CHAPTER 1

GENERAL INTRODUCTION

1.1 Bambara groundnut

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is a leguminous crop indigenous to tropical Africa especially West Africa where it is believed to have originated (Johnson, 1968; Kay, 1979). It is an annual herbaceous plant similar to the groundnut (*Arachis hypogaea L.)* in growth habit but botanically related to cowpea (*Vigna unguiculata* (L) Walp.) (Fig.1.1). It forms its pods below the soil surface. The pods are harder and less fibrous than those of the groundnut. Mature pods have a wrinkled surface and usually contain one or more seeds which are harder than those of the groundnut. The crop is adaptable to various climatic conditions and has the ability to produce high yields under optimal conditions and at least some yield under drought stress (Azam-Ali, 1992). Although it generally prefers hot climate, it can tolerate cold conditions but requires three to four frost-free months. It is adapted to a wide range of soils but thrives well on loose sandy, well-drained loam soils with a pH between 5.0 and 6.5 (Johnson, 1968; Kay, 1979).

Coudert (1982) estimated world production of bambara at 330000 tons. About 50 % of this is from West Africa. Yields are generally low because farmers plant bambara groundnut after the main crop and usually when the rainy season is coming to an end because of the believe that it can tolerate conditions which are unsuitable for other crops (Linneman, 1988). In Botswana unreliable source of seed supply in addition to a lack of agronomic information concerning production of bambara groundnut contribute to poor yields (Harris &

Azam-Ali, 1992). However, a survey of small-scale farmers revealed that most farmers prefer bambara groundnut to common groundnut because of its tolerance to erratic rainfall, which makes it difficult to successfully grow groundnuts (Von Rudloff, unpublished report).

Small-scale farmers throughout sub-Saharan Africa cultivate bambara groundnut mainly on a subsistence farming basis. It ranks third in importance after groundnut and cowpea (Rachie & Silvestre, 1977). Farmers favour bambara groundnut for its nutritional value and versatility. Mature seeds are rich in protein and carbohydrates but low in lipids (Brough & Azam-Ali, 1992). Immature kernels are boiled in their green state either shelled or unshelled and provide an early source of nutritious food for the family or they are sold as a snack. Dry seeds are soaked and boiled to prepare various types of dishes.

The commercial value of bambara groundnut remains unexplored though canning of seeds has been reported from Ghana and Zimbabwe (Linneman, 1987). According to Linneman (1988), the crop is the main source of income for small-scale farmers in Nigeria where it attains higher prices than groundnut.

1.2 Root-knot nematodes (*Meloidogyne species*)

Root-knot nematodes are a major problem affecting crop production throughout the world. Yield losses due to root-knot nematodes are estimated at 5 % on worldwide basis (Taylor & Sasser, 1978). These losses occur mainly in small-scale farmer's fields where losses as high as 25 % are reported. Major species of root-knot nematodes such as *M. incognita* (Kofoid & White) Chitwood, *M. javanica* (Treub) Chitwood, and *M. arenarea* (Neal) Chitwood are found within the tropics between 35 °S and 35 °N latitudes and more are common towards the equator while *M. hapla* (Chitwood), is a cool-temperate species. These species account for 95 % of the root-knot nematodes received by the International *Meloidogyne* Project (IMP) from agricultural soils (Sasser and Carter, 1985). The species were identified through the investigations of differences in their host preferences and morphological characteristics such as perineal patterns of females, stylets of females, heads and stylets of males, stylets of second-stage juveniles and tails of males and second-stage juveniles. Cytology and biochemistry were also used (Eisenback, Hirschman & Triantaphyllou, 1980; Eisenback, 1985; Jepson, 1983a & b; Taylor & Sasser, 1978; Triantaphyllou, 1985; Hussey, 1985). Because of the variations in responses of some species to different hosts, the North Carolina Differential Host Test was developed to further distinguish species into host specific races (Sasser & Triantaphyllou, 1977). On this basis, *M. incognita* was found to have four distinct host races and *M. arenarea* two, whereas *M. hapla* and *M. javanica* do not have host races. Although *M. incognita* is the most abundant root-knot nematode in the world, in South Africa it is second to *M. javanica* in distribution and host range (Kleynhans, Van den Berg, Swart, Marais & Buckley, 1996). *M. incognita* race 2 constitutes most of the South African population and has a wide host range while host race 4 is common in tobacco and cotton growing areas and host race 1 was reported only once on banana (Kleynhans et al., 1996).

1.3 Damage caused by *Meloidogyne species*

Root-knot nematode *M. incognita* race 2 attacks almost all cultivated crops in Botswana (Busang, 1983). Hosts include vegetables such as tomato (*Lycopersicon esculentum* Mill.), spinach (*Spinacia oleracea* L.), beetroot (*Beta vulgaris* L.), carrot (*Daucus carota* L.), cabbage (*Brassica oleracea capitata* L.), pepper (*Capsicum frutescens* L.) and pea (*Pisium sativum* L.). An unidentified root-knot nematode species was found on pigweed (*Amaranthus thunbergii* Morq.), prostrate globe amaranth (*Gomphrena celoides* Matt.) and *Pavonia trocumbens* (Department of Agricultural Research, Botswana, unpublished). Serious damage caused by root-knot nematodes was observed on bambara groundnut in Sebele, Botswana (D. Wigglesworth, Grooms Cottage, Scarborough, Beaminister, Dorset, UK). Similar observations were made in the Botswana College of Agriculture fields (Phadima, 1994). Affected plants were stunted and chlorotic, had few or no pods and in severe cases plants died prematurely. Mwindilila (1994) observed root-knot nematodes and *Fusarium oxysporum* Schelcht. emend. Snyd. & Hans on bambara groundnut in Content Farm, Sebele. Root-knot nematodes were also reported on bambara groundnut in the former Rhodesia (Martin, 1959; Johnson, 1968), South Africa (Mc Donald & De Waele, 1989), Nigeria (Ogbuji, 1979) and Malawi (Hillocks, Stokes & Jones,1995). *M. javanica* was the most common species identified from infested fields although *M. incognita* was also encountered in Botswana and Nigeria. Although the disease was reported to be severe in all the areas it was found, no statistical data is available to support these findings.

