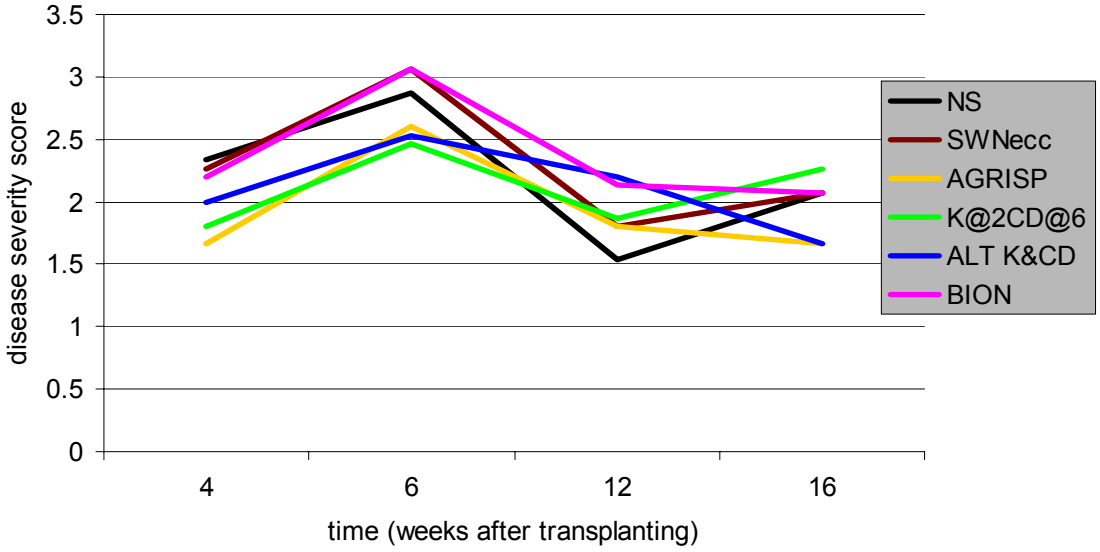


Figure 6.2 Disease Progress Curves for Dengedza site in the 2000/2001 rainy season

NS= No spraying. (Control), SWNecc = Spraying when necessary after scouting, AGRISP= Weekly recommended spraying programme, K@ 2CD@ 6= Applying Sulphur at 2WAT and copper-oxychloride + Mancozeb at 8WAT, ALT K &CD= Alternate Sulphur and copper oxychloride+ Mancozeb after every two weeks, Bion= Spraying Acibenzolar-S-methyl (Bion) at 10 days after transplanting then after every 14 days

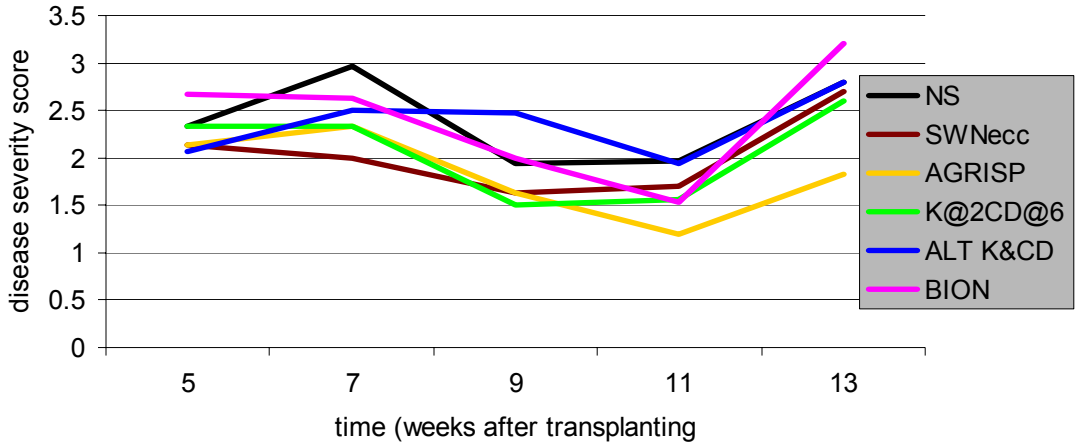


Figure.6.3 Disease Progress Curves at Mugadza site in the 2001/2002 season

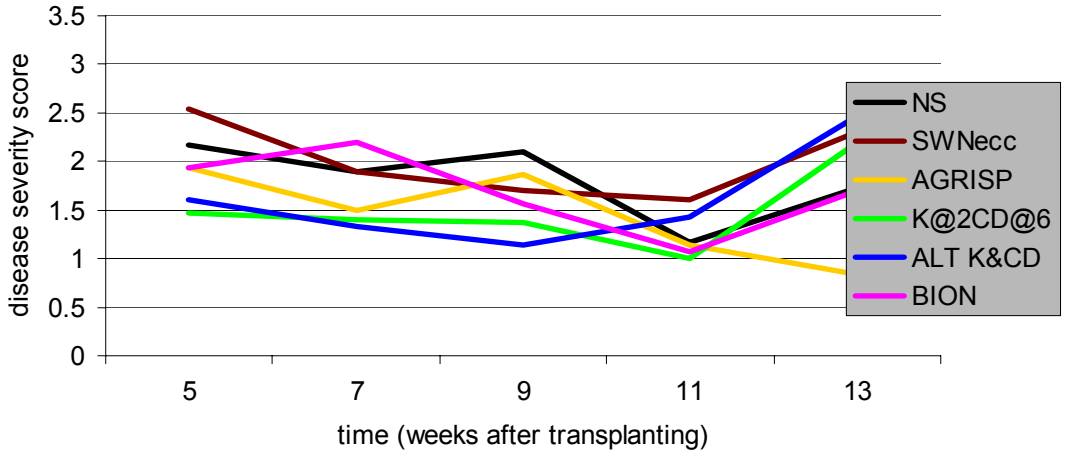


Figure 6.4 Disease Progress Curves at the Mukada site in the 2001/2002 rainy season

NS= No spraying. (Control), SWNecc = Spraying when necessary after scouting, AGRISP= Weekly recommended spraying programme, K@ 2CD@ 6= Applying Sulphur at 2WAT and copper-oxychloride + Mancozeb at 8WAT, ALT K &CD= Alternate Sulphur and copper oxychloride+ Mancozeb after every two weeks, Bion= Spraying Acibenzolar-S-methyl (Bion) at 10 days after transplanting then after every 14 days

6.3.1.1.2 Percentage Infection AUDPC

There were no significant differences ($p>0.05$) among treatments for AUDPC percentage infection at the Mukada site in the 2001/2002 season. The control

(unsprayed) and spraying when necessary treatments were the least effective in controlling diseases at the Mugadza site in the 2000/2001 season.(Table 6.1)

6.3.1.1.3 Leaf spots AUDPC

There were no significant differences in leaf spots AUDPC in the 2001/2002 season at Mugadza and Mukada sites (Table 6.1).

6.3.1.2 Disease incidence

There were no significant differences ($p>0.05$) for disease incidence for all sites in both seasons.

Table 6.1 Overall, percentage infection and leaf spot AUDPC of bacterial and fungal disease as influenced by fungicide treatments at Mhiripiri, Dengedza, Mukada and Mugadza during the 2000/2001 and 2001/2002 seasons

	2000/2001				2001/2002			
Treatment	Overall AUDPC				Percentage Infection AUDPC		Leaf spot AUDPC	
	Dengedza	Mhiripiri	Mugadza	Mukada	Mugadza	Mukada	Mugadza	Mukada
1	29.10	24.80	26.5	8.03	8.30	31.67	5.33	22.33
2	23.60	38.80	13.30	6.80	7.70	14.00	4.67	13.40
3	24.80	27.60	15.40	5.63	6.30	18.67	5.07	15.53
4	25.80	32.40	18.7	5.40	4.70	20.67	5.60	20.00
5	27.00	28.00	19.5	7.90	8.00	19.67	5.87	18.48
6	26.50	28.00	29.9	8.07	7.30	34.00	5.33	28.60
C.V (%)	3.83	12.61	14.52	13.39	24.23	18.9	18.13	27.66
$LSD_{0.05}$	1.82	NS	5.43	NS	NS	7.95	NS	NS

1; spraying after scouting; **2** weekly interval spray, **3**; Sulphur at 2WAT and copper oxychloride-Mancozeb mixture at 6WAT, **4**; alternating Sulphur and copper oxychloride- Mancozeb every two weeks , **5**; Bion and 6 unsprayed

6.3.2 Pod yield

6.3.2.1 Number of pods per plant

There were no significant differences for the number of pods per plant for both sites in the 2001/2002 season.

6.3.2.2 Total pod yield

Total yield of paprika pods was not significantly influenced by the various fungicide application treatments at Dengedza in 2000/2001 season at Mukada and Mugadza during the 2001/2002 season (Table 6.2).

Table 6.2 Total pod yield of paprika as influenced by fungicide application at Mhiripiri, Dengedza, Mukada and Mugadza during the 2000/2001 and 2001/2002 seasons

	2000/2001	2001/2002		
Treatment	Total Yield (with calyxes)			
	Mhiripiri	Dengedza	Mukada	Mugadza
1	-	0.53	0.50	0.54
2	-	0.99	0.62	0.63
3	-	0.58	0.65	0.62
4	-	0.78	0.90	0.70
5	-	0.48	0.44	0.54
6	-	0.71	0.55	0.48
C.V (%)	-	56.67	38.99	13.95
$LSD_{0.05}$	-	NS	NS	NS

*****No data -the farmer accidentally bulked pods at this site before records were taken; **1**; spraying after scouting; **2;** weekly interval spray, **3**; Sulphur at 2WAT and copper oxychloride-Mancozeb mixture at 6WAT, 4; alternating Sulphur and copper oxychloride- Mancozeb every two weeks, **5**;Bion and 6; unsprayed

6.3.2.3 Total marketable yield

In 2000/2001 at Mhiripiri site no yield data was collected as the farmer who hosted the trial harvested and bulked all treatments before we recorded the data

thinking the crop was over due for harvesting, yet it had not reached the harvesting stage as described in Chapter 3.

The highest mean total marketable yield was obtained from the weekly spraying interval of fungicides and alternating sulphur and a mixture of copper oxychloride + mancozeb after every fortnight at the Dengedza site in the 2000/2001 season (Figure 6.5). The best three treatments at Dengedza were weekly spraying of fungicides, application of sulphur 2 WAT plus mixture of copper oxychloride + mancozeb mixture, and alternating sulphur and mixture of copper oxychloride + mancozeb. The ineffective treatments were no spraying control and spraying when necessary after scouting. At Mukada during the 2001/2002 season, treatments involving alternate spraying of sulphur and mixture of copper oxychloride + mancozeb fortnightly intervals produced the highest marketable yield of paprika. There were no significant differences among the other treatments, including the no spray control (Figure 6.6).

The highest mean yield was obtained by alternating sulphur and copper oxychloride-mancozeb mixture after every two weeks at Mugadza site in the 2001/2002 season. There were no observable differences in marketable yield among the various treatments (Figure.6.7). There were no significant differences ($p>0.05$) among treatments observed for mean total marketable yield at the Mukada site in the 2001/2002 seasons.

