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ECOLOGY AND MANAGEMENT OF *PRATYLENCHUS ZEAE* ASSOCIATED WITH MAIZE PRODUCTION IN ZIMBABWE COMMUNAL FARMS

By

Paul Muchena

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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Department of Entomology

1988

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ABSTRACT

ECOLOGY AND MANAGEMENT OF PRATYLENCHUS ZEAE ASSOCIATED WITH MAIZE PRODUCTION IN ZIMBABWE COMMUNAL FARMS

By

Paul Muchena

Pratylenchus zeae and Pratylenchus brachyurus, the major nematode pests of maize in Zimbabwe communal farms, had relative population densities of 50 and 38.5% and absolute frequencies of 52.6 and 21.9% during a 1985/86 survey, respectively. Maize plants which were infected with >1,000 Pratylenchus spp. per 10.0 grams of fresh root weight during the survey had a 48% mean yield reduction. P. zeae were identified to be a major problem of maize especially in natural regions II to IV with sandy soils and a soil pH of 4.8-6.8. High population densities of P. zeae were recovered from maize roots from farms with rainfall range of 600-1,000 mm per year and temperature range of 22.6-30.1°C.

Third to fourth stage juveniles and mature females were identified as the main overwintering stages of P. zeae in a field study and these stages constituted 51.9 and 46.3% of the total population of vermiform stages, respectively. The population was aggregated at depth 0-20 cm but migrated to lower depths during hot and dry months. Clean fallow for one year reduced P. zeae in the soil by 87.5%.

Maize roots and P. zeae were aggregated at depth 0-20 cm in a study conducted in pits. P. zeae in this study had a Pf/Pi ratio of 170. Very few second stage juveniles were recovered in this study. The optimal time for sampling maize roots for P. zeae was 4 weeks after planting at a soil depth 10-20 cm and radius of 0-10 cm.

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Maize root growth was reduced at 11.7% gravimetric soil moisture in loamy sand soil and P zeae population density was only slightly reduced at 5.0% gravimetric soil moisture in a greenhouse study. Another greenhouse study demonstrated the importance of applying adequate soil nutrients in maize plants infected with P. zeae.

Carbofuran, fenamiphos, isazofos and terbufos reduced P. zeae in maize roots by 95, 96, 95 and 93% and increased yield by 67, 54, 37 and 66%, respectively, in a field study. Organic amendments in field and greenhouse studies reduced P. zeae and increased maize growth and grain yield.

Research and literature data on P. zeae were summarized in a P. zeae maize simulation model. The model predicted P. zeae in maize roots with mean error of 7% and below and above ground biomass of maize with mean errors of 17.7 and 11.1%, respectively.

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ACKNOWLEDGMENTS

I would like to thank my major professor, Dr. George Bird, for his excellent guidance and support during my graduate studies at Michigan State University and Plant Protection Research Institute, Zimbabwe; and for his discovery that when a map of Zimbabwe is turned upside down it looks like a root-knot nematode mature female. My appreciation is also extended to the members of my committee, Drs. Stuart Gage, Joe Ritchie, Don Hall, and Frank Fear, for their time, assistance, and enthusiasm in sharing their knowledge and experiences with me.

I have enjoyed and benefited from my association with the faculty, staff and students of the Entomology Department. I also would like to thank Mrs. Becky Mather for sacrificing her weekends while preparing this dissertation.

All members of the Zimbabwe "Nematology Group" deserve special thanks for their friendship and support of my research efforts. I also would like to thank the MSU "Nematology Group" for their friendship and support for all the time that I have been at MSU.

I would like to thank computer programmers Messers Ed Martin and Rodwell Zvarayi for their assistance with the Fortran coding. Also the biometricians in the Department of Research and Specialist Services deserve a special thanks for their help.

Finally, I would like to thank my family, Head of Plant Protection Research Institute, Assistant Director, Research Services, and Director, Research and Specialist Services for their support to the fulfillment of my educational goals.

TABLE OF CONTENTS

2.2.2

2.2.

2.2.

2.2.

2.2.

3. Experim

3.1 Pla
Zi

3.

3.

3.

3.

3.2 O
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3.

3

3

3

3

3.3 S
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s

3

3

3

3

3.3

3.4 Inf
sys

3.4

3.4

3.4

3.4

3.5 Ev
in

3.

3.

3.

3

3.6 In
g

3

3

3

3

3.7 I
r

3.8

3.

3

4.

5.

6.

LIST OF TABLES

Table

Table

Table

Table

Table

Table

Table

Table

LIST OF FIGURES

Figure

Figure

Figure

Figure

1.1 Zi

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1. INTRODUCTION

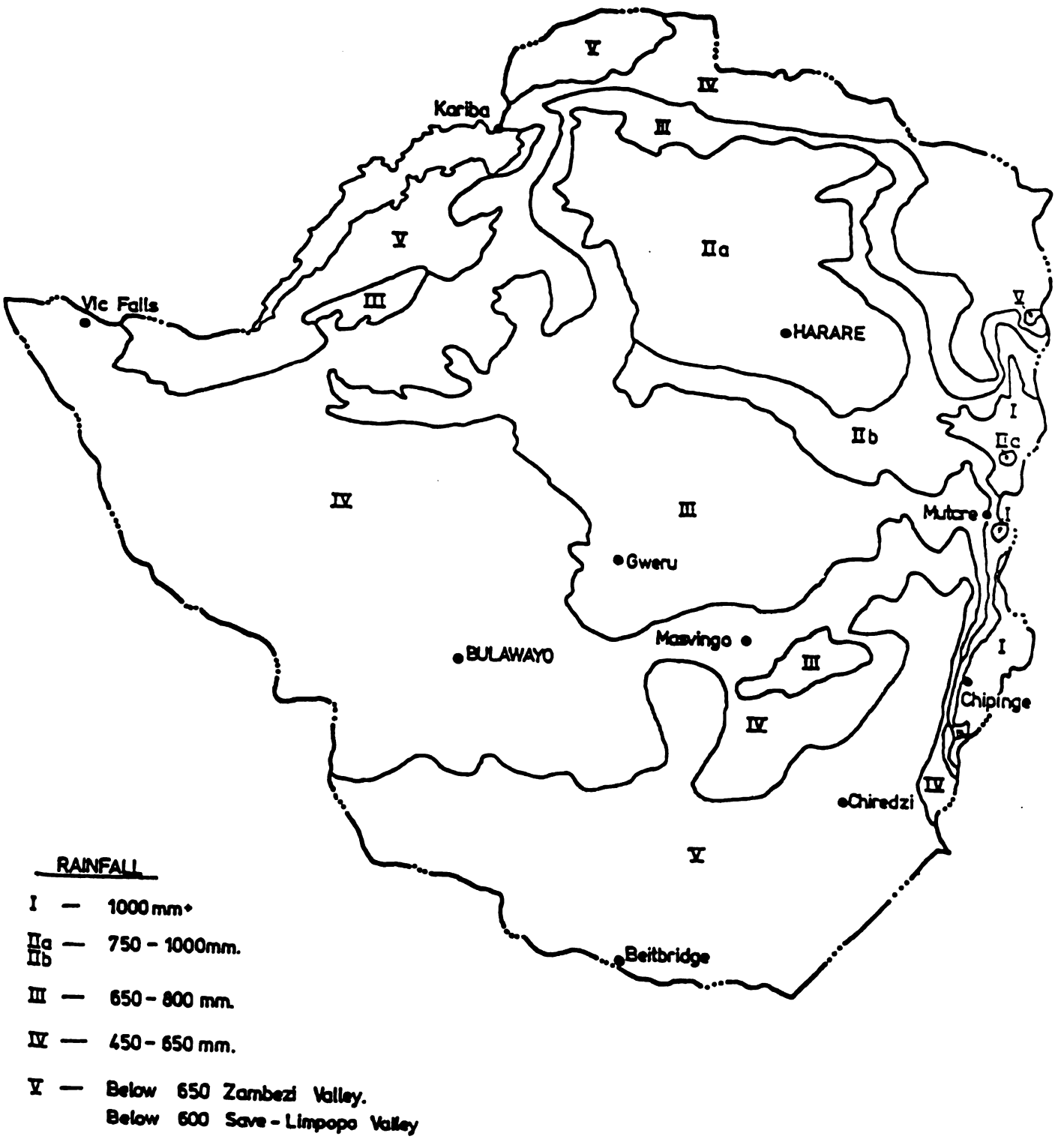
1.1 ZIMBABWE NATURAL REGIONS AND FARMING AREAS

Zimbabwe can be divided into five different natural regions and farming areas according to annual rainfall (Fig. 1.1). Natural regions I to III are in general ideal for intensive maize production and natural regions IV to V receive inadequate rainfall for intensive maize production.

A review of the 1984/85 growing season shows that about 5,485 commercial farmers occupy 9.2 million hectares of land whereas 923,312 communal farmers utilize 2.0 million hectares of agricultural land. The average size for a commercial farm is 1,669 hectares and the average size of a communal farm is 2.5 hectares. Almost all commercial agricultural farms are in natural regions I to III; whereas, only 30% of communal farms are in natural regions I to III. Commercial farmers had 194,586 hectares of land under maize with a mean yield of 3.4 tons/ha; whereas, communal farmers had 1.3 million hectares under maize with a mean yield of 1.0 ton/ha.

The distribution of commercial and communal farmers in Zimbabwe before independence in 1980, was a result of the Land Apportionment Act of 1930 and Land Tenure Act of 1969 which discriminated communal farmers from good agricultural land. Also before independence, communal farmers received very limited services from the Department of Research and Specialist Services, in particular, the Nematology Section which had one nematologist who primarily serviced the commercial farmers. After independence, the establishment of the Nematology Section expanded to four so that the

Fig.1.1 Zimbabwe natural regions and farming areas.



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services of the section were available to communal farmers and the research relevant to communal farm socio-economic considerations.

1.2 GENERAL NEMATOLOGY

Root-lesion nematodes (Pratylenchus spp. Filipjev, 1936) have a world-wide distribution. Corbett (1969) listed the species with the widest distribution as P. brachyurus, P. coffeae, P. crenatus, P. neglectus, P. penetrans, P. scribneri, P. thornei, and P. zeae. Oteifa (1962) found all of these except P. crenatus on crops in the Nile Delta. Egunjobi (1968) found 4 of these in one apple orchard in New Zealand. Gotoh and Ohshima (1963) observed 6 of Corbett's list in Japan, while Sethi and Swarup (1971) and Van Den Berg (1971) found all 8 in northern India and South Africa, respectively. Siddiqi et al. (1973) listed the following 12 species from California: P. brachyurus, P. coffeae, P. convallariae, P. crenatus, P. goodeyi, P. hexincisus, P. neglectus, P. penetrans, P. scribneri, P. thornei, P. vulnus, and P. zeae.

Thames (1982) listed crops of economic importance that are infected by Pratylenchus spp. as follows:

1. alfalfa and pasture legumes - P. coffeae, P. neglectus, P. penetrans, and P. scribneri.
2. cereal crops - P. crenatus, P. neglectus and P. thornei.
3. corn - P. brachyurus, P. hexincisus, P. penetrans, and P. zeae.
4. cotton - P. brachyurus.
5. peanut - P. brachyurus.
6. peppermint - P. penetrans.
7. potato - P. brachyurus, P. crenatus and P. penetrans.
8. rice - P. brachyurus, P. indicus and P. zeae.

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9. soybean - P. alleni, P. brachyurus, P. coffeae, P. crenatus, P. hexincisus, P. penetrans, P. scribneri, and P. zeae.
10. sugarcane - P. brachyurus, P. coffeae, P. delattrei, P. scribneri, P. thornei, and P. zeae.
11. tobacco - P. brachyurus, P. hexincisus, P. neglectus, P. penetrans, P. thornei, P. vulnus, and P. zeae.

All the 39 spp. of genus Pratylenchus (Loof, 1978) are phytoparasites and alter the physiology and ontogeny of host plants. Nematodes in this genus reduce growth, yield and marketability of host plants at high infestation levels.

Plant stress and resulting crop loss caused by plant-parasitic nematodes are governed by soil environment (especially physical structure and water content) and temperature, which in turn strongly dictates the population dynamics of plant-parasitic nematodes (Endo, 1959; Olowe and Corbett, 1976; Norton, 1979). The abundance of P. zeae also influences the population dynamics and pathogenicity of many species and other organisms contributing to plant damage. For example, infection of tobacco by P. zeae decreases the reproduction of Meloidogyne incognita (Johnson and Nusbaum, 1970). Holtzmann and Santo (1970 and 1971) reported that P. zeae increased 220-fold at 30 C in 12 weeks when inoculated alone to sugarcane; when inoculated in combination with Pythium graminicola, the increase was 8-fold. On the contrary, Khan (1959) found populations of P. zeae to be higher in sugarcane roots containing Phytophthora spp. than in those containing P. zeae alone.

Population dynamics of P. zeae are influenced by the initial population density (P_i) of P. zeae at the beginning of the growing period (Olowe and Corbett, 1976); soil texture (Endo, 1959); soil moisture (Townshend, 1972); temperature (Acosta and Malek, 1979; Olowe and Corbett, 1976); complex

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biological associations (Holtzmann and Santo, 1971; Khan, 1963); soil pH (Willis, 1972); and management practices (Endo, 1967; Johnson et al. 1975). To adequately assess the population dynamics of P. zeae, it is necessary to understand the nature of the association among these factors, and the life history of this plant-parasitic nematode. This information is required for the development of predictive pest-crop ecosystem simulations and integrated nematode management programs appropriate to Zimbabwe small-scale farmers.

1.3 THESIS, GOAL AND OBJECTIVES

Thesis

The standard of living of Zimbabwe communal farmers can be improved by appropriate management of the maize root-lesion nematode host-parasite relationship.

Goal

Evaluate the ecology and host-parasite relationships of P. zeae associated with maize (Zea mays L.) in relation to the development of future integrated nematode management programs which can be incorporated into the national rural development programs to:

a) improve crop production so that self-sufficiency in food is achieved,

b) raise the living standards of the rural population,

c) improve the local diet,

d) educate the communal farmers about nematode pests of maize.

Objectives

1.3.1. Identify plant-parasitic nematodes of socio-economic significance associated with maize in Zimbabwe communal farms.