1.4 Control of *Meloidogyne* species

Very little research has been conducted on pests and diseases of bambara groundnut although indications are that the crop is not free from pests and diseases as previously thought (Karikari, 1971; Linneman, 1990). It is therefore necessary to investigate appropriate control measures that will reduce yield losses reported under small-scale farmer production systems. Although chemical control through use of nematicides has proved to be most effective, nematicides are generally expensive and small-scale farmers cannot afford them. Many nematicides are being removed from the market because of their hazardous effects on the environment. Available alternatives could be non-chemical methods that utilise resources that are easily accessible to the farmer and/or are part of his production practices, including amongst others the use of resistant/tolerant crop varieties, organic soil amendments, solarization and biological control. An integrated control strategy will provide a solution to the escalating pest and disease problem limiting crop production under small-scale farmers' situation.

1.4.1 Resistance/Tolerance

Resistance in plants to parasitic nematodes is defined as an active defence mechanism that inhibits, restricts, retards or alters nematode development (Dalmasso, Castagnone-Serero & Abad, 1992). Resistant varieties suppress reproduction and development of the nematode resulting in lower initial populations and consequently less potential damage for the next crops (Fassuliotis, 1987; Cook & Evans, 1987; Trudgill, 1991). Although initial infection occurs, most resistant cultivars have tolerance to injury and produce reasonable yields (Roberts, 1995). Hence resistance has been used on a number of crops to manage nematodes effectively (Cook & Evans, 1987; Fassuliotis, 1979; Evans & Trudgill, 1978; Trudgill, 1991; Roberts, 1995). With the growing concern about the hazardous effects of nematicides on the environment coupled with their expensiveness and unavailability, resistant varieties have proved to be a good alternative strategy for controlling plant-parasitic nematodes (Dalmasso et al., 1992). Some resistant varieties have an added advantage in that they are easy to use and provide resistant green manure. Unfortunately it has been observed that the efficiency of resistant varieties is limited to a few species or pathotypes and ultimately the nematode may overcome the resistance (Trudgill, 1991).

Tolerance is a general adaptive phenomenon of plants faced with multiple environmental stresses and is therefore not a true mechanism of resistance (Canto-Saenz, 1985; Wallace, 1987; Trudgill, 1991). A tolerant variety is an efficient host of the nematode but it has the ability to endure attack without sustaining severe losses in yield (Evans & Trudgill, 1990). Wallace (1987) attributes this to some environmental conditions that influence tolerance. Although tolerance is a desirable characteristic of the plant, tolerant varieties have the potential to increase nematode population densities to extremely damaging levels (Dalmasso et al., 1992).

The mechanisms involved in resistance are complex and have been investigated by several researchers (Jatala & Russell, 1972; Rich, Keen & Thomason, 1977; Kaplan, Thomason & van Gundy, 1979; Kaplan, & Keen, 1980; Veech, 1981; Giebel, 1982; Trudgill, 1991). Two types of resistance, passive and active resistance were identified as similar to genetically operating mechanisms in plants (Giebel, 1982). Passive resistance is pre-infectional and is conditioned by anatomical, physiological and chemical barriers that may hinder invasion of the plant by the nematode. Mechanisms involved in passive resistance include production of toxins that kill the nematode and a lack of, or inadequacy of substances necessary for development and reproduction of a certain nematode species. For example, α terthienyl contained in *Tagetes* species is toxic to *Meloidogyne* and *Pratylenchus* species (Veech, 1981). Coumestrol from lima beans (*Phaseolus lunatus* L.) inhibits nematode activity in resistant cultivars (Rich et. al., 1977) while resistance of soybean (*Glycine max* L.) can be attributed to the production of glyceolin-resistant soybean roots (Kaplan & Keen, 1980). A lack of hatching factor in certain resistant sweet potato (*Ipomoea batatas* L.) hybrids is associated with the inability of cyst nematode eggs to hatch (Jatala & Russell, 1972). Unlike passive resistance, active resistance is post-infectional and operates in host plants due to contact with parasites (Giebel, 1982). It is based on tissue hypersensitivity to nematode infection due to presence of the parasite.

Very little is known about the mechanisms responsible for tolerance. However, it is believed that host tolerance is related to the physiology of the whole plant, which depends on multiple genes interacting with crop conditions and the age of the plant (Dalmasso et. al., 1992). Spiegel, Cohn & Kafkafi (1982) showed that tomato plants grown in soil with a high nitrate level were tolerant to root-knot nematodes. Similarly, deficiencies in irrigation or in nutritive elements often affect the growth and yield of plants infected by nematodes (Evans & Haydock, 1990). Canto-Saenz & Brodie (1982) reported that plant age at time of inoculation with *M. incognita* did not affect host efficiency of potatoes (*Solanum tuberosum* L.). However, roots of plants inoculated when five and ten days old were significantly reduced.