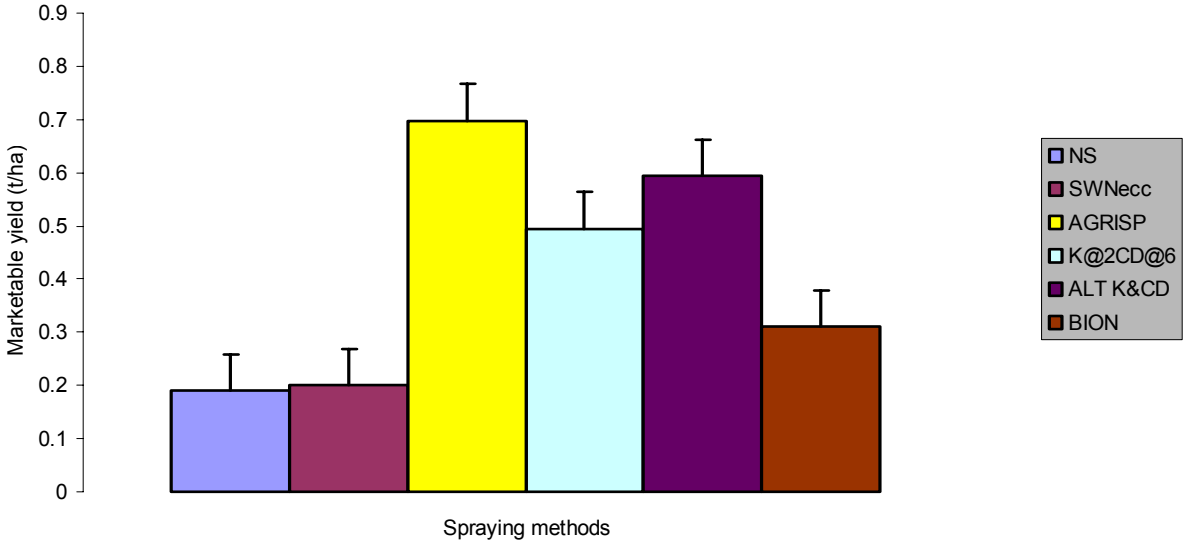


Figure 6.5 Dengedza 2000/2001 season marketable yield

NS= No spraying. (Control), SWNecc = Spraying when necessary after scouting, AGRISP= Weekly recommended spraying programme, K@ 2CD@ 6= Applying Sulphur at 2WAT and copper-oxychloride + Mancozeb at 8WAT, ALT K &CD= Alternate Sulphur and copper oxychloride+ Mancozeb after every two weeks, Bion= Spraying Acibenzolar-S-methyl (Bion) at 10 days after transplanting then after every 14 days

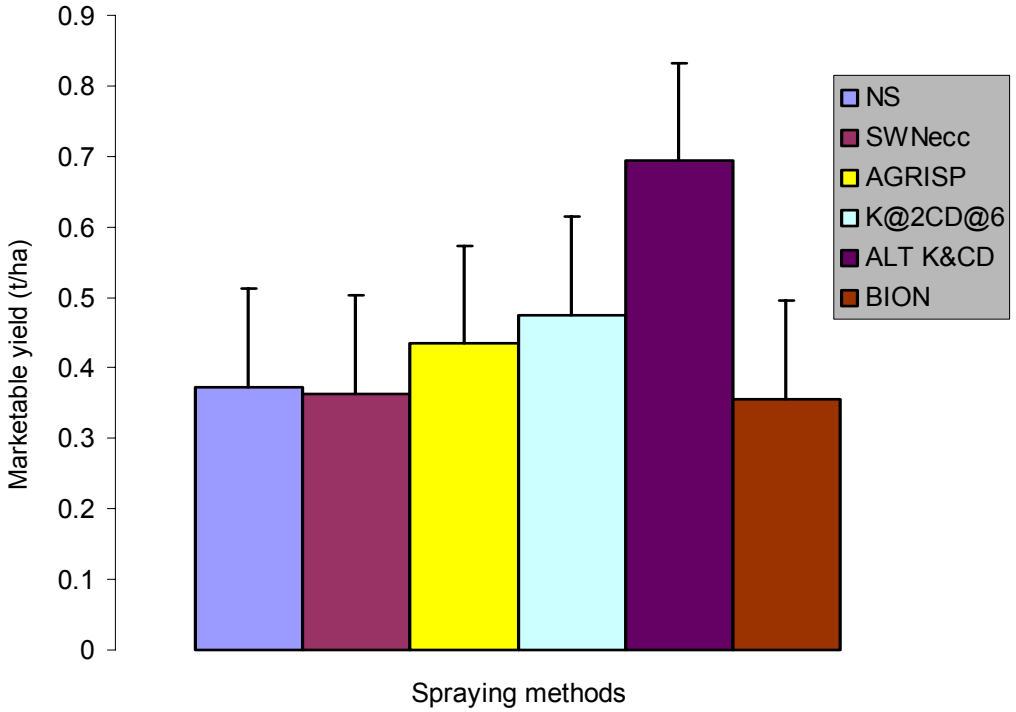


Figure 6.6 Mukada 2001/2002 season marketable yield

NS= No spraying. (Control), SWNecc = Spraying when necessary after scouting, AGRISP= Weekly recommended spraying programme, K@ 2CD@ 6= Applying Sulphur at 2WAT and copper-oxychloride + Mancozeb at 8WAT, ALT K &CD= Alternate Sulphur and copper oxychloride+ Mancozeb after every two weeks, Bion= Spraying Acibenzolar-S-methyl (Bion) at 10 days after transplanting then after every 14 days

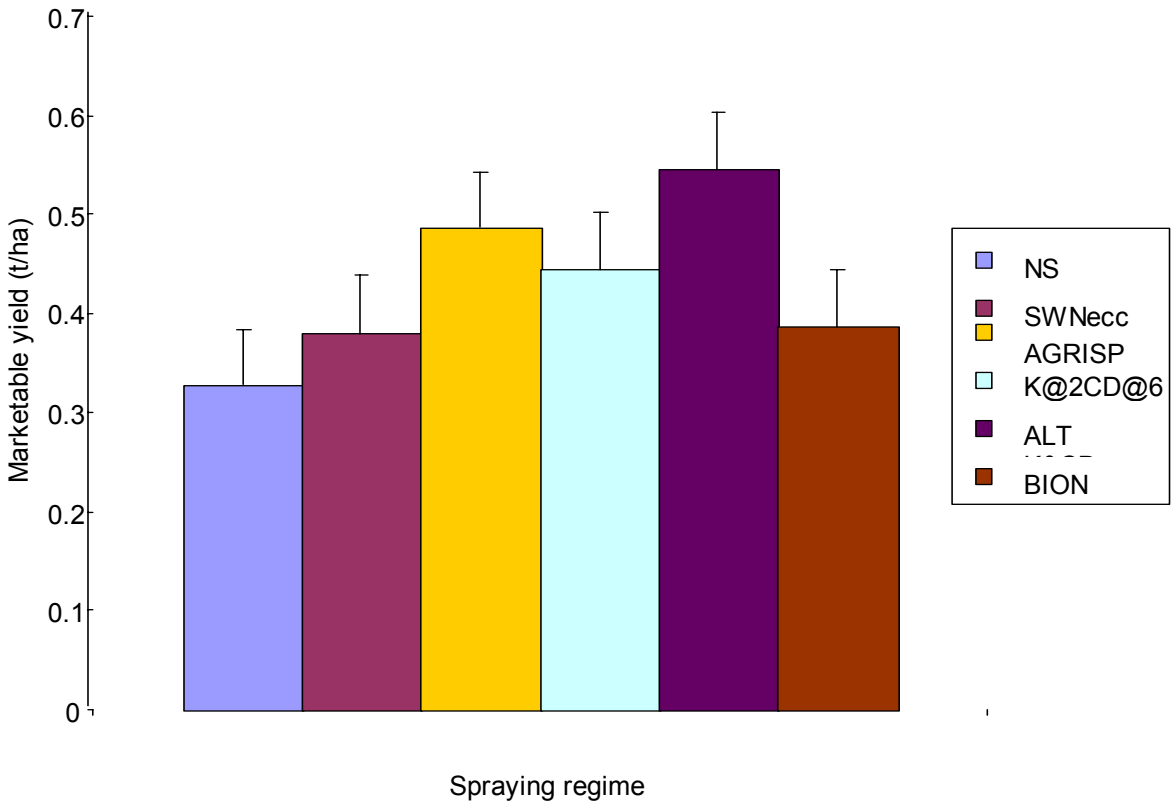


Figure 6.7 Mugadza 2001/2002 marketable yield

NS= No spraying. (Control), SWNecc = Spraying when necessary after scouting, AGRISP= Weekly recommended spraying programme, K@ 2CD@ 6= Applying Sulphur at 2WAT and copper-oxychloride + Mancozeb at 8WAT, ALT K &CD= Alternate Sulphur and copper oxychloride+ Mancozeb after every two weeks, Bion= Spraying Acibenzolar-S-methyl (Bion) at 10 days after transplanting then after every 14 days

6.3.3 Economic analysis

No economic analysis was perfomed for the Mhiripiri due to absence of yield data in 2000/2001 season and Mukada where marketable yields were similar.

The standardized AUDPC (SAUDPC), actual marketable yield, yield gain over non-sprayed and added profit were significantly influenced by fungicide treatments during the 2001/2002 season (Table 6.3). Clearly the highest actual marketable yield, yield gain and added profit came from the treatment involving the weekly regime i.e. alternative weekly spraying of sulphur, mancozeb. Among the five spray treatments, the least effective one was spraying Bion (2.5g a.i/ha) 10 days after transplanting and thereafter every 14 days. With respect to SAUDPC values, the treatment which gave the highest value was spraying of fungicides only after scouting (Table 6.3).

Table 6.3 Marketable yield (t/ha) and added profit for frequency of fungicide spray treatments at Dengedza in 2000/2001

Fungicide Treatment	SAUDPC	Actual marketable yield (t/ha)	Yield gain over non-sprayed (t/ha)	Added profit (Z$ 000'/ha)
1	2.43	0.20	0.01	0.99
2	1.97	0.70	0.51	75.93
3	2.07	0.50	0.30	45.33
4	2.15	0.31	0.40	59.41
5	2.25	0.19	0.12	17.25
Non Sprayed	2.21			
CV (%)	3.83	20.22	34.16	34.92
LSD (5%)	0.15	0.15	0.18	26.05

1; spraying after scouting; **2;** weekly interval spray, **3**; Sulphur at 2WAT and copper oxychloride-Mancozeb mixture at 6WAT, 4; alternating Sulphur and copper oxychloride- Mancozeb every two weeks and **5**; Bion

Table 6.4 Marketable yield (t/ha) and added profit for frequency of fungicide spray treatments at Mugadza in 2001/2002

Fungicide Treatment	SAUDPC	Actual marketable yield (t/ha)	Yield gain over non-sprayed (t/ha)	Added profit 000' (Z$/ha)
	Mugadza	Mugadza	Mugadza	Mugadza
1	2.21	0.38	0.05	12.67
2	1.11	0.49	0.16	32.34
3	1.28	0.45	0.11	33.26
4	1.56	0.55	0.21	57.89
5	1.63	0.39	0.06	16.83
Non Sprayed	2.49	0.33		
CV (%)	14.42	16.11	63.08	67.15
LSD (5%)	0.45	0.13	NS	NS

1; spraying after scouting; **2;** weekly interval spray, **3**; Sulphur at 2WAT and copper oxychloride-Mancozeb mixture at 6WAT, **4**; alternating Sulphur and copper oxychloride- Mancozeb every two weeks and **5**; Bion

In the case of Mugadza site in the 2001/2002 season, it was only on the standardized AUDPC and actual marketable yield that fungicide treatments had significant influence (Table 6.3). Similarly to what was obtained in the case of Dengedza site, the highest actual marketable yield was from the treatment involving alternate spraying of sulphur and mancozeb treatment and alternating sulphur and a copper oxychloride + mancozeb mixture while the highest SAUDPC value was from spraying of Bion. The actual marketable yield for the most effective was about 48.5 percent higher than the least effective treatment.

6.3.3.1 Yield gain

Weekly spraying regime and alternating sulphur and Copper oxychloride+ mancozeb mixture fortnightly had the highest yield gain at Dengedza site in 2000/2001 season. The least yield gain (0.12t/ha) was achieved by Bion

application and spraying after scouting treatments. At Mugadza site the yield gains were not significantly ($p>0.05$) different from each other. Overally, Dengedza site in 2000/2001 rainy seasons had a better yield gain than Mugadza site in 2001/2002.

6.3.3.2 Added profits

The highest added profit of $75 930/ha was recorded in weekly sprayed plots but was not significantly ($p>0.05$) different from $59 410/ha achieved by alternating Copper oxychloride and Mancozeb fortnightly at Dengedza site in 2000/2001 rainy season. Spraying after scouting and Bion application treatments were significantly ($p>0.05$) the same as they added $990/ha and $17 250 profits respectively at the same site in the same season. There were no significant differences ($p>0.05$) in added profits from different spraying regimes at Mugadza site in the 2001/2002 rainy season (Table 6.4).

6.4 Discussion

There were generally lower disease severity levels in 2001/2002 than in 2000/2001 season as reflected by the SAUDPC values for the respective seasons. In terms of rainfall received, 2000/2001 rainy season was better than 2001/2002 season. The mean annual rainfall for Chinyudze and Bingaguru sites in the 2000/2001 season was 636.8mm and 491.3mm in 2001/2002 (Figures 3.1 and 3.2). This could have contributed to the relatively higher disease severity in 2000/2001 season, thus significant differences among some of the fungicide

treatments were recorded.