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1.3.2. Evaluate the overwintering mechanisms of P. zeae under clean fallow.

1.3.3. Assess the temporal and spatial distribution of gravimetric soil moisture and how this influence P. zeae population density and maize root density.

1.3.4. Evaluate the impact of organic and inorganic nutrients on P. zeae and subsequent maize growth.

1.3.5. Evaluate the role of cultural practices as alternative control methods of P. zeae associated with maize in communal farms.

1.3.6. Develop a predictive P. zeae simulation model that will be interfaced with an existing CERES-MAIZE simulation model.

1.4 RATIONALE AND RESEARCH APPROACH

Maize was first cultivated in Southern Africa before the arrival of Jan Van Riebeeck in 1652 (Louw, 1982), and is the most important crop in Zimbabwe communal areas. During the 1985/86 growing season, 1,314,000 hectares were under maize production and about 76.1, 15.2, 5.6 and 3.1% of this area under maize was in communal farms, large scale commercial farms, resettlement farms and small scale commercial farms, respectively. The average yield of maize in the respective farming systems were 1.2, 5.7, 1.6 and 2.0 tons/ha. It is apparent that except for the large scale commercial farms, the yield of maize was sub-optimal. The low yield of maize, especially in communal farms, could have been a result of several factors which include pests and diseases. In particular, plant-parasitic nematodes appear to contribute to low yields of maize in communal farms. The magnitude of plant-parasitic nematode problems in Zimbabwean communal farms, where about 80% of the population live (Africa South of the Sahara, 1982-83) is not known. Hence, research associated with improvement of agricultural yields is

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imperative to achieve the national rural development goals. The research was divided into four components (Fig. 1.4.1), presented in relation to the objectives (Table 1.4.1).

A survey to identify the extent of plant-parasitic nematode problems associated with maize production will increase the awareness of communal farmers to plant-parasitic nematode problems and possible diagnostic symptoms. Also, this will identify farms with plant-parasitic nematode populations above the potential pathogenicity thresholds. The survey will also identify plant-parasitic nematode species which are of economic importance in maize production in the communal farms. Once the primary nematode pests of maize have been identified, this information can be used to help structure future research requirements for the communal farms in relation to achievement of some of the national rural development goals.

The current survey was conducted so that it would equally cover all soil textures, rainfall and temperature regimes and different farming systems. Because of logistical problems, it was not possible to cover the whole country in great detail, therefore the detailed survey was conducted in Manicaland province, because this province has examples of all the different farming regions, soil textures and temperature regimes.

After host and soil texture, soil moisture is the most important parameter which dictates nematode population densities, directly or indirectly (Norton, 1979). There are three major methods of measuring soil moisture; volumetric, gravimetric and soil water potential. In the past, soil moisture has been measured using all the three methods, but lack of detailed specifications of soil texture for the first two methods, has led to contradictory results with regards to critical soil moisture for plant-parasitic nematodes (Townshend, 1972; Trivedi et al., 1978; Upadhyay et al., 1974). It

Figure

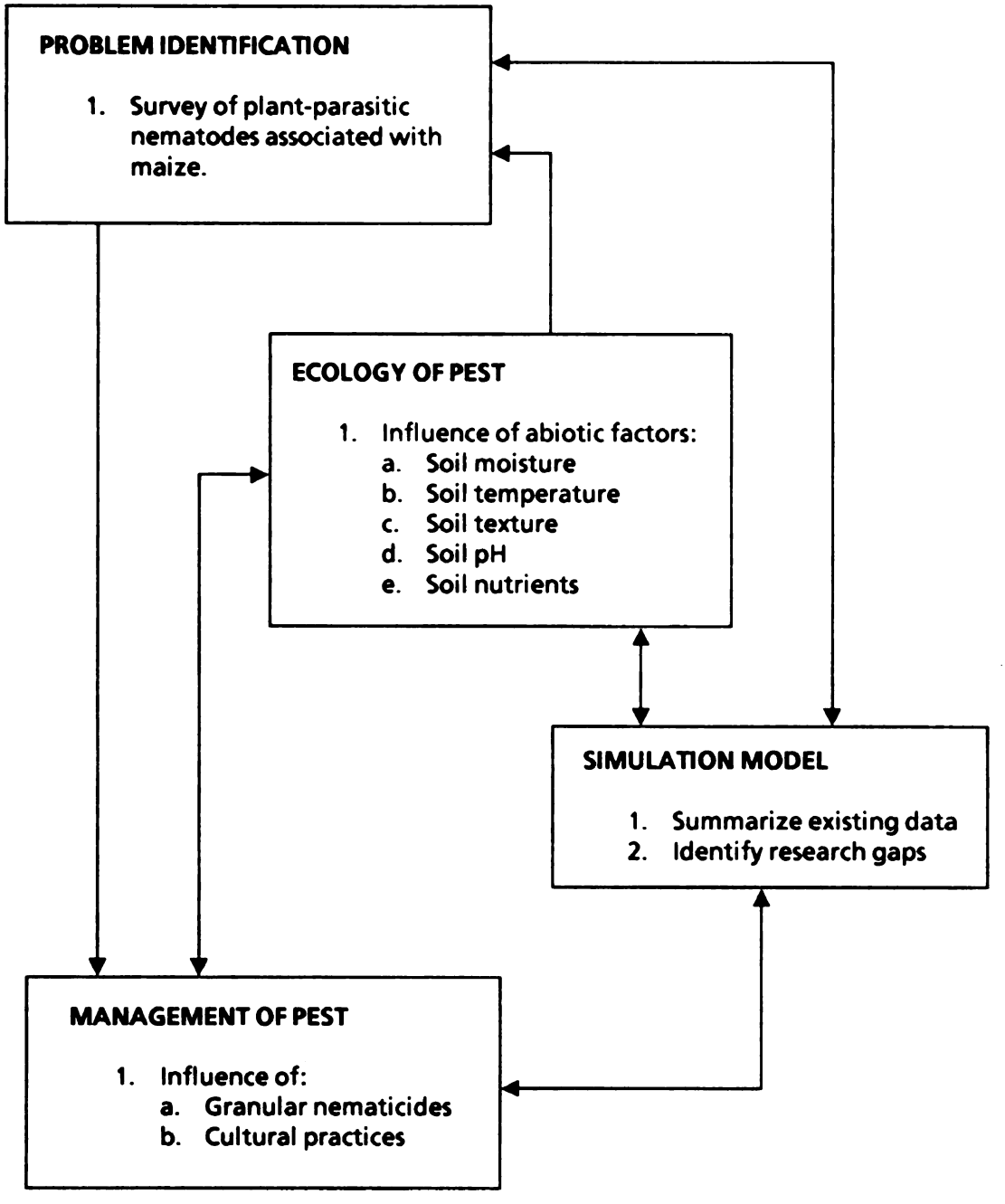

Figure 1.4.1. Conceptual diagram of how the various research components are inter-related.

Table

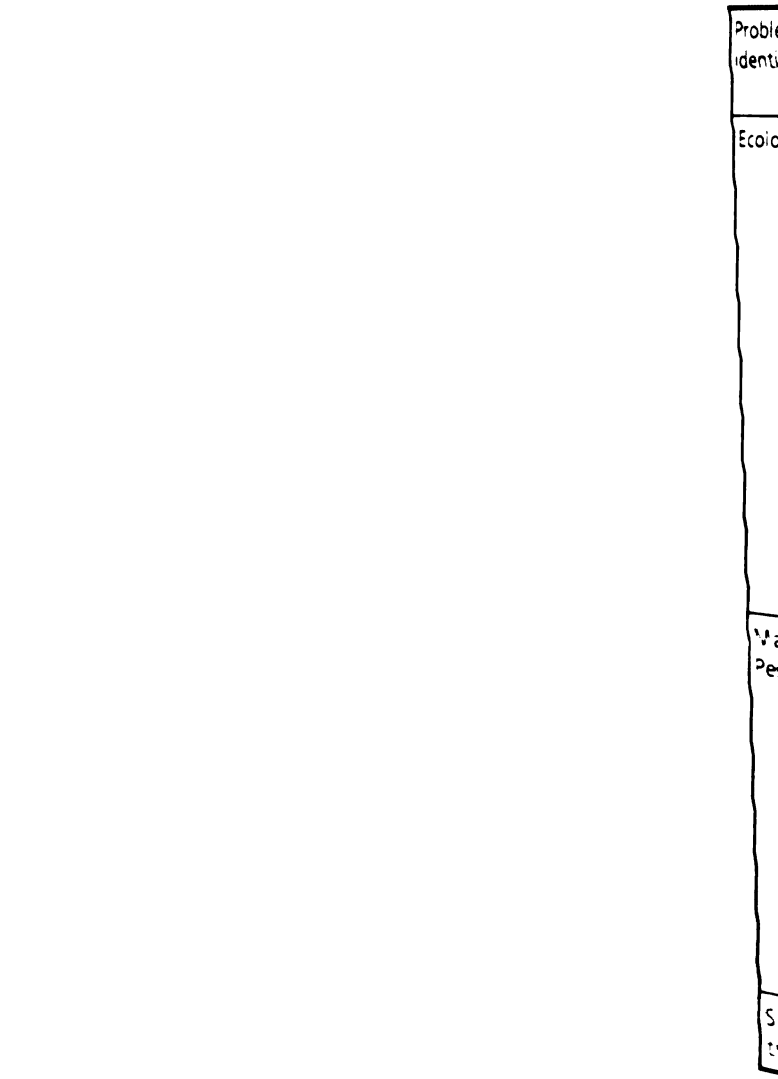

Table 1.4.1. Research program overview.

Problem Identification	Exp. No. 3.1	Plant-parasitic nematodes associated with maize in Zimbabwe	Obj. No. 1.3.1
Ecology of the Pest	Exp. No. 3.1	Plant-parasitic nematodes associated with maize in Zimbabwe	Obj. No. 1.3.1
	Exp. No. 3.2	Overwintering and vertical distribution of P. zeae under clean fallow	Obj. No. 1.3.2
	Exp. No. 3.3	Temporal and spatial distribution of gravimetric soil mositure, maize root system and P. zeae	Obj. No. 1.3.3
	Exp No. 3.4	Influence of gravimetric soil moisture on P. zeae and maize root system development	Obj. No. 1.3.3
	Exp. No. 3.6	Influence of soil nutrients on P. zeae population density and maize growth	Obj. No. 1.3.4
Management of the Pest	Exp. No. 3.5	Evaluation of maize varieties and inbreeds against P. zeae infection	Obj. No. 1.3.5
	Exp. No. 3.7	Effect of granular nematicides on P. zeae associated with maize	Obj. No. 1.3.5
	Exp. No. 3.8	Influence of organic amendments and early plowing on P. zeae pathogenicity on maize	Obj. No. 1.3.5
	Exp. No. 3.9	Effect of organic amendments and the time of application on P. zeae pathogenicity on maize	Obj. No. 1.3.5
Simulation Model of the Pest	Exp. No. 3.10	Simulation model of P. zeae infecting maize	Obj. No. 1.3.6

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is therefore essential to relate all soil moisture measurements to soil water availability (soil moisture potential) in nematology, which will take into account different soil textures.

Influence of soil moisture on P. zeae population dynamics is not documented in the literature. It was imperative, therefore, to evaluate the spatial distribution of P. zeae in relation to soil moisture for an entire year at one month-intervals. Information on soil moisture is required for the initialization of computer simulation models of P. zeae. This information can also be used to show the impact of soil moisture on P. zeae mortality and fecundity. Once the computer initialization has been completed and P. zeae has penetrated root tissue of the host, then the crop will dictate the population dynamics of the nematode. Limits of available water for growth of plants is between the 'permanent wilting point' and 'field capacity' with water contents at potentials of -15 bar and -0.33 to -0.10 bar, respectively (Ratliff et al., 1983; Ritchie, 1981).

Information on the influence of soil moisture on temporal and spatial distribution of maize root density and P. zeae population densities was generated in studies conducted in large pits (3.0 m x 1.0 m x 0.75 m). The pits were ideal for this study because maize root system could grow for at least sixteen weeks without being pot-bound. Soil and root systems were sampled at two weeks intervals so that changes in the P. zeae population densities and maize root system densities could be observed in detail. This detailed information can be used to validate P. zeae - maize computer simulation model output data. Also this information can be used in the development of equations for calculating certain parameters in the computer program.

The impact of P. zeae on maize is documented in the literature (Chevres-Roman et al., 1971; Endo, 1959; Olowe and Corbett, 1976; Martin et al.,

1975). The cited information, however, does not have detailed studies on the influence of different initial population densities of P. zeae, soil texture and different fertilizer levels on maize below ground (root-weight, length and volume) and above ground (shoot weight, leaf length, number of leaves, number of degree days to silking and physiological maturity and total grain yield) biomass.

This information was generated in a host-parasite relationship study conducted in large clay pots at the Plant Protection Research Institute. The study was carried out at this location to enable frequent monitoring of the experiment. The experiment was conducted in large pots to enable harvesting of the entire root system on sampling days.

P. zeae can be controlled with several management strategies. Selection of a specific tactic is influenced by social constraints, economics, biotic and abiotic environments, crop, and level of nematode infestation. When the level of infestation is above a pathogenicity threshold, chemical control is generally an option because of its immediate reduction of the nematode population density. Fumigant nematicides can be used to lower population densities of P. zeae (Johnson and Chalfant, 1973; Martin et al., 1975). Fumigant nematicides, however, have encountered major concerns including phytotoxicity and persistence of residues in the environment. Increasingly, nonfumigant nematicides have been adopted during the last 25 years. They are less phytotoxic, relatively easier to apply, compared to fumigants; require no special equipment, are effective in controlling nematodes at much lower dosages, and leave less persistent residues in the environment (Wright, 1981). The major concerns related to nonfumigant nematicides include their high toxicity to humans. During the last 10 years, nematode control strategies have concentrated towards the integrated

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nematode management (INM). With this approach, cultural and biological control of plant-parasitic nematodes have become increasingly important. Cultural control of P. zeae in Zimbabwe is compatible with the socio-economic structure of the communal farmers. Research was conducted in a communal farm to assess the role of several cultural practices as alternative methods for controlling P. zeae associated with maize. This information is required in the implementation of integrated nematode management programs favorable to beneficial microorganisms in the soil. Also, this information can be incorporated into the P. zeae-maize simulation model and used as a decision-support system.

