THE EFFECTS OF RAMIAL CHIPPED WOOD (RCW) AND LITTER COMPOST OF *Casuarina equisetifolia* Forst & Forst ON GROWTH OF TOMATOES, SOIL FERTILITY IMPROVEMENT AND PHYTONEMATODE DYNAMICS IN SANDY SOILS OF NIAYES, SENEGAL.

BY

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Alice, December 2000

DECLARATION

I declare that this dissertation describes my own work, except where specific acknowledgement is made to the work of others who are cited as sources.

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Date this..04....day of..December...2000

Place: Alice

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ABSTRACT

Plantations of *Casuarina equisetifolia* in the Niayes area Senegal produce two important by-products, namely, litter and ramial chipped wood (RCW) which are organic materials that were suspected to have potential as organic soil amendments. However, their potential as sources of nutrients and their effects on biological pest control upon decomposition in soils remained to be established in infertile sandy soils of Niayes area.

In order to determine their effectiveness, a field experiment was conducted to study their effects on tomato growth, soil fertility and phyto-nematode dynamics. Ramial chipped wood and Litter Compost were incorporated to a sandy soil at three different levels: 10 tons/ha, 20 tons/ha and 40 tons/ha, and compared to a reference control and locally recommended fertilizer mixture made up of 20tons/ha of horse manure + 300 kg/ha of fertilizer 10-10-20. Soils and plants were sampled at 45 days of tomato growth and at the end of harvesting, and analysed for nutrient contents and soil properties. The residual effects of the materials were also studied through the establishment of a second crop on the same plots.

The results obtained showed that soil physical and chemical properties were significantly improved following the incorporation of LC, and the higher the applied rate the greater the improvement. Soil properties were not significantly improved by RCW incorporation. Tomato growth and yield were also increased in the same plots treated with LC and especially at the highest rate. RCW incorporation induced nutrient immobilization in soil, which resulted in depressed tomato growth and fruit yields.

Results of the residual study showed that LC had low residual effectiveness suggesting that most of its nutrients were released and utilized during the first crop. By contrast, RCW had a greater effect on tomato growth during the second crop indicating that it released its nutrients more slowly.

Both soil amendments had a regulatory effect on soil and plant nematode dynamics. Their incorporation in soil helped to keep nematode populations lower than that of the reference control.

Key words: Ramial Chipped Wood, Litter Compost, *Casuarina equisetifolia*, decomposition, tomato, nematodes, Senegal.

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CHAPTER 1

INTRODUCTION

Plantations of *Casuarina equisetifolia* (Forst & Forst) were established in the Niayes region of Senegal through a re-forestation program begun in 1948. Species trials conducted in the region subsequently showed *C. equisetifolia* to be the only tree species sufficiently adapted to the prevailing environmental conditions (Maheut and Dommergues, 1963). These plantations play an important role in stabilizing the coastal sand dunes, and help to protect adjacent agricultural areas by acting as windbreaks. The *C. equisetifolia* trees produce and accumulate large quantities of organic material on the plantation floor. For example, Mailly and Margolis (1992) estimated that a 13-year-old plantation produces up to 3.3 kg/m^2/year, which accumulates as litter on the plantation floor. This organic matter is made up of male and female spikes and dead tree leaves. The litter on the plantation floor is mostly used as firewood for fish roasting and, by few farmers, as growing media for ornamental plants in containers. It is not actually used as an amendment in either crop or vegetable farming as its potential for such use had yet to be investigated.

C. equisetifolia plantations do not regenerate naturally, so the only way by which these plantations are regenerated in Senegal is to cut down 45-50 year old trees just before the rainy season. After it rains, shoots sprout from the stumps, which upon pruning grow to form new plants. This method of plantation management, however, results in the production of large quantities of trash in the form of pruned small branches and twigs. Branches and brush wood have been for centuries viewed as to be of no value and as trash in modern forest economy that has developed during the last century. Actually there is growing evidence, however, that such brush wood and twigs, when applied to soil as ramial chipped wood (RCW), could result in the improvement of soil fertility and general soil productivity (Lemieux, 1993; Seck and Lemieux, 1993; Sylvestre and Despatie, 1995). In other words, the debris can be transformed into "soil food". The trash from the regeneration of *C. equisetifolia* plantation is, therefore, a by-product that should be given serious consideration as a soil amendment in the form of ramial chipped wood. Soil amendment with RCW of *Bosecia senegalensis* has also been reported to result in the reduction in root knot nematodes in roots of tomato plants (Seck *and Lemieux,* 1993).

Plantations of *C. equisetifolia* in the Niayes area produce two important by-products, namely, litter and ramial chipped wood which are organic materials that could have potential as organic soil amendments. However, the potential of these organic materials as sources of nutrients and their effect on biological pest control upon decomposition in soils remains to be established in sandy and infertile soils such as those of the Niayes area.

The Niayes area accounts for more than 80% of the vegetables produced in Senegal for local consumption and export. The vegetables are mainly produced under irrigation on sandy soils that are inherently low in fertility. Due to continuous cultivation with the same crop species, nematode infestation is reported to be a problem in the area (Netscher, 1970). Farmers maintain their production levels by using chemical fertilizers and pesticides, often in excessive amounts. This practice is actually known to be an unsustainable method of land use. It reduces organic matter contents and thus enhances soil erosion, especially in drifting sand dune soils. Farmers continue to use chemical fertilizers and pesticides because of their highly visible short-term benefits, but are generally not conscious of environmental pollution, accumulation of pesticides and nitrates in the ecosystems and the high levels of pesticides in their produce. The limitations that are apparent today in the use of chemical fertilizers and their secondary effects, point to the importance of alternative methods.

However, the recent sustained pressure exerted by ecologists from developed countries has resulted in movements encouraging "low input sustainable agriculture ". This approach calls for big reductions in the use of chemicals in agriculture and, where possible, encourages the use of organic products. The merit of this approach is not only based on annual yields but also on long-term sustainability of yields, environmental preservation and affordability of the control methods. This approach is also very relevant to developing countries like Senegal.

As noted earlier, the *C. equisetifolia* plantations in the Niayes have two by-products, namely the litter and ramial chipped wood, which are sources of renewable biomass with a potential to be used as soil amendments. Both by-products are suspected to have potential for soil fertility improvement as well as phytonematodes control. However, their effectiveness in this regard remains to be established. The objectives of this study were, therefore, to (i) determine the effectiveness of litter compost and RCW of *C. equisetifolia* on tomato growth, on improving soil fertility and controlling nematodes for tomato production in that region of Senegal, and (ii) to determine rates of application for litter compost and RCW that would result in maximum tomato growth and production.

CHAPTER 2

LITERATURE REVIEW

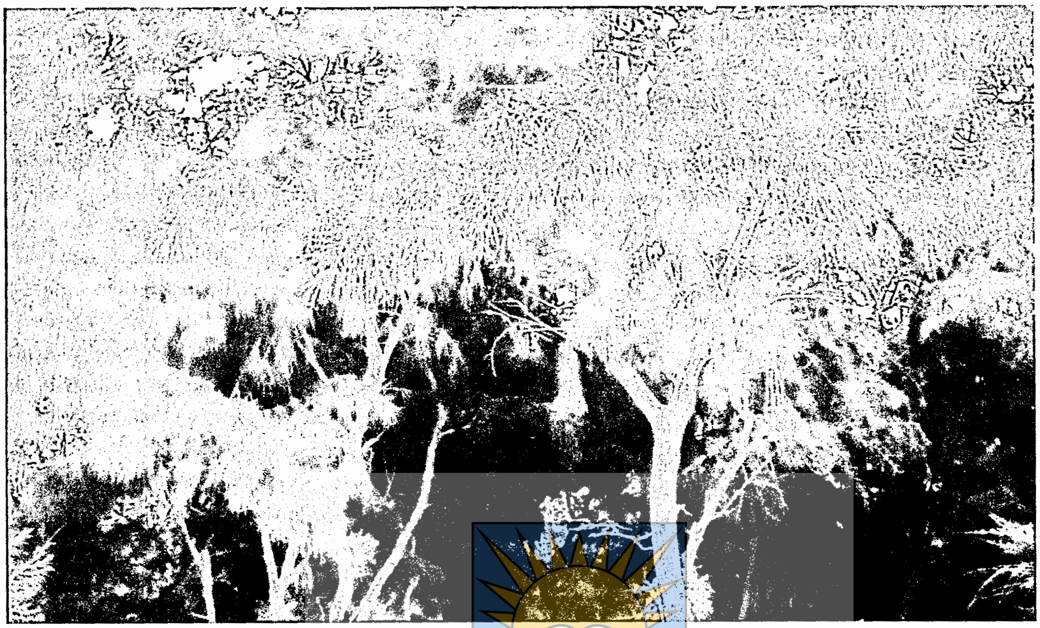
2.1 Types of organic residues

Organic materials or residues have been used for centuries to enhance plant growth. However, lately there has been greater awareness of their unique value as a companion to chemical fertilizer for obtaining maximum yield. Farmers, gardeners and other land managers have been using more organic residues in recent years, and predictions are that the trend in their use will accelerate for agronomic, economic and environmental reasons (Follett *et al.,* 1981). There are many and different types of organic materials that can be used as soil amendments, either in the raw form or after processing. Examples of such organic materials include crop residues (tops and plant roots), wood products (sawdust, wood bark, wood chips and wood fibre), livestock manures, sewage effluents, domestic wastes, urban and industrial wastes and composts.

In developing countries, the availability and subsequently the utilization of organic materials in agriculture, especially crop residues as soil amendments, is relatively limited (Magdoff *et al.*, 1997) because they serve as sources of fuel or forage and building materials. The kind of competition for organic materials is not happening yet with litter and ramial wood from *C. equisetifolia* plant which we were dealing with in this particular study.

2.2 *Casuarina equisetifolia*

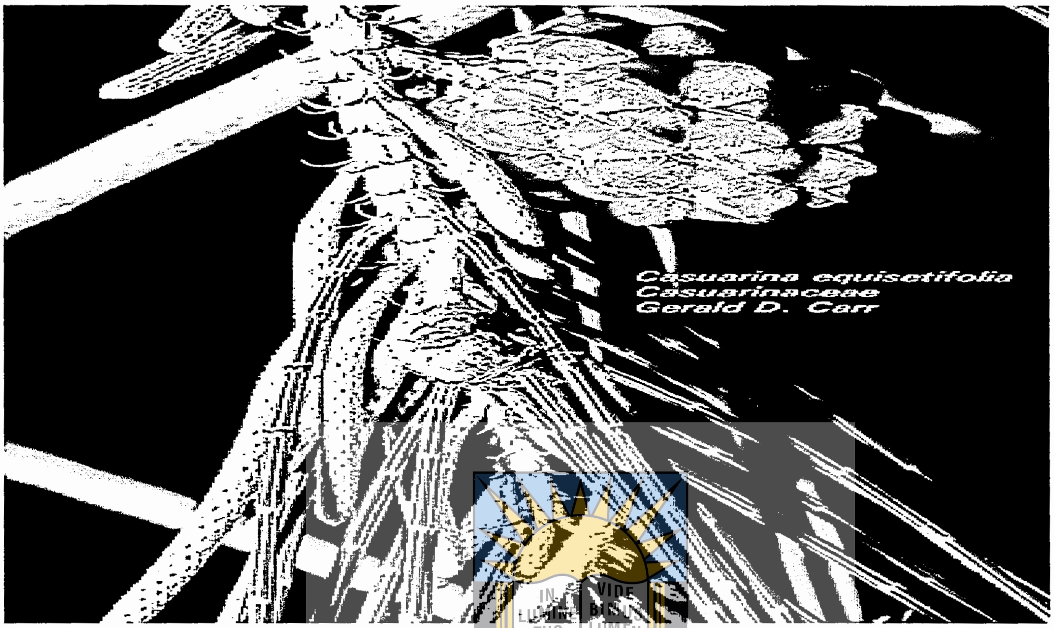
Plantations of *C. equisetifolia* were established in the Niayes region of Senegal through a re-forestation program started in 1948 (Photograph 1). Their main role is to stabilize the coastal sand dunes and to protect adjacent agricultural valleys against the wind. This species is highly tolerant to water and nutrient stresses.



Photograph 1: *Casuarina equisetifolia* plantation in the Niayes area.

Worldwide, *C. equisetifolia* is widely cultivated as a windbreak and also for many other uses. For example, the hill tribes of New Guinea use *Casuarina* species in crop rotations to restore nitrogen in soils, while in the Dominican Republic it has been used to reclaim strip-mine lands. Egyptians plant the tree along the coast to protect houses from the wind and salt spray (Duke, 1983). It is also used for its medicinal properties as remedy against beri-beri, colic, cough, diarrhea, and as a laxative, diuretic and for other ailments (Duke, 1983).

Duke (1983) described mature *Casuarina* spp trees as evergreen, 20 to 30 m tall and having branches that are often drooping with 6 to 8 scale-like leaves. Internodes are 5 to 7.5 mm long on the branchlets and only 2.5 mm on main shoots. Main shoots are finely hairy with small and recurved scales 2.5 mm long and usually there are eight in the whorl. Branches bear male and female spikes (Photograph 2) The male spikes are usually more numerous, and have a cylindrical to fusiform shape. They are 12 to 24 mm long and terminate the branches on which female so-called "cones" are borne lower down. The female "cones" are subglobular to ellipsoid with a diameter of 10 to 20 mm. *Casuarina* spp seeds are so small that one kilogram can contain from 660 000 to 990 000 seeds.



Photograph 2: Details of *Casuarina equisetiflolia* spikes (females and males).

2.3 Plant residue decomposition and nutrient release

Plant residues are known to play important roles in the regeneration of soil nutrients and organic matter as well as in the amelioration of soil physical and biological properties (Kang *et al.,* 1981; Wade and Sanchez, 1983). However, the effect of plant residues on soil properties and crop differ, depending on their decomposition. Plant residue decomposition and subsequent nutrient release are affected by their chemical composition, the nature of soil organisms and the environmental conditions. Conditions conducive to rapid decomposition and mineralization include a near-neutral pH, sufficient soil moisture, good aeration (about 60 % of soil pore space filled with water) and temperatures about 25 to 35°C (Brady and Weil, 1999). It is also known (Mustin, 1981; Tian *et al.,* 1995) that plant residue decomposition is related to their C:N ratio and lignin and polyphenol content. Berendse *et al.* (1987) reported high correlations between nitrogen content, nitrogen release and biomass loss.

Generally plant residues with high nitrogen content decompose faster and release nutrients at high rates, and thus provide crops with a large amount of nutrients at early stages of crop growth. They do not, however, exert as strong an effect on soil physical conditions as plant residues that decompose more slowly. The role of lignin as a regulator in decomposition rate has been elucidated in many studies e.g. (Berendse *et al.,* 1987). Increasing lignin concentration reduces the decomposition rate of plant residues. Swain (1979) postulated that polyphenols reduce the decomposition by inhibiting enzyme action. The negative effect of polyphenols on decomposition and nutrient release was also reported by Melillo *et al.* (1982).

High lignin content of plant residues could also enhance nutrient immobilization, especially of nitrogen. The lignin, when added in soil, produces large amounts of polyphenolic inhibitors (Caron *et al.,* 1998).
N'dayegamiye and Dube (1986) incorporated bark amendments in soil and observed that their incorporation induced nitrogen immobilization in the soil. N uptake and organic C were very low in the soil due to the low decomposition of ligneous materials after the first year of incorporation.

N'dayegamiye and Angers (1993) applied annually three treatments of wood residues (25, 50, and 100 tons/ha) to a sandy loam soil. After 9 years they concluded that the soil C: N ratio was higher in the amended soil with 100 tons/ha of plant residues. The results also indicated that 25 tons/ha applied every year were sufficient to bring about significant changes in soil organic C level. Tian *et al.* (1992) studied the decomposition and nutrient release patterns of prunings of three woody agro-forestry plant species, viz *Acioa barteri*, *Gliricida sepium* and *Leucaena leucocephala*, on *Zea mays* stover and *Oryza sativa* straw yield using the litterbag method. They observed that both chemical composition of the plant residues and nature of the decomposer played an important role in plant residue decomposition. They concluded that the integrated effects of C:N ratio; and lignin and polyphenol contents of plant residues needed to be considered when assessing decomposition and nutrient release rates. In a later study, Tian *et al.* (1995)

developed an equation for the calculation of Plant Residue Quality Index (PRQI) and used it to evaluate the effects of residues on soils and crops. They found the PRQI to be related to decomposition rates of plant residues, soil microclimate, soil faunal density and maize crop performance. They concluded that PRQI could be used for selecting plant residue for their agronomic value in specific areas. They showed that in the maize cropped field with plant residue mulching, mean soil temperature decreased and mean soil moisture increased with the decrease of PRQI.