The difference between non sprayed plots and sprayed plots was quite distinct as the marketable yield for non sprayed plots was reduced by the disease. This could further explain the observed differences in yield gains and consequent differences in added profits at Dengedza site in 2000/2001 rainy season. The relatively low disease severity at Mugadza site in 2001/2002 season resulted in non significant differences between the values of marketable yield for the unsprayed and the sprayed plots. As was expected non-significance in yield gains resulted in non-significance in added profits. The weather conditions experienced during the period of study influenced disease incidence and severity in both seasons. This is so mainly because dry weather conditions are not favourable for the growth and development of causative pathogens for leaf spots and pod rots (Agrios, 1997).

Under relatively wet conditions in CRA, the most effective disease management was alternating sulphur and copper oxychloride + mancozeb fortnightly or weekly spraying. Copper oxychloride is a broad spectrum fungicide, which can also affect bacteria.

Spraying fungicides after scouting was the least effective contrary to what was highly expected. This could have been attributed to a lack of a documented research based threshold levels required in deciding whether or not to spray. In this study a threshold of an overall severity score of 3 on at least 25% of the total

plants was required for the plot to be sprayed. The use of lower threshold level than the one used in this study is likely to result in the improvement of the effect of spraying after scouting treatment and the consequent increase in the total marketable and gained yield and added profit. However, the major limitation with spraying after scouting are that most farmers are not familiar with paprika diseases, such that during scouting they may not really know what to look for. Vos and Duriat (1995) reported that pepper farmers in Indonesia lacked information concerning symptomalogy of pepper diseases as symptoms were difficult to distinguish. This also holds true in CRA paprika smallholder farmers as confirmed by the results of the survey on the level farmers knowledge on diseases (Chapter 4).

Acibenzolar-S-methyl (Bion) application consistently gave the least gain in yields over the two seasons and consequently produced the least added profits. This confirms some earlier findings on tobacco and pepper (Cole, 1999; Damicone, Hammer and Bostain, 2000) that the yield of plants treated with acibenzolar-S-methyl were very similar to untreated but the AUDPC was significantly reduced. Since paprika seedlings take between 8-10 weeks in the nursery, it may be necessary to induce the resistance to diseases by applying treatments when the crop is in its final stages of seedbed life.

Total pod yield was significantly the same across treatments in both seasons. However, significant differences ($p<0.05$) were noted for total marketable yield in

2001/2002 rainy season implying that there was disease effect on the quality of paprika. Probably, disease severity did not affect the quantity of paprika produced but rather the quality. Marketability of paprika is mainly based on the state of the pods in terms of blemish and colour. The disease management practices that farmers employ should not only focus on maintaining the high quantity of paprika pods but also the quality. It was the ability of a disease management practice to control diseases that affect the quality of pods, that mattered in 2001/2002 rainy season.

6.5 Conclusions and Recommendations

Smallholder paprika farmers can therefore adopt the alternation of sulphur and copper oxychloride + mancozeb mixture fortnightly for the effective control of paprika diseases and the best added profits as this will be as good as the weekly spraying of the pesticides. Under dry weather conditions, resulting in low disease pressure, smallholder paprika farmers can however, adopt a less costly fungicide spraying programme. The most cost – effective disease management practice in this case was alternating spray of sulphur and copper oxychloride + mancozeb mixture fortnightly. Under wet conditions, smallholder paprika farmers must never adopt a no spray disease management practice as this may result in very low economic yields.

The alternating of sulphur and copper oxychloride-mancozeb mixture fortnightly gave the same disease control effect and total marketable yield as the commercial weekly recommendation for fungicide spraying.

CHAPTER 7

EFFECT OF WEED MANAGEMENT ON DISEASE INCIDENCE, SEVERITY AND YIELD OF PAPRIKA.

7.1. Introduction

Yield of paprika obtained on farms in Zimbabwe vary from less than one tonne per hectare in the smallholder farming sector to around six tonnes per hectare in the commercial farming sector (Hyveld Seed, 1996). Weed management is one of the production-related problems in paprika production. Weeds limit efficient paprika production by competing with light, moisture and nutrients. Several studies have led to the conclusion that pepper (*Capsicum annuum*) is a poor competitor against weeds (Frank *et al*., 1998; Lagoke *et al*., 1998). Eshel *et al*., (1998) found that weed competition during one month after pepper emergence caused a 70% yield reduction. In addition, there have been reports of weeds serving as reservoir hosts for pests and diseases (Adigun, Lagoke and Karikari, 1987). Weed control is an important aspect of crop production but it requires a lot of human labour where chemical control is not used. This is why weed management accounts for a substantial proportion of total cost of crop production. Although chemical use appears to be the best alternative, environmental and economic concerns have increased interest in mechanical /manual weed control and reduced herbicide use (Edwards, 1987). Affordability, availability, technical know–how and environmental friendliness of a weed control method determines whether farmers will choose to use it or not. Farmers who

mainly rely on the hoe find it difficult to weed timely. At the beginning of the wet season, land preparation, planting and weeding all compete for available labour (Hammerton, 1974).

Weeds compete with the crop for nutrients and sunlight and they also serve as hosts for many pests and diseases (Labrada and Paredes, 1983 as cited in Lagoke et al 1998). Research has shown that transplanted pepper should be kept weed-free for the first 60 days after planting (Labrada and Paredes, 1983 as cited in Lagoke *et al* 1998). Pre- emergence application of metribuzin, alachlor and nitrofen gave significantly more yield than non-treated plots (Singh *et al*, 1984). Various herbicides have been reported to give selective weed control in pepper. These include diphenamid, alachlor, pendimethalin, chlorthal dimethyl, oxadiazon and metolachlor, which are effective on grasses and some substituted ureas like linurin, chlorobromuron and metobromuron which are mainly effective on broad - leaved weeds (Uwannah, 1982; Falalu, 1983).

Most of the existing pesticide and herbicide recommendations are too expensive and therefore unaffordable for the smallholder farmer. The majority of smallholder paprika growing farmers prefer re-ridging as a weeding control method as it maintains the already established ridges. However, there is no consistency in the frequency of weeding for a chosen method during the season. On the other hand, most herbicide recommendations do not state any need for additional hand hoe weeding during the crop's growing season. Singh *et al*.,

(1984) noted that hand hoe weeding done once, in addition to herbicide application significantly increased the yield of tomato. Differences in weed flora and their pattern of emergence during crop growth influence the performance of herbicides (Adigun *et al.*, 1987). In CRA, with its diverse weed flora, mixtures of herbicides which include both the grass and broad - leaved herbicides will be required to effect persistent broad spectrum weed control. On the other hand, manual weed management must be implemented in a manner that is cost effective considering labour requirements of other crops, such as maize, which will also compete for human labour. This experiment was therefore conducted to evaluate the effect of different weed management options on disease incidence, severity and final yield of paprika.

7.2. Materials and Methods

Experiments were established on–farm at Bingaguru and Chinyudze areas during 2000/2001 and 2001/2002 rainy seasons. In Bingaguru, the trials were hosted at Mufambi in 2000/2001 and Mhiripiri in 2001/2002 rainy seasons. In Chinyudze area all trials were hosted at Sanhi in both seasons. Transplanting was done when seedlings were 10-15cm in height. The five treatments that were tested are as follows:

1. No weeding (Control)
2. Hand hoe weeding 2 weeks and 6 weeks after transplanting (Farmer's practice).
3. Re-ridging 3 weeks after transplanting (WAT) and hand hoe weeding on

the ridge 6 and 9 WAT.

4. Lasso (Alachlor) (160l active ingredient (a.i)/ha) applied over the top immediately after transplanting.
5. Ronstar (Oxidiazon) (96l a.i/ha) + Lasso (80l a.i/ha) mixture applied 24 hours prior to transplanting.

Herbicides were applied using a 15 litre capacity knapsack sprayer fitted with a flat fan nozzle. The herbicide-water solution was applied at rate of 200 litres/ha. To allow reasonable influence of the treatment on disease severity and incidence no fungicides were applied during the course of this experiment. All operations were timed and data collected were used in the economic analysis. Costs of herbicides and labour used were as per that season's price rate (Appendix 8). Disease severity and incidence score data were collected at fortnightly intervals commencing two weeks after transplanting. Disease severity score was assessed using one scale in 2000/2001 and three in 2001/2002 (Chapter 3). A 0.3m x 0.3m quadrant was thrown three times in the paprika plots at random to assess weed density. The weeds within the quadrant were then uprooted and dried to measure biomass. Weeds biomass data was collected in the gross plot.

Weed spectrum was observed in both seasons and weed densities were recorded at 5 and 17 WAT in 2000/2001 season and 8 WAT and 17 WAT in 2001/2002 season. Weed biomass was measured at 5 WAT.Weed density and biomass data was Log (x+1) transformed before analysis of variance.

Number of primary branches per plant, plant height and number of pods per plant were the additional parameters introduced and measured in 2001/2002 season to aid the crop performance assessments in addition to yield data. All the generated data were subjected to ANOVA. The diseased plant tissue were collected and taken for analysis at the University of Zimbabwe Plant Pathology laboratory and handled as previously described in Chapter 3.

7.2.1 Economic analysis

Economic analysis was done on yield data that were significantly different (CIMMYT, 1988)

The gain in marketable yield (G) due to weeding treatment is the difference between yield with weeding treatment (Yc) and yield of the non-weeded treatment (Yo), as shown in equation (i):

G=Yc-Yo……(i)

The added profit attributable to weeding treatment (Pa) was calculated from the gain in yield (G) multiplied by the paprika price per tonne (R) less the costs of weeding (F), weeding operation (A) and the extra cost of harvesting the gain in yield (H), as shown in equation (ii):

Pa=(Gx R)-(F+A+ H)……(ii)

Added profit (Pa) reflects the estimated economic benefits of weeding as it shows the extra income less increased costs associated with weeding treatment.

7.3. Results

7.3.1 Weed Assessments

7.3.1.1 Weed Spectrum

Major weeds observed in paprika fields during the two seasons at both sites were; Mexican clover [*Ricardia scabra* (L)] black jack [*Bidens pilosa* (L.)], stinkblaar [*Datura stramonium* (L)] and Apple of Peru [*Nicandra physalodes* (L.)], which were predominant at the Sanhi sites.

7.3.1.2. Weed density

Weed density during the 2000/2001 season was not significantly different for both Sanhi and Mufambi sites. In 2001/2002 seasons weed density at 5 WAT was not significant ($p>0.05$) among the treatments. (Table 7.1)

TABLE 7. 1 Effect of weed management on weed density at 5WAT in 2000/2001 and 8 WAT in 2001/2002 at Sanhi, Mufambi and Mhiripiri sites

	2000/2001		2001/2002	
	Weed Density (number/m^2)			
Weeding Treatment	Sanhi*	Mufambi	Sanhi	Mhiripiri
Re-ridging at 3, 6 & 9 WAT	1.95(88.1)	1.09(11.3)	2.04(108.6)	1.36(21.9)
Hand weeding at 2 & 6 WAT	2.83(675.1)	1.95(88.1)	2.44(274.4)	2.19(153.9)
Lasso after transplanting	2.53(337.8)	1.62(40.7)	2.12(130.8)	1.78(59.3)
Lasso & Ronstar tank	2.35(222.9)	1.67(45.8)	2.03(107.2)	1.79(60.7)
No weeding	2.18(150.3)	1.81(63.6)	2.40(251.2)	2.66(457.1)
LSD (0.05)	0.20	Ns	Ns	0.34
CV%	4.49	28.31	8.01	9.17

*The figures outside and before the brackets represents Log (X +1) transformed data of the figures in brackets.

7.3.1.3 Weed biomass

TABLE 7.2 Effect of weed management on weed biomass at 5 WAT in 2000/2001 and 2001/2002 at Sanhi, Mufambi and Mhiripiri sites

	2000/2001		2001/2002	
	Weed Density (kilograms/m^2)			
Weeding Treatment	Sanhi*	Mufambi	Sanhi	Mhiripiri
Re-ridging at 3, 6 & 9 WAT	0.034(0.008)	0.021(0.050)	0.047(0.114)	0.037(0.089)
Hand weeding at 2 & 6 WAT	0.029(0.069)	0.019(0.045)	0.114(0.300)	0.047(0.114)
Lasso after transplanting	0.030(0.069)	0.025(0.059)	0.004(0.009)	0.023(0.054)
Lasso & Ronstar tank	0.038(0.091)	0.029(0.069)	0.01(0.023)	0.087(0.222)
No weeding	0.033(0.079)	0.027(0.064)	0.037(0.089)	0.167(0.469)
LSD (0.05)	Ns	Ns	0.085	Ns
CV%	10.4	8.5	9.6	8.9

*The figures outside and before the brackets represents Log (X +1) transformed data of the un transfomred data (kg/m^2) in brackets.