Very little research has been done on resistance of bambara groundnuts to *Meloidogyne* species. Ogbuji (1979) evaluated seven bambara groundnut cultivars for resistance to *M. incognita* and *M. javanica* in Nigeria and reported that all cultivars were susceptible to both species. Pod production (yield) in infected plants was significantly reduced or in most cases totally absent. Ogbuji (1979) concluded that both resistance and tolerance were lacking in the seven genotypes tested. In a related study in South Africa involving *M. javanica*, Mc Donald & De Waele (1989) reported absence of resistance in all fifteen bambara groundnut genotypes evaluated. Mc Donald & De Waele (1989) noticed a significant difference in yield amongst the genotypes and concluded that there is a possibility that tolerance exists in some bambara groundnut genotypes. Although so far no resistance has been reported on bambara groundnut, cowpea, a near relative of bambara groundnut is reported to be resistant to *M. incognita* (Fassuliotis, 1979; Sirohi & Dasgupta, 1993; Pandey et al., 1995). Thirty cowpea cultivars resistant to *M. incognita* were reported in the United States of America (Fassuliotis, 1979) and five in India (Pandey, Hasan, Bhaskar, Ahmad & Kohli, 1995). Sirohi & Dasgupta (1993) studied mechanisms of resistance in cowpea and concluded that the resistance present involves mRNA synthesis that directs the production of a set of proteins associated with expression of disease resistance. Groundnut, which is similar to bambara groundnut morphologically, is not attacked by *M. incognita* and is therefore resistant to this species (Taylor & Sasser, 1978; Ibrahim, Rezk & Ibrahim, 1991). However, the crop is reported to be highly susceptible to *M. javanica* (Taylor & Sasser, 1978).

1.4.2 Organic amendments

Soil organic amendment is an ancient agricultural practice involving incorporation of animal manure, composts, plant residues and other organic materials into the soil (Stirling, 1991; Bridge, 1996). It is practised by both small-scale and large-scale farmers alike with the aim of improving soil fertility and subsequently plant growth (Stirling, 1991). The practice also improves the physical characteristics of the soil and suppresses soil-borne pests and diseases (Chen, Hoitink, Schimittner & Tuoivinen, 1988; Stirling, 1991). The use of organic amendments to suppress plant-parasitic nematodes has gained a lot of attention recently. Commonly used amendments are mainly bioproducts and wastes from agricultural and other activities (Bridge, 1996). Manure from poultry and cattle has been used as soil amendments and significantly reduced plant parasitic-nematodes on a number of crops (Main & Rodriguez-Kabana, 1982; Sivakumar & Vidhyasekaram, 1990; Chindo & Khan, 1990; Poswal & Akpa, 1991; Gonzalez & Canto-Saenz, 1993; Kaplan & Noe, 1993; Gamliel & Stapleton, 1993a & b; Riegel, Fernandez & Noe, 1996). Addition of chicken litter to the soil reduced *M. arenarea* population on squash (*Cucurbita pepo L.*) significantly and subsequently increased growth and yield (Rodriguez-Kabana, 1982). Control was directly proportional to the amount of litter added within the range of 0-5 % w/w litter to dry soil. Chindo & Khan (1990) reported a remarkable reduction of *M. incognita* population on tomato with a concomitant increase in growth and yield. The population, however, increased again at harvest in treatments that received less than 4 ton/ha. Chindo & Khan (1990) attributed the fact that there was no increase in *M. incognita* population in treatments with 4 and 8 ton/ha to the prolonged residual effect at these dosages that effectively controlled the nematode throughout the season. An observed decrease in population density and increase in growth and yield could be ascribed to a number of factors such as: increased nutrient availability to the plant, improvement in soil physical condition that enabled plants to efficiently utilise nutrients consequently minimising nematode damage, changes in biotic and abiotic environment of the plant that ultimately altered the host-parasite relationships, and release of some toxic substances during decomposition of poultry manure (Chindo & Khan, 1990). This confirms previous findings by other researchers (Wilkinson, 1976; Main & Rodriguez-Kabana, 1982). Chindo & Khan (1990) recommended 4 ton/ha as a compromise level of poultry manure for both nematode and plant based on the fact that there was no significant difference in yield between plants amended with 4 ton/ha versus 8 ton/ha. Plants amended with 8 ton/ha tended to grow more vegetatively and flowered late, which could be contrary to what the farmer wanted. Riegel et al., (1996) in a study investigating the effects of chicken litter on *M. incognita* in cotton (*Gossypium hirsutum* L.) over a two-year period, recorded lower population density at the end of the season in litter-amended plots than in control plots. Plant growth and yield were enhanced by addition of litter and was attributed to high quantities of nutrients contained in chicken litter. Riegel et al. (1996) observed an increase in microbe densities in litter amended treatments than non-amended treatments. There was a rapid increase in bacterial numbers that lasted throughout the growing season after addition of the litter. *M. incognita* numbers were consequently lower in these plots at midseason and this, according to Riegel et al. (1996), could be the result of ammoniacal nitrogen released during decomposition of litter that decreased nematode numbers while other factors increased bacterial densities. Main & Rodriguez-Kabana (1982) concluded that addition of litter into the soil might have introduced new bacteria thus providing a source of food for existing and incoming organisms, hence stimulating the bacterial population. Riegel et al. (1996) isolated several bacteria and funji from litter and litter-amended soil, viz. *Arthobacter, Bacillus, Pseudomonas, Acremonium, Aspergillus, Eurotium, Paecilomyces, Petriella and Scopulariopsis.*

The effect of using cattle manure is not as widely researched as the use of poultry manure. Poswal & Akpa (1991) reported good control of *M. incognita* with cow dung in Nigeria.

M. incognita population on *Coleus forskohli* (Wild.) Briq. (Labiate) was effectively controlled with a combination of farmyard manure and *Paecilomyces lilacinus* (Thom) Samson (Sivakumar & Vidhyasekaram, 1990).

