CHAPTER 4

CONTROL OF *MELOIDOGYNE INCOGNITA* RACE 2 ON BAMBARA GROUNDNUT (*VIGNA SUBTERRANEA*) BY MEANS OF BIOFUMIGATION AND SOLARIZATION.

ABSTRACT

Experiments were conducted in the greenhouse and in microplots in the field to test the effects of biofumigation, and solarization individually and in combination on *M. incognita* race 2 on bambara groundnut (*Vigna subterranea* (L.) Verdc.). The greenhouse experiments evaluated biofumigation alone and consisted of soil amended with two *Brassica* species, B. *oleracea capitata* L. varieties Drumhead and Glory of Enkhuizen, and *B. napus* L. variety Forage Star. Other treatments included fenamiphos and an untreated control. The microplot experiments investigated the combined effect of biofumigation and solarization on *M. incognita*. Treatments comprised solarized soil amended with cabbage, unsolarized soil amended with cabbage, solarized non-amended soil, untreated control, and aldicarb. The greenhouse and microplot treatments were each inoculated with *M. incognita* race 2.

Biofumigation significantly reduced the *M. incognita* population during the first four weeks of incubation and control declined thereafter. Cabbage residues were effective when applied at higher rates (4 kg/m^2 and 6 kg/m^2). Phytotoxicity was observed with fenamiphos, Glory of

Enkhuizen, and forage rape treatments applied at 6 kg/m^2. Growth and yield increased in treatments with variety Drumhead at all application rates.

The microplot experiment revealed that combination of biofumigation and solarization resulted in better control of the nematode than each treatment alone. The control achieved with biofumigation combined with solarization was similar to that obtained with the aldicarb treatment.

4.1 Introduction

Control of soil-borne plant diseases by means of biofumigation is gaining much attention from researchers in different disciplines. The ability of some *Brassica* crops to release biocidal compounds suggests that incorporation of green tissues of such plants into the soil could be useful for the control of a wide range of soil-borne pathogens. A number of *Brassica* crops are reported to be effective in reducing populations of some nematode species (Lewis & Papavizas, 1971; Lazerri, Tacconi, & Palmieri, 1993: Motjahedi, Santo, Hang & Wilson, 1993; McLeod & Da Silva, 1994; Mayton, Olivier, Vaugh & Loria, 1996). This was attributed to the production of glucosinolates by the *Brassica* species (Lewis & Papavizas, 1971). According to Borek, Morra, Brown & McCaffrey (1994), glucosinolates release numerous compounds among them allylisothiocyanates (AITC) upon degradation. These are volatile compounds similar in toxicity to methylisothiocyanate (MITC), an active ingredient in fumigants such as metham sodium (Lewis & Papavizas, 1971).

The environmental and human health hazards posed by synthetic soil fumigants have greatly restricted their availability and use. As a result attempts are now being made to find suitable alternatives to synthetic fumigants. Biofumigation has therefore gained much attention as a possible alternative to most synthetic fumigants and the results obtained are promising. According to Motjahedi, et al. (1993), green tissue of rapeseed (*Brassica napus L.*) was successfully used to reduce *M. chitwoodi* populations in the soil. McLeod & Da Silva (1994) have also reported effective control of *M. incognita*, *M. javanica* and *Tylenchulus semipenetrans* with rapeseed in Australia. Motjahedhi, Sang, Hang & Wilson (1991) reported superior control of root-knot nematodes by green material of *Brassica* crops than other crops.

The usefulness of biofumigation may be limited by the low concentrations of toxic volatile compounds released during the breakdown of glucosinolates. Sang, Minchinton, Johnstone & Truscott (1984) reported that the nature and level of glucosinolates vary with different plant species. There is also a remarkable variation in the glucosinolate profile from tissues within one plant. Consequently, biofumigation may not always be effective unless it is complemented by additional control measures such as solarization.

Gamliel & Stapleton (1993) reported that solarized cabbage-amended soil induced the breakdown of more complex compounds and resulted in a wide range of volatile compounds such as alcohols, aldehydes, sulfides and isothiocyanates. Stapleton & Duncan (1998) observed that the level of biocidal activity in unsolarized cabbage-amended soil is often relatively weak and unpredictable compared to solarized cabbage-amended soil. *M.*

incognita galling on tomato was reduced by 95-100 % when cruciferous soil amendments were combined with a sublethal heating regime and by 38-100 % in amended soil without heating (Stapleton &Duncan, 1998).

The objectives of this study were to determine the effectiveness of different *Brassica* species as biofumigants for the control of *M. incognita* race 2 on bambara groundnut. The combined effect of biofumigation and solarization on *M. incognita* race 2 populations was also investigated.

4.2 Materials and Methods

Biofumigation experiment in the greenhouse

The experiment was conducted from September 1997 to April 1998 in the greenhouse with temperature maintained between 20 °C and 30 °C. The soil used was a steam-pasteurized sandy loam soil (80 % sand, 4 % silt, 14 % clay, and pH 6.0) prepared by mixing topsoil with river sand at the ratio of 2:1. The soil received a basal fertilizer dressing of NPK 2:3:2 applied at the rate of 500 kg/ha prior to planting. The volume of soil contained in a twenty-25 cm diameter pot was weighed and the amount of plant biomass required as amendment per pot calculated accordingly. Cabbage (*Brassica oleracea capitata* L.) varieties Drumhead and Glory of Enkhuizen, and forage rape (*Brassica napus* L.) variety Forage Star were grown in the field for three and a half months for use in this study. The plants were harvested and washed free of soil. The leaves and stems of each variety were chopped into small pieces and used as soil amendment.

The experiment comprised the following four treatments:

- Soil amended with cabbage varieties Drumhead and Glory of Enkhuizen applied at 2; 4 and 6 kg/m^2
- Soil amended with forage rape variety Forage Star applied at 2; 4 and 6 kg/m^2
- Fenamiphos applied at 2 liter/ha
- Non-amended control

Each treatment was replicated six times and was applied separately to *M. incognita* inoculated and uninoculated plants respectively. Quantities of 8 kg of soil were augmented with the various plant materials, put into clear plastic bags, and watered to field capacity. The bags were subsequently kept for four weeks in the greenhouse at a temperature of 20 to 30 °C.

