EVALUATION OF NON-CHEMICAL METHODS OF SOIL STERILISATION IN PAPRIKA (*Capsicum annuum* L.) SEEDLING PRODUCTION IN THE SMALLHOLDER FARMING SECTOR OF ZIMBABWE

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Abstract

The production and use of methyl bromide, a traditional soil biofumigant in vegetable nurseries in being phased out because it depletes the ozone layer in the stratosphere. An affordable and effective alternative method, preferably a non-chemical one, for seedbed sterilisation is needed. On-farm seed-bed trials were established in Chinyika Resettlement Area, Zimbabwe in 2001–2003 cropping seasons to evaluate the effectiveness of some non-chemical alternatives to methyl bromide for soil sterilization. Methyl bromide, soil solarisation and dry heat by burning cowdung, maize cob, and brushwood (twigs) as a source of heat were evaluated for sterilisation of paprika nursery seedbed soil. Burning of brushwood and cowdung treatments resulted in highest soil temperatures at the two sites and in both seasons. Area under disease progress curve for disease incidence was least in the brushwood treated seedbeds. Methyl bromide and use of brushwood had a seedling emergence which 61% and 57.3% higher, respectively than non-sterilised control in 2001/2002 season. The inconsistencies associated with dry heat methods in controlling soil microbes and weeds requires a combination of them with other sterilising agents such as chloropicrin, methyl iodide and dazomet, if they have to match the efficacy of methyl bromide treatment for soil sterilisation.

Key words: *Capsicum annuum* L., sterilisation, methyl bromide, seedbed, dry heat

INTRODUCTION

Paprika (*Capsicum annuum* L.) production the use 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, but the existing ban on methyl bromide has created a challenge to researchers world-wide to find a suitable alternative to replace it. Methyl Bromide is a toxic chemical used to control a broad spectrum of pests in soil, commodities and structures. In the early 1990s, scientists identified methyl bromide as one of the substances contributing to ozone depletion. Methyl bromide production and use have therefore been phased out because it depletes the protective ozone layer in the stratosphere (Csinos et al., 2000). Since methyl bromide, a pre-plant soil fumigant, 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 et al., 1955; Todd and Lucus, 1956). Target soil-borne pests include weeds, nematodes (such as root-knot nematodes *Meloidogyne*) and a range of fungal pathogens (such as *Fusarium*, *Sclerotinia*, *Pythium*, *Rhizoctonia*, *Vertici-llium* and *Phytophthora*) (Batchelor, 2002). There is no known single pesticide that has such a wide spectrum of activity and as cost-effective and easy to use as methyl bromide. Unfortunately, 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 would need to be seriously considered. Therefore, there is need for an affordable and effective alternative method, preferably a non-chemical one, for seedbed sterilisation.

To this end, farmers growing paprika in Zimbabwe, particularly in the smallholder sector, were being encouraged to burn combustible materials, such as brushwood, on their paprika seedbeds for dry heat soil sterilisation (AGRITEX, 2000). In addition to these sterilisation methods, the smallholder farmers have been using, promising practices such as solarisation need to be investigated under their conditions. Soil solarisation is a hydrothermal method of soil disinfestations using solar that is trapped and conserved through 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 the 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 soil-inhabiting heat-tolerant pests (Katan, 1981). Too high temperatures also eliminate some beneficial micro-organisms 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 even be higher than that in the non treated soil due to a "biological vacuum" (Baker, 1962). There is therefore a need to evaluate various methods of soil sterilization, whether or not they are currently being used by the farmers. The effectiveness of the sterilisation method should mainly be 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 therefore to identify an effective method of soil sterilisation in paprika seedbeds by comparing the effectiveness of various non-chemical materials for soil fumigation under smallholder farming conditions.

MATERIALS AND METHODS

Background of the research location

The Chinyika Resettlement Area (CRA) is located in the Makoni District of Manicaland province in Zimbabwe. The area lies between lat 18°02' and 18°17' S, and long 32°09' and 32°24' E with an altitude ranging from 700 to 1 200 metres above sea level. The CRA is 140 km north east of Harare. It is divided into Chinyika East (Bingaguru) and West (Chinyudze) and is one of the first resettlement areas in Zimbabwe. The major crops grown in CRA include tobacco, and the recently fast-adopted paprika, both of which need to be raised in nursery seedbeds prior to transplanting on to the field.