The mode of action of organic amendments is complex and involves several mechanisms (Stirling, 1991). These mechanisms include improvement of soil structure and fertility, release of nematoxic compounds and stimulation of predators and antagonistic microbes. A decrease in *M. incognita* population and an increase in tomato yield in soil amended with poultry manure was attributed to factors such as increased nutrient availability to the plant, improvement in soil physical condition, changes in biotic and abiotic environment of the plant, and release of nematoxic substances during decomposition of manure (Chindo & Khan, 1990). Riegel et al. (1996) suggested that the observed reduction in *M. incognita* population at midseason could have been due to increased bacterial numbers resulting from the addition of chicken litter. According to Riegel et al. (1996), chicken litter could have stimulated microbial activity and resulted in increased bacterial numbers that lasted throughout the growing season. The ammoniacal nitrogen released during decomposition could also have contributed to the low *M. incognita* population at midseason. The ammoniacal nitrogen decreased nematode numbers while other factors increased bacterial densities. Main & Rodriguez-Kabana (1982) suggested that addition of litter to soil might have introduced new bacteria thus providing a source of food for existing and incoming organisms, hence stimulating the bacterial population. Chicken litter contains a wide range of bacteria and fungi, some of which are toxic/antagonistic to nematodes and other microorganisms (Lovett, 1972; Jatala, 1986; Stirling, 1991; Siddiqui & Husain, 1991; Riegel, et al.,1996). Lovett (1972) isolated toxigenic fungi such as *Aspergillus*, *Penicillium*, *Fusarium* and *Scopulariopsis* from litter and feeds. Riegel et al. (1996) isolated fungal and bacterial genera, which include *Acremonium*, *Aspergillus*, *Eurotium*, *Paecilomyce*s, *Petriella*, *Scopulariopsis*, *Arthrobacter*, *Bacillus* and *Pseudomonas* from litter, and litter-amended soil. Some of these micro-organisms are reported to be antagonistic to nematodes (Jatala, 1986; Stirling, 1991, & Siddiqui and Husain, 1991).

1.4.3 Biofumigation

Biofumigation is the process of amending soil with organic matter that release toxic gases which reduce or eliminate soil-borne pests and pathogens. Organic matter from cruciferous crops is of interest for use in biofumigation since these crops are known to contain different types and concentrations of sulfur-containing glucosinolates in their tissues (Sang, Minchinton, Johnstone & Truscott, 1984). These glucosinolates break down upon decomposition to release volatiles such as allylisothiocyanate (AITC); methylisothiocyanates (MITC); butylisothiocyanates (BITC); phenylisothiocyanates (PITC); volatile aldehydes and sulfides (Lewis & Papavizas, 1971). Of these, MITC and AITC are the most volatile with the highest vapour pressure and have well-documented biocidal activity (Lewis & Papavizas, 1971). The ability of some B*rassica* species to release volatile biocidal compounds suggests that incorporation of green tissue of these plants, as "green manure" could be useful for the control of a wide range of soil-borne pathogens. MITC is an active ingredient of metham sodium, which is widely used as a soil fumigant against many soil-borne pathogens (Gamliel & Stapleton, 1997). Allylisothiocyanates were found in leaf extracts of various *Brassica* species and were effective in suppressing several fungal pathogens (Mayton, Olivier, Vaugh

& Loria, 1996). However, there was variability in the suppressive activity of volatile biocidal compounds and AITC concentration within and across *Brassica* species tested. Mayton et al. (1996) suggested that *Brassica* species with high concentrations of AITC might provide greater control of soil-borne pathogens than species with little volatile activity. For example, hemp (*B. juncea* L.) contained the highest concentration of AITC amongst *Brassica* species included in their study, and had the highest degree of suppressive activity. Mojtahedi, Santo, Wilson & Hang, (1993) reported that when green tissue of rapeseed (*B. napus* cv. Jupiter) was used as a soil amendment, it effectively reduced *M. chitwoodi* population densities at the zone of incorporation. The amendment provided protection from the nematode for up to six weeks. This contradicts earlier findings by Brown, Morra, McCaffrey, Auld & Williams (1991) that green materials releasing volatile AITC is unlikely to be effective in soil after four weeks. Mojtahedi et al. (1993) observed that the concentration of glucosinolates increased with the age of the plant. Two-month old rapeseed plants were more effective in controlling *M. chitwoodi* population (Mojtahedi, Santo, Hang & Wilson, 1991). Johnson, Golden, Auld & Summer (1992) reported that six-month old plants were less effective. The effectiveness of green manure amendment from rapeseed cv. Jupiter increased with increase in the dosage added to the soil. According to Mojtahedi et al. (1993), second-stage juveniles were more sensitive than eggs within egg masses. Most eggs did not yield infective juveniles when rapeseed cv. Jupiter was applied at 49 mg/g soil. The second-stage juvenile population density declined sharply with no nematode survival at 39 mg/g soil. Rapeseed was only effective in the amended zone (top 5 cm). McLeod , Somers & Gendy (1995) reported that rapeseed varieties Rangi, Humus and Arran reduced root-knot and citrus nematode population densities while non-*Brassica* crops included in the study failed.

McLeod & Da Silva (1994) observed that rapeseed var. Humus applied at 20 and 40 g/550 g soil was as effective as 8 mg of fenamiphos nematicide treatment.

Although biofumigation has potential as an alternative control to nematicides, it is likely to have some disadvantages such as the release of phytotoxic compounds and additional time before planting for amendment decomposition.

1.4.4 Solarization

Soil solarization is a non-chemical method of disease control accomplished by sealing the soil surface with a clear plastic tarpulin to trap solar radiation and accumulate heat (Chen & Katan, 1980; Chen et al., 1988; Pullman, De Vay & Garber, 1981 and Gamliel & Stapleton, 1997). In order for soil solarization to be more effective, it must be carried out during the hottest season of the year and the plastic tarpulins must be kept tight against the soil surface. The soil must be kept moist during the solarization period (Heald & Robinson, 1987). Under ideal conditions, soil temperatures can be raised to levels that are lethal to many soil-borne pests and pathogens (Gamliel & Stapleton, 1997). Solarization is reported to have controlled a wide range of pathogens including plant-parasitic nematodes such as *Meloidogyne, Heterodera, Pratylenchus and Paratylenchus* (Gamliel & Stapleton, 1997; Stapleton & De Vay, 1983). According to Stapleton & De Vay (1983), population densities of total plant-parasitic nematodes were reduced by 61-96 % compared with the control. In order to attain pathogen control down to 45-60 cm depth, solarization is usually conducted for a period of four weeks or longer (Gamliel & Stapleton, 1997). Significant nematode control was achieved at various depths under ideal soil solarization conditions.