Meloidogyne inoculum consisted of 10 g of heavily galled tomato roots (gall/egg mass index = 5) infested with a Botswana isolate of *M. incognita* race 2. Each egg mass had an estimated content of 250 eggs. Roots were washed free of soil and cut into small pieces, which were incubated in petri dishes for 12 hours to facilitate hatching of eggs. The resulting inoculum consisted of a mixture of eggs and juveniles. The inoculum was incorporated into the soil, the bags sealed tightly to prevent fumes from escaping, and incubated for four weeks at room temperature. During this period, bags were occasionally shaken to mix the contents. At the end of the incubation period, bag contents were transferred to 25 cm diameter plastic pots placed on benches in the greenhouse. The soil mixture was aerated for two weeks to expel volatile compounds. The fenamiphos treatment was applied at this stage. Three seeds of bambara groundnut variety DIPC were sown per pot and watered to maintain soil

moisture. After emergence, plants were fertilized weekly with a solution of Multifeed P_{43} ® applied at 100 g/liter (Plaaskem Pty Ltd, P.O. Box 87005, Houghton, 2041). After four weeks (midseason) plants were thinned to one seedling per pot and the removed seedlings were assessed for nematode damage. Roots were washed, stained with Phloxine B and evaluated for gall and egg mass incidence using a rating scale of 0-5 (Taylor & Sasser, 1978). Shoots were dried in an oven at 60 °C for three days and the dry mass determined.

Plants were harvested after eight weeks and assessed following the same procedures used at midseason. The fresh weight of roots was obtained prior to evaluating roots for galls and egg masses. Pods were counted, dried in an oven at 60 °C for six days, and weighed.

Biofumigation and solarization experiment in the field

Fifteen microplots each measuring 1.5 m x 1.5 m and 1 m deep were constructed in an orchard at the University of Pretoria experimental farm. The microplots consisted of holes in the ground, lined with pre-fabricated fiberglass walls. The bottoms of the microplots were open to facilitate drainage. These were filled with sandy loam soil (75 % sand, 5 % silt, 20 % clay and pH 6.0) prepared by mixing topsoil with coarse river sand at the ratio of 2:1. The soil was fumigated for six weeks using dazomet applied at the rate of 500 g/m^2. An aeration period of two weeks was allowed.

The experiment consisted of five treatments:

- Soil amended with cabbage at 4 kg/m^2
- Soil amended with cabbage at 4 kg/m^2 and solarized

- Non-amended solarized soil
- Untreated control
- Aldicarb applied at 5 g/m^2

The experimental design comprised a completely randomized design with 3 replicate micro plots per treatment. Each microplot contained sixteen plants (total of 48 plants per treatment).

Cabbage variety Drumhead was raised in the field for three and a half months for use as an amendment in this study. The crop was harvested, green tissue (heads, leaves and stems) were cut into small pieces, applied to the soil at the rate of 4 kg/m^2 and mixed thoroughly. The soil was watered to field capacity throughout the biofumigation period.

Each plot was inoculated before application of treatments with tomato roots heavily infested with a South African isolate of *M. incognita* race 2 with an egg mass index rating of 5 (Taylor & Sasser, 1978). Roots were chopped into small pieces and placed in each plot in 15 cm-deep holes in the previously marked spots where the plants would be planted. Each hole received 5 g of inoculum.

Solarization commenced in January 1999. Soil in the microplots was covered with 30 µm clear polyethylene sheets for four weeks coinciding with biofumigation. A digital data logger (1200 series Grant squirrel logger, UK) was used to measure soil temperature in four plots selected at random to measure soil temperature in solarized amended soil, unsolarized amended soil, solarized non-amended soil and the untreated control. Thermocouples were

inserted at 15 and 30 cm depths and calibrated to record temperature hourly. The temperature data was down loaded weekly at 12:00 noon. The polyethylene was removed after four weeks and the soil aerated for two weeks to expel residual fumes resulting from biofumigation.

Planting was done in March 1999. All plots received a basal dressing of NPK (2:3:2) applied at 500 kg/ha prior to planting. Aldicarb treatment was applied to the designated plots at 5 g/m^2. Three seeds of bambara groundnut (variety DIPC) were planted together at a depth of 15 cm where the inoculum was previously placed. There were two rows per plot with a spacing of 60 cm between rows and each row consisted of eight holes with a 15 cm spacing in between. The plants were watered by means of a watering can with each plot receiving twenty liters of water per day. Plants were thinned to one seedling per hole four weeks after emergence (leaving sixteen plants per plot). Ammonium nitrate was applied at the rate of 100 kg/ha. Aphids were controlled by means of cypermethrin applied as a foliar spray at the rate of 150 ml/ha.

Six plants per row were harvested eight weeks after planting and evaluated for galls and egg masses. Shoots were dried in an oven at 60 °C for three days and weighed. Roots were washed to remove soil and their fresh weight determined. Roots were subsequently placed in a 0.15 g/liter aqueous solution of Phloxine B for 15 minutes to stain egg masses. The incidence of root galls and egg masses was assessed according to a scale of 0-5 (Taylor & Sasser, 1978). Yield was measured by counting the number of pods per plant. Pods were dried in an oven at 60 °C for four to five days and weighed.

All data were analyzed statistically using ANOVA (SAS, BMDP Statistical Software Inc, Los Angeles, CA). Gall and egg-mass index data were ranked before analysis. Mean separation was done according to Duncan's multiple range test.

4.3 Results

Biofumigation experiment in the greenhouse

At the end of the incubation period the cabbage and forage rape residues in the soil were decomposing. Amended soil was wetter than the untreated control soil because of the sap released from disintegrating plant tissues. There was a pungent odor released from bags containing *Brassica* amendments. Germination of bambara groundnut seed was poor and slow in soil amended with Glory of Enkhuizen at all dosages, forage rape at 6 kg/m^2 and in fenamiphos treated soil. Plants grown in soil receiving these treatments showed phytotoxicity symptoms. These plants were stunted, with varying degrees of chlorosis and tiny puckered leaves Fig. 4. 1). Roots showed various degrees of discoloration and browning. In most cases, roots were very short and thin, had no rootlets and were disintegrated.

At midseason, there were more galls and egg masses on plants grown in non-amended soil (control) than in amended soil (Fig. 4.2). There was however no significant difference between the control and the *Brassica* amendments applied at the lower dosage (2 kg/m^2). Drumhead applied at 4 kg/m^2 was not significantly different from the control treatment. Gall and egg mass indices decreased with an increase in dosage (Fig. 4. 2).

Forage rape applied at 2 kg/m^2 and 4 kg/m^2 and Drumhead at 2 kg/m^2 differed significantly from other treatments in terms of the dry mass of shoots. The dry mass of shoots increased by 83 % and 88 % in treatments receiving forage rape at 2 kg/m^2 and 4 kg/m^2 respectively, 37 % in treatments receiving Drumhead at 2 kg/m^2, and 6 % in treatments receiving Glory of Enkhuizen at 2 kg/m^2 compared to the untreated control (Table 4.3a). A decrease in shoot mass was recorded for the other treatments. No significant differences were detected in the dry mass of shoots of plants grown in soil treated with Glory of Enkhuizen applied at 4 kg/m^2 and 6 kg/m^2. The dry mass of shoots of plants receiving forage rape applied at 2 kg/m^2 was not significantly different from those receiving 4 kg/m^2 but differed significantly from those treated with 6 kg/m^2. Plants grown in soil treated with fenamiphos differed significantly from those receiving forage rape at 2 kg/m^2 and 4 kg/m^2 in terms of shoot dry mass. These plants however did not significantly differ from plants in the other treatments (Fig. 4.3).