Treatments and experimental design

On-farm seedbed 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 1 m × 5.25 m, were prepared. The experiment was laid out in a randomized complete block (RCBD) with three replications for each treatment. The seedbed sterilisation methods tested in the paprika nursery include burning dry cow dung on the seedbeds at 12 kg/m^2, burning brushwood on the seedbeds at 7 kg/m^2 (farmer practice), burning maize cobs at 8 kg/m^2, solarisation for 10 weeks using black plastic, and application of methyl bromide at 30 g/m^2 (standard). A non-treated soil was included as a control.

Methyl bromide

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

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 daily using a T350 thermocouple temperature probe daily beginning two days after covering the seedbeds at between 13:00 H and 14:00 H. The seedbeds were divided into three equal parts from which measurements at 5, 10 and 15 cm soil depth were taken at each point. Temperature measurements were also done at the same depths for unsolarised seedbeds. The data were compared as means of solarised and unsolarised seedbeds at the three different soil depths, no ANOVA was perfomed on this data as the factors had no acceptable degrees of freedom.

Burning

The quantities of cow dung, brushwood and maize cobs required per seedbed for heat treatment were determined by asking five different farmers to lay out the sterilisation materials independently and then finding the mean weight. This was done at three different sites in each CRA East and West. The means were found to be within the same range. The mean values were then used as the rates during the two cropping seasons. After the even distribution of brushwood, cow dung and maize cobs in their respective seedbeds they were set alight. The seedbeds were then al-

lowed to cool for two days after which the ash was carefully and completely removed before seed sowing.

Estimating of soil temperatures for the burning treatments

The temperatures attained 30, 60 and 90 minutes after the flame died out at 5, 10 and 15 cm soil depths were determined 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 15 cm soil depths were taken at each point at 30-, 60- and 90-minute intervals after the flame had died out. Temperature readings from the same soil depth within each seedbed were then combined and the mean value was used for data presentation.

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. Soil samples were taken immediately after sterilisation of seedbeds. Soil samples of approximately 200 g were collected from three randomly selected points in each seedbed in three blocks from depths of 5, 10 and 15 cm. 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 gram from each sample of soil was air-dried and suspended in 95 ml 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, 0.5 ml 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 0.5 ml of sterile water onto the PDA and NA plates three times for each medium and dilution. The plates were incubated at 25°C, for three days, before counting the numbers of fungal and bacterial colonies on each plate. For each sample, estimates of colony forming units (CFU) in 1 g dry soil were made. Data on the microbial colony number were then square root transformed (Csinos, 1998).

Seed sowing

Paprika (var. PapriKing) seeds were sown on seedbeds five days after dry heat sterilisation with brushwood. Compound S (7% N; 27% P_2O_5; 7% K_2O) fertilizer was incorporated in the seedbed at a rate of 1 kg/m^2. Rows spaced 5 cm apart were marked across the seedbed length. The seedbeds were sown by hand drilling 100 seeds/m. Seedbeds were dry grass-mulched soon after sowing and the mulch removed soon after seedling emergence. Watering was done three times daily at 08:00 H, 12:00 H and 17:00 H with a watering can fitted with a fine sprayer until seedling emergence. After emergence the seedbeds were watered twice daily at 08:00 H and 17:00 H.

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. Area under disease progress curves (AUDPC) (Shanner and Finney, 1977) were calculated before the analysis of variance using the formula:

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

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. Disease incidence data were used to compute in AUDPC disease incidence.

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°C and the dry weight obtained. Values for the mean height and weight of the seedlings were used for data analysis. Weed density was estimated at 2, 4 and 8 WAS. Weed data were collected from the area defined by a 0.3 × 0.3 m quadrant. The quadrants were thrown randomly 3 times in the seedbed. Using identification aids, dominant weed flora were identified to the species level. The weeds within the quadrant were then uprooted and dried to determine their biomass. Weed biomass data were collected from the gross plot. Weed density and biomass data were Log (x+1) transformed before subjecting same to analysis of variance.