Temperatures in excess of 50 °C were measured in the top few centimetres of the soil under these conditions (Katan, 1981, Stapleton & De Vay, 1983 and Heald & Robinson, 1987). Control of phytoparasitic nematodes was satisfactory near the soil surface and population density reduction decreased with increasing soil depths. Gamliel & Stapleton (1997) reported low soil temperatures in field soil during soil solarization compared with artificial heating methods. They also suggested that the effects on living and non-living soil components are likely to be less drastic especially for high temperature tolerant nematode species such as *Meloidogyne incognita.* Stapleton & De Vay (1983) concluded that the degree of reduction of phytoparasitic nematodes depend on several factors such as the degree of solar heating, crop and cropping history, nematode distribution in the soil and soil depth. Stapleton & De Vay (1983) suggested that a significant part of the nematicidal effect of soil solarization may be directly or indirectly due to maintaining a high soil moisture content for several weeks, changes in soil gas composition and/or accumulation of volatile compounds. Although there are changes in soil gas composition as well as accumulation of volatile compounds, no negative side effects such as phytotoxicity have been reported with soil solarization (Gamliel & Stapleton, 1997).

Soil solarization has advantages and disadvantages. The main disadvantage of soil solarization is the long duration of the treatment, its dependency on warm climate and the fact that it does not control all pathogens (Gamliel & Stapleton, 1995). Stapleton & De Vay (1983) reported partial control of *M. incognita* in solarized soil. It is therefore necessary to improve the efficacy of the technique to enable it to be used under a wider range of conditions and to shorten the duration of the treatment. There are several reports of successful control when solarization was used in combination with other methods such as soil organic amendment, biofumigation and chemical control (Ramirez-Villapudua & Munnecke, 1987, 1988; Ristaino, Perry & Lumsden, 1991; Gamliel & Stapleton, 1993a & b, 1995).

1.4.5 Integrated pest management (IPM)

Integrated pest management (IPM) has been described as a system of management which considers the interactions amongst the whole range of organisms, whether beneficial, neutral or pests, with the long-term objective of increasing the level of pest suppression by means of natural as opposed to chemical means (Tait, 1987). According to Tait (1987), IPM is a holistic approach in which pest control by natural factors is the controlling influence on decision making. IPM seeks to reduce the use of pesticides, and to determine better ways of maintaining their effectiveness as pest control agents so as to alleviate environmental and health concerns. Hence, most IPM systems will involve minimum use of pesticides. It has also been stated that the purpose of IPM is to make crop production more efficient and to protect the environment from the misuse of pesticides (Hall, 1995). According to Hall (1995), this could be achieved by utilising all relevant pest control technologies in an integrated program. Hall (1995) suggested that such integration could consist of any of the following approaches:

1. Monitoring pest population or weather conditions and applying pesticides as required to control pests
2. Integration of many practices to control one pest or one kind of pest
3. Integration of all farming practices to provide protection against all pests within a crop, or on a farm, or over a wider geographic area.

The increase in food requirements for the increasing world population has made it necessary to investigate suitable pest control methods that will minimise damage to crops without compromising the safety of humans, livestock and the environment. IPM therefore holds promise as an alternative to hazardous chemicals. However, the implementation of IPM requires several kinds of integration in order for it to be successful. These include the integration of pesticides with other pest control techniques such as genetic resistance in plants, cultural practices, biological control, and biotechnology. It is also essential that technologies for the control of one group of pests must be integrated with those for the other pests (Hall, 1995). Most researchers involved with IPM have implemented these requirements (Stapleton & DeVay, 1983, Rammirez-Villapudua, 1987, 1988, Duncan, 1991).

1.5 Objectives

The study was conducted to evaluate different nematode control strategies with the aim of developing an IPM model for the control of *M. incognita* on bambara groundnut. Several experiments were conducted in the greenhouse and microplots to:

- Identify bambara groundnut genotypes with resistance/tolerance to *Meloidogyne incognita* race 2
- Determine the effectiveness of soil organic amendment as a control measure for *M. incognita* race 2 on bambara groundnut
- Determine the effectiveness of biofumigation on *M. incognita* race 2 on bambara groundnut
- Determine the effectiveness of biofumigation combined with soil solarization on root-knot nematodes on bambara groundnut.

1.6 REFERENCES

Azam-Ali, S. N. 1992. Evaluating the potential of bambara (*Vigna subterranea*) as a food crop for semi-arid Africa. Proceedings of the third SADC regional conference on land and water management, pp. 203-217.

Bridge, J. 1996. Nematode management in sustainable agriculture. *Annual Review of Phytopathology* 34: 201-225.

Brough, S. H. & Azam-Ali, S. N. 1992. The effect of soil moisture on the proximate composition of bambara groundnut (*Vigna subterranea* (L.) Verdc.). *Journal of Science Food and Agriculture* 60: 197-203.

Brown, P. A., Morra, M. J., McCaffrey, J. P., Auld D. I. & Williams, L. 1991. Allelochemicals produced during glucosinolate degradation in soil. *Journal of Chemical Ecology* 17 (10): 2021-2035.

Busang, B. C., 1983. Studies on a Botswana isolate of *Meloidogyne incognita*, Msc. Thesis South Dakota State University 1983, 71pp.