At harvest plants from the untreated control were significantly different from those receiving fenamiphos, forage rape, and Glory of Enkhuizen at 6 kg/m^2 in terms of gall and egg mass indices. The fenamiphos treatment decreased gall and egg mass incidence by 80 % compared with the untreated control. Very few galls (72 % decrease compared to the control) formed on plants grown in soil amended with forage rape, and glory of enkhuizen at 6 kg/m^2 (Table 4.3b, Fig. 4.4)

The fresh weight of roots of plants from the untreated control and forage rape treatment applied at 2 kg/m^2 differed significantly from those receiving other treatments except for Drumhead at 2 kg/m^2 and forage rape treatment at 4 kg/m^2. With the exception of forage

rape applied at 4 kg/m^2, application of amendments at 4 kg/m^2 and 6 kg/m^2 did not have any significant effect on the fresh weight of roots. The root mass decreased with an increase in application rate (Fig. 4.5).

The dry weight of shoots of plants from the untreated control and treatments with drumhead at 2 kg/m^2, and forage rape at 2 kg/m^2 and 4 kg/m^2 did not differ significantly but were significantly different from other treatments. There were no significant differences in dry weight of plants from treatments with fenamiphos and those receiving Drumhead at 4 kg/m^2, and forage rape at 2 kg/m^2 and 4 kg/m^2. The dry mass of shoots of plants from treatments with Drumhead applied at 4 kg/m^2 and 6 kg/m^2 were not significantly different from those treated with Glory of Enkhuizen at 2 kg/m^2. No significant differences in dry mass of shoots were noticed in plants receiving Glory of Enkhuizen at 2 kg/m^2 and 4 kg/m^2. These plants were also not significantly different from plants from treatments with Drumhead at 4 kg/m^2 and 6 kg/m^2, and forage rape at 6 kg/m^2 (Fig. 4.6).

The lowest yield (number of pods) was recorded in plants grown in soil amended with Glory of Enkhuizen at 6 kg/m^2 while the highest number was recorded in plants from forage rape at 2 kg/m^2. There was no significant difference in the number of pods from plants receiving forage rape at 2 kg/m^2 and 4 kg/m^2, the untreated control, and Drumhead at 2 kg/m^2. The number of pods from plants treated with fenamiphos differed significantly with those from forage rape treatments applied at 6 kg/m^2 (Fig. 4.7). The dry mass of pods followed the same trend as the number of pods (Fig. 4.8).

Biofumigation and solarization experiment

The results are presented in Tables 4.3a & 4.3b. Plants from unsolarized non-amended treatments had the highest gall and egg mass indices. Solarization alone decreased gall and egg mass indices by 22 % compared with the untreated control. Biofumigation without solarization decreased gall and egg mass indices by 41 % while biofumigation combined with solarization decreased gall and egg mass indices by 66 %. Treatment with aldicarb did not differ significantly from the biofumigation and solarization treatments (Table 4.3c).

Root growth was increased by 50 % in plots treated with aldicarb compared to the untreated control. Generally root growth was reduced by the other treatments. Treatments differed significantly from each other except the solarized and unsolarized amended treatments, which did not differ from each other (Table 4.3d). There was no significant difference between solarized non-amended treatment and unsolarized amended treatments.

The dry mass of shoots of plants from treatments with aldicarb, solarized amended and unsolarized amended treatments did not differ significantly. An increase of 54 % and 46 % in dry mass was recorded in plants from plots treated with aldicarb and those amended with cabbage residues combined with solarization respectively. There were no significant differences between plants from solarized non-amended and unsolarized non-amended treatments (Table 4.3 d). The mean maximum weekly soil temperature was 37.6 °C in solarized amended soil and 36.2 °C in solarized non-amended soil at 15 cm depth. Temperatures at 30-cm depth averaged 31.1 °C in solarized non-amended treatments and 32.3 °C in solarized amended plots. Weekly minimum temperatures averaged 25.6 °C and

27.7 °C at 15 cm in solarized non-amended plots and solarized amended plots respectively. Maximum weekly temperatures at 30 cm averaged 26.9 °C and 28.1 °C respectively in solarized non-amended and solarized amended treatments. Temperatures in unsolarized non-amended and unsolarized amended treatments followed the same trend as in solarized non-amended and solarized amended treatments at both 15 and 30 cm depths. Comparison of solarized amended and unsolarized amended treatments revealed great differences in mean weekly temperatures at both depths. The maximum weekly temperatures in these two treatments differed by an average of 5.8 and 3.9 °C while the weekly minimum temperatures differed by 4 and 2.7 °C at 15 and 30 cm respectively (Table 4.3e).

Weekly maximum temperatures in unsolarized non-amended and solarized non-amended treatments differed by an average of 5 °C and 2.9 °C and weekly minimum temperatures by an average of 2.6 ° C at 15 cm and 2.3 °C at 30 cm respectively (Table 4.3 f).

4.4 Discussion

Soil amendment with *Brassica* residues significantly reduced gall formation caused by *M. incognita* race 2 on bambara groundnut in this study. However, the measure of control declined towards harvest in all amendments at all dosages. This confirms an earlier report that brassica residues can only be effective as biofumigants for a period of six weeks (Motjahedi et. al., 1993). Other reports suggested that control of nematodes from green material releasing isothiocyanates is unlikely after four weeks (Brown, Morra, McCaffrey, Auld & Williams, 1991). The significant reduction in gall and egg mass indices at midseason suggests that the greatest reduction of nematode populations occurred during the first four

weeks when residues were incubated in the soil. Thereafter there was little or no activity by the biofumigants on successive generations of the nematode. Although there are no previously reported studies involving biofumigation against *M. incognita* on bambara groundnut, there are reports of successful control of this nematode on other crops using *Brassica* residues (McLeod & Da Silva, 1994; McLeod, Somers & Gendy, 1995). Although previous studies evaluated brassica crops other than the ones used in this study, the overall potential of *brassica* crops as biofumigants is confirmed. Residues were not very effective in reducing galling and reproduction of the nematode when they were applied at 2 kg/m^2 (20 ton/ha). Significant reductions in nematode population occurred when forage rape and Glory of Enkhuizen were applied at 4 kg/m^2 and 6 kg/m^2 (40 ton/ha and 60 ton/ha) and Drumhead at 6 kg/m^2 (60 ton/ha). Previously, several rapeseed varieties were reported to be superior to cabbages in reducing populations of soil-borne diseases including nematodes (Motjahedi et al., 1993; Mayton et al., 1996). Mayton et al. (1996) reported variations in isothiocyanate production between and within *Brassica* species. This could account for the differences in performance between the brassica crops tested in this study. Cabbage variety Glory of Enkhuizen seemed to be similar to forage rape in its performance. Some reports suggested that cabbage contains little or no isothiocyanates and that this could account for its inferior performance when compared with other *Brassica* (Lewis & Papavizas, 1971). However in this study it was difficult to accurately conclude that the high reduction of *M. incognita* race 2 population experienced when forage rape and Glory of Enkhuizen were applied at higher dosages was due to biofumigation alone. The phytotoxicity observed at the onset in plants grown in soil receiving these treatments could have contributed to the reduction in nematode population in one way or another. Generally *Brassica* amendments are effective when they