RESULTS

Soil temperatures achieved by solarisation

In 2001/2002 at both Chinyudze and Homestead sites, there was a general increase in the temperature achieved in solarised than in unsolarised seedbeds (Tables 1 and 2). The highest mean temperature achieved by solarisation was 39.4°C at 5 cm soil depth, 35.9°C at 10 cm soil

depth and 31.7°C at 15 cm in 2002/2003 season. On the average, higher temperatures were achieved in the 2002/03 season, with the highest obtained being at the Homestead site, which had also the highest temperatures in the 2001/02 season.

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

Mean temperatures achieved by burning brushwood were significantly higher ($p < 0.05$) than those achieved by burning cow dung and maize cobs in 2001/2002 season at Chinyudze site and cow dung at the Homestead site. There was a general increase in mean temperatures as the soil 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 2002/03 season. The lowest temperature (52.2°C) was achieved by burning brushwood. The maximum temperatures achieved by the various seedbed sterilisation heat decreased as the depth increased from 5, or 10 to 15 cm. Time after the flame died out had no significance effect on the heat levels achieved at the Homestead site in the 2002/03 season. There was an interaction between sterilisation method, soil depth and time interval at Nare site in the 2002/03 rainy season (Figures 1–12). There was a general decrease in temperature with increase in soil depth for all the treatments at Nare site.

Soil microbial population

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 performed 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 3). The greatest reduction in bacterial population occurred when maize cobs were used as combustible material at 10 cm and solarisation were used at 15 cm soil depth.

The effect of the different sterilisation methods used on the soil-borne microbial population changed with soil depth at both Homestead and Nare sites in the 2002/03 rainy season though the trend was not clearly defined (Table 4). There was a general decrease in bacterial populations from 5, 10 to 15 cm soil depth in the control. At the 5 cm depth, the best soil control was achieved by the burning of maize cobs and brushwood only at Homestead. Solarisation and maize cobs gave the least bacterial colony forming units at 10 and 15 cm depths and was significantly lower than for methyl bromide treatment at Homestead, as well as at 15 cm soil depth at Nare site.

Fungi

There were no significant ($p>0.05$) differences between treatments for fungal populations at the Homestead site in the 2001/02 season (Table 5). The brushwood treatment gave the greatest reduction in fungal population at the Chinyudze site in the 2001/2002 season. At the Homestead site in 2002/03, sterilisation methods responded differently with an increase in soil depth (Table 6). There was significant interaction between sterilisation method and soil depth for fungal population. The number of fungal forming units decreased with increase in soil depth. There were no significant differences between treatments for fungal population at the Nare site in 2002/03.

Seedling emergence

In seedbeds sterilised with methyl bromide and burning maize cobs, seedling emergence was significantly ($p < 0.05$) higher, 61.0% and 57.3% respectively than from non sterilized seedbeds at the Chinyudze site in the 2001/02 season. Similarly, there were no significant differences for seedling emergence at the Homestead site in the 2001/02 season. There were no significant ($p < 0.05$) differences in emergence percentage as a result of the different sterilisation methods used at both sites in the 2002/03 season (Tables 7 and 8).

Seedling vigour

Seedling height

Significant ($p < 0.05$) differences were observed for seedling height, with seedlings from the methyl bromide and burning maize cobs seedbeds giving the highest seedling height. At the Chinyudze site in the 2001/02 season, there were no significant differences in seedling height between methyl bromide and maize cob treated seedbeds (Table 7). No significant differences were observed between these two treatments for seedling emergence and height at the Homestead site in the 2001/02 season. Different sterilisation methods did not result in significant ($p > 0.05$) differences in seedling height at transplanting at both sites in the 2002/03 rainy season.

Seedling dry weight

Treatments did not influence mean seedling weight at neither of the two sites nor at neither of the two seasons (Table 8) except at Homestead in the 2002/03 where methyl bromide, solarisation and maize cob treated seedbeds produced seedlings of significantly ($p < 0.05$)

higher dry weight than those from unsterilised seedbeds.

Seedling disease incidence

Significantly ($p < 0.05$) low AUDPC disease incidence at Chinyudze in the 2001/02 season and at Nare in the subsequent season (2002/03) was observed in the case of brushwood, methyl bromide, cowdung and solarisation treated seedbeds (Table 9).

Weed management

Weed density

At 2, 4 and 8 WAS at the Homestead site, brushwood resulted in the best suppressing effect on weed densities in the 2001/02 season, whereas at the Chinyudze site methyl bromide had the least weed density for the same season (Tables 10 and 11).