A preliminary P. zeae predictive simulation model was developed to structure existing information about P. zeae associated with maize and to identify knowledge gaps in the literature. The literature review show that several abiotic factors including temperature and soil texture heavily influence the population dynamics of P. zeae associated with maize (Olowe and Corbett, 1976; Endo, 1959).

The influence of soil moisture on P. zeae population dynamics on maize is not well documented in the literature. Also, it is apparent that P. zeae has been successfully controlled by several nematicides in maize (Johnson and Chalfant, 1973; Martin et al., 1975), but clearly there is lack of information pertaining to use of cultural and biological control and use of resistant maize cultivars in controlling P. zeae on maize. Consequently, research was tailored to address some of the knowledge gaps. The information collected was used to update the preliminary P. zeae predictive simulation model which uses temperature as the main abiotic input.

The updated preliminary P. zeae predictive simulation model was interfaced with an existing CERES-maize simulation model. The CERES-maize

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simulation model has world-wide applicability as long as all the initial inputs for a specific locality are fully specified. The P. zeae-maize simulation model can be used to predict the population dynamics of P. zeae and the impact of P. zeae on maize growth and development under defined environmental conditions. The P. zeae-maize simulation model was validated with research conducted in Chinamora communal area.

2. LITERATURE REVIEW

2.1 Pratylenchus zeae

2.1.1 Classification

Aschelmintha: Nematoda: Secernentea: Tylenchida: Tylenchina: Tylenchoidea: Pratylenchidae: Pratylenchinae: Pratylenchus Filipjev, 1936: type species P. zeae.

Pratylenchus zeae Graham, 1951 commonly known as the maize root-lesion nematode was described by Graham in 1951.

2.1.2 Description

Female: The female has a slender body which will be almost straight when relaxed by gentle heating. It has a lateral field with 4 incisures which extends along the tail beyond the phasmids. The female has a lip region with 3 annules and the stylet is 15-17 µm long with broad anteriorly flattened basal knobs. The dorsal esophageal gland opening is 3-4 µm behind the stylet base. The ovary does not extend to the esophagus and has oocytes in double rows. The monodelphic vulva for the mature female is 68-76% of the body length. The tail shape is generally round or sub-acute with about 20-25 annules (Fortuner, 1976; Nath et al., 1976).

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Male: Males are extremely rare and are not essential for reproduction. The body is ventrally curved when relaxed and is morphologically similar to the females. The male has testis which are outstretched and has multiple rows of spermatocytes. It has well developed spicules which are enveloped by a bursa which extends beyond the anterior end of the spicules (Fortuner, 1976; Nath et al., 1976).

Juveniles: The juveniles are similar to adults except in body size and development of the reproductive parts. The tail tip of second-stage juveniles is slightly pointed (Nath et al., 1976).

2.1.3. Distribution and Hosts

Fortuner, 1976 reported P. zeae as a pest of the following crops:

Cotton - USA

Maize - Brazil, Egypt, India, Panama, South Africa, USA, and Zimbabwe.

Rice - Brazil, Cuba, Ivory Coast, Malawi, Senegal, USA, and Zimbabwe.

Sugarcane - Hawaii, Iraq, Malawi, Nigeria, Trinidad, USA, Venezuela, and Zimbabwe.

Tobacco - Madagascar and USA.

Other hosts are sorghum, millet, rye, soybeans, tomato, oat, sweet potato, wheat, peanut, barley, strawberry, blue lupin, cowpea, Amaranthus spinosus, Ambrosia artemisiifolia, Andropogon virginicus, Chenopodium album, C. ambrosioides, Crotalaria mucronata, C. spectabilis, Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Diodia teres, Echinochloa crusgalli, Eremochola ophiuroides, Heterotheca subaxillaris, Lespedeza sp., Solidago gigantea, Tribulus terrestris, Xanthium pungens in the USA (Ayoub, 1961; Graham, 1951), Panicum maximum and P. purpurascens in Brazil (Fortuner, 1976), Pennisetum glaucum and sorghum x

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sudangrass hybrids (Johnson and Burton, 1973), Capsicum annum in Trinidad (Singh, 1974) and natural uncultivated grassland in Japan (Gotoh, 1970) and in South Africa (Van der Vegte and Heyns, 1963).

2.1.4 Biology and Life History

P. zeae has seven developmental states: egg, four juvenile stages, mature female and mature male. Relatively few eggs are laid, either singly or in scattered groups of 3-4 within a single lesion (Fortuner, 1976). The eggs undergo the process of embryogenesis, and the first-stage juvenile molts to the second-stage juvenile in the egg. Hatching takes about 10-20 days depending on temperature (Fortuner, 1976; Olowe and Corbett, 1976).

Second, third and fourth-stage juveniles and adults are all infective (can penetrate roots). Second stage juveniles are 0.21-0.26 mm in length and have a stylet of 11-15 µm in length (Nath et al., 1976). Second-stage juveniles molt and become third-stage juveniles. Third-stage juveniles are 0.38-0.46 mm in length and have a stylet 15-17 µm long (Nath et al., 1976). Third-stage juveniles molt and become fourth-stage juveniles. Fourth-stage juveniles, developing females are 0.41-0.56 mm in length and have stylet 11-15 µm long and a vulva at 66-70% body length (Nath et al., 1976). Developing females molt and become adult females. Females are 0.50-0.60 mm in length and have a stylet 15-18 µm long and a vulva at 70-80% of the body length (Nath et al., 1976). Very few developing juveniles molt to become males. Males are 0.40-0.42 mm in length and have a stylet 15 µm long (Fortuner, 1976; Nath et al., 1976).

P. zeae penetrates maize roots at the point of emergence of lateral roots with the main root (Olowe and Corbett, 1976). Penetration occurs at preferred sites in large numbers rather than singly (Olowe and Corbett, 1976). Krusberg (1960) assayed homogenates and extracts of P. zeae for

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The optimum temperature for invasion of maize roots by P. zeae is 20°C (Olowe and Corbett, 1976). After invasion, P. zeae moves both inter- and intra-cellular causing mechanical breakage of cells and necrosis resulting in cavities in the cortex and stele of maize root. P. zeae also cause a deposition of dense staining substances that occludes phloem tissues and xylem vessels (Olowe, 1976; Olowe and Corbett, 1976).

Optimum movement of P. zeae in the soil occurs when pore sizes range between 180 to 40 µm, when pore size is less than 40 µm, migration of P. zeae is markedly reduced (Olowe and Corbett, 1976; Endo, 1959). The presence of plant roots is conducive to nematode migration and there is little or no migration in the absence of root exudates (Endo, 1959).

P. zeae survives the dry season mainly in volunteer maize plants and weed species in harvested maize plots (Egunjobi and Bolaji, 1979; Fortuner, 1976). The main weed species in which P. zeae survives are Digitaria spp. (Fortuner, 1976), Axonopus compressus, Amaranthus viridis L. and Commelina nudiflora L. (Egunjobi and Bolaji, 1979). Nematodes are also able to survive the dry season in clean fallow soil(Fortuner, 1976) and eggs as well as motile stages are capable of surviving the dry season (Egunjobi and Bolaji, 1979).

2.1.5 Pathogenicity

Pathogenicity by nematodes on maize is a concept documented only relatively recently (Norton, 1984). Papers by Graham (1951) and Christie (1953) are important because they were some of the early works that implicated nematodes as pathogens of maize. Endo (1959) showed that

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maize, crabgrass, millet, rye, soybean, sorghum and sudan grass were good host plants for P. zeae reproduction.

Gross symptoms of damage caused by Pratylenchus spp. vary with the degree of nematode infestation and the environmental conditions. Above-ground symptoms range from severe stunting with no yield to losses demonstrated only by carefully controlled experiments (Norton, 1984). Chlorosis or other discoloration often is evident in severe instances, but frequently is absent in mild infestations.

Reduction of plant height, stalk diameter; and stalk and root weights of infected plants compared with noninfected ones has been demonstrated (Norton, 1984). These symptoms are common in the field when large populations of Pratylenchus spp. occur and agree with the negative correlations of yield with nematode numbers (Bergeson, 1978; Egunjobi, 1974).

Graham (1951) reported that early water-soaked root lesions containing P. zeae could be easily overlooked. Later the lesions become distinctly discolored, and contain up to 80 eggs and 80-100 nematodes in lesions 5 mm long. Feeding in the fibrous roots can result in the destruction of the cortical parenchyma, resulting in sloughing off of this tissue. Severe pruning of the roots can occur. Olowe and Corbett (1976) reported that P. zeae can damage maize roots in the absence of other organisms.

Maize yield increases of 13-14% in India (Bergeson, 1978), 31% in Georgia (Johnson and Chalfant, 1973), 33-52% in Zimbabwe (Martin et al., 1975; Muchena et al., 1987), 10% in Iowa (Norton et al., 1978), 54% in South Dakota (Smolik, 1978), and 33-100% in South Africa (Walters, 1978) have been attributed largely to control of root-lesion nematodes over small or wide areas. Extensive pathogenicity depends on optimum temperature

conditions and soil texture for development of the nematode and the disease (Olowe and Corbett, 1976; Endo, 1959).

2.1.6 Interaction Between P. zeae and Abiotic Factors

There are many abiotic factors that affect the development of P. zeae. The most important are temperature, moisture, soil texture, and soil pH.

2.1.6.1 Temperature

Temperature is one of the most thoroughly studied edaphic factors that affect Pratylenchus spp. Gradations in temperature may occur laterally in the field as well as vertically where there is a lag in diurnal fluctuation from the surface to the deeper layers. The degree of fluctuation and time lag at different depths are strongly influenced by soil texture and moisture (Norton, 1979).

Temperature affects all life stages of Pratylenchus spp. About 16-32% of P. zeae eggs hatch in 15-20 days at 24-27°C (Norton, 1984). Olowe and Corbett (1976) reported that penetration, reproduction and pathogenicity of P. zeae in maize are related to ambient temperature (Table 2.1.1). Olowe and Corbett (1976) also reported that percent invasion of P. zeae into maize roots is related to the population density of P. zeae in the soil (Table 2.1.2).

2.1.6.2 Moisture

Moisture and temperature often interact. Consequently, it is usually difficult to separate the effect of the two. Overall, however, moisture is an important abiotic parameter governing nematode populations, directly or indirectly (Norton, 1979). Constant soil moisture is difficult to maintain and thus there are a few direct observations on the effect of soil moisture on nematode population dynamics.

Optimum plant growth occurs between 75 and 100% of field capacity (Norton, 1979). It might be expected that when nematodes reach large

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population densities, the growth requirements relative to moisture and other abiotic parameters are those similar to the host. Townshend (1972) reported that penetration of P. penetrans and P. minyus peaked at moisture tensions between 10 and 100 cm H_20. Koen (1967) reported that decrease in soil moisture content significantly lowered the population density of P. brachyurus in the soil faster compared to the control in which moisture content was maintained around 12% (Table 2.1.3)

Penetration of roots by Pratylenchus spp. tend to peak at higher moisture tensions as temperature increases, particularly in loam soil, and thus nematodes gain access to roots from smaller pores. This increased penetration as temperature increases may be the result of reduced surface tension (74.2 dynes/cm at 10°C and 71.2 dynes/cm at 30°C) and viscosity (1.3 centipoises at 10°C and 0.8 centipoises at 30°C) of the soil moisture (Townshend, 1972). The quantity of available water is a major difference in two different soils and in part determines the degree of stress placed on a crop. Thus a crop on sandy loam with only 5% available water would be under greater stress than one on silt loam with 17% though both crops may be equally infected and damaged (Townshend, 1972).

2.1.6.3 Soil Texture

Certain nematodes develop more frequently and more abundantly or cause greater damage in certain soil textures than in others (Norton, 1979). For example, P. zeae is most common in sandy soils, but P. hexincisus is most common in medium to heavy textured soils (Norton, 1979). Endo (1959) reported that growth rate (dN/N dt) of P. brachyurus on cotton was 0.6, 27.9, 8.4 and 0.65 on sand, sandy loam, loam, and clay loam soil, respectively. This implies that nematode reproduction is influenced by soil aeration, pore

Table 2.1.1. Influence of temperature on P. zeae penetration, reproduction and pathogenicity in maize (Olowe and Corbett, 1976).

Temp. (°C)	% invasion after 60 hrs.	Days for a life cycle	Population density after 90 days	% decrease in root growth
≤ 15	45	84	158[1]	
20	55	42	2602	14
25	40	28	9011	21
30	30	21	13358	25
≥35	25	21	758	6

[1]Initial population density (Pi) = 275 ± 15.

Table 2.1.2. Influence of P. zeae initial population density on percent invasion into maize roots (Olowe and Corbett, 1976).

Initial population density in 10.0 cm^3 of soil	Percent invasion after 60 hours
10	20
50	45
80	65
100	75
200	76
400	70
700	60
800	45
1000	15

Table 2.1.3. Influence of drought on P. brachyurus over a period of 20 weeks (Koen, 1967).

Weeks	Soil left to dry		Control (wet soil)	
	P. brachyurus in 250 cm^3 soil	% soil moisture	P. brachyurus in 250 cm^3 soil	% soil moisture
0	188.2	12.1	188.5	12.2
4	102.6	4.2	90.0	12.4
12	46.3	2.1	71.2	12.3
20	30.3	2.0	56.1	12.5

space, particle size, and nematode motility. P. zeae motility in soil is heavily influenced by soil texture, Endo (1959) reported that after four months: 72.3, 24.5 and 3.2% of P. zeae (Pi) will travel one inch in sandy loam, loam and clay loam soil, respectively.

It is therefore quite apparent that soil texture plays a significant role in P. zeae growth and development. Soils of good tilth are of low bulk density (Db 1.5) and thus soil aggregates and pore sizes are most suitable for penetration of roots by a nematode (Townshend, 1972). It is now becoming generally recognized that pore sizes associated with different crumb sizes are as important or more important than sizes of the individual particles (Norton, 1979).