are applied at higher dosages. According to McLeod & Da Silva (1994), a dosage of 4 kg/m^2 (40 ton/ha) is appropriate to give significant control. Although attempts were made to reduce phytotoxicity by aerating the soil for two weeks before planting, this did not alleviate the problem in the present study. This was reflected in the poor germination of plants grown in soil amended with Glory of Enkhuizen at all dosages and forage rape at 4 kg/m^2 and 6 kg/m^2.

Addition of *Brassica* residues to the soil had a slight effect on plant growth at midseason compared to control. Forage rape at 2 kg/m^2 and 4 kg/m^2 increased dry mass of shoots by over 80 % while the two cabbage varieties were able to increase growth only when applied at 2 kg/m^2. This could possibly be ascribed to the nutrient effect as a result of addition of organic matter to the soil. Keinath (1996) observed increase in growth and yield of watermelon after incorporating cabbage residues into mulched soil.

At harvest, growth and yield were generally better in plants grown in soil amended with forage rape at 2 kg/ha and 4 kg/ha and Drumhead at 2 kg/m^2. The poor growth of plants grown in soil amended with Glory of Enkhuizen at all three dosages could be attributed to phytotoxicity. More severe phytotoxicity symptoms were exhibited on these plants than those receiving other treatments. The same applies to forage rape applied at 6 kg/m^2. Although forage rape at 4 kg/m^2 performed better than Drumhead at the same dosage, the later was less phytotoxic. Plants grown in soil treated with fenamiphos were expected to grow better than those receiving *Brassica* amendments but this was confounded by phytotoxicity. This is confirmed by results from pilot experiments in this study. It should be noted that fenamiphos is not registered for use on bambara groundnut.

Solarization and biofumigation individually were successful in reducing nematode populations under field conditions by 22 % and 41 % respectively. Notably, when biofumigation and solarization were combined, the nematode population was reduced by 66 % thus giving similar control as aldicarb. This confirms previous reports that the efficacy of solarization or biofumigation can be enhanced by combined application of the two methods (Gamliel & Stapleton, 1997). According to Gamliel & Stapleton (1997), pathogen control in solarized amended soil is attributed to a combination of thermal killing and biotoxic volatile compounds. Compounds such as allylisothiocyanate, phenylisothiocyanate and aldehydes are released in the vapour phase from solarized cabbage-amended soil and are reported to have biocidal activity (Gamliel & Stapleton, 1997). Although volatile compounds were not analyzed in this study, the pungent smell experienced from solarized cabbage-amended plots is an indication that volatile gases were liberated during decomposition. These compounds along with thermal heating could have contributed to the successful control achieved in this study. Stapleton & Duncan (1998) concluded that combination of soil amendment with solarization is a feasible option for the development and implementation of effective soil fumigation. The maximum average temperature in solarized amended treatments increased by 5.8 °C at 15 cm and 3.9 °C at 30 cm compared to unsolarized amended plots. Stapleton & De Vay (1983) reported that *M. incognita* can not be effectively controlled by solarization alone because it is resistant to high temperatures. Propagules of *M. incognita, Pythium ultimum* and *Sclerotium rolfsii* were previously killed by heating soil amended with different *Brassica* residues to a maximal temperature of 38 °C (Gamliel & Stapleton, 1995). The average maximum temperature at 15 cm in solarized

cabbage-amended soil in this study was 37.6 °C confirming previous findings by Gamliel & Stapleton (1995).

Combination of biofumigation with solarization was as good as using aldicarb in terms of increasing the dry mass of shoots of bambara groundnut in this study. Previously, increases in plant growth and yield of watermelon were reported following treatment with a combination of biofumigation and solarization (Katan, 1981; Keinath, 1996). This increase could be attributed to biological changes in the soil such as increases in microbes beneficial to plant growth (Katan, 1981). Keinath (1996) intimated that solarization improved the efficacy of organic amendments including biofumigation thus resulting in improvement in plant growth. Combination of biofumigation and solarization could therefore be a suitable alternative to the use of nematicides. The reduction in root growth in plants treated with a combination of biofumigation and solarization could be attributed to phytotoxicity. Although aldicarb has not been tested on bambara groundnut, it is registered on cowpea, a close relative of bambara groundnut.

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Fig. 4.1: Phytotoxicity symptoms on eight-week old *Vigna subterranea* treated with cabbage variety Glory of Enkhuizen at 6 kg/m^2.

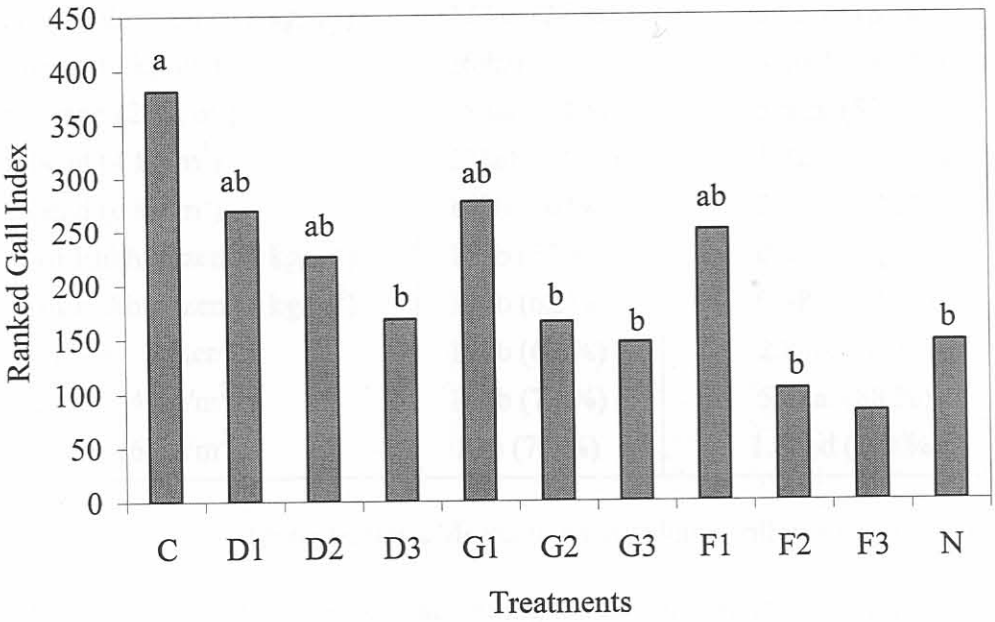

Fig. 4.2: Effect of soil amendment with different *Brassica* species and fenamiphos treatment on galling of *Vigna subterranea* infested with *M. incognita* race 2 at midseason. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to Kruskal-Wallis test. C = Control, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 = 6 kg/m^2.