Weed density was not significantly ($p > 0.05$) different at 8 WAS at the Nare site and 2.4 and 8 WAS at the Homestead site in the 2002/03 season. Sterilisation methods that resulted in the best weed suppressing effect at 2 WAS in the 2002/03 season were cowdung, methyl bromide and maize cobs (Tables 11 and 12). At 4 WAS, the best weed suppressing method was brushwood, which was not significantly different from cowdung and methyl bromide treatments at the Homestead site in the 2002/03 (Table 12).

DISCUSSION

It was envisaged that the different heat levels generated by heat generating methods such as solarisation, burning of maize cobs, brushwood and cowdung would effectively eliminate both weeds and the microbe population which is probably made up of both pathogenic and non-pathogenic microbes. Brushwood was effective in both microbe and weed management. Application of a temperature of 70°C for 30–60 minutes is sufficient to eradicate most of the soil-borne pathogens (Newhall, 1955; Runia, 1983; Bollen, 1985). Brushwood was effective in reducing microbial populations as indicated by the significantly low AUDPC recorded in the 2001/02 season. However, it was inconsistent in its effect on weed population.

Bacterial and fungal microbes in the soil at the Chinyudze site in the 2001/02 season were greatly reduced mainly because the temperatures achieved by the 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 reducing effect as the soil depth increased. Soil temperatures in plots mulched with a black plastic sheet were lower than those mulched with clear plastic (Katan, 1981). 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 (Yucel, 1995).

In the present study, however, solarisation was not as effective as is usually reported 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 had reported poor results with solarisation, especially with regards to weed control (Anonymous, 1997). The temperatures obtained with solarisation in the present investigation were 7–9°C lower than the work done by Yucel (1995). However soil temperatures obtained in solarised plots were 3–8°C higher than unsolarised plots. This result is similar tothe 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°C and weed controlwas poor (Mashingaidze, Chivinge and Mtetwa, 1996).

At Homestead site most of the treatment 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 determined by which of the treatments ensures that weed management is effective and pathogen reduction is to an extent that ensures healthy seedlings. In addition a sterilisation method that is effective but expensive or laborious may not be the best option for smallholder farmers.

CONCLUSION AND RECOMMENDATION

Brushwood may have proved effective for seedbed sterilisation, and solarisation was promising. However, the methods resulted in some inconsistencies, particularly on the aspect of microbe and weed management in the nursery. Such inconsistencies are very critical in paprika seedbeds. It may therefore be recommended that, for their efficacy to be improved upon 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.

FIGURES AND TABLES

Figures 1–3: Temperatures achieved at 5, 10 and 15 cm soil depth by burning of cow dung (T1), maize cobs (T2) and brushwood (T3) at Chinyudze site in 2001/2002