Canto-Saenz, M. 1985. The nature of resistance to *Meloidogyne incognita*. Pp. 225-217 In: An Advance Treatise on *Meloidogyne* Vol.1: Biology and Control. J. N. Sasser and C. C. Carter (eds). North Carolina State University Graphics, Raleigh.

Canto-Saenz, M. & Brodie, B. B. 1982. Factors affecting host efficiency of potatoes to *Meloidogyne incognita*. *Journal of Nematology* 14 (4): 433-434.

Chen, W., Hoitink, H. A. J., Schmittnner, F. & Tuoivinen, O. H. 1988. The role of microbial activity in suppression of damping-off caused by *Pythium ultimum*. *Phytopathology* 78: 314-322.

Chen, Y. & Katan, J. 1980. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties. *Soil Science* 130: 271-277.

Chindo, P. S. & Khan, F. A. 1990. Control of root-knot nematodes, *Meloidogyne* spp. on tomato, *Lycopersicon esculentum* Mill. with poultry manure. *Tropical Pest Management* 36 (4): 332-335.

Cook, R. & Evans, K. 1987. Resistance and tolerance. Pp. 179-231 In: Principles and Practice of Nematode Control in Crops. R. H. Brown and B. R. Kerry (eds). Academic Press, Sydney.

Coudert, M. J. 1982. Cowpea and bambara groundnut: prospects for regional trade development in West Africa. FAO microfische XF8332635. International Trade Centre YNCTAD/GATT, Geneva, 125 pp.

Dalmasso, A., Castagnone-Serero, P. & Abad, P. 1992. Seminar: Tolerance and resistance of plants to nematodes - knowledge, needs and prospects. *Nematologica* 38: 466-472.

Duncan, L. H. 1991. Current options for nematode management. *Annual Review of Phytopathology* 29: 469-90.

Eisenback, J. D. 1985. Diagnostic characters useful in the identification of the four most common species of root-knot nematodes (*Meloidogyne)* species. Pp. 95-112 In: An Advance Treatise on *Meloidogyne* Vol. 1: Biology and Control. J. N. Sasser and C. C. Carter (eds), North Carolina State University Graphics, Raleigh.

Eisenback, J. D., H. Hirschmann, H. & Triantaphyllou, A. C. 1980. Morphological comparison of *Meloidogyne* female head structures, perineal patterns and stylets. *Journal of Nematology* 12: 300-313.

Evans, K. & Haydock, P. P. J. 1990. A review of tolerance by potato plants of cyst nematode attack, with consideration of what factors may confer tolerance and methods of assaying and improving it in crops. *Annals of Applied Biology* 117: 703-740.

Evans, K. & Trudgill, D. L. 1978. Nematode pests of potatoes. Pp. 460-469 In: The potato Crop. Chapman and Hall, London.

Fassuliotis, G. 1987. Genetic basis of plant resistance to nematodes. Pp. 364-371 In: Vistas on Nematology: A Commemoration of the Twenty-fifth Anniversary of the Society of Nematologists. J. A., Veech and D. W. Dickson (eds). North Carolina State University Graphics, Raleigh.

Fassuliotis, G. 1979. Plant breeding for root knot resistance. Pp. 425-453 In: Root-knot Nematodes (*Meloidogyne* species): Systematics, Biology and Control. F. Lamberti and C. E. Taylor (eds). Academic Press, London.

Gamliel, A. & Stapleton, J. J. 1997. Improvement of soil solarization with volatile compounds generated from organic amendments. *Phytoparasitica* 25 (Suppl.): 31S-38S.

Gamliel, A. & Stapleton, J. J. 1995. Improved soil disinfestation by biotic volatile compounds generated from solarized, organic-amended soil. *Acta Horticulturae* 382: 129-137.

Gamliel, A. & Stapleton, J. J. 1993a. Effect of chicken compost or ammonium phosphate and solarization on pathogen control, rhizosphere microorganisms, and lettuce growth. *Plant Disease* 77 (9): 886-891.

Gamliel, A. & Stapleton, J. J. 1993b. Characterization of volatile compounds evolved from solarized soil amended with cabbage residues. *Phytopathology* 83 (9): 899-905.

Giebel, J. 1982. Mechanism of resistance to plant nematodes. *Annual Review of Phytopathology* 20: 257-279.

Gonzalez, A., & Canto-Saenz, M. 1993. Comparison of five organic amendments for the control of *Globodera pallida* in microplots in Peru. *Nematropica* 23: 133-139.

Hall, R. 1995. Challenges and prospects of integrated pest management. Pp 1-19 In: Novel Approaches to Integrated Pest Management. Reuveni, R. (eds). CRS Press Inc., Florida.

Harris, D. & Azam-Ali, S. N. 1983. Implications of daylength sensitivity in bambara groundnut (*Vigna subterranea*) for production in Botswana. *Journal of Agricultural Science* 120: 75-78.

Heald, C. H. & Robinson, A. F. 1987. Effects of soil solarization on *Rotylenchulus reniformis* in the lower Rio Grande Valley of Texas. *Journal of Nematology* 19 (1): 93-103.

Hillocks, R. J., Stokes, S. & Jones, M. 1995. Reproduction of *Meloidogyne javanica* on legume crops and some weed species associated with their cultivation in Malawi. *Nematologica* 41: 505-515.

Hussey, R. S. 1985. Biochemistry as a tool in identification and its probable usefulness in understanding the nature of parasitism. Pp. 127-133 In: An Advance Treatise on

Meloidogyne Vol. 1: Biology & Control. J. N. Sasser and C. C. Carter (eds). North Carolina State University Graphics, Raleigh.

Ibrahim, I. K. A., Rezk, M. A. & Ibrahim, A. A. M. 1991. Reaction of some gramineous and leguminous plant cultivars to *Meloidogyne incognita* and *M. javanica*. *Nematologia Mediterranea* Vol. 19 (2): 331-333.