Hand hoe weeding and herbicide treatments had the same reduction effect on weed density at 8 WAT for both sites and on weed biomass for Sanhi site (Table 7.1 and 7.2).

7.3.2. Disease assessment

Bacterial leaf spot (*Xanthomonas campestris* pv *vesicatoria*), Cercospora leaf spot (*Cercospora unamunoi (Cast.)*), Grey leaf spot (*Stemphylium solani*), bacterial soft rot (*Erwinia spp*), Powdery mildew (*Leveillula taurica (Lev)*), Alternaria (*Alternaria alternata*) and Anthracnose (*Colletotrichum capsici (Syd)*) were the major diseases that consistently occurred for all seasons and sites. Most stinkblaar that grew was affected by the same powdery mildew which also affected the paprika crop in both seasons.

7.3.2.1. Disease incidence

Weed control treatments had no influence on disease incidence on paprika in both 2000/2001 and 2001/2002 rainy season.

7.3.2.2 Disease severity

7.3.2.2.1 Overall AUDPC

Re-ridging at 3, 6 and 9 WAT had the lowest AUDPC at the Mufambi site in the 2000/2001 season. There were no significant differences for AUDPC at Sanhi in the 2000/2001 season (Table 7.3, Figure 7.1 and 7.4). The lowest AUDPC was recorded from re-ridging at 3, 6 and 9 WAT at the Mhiripiri site in the 2001/2002. The least AUDPC was recorded for Ronstar-Lasso tank, Lasso and re-ridging at 3, 6 and 9 WAT applied plots at the Sanhi site in the 2001/2002 season (Table 7.3, Figure 7.2 and 7.3)

TABLE 7.3 Overall, percentage infection and leaf spot AUDPC for Sanhi, Mufambi and Mhiripiri sites in 2000/2001 and 2001/2002 seasons as influenced by weed management.

Weeding treatment	2000/2001		2001/2002		2001/2002		2001/2002	
	Overall AUDPC				Percentage Infection AUDPC		AUDPC Leaf spot	
	Sanhi	Mufambi	Sanhi	Mhiripiri	Sanhi	Mhiripiri	Sanhi	Mhiripiri
Re-ridging at 3, 6 & 9 WAT	21.27	23.27	31.97	21.07	40.67	24.00	32.63	18.13
Hand hoe weeding at 2 & 6 WAT	24.07	25.73	35.40	28.67	42.67	36.33	31.93	31.47
Lasso after transplanting	23.07	34.73	30.37	27.17	40.33	34.67	25.33	26.67
Lasso & Ronstar tank	23.53	28.00	31.50	30.20	38.00	34.33	25.6	27.03
No weeding	22.87	28.27	46.50	51.93	56.67	64.67	41.67	46.6
LSD (0.05)	NS	4.24	4.73	6.31	8.73	8.86	3.73	4.48
CV%	8.5	8.1	7.2	10.5	10.62	12.13	6.3	7.97

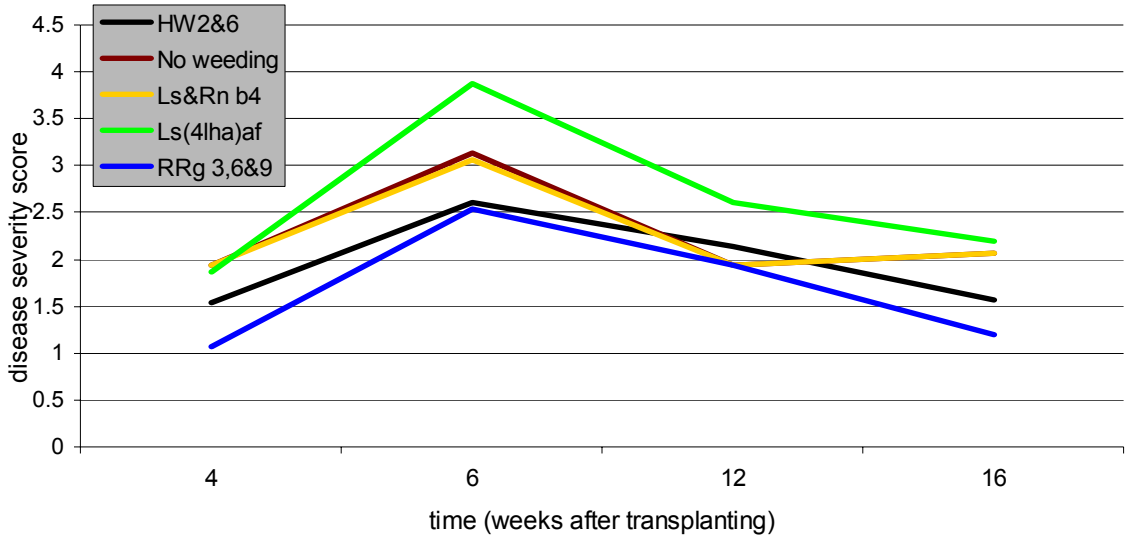


Figure. **7.1** Disease Progress Curves for Mufambi site in the 2000/2001 rainy season

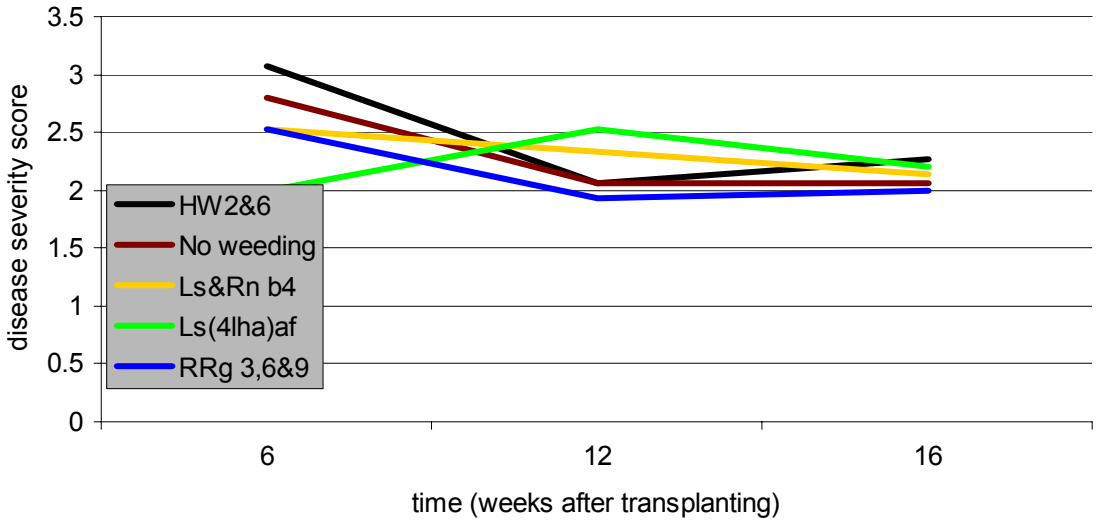


Figure 7.2 DPC for Sanhi site in the 2000/2001 season

HW2&6= Hand hoe weeding 2 weeks and 6 WAT, No weeding = No weeding (Control), Ls & Rn b4 = Ronstar (Oxidiazon) (2l/ha) + Lasso (2l/ha) mixture applied 24 hours prior to transplanting, Ls(4lha) af = Lasso (Alachlor) (4l/ha) applied over the top immediately after transplanting and RRg 3,6 & 9 = Re-ridging 3 WAT and hand hoe weeding on the ridge in 6 and 9 WAT.

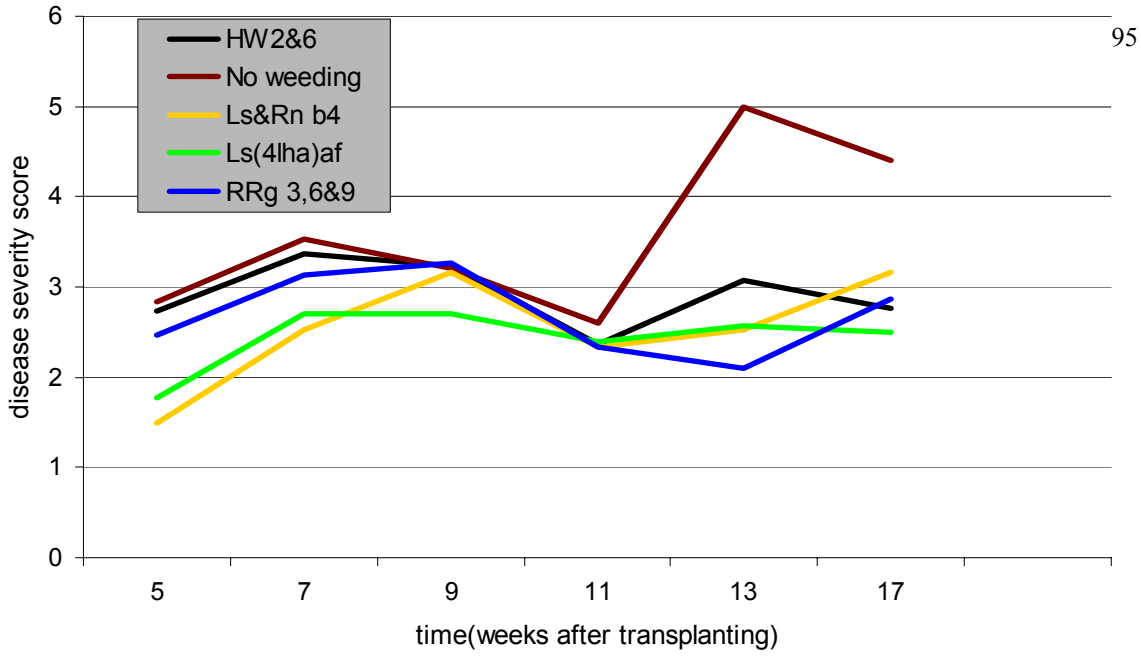


Figure. 7.3 Disease Progress Curve for the Sanhi site in the 2001/2002 rainy season

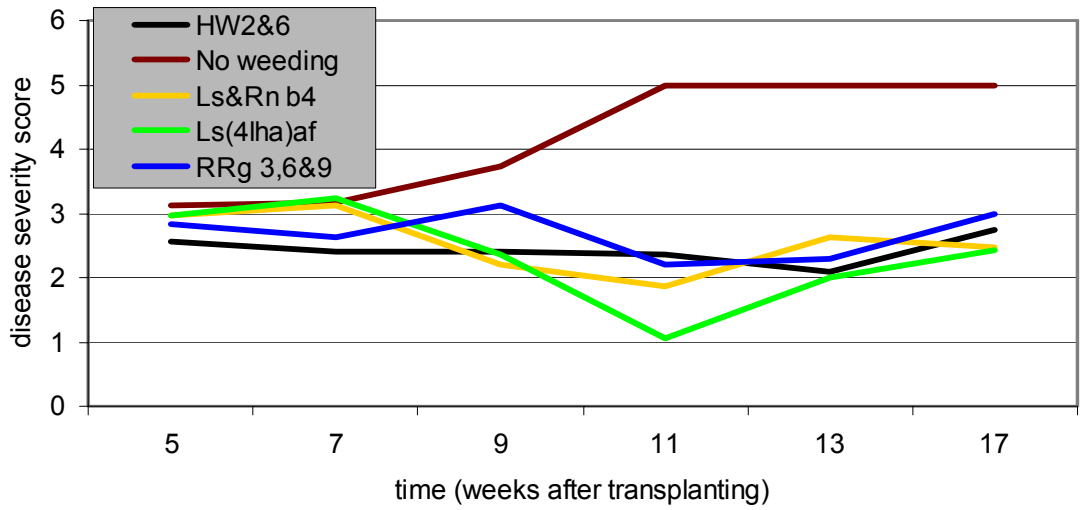


Figure. 7.4 Disease Progress Curve for the Mhiripiri site in the 2001/2002 rainy season

HW2&6= Hand hoe weeding 2 weeks and 6 WAT, No weeding = No weeding (Control), Ls & Rn b4 = Ronstar (Oxidiazon) (2l/ha) + Lasso (2l/ha) mixture applied 24 hours prior to transplanting, Ls (4lha) af = Lasso (Alachlor) (4l/ha) applied over the top immediately after transplanting and RRg 3,6 & 9 = Re-ridging 3 WAT and hand hoe weeding on the ridge in 6 and 9 WAT.