Table 4.3a: Effect of soil amendment with different *Brassica* spp. on galling of bambara groundnut roots and on plant growth.

Treatment	Ranked GI*	Dry wt. of shoots (g)
Control	381a -	3.07bc -
Glory of Enkhuiezen (2 kg/m^2)	277ab (27 %)	3.25bc (6 %)
Drumhead (2 kg/m^2)	269ab (30 %)	4.20ab (37 %)
Forage rape (2 kg/m^2)	250ab (34 %)	5.62a (83 %)
Drumhead (4 kg/m^2)	226ab (41 %)	1.32cd (-57 %)
Drumhead (6 kg/m^2)	168b (56 %)	2.10cd (-32 %)
Glory of Enkhuiezen (4 kg/m^2)	165b (57 %)	0.97d (-71 %)
Glory of Enkhuiezen (6 kg/m^2)	146b (62 %)	0.98d (-71 %)
Fenamiphos (2 liter/)	146b (62 %)	2.80bcd (-9 %)
Forage rape (4 kg/m^2)	103b (73 %)	5.78a (88 %)
Forage rape (6 kg/m^2)	82b (79 %)	1.83cd (-40 %)

Each value is the mean of 6 replicates. Means in each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. Ranked GI in a column followed by the same letter do not differ significantly according to the Kruskal-Wallis test. * GI = Gall index. Figures in brackets represent % decrease in gall index, and increase in dry wt. of shoots respectively, compared to the control.

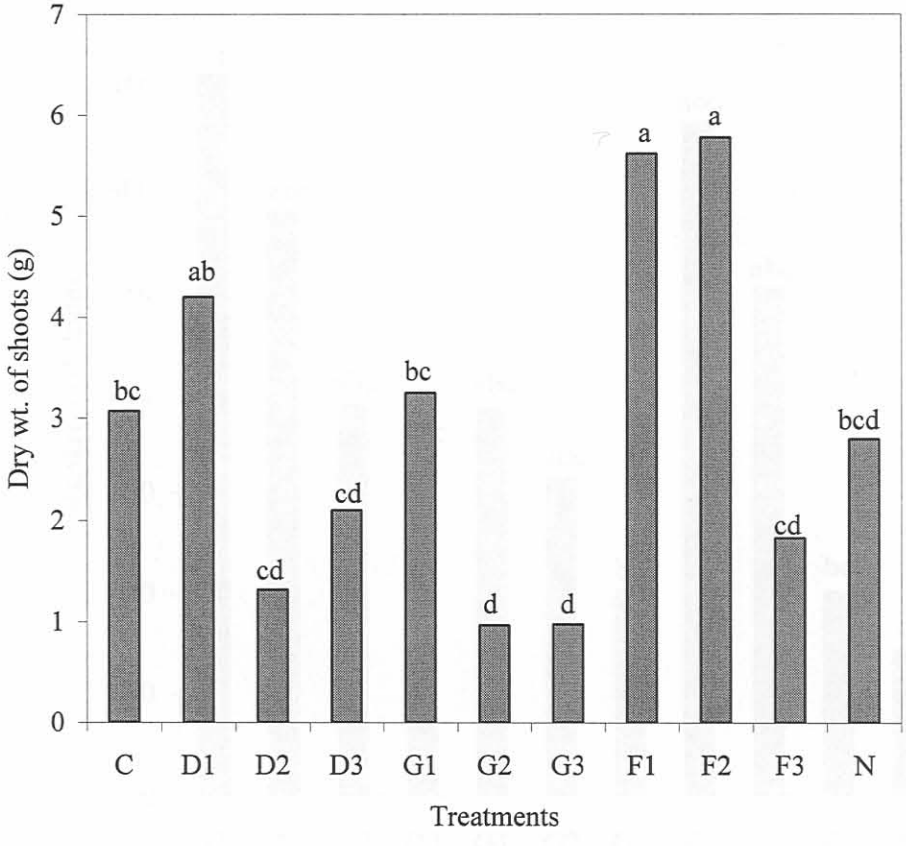

Fig. 4.3: Effect of soil amendment with different *Brassica* species on the dry wt. of shoots of *Vigna subterranea* grown for four weeks in soil infested with *M. incognita* race 2. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple rang test. C = Control, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 6 kg/m^2.