Jatala, P. 1986. Biological control of plant parasitic nematodes. *Annual Review of Phytopathology* 24: 453-458.

Jatala, P. & Russell, C. C. 1972. Nature of sweet potato resistance to *Meloidogyne incognita* and the effects of temperature on parasitism. *Journal of Nematology* 4: 1-7.

Jepson, S. B. 1983a. The use of second stages juvenile tails as an aid in the identification of *Meloidogyne species*. *Nematologica* 29: 11-25.

Jepson, S. B. 1983b. Identification of *Meloidogyne* species: Comparison of stylets of females. *Nematologica* 29: 132-143.

Johnson, A. W., Golden, A. M., Auld, D. L. & Summer, D. R. 1992. Effects of rapeseed and vetch as green manure crops and fallow on nematodes and soil-borne pathogens. *Journal of Nematology* 24 (1): 117-126.

Johnson, D. T. 1968. The bambara groundnut: A review. *Rhodesia Agricultural Journal* 105 (65) 1: 1-4.

Kaplan, M. & Noe, J. P. 1993. Effects of chicken-excrement amendments on *Meloidogyne arenaria*. *Journal of Nematology* 25 (1): 71-77.

Kaplan, D. T. & Keen, N. T. 1980. Association of glyceolin with the incompatible response of soybean roots to *Meloidogyne incognita*. *Physiological Plant Pathology* 16: 309-318.

Kaplan, D. T., Thomason, I. J. & van Gundy, S. D. 1979. Histological study of the compatible and incompatible reaction of soybeans and *Meloidogyne incognita*. *Journal of Nematology* 1: 338-334.

Karikari, S. K. 1971. Economic importance of bambara groundnut. *World Crops* 23 (4): 195-196.

Katan, J. 1981. Solar heating (solarization) of soils for control of soilborne pests. *Annual Review of Phytopathology* 19: 211-236.

Kay, D. E. 1979. Food Legumes. Pp. 17-25 In: Crop and Product Digest No. 3. Tropical Products Institute, London.

Kleynhans, K. P. N., Van den Berg, E., Swart, A., Marais, M. & Buckley, N. H. 1996. Plant nematodes in South Africa. Plant Protection Research Institute, Pretoria, South Africa. 165 pp.

Lewis, J. A. & Papavizas, G. C. 1971. Effects of sulfur-containing volatile compounds and vapors from cabbage decomposition on *Aphanomyces euteiches*. *Phytopathology* 61: 208-214.

Linneman, A. R. 1990. Cultivation of bambara groundnut (*Vigna subterranea*) in Western Province, Zambia. Report of a field study. *Tropical Crops Communication* No. 6. Wageningen Agricultural University.

Linneman, A. R. 1988. Cultivation of bambara groundnut (*Vigna subterranea*) in Northern Nigeria. Report of a field study. *Tropical Crops Communication* No. 15. Wageningen Agricultural University.

Linneman, A. R. 1987. Bambara groundnut (*Vigna subterranea* (L.) Verdc.) – a review. *Tropical Agriculture* 12 (7): 9-25.

Main, I. H & Rodriguez-Kabana, R. 1982. Soil amendment with oil cakes and chicken litter for control of *Meloidogyne arenarea*. *Nematropica* 12 (2): 205-220.

Martin, G. C. 1959. Plants attacked by root-knot nematodes in the Federation of Rhodesia and Nyasaland. *Rhodesia Agricultural Journal* 56: 62-175.

Mayton, H. S., Olivier, C., Vaughn, S. F. & Loria, R. 1996. Correlation of fungal activity of *Brassica* species with allyl isothiocyanate production in macerated leaf tissue. *Phytopathology* 86 (3): 267-271.

Mc Ddonald, A. H. & De Waele, D. 1989. Effect of *Meloidogyne javanica* on bambara groundnut (*Voandezeia subterranean*) in South Africa. *Phytophylactica* 21: 429-431.

McLeod, R., Somers, T. & Gendy, M. 1995. Cover crops and nematodes – some field observations. *The Australian Grapegrower and Winemaker*: 53-57

McLeod, R. 1994. Cover crops and inter-row nematode infestation in vineyards. *The Australian Grapegrower and Winemaker*: 45-48.

McLeod, R. & Da Silva, E. 1994. Cover crops and inter-row nematode infestation in vineyards. *The Australian Grapegrower and Winemaker*: 121-124.

McLeod, R. & Warren, M. 1993. Effects of cover crops on inter-row nematode infestation. 1. Relative increase of root-knot nematodes *Meloidogyne incognita* and *M. javanica* on legume, cereal and *Brassica* crops. *The Australian Grapegrower and Winemaker*: 28-30.

Mojtahedi, H., Santo, G. S., Wilson, J. H. & Hang, A. N. 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. *Plant Disease* 77 (1): 42-46.

Mojtahedi, H., Santo, G. S., Hang, A. N. & Wilson, J. H. 1991. Suppression of root-knot nematode populations with selected rapeseed cultivars as green manure. *Journal of Nematology* 23 (2): 170-171.

Mwindilila, C. N. 1994. Report of disease diagnosis at Content Farm, Sebele. Crop Science Department, Botswana College of Agriculture, Gaborone.

Ogbuji, R. O. 1979. Effects of two *Meloidogyne* species on growth and reproduction of bambara groundnut (*Voandezeia subterranea*) in Nigeria. *Tropenlandwirt* 80: 47-51.

Pandey, K. C., Hasan, N., Bhaskar, R. B., Ahmad, S. T. & Kohli, K. S. 1995. Genetic evaluation of cowpea (*Vigna unguiculata* (L).Wallp.) lines for multiple pest resistance. *Indian Journal of Genetics and Plant Breeding* 55 (2): 198-203.