Feng-Min Li *et al.* (1998) demonstrated that available nitrogen and total nitrogen content were positively correlated with organic matter content ($R^2 = 0.93$, $P = 0.01$). While available P content was unaffected, total P content appeared to increase linearly with increased organic matter content. They reported also that soil-adsorbed water increased with soil organic matter content. This means that the higher the organic matter content the higher the soil-absorbed water content. Under extreme dry conditions relatively higher soil-adsorbed water would be beneficial to maintain soil organisms alive, which is a key factor in soil quality.

2.3.1 Effect of organic residues on microbial activities

Mustin (1981) reported that the microbial biomass increase was proportional to the amount and nature of organic matter in soil. The biological activity of a soil is intimately related to the mineralizable organic matter fraction which is added in soil since it constitutes the source of energy for the microfauna responsible for that activity. An increase of actinomycetes, algae, bacteria, fungi populations and other organisms in soil reflects the stimulation of microbial activity. This proliferation of microorganisms results in increased enzymatic activities in the amended soil, increased availability of nutrients and an accumulation of specific end-product compounds (Mustin, 1981). However, the magnitude of microbial activities and qualitative nature of the response depends on the nature and chemical compounds of the added organic matter. In Quebec, organic amendments favoured an increase in earthworm population, in a natural sugar maple stand (Caron *et al.*, 1998). The enhanced faunal activities were also found to enhance nutrient immobilization.

2.3.2 Toxic effect of organic materials

Some of the end products from organic material decomposition are thought to be toxic to some soil organisms and, therefore, regarded as potential agents for biological control. Organic materials such as *Ricinus communes* and *Azadirachta indica*, for example, contain compounds toxic to nematodes (Mian and Rodriguez-Kabana, 1989). Others are thought to act against nematodes by microbiological activities and ammonia release (Mian and Rodriguez-Kabana, 1989). Toxicity effects of organic materials are also related to the nature of the added composted material because of their ability to increase heavy metal in the soils, depending on the sources used for making the compost (Mustin, 1981).

2.4 Ramial wood

2.4.1 Definition

Ramial wood refers to twigs that are less than 7 cm in diameter (Lemieux, 1993). These twigs contain soluble or little polymerized lignin, considered to be the basis for humus and soil aggregation. Interest in ramial wood began in the mid-seventies, when Edgar Guay, former Land and Forestry Deputy Minister in Quebec, Canada, began searching for new products that could be made from the huge piles of branches produced after logging operations (Caron *et al.*, 1998). Lemieux (1993) named and described "ramial wood" under the French name of "bois raméal". It later changed to “Bois Raméal Fragmenté” (BRF) in French or Ramial Chipped Wood (RCW) in English, since chipping of the ramial wood was found to be necessary for it to be effective as a soil amendment.

According to Caron *et al.* (1998), RCW as a humic amendment and a bioactivator improves the soil structure and regulates activity through polyphenolic chemistry. It is a pedogenetic amendment able to optimize or generate a true soil. This structural stability is the most efficient tool for regenerating soils (Toutain, 1993). This technique is different from composting where the basic materials come from diverse organic sources.

2.4.2 Tree species and parts of trees to use

The effective utilization of plant residues in soil fertility management depends on tree species and parts of trees chosen since the chemical compounds are highly variable even among the different parts of the same plant. As a result of chemical differences among plant species, some of them are digested within a few months by soil organisms, while others take a few years. According to Caron *et al.* (1998), RCW from coniferous trees should be restricted to 20% of ramial wood contents, because they tend to inhibit the soil pedogenesis mechanism. Their lignin, once in soil, produces a polyphenolic inhibitor in cold and temperate areas unlike lignin from deciduous tree species. This type of inhibitor lignin is also found in many tropical tree species, but high soil temperatures break the inhibition effect to some extent. According to Caron *et al.* (1998), the basic mechanisms lies in the role played by white rots which use enzymatic systems to produce both fulvic and humic acids from lignin, the base for aggregate formation. The best results are achieved with deciduous trees due to the structure of their lignin.

Branches under 7 cm in diameter, without their leaves, are the best for shredding to make ramial chipped wood because they have a narrow C:N ratio ranging from 30:1 to 170:1 compared to stem-wood which C:N ratio ranges from 400:1 to 750:1. Furthermore branches less than 7 cm in diameter contain more than 75 % of nutrients (N, P, K, Ca, Mg and traces elements) in a plant. The bigger the branches the lower the nutrient content and the less digestible they become (Caron *et al.* (1998).

2.4.3 Method of application

In Quebec, the best results were obtained when RCW was mixed with the first 5 cm of the topsoil at a rate of 150 to 200 m^3/ha (50 to 70 tons/ha). The reasons for surface incorporation are both physical and biological: (i) it is mechanically easier and (ii) in cultivated soil, microorganisms do not migrate very deeply in the soil because of soil dryness with depth, in addition to being sensitive to anaerobic conditions. For best results, RCW incorporation has to be repeated by adding from 10 to 20 m^3/ha (3.5 to 7tons/ha) in the fourth year and, every year thereafter. In a field treated with RCW, ploughing is delayed for three years in order to prevent deep burying and to provide aerobic conditions favourable to RCW decomposition and enzymatic activities of basidiomycetes (Caron *et al.,* 1998).

2.4.4 Decomposition

Soil microorganisms have an important and critical role to play in decomposition and nutrient release by plant residues. There are several organisms (e.g. fungi and symbiotic bacteria, microarthropods, insects, etc) found in forest soil that are essential to the RCW transformation, which are not found in cultivated soils. In fields, these organisms must be reintroduced with the first application (Caron *et al.,* 1998) otherwise RCW may not produce the desired effect.

According to Mustin (1981), the ratio of organic carbon to total nitrogen in the plant residues applied can also be a limiting factor for RCW decomposition. When C:N is about 30:1, ammonium and nitrates may be released by mineralization or immobilized, because the plant tissue resists microbial attack. At this C:N ratio, soil temperature or moisture may determine the direction of the mineralization/immobilization threshold. When the C:N ratio is wider than 30:1, nitrogenous fertilizer must be added to prevent nitrogen deficiency if a crop is to be sown soon after their incorporation into the soil. Crop residues with narrow C:N ratios, such as clovers, can be incorporated into soil and a crop planted immediately thereafter will not show any nutrients deficiency.

2.4.5 Effect on soil properties

Literature on the effects of RCW on soil properties is very limited. However, added organic materials in general are known to influence physical, chemical and biological properties of soils. For example, Gasser *et al.* (1995) observed that treatment of a sandy loam soil with wood residues improved soil water content during the flowering stage and increased potato yields and specific gravity. The improvement of potato yield and their quality were related to a short-term improvement in soil water content at the critical growth stage. They also showed that soils treated with wood residues were higher in organic carbon content than those without wood residues incorporation.

Mnkeni *et al.* (1995) studied the effects of alley cropping with *Leucaena leucocephala* and the incorporation of its prunings in an Andosol. Their results showed that the incorporation of organic residues from alley cropped trees partly influenced soil fertility status through its positive effects on P balance in the soil. Plots that received *Leucaena* prunings in combination with N fertilizer over 11 years had higher levels of total P, extractable P and organic phosphorus.

Tremblay and Beauchamp (1998) reported that split applications of supplementary N fertilizer following incorporation of chipped wood changed selected chemical properties of soil cropped with potatoes. Total C and water holding capacity increased with inputs of chipped wood, but C:N ratio and pH were not affected. Only available P content decreased following incorporation of chipped wood.

Zebarth *et al.* (1999) quantified the effect of organic soil amendments on selected physical and chemical soil properties of an infertile sandy soil. They observed that soil organic matter was increased by 2 % in response to the amendments. Soil bulk density was also higher for the control than for all other amendment treatments. Soil water retention was significantly lower in control than in all other plots with amendments. They noticed no significant differences between water retention in all soils treated with amendments. Soil CEC in the higher biowaste treatment was 42 % higher than the control, when considered on soil mass basic. However, N'dayegamiye and Dube (1986) observed no changes in CEC after the application of bark residues in soil.

Tremblay and Beauchamp (1998) also showed that bacteria and actinomycete populations were not influenced after the first year of RCW application. They also analysed the soil for its of heavy metal content and concluded that the application of RCW in soil did not increase its amount of heavy metals to a level that adversely affects soil quality and plant growth.

2.4.6 Effect on plant growth

The application of plant residues is known to have positive effects generally on plant growth. N'dayegamiye and Dube (1986) investigated the effects of bark application on plant growth and nitrogen immobilization on a sandy loam soil. They observed that wheat, barley, and red clover yields were depressed by wood residue applications in the first year of experimentation but improved significantly in the following years. Besides increases in dry matter yield, increases in frost and drought resistance in maize plants are other effects which have been attributed to RCW application (Sylvestre and Despathie, 1995). Seck and Lemieux (1993) obtained marginal yield increases during the first year and substantial yield increases during the second year of cropping for plants grown on plots amended with the RCW of *Bosecia senegalensis* compared to control. Tomato yields of 9.2 ton/hectare were obtained from test plots compared to only 1.7 tons/ha from the control plots. For the fresh biomass, 8.35 tons/ha for the test plots and 2.35 tons/ha from the control plot were observed. They attributed the increase in yield to RCW decomposition making available more nutrients for plants. In the second year, crop yield increases in plots treated with RCW indicated that the effectiveness of RCW was even greater. Tremblay and Beauchamp (1998) also reported that growth and yield decreased during the first year after split applications of supplementary N fertilizer following incorporation of wood residues for potato crop, but increased in following years.

Available literature on RCW effect on nematode dynamic is scarce but, organic materials, in general, are known to reduce nematodes in soils and plant roots. Seck and Lemieux (1993), studying the effect RCW of *Bosecia senegalensis* on cabbage crop yield, reported a decrease of root knot nematodes in plant roots treated with RCW. This same effect of organic materials on nematodes was also observed after the incorporation of different composts.

2.5 Compost

2.5.1 Definition of compost

Composting is a spontaneous process in nature, similar to the breakdown, decomposition and stabilization of organic residues in the soil (de Bertoldi *et al.*, 1983; Witter *et al.*, 1986). Some authors use the word composting for both anaerobic and aerobic decomposition of organic materials, but the school of thought prevalent in Europe proposes that it should be used only for the aerobic processes (Stentiford, 1986). Composting therefore can be defined as the controlled exothermic bio-oxidative decomposition of organic materials by indigenous microorganisms in a moist, warm, aerobic environment, leading to the production of carbon dioxide, water, minerals and a stabilized organic matter, defined as compost (Hutchinson and Richards, 1922; Gray *et al.*, 1971 cited by de Bertoldi *et al.*, 1983).

The composting process results in the loss of organic materials, but the enzymatic combustion favours the destruction of polyphenol and pathogenic organisms and seeds.

2.5.2 Effect on soil properties

The use of compost is also beneficial to the physical, chemical and biological soil properties. Soil property factors such as water holding capacity and water retention characteristics, hydraulic conductivity, bulk density, organic matter content, cation exchange capacity/nutrient retention capacity, pH, electrical conductivity and biological biomass are strongly related to soil quality (Arshad and Coen, 1992). Mature compost directly affects all of these factors and therefore soil quality (Dick and McCoy, 1993).

2.5.2.1 Physical and chemical soil properties as affected by compost

Soil organic matter is unanimously recognized to have direct effects on soil physical and chemical properties. It directly and indirectly affects soil pH, soil buffer capacity, soil CEC, soil aggregation, soil encrustation, water infiltration, soil penetrability, moisture content, drainage, tilth, aeration, temperature, and the supply and availability of nutrients for plant growth (Allison, 1973; Swift and Woomer, 1993).

2.5.2.1.1 Soil bulk density

Composted organic materials have a direct effect on soil bulk density, which is attributed to their low density and their tendency to increase soil pore size and number (Duggan and Wiles, 1976; Gallardo-Lara and Nogales, 1987). Bouranis *et al.* (1997) incorporated compost of sludge into soil at concentrations up to 25 % and observed that the apparent density decreased in comparison with the control. The residual effect of compost on soil bulk density can be observed for many years after application (Tester, 1990). Gasser et *al.* (1995) evaluated the short-term effects of crop rotations and organic amendments on soil properties. They observed that soil bulk density was increased significantly in plots under green manure autumn rye crop treatments than in plots treated with barley and ligneous materials.

2.5.2.1.2 Soil stability and aggregation

Humus content is known to be a determinant of soil structural stability and aggregation. As a consequence, the addition of small amounts of organic matter to soil will induce the formation of stable aggregates. These favorable effects were, however, found to be significantly smaller in clay soils than in sandy-loam soils (Gallardo-Lara and Nogales, 1987). Gasser et *al.* (1995) observed a temporary improvement in soil structure under green manure autumn rye cover crop when compared with plots where ligneous materials were incorporated.

2.5.2.1.3 Soil water content and soil water holding capacity

Organic matter can enhance the water-soil-plant relations in many ways, such as improving infiltration, reducing runoff, decreasing loss throughout evaporation, ameliorating drainage and improving root penetration (Allison, 1973). For example, the application of composted organic wastes to soil significantly increases soil water content and water holding capacity (Gallardo-Lara and

Nogales, 1987; Tester, 1990). Bouranis *et al.* (1997) also incorporated compost of sludge into the soil at concentrations up to 25 %, and observed that water holding capacity of soil was increased 17 times but water retention remained almost stable over the temperature range from $9^{O}C$ to $27^{O}C$. Similarly, Gasser et *al.* (1995) showed that barley residues and ligneous amendments significantly improved soil water content during the critical flowering stage in comparison to autumn rye treatments.

2.5.2.1.4 Soil pH and CEC

The presence of organic matter increases soil buffer capacity (Allison, 1973). Application of composted organic materials to acid soils induced dramatic increases in pH (Duggan and Wiles, 1976 Gallardo-Lara and Nogales, 1987). The same effect was not observed in neutral or basic soils (Gallardo-Lara and Nogales, 1987). Duggan and Wiles (1976) and Gallardo-Lara and Nogales (1987) observed a marked increase in CEC in soils treated with composted organic wastes. Similarly, Follett *et al.* (1981) studied the effect of composted residues in sandy soil and observed increases in cation exchange capacity by a factor of 5 to 10 times more by comparison to that of a clay soil. The buffering capacity of the sandy treated soil also increased. Gasser et *al.*, (1995) observed that partially humified bark incorporations induced rapid changes in soil cation exchange capacity compared with fresh tree cutting incorporations.

2.5.2.1.5 Soil mineral nutrients

The mineral content of composts is a reflection of the composition of the material or materials from which they derive, providing there are not significant losses in the composting process (Dick and McCoy, 1993). Mays *et al.* (1973) showed that the application of compost for two years produced a sufficient nitrogen residual effect to generate consistently higher yields in the third year. Significant increases in soil macronutrients following application of composted residues were also reported by Mays *et al.* (1973) and Duggan and Wiles (1976). Follett *et al.* (1981) studied the effect of composted residues in soil and observed that phosphorus and most micronutrients were more readily available to plants over a wider pH range. Del Zan *et al.* (1986) reporting trials on alluvial, loamy, calcareous, basic soil, showed that application of several and different composted materials after three years of consecutive applications, generated an increase in levels of N, P, K and C when compared to a control or chemical fertilizer treatments. The availability of nutrients such as N, P and S, was closely related to the maturity of the compost. Well stabilized composts will release nutrients at slow rates while fresh materials, with high C/N, C/P and C/S ratios, will demand nutrients from the soil to complete their decomposition, leading to a competition between soil microorganisms and plants for those elements (Gallardo-Lara and Nogales, 1987). The real contribution of compost to nutrient, and particularly N availability depends on their characteristics and maturity. N'dayegamiye *et al.* (1997) conducted a laboratory incubation experiment in parallel to a green house study with respectively, two peat rates (0, 20g/kg soil), five manure composts and four rates (0, 250, 500 and 750 g/kg). Compost N mineralization and N uptake were measured. They observed that total amount of N mineralization and N uptake for six cuts of orchard grass varied significantly with the type of compost and rate of application. Peat addition temporarily decreased compost N mineralization rate but not N uptake as compared to the peatless treatments. Mineralized N represented less than 3% of total N, whereas N uptake by orchard grass represented 13 to 40% of total N among composts. This low mineralized N value compared to total N and total N uptake was attributed to a high maturity of the compost studies.

Gasser et *al.* (1995) observed that more rapid changes of soil C content were observed with ligneous material incorporations than with autumn rye and barley residue additions. In addition, composted organic wastes were found to be rich in essential plant micronutrients such as B, Cu, Zn, and Fe (Mays *et al.*, 1973; Duggan and Wiles, 1976; Gallardo-Lara and Nogales, 1987).

Maynard (1993) worked with chicken manure compost and mushroom compost compared to the application of 6.5 tons/ha of a 10-10-10 fertilizer (N-P_2O_5-K_2O).