7.3.2.2.2 Percentage infection AUDPC

Re-ridging at 3, 6 and 9 WAT gave the least percentage infection AUDPC in the 2001/2002 season at the Mhiripiri site. At the Sanhi site, all treatments with the exception of the control had similar effects on AUDPC in the 2001/2002 season. (Table 7.3)

7.3.2.2.3 Leaf spot AUDPC

Lasso (4l/ha) and Lasso-Ronstar tank mixture gave the least leaf spot AUDPC at the Sanhi site in the 2001/2002 season. Re-ridging at 3, 6 and 9 WAT gave the least leaf spot AUDPC at Mhiripiri site in the 2001/2002 season. (Table 7.3)

7.3.3. Crop performance

7.3.3.1. Plant height

At Mhiripiri site the control plants were the shortest, and were significantly different from the treatments in 2001/2002 season. There were no significant ($p>0.05$) differences in plant height at Sanhi site in the same season (Table 7.4).

Table 7.4. Plant height, pod number and total yield (with calyxes) as influenced by weed management at Sanhi, Mufambi and Mhiripiri sites in the 2000/2001 and 2001/2002 season

	2001/2002		2001/2002		2000/2001		2001/2002	
	Plant height (cm)		Pod number Per plant		Total Yield (with calyxes) (t/ha)			
Weeding Treatment	Sanhi	Mhiripiri	Sanhi	Mhiripiri	Sanhi	Mufambi	Sanhi	Mhiripiri
Re-ridging at 3, 6 & 9 WAT	45.4	44.4	3.6	5.2	0.08	0.81	0.30	0.29
Hand hoe weeding at 2 & 6 WAT	43.2	53.0	5.2	5.3	0.14	0.36	0.26	0.38
Lasso after transplanting	36.1	49.4	1.5	4.7	0.01	0.22	0.77	0.20
Lasso & Ronstar tank	40.6	47.5	2.5	5.9	0.03	0.12	0.06	0.26
No weeding	37.1	31.6	1.2	2	0.02	0.12	0.07	0.17
LSD (0.05)	NS	8.6	1.5	1.9	0.06	NS	0.13	0.10
CV%	10.7	10.1	27.9	21.3	55.3	92.06	46.8	23.4

7.3.3.3. Pod yield

7.3.3.3.1 Number of pods per plant

The highest mean number of pods per plant was achieved by hand hoeing in the 2001/2002 season at the Sanhi site. All the treatments, with the exception of the non weeded control, gave the similar number of pods per plant at the Mhiripiri site in the 2001/2002 season. (Table 7.4)

7.3.3.3.2 Total yield with calyxes

In the 2000/2001 season, the highest mean total yield (0.143t/ha) was achieved by hand hoe weeding at 2 and 6 WAT at the Mufambi site. There were no significant differences ($p > 0.05$) at the Sanhi site in the same season. The highest mean yield was obtained by hand hoe weeding at 2 and 6 WAT in the 2001/2002 season at both sites (Table 7.4)

7.3.3.3.3 Total marketable yield

In the 2000/2001 season there were no significant differences ($P<0.05$) in marketable yield for both sites (Figure 7.5). At Sanhi in the 2001/2002 season the highest mean marketable yield (0.13 t/ha) was achieved by hand hoe weeding at 2 and 6 WAT and re-ridging at 3, 6 and 9 WAT. At Mufambi the highest mean marketable yield (0.20 t/ha) was achieved by hand hoe weeding at 2 and 6 WAT although re-ridging at 3, 6 and 9 WAT and Lasso (4 l/ha) application at one day after crop transplanting also gave similar marketable yields of 0.18 t/ha and 0.15 t/ha respectively in the same season (Figure 7.6)

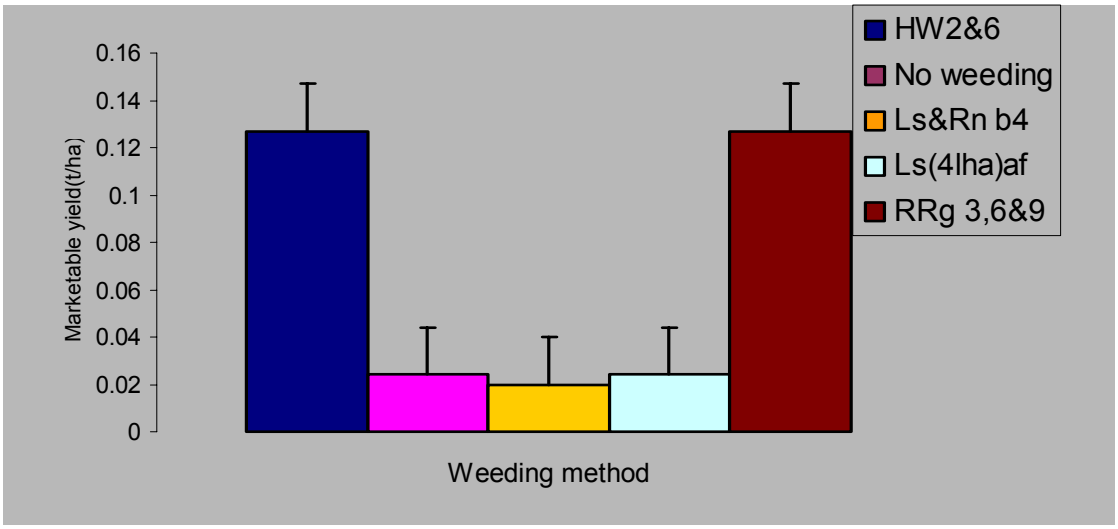


Figure 7.5 Marketable yield at the Sanhi site in 2000/2001 rainy seasons

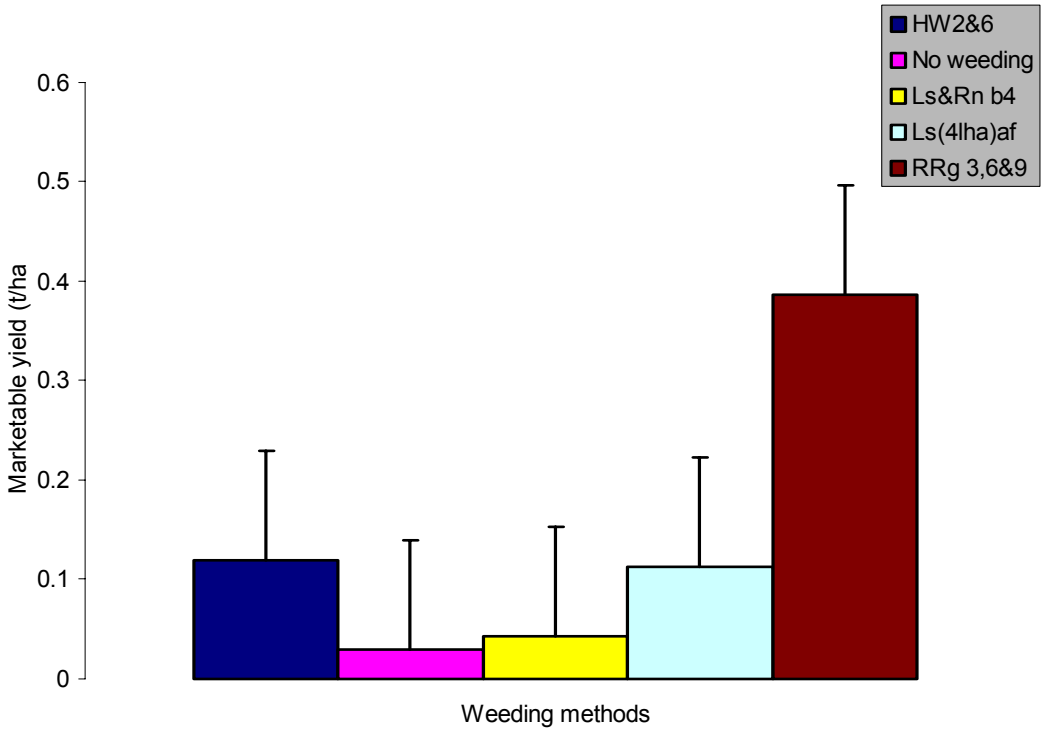


Figure 7.6. Marketable yield at the Mufambi site in the 2000/2001 rainy seasons

HW2&6= Hand hoe weeding 2 weeks and 6 WAT, No weeding (control) = No weeding (Control), Ls & Rn b4 = Ronstar (Oxidiazon) (2l/ha) + Lasso (2l/ha) mixture applied 24 hours prior to transplanting, Ls(4lha) af = Lasso (Alachlor) (4l/ha) applied over the top immediately after transplanting and RRg 3,6 & 9 = Re-ridging 3 WAT and hand hoe weeding on the ridge in 6 and 9 WAT.

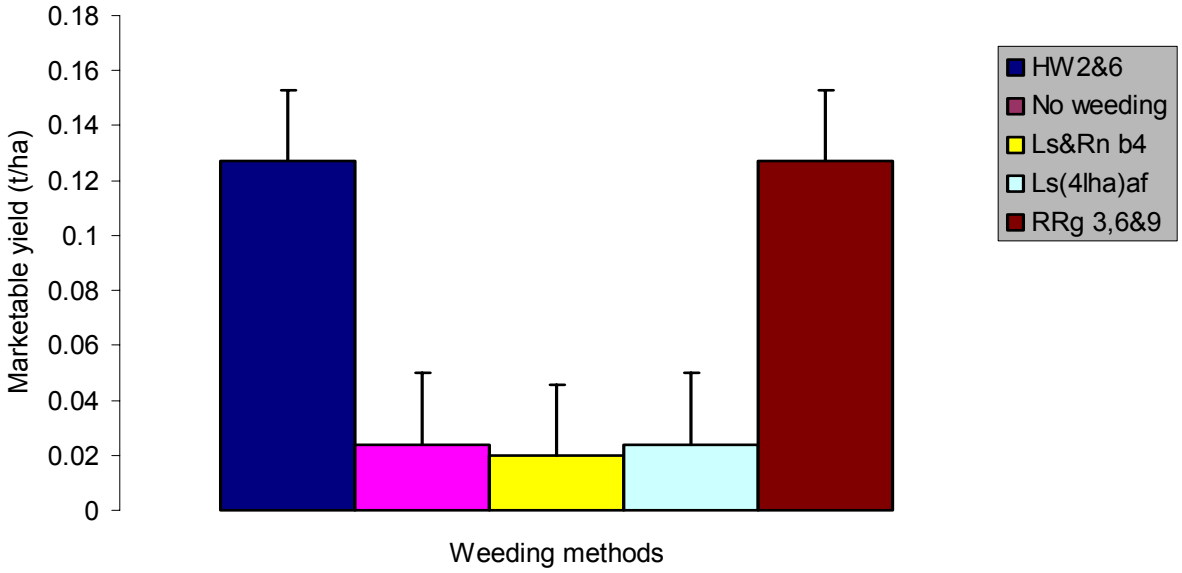


Figure 7.7 Marketable yield at Sanhi site in the 2001/2002 rainy season

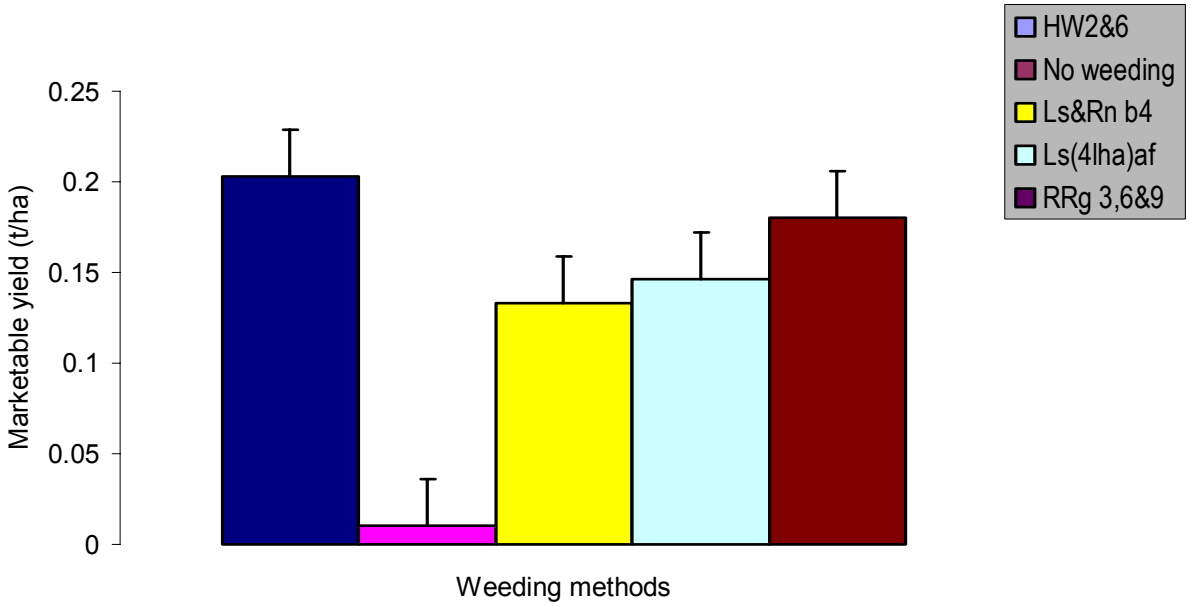


Figure 7.8.Marketable yield at Mhiripiri site in the 2001/2002

HW2&6= Hand hoe weeding 2 weeks and 6 WAT, No weeding (control) = No weeding (Control), Ls & Rn b4 = Ronstar (Oxidiazon) (2l/ha) + Lasso (2l/ha) mixture applied 24 hours prior to transplanting, Ls(4lha) af = Lasso (Alachlor) (4l/ha) applied over the top immediately after transplanting and RRg 3,6 & 9 = Re-ridging 3 WAT and hand hoe weeding on the ridge in 6 and 9 WAT.