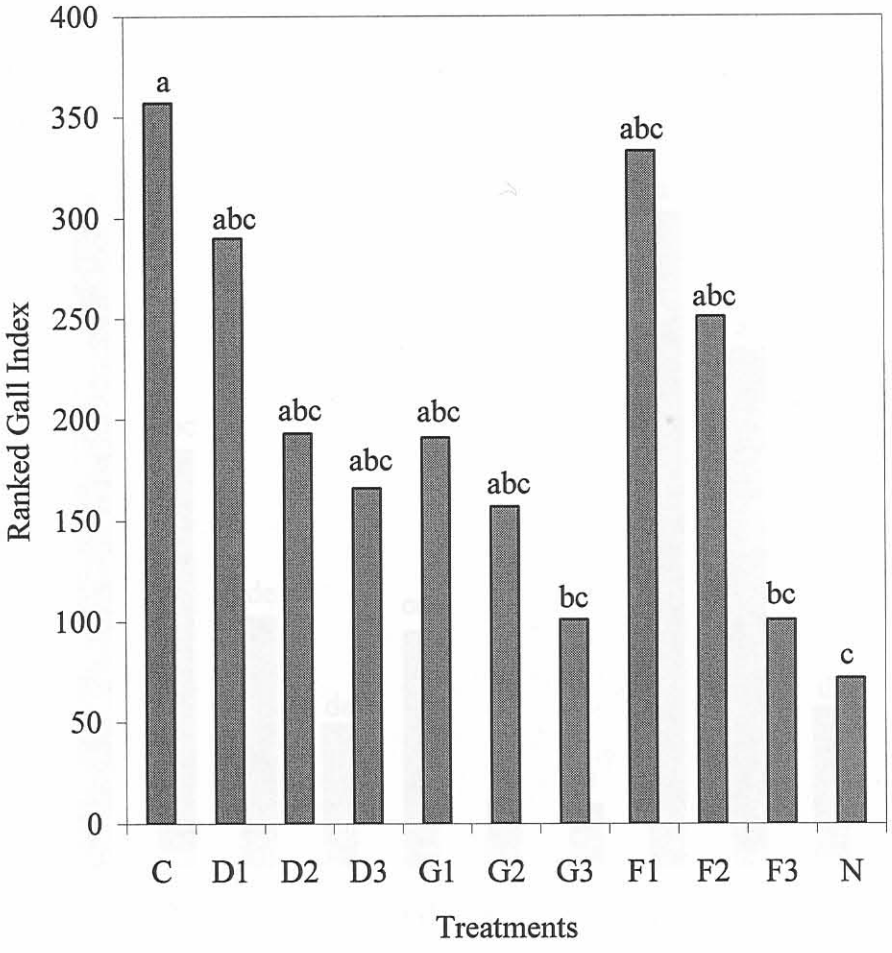

Fig. 4.4: Effect of soil amendment with different *Brassica* species on roots of eight-week old *Vigna subterranea* plants grown in the greenhouse in soil infested with *M. incognita* race 2. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to the Krukal-Wallis test. C = Control, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 = 6 kg/m^2.

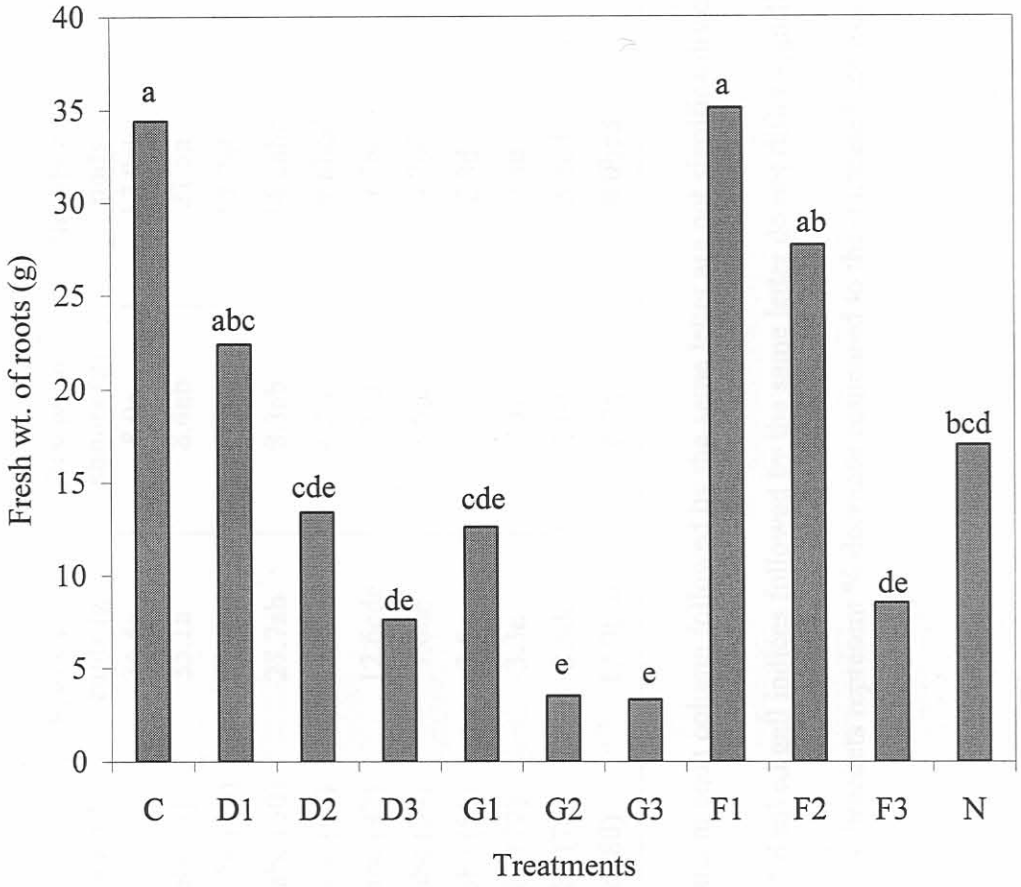

Fig. 4 5: Effect of soil amendment with different *Brassica* species on fresh wt. of roots of eight-week old *Vigna subterranea* plants grown in the greenhouse in soil infested with *M. incognita* race 2. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. C = Control, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 = 6 kg/m^2.

Table 4.3b: Effect of soil amendment with different *Brassica* species. on growth, yield, and galling of *Vigna subterranea* grown for eight weeks in soil infested with *M. incognita* race 2 in the greenhouse.

Treatments	Gall index*	Fresh wt. of roots (g)	Dry wt. of shoots (g)	Number of pods	Dry wt. of pods
Untreated control	357.0a -	34.4a	8.9a	17.0ab	4.6bc
Forage rape (2kg/m^2)	332.5abc (7)	35.1a	8.4ab	21.5a	9.7a
Drumhead (2kg/m^2)	290.0abc (19)	22.4abc	8.0ab	17.7ab	6.1ab
Forage rape (4kg/m^2)	251.0abc (30)	27.7ab	8.3ab	14.2abc	4.3bc
Drumhead (4kg/m^2)	193.0abc (46)	13.4cde	4.2cde	9.8bcd	2.4bc
Glory of enkhuizen (2kg/m^2)	190.5abc (47)	12.6cde	5.3cd	9.7bcd	4.1bc
Drumhead (6kg/m^2)	166.0abc (54)	7.6de	3.6de	4.7cd	1.3c
Glory of enkhuizen (4kg/m^2)	157.0abc (56)	3.5e	2.0e	2.3d	0.5c
Glory of enkhuizen (6kg/m^2)	101.0bc (72)	3.3e	2.1e	0.3d	0.1c
Forage rape (6kg/m^2)	101.0bc (72)	8.5de	3.0de	3.3cd	1.1c
Fenamiphos (2 liter/ha)	72.0c (80)	17.0bcd	6.2bc	8.0bcd	2.3bc

Each value is the mean of 6 replicates. Means in each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. * Ranked gall indices followed by the same letter do not differ significantly at $P \leq 0.05$ according to the Kruskal-Walis test. Figures in brackets represent % decrease compared to the untreated control.