He found that composts can be added for three consecutive years without major risk of nitrate groundwater contamination, but should be combined with fertilizer requirement supply if horticultural crops are grown. He also stipulated that, after a period of three years, a reduction in the application rates could be considered due to cumulative effect on the soil. Tester (1990) suggested that an annual amendment of 100 tons/ha of sewage sludge compost on a loamy sand soil would sustain adequate yields and provide substantial modifications in soil chemical and physical properties. Residual effects of compost in doses above 30 tons/ha are reported six years after application (Allievi *et al.*, 1993). When prepared according to a suitable technical system which will lead to its stabilization, composted organic residues are sufficiently rich in humus to ameliorate the quality of agricultural land and promote sustainable crop production (Piccolo *et al.*, 1992).

2.5.3 Effect of compost on agricultural crops

Composted organic residues have been used for production of several different crops, with as many degrees of success, or failure, as possible. The results in terms of yield and plant nutrition are always a function of the quality of the compost used. Problems related to phytotoxicity are, most of the time, the result of the use of feedstock materials loaded with heavy metals or non-stabilized compost (Epstein *et al.*, 1992).

Recommendations about rates of application vary with type of compost used, type of soil, crop to grow and environmental conditions prevailing in the area where the trials take place. In general, application rates vary between 25 to 100 tons/ha, however higher rates are not uncommon. Tester (1990) suggests that an annual addition of 100 tons/ha compost is sufficient to produce improved yields and to induce substantial changes in soil physical characteristics. But mostly, authors suggest that the combination of compost and mineral fertilizers produce higher beneficial effects on plant development and production, than the sole application of one or the other alone. The reasons for that may be because all composts at suitable rates do not have all the required nutrients available in doses that promote optimum plant growth. The combination of these two fertilization methods may also help to prevent the soluble minerals from chemical fertilizers, become unavailable to the crops by leaching. These soluble minerals will be combined with the organic fraction from the compost and released slowly, over a long period, in the form of microbial sub-products and/or under the action of organic acids (Allison, 1973).

2.5.4 Effect on horticultural crops

The use of composted organic societal wastes in horticulture has great possibilities of expansion in the near future due to the growing market for organic food and the need for substitutes for peat due to environmental concern (Lopez-Real, 1990). The human health aspects linked to the consumption of compost fertilized horticultural foods are cause for concern mainly in relation to heavy metal contamination. Considering the fragility of horticultural crops, when compared to the agricultural ones, the quality of the compost used for this purpose must be very carefully assessed. Because of the nature of their completely artificial conditions, pot-grown plants are particularly susceptible to possible deleterious side effects of compost utilization.

Buchanan and Gliessman (1991), reporting on the use of agricultural waste compost, vermicompost and mineral N and P for broccoli (*Brassica oleracea)* production on a sandy loam soil, observed that yields increased with increasing compost doses and that the best results were obtained with the higher application of 30 tons.ha^{-1}. They also concluded that compost at high doses resulted in higher N and dry matter accumulation.

Other experimental results on plants grown in containers indicated that they developed better when the percentage of composted bark is greater than 50% in the mixture with sand (Malek and Gartner, 1975). Daft *et al.* (1979) reported that composted hardwood bark could be used successfully as a major ingredient in plant container media.

Vogtman *et al.* (1993) worked with several horticultural crops: (i) tomatoes in a glasshouse, in pots containing 60% (volume) of biogenic waste compost, 25% of peat and 15% of loamy sand, compared to a commercial potting soil (40% clay and 60% peat, plus urea; (ii) cabbage, carrots and potatoes on a silty loam soil field treated with different doses of biogenic waste compost, farm yard manure compost and mineral fertilizers. They found that the volume of compost used in the pots induced calcium deficiency due to luxury uptake of potassium. Yields showed no significant difference between compost media and conventional media for tomato production. For the field experiment, significant yield increases were obtained with the compost treatments, with the best result obtained from biogenic waste compost. The authors point to a significant positive relationships between compost fertilization and plant nutritional qualities and conservation of soil properties, when compared to mineral fertilizers.

Maynard (1993) experimented with tomatoes grown a fine sandy loam soil fertilized with municipal solid waste compost at 25 and 50 tons/ha, and found that the lowest rates of compost application produced a 23% increase in production compared to the control without compost, but this difference was not statistically significant. At 50 tons/ha, the yield was increased by 38%. This positive effect on the yield was mainly related to the higher nutrient availability, increase in soil pH (from 5.5 in the control to 6.2), increase in the soil organic matter and liming effect of compost application. Similar experiments done on infertile sandy soil infested with nematodes in dune depressions by Lo and Gerard (1993) have shown a better average yield for tomato plants grown on plots amended with compost of butchery wastes than a control without organic amendment. Another trial in this same Niayes area on plots treated with compost of dry grass and prawn wastes resulted in 33 % increases in crop yield (Dia, 1995).

Similarly, intensive vegetable production trials conducted by Maynard (1994) showed that chicken manure compost could substitute for inorganic fertilizers for the production of tomatoes, pepper, broccoli and cauliflower. A significant build up of nutrients in the compost amended plots was observed which, in the case of

N, amounted to over six times what was observed on the control treatments. They concluded that there was no benefit in increasing rates of compost application from 56 to 112 tons/ha

2.5.5 Effect of compost on nematodes

Certain types of compost have been shown to suppress plant parasitic nematodes. For example Malek and Gartner (1975) observed that hardwood bark suppresses populations of plant-parasitic nematodes in addition to its horticultural attribute as a soil amendment. In the same way, Daft *et al.* (1979) showed that composted hardwood bark had a suppressing effect on soil nematodes.

In another experiment (Hointink and Kleener, 1993) composted sewage sludge was applied to a tomato field initially to look at water conservation. However, the researchers noticed that early blight disease was significantly less with compost than without, as was bacterial leaf spot. They also observed a dramatic difference in root knot nematode damage, with severe damage on the no compost plots versus no or decreased damage in the adjacent rows where compost had been applied. Dia (1995) observed that plots treated with compost of dry grass and prawn wastes resulted in a decreased nematode population to below the critical infection level.

Views differ concerning the mechanism by which organic materials added to soil act against nematode populations. The "specific suppression" that operates in natural disease-suppressive soils is superimposed over the background of general suppression and is due, at least in part, to the specific effects of individual or select groups of microorganisms. One view maintains that the addition of organic matter to soil results in the proliferation of organisms, resulting in increased enzymatic activities and accumulation of specific end-product compounds that adversely affect the pathogen during some phase of its life cycle which may be nematicidal. Another view attributes the nematicidal properties of compost to the ammonia released during organic material decomposition which is believed to be toxic to nematodes (Rodriguez-Kabana and Morgan-Jones, 1987). However, some other mechanisms are believed to be associated with some bacteria present in the soil which according to (Leon, 1993) attack and penetrate nematodes, castrate males and degenerate female ovaries

2.5.6 Other uses for composted organic materials

Composted organic residues can be used in other ways not directly related to their direct effect as fertilizers and soil ameliorators. Several other indirect effects of organic matter on soil may be exploited in order to improve soil quality and plant production (Allison, 1973).

2.5.6.1 Composts as mulch

Compost used as surface mulch may be highly beneficial in situations of extreme soil surface temperatures, rapid soil dehydratation with formation of crusts and high risk of erosion or runoff (Sanches *et al.*, 1989). Roe *et al.* (1993) used municipal solid waste compost as surface mulch for the control of weeds in pepper crop (*Capsicum annuum*) against herbicide (glyphosate) and a control. The soil was sandy and hyperthermic. Compost was applied at a rate of 224 tons/ha. The results showed that municipal solid waste compost were as effective as one to three applications of glyphosate for weed control but they concluded that long-term trials were needed to evaluate the real effectiveness of the treatment.

2.6 The Tomato crop and its nutritional requirements

2.6.1 Climatic conditions for tomato crop

Tomato (*Lycopersicon esculentum*) is a solanaceous crop, and like pepper and eggplant, belongs to the botanical family *Solanaceae*. These crops are grown as annuals and are produced for their fruits. Tomato is one of the most popular and important vegetables for fresh consumption as well as for processing. In the Horticultural Master Plan (July 1998) of Senegal, tomato is ranked after onion and cabbage, with the production of 1984 tons/year. Tomatoes require a warm and dry climate, the optimum mean day temperature for growth of tomatoes lying between 21^0C and 27^0C (Hartmann *et al.* 1981). The optimum mean day temperatures are relatively higher than 27^{0}C during fruit setting. The optimum temperatures should not be lower than 15^{0}C at night during growth and fruit setting (Anais *et al.,* 1981).

Tomato plants are known to produce best yields of good quality tomatoes on well-drained, fertile, sandy loam soils, that are neutral or slightly acid (pH: 5.5 to 7) Hartmann *et al.* (1981) and Anais *et al.* (1981).

2.6.2 Tomato growth habits

There are two different growth habits of tomatoes: determinate and indeterminate Anais *et al.* (1981). The plants of determinate varieties are bush-like, compact in growth, and mature their fruit within a relatively short period. The advantages of these varieties compared with indeterminate varieties are that staking for support and mechanical harvest is possible. The yields are comparable with indeterminate varieties.

2.6.3 Nutritional requirements

According to Hartman et *al.* (1981), the three major plant nutrients necessary for satisfactory growth of the tomato are nitrogen, phosphorus and potassium. A number of minor nutrients are also important including calcium, magnesium and sulfur, and the trace elements boron and manganese.

Nitrogen influences the quality of the tomato crop. Plants lacking nitrogen show yellow foliage. Phosphorus is of prime importance in the tomato fertility programme. Phosphorus influences the quality of fruit in several ways: it stimulates vigorous root growth, which accounts for a better utilization of the nutrients in the soil, it increases the efficiency of the plant by promoting a sturdy stem and healthy foliage (Follett *et al.,* 1981). According to Anais *et al.* (1981) the composition of phosphorus deficient tomato leaves is 0.11 to 0.16% of phosphorus while leaves of plants that received sufficient phosphorus contain 0.35 to 0.56 % of phosphorus. He also observed that leaves containing more than 0.42 % phosphorus did not respond to additions of phosphorus. Potassium content of tomato leaves is highest (3 to 4 %) during the vegetative stage of the plant and it then declines during the fruiting period. Ideally, the leaf K content should remain above 2 % throughout the growth of the plant (Anais *et al.*, 1981). Potassium plays an important role in plants physiology, including water regulation, carbohydrate metabolism and translocation, nitrogen metabolism and protein synthesis, regulation of cell sap concentration, and as an enzyme activator (Follett *et al.* 1981). Its deficiency results in poor lycopene development in the fruits as they approach maturity (Odet, 1989).

Calcium, magnesium and sulfur have been classed as nutrients of minor importance. According to Anais *et al.* (1981) it is not easy to measure the importance of calcium and magnesium on the quality of fruit. Calcium and magnesium serve two functions in the soil: they neutralize the acidity and they serve as nutrients for the plant. Magnesium is known as essential in chlorophyll formation in the plant. Although needed only in small amounts by the plant, trace elements are essential for optimum development.

2.6.4 Agricultural practices for tomato crop

The time to transplant tomato plants or to direct seed tomatoes in the field is governed by weather and soil conditions (Anais *et al.*, 1981). Consequently, the planting schedule may be based on calendar dates for mid and late season planting (Table 1). Tomatoes for hand harvesting are transplanted at the rate of 33 000 to 66 000 plants per ha. The spacing is 50 cm between rows and 50 cm within rows (Beniest, 1987). Cultivation to remove weeds is done by hand tools, tractor or herbicides. Under conditions in the Niayes area, flowering time is between 40 to 50 days after sowing. The period between flowering and fruit maturity takes 40 to 45 days and some 80 to 95 days between sowing and the first harvest.

Table 1: Some agricultural practices for tomato growing in Niayes area, Senegal.

Sowing time	From September to April Or year round, depending on the variety to grow
Planting time	Vigorous plant at 15cm height, from October to May or year round for variety grown during rainy seasons
Organic matter and fertilizer application at 15cm depth	200 to 300kg per m^2 of manure and 4 kg per m^2 of 10-10-20 before planting
Spacing between rows	0.5m for determinate growth; 1m for indeterminate growth
Mineral fertilizers during plant development.	2kg per m^2 (10-10-20) every 15 days until 80 days.
Sprinkle irrigation	Every day especially during fruiting times

Source: Beniest (1987)

2.7 Nematodes infesting tomato crop

2.7.1 Definition and biology

A nematode is a tiny and elongate threadlike worm resembling but not closely related to an earthworm and very much smaller. Nematodes successfully colonize a greater variety of habitats than any other group of multicellular animals. They are found in very different places from the polar regions to the equator, in ocean, freshwater lakes, rivers and all soils from the poles to the tropics (Dropkin, 1980). However, despite such ecological diversity, they are surprisingly similar in structure. The life cycle of strict parasite nematode is represented on Figure 1.

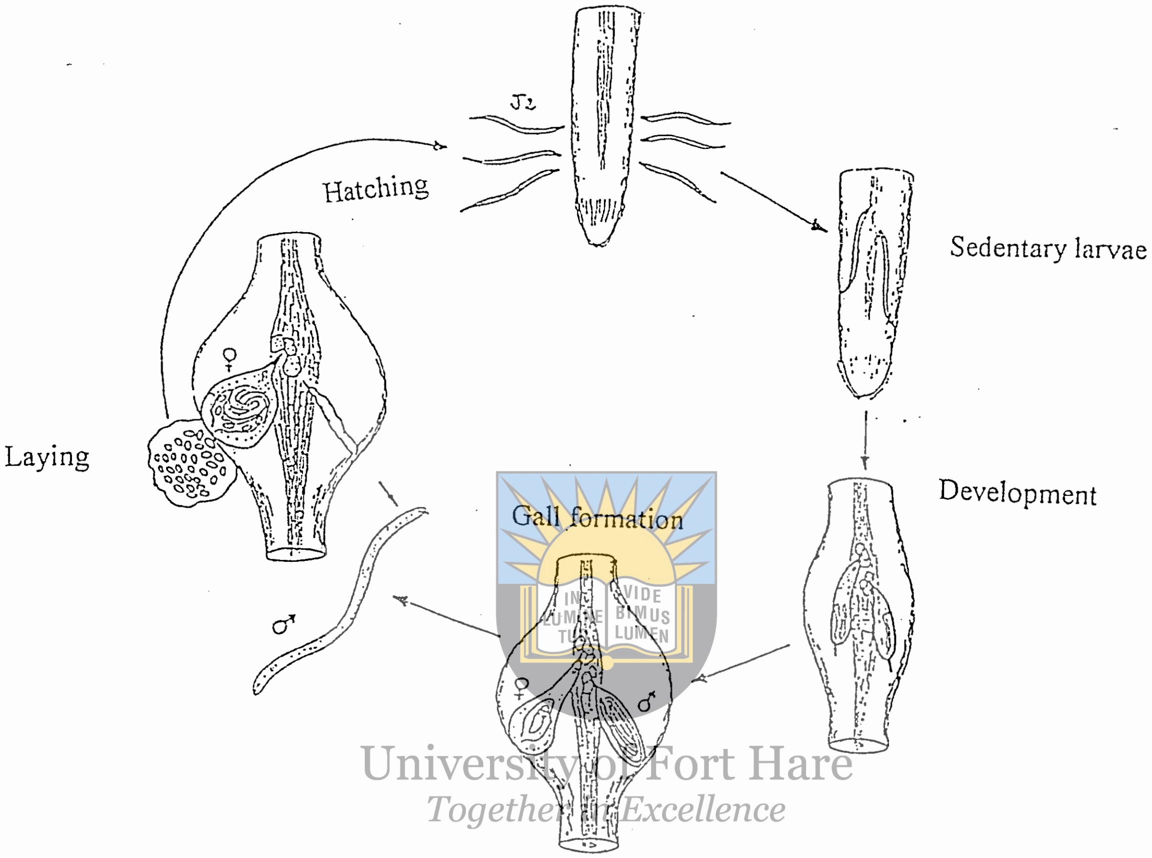


Fig. 1: Life cycle of *Meloidogyne* spp (Netscher, 1970).

Nematodes are broadly divided into three groups: the tylenchs, the longidorids, and the trichodorids (Dropkin, 1980). The most important group, according to their number and damage caused to plants (Netscher, 1970) are the tylenchs. They are a more serious and complex problem in many developing countries. Most soils in these countries, tropical or subtropical regions, have a highly suitable climate for nematode activity and reproduction throughout the year. Warm, sandy soils are favorable to nematode infection (Dropkin, 1980), especially in irrigated areas used for continuous crop production. Perennial crops and annual crops grown in the same fields year after year are often so seriously attacked by nematodes that such crops can barely survive (Cadet, 1990). Yet the people in these developing countries often depend on perennial crops and non-rotated annual crops for their food supply. In general, nematodes are less important under more extensive and varied growing systems typical of shifting cultivation, with widely spaced rotations than in more intensive production where monocropping and narrow rotations are practiced. This was observed in Senegal where crops grown under local cropping conditions were not parasitized by root knot nematodes while neighbouring irrigated vegetable fields were heavily infested (Netscher, 1970). Nematode populations do not remain static but decrease when conditions are unfavorable and increase when conditions are favorable. Their eggs can survive for a year or more in the soil (De Guiran and Netscher, 1970). Nematodes have been found alive in soil flooded for up to 22 months. Some species are killed if subjected to drying but others enter a dormant state from which they can revive within a short time if moistened. For example, the nematode that parasitizes rye has been revived after dry storage for 39 years (Netscher and Sikora, 1990). Nematodes are very active in warm and damp soils. As the temperature cools, they become less active (Dropkin, 1980). According to De Guiran and Netscher (1970), the combined effects of sunlight and drying kill the eggs of many nematodes within 30 mm in soil surface. However, the larvae are the weakest link in the nematode's life cycle. The larvae are most active in moist soils, under conditions that favour rapid plant growth, but usually cause more damage during dry weather, but they die quickly when exposed to direct sunlight, excessive heat or cold, or a lack of moisture. As long as the moisture content in the soil is favourable for the growth of plants, nematodes prosper and multiply. Nematodes are notorious partners in plant disease complexes (Netscher and Sikora, 1990).