Figure 1: 5 cm soil depth

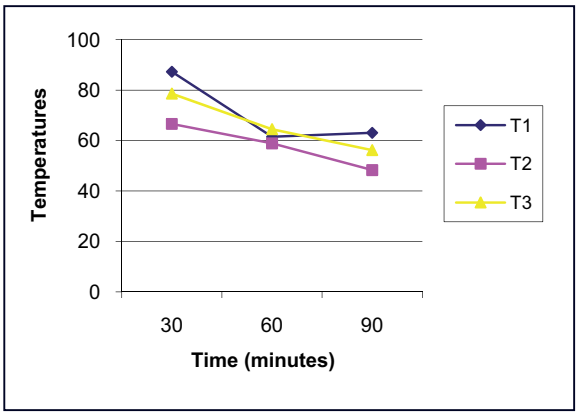


Figure 2: 10 cm soil depth

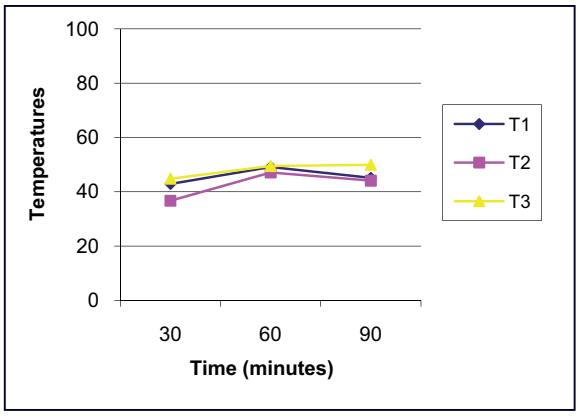


Figure 3: 15 cm soil depth

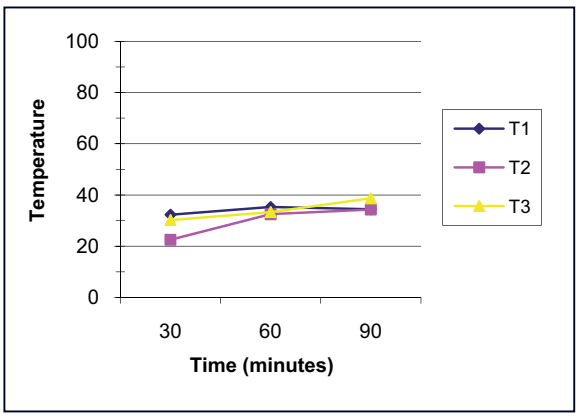


Figure 4: 5 cm soil depth

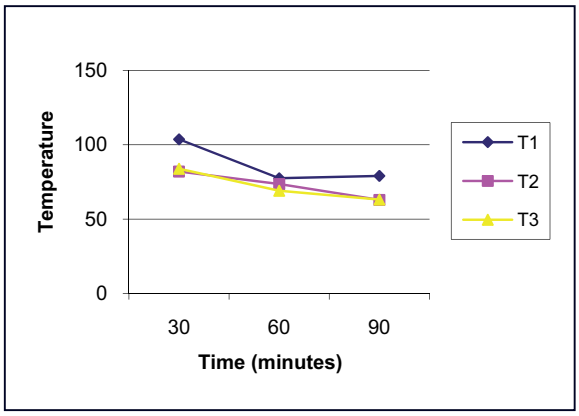


Figure 5: 10 cm soil depth

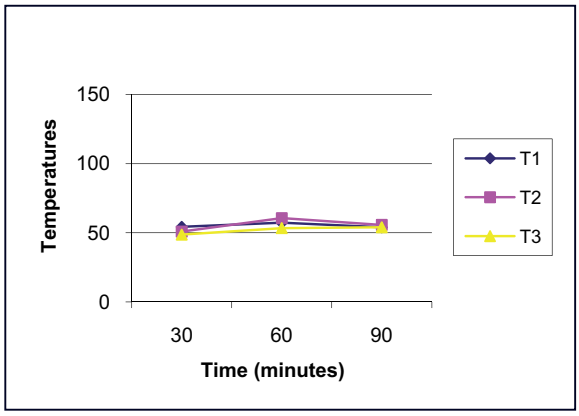
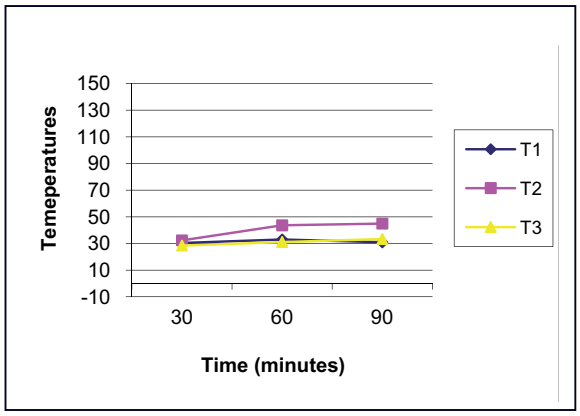


Figure 6: 15 cm soil depth



Figures 4–6: Temperatures achieved at 5, 10 and 15 cm soil depth by burning of cow dung (T1), maize cobs (T2) and brushwood (T3) at Homestead site in 2001