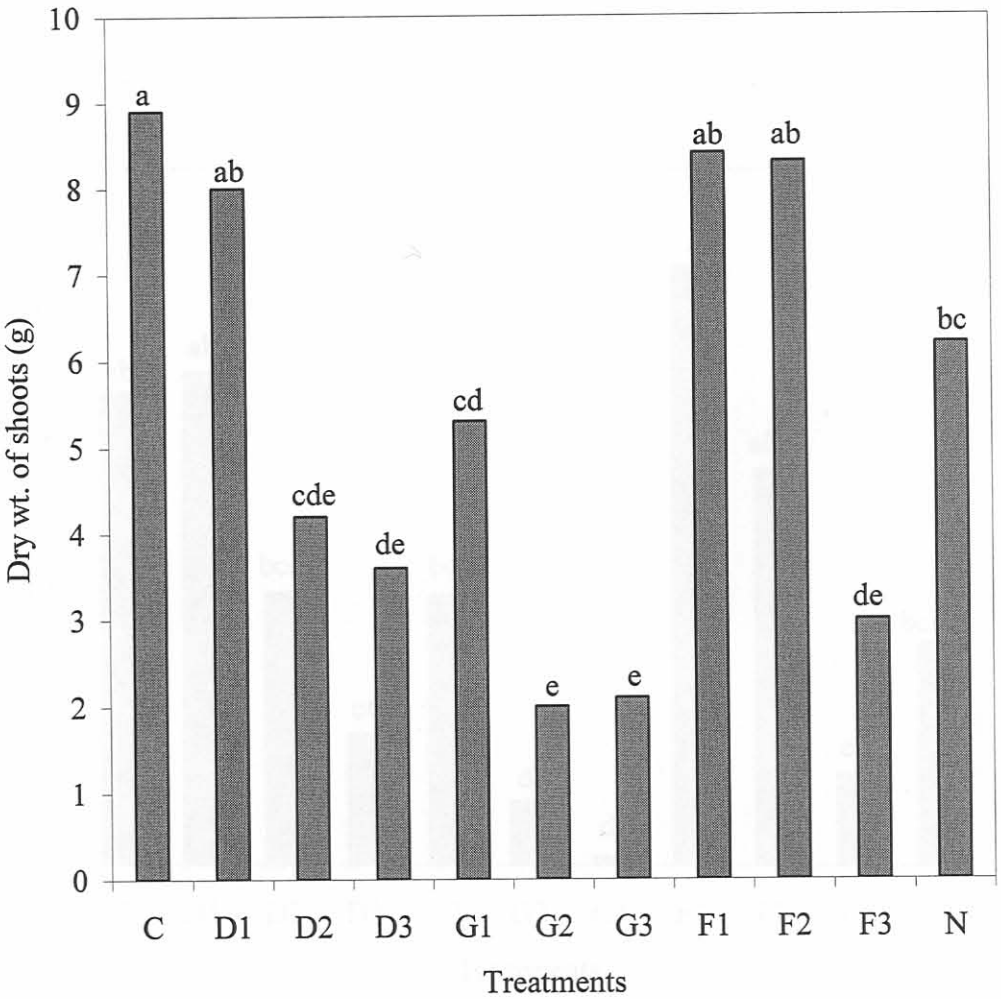

Fig. 4.6: Effect of soil amendment with different *Brassica* species on the dry wt. of shoots of eight-week old *Vigna subterranea* plants grown in the greenhouse in soil infested with *M. incognita* race 2. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. C = Control, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 = 6 kg/m^2.

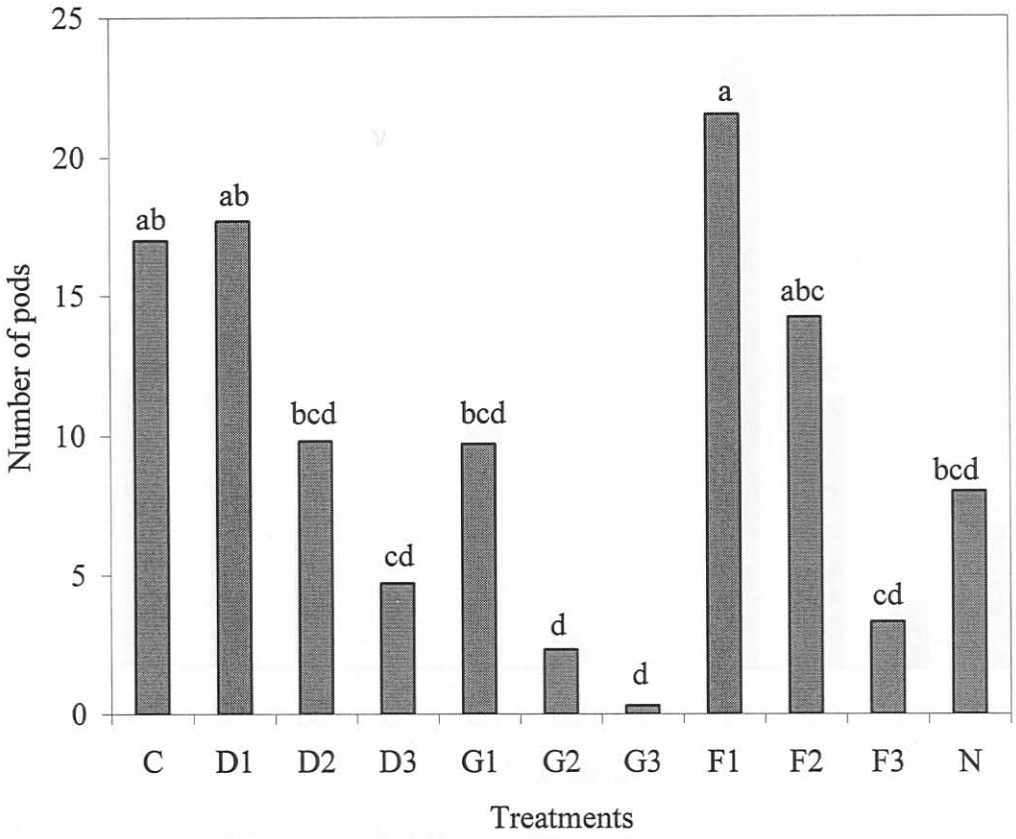

Fig. 4.7: Effect of soil amendment with different *Brassica* species on the number of pods of eight-week old *Vigna subterranea* plants grown in the greenhouse in soil infested with *M. incognita* race 2. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. C = Control, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 = 6 kg/m^2.