Plants attacked by both nematodes and other pathogens (bacteria, fungi, or viruses) often suffer severe injury, resulting in drastically reduced yields.

2.7.2 Nematode parasites of tomato crop

Most of the nematode species which infect tomato plants are *Meloidogyne* spp (Netscher, 1970). The genus *Meloidogyne* spp is in the order of *Tylenchida,* Family of *Heteroderidae.* These kinds of nematodes are the so-called root knot nematodes; there are at least 36 species but the four most widespread that do the most damage, in order of their importance, are: *Meloidogyne incognita*, *M. Javanica*, *M. hapla* and *M. arenania* (Netscher and Sikora, 1990). The role *Meloidogyne* plays in total crop loss is difficult to ascertain in cases where crops are suffering from simultaneous attack by fungi, viruses, insects and other nematodes, a situation, very common in tropical countries. Estimations of vegetable crop losses in the tropics ranged from 24 to 38% on tomato (Netscher and Sikora, 1990).

2.7.3 Nematode control

The most important control option against nematodes is to exclude them by crop rotation and by planting healthy plants.

Tolerant rootstocks should be used, where possible, as a nematode control method. Control can be achieved through hydrothermal heating of the soil. This is accomplished by covering moist soil with 30 to 150 μm thick transparent polyethylene sheeting during the hottest months for a period of nine weeks. Over time juvenile reserves are depleted rapidly at high temperatures. They lack energy to locate and infest plant roots and therefore die-off. However, this method is extremely dependent on climatic conditions and will not be effective in cloudy weather (Netscher and Sikora, 1990).

Another alternative control measure is soil preparation (Dropkin, 1980). The soil should be allowed to dry out completely after soil preparation by deep ploughing or ripping. This will totally eliminated the juvenile stages but not the eggs. As the plants develop eggs will re-establish the nematode population and, at that stage, chemical treatment may again become necessary. Chemical treatment is widely practiced in cropping and many the products, classified as fumigants and none fumigants, are readily available in the market. However, chemical treatments are expensive and are generally efficient for just one cropping cycle. They are also a to as a factor contributing to environmental pollution.

According to Cadet (1990), crop rotation is the most common cultural method used in nematode management. Nematode management by crop rotation is based on the fact that parasitic nematodes can live and reproduce only when they feed on suitable crop species. Therefore, in a crop rotation, susceptible crops are alternated with immune or highly resistant ones. At the end of one or more growing season, the nematode population will decrease to a point where the susceptible crop can be grown with a little damage.

Cadet, (1990) has demonstrated that after three years of *Panicum maximum* susceptible crop plants can be grown for one year without important attacks. Thereafter, yield declines dramatically and the soil needs to be left fallow for a period of at least three years. However, this is not feasible for subsistence farmers who need to cultivate, feed and support their families generally from small pieces of land. These farmers cannot afford to wait for three years and cultivate just for one year.

Another important method used against nematodes is the biological control method. Microbial agents attacking plant nematodes do exist. They are bacteria, fungi and actinomycetes such as *Arthrobotys* and *Monacrosporium*. *Pasteuria penetrans* is an actinomycetes that parasitizes *Meloidogyne* and which is used in biological control against nematodes (Diop, 1994; Mankau *et al.,* 1974; Mian *et al.*, 1982), Spiegel and Cohn (1985) have all demonstrated that the presence of chitin in a cropping soil helps to protect the plant against nematodes. The addition of chitin amendment to soil results in the stimulation of microflora capable of decomposing this polymer into chitobiose and N-acethyl-glucosamine and leads to a very sharp increase in chitinase activity. They observed a relationship between the chitinolytic ability of fungi and their capacity to destroy nematode eggs. They concluded that the addition of chitin to soil would stimulate development of microbial species, capable of degrading similar compounds present in nematodes and in their eggs.

CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental site

The experiments were carried out in one of the Developing Centre for Horticulture (CDH) fields. The site covers an area of 40 ha divided into many fields in Niayes area, Dakar, Senegal (12^{0}'30'E, 17^{0}30'W). This region consists of a coastal band, 15 to 20 km wide along the Atlantic Ocean to the North of Dakar. From November to June this area is under the influence of maritime trade winds so-called "Alizés" and benefits from a relatively milder climate (mean temperatures: 17°C to 24°C) compared to temperatures of other parts of the country (27°C to 30°C). The average precipitation in Senegal varies from 250 mm in the south to around 1000 mm per annum in the north. The soil is classified as a regosol (Sanchez, 1976). The site was previously cropped with onions from March to June 1999 after which it was left uncultivated until the planting time for this experiment on October 28th 1999.

3.2 Materials

3.2.1 Ramial chipped wood (RCW)

Fresh ligneous twigs less than 3 cm in diameter were harvested from *Casuarina* plantation and transported to the experimental field where they were fragmented manually using a bush knife, into small pieces of around 15 to 20 mm long (photograph 3). The resulting product is what was used as ramial chipped wood in this study.

Photograph 3: RCW preparation by manual fragmentation.

3.2.2 Litter compost (LC)

The *C. equisetifolia* litter was collected from the plantation floor and composted for three months (July to October). The heap method, utilizing natural aeration (passive aeration), was used. The dimensions of each of the three heaps used were 3 m long, 1.5 m wide and 1 m high. Parameters like pH, humidity and temperature were monitored as composting progressed. The humidity was kept between 30% and 50% and the heaps were watered whenever humidity was less than 30%.

A germination bioassay trial was conducted to monitor litter compost maturity as the composting process progressed. In this trial, the decomposing compost was sampled at the end of every week and put in containers. Twenty-five lettuce seeds were then sown and their germination percentage determined after 3 days. The results obtained (Table 2) showed that seed germination was almost completely inhibited during the first five weeks. However, the germination percentage increased steadily thereafter and reached 100% during the 10th week indicating that compost maturity had been achieved. The process was allowed to continue for a further two weeks at which time the compost was used for the field trials.

Table 2: Bioassay for residual toxicity during composting of *C. equisetifolia* litter

Duration of composting for sampled litter	Germinated lettuce seeds after 3 days	Percentage of germinated seed
1 week	0	0
3 weeks	0	0
5 weeks	1	4
7 weeks	4	16
8 weeks	10	40
9 weeks	20	80
10 weeks	25	100
11 weeks	25	100

3.2.3 Test crop

A CDH tomato variety, called XINA was used as the test crop. It has determinate growth and produces round and firm fruits of medium size. This variety was chosen because of its known susceptibility to phytonematodes and the fact that it is not season sensitive and can therefore be grown at any time during the year.

3.3 Methods

3.3.1 Field experiment

3.3.1.1 Treatments and experimental layout

A randomized complete block experimental design (RCBD) with four replications was used for the field study. Treatments included a control; recommended fertilizer rate for N P and K; recommended fertilizer rate for N P and K plus mocap powder (nematicide); LC and RCW at three levels each (10 tons/ha, 20 tons/ha and 40 tons/ha) for a total of 9 treatments. The materials were applied to plots measuring 5 m long by 3.5 m wide. The RCW was applied fresh and mixed using a spade in the top 5 to 7 cm of soil. Litter compost was applied and mixed with the top 15 cm of soil. The treatments and actual amounts of materials applied are summarized below:

Treatments names:

Cont. = control (no amendment added).

RF = 2 kg of manure + 30 g of fertilizer 10-10-20(N-P-K) per m^2 to a depth of 15 cm deep and three other incorporations of 15 g of the same fertilizer every 15 days.

RF + N = 2 kg of manure + 30 g of fertilizer 10-10-20 (N-P-K) per m^2 to a depth of 15 cm deep + 2 g of mocap (nematicide) per m^2 and three other incorporations of 15 g of the same fertilizer every 15 days.

RCW 10tons/ha = 1 kg of RCW per m^2
RCW 20tons/ha = 2 kg of RCW per m^2
RCW 40tons/ha = 4 kg of RCW per m^2
LC 10tons/ha = 1 kg of LC per m^2
LC 20tons/ha = 2 kg of LC per m^2
LC 40tons/ha = 4 kg of LC per m^2

3.3.1.2 Planting and harvesting

Tomato seeds were sown and raised in a nursery until the three-leaf stage (around 10-15 cm tall). At that time the field was ready and treatments already applied. The field soil was pre-irrigated before the transplanting of the tomato seedlings was done. The seedlings were transplanted at a spacing was 50 cm within rows and 50 cm between rows. The tomato plants were regularly monitored and treated against insect pests as well as fungus and bacteria infections.

Treatment effects on plant growth were evaluated by measuring plant height at 45 days of growth and tomato fruit yield at harvest time. Harvesting began 80 to 90 days after planting and was done three times a week. The harvest area was 4.5 m long and 3 m wide for each plot. 0.5m from each side of the plot were left as guard rows. The number of fruits was counted and weight determined. Treatment effects on fruit quality were evaluated by determining average tomato weights as well the proportions of healthy and reject fruits.

3.3.1.3 Leaf, soil and root sampling

Leaf, soil, and root samples were taken at specific times to assess treatment effects on soil and plant nutrient content as well as nematode dynamics. Leaf sampling was done at 45 days of growth and at harvest time. This was done by taking the third tomato leaf from the growing tip of each of 20 tomato plants selected randomly from every plot. Soil sampling for purposes of assessing treatment effects on soil properties was done after the second harvest.

Soil and root sampling for purposes of monitoring nematode dynamics was done at 15, 30, 45 and 60 days after planting. The procedure followed involved pulling out one tomato plant randomly from each plot and sampling soil from the rhizosphere. The number of nematodes in the soil was then determined and counted following the elutriation method of Sheinhorst (1962), as cited by Netscher (1970). The extraction method of Sheinhorst (1954) as cited by Netscher (1970) was followed for determination of nematodes in plant roots.

3.3.1.4 Second cropping for evaluation of residual effects

A second tomato crop was grown on the same plots in succession to the first one without further organic amendment applications. The RF treatments were, however, reapplied. After harvesting the first crop, the field was cleared and another tomato crop was established. The planting and the management procedures were done exactly as done for the first crop.

3.3.2 Methods of soil, amendments and plant tissue analysis

The pre-cropping soil and soil samples taken from treatment plots after harvest were characterized for pH (Mc Lean, 1982), organic carbon (Nelson and Sommers, 1982), Total-N (Bremner and Mulvaney, 1982), extractable P (Olsen and Sommers, 1982) and exchangeable K (Knudsen, Peterson and Pratt, 1982), dry bulk density (Blake and Hartge, 1986) particle size analysis (Gee and Bauder, 1986) water holding capacity (Gassel and Nielse, 1986) cation exchange capacity (Rhoades and Miyamoto 1990) and electrical conductivity (Rhoades, 1982).

Litter compost and RCW samples were analyzed for pH and for carbon by the wet oxidation method utilizing acidified dichromate as described by Nelson and Sommer (1982). In addition, RCW and LC along with tomato leaf samples were analyzed for N by the Kjeldahl method (Bremner and Mulvaney, 1982) as well as for P by vanadomolybdophosphorus method (Okalebo *et al.*, 1993) K by flame photometer and Ca and Mg by EDTA titration (Lanyon and Heald, 1982). The results for the organic amendments together with those of the pre-cropping soil are summarized in Table 3.

Table 3: Selected properties of the experimental soil, ramial chipped wood (RCW) and litter compost (LC).

Chemical or physical property	**Soil**	**LC**	**RCW**
C (%)	1.2	40	58.8
N (%)	0.08	1.3	1.15
C:N ratio	15	31	51
P (%)	0.02	2.3	0.11
C:P ratio	60	17	535
K (%)	0.08	2.8	0.53
Ca (%)	-	2.6	1.39
Mg (%)	-	0.4	0.12
EC(dS/m)	1.52	-	-
OM (%)	2.10	64	78
CEC (cmol(+)kg^{-1})	7	-	-
pH (H_20)	5.4	6.8	5.2
DBD (Mg/m^3)	1.8	-	-
Particle Size analysis (%)		-	-
▪ Sand	95		
▪ Silt	4.5		
▪ Clay	0.5		
WHC (mm/m)	80	-	-

3.4 Data Analysis

The raw data obtained were statistically analyzed following procedures described by Gomez and Gomez, (1984). Analysis of variance (ANOVA) was performed to evaluate treatment effects on the different parameters that were measured. The Least Significant Difference (LSD) test was used to separate treatment means, and means were declared as significantly different at $P < 0.05$. The relative effects of the amendments on plant height (RH) and fruit yield (RY) were calculated using a formula described by Engelstad *et al.* (1974), viz:

$$RH = \frac{HA - HC}{HF - HC} x100$$

$$RY = \frac{YA - YC}{YF - YC} x100$$

Where:

HF and YF = plant height and fruit yield observed in the reference fertilizer treatment plots, respectively.

HA and YA = plant height and fruit yield observed in a given amendment treatment plots, respectively

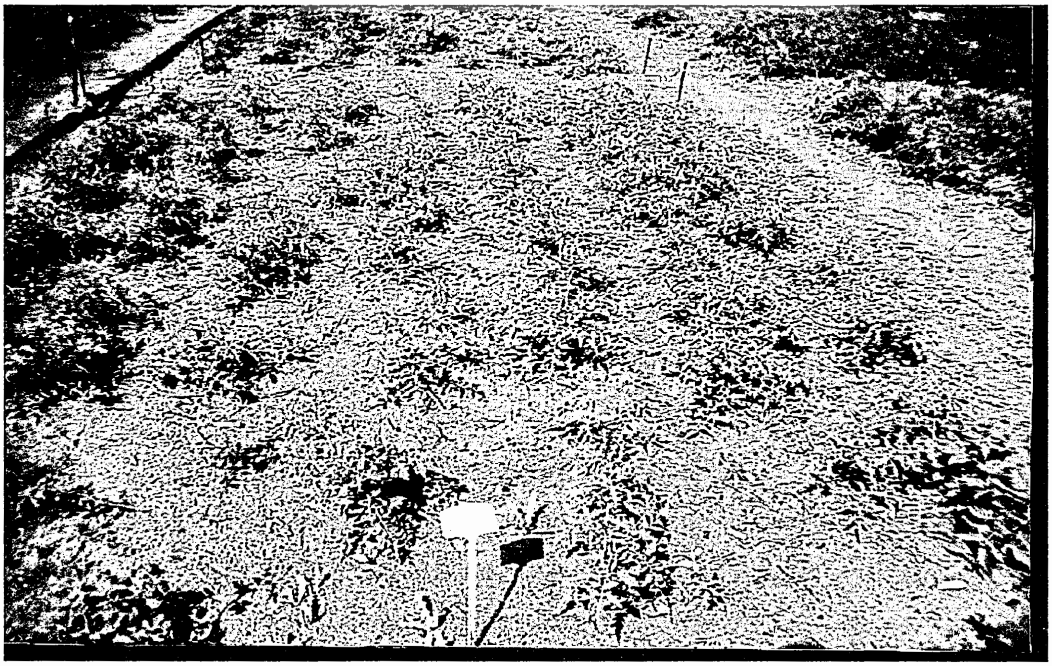
HC and YC = plant height and fruit yield observed in the control treatment plots, respectively