Figure 7: 5 cm soil depth

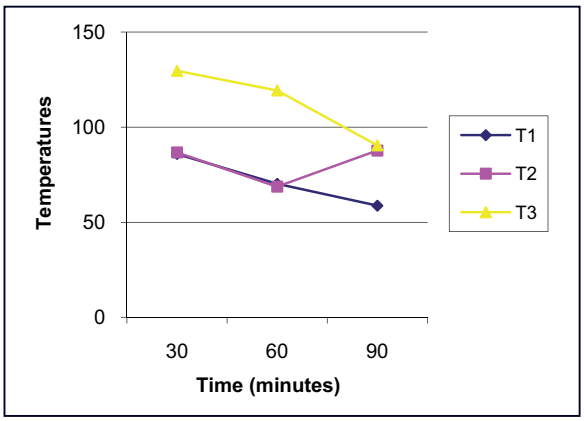


Figure 8: 10 cm soil depth

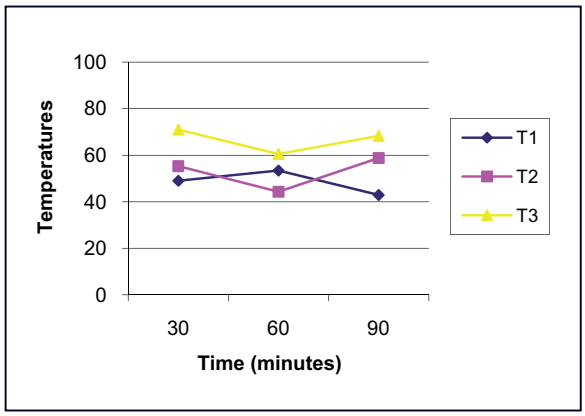


Figure 9: 15 cm soil depth

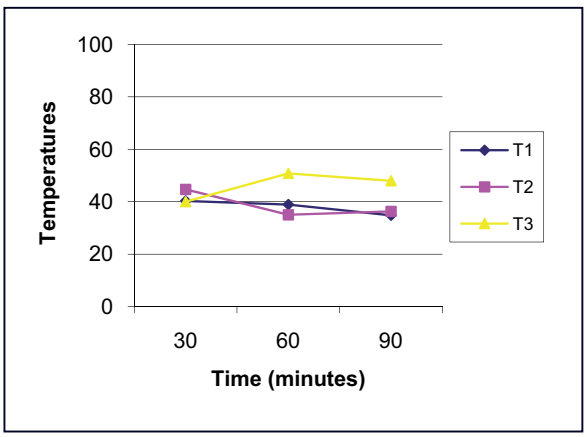


Figure 10: 5 cm soil depth

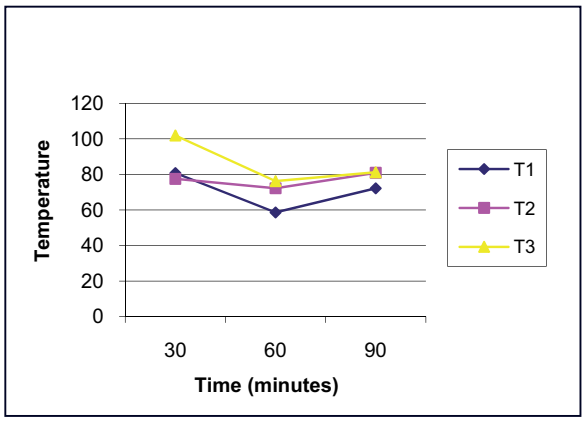


Figure 11: 10 cm soil depth

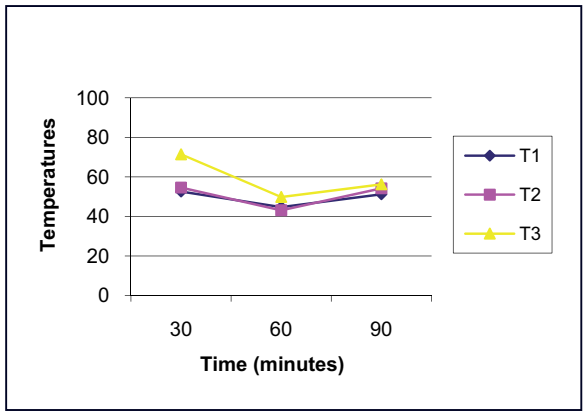
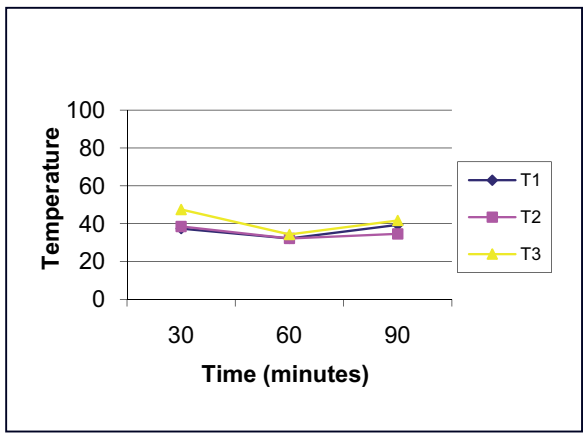