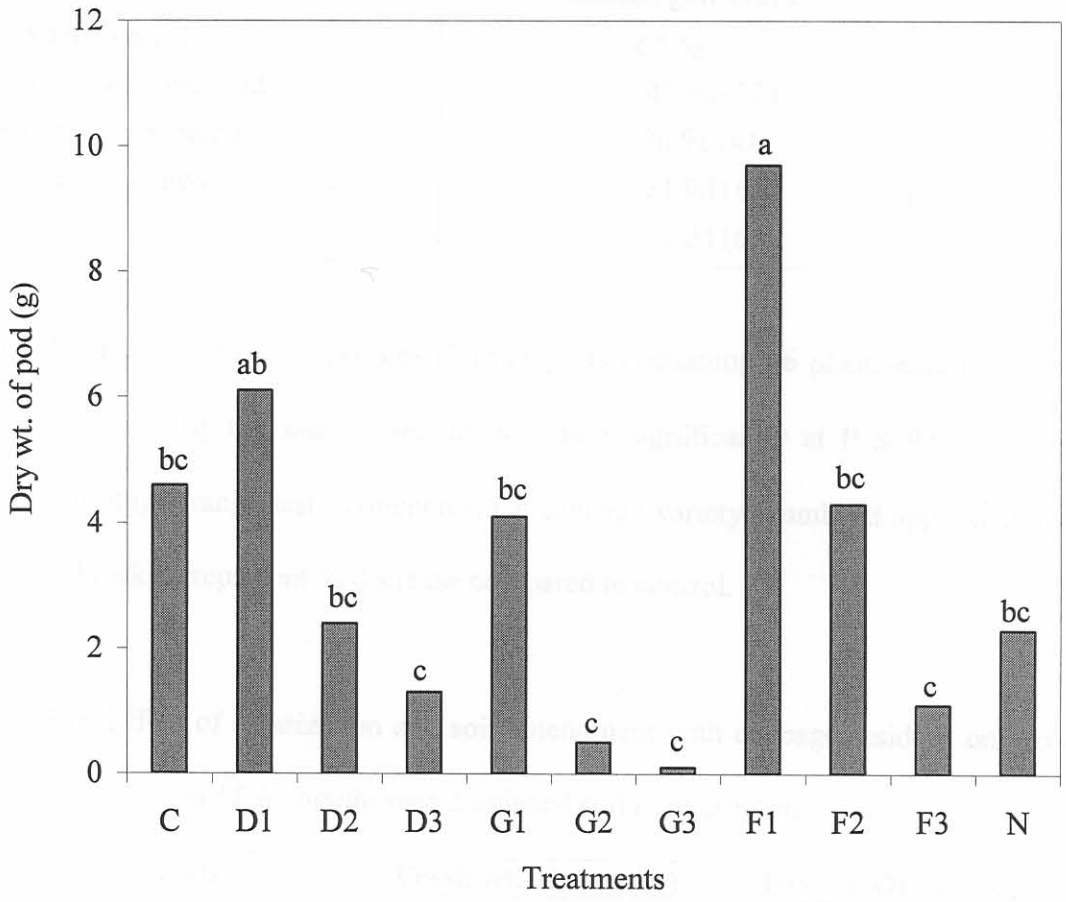

Fig. 4.8: Effect of soil amendment with different *Brassica* species on the dry wt of pods of eight-week old *Vigna subterranea* plants grown in the greenhouse in soil infested with *M. incognita* race 2. Bars followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test. C = C0ntrol, D = Drumhead, G = Glory of Enkhuizen, F = Forage rape, N = Fenamiphos. 1 = 2 kg/m^2, 2 = 4 kg/m^2, 3 = 6 kg/m^2

Table 4.3c: Effect of biofumigation and solarization on galling of *Vigna subterranea* roots and on incidence of *M. incognita* race2 egg masses after eight weeks in microplots.

Treatments	Ranked gall index
Untreated control	62.5a -
Solarized non-amended	48.6b (22)
Unsolarized amended	36.9c (41)
Solarized amended	21.0d (66)
Aldicarb	21.0d (66)

Each value is a mean of 3 replicates (3 microplots containing 16 plants each). Means in a column followed by the same letter do not differ significantly at $P \leq 0.05$ according to Duncan's multiple range test. Amendment = cabbage variety drumhead applied at 4 kg/m^2. Figures in brackets represent % decrease compared to control.

Table 4.3 d: Effect of solarization and soil amendment with cabbage residues on growth of *Vigna subterranea* in *M. incognita* race 2 infested soil in microplots.

Treatments	Fresh wt. of roots (g)	Dry wt. Of shoots (g)
Aldicarb	5.5a (50 %)	2.1a (54 %)
Untreated control	3.5b -	1.4bc -
Solarized non-amended	2.2c (-59 %)	1.1c (-21 %)
Unsolarized amended	2.0cd (-47 %)	1.7ab (26 %)
Solarized amended	1.0d (-71 %)	2.0a (46 %)

Each value is the mean of 3 replicates (3 microplots containing 16 plants each). Means in each column followed by the same do no differ significantly at $P \leq 0.05$ according to Duncan's multiple range test. Amendment = cabbage variety drumhead applied at 4 kg/m^2. Figures in brackets represent % increase compared to control.

Table 4.3e: Soil temperature* (°C) at depths of 15 and 30 cm depths in solarized-amended and unsolarized-amended soil in microplots in the field.

Week	Mean temperature (°C) in solarized-amended soil				Mean temperature (°C) in unsolarized- amended soil				Differences in temperature between solarized and unsolarized soil			
	Maximum		Minimum		Maximum		Minimum		Maximum		Minimum	
Soil Depth	**15**	**30**	**15**	**30**	**15**	**30**	**15**	**30**	**15**	**30**	**15**	**30**
1	30.6	27.5	22.9	24.7	37.5	31.8	26.7	27.3	6.9	4.3	3.8	2.6
2	30.2	27.1	23.2	24.6	36.0	30.9	27.3	27.5	5.8	3.8	4.1	2.9
3	34.6	29.9	24.4	26.1	40.0	33.9	28.4	28.7	5.4	4.0	4.0	2.6
4	31.8	29.1	24.0	26.1	36.7	32.6	28.2	28.7	4.9	3.5	4.2	2.6
Average	31.8	28.4	23.6	25.4	37.6	32.3	27.7	28.1	5.8	3.9	4.0	2.7

*Temperature was measured by means of a 1200 series Grant squirel digital logger.

Table 4.3f: Soil temperature* (°C) 15 and 30 cm depths in solarized non-amended and unsolarized non-amended soil microplots in the field.

Week	Mean temperature (°C) in solarized non-amended soil				Mean temperatuer(°C) in solarized Non-amended soil				Differences in temperature between solarized and unsolarized soil			
	Maximum		Minimum.		Maximum.		Minimum.		Maximum.		Minimum	
Depth	15	30	15	30	15	30	15	30	15	30	15	30
1	29.6	27.0	22.2	23.8	35.7	30.1	24.8	26.0	6.1	3.1	2.6	2.2
2	29.5	26.7	22.5	24.0	34.5	29.4	25.0	26.3	5.0	2.7	2.5	2.3
3	34.0	29.9	23.9	25.4	38.5	32.9	26.3	27.4	4.5	3.0	2.4	2.0
4	31.4	28.9	23.5	25.3	35.8	31.8	26.3	27.9	4.4	2.9	2.8	2.6
Ave.	31.1	28.1	23.0	24.6	36.1	31.1	25.5	26.9	5.0	2.9	2.6	2.3

* Temperature was measured by means of a 1200 series Grant squierel digital data logger.