CHAPTER 4

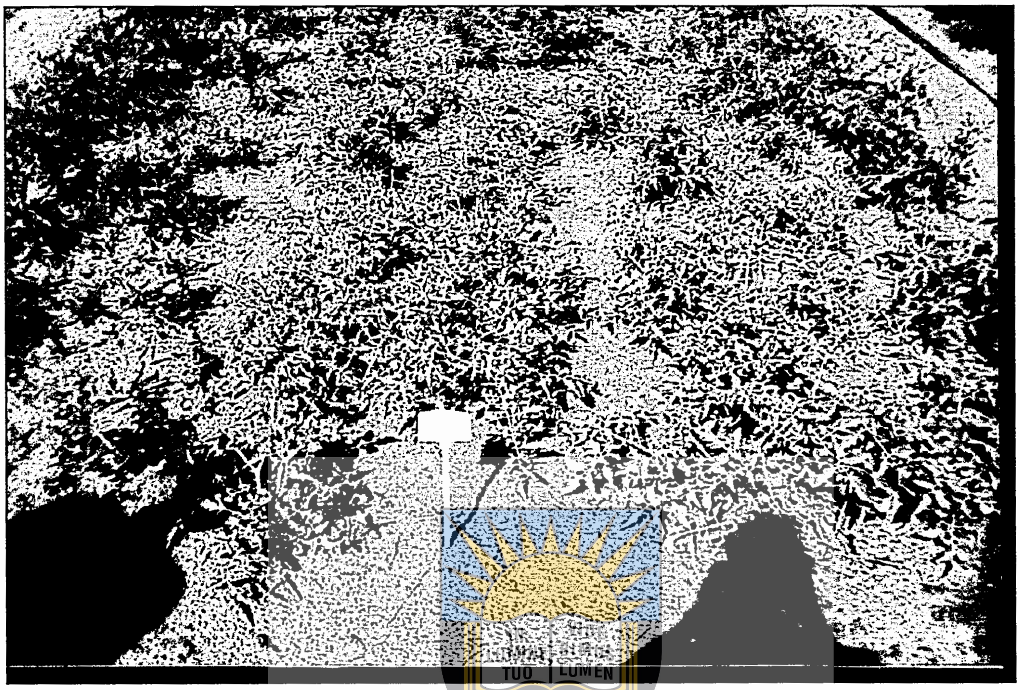
RESULTS

4.1 The effect of RCW and LC on tomato growth

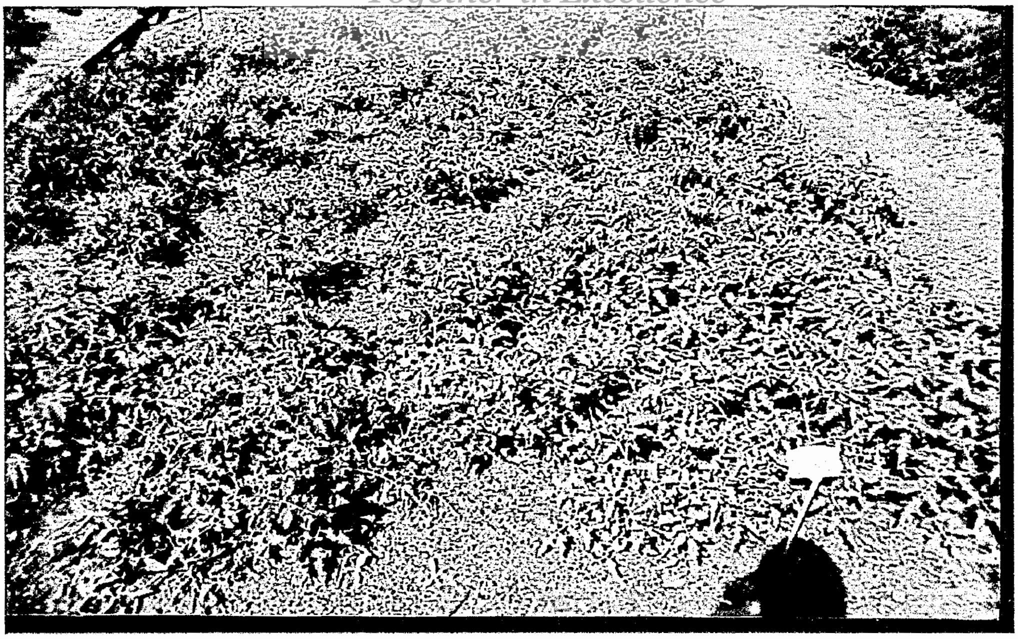
Treatment effects on tomato growth were determined by measuring plant height at 45 days of growth and fruit yield at maturity. The results obtained for both crops 1 and 2 are shown in Table 4. Ramial chipped wood treatments significantly depressed plant height and yield of the first crop relative to the control and the recommended fertilizer (RF) treatments (photographs 4, 5 and 6). The lowest heights and yields in crop 1 were observed in plots treated with RCW at the highest level (40 tons/ha). This situation changed during the second crop where all RCW treatments positively influenced tomato growth. However, the highest rate of RCW application (40 tons/ha) still resulted in the least growth, and observed improvements on growth were still much lower those obtained with the RF treatment.



Photograph 4: Effect of RCW (40 tons/ha) on tomato growth at 45 days after planting

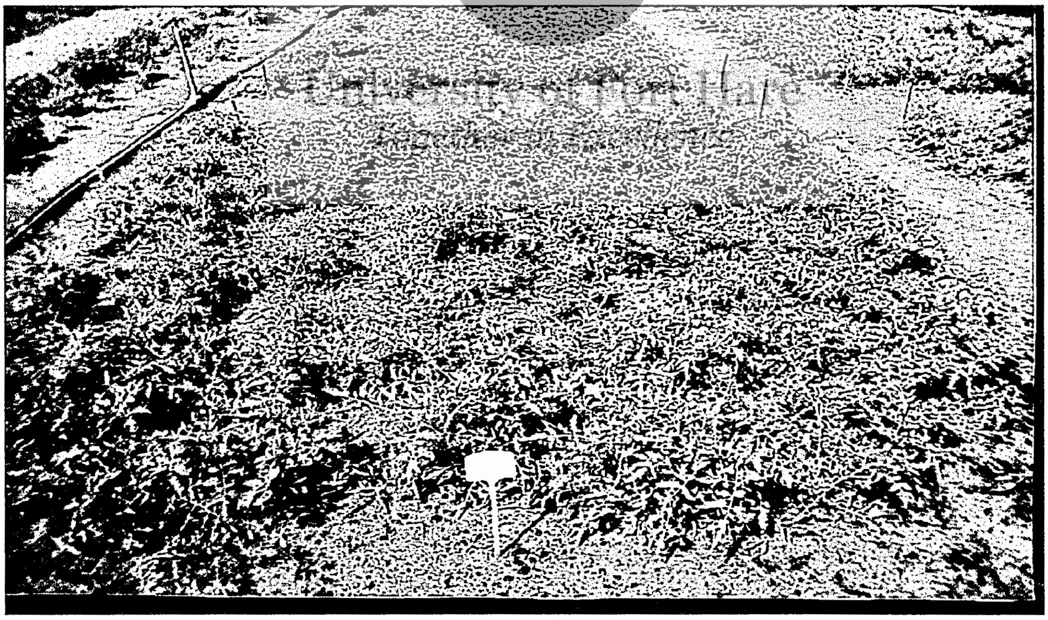


Photograph 5: Tomato growth in the control plots at 45 days after planting



Photograph 6: Tomato growth in the RF plots at 45 days after planting

Unlike RCW, litter compost increased the growth (photograph 5) of both tomato crops as measured by plant height and fruit yield (Table 4). Both tomato height and yield increased with each increment of added LC (photograph 7). Thus the largest effect on tomato growth for both crops was observed with the highest level of LC application (40tons/ha). The relative heights associated with this treatment were 100% and 97% for crops 1 and 2, respectively. The corresponding relative yield increases were 115% and 132%, respectively (Table 4). These results indicated that at 40tons/ha, litter compost performed as well as or better than the recommended fertilizer (RF) treatment. The relative yield increase for LC at the highest level of application was 30% higher than that associated with the RF treatment.



Photograph 7: Effect of LC (20 tons/ha) on tomato growth at 45 days after Planting.

Table 4: The effect of RCW and LC on the growth and yield of two successive tomato crops.

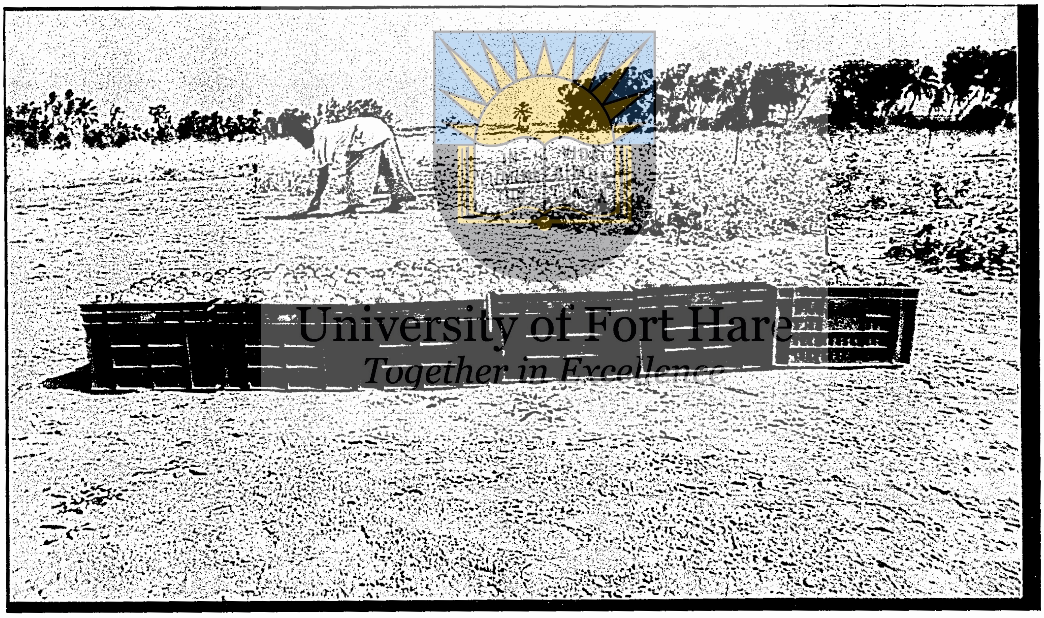
Treatments	**First crop**				**Second crop**				
	Height (cm)	**RH (%)**	**Yield (tons/ha)**	**RY (%)**	**Height (cm)**	**RH (%)**	**Yield (tons/ha)**	**RY (%)**	**Total Yield (tons/ha)**
Cont.	50.1e**		19.83e		34.9h		16.51g		56.17
RF	62.3b		26.63b		65.2b		28.63b		55.26
RF+N	61.1c		28.51b		64.8a		28.68b		57.19
RCW$_{10tons/ha}$	45.6g	-37	19.03f	9.7	51.7e	56	24.05e	62	43.08
RCW$_{20tons/ha}$	48.8f	-10	19.54ef	-3.4	55.2d	67	25.94d	78	45.48
RCW$_{40tons/ha}$	40.6h	-78	17.71g	-25	50.3f	51	22.86f	52	40.57
LC$_{10tons/ha}$	55.8d	46	23.81d	47	49.5g	48	26.91c	87	50.72
LC$_{20tons/ha}$	61.1c	90	27.74c	82	60.7c	85	28.63b	100	56.37
LC$_{40tons/ha}$	65.3a	100	29.20a	115	64.2a	97	29.14a	132	58.34
LSD (0.05)	0.53		1.0		0.21		0.35		
CV (%)	0.67		1.64		0.26		0.53		

* The recommended fertilizer contained also horse manure (20 tons/ha)

** Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test.

4.2 The effect of RCW and LC on tomato fruit quality

The effect of treatments on fruit quality was evaluated on the basis of fruit size and proportion of reject fruits. The average unit tomato weights in all amended plots were significantly higher than that of tomatoes from the control plots (Table 5). Litter compost treatments resulted in relatively larger fruits compared to RCW treatments. However, the differences in unit tomato weights were not significant (photograph 8).



Photograph 8: Healthy tomato fruits separated from rejects at one harvest.

The RCW and LC treatments resulted in the least number of reject tomatoes (Table 5). By contrast, the control and RF treatments produced large numbers of reject tomato fruits.

Table 5: The effect of RCW and LC on tomato fruit quality.

Treatments	Average weight of tomato fruit (g)	Number of rejected fruits	% of reject fruits
CONTROL	18.7d**	1520a	26a
RF	27.6c	1310b	20b
RF+N	32.7abc	1193b	16c
RCW$_{10tons/ha}$	31.1abc	360c	14d
RCW$_{20tons/ha}$	31.5abc	290cd	12e
RCW$_{40tons/ha}$	28.7bc	252cd	10f
LC$_{10tons/ha}$	36.9ab	237cd	9g
LC$_{20tons/ha}$	38.1a	225cd	7h
LC$_{40tons/ha}$	38.5a	172d	4i
LSD	7.9	154	1.23
CV (%)	17.2	17.1	5.7

* The recommended fertilizer contained also horse manure (20 tons/ha)

** Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test.

4.3 The effect of RCW and LC on leaf N, P and concentration at 45 days of growth and at harvest time

4.3.1 Nitrogen content

Leaf N, P and K concentrations determined at 45 days of tomato growth and at harvest time are shown in Tables 6 and 7, respectively. The leaf N concentrations of the first and second crops ranged from 0.14% to 7.27% and 0.21% to 3.88%, respectively (Table 6). The recommended fertilizer (RF) treatments increased leaf N concentration relative to the control in both the first and second crops. However, the effect of RCW on leaf N varied sharply with cropping. In the first crop, RCW depressed leaf N concentration but the situation changed in the second crop where increases in leaf N concentration were observed with each addition of RCW. By contrast, LC significantly increased leaf N concentration in both the first and second crops (Table 6). However, leaf N values of the second crop were lower than those of the first crop at all rates of LC application.

The leaf N concentration of crops 1 and 2 at harvest time ranged from 0.55% to 3.67% and 0.10% to 2.12%, respectively (Table 7). Interestingly, the pattern of leaf N response to the different treatments noted above was maintained at harvest time for all treatments (Tables 6 & 7). However, the leaf N values at harvest time were much lower than those observed at 45 days of growth.

4.3.2 Phosphorus content

The leaf P concentration at 45 days of growth ranged from 0.23% to 0.75% and 0.01% to 0.31% in the first and second crops, respectively (Table 6). As observed for nitrogen, the RF treatment increased leaf P concentration of both the first and second crops relative to the control. Application of RCW, regardless of the amount added, did not significantly influence the leaf P concentration of the first crop. It did, however, increase the P concentration of the second crop significantly though no difference was observed between different rates of application.

Application of LC significantly increased leaf P concentration of both the first and second crops but the concentrations were consistently lower in the second crop as observed for leaf N (Table 6). The leaf P concentrations increased with rate of LC application.

The leaf P concentration of crops 1 and 2 at harvest time ranged from 0.09% to 0.31% and 0.01% to 0.54%, respectively (Table 7). Remarkably, the pattern of leaf P response to the different treatments observed at 45 days of growth (Table 6) was consistently repeated at harvest time (Table 7). However, as observed for leaf N the leaf P concentrations of both crops at harvest time were much lower than those observed at 45 days of growth.

4.3.3 Potassium content

The leaf K concentration after 45 days of growth for the first and second crops ranged from 1.11% to 4.33% and 0.01% to 3.34%, respectively (Table 6). The RF treatment increased the leaf K concentration of both crops to the same extent. However, as was the case with leaf P, application of RCW had no significant effect on the K concentration of the first crop. It did, however, significantly increase that of the second crop (Table 6).

Leaf K concentration of plants on plots treated with LC increased with each increase in the amount of added LC, and was significantly higher than that observed on control plots for both crops (Table 6). However, the K concentration values of the second crop were much lower than those of the first crop similar to observations made earlier for N and P.

The leaf K concentration of crops 1 and 2 at harvest time ranged from 0.08% to 2.37% and 0.01% to 2.29%, respectively (Table 7). For all treatments, the pattern of response observed was similar to that observed at 45 days of growth (Tables 6 & 7). However, except for RCW treatments, the concentration of K in leaves was much lower than that observed at 45 days of growth.

Table 6: The effect of RCW and L C on tomato leaf N, P and K concentration after 45 days of growth for the first and second crops.

Treatment	**First crop**			**Second crop**		
	N (%)	**P** (%)	**K** (%)	**N** (%)	**P** (%)	**K** (%)
Cont.	0.95d**	0.23d	1.11c	0.21d	0.01d	0.01d
RF	3.90c	0.49b	3.31b	1.37c	0.49a	3.34a
RF+N	4.10c	0.48b	2.61b	1.41c	0.44a	3.12a
RCW$_{\text{10tons/ha}}$	0.22e	0.31cd	1.12c	1.51c	0.42a	1.25c
RCW$_{\text{20tons/ha}}$	0.22e	0.34c	1.25c	2.80b	0.45a	2.35 b
RCW4$_{\text{0tons/ha}}$	0.14e	0.21c	1.19c	3.88a	0.47a	2.29 b
LC$_{\text{10tons/ha}}$	3.46c	0.51b	1.58c	1.42c	0.21c	0.97c
LC$_{\text{20tons/ha}}$	4.72b	0.71a	2.66b	1.20c	0.25bc	1.03c
LC$_{\text{40tons/ha}}$	7.27 a	0.75a	4.33a	2.71b	0.31b	2.28 b
LSD (0.05)	0.656	0.10	0.71	0.65	0.08	0.35
CV (%)	15	14	19.3	17.6	16	11.4

*The recommended fertilizer contained also horse manure (20tons/ha)

** Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test.

Table 7: The effect of RCW and LC on leaf N, P and K concentration after harvest for the first and second tomato crops.