2.1.6.4 Soil pH

The literature suggests that the pH of the soils may well be a significant factor in nematode behavior (Norton, 1979). Using initial pH values of 4.0, 6.0 and 8.0, Burns (1971) found that the greatest colonization of soybean roots by P. alleni was at pH 6.0 ($P = 0.01$). Morgan and MacLean (1968) found that *P. penetrans* grew best in vetch roots at pH 5.5-5.8 and declined rapidly

at pH 6.6 and above. In greenhouse studies, 30-week specific growth rates of P. penetrans in alfalfa were 64.4 and 47.1 at pH 5.2 and 6.4 respectively, but only 4.1 and 2.9 at pH 4.4 and 7.3, respectively (Willis, 1972). There are no studies on pH that have been related to P. zeae. It is, however, believed that the behavior of P. zeae in relation to pH should be similar to other Pratylenchus spp. studies cited.

2.1.7 Control

Plant-parasitic nematodes cause economically significant crop losses in tropical, subtropical, and temperate agricultural production systems (Bird, 1981). Recognizing the significance of plant-parasitic nematodes is an important part of early modern nematology, 1845-1907 (Bird, 1981). In the last century, few economically appropriate nematode control tactics were available for protecting major food and fiber commodities from nematodes (Bird and Thomason, 1980). In the 1940's, the discovery of the soil fumigants, suitable for controlling phytopathogenic nematodes, gave added impetus to the Science of Nematology. Much more recently, the development and availability of non-fumigant organophosphate and organocarbamate nematicides, increased the range of agricultural crops where nematode populations can be managed with chemicals. In the past 10 to 15 years, the effort to include all plant protection disciplines in a systems approach to integrated pest management (IPM) greatly enhanced nematological studies (Bird and Thomason, 1980). Integrated pest management can be defined as: a systems approach to reduce pests to tolerable levels through a variety of techniques, including predators and parasites, genetically resistant hosts, natural environmental modifications, and when necessary and appropriate, chemical pesticides (Bird, 1981). Management procedures should usually be

implemented when the marginal revenue derived from the management input is equal to or exceeds the marginal cost (Ferris, 1978).

$$MC = \frac{\alpha TC}{\alpha N}$$

where MC = marginal cost, TC = total cost of production, N = total yield, d = derivative, and

$$MR = \frac{\alpha TR}{\alpha N}$$

where MR = marginal revenue, TR = total revenue, N = total yield or output and d = derivative. The economic threshold (MC = MR) is a dynamic concept. It depends on the cost of the management input, agricultural production system economics, nature of the nematode and population density, and other environmental parameters (Bird, 1981).

There are four primary means of controlling plant-parasitic nematodes: cultural, chemical, biological, and physical.

a. Cultural means of control

The cultural means of nematode control can involve several different practices used separately or jointly. These are fallow, crop rotation, organic amendments, early plowing during the dry season, time of planting, and resistant varieties.

Fallowing. The land should be kept free of all vegetation, including weeds, for varying periods of time by frequent soil disking, plowing, harrowing or application of herbicides to prevent plant growth. The end result is the reduction of the nematode population through starvation and desiccation (Lehman, 1978; Norton, 1978; Smolik, 1979). At planting, seeds

are placed in upper layers with low plant-parasitic nematode populations. If, however, the farmer plows the field just before planting, the soil that was least exposed to solar radiation and drying will be turned up and the seedlings will be exposed to much higher plant-parasitic nematode population densities (Lehman, 1978). Fallow is primarily effective under conditions of high soil temperatures and no spring rainfall (Ayoub, 1980).

Egunjobi and Bolaji (1979) reported that clean fallow reduced the population density of Pratylenchus spp. in Western Nigeria during the dry season. This method may be a viable nematode control option in Zimbabwe where spring temperatures are generally very high and its dry.

Crop rotation. Crop rotation is the oldest and still most widely used field control measure for nematodes (Mai, 1971). An effective crop rotation involves the introduction of a nematode-resistant plant which can be grown successfully within the same climatic conditions as the principle crop. Unfortunately, it is difficult to pick crops which will be compatible because some plant-parasitic nematodes thrive on a wide range of host plants (Ayoub, 1980); Endo (1959) reported the following crops as non-hosts for P. zeae: bean (Phaseolus vulgaris L. var. Cotender), clover (Trifolium repens L. var. Crimson, Ladino and Red), cotton (Gossypium hirsutum L. var. Coker 100-W) and water melon (Citrullus vulgaris Schrad. var. Congo). Therefore, where possible, these non-host plants should be rotated with maize.

Crop rotation has some limitations. Most notably, populations of nematode species which do not feed on one crop in the rotation may occur on the alternate crop. There are also some economic problems involved with this method since the non-host crop grown in the rotation may be of low monetary value. The most serious limitation of this method in Zimbabwe is that most communal farmers have land resources of very limited sizes and

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they can not afford to grow any other crop besides maize which is the staple food crop. Crop rotation is also disadvantageous because the various crops in the rotation may require different equipment and expertise (Ayoub 1980).

Organic amendments. Tarjan (1977) found the application of municipal solid waste compost to one-year-old Citrus limon seedlings infested with P. coffeae at rates of 2, 4, 9, or 18 MT per ha increased weights of all plants treated over weights of controls. Miller (1978) found that freshly ground green leaves of some plants, reduced populations of P. penetrans when mixed with soil in a ratio of 1:25. After 21 days, the number of P. penetrans were reduced to less than 20 percent compared to those in untreated soil by leaf homogenates of Pachysandra terminalis, dogwood (Cornus florida), tomato (Lycopersicon esculentum), white pine (Pinus strobus L.), red oak (Quercus borealis), and blue-grass (Poa pratense). Gommers (1981) listed the toxic effects of asparagusic acid and dihydroasparagusic acid from asparagus on P. penetrans. Organic amendments appear to be a viable nematode control option in small scale farming.

Resistant varieties. Veech (1982), in discussing the resistance of plants to nematodes, stated that there are two general classes of resistance: preinfection resistance and postinfection resistance. In postinfection resistance the plant may produce morphological defenses ('walling off') or biochemicals such as hydrolytic enzymes, protein inhibitors, or phytoalexins that interfere with development of the invading organism. In his review of the production of phytoalexins in response to infection by Pratylenchus, the author included the production of phaseolin by red kidney bean (Phaseolus vulgaris) inoculated with P. penetrans and the production of coumestants by lima bean (Phaseolus lunatus) invaded by P. scribneri. While there may be other examples of resistance to Pratylenchus based on phytoalexins

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production by the host, these appear to be the only ones in which the phytoalexin has been isolated and identified.

Graham and Heggestad (1959) found some evidence for a hypersensitive reaction to P. brachyurus in certain tobacco cultivars and breeding lines. Tobacco cultivar 'PD 406' was found to be resistant to P. brachyurus. Resistance of maize plants to P. zeae has also been reported. Maize varieties Nab Elgamal, Early American and Giza Baladi showed less damage from P. zeae than Single Cross 14 and Double Cross 67 (Oteifa and Taha, 1964). Tiflate pearl millet is more resistant than other millets and sorghums to injury by P. zeae (Johnson and Burton, 1973).

b. Biological control

Mankau (1980) reviewed recent developments in biological control of plant-parasitic nematodes and concluded that research on natural enemies of nematodes showed promise for the future. Pastueria penetrans was shown to reduce the numbers of P. scribneri recovered from soil and roots of beans. Other tests demonstrated that small amounts of soil infested with spores of Pastueria penetrans could be used to transmit the organism to uninfested sites. Tests with seven nematicides currently used for control of nematodes did not show noticeable effect on the parasite.

c. Chemical control

A "good" nematicide should have most of the following characteristics: (1) penetrate barriers such as soil, plant tissue and the nematode cuticle; (2) control the major groups of plant-parasitic nematodes (sedentary, semi, and migratory endoparasites and ectoparasites); (3) not phytotoxic to the plants; (4) not leave harmful residues in soil or plants; (5) degrade within a reasonable time after application; (6) offer no hazard to man, domestic animals or wildlife; (7) have a short waiting period or none at all between

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treatment and planting; (8) be easy and safe to apply; (9) be inexpensive and effective in small amounts; (10) not permit the nematode to build up resistance to the toxic effects.

There are two basic types of nematicides: fumigants and non-fumigants. Soil fumigants are injected into soil, vaporize, and extent their toxic action as a gas. Non-fumigants do not vaporize and are applied as granules or liquid.

Soil fumigation is a widespread form of nematode control (Ayoub, 1980). This method of applying chemicals to soil originated in France in the early 1860's. The present soil fumigants, however, originated in 1943 with the discovery of dichloropropene-dichloropropane (D-D). Soil fumigants can be divided into classes based on the method of application: pre-plant, at planting and post-plant treatments. All of them are designed to inject the fumigant into the soil or to mix it with soil. The equipment used in the fumigation is basically the same. There may be slight modifications in equipment to accommodate the root structure for existing plants during post-plant treatments.

Pre-plant treatments. In some cases, a soil fumigant is too phytotoxic to be applied directly in the presence of a plant. When this is true, the pre-plant method of application is used. The soil is fumigated before the crop is planted and significant time is allowed to elapse before planting so that the chemical vapors dissipate. Although this treatment usually does not eradicate the nematode population, a very high percentage of control is obtained.

Pre-plant treatments should only be applied after the land is properly prepared so that the volatile gases of the fumigant will be most effective. This involves plowing, chiseling, or disking the soil to the proper depth. The

release of volatile gases requires maintenance of an adequate moisture level in the soil. The temperature of the soil is also important. Depending on the specific fumigant, the soil temperature at the depth of application should generally be at least 10°C. For maximum effectiveness, the soil should be sealed by ringroller or tarpaulin immediately after the fumigant has been applied so that the nematicidal chemicals can not escape. At-plant treatments can also be applied like the pre-plant treatments.

In Zimbabwe, P. zeae has been controlled by the following fumigant applied two weeks before planting (Martin et al., 1975):

EDB 99% 3.5 ml/planting station.

In Georgia, P. zeae has been controlled by the following fumigants (Johnson and Chalfant, 1973):

1,3-D 15.3 liters active ingredient/ha

EDB 3.8 liters active ingredient/ha

Non-fumigant nematicides. Non-fumigant nematicides have several advantages when compared to fumigants which sometimes outweigh their greater basic cost. They are generally much less phytotoxic, relatively easier to apply, are effective in controlling at much lower dosage rates, and have less persistent residues (Wright, 1981). Non-fumigant nematicides can be grouped into organophosphate and organocarbamate compounds. It is generally accepted that nematicides belonging to these groups act by impairing nematode neuromuscular activity, thereby reducing movement, invasion, feeding, and consequently the rate of development and reproduction (Starr et al., 1978; Steele, 1977; Wright, 1981). It is also apparent that low concentrations of these compounds can affect the sensory behavior of nematodes and this may be an important component in crop protection (Wright, 1981).

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Organophophates and carbamates act principally by inhibition of acetylcholinesterase (AChE) at cholinergic synapses in the nematode nervous system (Ware, 1978). AChE is thought to be the most important enzyme involved in transmitter destruction at cholinergic synapses, although pseudocholinesterase (acycholine acylhydrolase) may also contribute (Wright, 1981). One of the general features of the action of organophosphate and carbamate nematicides is that effects on the nematode are reversible on removal from the pesticide (Steele, 1977; Wright, 1981). Wright (1981) reported that recovery of nematodes can be more pronounced following treatment with carbamates than with organophosphates.

In Zimbabwe maize production, P. zeae can be controlled by carbofuran (Furadan 10G) applied at a rate of 20 kg/ha at-planting in furrows and incorporated (Martin et al., 1975). Muchena et al. (1987) have also shown that effective control can be obtained by applying isazofos (Miral 10G) and terbufos (Counter 10G) applied at 20 and 10 kg/ha, respectively in furrow and incorporated.

P. zeae has been controlled by aldicarb (Temik), carbofuran (Furadan), phenamiphos (Nemacur), and ethoprop (Mocap) in Georgia applied at a rate of 6.7 kg a.i./ha (Johnson and Chalfant, 1973).

2.2 Zea mays L.

Maize (Zea mays L.) differs from most other species of the grass family in being monoecious. The terminal inflorescence (the tassel) produces pollen only; whereas, the ear shoot, with the grain, develops as a lateral branch from the lower central portion of the stem. In the inflorescence of maize and other Gramineae the flowers are borne in 'spikelets'. These occur in pairs and each spikelet contains two flowers. In the tassel the flowers have three

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anthers and each produces about 10,000 pollen grains for every potentially fertilizable ovule (Bunting, 1978). Only one of the two flowers in the female inflorescence in each spikelet normally develops. In each female flower the single ovary terminates in a long style, and together the styles form the 'silks'. The fertilized ovary develops into a kernel, the rate of development depends primarily on temperature. The row number of an ear is genetically controlled and extends from 4-30, though 8 to 16 is the range most commonly encountered in most varieties (Bunting, 1978).

The maize kernel is botanically a fruit, a caryopsis, as in all Gramineae. A thin, normally colorless, pericarp surrounds the endosperm and embryo. The endosperm comprises about 85% of the seed weight and consists mainly of starch. In maize, the hot water soluble starch, amylase fraction, usually comprises about 25% of the total, and the insoluble amylopectin fraction the other 75% (Bunting, 1978).

Characteristics of the endosperm starch are the basis of commercial classification of maize into flour, flint, pop, dent, sweet, and waxy corns. Flour corns have a mealy endosperm. Flints have a central core of softer starch completely surrounded by hard starch, so that the kernel retains its round shape as it ripens. Most popcorns have a smaller and more pointed kernel than the flints, with an even greater percentage of hard starch, which ruptures (pops) when ripe kernels are heated. The dents have hard starch at the sides of the grain but the soft starch in the central reaches the crown, and during the later stages of ripening the soft starch shrinks to produce the characteristic indentation. In sweet corn, a single gene mutation slows down the conversion of sugar to starch in the ripening kernel and ripe sweet corn 'seed' has a very wrinkled appearance, while in waxy corn a different gene

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mutation produces starch composed entirely of amylopectin, used commercially as a substitute for tapioca (Bunting, 1978).