7.3.4 Economic analysis

7.3.4.1 Yield gain

Re-ridging at 3, 6 and 9 WAT and hand hoe weeding at 2 and 6 WAT had significantly ($p<0.05$) the highest yield gain at Sanhi site in 2001/2002. (Table 7.5). The least yield gain in 2001/2002 season at Sanhi site was achieved by the application of Lasso and Lasso-Ronstar tank treatments. On the other hand, even though there were significant ($p<0.05$) differences in the marketable yield, yield gain was not significantly different ($p>0.05$) at the Mufambi site in 2001/2002 rainy season (Table 7.6).

Table 7.5 Marketable yield (t/ha) and added profit for different weeding method treatments at Sanhi site in 2001/2002 rainy season

Weeding Treatment	SAUDPC	Actual marketable yield (t/ha)	Yield gain over non-weeded (t/ha)	Added profit 000' (Z$/ha)
Re-ridging at 3, 6 and 9 WAT	2.664	0.127	0.103	20.172
Hand hoe weeding at 2 and 6 WAT	2.950	0.127	0.103	23.205
Lasso 4l/ha after transplanting	2.531	0.024	0.000	(10.684)*
Lasso – Ronstar mix	2.625	0.020	(0.004)	(8.945)
Non weeded	3.875	0.024		
CV (%)	7.21	51	61.86	99.63
LSD (5%)	0.3994	0.05954	0.06318	22.45

*Figures in brackets are negative

Table 7.6 Marketable yield (t/ha) and added profit for different weeding method treatments, at Mhiripiri site in the 2001/2002 rainy season

Weeding Treatment	SAUDPC	Actual marketable yield (t/ha)	Yield gain over non-weeded (t/ha)	Added profit 000' (Z$/ha)
Re-ridging at 3, 6 and 9 WAT	2.5	0.18ab	0.17	40.272
Hand hoe weeding at 2 and 6 WAT	2.4	0.20	0.19	50.305
Lasso at 4l/ha after transplanting	2.3	0.15	0.14	37.653
Lasso - Ronstar tank mix	2.5	0.13	0.12	29.054
Non weeded	4.3	0.01		
CV (%)	10.52	22.26	21.74	25.84
LSD (5%)	0.5	0.06	NS	NS

7.3.4.2 Added profit

The highest added yield profit of $23 205/ha was obtained by hand hoe weeding at 2 and 6 WAT which was significantly similar to $20 172/ha yield profit achieved by re-ridging at 3, 6 and 9 WAT at Sanhi site in 2001/2002 rainy season. Application of Lasso and Lasso-Ronstar treatments resulted in statistically similar losses of $10 684 /ha and $8 945/ha respectively at Sanhi site in 2001/2002. Added profits were not significantly ($p>0.05$) different at Mufambi site in the 2001/2002 rainy season. However, the least added profit of $29 054/ha achieved at Mufambi site in 2001/2002 rainy season was better than the highest achieved at Sanhi site ($23 205/ha) in the same season (Tables 7.5 and 7.6)

7.4 Discussion

The variations in the weed spectrum among the sites would account for the differences in the effect of different weeding methods on paprika. Of note is the

occurrence of the highly ranked stinkblaar at Sanhi site in both seasons. Santin (2001) reported that growth and fruit yield of tomato and (much so) pepper were very sensitive to the pressure of *Datura stramonium* .L and the damage results from its more aggressive and earlier competitive capacity for environmental resources, such as water and nutrients. Stinkblaar is a very persistent weed in paprika fields. This weed species is regarded as a major threat in paprika production (Paprika Zimbabwe, 1998). In addition, this particular weed is usually associated with the high occurrence of powdery mildew and leaf spots, thereby adversely affecting paprika quality. Hand hoe weeding and re-ridging ensured the effective control of weeds including stinkblaar as they are effective in the elimination of the germinating and already emerged weeds.

Lanini and Le Strange (1994) noted that weeds were small and easy to remove when hand weeded at 2-week intervals, but were well rooted and difficult to remove if 4 weeks elapsed between weedings. Bell pepper was especially sensitive to root disturbances with the removal of large weeds and resulted in injury or death of some pepper plants. Consistency in performance of hand hoe weeding treatments, which had intervals ranging from 3-4 weeks in this experiment, may suggest that a 3-week interval is probably as ineffective as the prolonged interval of 4 weeks.

The first season was very dry, such that transplanting was done as late as January, hence the effects of weed spectrum and density were not different.

Those weeds which had emerged earlier because of the very little rain received in late October were controlled during the land re-preparation operation, thus reducing weed pressure. The incidence of powdery mildew and leaf spots diseases on stinkblaar was less in 2000/2001 than in 2001/2002 rainy season. This low disease incidence was attributed to the generally dry weather that prevailed in that season.

In the second season, Lasso had the same effect as hand hoe weeding probably due to the fact that the second season was relatively wetter than the first one, and for the fact that transplanting was done at an earlier date. In addition, it rained lightly only some hours after the application as if to fulfill the requirement of a light irrigation after the application of the herbicide (Paprika Zimbabwe, 1998). This must have produced favourable conditions for Lasso application. However, the costs of herbicides also reduced the added profits more than the hand hoe weeding operations. In the first season the recommended application of the herbicides alone was done at the beginning of the season It was felt that in addition to the herbicide application hand hoe weeding had to be done at 8WAT so as to salvage the crop from the menacing effect of the weeds. Several workers (Orsenigo and Ozaki, 1965; Americanos, 1976; Uwannah, 1982) reported effective weed control and high pepper fruit yields with grass-weeded potent herbicides such as alachlor (Lasso), oxadiazon (Ronstar), diphenamid, metolachlor and pendimethalin. On the other hand, the consistency of hand hoe weeding over the 2000/2001 and 2001/2002 rainy season in CRA is similar to the

findings of Adigun *et al*. (1987) that two and three hoe weedings resulted in comparable pepper fruit yields in the wet season and dry season suggesting that any weeding done at 6 WAT as a supplementary to either hoe weeding or pre-transplant herbicide would be adequate to provide effective weed control in pepper.

Generally, the marketable yield levels achieved during the two rainy seasons of the present study were lower than normal. Lanini and Le Strange (1994) reported similarly that lack of irrigation water in 1990 prevented crop development after the first harvest, consequently total paprika fruit yield and net return were reduced. This resulted in lower yields than the ones normally attributed to the smallholder paprika farms. The average paprika yield for the smallholder paprika farms under dry land production system in a normal rainy season is about 0.7t/ha (Anonymous, 2002) as compared to yields of 0.34t/ha in this study. The low marketable yields were attributed to very low amounts of rain received during 2000/2001 and 2001/2002 rainy seasons. The higher levels of added profits achieved at Mufambi site as compared to the Sanhi site is attributable to the high marketable yield achieved at Mufambi site. The relatively high marketable yield is as a result of the lower occurrence of *Datura* spp weed, which was very predominant at the Sanhi site. Santin (2001) noted that in order to avoid loss of fruit yield due to the presence of *Datura stramonium*, it should be controlled between the 4 - and 8 - leaf stages of pepper. The association of *Datura* spp weed and the powdery mildew disease may have contributed to the reduction of

yield as well. Hand hoe weeding operations were very effective and consequently gave the highest added profits, mainly because of its effect on major weeds such as *Datura spp*. Herbicides did not effectively control *Datura spp*. Since *Datura spp* weed was not very prevalent at Mufambi site, the herbicide treatments improved paprika yield to the level of hand hoe weeding. Consequently, the herbicide application and hand hoe weeding treatments were similar in their effects at the Mufambi site during 2001/2002 rainy season.

7.5 Conclusion and recommendations

Hand hoe weeding produced the highest added profits in fields infested with *Datura* spp. On the other hand, all the weeding treatments had the same effect on added profits in fields with lesser *Datura* spp infestation. The implication of this is that smallholder paprika farmers can hand weed at 2 and 6 WAT or 3, 6 and 9WAT in areas dominated by the *Datura* spp for the highest economic benefits. In areas of low *Datura* spp infestation farmers can choose between hand hoe weeding and herbicide weed control. Under low weed pressure, smallholder paprika farmers can therefore hand weed at 2 and 6 WAT or re–ridge at 3, 6 and 9 WAT for effective weed management and higher paprika marketable yield. Use of the herbicide Lasso at 4l/ha is very effective when combined with a supplementary hand hoe weeding in 6-8WAT. An effective weed management practice was also associated with a low disease severity, implying that in paprika, weeding can go a long way in enhancing effective disease management. These results indicate that paprika could be grown profitably

without herbicides, however, when herbicides are used a supplementary hand hoe weeding between 5-6 WAT must be implemented. It may be recommended that when availability and cost of labour during the typical paprika growing season are prohibitively high, the use of herbicides and a supplementary hand - weeding may be the best option.

CHAPTER 8

GENERAL DISCUSSION AND RECOMMENDATIONS

The major limiting factor as indicated by the results of the survey that was conducted in the CRA is the lack of paprika disease management and production technical know- how. Proper disease management practices may be very difficult to implement, especially when there is a general lack of knowledge on disease identification. National annual production figures for paprika yield are going to increase as indicated by an increasing number of smallholder farmers going into paprika production per year. To ascertain that increase in paprika tonnage however, there is need for training on disease and weed management in addition to general production practices. Training must be initiated by both public and private stakeholders to target the new paprika farmers and those already in production.

Poorly raised seedlings will begin to lose yield potential in the nursery thus yield will be reduced regardless of optimum agronomic conditions and practices that may be applied in the field. The smallholder paprika farmers must therefore, adopt a cost - effective seedbed sterilisation method that guarantees that healthy seedlings are transplanted onto the field. The potential of brushwood burning and solarisation for seedbed sterilisation as shown by the results of this study can be further enhanced if these treatments were combined with other chemical treatments to ensure that the weaknesses, particularly in weed management are overcome. The use of brushwood for seedbed sterilisation must be done in a

sustainable way, replenishing trees as part of a forestation programme. Paprika seedlings should be raised on sterilised seedbeds and preferably not on seedbeds in which other solanaceous crops had previously been grown. Farmers can consider solarising seedbeds in late August when temperatures are relatively higher for effective disease management.

Alternation of sulphur and copper oxychloride + mancozeb mixture will go a long way not only in reducing production cost, but also ensuring that Maximum Residual Limits of pesticides in paprika pods are not exceeded. In addition, it also reduces the chances of inducing partial resistance to pesticides by pathogens. If the smallholder farmers are trained to correctly identify paprika pests and disease, spraying after scouting could further reduce production cost. The efficacy of acibenzolar s-methyl can be improved by applying it during seedling production as is the case in tobacco production (Cole, 1999). Paprika farmers can still benefit from adopting research findings of this study as it clearly reveals that yield quantity and quality from weekly-sprayed paprika is the same as the reduced fungicide application.