Treatment	First crop			Second crop		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Cont.	0.65d**	0.09g	0.08f	0.10f	0.01i	0.01e
RF	1.32c	0.10f	1.53d	0.36d	0.12d	0.17d
RF+N	1.27c	0.10f	1.59d	0.35d	0.12d	0.16d
RCW$_{10tons/ha}$	0.55e	0.16d	1.94c	1.76b	0.41c	1.27c
RCW$_{20tons/ha}$	0.72d	0.16e	2.18ab	2.12a	0.53b	2.29a
RCW4$_{0tons/ha}$	0.31f	0.18c	1.39de	1.45c	0.54a	2.13b
LC$_{10tons/ha}$	1.28c	0.10f	2.04bc	0.13e	0.03g	0.17d
LC$_{20tons/ha}$	2.15b	0.21b	1.29e	0.14e	0.05f	0.16d
LC$_{40tons/ha}$	3.67a	0.31a	2.37a	0.24de	0.09e	0.13d
LSD (0.05)	0.09	0.27	0.18	0.16	0.02	0.07
CV (%)	4.39	0.12	7.58	14.3	0.08	6.32

*The recommended fertilizer contained also some horse manure (20 tons/ha).

** Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test.

4.4 Effect of RCW and LC on soil N, P and K after harvest

After each tomato crop harvest, soil was analyzed for total nitrogen, extractable phosphorus and exchangeable potassium. The results obtained are shown in Table 8.

4.4.1 Soil nitrogen after harvest

After the first harvest, soil total N level was very low in all plots treated with RCW and was not significantly different from the control (Table 8). Increasing the rate of application did not result in increasing levels of total N in soil. Conversely, LC treatments resulted in higher total soil N levels compared to RCW treatments and were all significantly different from the control. Each increment in LC applied resulted in a corresponding increase in soil total N.

After the second harvest the total N content in soil from plots treated with RCW was increased compared to that obtained after the first crop, and values obtained were significantly different from the control. However, the rate of RCW application did not significantly influence total N values. In contrast, total N in plots treated with LC decreased after the second harvest but values were still significantly higher than those obtained from the control.

4.4.2 Soil phosphorus level after harvest

Ramial chipped wood treatments depressed soil extractable P levels relative to the control after the first crop (Table 8). Extractable P values in RCW treated plots increased considerably after the second crop but they were still significantly lower than those observed on control plots. By contrast, extractable P values from LC treated plots were significantly higher than values obtained in the control and RF treatments for both the first and second crops. For both crops, extractable P in soil increased with increases in the LC application rate. However, extractable values observed after the second crop were much lower.

4.4.3 Soil potassium content after harvest

Ramial chipped wood treatments increased extractable K values after both the first and second tomato harvests (Table 8). However, extractable K values observed after the second harvest were slightly higher than those observed after the first crop. Litter compost treatments increased extractable K significantly after the first harvest at all rates of application. However, drastic reductions in extractable K were observed in LC treated plots after the second harvest (Table 8).

4.5 Effect of amendments on soil physical and chemical properties

At the final harvest for the second crop, soil was analysed for organic matter content, cation exchange capacity, water holding capacity, pH, bulk density and electrical conductivity. The results are indicated in Table 9.

4.5.1 Soil organic matter content after the second harvest

Soil organic matter was variable among treatments. The incorporation of RCW did not increase significantly the amount of organic matter in soil after the second harvest. However, LC application increased the amount of organic matter in soil significantly relative to the control and RF treatments.

4.5.2 Soil cation exchange capacity

Soil cation exchange capacity was increased in all treatments relative to the control (Table 9). Nevertheless, the effect of RCW on CEC was much smaller compared to LC, which increased CEC substantially at each level of application. Soil CEC determined from the control was lower than values obtained from the same plots before planting

Table 8: The effect of RCW and LC on soil N, P and K contents after harvesting the first and second tomato crops.

Treatment	**First crop**			**Second crop**		
	N (%)	**P** (mg.kg^{-1})	**K** (%)	**N** (%)	**P** (mg.kg^{-1})	**K** (%)
Cont.	0.15d	8.8c	0.08e	0.03c	9.37c	0.01e
RF	0.29c	11.68ab	0.18e	0.27a	12.68b	0.17c
RF+N	0.27c	11.32b	0.17e	0.29a	13.32b	0.17c
RCW$_{10tons/ha}$	0.12d	6.21d	1.10e	0.33a	7.22de	1.93a
RCW$_{20tons/ha}$	0.15d	5.95d	1.18d	0.33a	6.45e	1.96a
RCW$_{40tons/ha}$	0.13d	6.25d	1.17d	0.39a	6.94de	1.35b
LC$_{10tons/ha}$	0.36b	7.8c	1.943c	0.16b	8.75cd	0.15cd
LC$_{20tons/ha}$	0.40b	10.40b	2.78b	0.16b	11.82b	0.17c
LC$_{40tons/ha}$	0.51a	13a	3.51a	0.17b	17.05a	0.11d
LSD (0.05)	0.05	1.34	0.040	0.06	2	0.05
CV (%)	13.30	9.11	2.46	18.7	11.75	4.8

* The recommended fertilizer contained also horse manure (20tons/ha)

** Means in each column followed by the same letter are not significantly different at $p \leq 0.05$ according to the LSD test.

Table 9: Effect of RCW and litter compost on selected soil properties after the second harves

Treatment	**OM** (%)	**CEC** (cmol(+).kg^{-1})	**WHC** (mm.m^{-1})	**pH**	**DBD** (Mg.m^{-3})	**EC** (dS.m^{-1})
Cont.	1.93e	5.2h	99.5c	5.4cd	1.60a	1.49bcd
RF	4.38b	7.5d	103.7c	5.4cd	1.39bc	1.53abcd
RF+N	4.39b	7.2e	102.5c	5.6bc	1.39bc	1.49bcd
RCW$_{10tons/ha}$	2.80e	5.8g	125.0b	5.2cd	1.40bc	1.47bcd
RCW$_{20tons/ha}$	2.68e	6.1f	127.5b	5.1cd	1.39bc	1.45d
RCW4$_{0tons/ha}$	2.75e	5.8d	125.5b	5.0d	1.47b	1.45cd
LC$_{10tons/ha}$	3.94d	10.1c	131.5b	6.3a	1.34cd	1.55abc
LC$_{20tons/ha}$	4.16c	15.1b	148.7a	6.4a	1.3d	1.56ab
LC$_{40tons/ha}$	4.85a	20.4a	143.25a	6.3a	1.31cd	1.61a
LSD (0.05)	0.13	0.19	10.1	0.51	0.075	0.086
CV (%)	2.35	1.42	5.62	6.12	3.65	3.88

*The recommended fertilizer contained also horse manure (20tons/ha)

** Means in each column followed by the same letter are not significantly different at p ≤ 0.05 according to the LSD test.

4.5.3 Soil water holding capacity

Soil water holding capacity was significantly higher in plots treated with LC and RCW compared to the control and RF treatments (Table 9); but the influence on water holding capacity from RCW treatments was smaller than that for LC.

4.5.4 Soil pH

No significant variation in the soil pH was associated with RCW application relative to the control and RF treatment. However, the incorporation of LC treatments increased soil pH by up to one pH unit.

4.5.5 Soil bulk density

All amendments reduced soil bulk density significantly relative to the control (Table 9). However, RCW at all rates of application did not significantly decrease BD relative to the RF treatments. Litter compost treatments resulted in the lowest bulk density values but rate of application did not have any effect.

4.5.6 Soil electrical conductivity (25°C)

There was no significant difference between the electrical conductivity of the RCW relative to the control and RF treatments. The application of RCW had no effect on soil electrical conductivity (Table 9). However, compared to the control and RF treatments, LC application increased the EC of the soil; and the higher the applied LC rate was, the higher also its effect on soil EC.

4.6 Effect of RCW and LC on nematodes

4.6.1 Effect of treatments on nematode species composition and population

The species composition of nematodes in the soil (Fig. 2) showed that the nematode population in the soil was very diversified. However, the *Meloidogyne* sp. was the dominant species in the soil. This is a characteristic of Niayes area and confirms earlier findings that *Meloidogyne* sp. are the main parasitic nematodes in the Niayes area. The comparison between the number of nematodes in the amended plot and the control and the RF showed a decrease in nematode populations in all soil treatments. However, the species composition of nematodes was affected very little by RCW and LC treatments (Fig. 2).

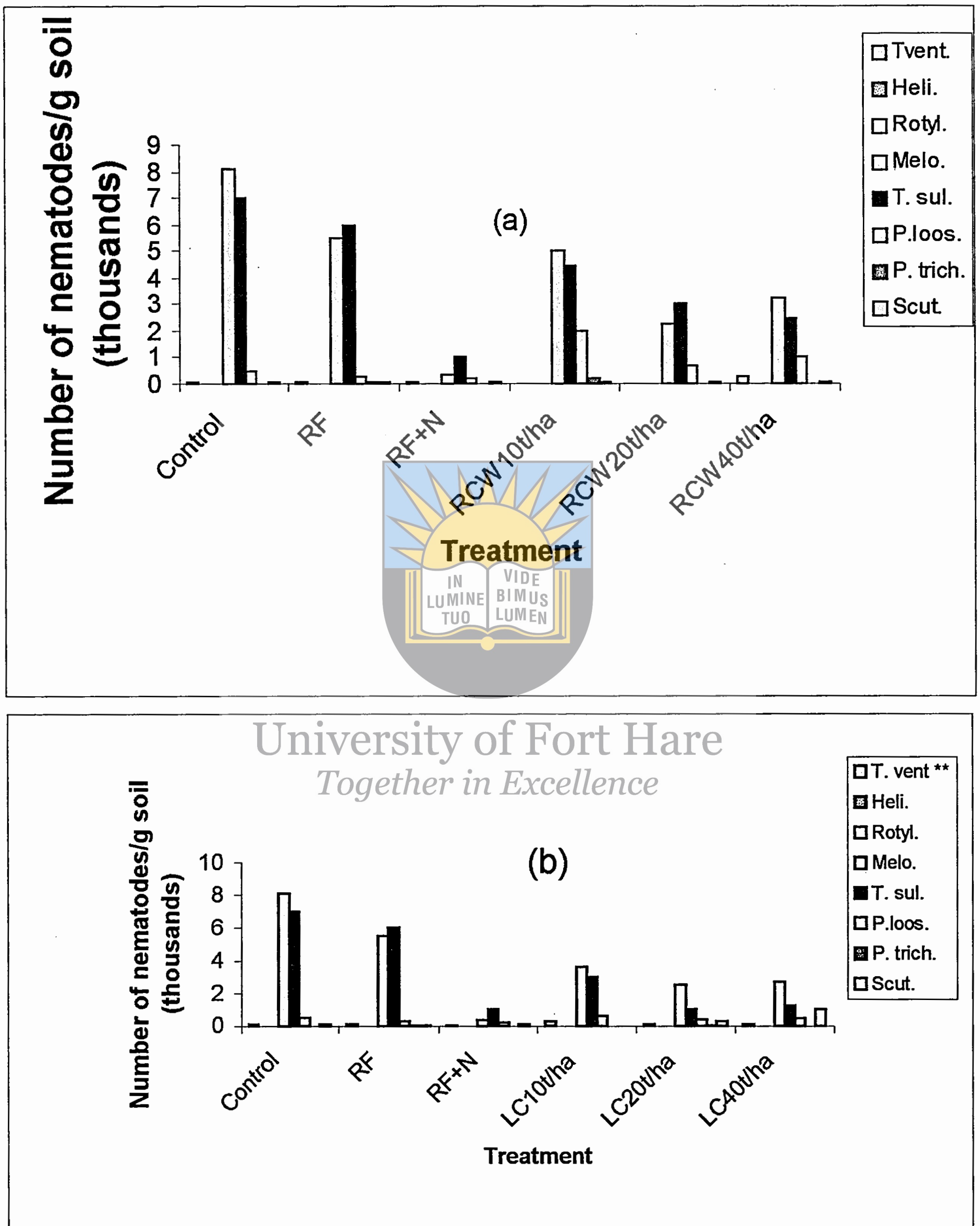


Fig. 2: Effects of RCW (a) and LC (b) on nematode species composition in soil after 60 days of tomato growth.

** T. vent.: *Tylenchorynchus ventralis*
Heli.: *Helicotylenchus multicintus*
Rotyl.: *Rotylenchulus reniformis*
Melo.: Meloidogyne spp

T sul.: *Tylenchorynchus sulcatus*
Ptrich.: *Paratrichodorus minor*
P. loos.: *Pratylenchus loosi*
Scut.: *Scutellonema cavenesi*

4.6.2 Effect of amendments on soil nematode dynamics

The effect of treatments on *Meloidogyne* population dynamics is shown in Figure 3. Nematodes started to appear 30 days after planting and had reached fairly large numbers at 45 days after planting. The number of nematodes remained much higher in soil treated with RCW and LC compared to the control until 45 days after planting. After that the number of nematodes in the control increased steadily with time. The treatment with RF+N had the lowest number of nematodes in the rhizosphere. By contrast the number of nematodes in the treatment with recommended fertilizer without nematicide was much higher compared to the RF+N and organic amendments treatments.

4.6.3 Effect of amendments on plant nematode species composition and population.

The species composition of root nematodes associated with the different treatments (Fig. 4) was less diversified compared to nematodes in soil. However *Meloidogyne* remained the dominant nematode species in plant roots just as it was in the soil.

4.6.4 Effect of amendments on plant nematode dynamics

The effect of treatments on nematodes (*Meloidogyne* sp) population dynamics in plant is indicated in (Fig. 5). Nematodes started to appear 45 days after planting in all treatments except for the control and RF treatments, where they were started appearing 30 days after planting. Their number was much smaller in all plots treated with plots RCW and LC relative to the control. As expected, the lowest number of nematodes was observed in RF+N treatment in contrast to the RF treatment where their number increased in plant roots with time.

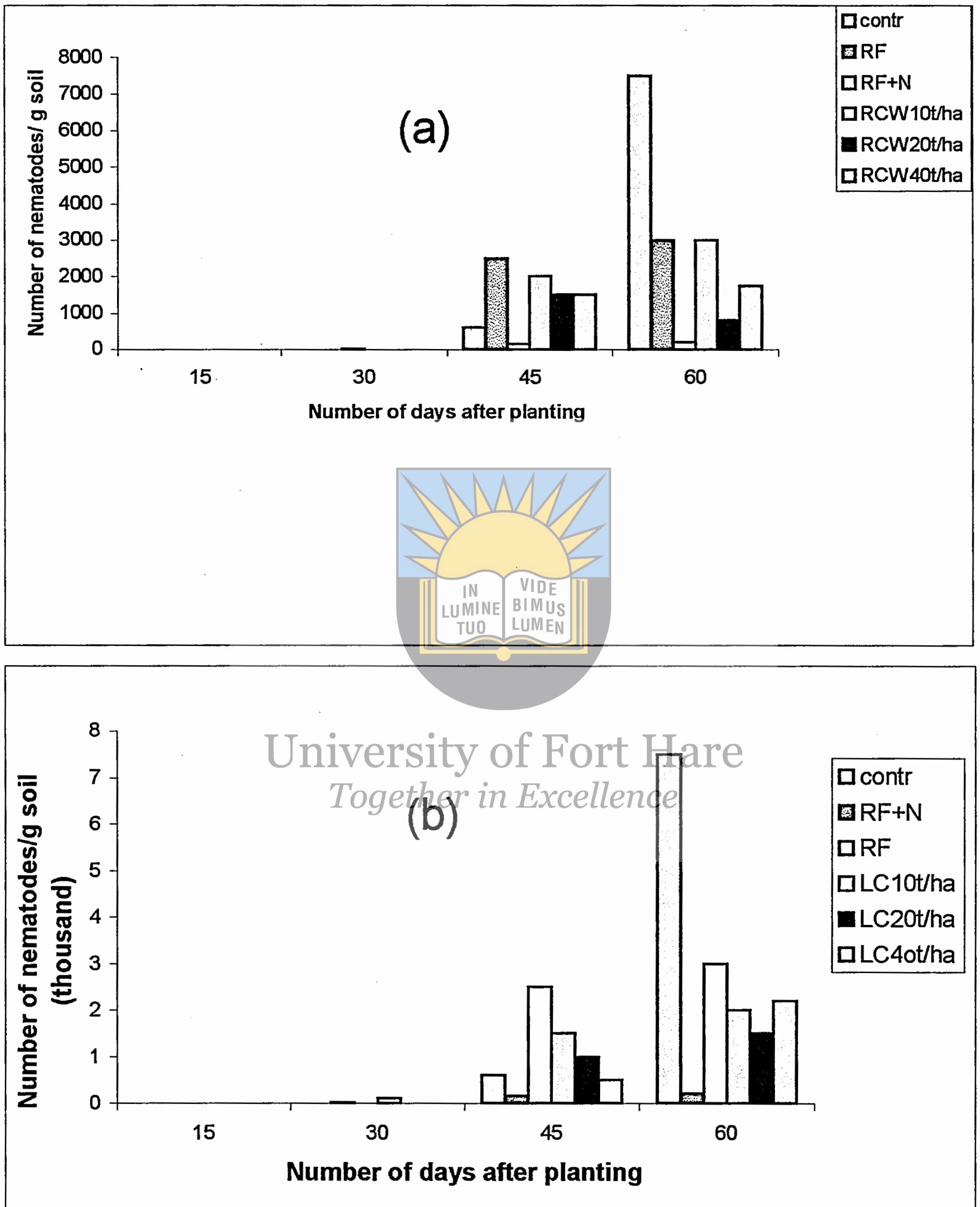


Fig. 3: Changes in nematodes population in soil with time as influenced by added RCW (a) and LC (b).