2.2.1 The origin of maize

The closest relative of maize is annual teosinte, which survives in the wild in Western Mexico, Guatemala and Honduras (Bunting, 1978). Teosinte has the same number of chromosomes as maize (n = 10), crosses readily with it and the hybrids backcross to either parent. Maize has been cultivated for about 10,000 years (Galiant, 1978).

2.2.2 Life history

Growth of maize plants can be divided into 11 different stages (Table 2.2.1) and these stages have definite characteristics which can be observed in the field (Hanway, 1963).

2.2.3 Influence of temperature on maize growth and development

Temperature has a profound influence on the time taken for crops to reach maturity and on the final yield of the crop. Seeds of most maize hybrids germinate very slowly at temperature below 10°C, although cultivars capable of germinating at 6 to 8°C have been reported. There appears to be no close correlation between the minimum temperature for germination determined in the laboratory and seedling growth in the field (Carr and Hough, 1978). The start of the growing season for maize is therefore normally determined in temperate areas by the expected date when soil temperatures stabilize at 10°C or above. Provided seeds are planted in contact with moist soil, the time taken for seedlings to emerge is then a function of soil temperature. Even after emergence, soil temperature is important, as the growing point remains below the soil surface for 6 to 8 weeks after sowing (Beauchamp and Lathwell, 1967; Reinhardt, 1971). The leaves of young seedlings are yellow if soil temperature remain low or if maximum daytime temperatures do not

Table 2.2.1. Identifying characteristics and approximate average dates and days from emergence for the different stages of growth of corn (Hanway, 1963).*

Growth stage	Date**	Days***	Identifying characteristics for field use
0	May 24	0	Plant emergence. Tip of coleoptile of plant visible at soil surface.
1	June 8	14	Collar of 4th leaf visible.
2	June 22	28	Collar of 8th leaf visible. Leaves 1 and 2 may be dead.
3	July 6	42	Collar of 12th leaf visible. Leaves 3 and 4 may be dead.
4	Jul 20	56	Collar of 16th leaf visible. Tips of many tassels visible. Leaves 5 and 6 may be dead.
5	Jul 30	66	75% of plants have silks visible. Pollen shedding.
6	Aug 11	78	12 days after 75% silked. Kernels in "blister" stage.
7	Aug 23	90	24 days after 75% silked. Very late "roasting ear" stage.
8	Sep 4	102	36 days after 75% silked. Early dent stage.
9	Sep 16	114	48 days after 75% silked. Full "dent" stage.
10	Sep 28	126	60 days after 75% silked. Grain physiologically mature.

*Average for adapted hypreds in central Iowa. Appropriate modifications should be employed for other hybrids and other areas.
**When planted on May 15.
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exceed 15°C because higher temperatures are needed for chlorophyll formation than for germination (Alberda, 1969).

When the stem starts to extend, air temperatures assume a greater importance. In southern England, mean monthly maximum and minimum temperatures reach about 20 to 22°C and 11 to 13°C, respectively in July and August. In Michigan mean monthly maximum temperature reach about 26 to 28°C in July. In Zimbabwe mean monthly maximum temperature reach about 27 to 29°C and 25 to 27°C for the lowveld and highveld, respectively. Daily maxima are nearly always below the optimum (30 to 33°C) for photosynthesis and development in maize (Carr and Hough, 1978). Differences in rates of development of maize from place-to-place and year-to-year are therefore influenced by soil and air temperatures.

Accumulated temperatures and maize development. Traditionally, maize cultivars have been classified according to the average number of days taken from sowing to maturity at a standard location. This approach leads to many anomalies, as it fails to take into account the effect of temperature differences between sites or between years.

Many attempts have been made to define the relationship between temperature and plant development in simple quantitative terms. Despite both theoretical and practical limitations, accumulating temperature as 'day degrees' or so-called 'heat units' has proved to be a useful guide for classifying maize hybrids according to their earliness and for delineating the areas most suitable for production. This is a particularly useful approach in places such as Canada or northern Europe where it is important to define as closely as possible the areas where maize is likely to be grown successfully and/or the most suitable cultivars for a given locality (Carr and Hough, 1978).

Many different methods of accumulating temperature have been devised and used for predicting rate of development in maize, and other crops. Often a base temperature, considered to be the minimum required for growth and development, is subtracted from the daily mean temperature to give the effective daily temperature. Positive values of effective temperatures are then accumulated between prescribed stages of development. The base temperature for maize is usually taken to be 10°C, but thresholds between 6 and 8°C have been advocated for northern Europe conditions. In the USA, limits are often prescribed to the recorded maximum and minimum temperatures. The method now adopted by the USA National Weather Service regards all maximum temperatures above 30°C as 30°C and all minima below 10°C as 10°C. All these methods assume that the rate of development is a linear function of temperature over the range considered.

2.2.4 Influence of moisture on maize growth and development.

One of the more important factors in maize production is the supply and use of water (Shaw and Burrows, 1967). When moisture is not available to the plant, evapotranspiration is reduced, a moisture stress is created. This results in yield reduction. Limits of available water for growth is between the 'permanent wilting point' and 'field capacity', with water contents at potentials of -15 bar and -0.10 bar, respectively (Ratliff, et al., 1983; Ritchie, 1981). Available soil moisture is the result of the amount of moisture in the soil, and soil texture (moisture in sand tend to be more available than in clay).

Crop establishment. It is important to make sure that seeds are sown in soil with adequate moisture level to avoid uneven establishment and low plant populations. Under dry seedbed conditions a sowing depth in excess of 5.0 cm may be beneficial, and a single pass with a ring-roll will usually ensure

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good seed-soil contact. Under wet soil conditions, however, compaction of the soil above the seed can reduce seedling establishment. Once the seeds have germinated, the roots start to extend into moist soil. Provided there is no restriction to root growth, or excessive weed competition, maize seedlings growing at relatively low temperatures (15-20°C) will tolerate periods of dry weather without any apparent adverse effect.

Vegetative growth. Six to seven weeks after sowing the plant reaches the 6-leaf stage and rates of stem extension and leaf expansion begin to increase rapidly. Water stress at this time leads to a reduction in the rate of cell and leaf expansion. If leaf growth is restricted, less incident radiation is intercepted and crop growth rates and plant size are reduced. In areas of Australia where the maize crop is normally irrigated, severe water stress during male meiosis, two or three weeks before the tassels begin to emerge from the upper leaf whorl, reduced final yield of dry matter by 29% (Downey, 1971).

Water stress during the period of rapid stem elongation reduces plant height, although only the two or three internodes in the elongation phase during the stress period are normally affected (Claasen and Shaw, 1970a; Duncan, 1975). Stress during the elongation of the tassel and/or upper leaf internodes also cause a delay in tasseling and silking, leading to a reduction in grain yields (Claasen and Shaw, 1970b). In extreme cases, silking can be delayed until nearly all the pollen has been shed.

Flowering. Early work in the USA showed that grain yield was reduced by as much as 22% following wilting for only one or two days during pollination, and by 50% if the period of stress was extended to six or eight days (Reinhardt, 1971). Similar studies with container grown plants have confirmed that grain yield is very sensitive to water stress during flowering

(Claasen and Shaw, 1970b). Possible reasons for this include resultant abnormalities in embryo-sac development and delayed silk emergence (Moss and Downey, 1971) although other factors such as desiccation of the pollen or of the silks may also prevent fertilization (Boyer and McPherson, 1975). Recent work in California, however, has indicated that susceptibility of maize plants to water stress during pollination is reduced if plants are previously stressed or 'conditioned' during the late vegetative stage (Stewart et al., 1975). A consequence of severe water stress during pollination is that grain develops on only part of the cob. Although some yield compensation can occur by increase in individual grain size and weight, there is evidence that this will be limited (Begg and Turner, 1976).

Grain development. In contrast to the effect of stress during flowering, water stress during the period of grain development may be more important for forage maize production than for grain. Low leaf water potentials and stomatal closure will restrict photosynthesis, but the translocation of reserves from the stem to the ear continues (Boyer and McPherson, 1975). Although this will minimize losses in the yield of grain, the yield of forage will be reduced. Water stress during ripening causes premature leaf senescence, beginning with the lower leaves.

2.2.5 Nutritional requirements of maize

An adequate supply of nutrients is essential for normal growth of maize and the production of high yields of grain. Soils generally contain large quantities of plant nutrients but they are often in complex compounds that cannot be absorbed by plants. These reserves are replenished naturally by rainfall, decomposition of plant and animal remains and by weathering of parent rock. Soils continually release nutrients in simpler forms that can be taken up by plants, but rarely at a rate sufficient to match the needs of an

actively growing and high yielding crop. The amount of fertilizer needed to give maximum yields, or the most profit from an area of land, varies with soil condition, climate and crop management. An understanding of these interactions is necessary to implement an effective fertilizer policy.

Supplies of plant nutrients can be provided by rain, soil reserves, plant residues, chemical fertilizers and manures:

Rain. The amounts (kg/ha) of plant nutrients in the annual rainfall in eastern England have been estimated to be 16 nitrogen, 0.2 phosphorus, 3 potassium, 13 calcium, 4 magnesium, 18 sulphur, 27 sodium and 50 chlorine (Bunting, 1978).

Soil. Most of the nitrogen (N) in soils is in the organic form and constitutes a reserve that continuously releases plant-available N through mineralization. This can supply 80 to 100 kg/ha N in fertile soils. When manure or crop residues are freshly added to the soil, much of the N they contain is unavailable to plants until the organic matter is decomposed by microorganisms. Nitrogen is released from organic matter with a C:N ratio of less than 20 at an early stage of decomposition. Well-decomposed manure, where the C:N ratio has been reduced, will rapidly release plant available N when incorporated into the soil.

A proportion of the phosphorus (P) in soils is also in the organic form and unavailable to plants until decomposition releases inorganic phosphates. Phosphates do not move easily in soils and are generally precipitated in forms with low solubilities which cannot be absorbed by maize.

Potassium (K) is not leached from soils like N, nor is it combined into insoluble forms to the same extent as P. Although most soils, especially clays, contain large amounts of K, only a small fraction is soluble in the soil solution

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and available to plants. Even in fertile soils, this cannot supply the major requirement of a crop such as maize, which has a high demand for K.

Exchangeable magnesium (Mg) in soils is derived from the weathering of a number of minerals. Generally soils provide 5 to 25 kg/ha of Mg per year (Cooke, 1975). This is often sufficient for crop requirements. Clay and silt soils contain the largest amounts and additional Mg is most likely to be needed on acid, sandy soils, in regions of moderate to heavy rainfall.

All calcareous soils contain free calcium carbonate, and most soils in temperate regions contain large amounts of exchangeable calcium (Ca). Unlike K, there is no mechanism for conserving surplus Ca in the soil. Most Ca is lost by leaching. The amounts lost, depend on rainfall, Ca reserves in the soil and soil texture. Shortages can lead to soil acidity and eventually crop failure. Some fertilizers, especially ammonium salts, accelerate the loss of Ca and thus increase acidity.

Sulphur (S) is present in soils in both inorganic and organic compounds but in very variable amounts. Deficiencies are most likely in well-drained soils with low organic matter in non-industrialized areas.

Chemical fertilizers. The value of fertilizers is usually measured in forms of the N, P and K content, although they may also contain other useful nutrients.

Livestock manures. Most of the N, P and K ingested by farm animals in their diet is voided in the feces or urine. This can be re-used to grow crops. Livestock manures may be a mixture of feces plus urine, with or without additional water. It may be in the form of a semi-liquid slurry, or mixed with bedding as farmyard manure. The amounts and composition of the manure produced depend on the type of livestock, housing and diet. Chumbley (1977) reported median values for the quantities of plant available nutrients

in undiluted slurry (Table 2.2.2). Cooke (1975) reported the median values for the quantities of plant available nutrients in solid farmyard manure (Table 2.2.3).

Crop residues and green manuring. Growing legumes add N to cropping systems and it has been estimated that symbiotic fixation ranges from 50 to 150 kg N/ha by arable legume crops to 200 to 400 kg N/ha by clovers and lucerne (Cooke, 1975). Much N, however, may be lost by leaching during wet springs as the roots decay. This, however, does not usually happen in Zimbabwe because the springs are relatively dry.

Table 2.2.2. Quantities (kg/t) of major nutrients available to crops in undiluted slurries (Chambley, 1979).

Type of slurry	N	P_2O_5	K_2O
Cattle	2.5	1.0	4.5
Pigs (dry meal fed)	4.0	2.0	2.7
Poultry	9.0	5.5	5.5

Table 2.2.3. Quantities (kg/t) of major nutrients available to crops in farmyard manure (Cooke, 1975).

Type of slurry	N	P_2O_5	K_2O
Cattle	1.5	2.0	4.0
Pigs	1.5	4.0	2.5
Poultry (deep litter)	10.0	9.0	10.0
Poultry (broiler litter)	14.5	11.0	10.5

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Nitrogen. Nitrogen is essential for plant growth because it is a constituent of all protein and is taken up by plants as ammonium or nitrate ions. When soil conditions are favorable for the growth of maize, ammonium N is rapidly converted to nitrate by nitrifying bacteria. Cold, wet, acid soil conditions that inhibit nitrification of ammonium N are unsuitable for maize. Nitrogen is the most important nutrient in determining the yield of maize. When N is deficient, the embryonic leaf bud does not develop to its full potential, cell division in the growing tip is retarded, and the result is a reduction in leaf area, plant size and productivity.

Phosphorus. Phosphorus is a contituent of the cell nucleus. It is essential for cell division and for the development of meristematic tissue. It is thought that P also stimulates root formation in the maize plant, aids crop maturity and affects the development of the grain (Arnon, 1974).

Potassium. Potassium, absorbed through the roots as the K^+ ion, is necessary for the normal progression of many physiological processes and directly affects the rate of growth and yield of the crop. It contributes to the strengthening of the schlerenchyma in the fibres and so increases the resistance to lodging, a matter of special importance when high N has been applied to maximize yields. Photosynthesis is markedly affected by the concentration of extractable K in the leaves. Potassium is important for the efficient use of water by maize and also has a considerable influence on the proportion of grain in the ear.

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Calcium. Calcium is important in the formation of cell walls and in neutralizing organic acids. It is an essential nutrient but soils usually contain sufficient for crop requirements.

Magnesium. Magnesium forms a central part of the chlorophyll molecule, and the rate of photosynthesis in maize leaves is closely related to Mg concentration in the leaf tissue.