Phadima, A. 1994. Screening of bambara (*Vigna subterranea*) landraces for susceptibility to root-knot nematodes (*Meloidogyne* species), Diploma Project Report, Botswana College of Agriculture, Gaborone.

Poswal, M.A.T. & Akpa, A. 1991. Current Trends in the use of traditional and organic methods for the control of crop pests and diseases in Nigeria. *Tropical Pest Management* 37 (4): 329-333.

Pullman, G. S., De Vay J. E. & Garber, R. H. 1981. Soil solarization and thermal death: A logarithmic relationship between time and temperature for four soil-borne plant pathogens. *Phytopathology* 71 (9): 959-964.

Rachie, K. O. & Silvestre, P. 1977. Grain Legumes. Pp. 41-74 In: Food Crops of the Lowland Tropics. C. L. A. Leakey and J. B. Wills eds. Oxford University Press, London.

Ramirez-Villapudua, J. & Munnecke, D. E. 1988. Effect of solar heating and soil amendments of cruciferous residues on *Fusarium oxysporum f.sp. conglutinans* and other microorganisms. *Phytopathology* 78: 289-295.

Ramirez-Villapudua, J. & Munnecke, D. E. 1987. Control of cabbage yellows (*Fusarium oxysporum f. sp. conglutinans)* by solar heating of soils amended with dry cabbage residues. *Plant Disease* 71 (3): 217-221.

Rich, J. R., Keen, N. T. & Thomason, J. J. 1977. Association of coumestans with hypersensitivity of Lima bean roots to *Pratylenchus scibneri*. *Physiological Plant Pathology* 10: 105-116.

Riegel, C., Fernandez, F. A. & Noe, J. P. 1996. *Meloidogyne incognita* infested soil amended with chicken litter. *Journal of Nematology* 28 (3): 369-378.

Ristaino, J. B., Perry, K. B. & Lumsden, R. D. 1991. Effect of solarization and *Gliocladium virens* on sclerotia of *Sclerotium rolfsii* soil microbiota, and the incidence of southern blight of tomato. *Phytopathology* 81: 17-1124.

Roberts, P. A. 1995. Conceptual and practical aspects of variability in root-knot nematodes related to host plant resistance. *Annual Review of Phytopathology* 33: 99-221.

Sang, J. P., Minchinton, I. R., Johnstone O. K. & Truscott, R. J. W. 1984. Glucosinolate profiles in the seed, root and leaf tissue of cabbage, mustard, radish and swede. *Canadian Journal of Plant Science* 64: 77-93.

Sasser, J. N. & Carter, C. C. 1985. Overview of the International *Meloidogyne* Project 1975-1984. Pp. 19-24 In: An Advance Treatise on Meloidogyne Vol.1: Biology and Control. J. N. Sasser and C. C. Carter (eds). North Carolina State University Graphics, Raleigh.

Sasser, J. N. & Triantaphyllou, A. C. 1977. Identification of *Meloidogyne* species and races. *Journal of Nematology* 9 (abs): 2283.

Siddiqui, Z. A. & Husain, S. I. 1991. Studies on the biological control of root-knot nematode. *Current Nematology* 2 (1): 5-6.

Sirohi, A. & Dasgupta, D. R. 1993. Mechanisms of resistance in cowpea to the root-knot nematode *Meloidogyne incognita* race 1 and 2: De novo synthesis of phenylalanine ammonialyase (E. C. 4.3.1.5). *Indian Journal of Nematology* 23 (1): 42-52.

Sivakumar, C. V. & Vindyasekaram, P. 1990. Control of *Meloidogyne incognita* on *Coleus forskohli* with *Paecilomyces lilacinus* and farmyard manure amended and non-amended soil. *Journal of Biological Control* 4 (1): 68-69.

Spiegel, Y., Cohn, E. & Kafkafi, U. 1982. The influence of ammonium and nitrate nutrition of tomato plants on parasitism by the root-knot nematode. *Phytoparasitica* 10: 33-40.

Stapleton, J. J. & De Vay, J. E. 1983. Response of phytoparasitic and free-living nematodes to soil solarization and 1,3-Dichloropropene in California. *Phytopathology* 73 (10): 1429-1436.

Stirling, G. R. 1991. Biological Control of Plant Parasitic Nematodes: Progress, Problems and Prospects. Commonwealth Bureaux International, Wallingford, Oxon. 282pp.

Tait, E. T. 1987. Planning an integrated pest management systems. Pp. 189-207 In: Integrated Pest Management. A. J. Burn, T. H. Coaker and P. C. Jepson (eds). Academic Press, London.

Taylor, A. L. & Sasser, J. N. 1978. Biology, identification and control of root-knot nematodes (*Meloidogyne* species). North Carolina State University Graphics, Raleigh, 111pp.

Triantaphyllou, A. C. 1985. Identification of major *Meloidogyne* species employing enzyme phenotypes as differentiating characters. Pp. 135-140 In: An Advanced Treatise on *Meloidogyne* Vol.1: Biology and Control. J. N. Sasser and C. C. Carter (eds). North Carolina State University Graphics, Raleigh.

Trudgill, D. L. 1991. Resistance to and tolerance of plant parasitic nematodes in plants. *Annual Review of Phytopathology* 29: 167-193.

Veech, J. A. 1981. Plant resistance to nematodes. Pp. 377-403 In: Plant Parasitic Nematodes Vol. 3. B. M. Zuckerman and R. A. Rohde (eds). Academic Press, London.

Wallace, R. H. 1987. A perception of tolerance. *Nematologica* 33: 419-432.

Wilkinson, S. R. 1979. Plant nutrient and economic value of manures. *Journal of Animal Science* 48 (1): 121-133.

Fig. 1.1: Eight-week old *Vigna subterranea* plant grown in the greenhouse