Figure 12: 15 cm soil depth



Tab. 1. Mean soil temperatures recorded daily between 13:00 and 14:00 hrs for 10 weeks in the solarised and unsolarised paprika seedbeds at Homestead and Chinyudze sites in Zimbabwe in the 2001/02 season

Soil depth (cm)	Soil temperature (°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

Tab. 2. Mean soil temperatures recorded daily between 13:00 and 14:00 hrs for 10 weeks in the solarised and unsolarised paprika seedbeds at Homestead and Nare sites in Zimbabwe in the 2002/03 season

Soil depth (	Soil temperature (°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

Tab. 3: Number of bacterial colony forming units (CFUs) in 1g dry soil after different soil sterilisation methods at 5, 10 and 15 cm depths at Homestead and Chinyudze sites in the 2001/02 season

Soil depth (cm)	Homestead*			Chinyudze		
	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)
Cowdung	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 parentheses represent square root transformed data of the figures in parentheses

Tab. 4: Number of bacterial colony forming units (CFU) in 1g dry soil after different soil sterilisation method at 5, 10 and 15 cm depths at Homestead and Nare sites in the 2002/03 season

Soil depth (cm)	Homestead*			Nare		
	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)
Cowdung	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 parentheses represent square root transformed data of the figures in parentheses

Tab. 5: Number of fungal colony forming units (CFUs) in 1 g dry soil after different soil sterilisation methods at 5, 10 and 15 m depths at Homestead and Chinyudze sites in the 2001/02 season

Soil depth (cm)	Homestead*			Chinyudze		
	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)
Cowdung	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 parentheses represent square root transformed data of the figures in parentheses

Tab. 6: Number of fungal colony forming units (CFUs) in 1 g dry soil after different soil sterilisation method at 5, 10 and 15 cm depths at Homestead and Nare sites in the 2002/03 season

Soil Depth (cm)	Homestead*			Nare		
	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)
Cowdung	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 parentheses represent square root transformed data of the figures in parentheses

Tab. 7: Paprika seedling emergence percentage, height and dry weight of paprika seedlings as influenced by sterilisation method at Chinyudze and Homestead sites in the 2001/02 season

Sterilisation method	Emergence (%)		Plant 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)
Cowdung	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 cobs	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 parentheses represent Log (X + 1) transformed data of the figures in parentheses

Tab. 8: Paprika seedling emergence percentage, plant height and dry weight of paprika seedlings as influenced by sterilisation method at Nare and Homestead sites in the 2002/03 season

Sterilisation method	Emergence (%)		Plant 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)
Cowdung	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 cobs	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 parentheses represent Log (X + 1) transformed data of the figures in parentheses

Tab. 9: The effect of seedbed sterilisation method on Area under Disease Progress curve (AUDPC) for disease incidence on paprika seedling at Homestead in the 2001/02 and 2002/03 seasons

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

Tab. 10: The effect of seedbed sterilisation method on weed density in paprika seedbeds at Homestead and Chinyudze sites in the 2001/02 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 parentheses represent Log (X + 1) transformed data of the figures in parentheses
WAS – weeks after sowing

Tab. 11: The effect of seedbed sterilisation method on weed density 8 weeks after sowing (WAS) paprika seedbeds at Homestead, Chinyudze and Nare sites in the 2001/02 and 2002/03 seasons

Sterilisation method	Weed density (number/m^2)			
	2001/02		2002/03	
	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 parentheses represent Log (X + 1) transformed data of the figures in parentheses

Tab. 12: The effect of seedbed sterilisation method on weed density at 2 and 4 weeks after sowing (WAS) of paprika seedlings at Homestead and Nare sites in the 2002/03 season

Sterilisation method	Weed density (number/m^2)			
	2 WAS		4 WAS	
	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 parentheses represent Log (X + 1) transformed data of the figures in parentheses

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