Factors affecting the response of maize to fertilizer. The magnitude of the response of maize to fertilizer is not only dependent on the nutrient, moisture and temperature status of the soil, but is also affected by other cultural practices involved in growing the crop.

Soil nutrient, temperature and moisture. The effect of the soil nutrient status on the response of maize to fertilizer is dependent on the estimated availability of N, P and K in the soil (Pain, 1978). The supply of nutrients must be balanced according to the requirements of the maize crop to obtain maximum yields. Abiotic factors that adversely affect soil aeration, such as water-logging or compaction, can reduce nutrient uptake and hence the response to fertilizers, especially on clay soils. Maize with an adequate water supply has a deeper and more extensive root system that takes up more nutrients by exploring a greater volume of soil (Arnon, 1974). Generally, there is a yield response to larger amounts of N fertilizer in years with ample rainfall than in dry years (Black, 1966). Increases in soil moisture increase the amount of P in the soil solution and its availability to plants (Cooke, 1975).

Crop management practices. Fertilizer is only partially effective when yield is limited by other supporting practices involved in growing the crop such as poor seed bed preparation, late planting, low plant population, or heavy weed infestation. The high plant densities necessary for maximum yields from modern hybrids cause severe competition for plant nutrients. Plant density and fertilizer rates must be increased simultaneously, assuming that other factors are not limiting yield. For example, in the USA, the N fertilizer needed to maximize forage yields of irrigated maize increased from

100 to 300 kg N/ha as plant density increased from 37,500 up to 75,000 plants/ha.

Cultivation improves soil aeration and the rate of decomposition of organic matter, assuming soil moisture is adequate, and increases the amount of N available to the crop. It has been reported that direct drilling, or zero tillage, necessitates high rates of fertilizer application (Aldrich *et al.*, 1975). However, the mulching effect of the herbicide-treated crop residues left on the surface can help to maintain adequate moisture for root growth in the upper soil layers and improve the availability of nutrients to the crop.

Response to fertilizer in different maize growing areas. The results of many field experiments in the USA suggest that 160 kg N/ha is required to produce maximum yields of forage from modern hybrids. In France, in the main maize growing areas in the south-west, where summer months are relatively moist, 120 to 150 kg N/ha is recommended as a split-dressing. In Germany and Austria, rates in kg/ha range from 100 to 140 for N, 50 to 60 for P, and 125 to 175 for K. In Italy, best results are obtained with applications of 160 to 200 kg N/ha, 45 to 50 kg P/ha and 80 to 100 kg K/ha. In Zimbabwe, 300 kg/ha of compound D fertilizer (8% N, 14% P2O5, 7% K2O and 6.5% S) and 150 kg/ha of ammonium nitrate fertilizer (34.5% N) are recommended rates for most maize growing areas.

2.2.6 Influence of pests on maize growth and development.

2.2.6.1 Weeds

Weeds are a major hazard to successful maize production. The risk of severe weed infestation during the period of crop establishment is considerable, especially for maize grown in the cool climate.

Couch grass (Agropyron repens). Recommendations for control of heavy infestations of couch grass involves a two-year program with split

applications of atrazine in the first year. A fairly heavy rate of atrazine (2.2 kg a.i./ha) is applied to growing couch grass in autumn before sowing, followed by ploughing a few weeks later and then after cultivations to level the land, then spraying a similar quantity of atrazine again. The residual effects from atrazine applied in these amounts means that a second maize crop must be taken, and a relatively low rate of atrazine (1.0 kg a.i./ha) is applied a month before this is sown. EPTC is approved for couch control, but satisfactory results are very dependent on accompanying cultivation treatments. The herbicide should be applied to actively growing rhizomes about two weeks before the maize crop is sown.

Perennial broad-leaved weeds. Deep-rooting weeds such as creeping thistle (Cirsium arvense), dock (Rumex spp.) and bindweed (Convolvulus spp.) can be controlled by application of 2,4-D amine (1.1 kg a.i./ha) when the crop is 8-15 cm tall with 4-6 leaves.

Late germinating annual weeds. Such weeds as fathen (Chenopodium album), knotgrass (Polygonum aviculare), redshank (P. persicaria) and nightshade (Solanum nigrum) may emerge late in the season when atrazine activity has been largely dissipated or arrested by drought. In such emergencies, 2,4-D amine is the most useful herbicide. Post-emergence applications of mecoprop, dicamba + MCPA and other hormone weedkillers also have possibilities for commercial use. Herbicides used for weed control in maize in Zimbabwe are listed together with the rates normally applied (Table 2.2.4).

2.2.6.2 Diseases

Seed-borne fungi. The most common fungi found on seed in the soil are the Fusarium spp. which are responsible for root, stalk and ear rots in mature plants. Surveys in 1984-85 showed that Fusarium graminearum,

Table 2.2.4. Commercial herbicide treatments for control of annual weeds in maize in Zimbabwe.

Herbicide	Trade name	Recommended dosage rate/ha (kg or litres)	
		Herbicide kg a.i/ha	Commercial product litres/ha
Metolachlor	Dual 72 EC	0.94 - 1.08	1.3 - 1.5
Metolachlor + atrazine	Dual 72 EC + Gesaprim 80 WP	0.94 - 1.08 1.76 - 2.80	1.3 - 1.5 2.2 - 3.4
Atrazine	Gesaprim 80 WP	1.76 - 2.80	2.2 - 3.4
Cyanazine	Bladex 50 WP	0.75 - 1.75	1.5 - 3.5
EPTC	Eptam Super 72 EC	1.51 - 3.02	2.1 - 4.2
Bentazon	Basagran 48 SL	1.44	3.0
Terbuthylazine + metolachlor	Gesaprim	---	3.5 - 5.5
Atrazine + EPTC	Gesaprim 80 WP + Eptam 72 EC	1.76 - 2.80	2.2 - 3.4 3.2 - 5.3

Fusarium moniliforme and Diplodia maydis are the major causal agents of cob rots (Page et al., 1985). Control measures include use of resistant varieties, early harvest and use of carbofuran 10G or dimethoate 40 e.c.

Seedling blight. Pythium spp. are widely distributed in all soils and are most active in wet conditions. These fungi cause root and hypocotyl rot with brown, water soaked, lesions and sloughing of the cortex. Soil-borne Fusarium spp. can also infect and kill seedlings. Because of the risk of soil- and seed-borne fungi infecting maize, the application of a seed treatment chemical is essential. The best protection is given by captan or thiram.

Stalk rot. The main causal organism of stalk rot include Diplodia maydis, Gibberella zeae, Erwinia carotovora and Fusarium spp. (Page et al., 1985). The symptoms of stalk rot are similar regardless of the species of

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Fusarium responsible. Weakened stems collapse at the nodes and lodging may be severe in wet windy weather. Reductions in grain yield and quality caused by stalk rot have been reported from many countries and Cook (1978) estimated that stalk rot can reduce the dry-matter yield of a 12t/ha crop by 0.5 t/ha.

Smut diseases. Maize is susceptible to two smut diseases; head smut and common boil smut. The latter is widespread and occurs in most regions. Head smut is of minor importance. Common smut is caused by Ustilago maydis. This disease causes yield reductions of up to 10%.

The build-up of spores in soil is best prevented by use of cropping system in which maize is not grown on the same land at frequent intervals. The removal and destruction of galls from lightly infected crops may reduce the build-up of inoculum. Seed treatment with benomyl can reduce smut infection.

Leaf diseases. Southern leaf blight caused by Helminthosporium maydis is an important disease of maize. Typical lesions of southern leaf blight are oblong (6 x 20 mm), have parallel sides and are tan or straw colored.

Northern leaf blight caused by Helminthosporium turcicum reduces yield in maize. This fungus causes the development of long, elliptical lesions which are larger than those found in southern leaf blight.

Common maize rust (Puccinia sorghi) occurs sporadically on maize. Occasionally up to 25% of the leaf area may be affected. Also P. polysora has been reported in Zimbabwe.

Virus diseases. Maize streak virus (MSV), which is transmitted by Cicadulina mbila (Naude), is the most important virus disease of maize in Zimbabwe. Control of the vector with carbofuran 10G applied at 2.0 kg a.i./ha effectively increases maize yield by up to 40% (Mzira, 1984).

2.2.6.3 Insects

As the acreage of maize has increased , population densities of insects, as well as the number of species attacking maize has increased. With each new development in maize production, whether in plant breeding, fertility, irrigation, or even insecticides, insects adapt to the new environment.

Insects that attack seed. Seed-maize maggot (Hylemya platura) may devour the entire seed contents leaving only the seed coat. Attacks by this insect reduce maize stands.

Seed-maize beetles (Agonoderus lecontei and Clivina impressifrons) devour the contents of the seed. Any condition which retards germination results in increased seed bettle damage.

Wireworms (Elateridae spp.) hollow out maize seeds before germination occurs. After germination the worms feed on the underground stem or drill holes in the base of the stalk.

Delay in maize planting until soil temperature and moisture are conducive to rapid germination is a cultural method used to control insects attacking maize seeds. Summer fallowing, autumn plowing, and control of weed growth are said to aid in controlling wireworms. Aldrin insecticide is also used to control these insects.

Insects that parasitize maize roots. White grubs such as (Eulepida mashona) feed on the roots of the maize plant; this results in severe stunting. In light infestations, lodging may occur because of the weakened root system and yields may be reduced. Autumn plowing will reduce the population of white grubs in the soil. Also aldrin and carbofuran insecticides can be used to control white grubs.

Insects that feed on the underground portion of the stalk. The black cutworm (Agrotis ipsilon) is most damaging to small maize plants. Cutworms

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normally remain hidden in the soil during the day and feed at night. Crop rotation with some other crops other than maize can reduce cutworm populations. Aldrin, carbofuran and cypermethrin can be used to control cutworms.

Insects that feed on exposed maize leaves. The true armyworm (Pseudaletia unipuncta) cause a serration or stripping of the leaves. If infestations are severe, yield losses may be great. Armyworm can be controlled by carbaryl.

Grasshoppers (Melanoplus spp.) are chewing insects that feed from the outer edges of leaves inward. When numerous on maize, they may eat part of the stalk and ears. They attack fresh silks, reducing pollination and often causing the ears to be barren. Plowing buries the eggs so that young hoppers never reach the surface, or it exposes the eggs to weather and natural enemies. Carbaryl, diazinon, fenitrothion and malathion can be used to control grasshoppers.

Maize leaf aphid (Rhopalosiphum maidis), when heavily infesting maize leaves, will cause wilt, curl, and show yellow or even dead patches. Tassels and silks may be covered with honeydew. Malathion can be used to control aphids.

Insects that feed in whorls, stalks and ears. European corn borer (Ostrinia nubilalis) first generation decreases yields by 3 to 4 percent for each borer that matures per plant. Second generation borer decreases yields by ½ to 1½ percent for each mature borer per plant. Midseason plantings of maize is recommended for control of the European corn borer. Also carbaryl and diazinon can be used to control borers.

Maize stalk borer (Busseola fusca) and pink stem borer (Sesamia calamistis) are the stem borers which are commonly found in Zimbabwe.

Larvae of these insects damage leaves (causing windows and short holes), create tunnels in the maize stems and destroy grain on cobs.

Other insect pests of maize. Termites (Hodotermes and Microtermes spp.) cause high maize crop losses in Zimbabwe by cutting down plants using their sharp mandibles prior to damaging cobs on the fallen stalks. Termites can be controlled by aldrin.

Leaf hopper (Cicadulina mbila) is an important vector of the maize streak virus. This hopper can be controlled by applying carbofuran or dimethoate. Culturally, the insect can be controlled by eliminating weeds and volunteer maize plants, practicing crop rotation and planting early before high C. mbila populations.

Snout beetles, comprising three main species, Systates exaptus, Mesoleurus dentipes and Tanymecus destructor, normally damage maize seedlings. These beetles can be controlled by applying carbaryl 85 w.p. Good weed control together with delay by three weeks in planting also provide effective control. A delay in planting by three weeks permits the grubs to undergo pupation, the developmental stage which does not damage seedlings.

Elegant grasshopper (Zonocerus elegans) is a polyphagous insect capable of damaging young maize severely. This insect is a periodic pest of maize in Zimbabwe communal farms. Carbaryl 85 w.p. and diazinon 30 e.c. are effective for the control of this pest whenever it occurs in numbers large enough to warrant chemical application.

2.2.6.4 Nematodes

Maize is an important crop in the world and about 120 million hectares are under annual production (Norton, 1984). Several plant-parasitic nematodes are, however, of economic importance in maize production.

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Plant-parasitic nematodes that have been found associated with maize, either singly or jointly with other plant-parasitic nematodes are listed in Table 2.2.5.

Root-lesion nematodes, Pratylenchus spp. Different species of Pratylenchus can affect the growth of maize. Bird (1978) and Laughlin (1977) reported that P. penetrans was an important pest of maize in Michigan and in Texas, P. zeae caused considerable damage to maize roots in localized spots in the field (Harrison, 1952). Endo (1959) showed that maize was an excellent host of P. brachyurus and P. zeae. In Zimbabwe, Martin et al. (1975) reported that P. brachyurus and P. zeae can cause maize yield loss of up to 30% and population densities of the nematodes can be as high as 2,100 per 1.0 gram of root. Koen (1967) found P. brachyurus and P. zeae population densities in excess of 1,300 per 1.0 gram of maize root in S. Africa with percent incidence of 29 and 51, respectively. Chevres-Roman et al. (1971) showed that P. zeae was a serious parasite to both maize and sorghum in greenhouse studies in North Carolina. The population at which damage occurred appeared to be 6,000 and 8,000 nematodes per 475 cm^3 of soil.

Olowe and Corbett (1976) demonstrated that P. brachyurus and P. zeae are pathogens of maize in Nigeria. They found in monoxenic culture that both nematodes broke through cells of the endodermis of maize and penetrated the stele. This feeding led to the deposit of a reddish-brown substance in phloem and xylem tissues which occluded many of the elements. Zirakparvar (1980) found that P. hexincisus caused significant reduction in height and in top and root weights of maize in clay pots 90 days after inoculation with 20,000 nematodes per pot. Norton and Hinz (1976) increased maize yields in sandy soils in Iowa up to 26 percent by application

Table 2.2.5. Plant-parasitic nematodes associated with maize.