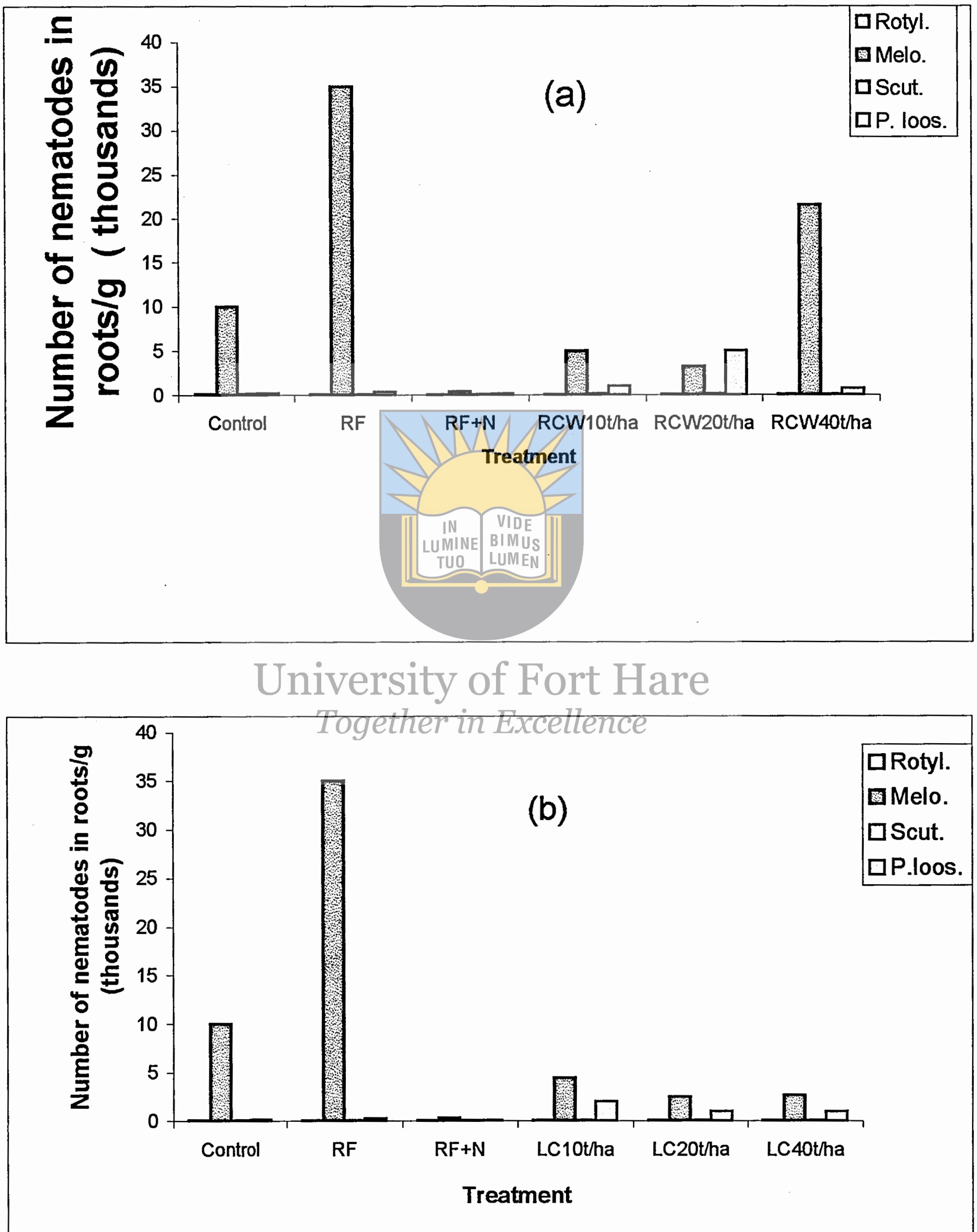


Fig. 4: Effects of RCW (a) and LC (b) on nematode species distribution in plant roots after 60 days of tomato growth.

** Rotyl.: *Rotylenchulus reniformis*
Melo.: *Meloidogyne* spp
P. loos.: *Pratylenchus loosi*
Scut.: *Scutellonema cavenesi*

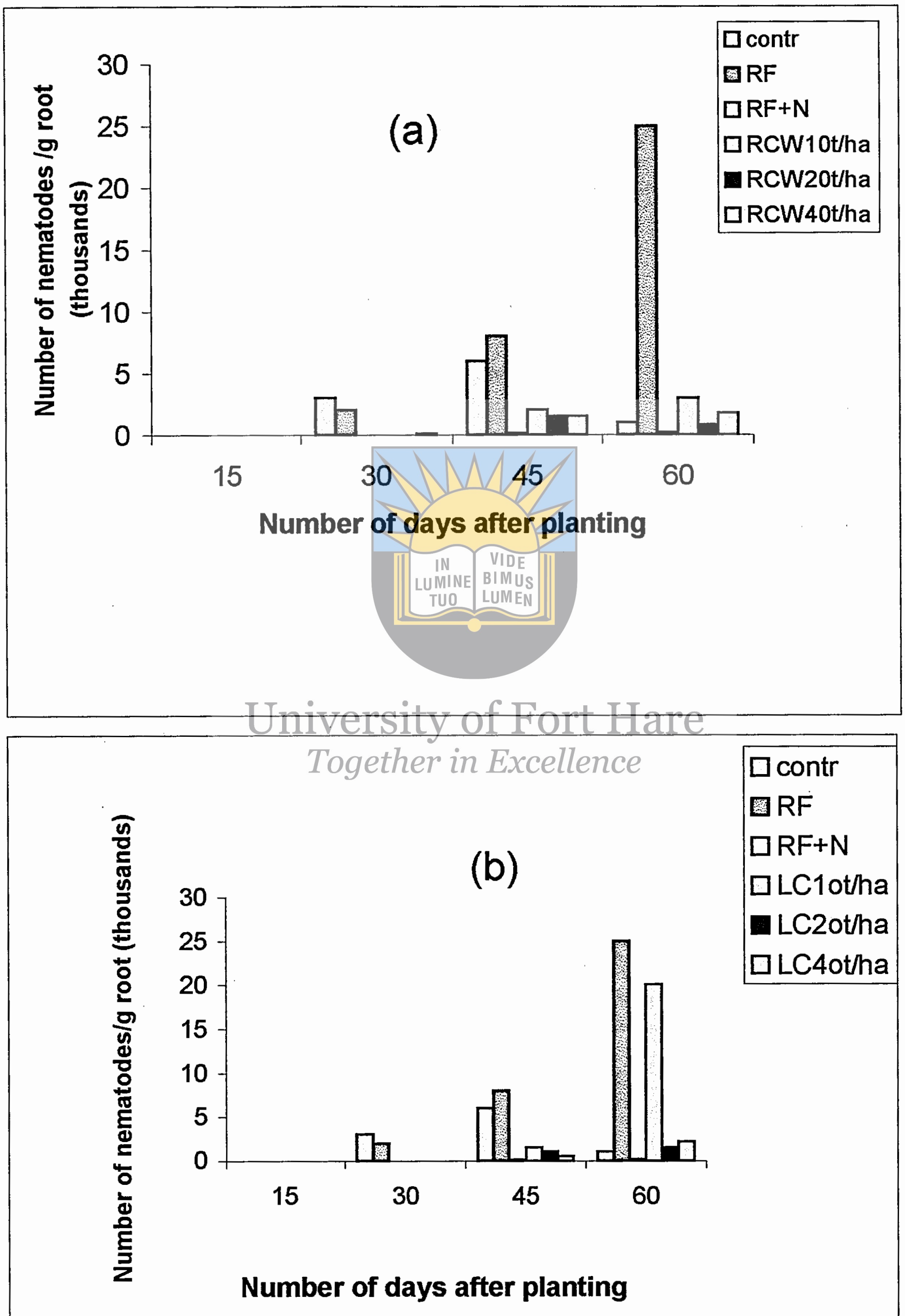


Fig. 5: Changes in nematode population in plant roots with time as influenced by added RCW (a) and LC (b).

CHAPTER 5

DISCUSSION

5.1 Soil analysis before planting

Data represented in Table 2 confirmed that the soil was a poor sandy soil with low levels of N, P, and K but had an acceptable pH for tomato growth. The water holding capacity of the soil was less than the critical level of 120 mm/m (Landon, 1991) indicating that frequent irrigation was necessary to maintain adequate moisture levels for plant growth. The bulk density of 1.8 $Mg.m^3$ is considered reasonable for a sandy soil.

5.2 Effect of amendments on tomato growth

5.2.1 Effects of RCW on tomato growth

The results obtained showed that RCW had a negative effect on plant growth during the first cropping. The relative effects on height (RH) at low, medium and high rates of RCW application were – 37%, –10% and –78%, respectively (Table 4). Similarly, tomato fruit yield obtained for the first crop was depressed by RCW treatments. The RY values were 9.75 %, -3.43 % and –25% for low, medium and high rates of RCW application, respectively. The observed depression in tomato growth and yield was likely a result of N immobilization by soil microorganisms. According to Bartholomew (1965), addition of organic materials with a total N content of ≤ 1.5 % can trigger N immobilization in soil. The RCW that was applied in the present study had a total N content of only 1.15 % (Table 2) which was below the critical level suggested by Bartholomew (1965). The suspected nutrient immobilization can also be explained in terms of the C:N and C:P ratios of the applied materials. Gallardo-Lara and Nogales (1987) reported N immobilization following the incorporation of fresh materials with high C/N and C/P ratios and attributed it to a high nutrient demand of microorganisms from the soil to decompose organic residues with wide C:N ratio, leading to a competition between soil microorganisms and plants for those elements. The optimum C:N ratio for a rapid decomposition and N mineralization was found to be equal or less than 30 (Brady and Weil (1999) or about 30 to 35 (Mustin,1981). With respect to C:P ratios, Rustad and Cronan (1988), cited by Tremblay and Beauchamp (1998), reported that the critical C:P ratio of organic residues above which net immobilization occurs is between 350 to 480. The C:N and C:P ratios of the RCW used in the present study were 51 and 535, respectively. Both values were above the critical values suggesting that RCW could have induced N and P immobilization thus reducing the availability of these nutrients in the soil and their subsequent uptake by plants. The N immobilization is confirmed by leaf N concentrations data observed at 45 days of growth for the first crop (Table 6) that show that leaf N values in RCW treatments were less than those observed in control treatments. Similar findings were reported by Gasser *et al.* (1995), Ndayegamine and Dube (1986) and Tremblay and Beauchamp (1998). However application of RCW had no effect on the leaf concentrations of P in the first crop (Table 6) most likely because the P immobilization was not intense enough to bring significant changes. Similarly, RCW incorporation had no effect on the leaf concentrations of K for the first crop (Table 6) indicating that the observed reductions on tomato growth were largely a result of the effects of added RCW on soil N.

The incorporated RCW had positive effects on the growth and yield of the second tomato crop. The relative effects on height (RH) at low, medium and high rates of RCW application were 56%, 67% and 51%, respectively (Table 4). The corresponding RY values were 62%, 78%, and 53% for low, medium and high rates of RCW application, respectively. Based on these results, 20 tons/ha of RCW application seems to result in maximum yields but needs to be confirmed. The observed improvement in plant growth appears to be related to improved nutrient supply and availability. In contrast to the first crop, the incorporated RCW resulted in increased leaf N, P, and K concentrations (Table 6). The most remarkable increases were observed with leaf N which changed from a depressed situation in the first crop to a situation where significant increases in leaf N were observed at each level of RCW application (Table 6). This suggests that by the time the second crop was planted the C:N ratio of the incorporated RCW had narrowed sufficiently to result in net N mineralization instead of immobilization. These results imply that, in order to derive maximum short-term crop benefits from the RCW of *C. equisetifolia* it ought to be allowed to undergo some decomposition in the soil first before a crop is planted. Studies are therefore required to determine how long before planting should the RCW be incorporated. If the incubation period of RCW before planting is too long, other studies can be conducted to find ways to shorten the period, possibly through co-application with limited quantities of inorganic fertilizers. However, for longer-term crops, the RCW can be used as is without co-application with other materials.

The results of this study indicate that RCW is potentially a good organic amendment that should be seriously considered for use in the Niayes area. If this idea is adopted, it will be necessary to work out a sustainable ramial wood harvesting regime. At the moment the ramial wood becomes available only after the trees have been coppiced. However, it is also practically possible to provide a regular supply of the ramial wood through regular pruning of small branches in between coppicing periods.

5.2.2 Effects of LC on tomato growth

Application of LC to soil stimulated plant growth. The relative effects on height for LC at low, medium and high level were 46%, 90% and 100 %, respectively (Table 4). For LC treatment, the relative yield increase during the first crop was 47% for LC at low level, 81% at medium level and 115% at high level. It was even better during the second crop with 86% for the LC at low level, 100% for the medium level and 132% for the high level.

During the first crop, tomato growth and yield was increased with each increment in LC application, especially when the rate of applied LC was increased from 20 to 40 tons/ha. This indicated that maximum tomato growth and yield was not achieved with the rates of LC application used in the present study.

The positive effects of LC on the growth of the first tomato crop were associated with its effect to increase soil levels of N, P and K. This was in turn reflected in corresponding increases in the plant uptake of the nutrients. According to Foth and Ellis (1988), young mature leaves of tomato are considered to have adequate levels of N, P and K when they contain at least 1.2% N, 0.3% P and 0.3% K. The concentration of nutrients in tomato leaves after 45 days growth, in plots treated with LC was higher than the critical levels reported by Foth and Ellis (1988).

The effect of LC on nutrient supply in the soil was much less during the second cropping compared to the first cropping. However, soil levels of N, P and K associated with the LC treatments were still greater than those observed for the control. The leaf concentration of these nutrients was even lower. Interestingly, tomato growth was not affected by this negative nutrient trend. This indicated the nutrient levels maintained by the treatments were still adequate for plant growth. Nevertheless the results conclusively indicate that litter compost of *C. equisetifolia*, unlike ramial chipped wood, releases most of its nutrients soon after its incorporation into soil. This implies that at least for the first two crops, the litter compost of *C. equisetifolia* can be used as the sole source of nutrients for tomato without supplementing it with inorganic fertilizers. More work is needed to establish the residual effects of this amendment as well as additional amounts that need to be applied regularly in order to maintain yields at reasonable levels.

The availability of LC in Niayes area is not thought to be a limiting factor. This is because there are 10 000 ha of *Casuarina equisetifolia* plantations in the area that, according to Mailly and Margolis (1992) accumulate litter on the forest floor at a rate of 3.3 kg/ m^2/year. The accumulated litter is so thick that it is suspected to prevent *Casuarina* seeds from germinating by isolating them from the mineral soil. In addition, the decomposition of the litter releases acids that further inhibit the germination of the seeds. The partial removal of litter from the forest floor will therefore help to solve the problem of germination of the *C. equisetifolia* seeds and thereby facilitate the natural regeneration of the plantations. Work is, however, needed to establish sustainable levels of the litter compost harvesting taking into account their local contribution to nutrient cycling in the plantation ecosystem.

5.2.3 Effect on soil physical and chemical properties

Soil organic matter increase in soil for plots treated with composted Litter could be attributed to its advanced state of decomposition due to composting, which increased the proportion of oxidizable organic matter less than 2 mm in the soil. RCW in the soil was not decomposed at a noticeable rate and subsequently did not increase organic matter in soil. The improvements observed with the other soil physical and chemical properties were related to the improvement of decomposed organic matter in the soil.