Farmers in the CRA seem to appreciate the importance of weeding more than fungicide application. Most preferred ox drawn re-ridging in the 9 WAT to hand hoe weeding, but this resulted in a lot of pods falling off due to the movement of oxen during the operation. Before farmers can decide to use herbicides in paprika production they must understand the composition of the weed flora in

their fields, particularly when species such as *Datura stramonium* are present. Herbicide application supplemented with hand hoe weeding at 6-8 WAT was effective in weed management and should therefore be recommended to farmers.

Generally, the onset and the amount of rain experienced in both seasons accounts for the low fruit yields achieved in the two seasons. In both seasons transplanting of paprika seedlings was done late in December, this shortened the growing season, resulted in a reduced number of harvesting times. The generally dry weather experienced during the period of this study probably affected the weed spectrum, number and severity of paprika disease that occur in paprika under normal rainy conditions. While all such limitations are conceded, the fact that most treatments had positive economic returns suggest that farmers are assured of some income, even with the minimum amount of rains received.

In conclusion, this study is not an end in itself but just the beginning of the search for ways to improve production under smallholder farming conditions. To this end, further studies on paprika crop protection management should give priority to the following : -

1) Combining chemical and non- chemical seedbed sterilisation methods in paprika nurseries.
2) An assessment on effect of viral disease incidence in the nursery on crop perfomance in the field.

3) An assessment of the effect of retained dressed seed on disease incidence, severity and final yield of paprika.
4) Testing the reduced fungicide application and weed management trials under irrigation.
5) Determination of fungicide spraying thresholds in paprika disease management.
6) Assess the effect of reduced concentrations of herbicide and supplementary hand hoe weeding (timing after transplanting) on weed management and final yield of paprika.

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APPENDICES

Appendix 1: Characteristics of NR II and NR III

NR	Characteristics
II	Intensive farming region. Lies between 1000-1830 m above sea level (masl). Moderately high rainfall averaging 750-1000mm per annum (pa) enjoying an average of 16 to 18 rainy pentads*. Mean temperatures 21-27^{0}C are experienced. Frost incidence is high. The soils are largely coarse to medium grained sands which belong to the peraferralitic group. The predominant parent material is granite but associated areas of chlorite are encountered.
III	Semi-extensive farming. Lies between 1000-1600 masl. Rainfall ranges between 570-750 mm pa. Has 14-16 rainy pentads. Mean temperature of 23.8-27.7^{0}C are experienced. Has mixed soils (Regosols, Lithosols, Siallitic, Fersiallitic, Paraferrallitic and Orthoferrallitic soils) are found in various proportions.

Source: Norton in Agritex and DR&SS (1987) as cited in Chiduza (1994).
*Pentad – A division of the year into five day periods.

Appendix 2: Questionnaire on farmer perception

1.FARMER'S NAME……..

2.SITE…….. 3.CODE NUMBER……

4.Year of initial paprika production……...

5.Current total land under paprika production……...

6.Which variety is currently in your field
1. Red Tsar 2.UF15 3.Papriking 4 PapriAce 5.PapriQueen 6.Others

DISEASE AWARENESS

7.WHICH PAPRIKA DISEASE DO YOU KNOW BY NAME
(tick where appropriate) ASSOCIATED SYMPTOMS

Powdery mildew ……
Bacterial leaf spot ……
Anthracnose ……
Blossom end rot ……
Cercospora leaf symptom ……

Sclerotium rolfsii ……
Stemphylium leaf spot ……
Phytophthora blight ……
Bacterial leaf spot ……
Alternaria rot ……
OTHERS ……

8.DESCRIBE DISEASE BY SYMPTOMS AS OBSERVED DURING PRODUCTION COURSE

Initial stage (At the beginning of the season) Eventual stage(towards the end of season)

……
……..
……

METHODS OF IDENTIFICATION AND CONTROL

9.How do you identify paprika diseases in your field ?
1.Agritex 2.Visual aids 3.Lab tests 4.Contractor extension 5.Just spray

6.Self 7.Other methods

10.Which method of disease control do you use ?
1.Chemical 2.Biological 3.Cultural 4.None

11.Give details on frequency
……
……

12.Name substances/chemicals you use and quantity per 15lknapsack sprayer

13.State method of chemical application
1.Knapsack 2. Broom 3.Others

14.In your opinion what has been the major paprika disease in your field for the past two seasons ?
……
……

15. What has been the control method(s) of this disease?
1.Chemical 2. Biological 3.Cultural

16.Name substances/ Chemicals used and dosage rate used where applicable
1.Chemical 2.Biological 3.Cultural

17.Did you receive any formal training in paprika production or scouting in paprika

18.What has been your primary and helpful source of information on paprika disease identification and control
……
……

19.What method of weed control do you use and at what frequency per season ?
……
……

DIRECT OBSERVATION DURING SAMPLE COLLECTIONS

Ask the farmer to allow you to take samples of leaves and plants for laboratory use.

20.Weediness:(tick where appropriate)
WD1 (Weeded at least once and absence of visible weeds)
WD2 (weeds present but no choking the crop)
WD3 (field not weeded at all and competition is high)

DISEASE	Present in the field confirmed lab tests
Alternaria rot	
Bacterial leaf spot	
Phytophthora blight	
Stemphylium leaf spot (GLS)	
Cercospora leaf symptom	
Sclerorium rolfsii	
Cercospora leaf symptom	
Blossom end rot	
Anthracnose	
Powdery mildew	
Others	

……

……

21.What method of seedbed sterilisation did you use?

1.Methly bromide 2.Cowdung 3.Brushwood 4.Maizecobs

5.Others

Appendix 3: Potato Dextrose Agar (PDA)

INGREDIENTS:

	Per 1 litre of distilled water
Potato Dextrose Broth	200 g
Dextrose	20 g
Agar	17.5 g

Appendix 4: Nutrient Agar

INGREDIENTS:

	Per Litre of distilled water
Bacto beef extract	3 g
Bacto Peptone	5 g
Agar	20 g

Appendix 5:Gram staining method

1. From a solid medium , make a fairly turbid suspension of bacterial growth in sterile water
2. Smear the bacterial suspension on slide and allow to dry
3. Fix the smear by passing the slide rapidly and allow to dry
4. Flood the slide with Crystal Violet for 1 minute
5. Wash in gentle stream of tap water until no more stain is being removed
6. Flood the smear with Lugol's Iodine for 1 minute

7. Wash in a gentle stream of tap water and blot dry

8. Decolourise by washing in a gentle stream of 95% Ethanol for not more than 30 seconds to remove any stain that will easily wash away , blot dry

9. Counterstain by flooding with Safranin for 20 seconds

10. Wash under running tap water , blot dry and examine

Interpretation of results

Gram positive…….blue –violet

Gram negative……..pink-red

Appendix 6: Oxidase reaction

1) Culture yellow pigmented colonies on *King's media B at 26^0C for 24 hours.

2) Pick some colonies off the media using a sterile platinum loop.

3) Rub the loop with colonies on filter paper impregnated with1% aqeous tetra methyl-p-phenylenediamine dichloride solution.

Results-Purple colour produced 1to 10 minutes time------positive for Xanthomonas

*Kings Medium B ingredients/L of water

Proteose peptone Difco No.3	20g
Bacto Agar	15g
Glycerol	15ml

Appendix 7: Nitrate reduction test

1) Inoculate tubes containing *nitrate-semi-solid medium by adding a loopful of growth to each tube.
2) Mix by rotation between palms before agar sets.
3) Include a control test (non –inoculated medium)
4) Incubate at 27^0C for
5) 3-7 days.
6) Add to each tube Gries-IIIosvay A and Gries-IIIosvay B.

Results—blue –black colour---------- nitrate reduction (negative for Xanthomonas spp)

*Ingredients of Nitrate – semi-solid medium g/litre of distilled water

Peptone	10g
NaCl	5g
KNO_3	2g
Agar	3g

Appendix 8: Variable costs for economic analysis

Item	**Cost (Z$)**	
	2000/2001	2001/2002
Chemicals/Fungicides		
Mancozeb	772/kg	4004/kg
Copper oxychloride	255/kg	2415/kg
Sulphur	285/kg	1000/kg
Bion	41.53/g	75.50/g
Herbicides		
Lasso	632.40/litre	840.40/litre
Ronstar	2985.50/litre	3704.50/litre
Labour	15/hour	20/hour
Paprika selling price	150/kg	300/kg

Appendix 9: Soil temperature achieved by burning cowdung, maizecobs and brushwood at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	488.455	244.228	3.1674	0.0503
Sterilisation method	2	757.640	378.820	4.9130	0.0111
Soil depth	2	14317.774	7158.887	92.8451	0.0000
Sterilisation x soil depth	4	238.230	59.558	0.7724	
Time	2	145.886	72.943	0.9460	
Sterilisation x time	4	263.271	65.818	0.8536	
Soil depth x time	4	2579.447	644.862	8.3633	0.0000
Sterilisation x soil depth x time	8	164.137	20.517	0.2661	
Error	52	4009.499	77.106		
Total	80	22964.338			

Appendix 10: Soil temperature achieved by burning cowdung, maizecobs and brushwood at Homestead in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	200.144	100.072	1.0117	0.3707
Sterilisation method	2	510.122	255.061	2.5785	0.0856
Soil depth	2	24586.285	12293.142	124.2776	0.0000
Sterilisation x soil depth	4	1394.301	348.575	3.5239	0.0128
Time	2	187.487	93.743	0.9477	
Sterilisation x time	4	393.676	98.419	0.9950	
Soil depth and time	4	2561.218	640.305	6.4732	0.0003
Sterilisation x soil depth x time	8	180.106	22.513	0.2276	
Error	52	5143.675	98.917		
Total	80	35157.013			

Appendix 11: Soil temperature achieved by burning cowdung, maizecobs and brushwood at Homestead in 2002/2003

Source	DF	SS	MS	F	P
Replication	2	664.283	332.142	11.5112	0.0219
Sterilisation method	2	1541.852	770.926	26.7185	0.0048
Error	4	115.415	28.854		
Soil depth	2	22447.053	11223.527	135.5336	0.0000
Sterilisation x soil depth	4	292.630	73.157	0.8834	
Time	2	2371.281	1185.641	14.3176	0.0000
Sterilsation x time	4	569.480	142.370	1.7192	0.1612
Soil depth x time	4	209.963	52.491	0.6339	
Sterilsation x soil depth x time	8	331.498	41.437	0.5004	
Error	48	3974.877	82.810		
Total	80	32518.332			

Appendix 12: Soil temperature achieved by burning cowdung, maizecobs and brushwood at Nare in 2002/2003

Source	DF	SS	MS	F	P
Replication	2	42.442	21.221	1.5705	0.3138
Sterilisation method	2	7731.321	3865.660	286.0875	0.0000
Error	4	54.049	13.512		
Soil depth	2	32060.739	16030.370	300.3814	0.0000
Sterilisation x soil depth	4	2818.425	704.606	13.2031	0.0000
Time	2	1047.011	523.505	9.8096	0.0003
Sterilisation x time	4	1202.521	300.630	5.6333	0.0008
Soil depth x time	4	1331.243	332.811	6.2363	0.0004
Sterilisation x soil depth x time	8	1774.373	221.797	4.1561	0.0008
Error	48	2561.602	53.367		
Total	80	50623.725			

Appendix 13: Bacterial populations at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	3.673	1.837	1.5206	0.2651
Sterilisation method	5	713.796	142.759	118.1894	0.0000
Error	10	12.079	1.208		
Soil depth	2	6.859	3.429	2.9168	0.0589
Sterilisation x soil depth	10	30.150	3.015	2.5643	0.0086
Dilution factor	2	8.929	4.465	3.7971	0.0259
Sterilisation x dilution	10	103.107	10.311	8.7694	0.0000
Soil depth x dilution	4	3.732	0.933	0.7936	
Sterilisation x soil depth x dilution	20	27.772	1.389	1.1810	0.2875
Error	96	112.874	1.176		
Total	161	1022.971			

Appendix 14: Bacterial populations at Homestead in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.274	0.137	0.6952	
Sterilisation	5	30.027	6.005	30.4305	0.0000
Error	10	1.973	0.197		
Soil depth	2	6.222	3.111	2.8373	0.0635
Sterilisation x soil depth	10	26.360	2.636	2.4042	0.0135
Dilution factor	2	73.260	36.630	33.4090	0.0000
Sterilisation x dilution	10	2.659	0.266	0.2425	
Soil depth x dilution	4	2.931	0.733	0.6684	
Sterilisation x soil depth x dilution	20	10.152	0.508	0.4630	
Error	96	105.255	1.096		
Total	161	259.113			