Nematodes	Distribution
Aphelenchoides spp.	Zimbabwe (Martin, 1955; Martin et al., 1969)
Aphelenchus spp.	Zimbabwe (Martin et al., 1969)
Belonolaimus longicaudutus	Georgia (Johnson and Chalfant, 1973)
Belonolaimus spp.	South Africa (Louw, 1982)
Criconemella ornatus	Georgia (Johnson and Chalfant, 1973)
Criconemella spp.	Zimbabwe (Martin, 1955)
Ditylenchus dipsaci	Europe (Kort, 1972), S. Africa (Louw, 1982) and Zimbabwe (Martin, 1955)
Helicotylenchus erythrinae	Malawi (Mughogho and Choo, 1969)
H. multicinctus	Malawi (Mughogho and Choo, 1969)
Helicotylenchus spp.	Malawi (Mughogho and Choo, 1969), S. Africa (Louw, 1982) and Zimbabwe (Martin, 1955)
Heterodera avenae	S. Africa (Louw, 1982; Walters, 1979)
H. zeae	India (Kaul and Sethi, 1982a; Kaul and Sethi, 1982b)
Hoplolaimus galeatus	Iowa (Norton and Hinz, 1976)
H. indicus	India (Siyanand et al., 1982)
H. pararobustus	Zimbabwe (Page et al., 1985)
Hoplolaimus spp.	Zimbabwe (Page et al., 1985)
Longidorus brevinculatus	Michigan (Bird, 1985 pers. comm.)
Meloidogyne arenaria	Zimbabwe (Martin et al., 1969)
M. javanica	Malawi (Mughogho and Choo, 1969) and Zimbabwe (Martin et. al., 1969)
M. incognita	India (Kaul and Sethi, 1982a; Kaul and Sethi, 1982b), Tennessee (Southards, 1971) and Zimbabwe (Martin et al., 1969)
Meloidogyne spp.	Malawi (Mughogho and Choo, 1969), S. Africa (Louw, 1982; Walters, 1979) and Zimbabwe (Martin, 1955)
Paralongidorus spp.	Zimbabwe (Page et al., 1985)
Paratrichodorus spp.	S. Africa (Walters, 1979)
Pratylenchus brachyurus	Nigeria (Egunjobi, 1974; Egunjobi and Bolaji, 1979; Olowe, 1977; Olowe and Corbett, 1976), North Carolina (Endo, 1959), S. AFrica (Louw, 1982; Koen, 1967) and Zimbabwe (Martin et. al., 1975; Martin et al., 1969).
P. crenatus	Europe (Kort, 1972)
P. hexincisus	Iowa (Zirakparvar, 1980; Zirakparvar, 1979; Zirakparvar et al., 1980)
P. minyus	Ontario (Townshend, 1972)
P. neglectus	Europe (Kort, 1972)
P. penetrans	Michigan (Bird, 1978; Caswell, 1982; Laughlin, 1977), Ontario (Townshend, 1972) and S. Africa (Louw, 1982)
P. thornei	Europe (Kort, 1972) and India (Siyanand et al., 1982)

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Table 2.2.5. Continued.

Nematodes	Distribution
P. zeae	Nigeria (Olowe, 1977; Olowe and Corbett, 1976), North Carolina (Endo, 1959), Panama (Tarte, 1971), S. Africa (Louw, 1982; Koen, 1967), Tennessee (Chevres-Roman et al., 1971; Southards, 1971), Texas (Harrison, 1952) and Zimbabwe (Martin et al., 1975; Martin et al., 1969)
Radopholus similis	S. Africa (Keetch, 1972) and Zimbabwe (Anon, 1973; Martin et al., 1969)
Rotylenchulus parvus	S. Africa (Furstenberg, 1974) and Zimbabwe (Martin et al., 1969; Page et al., 1985)
R. variabilis	Zimbabwe (Anon, 1973)
Rotylenchulus spp.	S. Africa (Louw, 1982) and Zimbabwe (Martin, 1955)
Rotylenchus incultus	Zimbabwe (Page et al., 1985)
Rotylenchus spp.	S. Africa (Louw, 1982)
Paratrophurus spp.	Zimbabwe (Page et al., 1985)
Scutellonema brachyurum	Malawi (Mughogho and Choo, 1969) and Zimbabwe (Page et al., 1985)
S. magniphasmum	Malawi (Mughogho and Choo, 1969) and Zimbabwe (Page et al., 1985)
S. unum	Zimbabwe (Page et al., 1985)
Telotylenchus obtusus	Zimbabwe (Page et al., 1985)
Telotylenchus spp.	S. Africa (Louw, 1982)
Trichodorus christei	Georgia (Johnson and Chalfant, 1973)
Trichodorus spp.	Malawi (Mughogho and Choo, 1969), S. Africa (Louw, 1982) and Zimbabwe (Anon, 1969; Martin, 1955 and Martin et al., 1975)
Tylenchorhynchus nudus	Michigan (Bird, 1978)
T. vulgaris	India (Kaul and Sethi, 1982a; Kaul and Sethi, 1982b; Siyanand et al., 1982)
Tylenchorhynchus spp.	S. Africa (Louw, 1982) and Zimbabwe (Martin, 1955)
Xiphinema louisi	Zimbabwe (Page et al., 1985)
Xiphinema cf. variable	Zimbabwe (Page et al., 1985)
Xiphinema spp.	S. Africa (Louw, 1982) and Zimbabwe (Page et al., 1985; Martin 1955)

of nematicides. The difference between treated and untreated plots was attributed to damage caused by P. hexincisus and Hoplolaimus galeatus. Bergeson (1978) reported that maize plants that were infected by Pratylenchus spp. had 14% lower yeield in Indiana.

The penetration of maize roots by P. penetrans and P. minyus was tested by Townshend (1972) in three Ontario soils. Low bulk densities generally favoured nematode penetration of maize roots in all soils. Kort (1972) reported that P. crenatus, P. neglectus and P. thornei caused more damage in maize in light soils, loamy soils and heavier soil textures, respectively.

Stubby root nematodes, Trichodorus spp. In Zimbabwe, Martin et al. (1975) found that Trichodorus spp. can cause severe early stunting of maize plants. Perry (1956) found that Trichodorus spp. caused damage to maize in the USA. Johnson and Chalfant (1973) also showed that Belonolaimus longicaudatus, Trichodorus christei, Pratylenchus zeae and Criconemella ornatus reduced maize yield by up to 31% in Georgia.

Root-knot nematodes, Meloidogyne spp. The root-knot nematode, M. javanica, induced pathological symptoms including galling of roots and depressed growth vigor on maize in Egypt (Ibrahim and Rezk, 1976). In Zimbabwe, when maize was sown in sandy soils heavily infested with M. javanica, 350 root-knot juveniles parasitized the root system of a single plant within seven days of sowing, and by the 33rd day, egg-producing females were seen in small galls (Martin et al., 1969). Martin (1955) found swellings on the roots of maize infested with M. arenaria and moderate infestations of M. incognita acrita, although there were few females with egg masses. Van der Linde (1956) tested different maize cultivars for their susceptibility to Meloidogyne species and found infestation with M. incognita acrita, M.

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javanica and M. arenaria thamesi but not with M. hapla. Kaul and Sethi (1982a and 1982b) observed 72% and 61% penetration of Heterodera zeae and M. incognita in maize roots, respectively when inoculated simultaneously in the presence of Tylenchorhynchus vulgaris. Southards (1971) reported that fall tillage in Tennessee, significantly reduced the population density of M. incognita the following growing season.

Other nematodes. Kort (1972) reported that Ditylenchus dipsaci cause local hypertrophy and hyperplasia in maize. Others symptoms include basal swellings, dwarfing, twisting of stalks and leaves, and shortened internodes. D. dipsaci is a problem on sandy loam but is rarely a problem on light sandy soils. In Zimbabwe, Radopholus similis, root-lesion nematode and root-knot nematode juveniles were found in dissected lesions (Martin et al., 1969). In addition to the above mentioned nematodes, Aphelenchus spp., Aphelenchoides spp. and Helicotylenchus spp. were observed in small numbers in the roots. In Zimbabwe, R. similis often parasitize maize (Anon, 1969) and Keetch (1972) found in South Africa that the root damage caused by R. similis on maize was extensive and consisted of large brown to reddish black lesions along the roots.

Anon (1973) found that the most numerous plant-parasitic nematodes in maize included species of Rotylenchulus and Helicotylenchus. The population density of Rotylenchulus variabilis rose rapidly under maize in March and April, falling again slightly when the plot was plowed, but moderately high levels of Helicotylenchus spp. were maintained. Cultivation o f maize on previously undisturbed land in South Africa was followed by a massive increase in the population density of Rotylenchulus parvus (Furstenberg, 1974). High population densities of R. parvus have also been recovered in maize roots in Zimbabwe (Page et al., 1985).

In Michigan, Longidorus brevinculatus is reported to cause extensive damage to maize plants grown in sandy soils (Bird, 1985 pers. comm.). This nematode is a major problem is areas which have been recently put under maize cultivation with the advent of extensive irrigation facilities/machinery. In Zimbabwe, Paralongidorus spp. was associated with extensive damage of maize plants in one communal area with very sandy soils. The pathogenicity of this nematode on maize, has not been established. Also Hoplolaimus pararobustus was found parasitizing maize roots in Zimbabwe but damage caused by this nematode on maize has not been established (Page et al., 1985).

Other plant-parasitic nematodes that have been found associated with maize production include Xiphinema louisi, X. cf. variable, Scutellonema brachyurum, S. magniphasmum, S. unum, Telotylenchus obtusus, Paratrophurus spp., and Rotylenchus incultus (Page et al., 1985), but their pathogenicity on maize has not been established.

3. EXPERIMENTATION

3.1 PLANT-PARASITIC NEMATODES ASSOCIATED WITH MAIZE IN ZIMBABWE

3.1.1 Introduction

The extent of damage on maize that plant-parasitic nematodes cause in communal areas, has not been accurately assessed. Also, the incidence and population densities of the major nematode pests of maize have not been related to edaphic factors which are known to influence the population dynamics and pathogenicity of plant-parasitic nematodes.

The objectives of this study were to: (a) assess the incidence and population densities of plant-parasitic nematodes associated with maize in communal farms, (b) evaluate the relationships between the population densities of Pratylenchus spp. and natural farming regions, (c) evaluate the relationships between population densities of P. zeae and environmental factors such as soil temperature, moisture, texture and pH, and (d) evaluate the relationships between population densities of P. zeae and maize yields in Manicaland province.

3.1.2 Materials and Methods

A nematode survey was used to identify plant-parasitic nematodes associated with maize in Zimbabwe communal farms. Three months before the survey was started, data on communal farms was collated from the Department of Agriculture Technical and Extension Services. The data collection included grouping all the communal areas into their respective provinces, then information on the natural farming regions, soil type, average summer and winter temperatures, number of farming families and

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area under maize for each communal area were tabulated. Communal areas which were to be sampled for plant-parasitic nematodes associated with maize were selected so that all the natural farming regions in the province would be equally covered. About 25% of the communal areas were selected for plant-parasitic nematode sampling in each province. The number of soil and root samples which were to be collected from each selected communal area were a function of the area under maize in the communal area. The ratio was one soil and root sample per 1,000 hectares under maize.

The survey was conducted in all the provinces from 3rd February, 1986 to 21st March, 1986, when symptoms of plant-parasitic nematode damage could be easily observed. The symptoms included patchy stunted growth and chlorotic maize plants. Logistical problems caused the detailed survey to be restricted to one province, Manicaland. This province was selected for the detailed survey because it has all of the five farming regions found in Zimbabwe. Visits to all the communal areas were made with the Department of Agricultural Technical and Extension Services so that their local staff would assist us in locating farms to be sampled. A questionnaire was administered to most of the farms that were visited, especially in Manicaland province, before any samples had been collected. The questionnaire was designed so that it evaluated location of the farm, name of the farmer, crops grown and their estimated yields, crop rotation used, fertilizer and pesticides used and their estimated expenses, seed grown, size of the farm, size of the household, and whether the farmer was self-sufficient (Appendix 5.1.2).

Soil and root samples were collected from 49 communal areas (Fig. 3.1.1) and 18 of these communal areas were in Manicaland province. (Fig. 3.1.2) A sample was composed of five sub-samples collected at random from about one tenth of a hectare where maize plants were stunted and chlorotic.

Fig. 3.1.1. Communal farms sampled for plant-parasitic nematodes in Zimbabwe.