The different CEC obtained from LC and RCW treatments could be related to increased humic compounds in plots treated with LC, and very little humic compounds in soil treated with RCW. This corroborates the observation of Jokova *et al.* (1997) that the CEC of the organic materials increased as the composting progressed. The more highly decomposed the soil organic matter, the greater the CEC. In a sandy soil such as the one in this study, which is low in clay content, the increase in soil CEC is mainly due do the presence of organic matter. The increase of soil organic matter in the soil increases also ion adsorption (Brady and Weil, 1999) and hence soil CEC. Similarly, as a consequence of soil organic matter improvement, soil buffering capacity increased and hence soil pH. The direction of the change in soil pH as a result of treatment application reflected the initial pH of the amendment materials. Soil pH increased in the LC treatment and decreased with the RCW treatment. Besides, considering the pH obtained from this organic materials, LC had the highest pH in solution and soil pH after their incorporation was also higher on that soil. The sensitivity of the soil pH to the organic amendments was likely due in part to the low buffering capacity typical of the soil used in this study. The acids released during RCW decomposition might also contribute to the decrease of the pH in soil treated with ramial wood. According to Duggan and Wiles (1976) the application of composted organic materials to acid soils induced increases in pH. This slight decrease in pH noticed in plots treated with RCW might also have a negative effect on plant growth because, it is known that nitrogen maximum availability is between pH 6 and 8, because mineralization is maximum.

The significant increase of soil water holding capacity in soil treated with litter compost is likely to be due to the capacity of applied material to hold water and, on the other hand, to humic compounds in the soil, which can hold more water than their dry weight. The potential benefit of different organic amendment in enhancing water holding is therefore related to the properties of the amendment in increasing soil pores and soil humic compounds.

The significant improvement of soil bulk density in plots treated with LC could also be explained by the presence of more organic residues decomposed in those plots. Duggan and Wiles (1976), Gallardo-Lara and Nogales (1987) obtained similar results and attributed it to the low density of composted materials and their tendency to increase soil pore size and number. In non-aggregated soil such as the one used in the study, it is likely that any change in bulk density was due to the effect of soil amendments. In this respect it was primarily due to polysaccharides present in the decomposing amendments to humus, which are able to cement soil particles together (Mustin, 1981), resulting in reduced soil compaction and subsequent reduction in soil bulk density. The results suggest that immediate beneficial increases in soil DBD and soil CEC do not automatically follow from the addition of organic amendments, but can be effected by composting the materials before their applications.

The application of RCW did not increase soil EC. However, Mustin, 1987 mentioned the risk of soil contamination by RCW harvested in salted and saline soils. Application of LC to soil increased the electrical conductivity due a high concentration of soluble salt in the litter compost. According to Landon (1991), a soil with an EC varying from 0 to 3 mS/cm is designated as a salt free soil. Although, the slight increase in EC in soil treated with LC at the higher rate was still negligible, these results suggested that care should be taken with compost application at high rates as in the long-term it may result in undesirable increase in soil EC.

In this study no investigations were carried out to assess how RCW decomposes in soil, but considering the nutrient release, their decomposition seemed to be very slow and not sufficient to result in significant changes on soil chemical and physical properties after the second crop. Others studies have reported positive effects from plant residue incorporation two years after their application. Improvement in soil physical and chemical properties from the application of plant residues is related to the rapidity at which the decomposition and humification of the applied material occurs. The C:N and C:P ratios obtained from the applied materials could help to explain their different behaviours. LC amendment had a C:N ratio of 31 and a C:P ratio of 17 which is within the acceptable ranges of organic materials easy to decompose and mineralize while the C:N ratio of RCW was 51 and the C:P ratio 535 which are higher than those considered as optimum for materials easy to decompose.

5.3 Effect on nematode dynamics

The number of nematodes in plant roots of soils treated with organic materials was higher than soil treated with Recommended fertilizer + nematicide (RF+N). This was expected because the nematicide kills nematodes which is not the case with the other treatments. However, the nematode population was much lower in plots amended with RCW and LC compared to the control. This effect could be related to the decomposition of the organic materials in soil that could have resulted in the production of substances that are unfavourable to the growth of the nematodes.

However, with the control, plant development was not as important and, the little root area available was quickly full and while in actual numbers, nematode counts stayed low. In addition, the appearance of nematodes in the roots of plants growing in plots amended with these organic materials after about 45 days. Thus, even if nematodes were present in the rhizosphere, their penetration in the roots was delayed until 45 days after planting and that was enough time for the plants to get well established. This meant that subsequent infestations would not seriously affect production. According to Rodriguez-Kabana and Morgan-Jones, (1987), the addition of organic matter to soil, stimulates organisms proliferation resulting in increased enzymatic activities and accumulation of specific end product compounds that adversely affect the pathogen during some phase of its life cycle. The late infestation of roots plant by nematodes noticed during the study was likely due to the presence of end product which probably affected nematodes during that time. However, Leon (1993) attributed these effects on nematodes to some other mechanisms associated with some bacteria present in the treated soil that attack and penetrate nematodes, castrate males and degenerate female ovaries.

If plants are protected at the beginning of the growing season, and they are able to grow and develop a good root system with a high root surface, they will be vigorous enough even if late penetration occurs, for production to remain very good. According to Cadet *et al.* (1990) an early massive penetration inside the plant root can cause serious damage and subsequently a decrease in root volume. The loss of roots occurs due to the presence of nematodes inside the plant roots. Even if the number of population is decreased in the remaining root system, the possibility of obtaining high production has already been lost. The number of nematodes in the roots of the plants in the RF and the control plots, was an indication of the amendment effect on nematodes. The number in the roots of the RF plants was very high. This was because the soil was well supplied with nutrients, the root systems were well developed and there was no nematicide effect or organic matter protection against an early nematode invasion of roots.

CHAPTER 6

CONCLUSIONS

The application of RCW depressed tomato growth and yield during the first cropping. This was attributed to the effect of RCW to induce intense N immobilization in the soil due its wide C:N ratio, and hence the reduced N uptake of the by tomato plants. Some improvements in growth and yield were observed during the second cropping. These were ascribed to improved nutrient, and especially nitrogen release from RCW following its extended incubation in soil. These results indicated that in order to derive short-term benefits from RCW application it may have to be applied in combination with experimentally determined amounts of mineral fertilizers. A longer-term investigation is, however, necessary to establish the long-term effects of this amendment on the productivity of the experimental soil.

Incorporation of LC resulted in improved tomato growth and production as reflected by increased tomato height and yield relative to the absolute control and recommended fertilizer (RF) treatments during the two croppingss. The positive effect of LC to improve soil and tomato uptake of N, P and K, and possibly other nutrients that were not measured by tomato, was associated with the narrower C:N ratio of the composted litter. The observed effects were greater in the first than the second crop indicating that it had limited residual nutrient value.

Application of LC also improved soil organic matter content, dry bulk density and water holding capacity suggesting that its regular use could result in the long-term improvement of the productivity of the experimental site.

Both RCW and LC treatments inhibited nematode populations in the experimental soil though not as effectively as the nematicide treatment. This, however, indicated that these amendments had the potential to reduce nematode populations in the study area. This finding warrants further investigation to establish the mechanisms involved in nematode population reduction after organic material additions.

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APPENDICES

Appendix 1

Soil Nitrogen after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.00	0.001	0.82	0.49
Treatment	8	0.62	0.077	63.80	0.00
Error	24	0.03	0.001		
Total	35	0.65			

Grand Mean = 0.261
CV = 13.30%

Grand Sum = 9.410
LSD (0.05) = 0.051

Soil phosphorus after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	10.19	3.397	5.01	0.0078
Treatment	8	226.85	28.356	41.80	0.00
Error	24	16.28	0.678		
Total	35	1253.32			

Grand Mean = 9.042
CV = 9.11%

Grand Sum = 325.52
LSD (0.05) = 1.343

Appendix 2

Soil Potassium after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.00	0.001	1.68	0.197
Treatment	4	59.76	7.47	12381.73	0.00
Error	24	0.01	0.001		
Total	35	59.77			

Grand Mean = 0.997
CV = 2.46%

Grand Mean = 35.90
LSD (0.05) = 0.036

Soil nitrogen after harvest for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.00	0.001	0.45	0.72
Treatment	8	0.32	0.04	22.75	0.00
Error	24	0.04	0.002		
Total	35	0.37			

Grand Mean = 0.225
CV = 18.74%

Grand Mean = 8.089
LSD (0.05) = 0.061

Appendix 3

Soil phosphorus after harvest for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	23.83	7.943	5.32	0.059
Treatment	8	405.75	50.719	33.95	0.00
Error	24	35.85	1.494		
Total	35	465.43			

Grand Mean = 10.401
CV = 11.75%

Grand sum = 374.42
LSD (0.05) = 1.993

Soil potassium after harvest for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.00	0.001	1.36	0.28
Treatment	8	21.88	2.734	2699.38	0.00
Error	24	0.02	0.001		
Total	35	21.90			

Grand Mean = 0.668
CV = 4.76%

Grand Sum = 24.055
LSD (0.05) = 0.046

Appendix 4

Plant nitrogen after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.00	0.001	0.18	0.91
Treatment	8	33.37	4.17	1172.55	0.00
Error	24	0.09	0.004		
Total	35	33.36			

Grand Mean = 1.359
CV = 4.39%

Grand Mean = 48.92
LSD (0.05) = 0.087

Plant Phosphorus after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	14.97	4.991	1.40	0.26
Treatment	8	016060908.7	2007613.59	565009.17	0.00
Error	24	85.28	3.553		
Total	35	160611008.97			

Grand Mean = 1548.028
CV = 0.12%

Grand Mean = 55729
LSD (0.05) = 2.751

Appendix 5

Plant phosphorus after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Repetition	3	14.97	4.991	1.40	0.26
Treatment	8	016060908.7	2007613.59	565009.17	0.00
Error	24	85.28	3.553		
Total	35	160611008.97			

Grand Mean = 1548.028
CV = 0.12%

Grand Mean = 55729
LSD (0.05) = 2.751

Plant potassium after harvest for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of Square	Mean Square	F value	Probability
Replication	3	0.06	0.020	1.33	0.287
Treatment	8	14.75	1.843	125.27	0.00
Error	24	0.35	0.015		
Total	35	15.16			

Grand Mean = 1.601
CV = 7.58%

Grand Sum = 57.641
LSD (0.05) = 0.157

Appendix 6

Plant nitrogen after harvest for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of Square	Mean Square	F value	Probability
Replication	3	0.02	0.007	0.65	0.59
Treatment	8	20.02	2.503	261.32	0.00
Error	24	0.28	0.012		
Total	35	20.32			

Grand Mean = 0.752
CV = 14.30%

Grand Sum = 27.080
LSD = 0.157

Plant phosphorus after harvest for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of Square	Mean Square	F value	Probability
Replication	3	17.42	5.806	2.01	0.139
Treatment	8	154135907.5	19266988	6669342.15	0.00
Error	24	69.33	2.889		
Total	35	154135994.3			

Grand Mean = 2100.63
CV = 0.08%

Grand Sum = 75623
LSD = 2.48

Appendix 7

Plant potassium after harvest for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.01	0.002	0.82	0.493
Treatment	8	27.43	3.429	1646.84	0.00
Error	24	0.05	0.002		
Total	35	27.48			

Grand Mean = 0.722
CV = 6.32%

Grand Sum = 26.008
LSD (0.05) = 0.067

Plant nitrogen at 45 days of tomato growth: first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.13	0.043	0.26	0.85
Treatment	8	217.26	27.157	167.20	0.00
Error	24	3.90	0.162		
Total	35	221.28			

Grand Mean = 2.689
CV = 14.99%

Grand Sum = 96.80
LSD (0.05) = 0.656

Appendix 8

Plant phosphorus after 45 days of tomato growth: first crop
ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	1205277.78	401759.25	1.02	0.399
Treatment	8	119300000	14912500	37.98	0.00
Error	24	9422222.22	237759		
Total	35				

Grand Mean = 4477.77
CV = 14%

Grand Sum = 161100
LSD (0.05) = 1022

Plant potassium after 45 days of tomato growth: first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.31	0.104	0.56	0.64
Treatment	8	40.09	5.011	26.73	0.00
Error	24	4.50	0.187		
Total	35	44.90			

Grand Mean = 2.239
CV = 19.34%

Grand Sum = 80.62
LSD (0.05) = 0.705

Appendix 9

Plant nitrogen at 45 days of tomato growth: second crop

ANOVA Table

Source	**Degree of Freedom**	**Sum of square**	**Mean Square**	**F value**	**Probability**
Replication	3	0.32	0.108	0.72	0.54
Treatment	8	41.10	5.138	34.46	0.00

Grand Mean = 1.814
CV = 17.61%

Grand Sum = 65.310
LSD (0.05) = 0.654

Plant phosphorus at 45 days of tomato growth: second crop

ANOVA Table

Source	**Degree of Freedom**	**Sum of square**	**Mean Square**	**F value**	**Probability**
Replication	3	0.02	0.008	2.79	0.062
Treatment	8	0.82	0.102	34.58	0.00
Error	24	0.07	0.003		
Total	35	0.91			

Grand Mean = 0.339
CV = 16.03%

Grand Sum = 12.190
LSD (0.05) = 790

Appendix 10

Plant potassium after 45 days of tomato growth: second crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.16	0.054	1.21	0.32
Treatment	8	38.64	4.830	108.33	0.00
Error	24	1.07	0.045		
Total	35	39.87			

Grand Mean = 1.851
CV = 11.41%

Grand Sum = 66.63
LSD (0.05) = 0.345

Plant growth for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of Square	Mean Square	F value	Probability
Replication	3	0.52	0.175	1.32	0.29
Treatment	8	2359.06	294.883	2220.65	0.00
Error	24	3.19	0.133		
Treatment	35	2362.77			

Grand Mean = 54.51
CV = 0.67%

Grand Sum = 1962.37
LSD = 0.532

Appendix 11

Yield for the first crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	8.77	2.924	6.34	0.0025
Treatment	8	214.047	267.55	580.32	0.00
Error	24	11.07	0.461		
Total	35	2160.31			

Grand Mean = 41.367
CV = 1.64%

Grand Sum = 1489.23
LSD (0.05) = 0.991

Plant growth for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of Square	Mean Square	F value	Probability
Replication	3	0.15	0.050	2.53	0.081
Treatment	8	3061.92	382.74	19397.83	0.00
Error	24	0.47	0.020		
Total	35	3062.54			

Grand Mean = 55.044
CV = 0.26%

Grand Sum = 1981.59
LSD = 0.205

Appendix 12

Yield for the second crop

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.41	0.135	2.36	0.09
Treatment	8	1645.41	205.676	3589	0.00
Error	24	1.38	0.057		
Total	35	1647.19			

Grand Mean = 44.97
CV = 0.53%

Grand Sum = 1619
LSD (0.05) = 0.349

Mean weight of tomato fruits

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	21.21	7.069	0.24	0.86
Treatment	8	1242.33	155.292	5.28	0.00
Error	24	705.26	29.386		
Total	35	9.23			

Grand Mean = 31.533
CV = 17.19%

Grand Sum = 1135.17
LSD (0.05) = 7.911

Appendix 13

Number of fruits in poor quality (rejects)

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	51918.97	17306.32	1.56	0.22
Treatment	8	9722683.50	1215335.43	109.46	0.00
Error	24	266478.28	11103.26		
Total	35	264969.18			

Grand Mean = 618.083
CV = 17.05%

Grand Sum = 22251
LSD (0.05) = 153.8

Percentage of fruit rejects

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.99	0.331	0.59	0.62
Treatment	8	1398.79	174.848	309.53	0.00
Error	24	13.56	0.565		
Total	35	1413.14			

Grand Mean = 13.204
CV = 5.69%

Grand Sum = 475.36
LSD (0.05) = 1.097

Appendix 14

Soil organic matter after harvest

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Repetition	3	0.01	0.003	1.35	0.283
Treatment	8	8.32	1.040	418.68	0.00
Error	24	0.00	0.002		
Total	35	8.39			

Grand Mean = 2.177
CV = 2.35%

Grand Mean = 76.21
LSD (0.05) = 0.073

Soil CEC after harvest

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.08	0.027	1.56	0.22
Treatment	8	865.67	108.20	6244.46	0.00
Error	24	0.42	0.017		
Total	35	866.17			

Grand Mean = 9.23
CV = 1.42%

Grand Sum = 332.59
LSD (0.05) = 0.192

Appendix 15

Soil dry bulk density after harvest

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.02	0.005	2.	0.14
Treatment	8	0.27	0.034	13.03	0.00
Error	24	0.060	0.003		
Total	35	0.35			

Grand Mean = 1.40
CV = 3.65%

Grand Sum = 50.42
LSD (0.05) = 0.075

Soil water holding capacity

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	170.08	56.694	1.19	0.33
Treatment	8	10075.72	1259.46	26.35	0.00
Error	24	1147.17	47.799		
Total	35	11392.97			

Grand Mean = 123.028
CV = 5.62%

Grand Sum = 4429
LSD (0.05) = 10.09

Appendix 16

Soil electrical conductivity

ANOVA Table

Source	Degree of Freedom	Sum of square	Mean Square	F value	Probability
Replication	3	0.00	0.001	0.32	0.81
Treatment	8	0.09	0.011	3.15	0.01
Error	24	0.08	0.003		
Total	35	0.17			

Grand Mean = 1.51
CV = 3.88%

Grand Sum = 54.44
LSD (0.05) = 0.086