Appendix 15: Bacterial populations at Nare in 2002/2003

Source	DF	SS	MS	F	P
Replication	2	4.949	2.474	1.8334	0.2097
Sterilisation	5	33.509	6.702	4.9655	0.0152
Error	10	13.497	1.350		
Soil depth	2	5.447	2.724	2.6862	0.0733
Sterilisation x soil depth	10	35.588	3.559	3.5099	0.0006
Dilution factor	2	110.394	55.197	54.4384	0.0000
Sterilisation x dilution	10	62.329	6.233	6.1473	0.0000
Soil depth x dilution	4	6.967	1.742	1.7177	0.1524
Sterilisation x soil depth x dilution	20	86.369	4.318	4.2591	0.0000
Error	96	97.338	1.014		
Total	161	456.387			

Appendix 16: Bacterial populations at Homestead in 2002/2003

Source	DF	SS	MS	F	P
Replication	2	0.844	0.422	0.2324	
Sterilisation	5	68.006	13.601	7.4929	0.0036
Error	10	18.152	1.815		
Soil depth	2	37.034	18.517	11.7574	0.0000
Sterilisation x soil depth	10	36.845	3.685	2.3395	0.0162
Dilution factor	2	28.253	14.126	8.9696	0.0003
Sterilisation x dilution factor	10	125.021	12.502	7.9383	0.0000
Soil depth x dilution factor	4	56.987	14.247	9.0461	0.0000
Sterilisation x soil depth x dilution	20	146.889	7.344	4.6634	0.0000
Error	96	151.192	1.575		
Total	161	669.224			

Appendix 17: Fungal population in the soil at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.229	0.115	0.1418	
Sterilisation method	5	194.422	38.884	48.1440	0.0000
Error	10	8.077	0.808		
Soil depth	2	8.519	4.259	7.1617	0.0013
Sterilisation x soil depth	10	41.799	4.180	7.0278	0.0000
Dilution factor	2	3.168	1.584	2.6635	0.0749
Sterilisation x dilution	10	94.979	9.498	15.9693	0.0000
Soil depth x dilution	4	4.996	1.249	2.0999	0.0868
Sterilisation x depth x dilution	20	21.676	1.084	1.8222	0.0285
Error	96	57.097	0.595		
Total	161	434.961			

Appendix 18: Fungal population in the soil at Homestead in 2002/2003

Source	DF	SS	MS	F	P
Replication	2	0.553	0.276	0.4959	
Sterilisation method	5	48.421	9.684	17.3817	0.0001
Error	10	5.571	0.557		
Soil depth	2	2.102	1.051	2.2161	0.1146
Sterilisation x soil depth	10	15.666	1.567	3.3038	0.0010
Dilution factor	2	78.089	39.045	82.3426	0.0000
Sterilisation x dilution	10	28.424	2.842	5.9944	0.0000
Soil depth x dilution	4	11.492	2.873	6.0590	0.0002
Sterilisation x soil depth x dilution	20	34.809	1.740	3.6705	0.0000
Error	96	45.521	0.474		
Total	161	270.647			

Appendix 19: Seedling emergence at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	367.953	183.976	1.5858	0.2522
Sterilisation method	5	2049.072	409.814	3.5323	0.0424
Error	10	1160.183	116.018		
Total	17	3577.207			

Appendix 20: Seedling height at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	30.381	15.191	2.2734	0.1535
Sterilisation method	5	355.471	71.094	10.6398	0.0009
Error	10	66.819	6.682		
Total	17	452.671			

Appendix 21: Weed density at 2WAS at Homestead in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.968	0.484	2.5846	0.1245
Sterilisation method	5	10.969	2.194	11.7181	0.0006
Error	10	1.872	0.187		
Total	17	13.809			

Appendix 22: Weed density at 4WAS at Homestead in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.141	0.071	0.6195	
Sterilisation method	5	7.889	1.578	13.8546	0.0003
Error	10	1.139	0.114		
Total	17	9.169			

Appendix 23: Weed density at 8WAS at Homestead in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.120	0.060	4.0909	0.0503
Sterilisation method	5	4.333	0.867	59.0909	0.0000
Error	10	0.147	0.015		
Total	17	4.600			

Appendix 24: Weed density at 2WAS at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.823	0.412	5.6393	0.0229
Sterilisation method	5	9.967	1.993	27.3059	0.0000
Error	10	0.730	0.073		
Total	17	11.520			

Appendix 25: Weed density at 8WAS at Chinyudze in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.488	0.244	2.6351	0.1204
Sterilisation method	5	1.623	0.325	3.5066	0.0433
Error	10	0.926	0.093		
Total	17	3.036			

Appendix 26: Overall AUDPC at Dengedza in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	1.560	0.780	0.7800	
Spraying interval	5	53.980	10.796	10.7960	0.0009
Error	10	10.000	1.000		
Total	17	65.540			

Appendix 27: Overall AUDPC at Mugadza in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	7.750	3.875	0.4354	
Spraying interval	5	621.552	124.310	13.9669	0.0003
Error	10	89.003	8.900		
Total	17	718.305			

Appendix 28: Percentage infection AUDPC at Mugadza in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	85.778	42.889	2.2468	0.1564
Spraying interval	5	937.111	187.422	9.8184	0.0013
Error	10	190.889	19.089		
Total	17	1213.778			

Appendix 29: Total marketable yield at Dengedza in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	0.005	0.003	0.3684	
Spraying interval	5	0.676	0.135	19.2454	0.0001
Error	10	0.070	0.007		
Total	17	0.751			

Appendix 30: Total marketable yield at Mugadza in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.256	0.128	26.8799	0.0001
Spraying interval	5	0.095	0.019	4.0098	0.0295
Error	10	0.048	0.005		
Total	17	0.399			

Appendix 31: Standardised AUDPC for Dengedza in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	0.011	0.005	0.7800	
Spraying interval	5	0.375	0.075	10.7960	0.0009
Error	10	0.069	0.007		
Total	17	0.455			

Appendix 32: Yield gain over non-sprayed at Dengedza in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	0.012	0.006	0.7266	
Spraying interval	4	0.495	0.124	14.5385	0.0010
Error	8	0.068	0.009		
Total	14	0.575			

Appendix 33: Added profit at Dengedza in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	278100002.38	139050001.19	0.7266	
Spraying interval	4	11395264417.90	2848816104.47	14.8870	0.0009
Error	8	1530899987.55	191362498.44		
Total	14	13204264407.83			

Appendix 34: Standardised AUDPC for Mugadza in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.054	0.027	0.4354	
Spraying interval	5	4.316	0.863	13.9669	0.0003
Error	10	0.618	0.062		
Total	17	4.988			

Appendix 35: Weed density at 5WAT at Sanhi in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	0.148	0.074	6.5885	0.0204
Weeding method	4	1.355	0.339	30.0626	0.0001
Error	8	0.090	0.011		
Total	14	1.593			

Appendix 36: Weed density at 17WAT at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.137	0.069	3.6786	0.0736
Weeding method	4	0.531	0.133	7.1071	0.0096
Error	8	0.149	0.019		
Total	14	0.817			

Appendix 37: Weed biomass at 17WAT at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.023	0.011	1.0310	0.3996
Weeding method	4	0.283	0.071	6.3691	0.0132
Error	8	0.089	0.011		
Total	14	0.395			

Appendix 38: Weed density at 5WAT at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.241	0.121	2.3430	0.1581
Weeding method	4	1.044	0.261	5.0680	0.0248
Error	8	0.412	0.051		
Total	14	1.697			

Appendix 39: Overall AUDPC at Mufambi in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	31.408	15.704	3.0930	0.1011
Weeding method	4	218.853	54.713	10.7760	0.0026
Error	8	40.619	5.077		
Total	14	290.880			

Appendix 40: Overall AUDPC at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	4.489	2.245	0.3493	
Weeding method	4	525.664	131.416	20.4523	0.0003
Error	8	51.404	6.425		
Total	14	581.557			

Appendix 41: Overall AUDPC at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	3.161	1.581	0.1411	
Weeding method	4	1663.203	415.801	37.1063	0.0000
Error	8	89.645	11.206		
Total	14	1756.009			

Appendix 42: Percentage AUDPC at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	22.533	11.267	0.5236	
Weeding method	4	666.667	166.667	7.7459	0.0074
Error	8	172.133	21.517		
Total	14	861.333			

Appendix 43: Percentage AUDPC at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	33.600	16.800	0.7590	
Weeding method	4	2793.733	698.433	31.5557	0.0001
Error	8	177.067	22.133		
Total	14	3004.400			

Appendix 44: Leaf spot AUDPC at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	4.097	2.049	0.5221	
Weeding method	4	532.947	133.237	33.9572	0.0000
Error	8	31.389	3.924		
Total	14	568.433			

Appendix 45: Leaf spot AUDPC at Mhiripiri 2001/2002

Source	DF	SS	MS	F	P
Replication	2	5.812	2.906	0.5094	
Weeding method	4	1315.317	328.829	57.6455	0.0000
Error	8	45.635	5.704		
Total	14	1366.764			

Appendix 46: Plant height at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	56.177	28.089	1.3455	0.3135
Weeding method	4	805.143	201.286	9.6419	0.0038
Error	8	167.009	20.876		
Total	14	1028.329			

Appendix 47: Pod number per plant at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.145	0.073	0.0754	
Weeding method	4	27.797	6.949	7.2064	0.0092
Error	8	7.715	0.964		
Total	14	35.657			

Appendix 48: Pod number per plant at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	2.204	1.102	1.8028	0.2258
Weeding method	4	32.538	8.134	13.3090	0.0013
Error	8	4.890	0.611		
Total	14	39.631			

Appendix 49: Total yield with calyx at Sanhi in 2000/2001

Source	DF	SS	MS	F	P
Replication	2	16888.576	8444.288	1.9821	0.1999
Weeding method	4	132603.244	33150.811	7.7813	0.0073
Error	8	34082.725	4260.341		
Total	14	183574.544			

Appendix 50: Total yield with calyx at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.003	0.002	0.5884	
Total yield	4	0.217	0.054	18.9702	0.0004
Error	8	0.023	0.003		
Total	14	0.243			

Appendix 51: Total marketable yield at Sanhi in 2000/2001

Source	DF	MS	SS	F	P
Replication	2	0.004	0.002	2.0337	0.1931
Weeding method	4	0.039	0.010	9.1059	0.0045
Error	8	0.009	0.001		
Total	14	0.052			

Appendix 52: Total marketable yield at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	3376.324	1688.162	2.3497	0.1575
Weeding method	4	29808.950	7452.238	10.3725	0.0030
Error	8	5747.663	718.458		
Total	14	38932.937			

Appendix 53: Total marketable yield at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.001	0.001	0.6753	
Weeding method	4	0.067	0.017	18.7495	0.0004
Error	8	0.007	0.001		
Total	14	0.076			

Appendix 54: Standardised AUDPC at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.031	0.016	0.3493	
Weeding method	4	3.650	0.913	20.4523	0.0003
Error	8	0.357	0.045		
Total	14	4.039			

Appendix 55: Yield gain at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.013	0.007	6.8220	0.0285
Weeding method	3	0.033	0.011	11.1568	0.0072
Error	6	0.006	0.001		
Total	11	0.052			

Appendix 56: Added profit at Sanhi in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	670.277	335.138	2.6537	0.1494
Weeding method	3	1891.996	630.665	4.9938	0.0453
Error	6	757.732	126.289		
Total	11	3320.005			

Appendix 57: Standardised AUDPC at Mhiripiri in 2001/2002

Source	DF	MS	SS	F	P
Replication	2	0.022	0.011	0.1411	
Weeding method	4	11.550	2.888	37.1063	0.0000
Error	8	0.623	0.078		
Total	14	12.195			

Appendix 58: Yield gain at Mhiripiri in 2001/2002

Source	DF	SS	MS	F	P
Replication	2	0.002	0.001	0.6610	
Weeding method	3	0.009	0.003	2.6416	0.1437
Error	6	0.007	0.001		
Total	11	0.017			

Appendix 59: Added profit at Mhiripiri in 2001/2002

Source	DS	SS	MS	F	P
Replication	2	136.500	68.250	0.6610	
Weeding method	3	689.238	229.746	2.2251	0.1859
Error	6	619.500	103.250		
Total	11	1445.238			