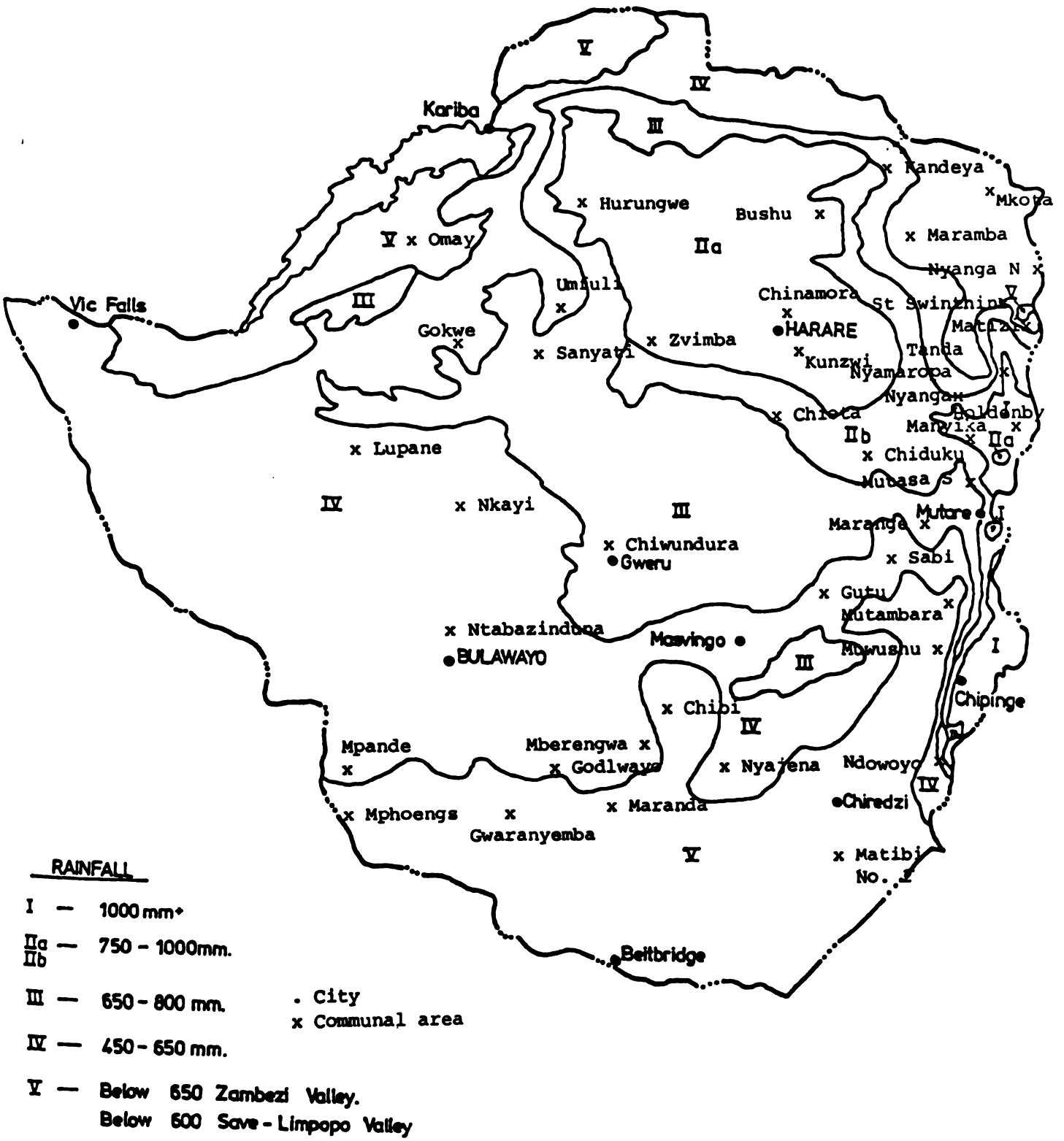
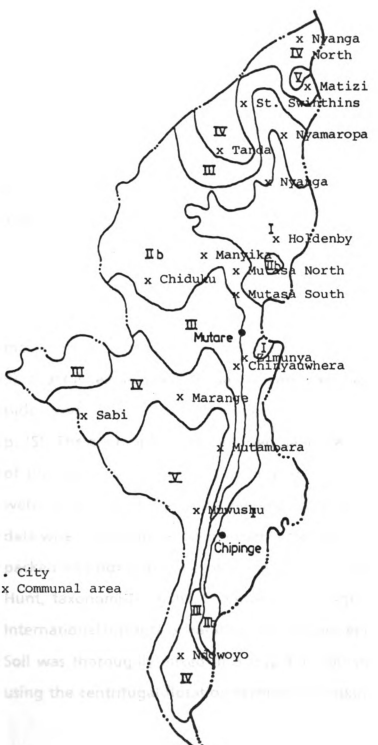


Fig.

Fig. 3.1.2. Communal farms sampled for plant-parasitic nematodes in Manicaland province.



Moist soil samples were collected from a depth of about 10-20 cm and put into a labeled plastic bag and sealed. Root samples were collected by randomly digging the root system of five plants then soil was shaken off the root system and part of the root system was cut into labeled plastic bags. The samples were put into a wooden cooler box (100 x 50 x 50 cm) painted white and lined with a thin layer of tin inside. The following parameters were evaluated from the collected samples:

1. The maize root system was chopped into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the marceration-centrifugal-flotation technique (Southey, 1985 p. 54) and the recovered nematodes were fixed using the killing heat technique (Southey, 1985 p.65). The fixed nematodes were counted under a stereoscopic microscope. After identifying the nematodes to genera level, the nematodes were prepared for mounting using the rapid lactophenol method (Southey, 1985 p. 68-9). Several nematodes of the same genera were mounted on a glass slide using the mounting microscope slide technique (Southey, 1985 p. 75). The mounted slides were then clearly labeled with the name of the farmer and communal area, crop in which the nematodes were recovered, name of the nematode genera on the slide and date when the sample was collected. After labeling, the slides were packed into boxes and they were sent to Drs. M.R. Siddiqi and D.J. Hunt, taxonomists at the Commonwealth Agricultural Bureaux, International Institute of Parasitology, for species identification.
2. Soil was thoroughly mixed in a tray and 100 cm^3 was processed using the centrifugal-flotation technique (Jenkins, 1964) then the

fixing, counting, mounting and labeling techniques outlined for roots were followed.

3. Soil samples from Manicaland province were also submitted to the Chemistry and Soils Research Institute for texture analysis and pH measurements (Appendix 5.1.2).
4. Population densities of P. zeae spp. which were generated from the study were related to environmental factors, namely, rainfall and temperature for 1985/86 growing season. The weather data was collated from 41 stations and 71 sub-stations under the Zimbabwe Department of Meteorological Services (Appendices 5.1.3-5.1.4).
5. P. zeae and maize yield data that were estimated during the survey were transformed (logarithmic transformation) during analysis because the data exhibited a lognormal distribution. The data were analyzed using a statistical package GENSTAT. One way analysis of variance with unequal number of replications between P. zeae population densities and different natural regions, rainfall and temperature regimes was carried out using the national survey data. Also one way analysis of variance with unequal number of replications was carried out between P. zeae population densities and soil texture and pH regimes and level of nutrient applications. After the analysis of variance, parameters which had greater than two levels, orthogonal comparisons were carried out. To contrast the totals, the following formula was used for the F-test:

$$F = \left[\left(\frac{Q^2}{\sum ci^2 r_i} \right) / MSE \right]$$

where: MSE (residual mean square error) is taken from the ANOVA table.

r_i = number of observations (replications) within the level

c_i = orthogonal contrast coefficient for the totals to be compared

The totals of the variables to be compared were derived by multiplying the mean in the ANOVA table for each level by the number of observations within that level.

$Q = \Sigma c_i x_i$ the linear function for the contrast

where: x_i are the totals to be compared.

An example for 2 totals, x_1, x_2

$Q = 1 * x_1 + (-1) * x_2$ linear function for contrasting totals x_1, x_2

where: $c_1 = 1$ and $c_2 = -1$ the orthogonal contrast coefficients.

Regression analysis was also carried out between the population densities of P. zeae that were recovered and annual rainfall, February and March temperatures and maize yield in the respective farms.

3.1:3 Results

Thirteen plant-parasitic nematode genera were found associated with maize plants from the 114 soil and root samples that were collected (Table 3.1.1). The most prevalent plant-parasitic nematodes were Pratylenchus zeae, Scutellonema spp., Helicotylenchus spp., Rotylenchulus spp., Pratylenchus spp., Pratylenchus brachyurus, Criconemella spp., Rotylenchuslus parvus and Scutellonema unum. Plant-parasitic nematodes which were occasionally found associated with maize were Meloidogyne spp., Trichodorus spp., Tylenchorhynchus spp., Paratrichodorus minor,

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Table 3.1.1. Plant-parasitic nematodes found associated with maize in Zimbabwe communal farms.

Plant-parasitic nematodes	Absolute frequency (%)[1]	Nematode population density/ 10.grams roots + 100 cm^3 soil
Aphelenchoides sp.	0.9	42.0
Aphelenchus avenae	0.9	13,315.0
Aphelenchus sp.	0.9	78.0
Criconemella sphaerocephala	1.8	7.0
Criconemella sp.	16.7	7.0
Helicotylenchus sp.	32.5	10.0
Hoplolaimus sp.	0.9	1,191.0
Meloidogyne sp.	6.1	35.3
Paratrichodorus minor	2.7	319.0
Pratylenchus sp.	21.9	107.0
Pratylenchus brachyurus	21.1	4,415.1
Pratylenchus goodeyi	1.8	836.0
Pratylenchus zeae	52.6	2,284.9
Rotylenchulus sp.	38.9	129.8
Rotylenchulus parvus	15.8	224.3
Rotylenchus brevicaudatus	1.8	175.0
Scutellonema sp.	52.6	21.5
Scutellonema brachyurum	2.7	46.8
Scutellonema labiatum	0.9	24.0
Scutellonema magniphasmum	2.7	51.0
Scutellonema unum	13.2	53.0
Trichodorus sp.	4.4	22.4
Tylenchorhynchus sp.	3.5	3.7

Key

[1]Absolute frequency (%) = $\frac{\text{no. of samples containing a species}}{\text{no. of samples collected}}$

Scutellonema brachyurum, Scutellonema magniphasmum, Pratylenchus goodeyi, Criconemella sphaerocephala, Rotylenchus brevicaudatus, Aphelenchoides spp., Aphelenchus avenae, Aphelenchus spp., Hoplolaimus spp., and Scutellonema labiatum.

Only a few species of plant-parasitic nematodes were, however, recovered in high population densities from all the samples that were collected. Plant-parasitic nematodes which had high population densities were P. brachyurus and P. zeae which constituted 38.5 and 50.0% of the total population of plant-parasitic nematodes that were recovered from all the samples, respectively. Rotylenchulus spp., R. parvus and Pratylenchus spp., had intermediate population densities and they each contributed 1.6, 1.5, and 1.0% of the total population of plant-parasitic nematodes that were recovered from all the samples (relative density), respectively. Plant-parasitic nematodes which had low population densities were Aphelenchoides spp., A. avenae, Criconemella spp., C. sphaerocephala, Helicotylenchus spp., Hoplolaimus spp., Meloidogyne spp., P. goodeyi, P. minor, R. brevicaudatus, Scutellonema spp., S. brachyurum, S. labiatum, S. magniphasmum, S. unum, Trichodorus spp., and Tylenchorhynchus spp., which each constituted less than 0.6% of the total population of plant-parasitic nematodes recovered from the samples that were collected.

Different natural farming regions affected the diversity and population densities of plant-parasitic nematodes (Table 3.1.2). The number of plant-parasitic nematodes species that were recovered from samples were 4, 16, 16, 18, and 7 for natural regions I, II, III, IV, and V, respectively. P. brachyurus and P. zeae were equally prevalent in natural regions II to IV, but in natural regions I and V, P. zeae was more prevalent than P. brachyurus (Table 3.1.3). Similarly, Scutellonema spp. were equally prevalent in natural regions I to IV

Table 3.1.2. Plant-parasitic nematodes found associated with maize in different natural regions of Zimbabwe.

Natural region	Plant-parasitic nematodes	Absolute frequency (%)[1]	Nematode population density/10.0 grams roots + 100 cm^3 soil
I	Helicotylenchus sp.	25.0 (n = 4)	68.0
	Pratylenchus brachyurus	25.0	3,676.0
	Pratylenchus zeae	75.0	1,140.7
	Scutellonema sp.	100.0	11.8
II	Criconemella sp.	10.3 (n = 29)	17.0
	Criconemella sphaerocephala	3.4	11.0
	Helicotylenchus sp.	34.5	17.4
	Meloidogyne sp.	13.8	53.8
	Pratylenchus sp.	10.3	22.7
	P. brachyurus	34.5	3,800.3
	Pratylenchus goodeyi	3.4	815.0
	P. zeae	51.7	6,343.5
	Rotylenchulus sp.	31.0	240.9
	Rotylenchulus parvus	10.3	260.7
	Rotylenchus brevicaudatus	3.4	340.0
	Scutellonema sp.	58.6	32.3
	Scutellonema unum	10.3	148.7
	Trichodorus sp.	6.9	46.5
	Tylenchorhynchus sp.	3.4	3.0
III	Aphelenchus avenae	4.2 (n = 24)	13,315.0
	Criconemella sp.	12.5	3.3
	C. sphaerocephala	4.2	3.0
	Helicotylenchus sp.	29.2	14.7
	Paratrichodorus minor	12.5	319.3
	Pratylenchus sp.	33.3	283.8
	P. brachyurus	37.5	5,649.6
	P. goodeyi	4.2	846.0
	P. zeae	29.2	3,502.6
	Rotylenchus sp.	4.2	23.0
	R. parvus	16.7	183.8
	R. brevicaudatus	4.2	10.0
	Scutellonema sp.	54.2	24.0
	S. brachyurum	4.2	51.0
	Trichodorus sp.	4.2	12.0
	Tylenchorhynchus sp.	4.2	2.0
IV	Aphelenchoides sp.	2.0 (n = 51)	42.0
	Aphelenchus sp.	2.0	78.0
	Criconemella sp.	23.5	7.3
	Helicotylenchus sp.	31.4	45.5
	Hoplolaimus sp.	2.0	1,191.0
	Meloidogyne sp.	5.9	20.7

Table 3.1.2. Continued.

Natural region	Plant-parasitic nematodes	Absolute frequency (%)[1]	Nematode population density/10.0 grams roots + 100 cm^3 soil
	Pratylenchus sp.	17.6	64.7
	P. brachyurus	7.8	3,661.7
	P. zeae	64.7	2,281.5
	Rotylenchulus sp.	35.3	144.0
	R. parvus	21.6	217.0
	Scutellonema sp.	49.0	11.3
	S. brachyurum	3.9	45.5
	S. labiatum	2.0	48.0
	S. magniphasmum	5.9	59.0
	S. unum	21.6	51.7
	Trichodorus sp.	3.9	3.5
	Tylenchorhynchus sp.	2.0	8.0
V	Criconemella sp.	16.7	9.0
	Helicotylenchus sp.	50.0	23.3
	Pratylenchus sp.	66.7	33.8
	P. zeae	16.7	340.0
	Rotylenchulus sp.	50.0	111.7
	Scutellonema sp.	16.7	14.0
	Tylenchorhynchus sp.	16.7	1.0

Key

[1]Absolute frequency (%) = $\frac{\text{no. of samples containing a species}}{\text{no. of samples collected}}$

Table 3.1.3. Relationships observed between natural farming regions of Zimbabwe and population densities of Pratylenchus brachyurus and Pratylenchus zeae recovered from maize roots.

Natural farming region	P. brachyurus/10.0 grams roots
I (n = 1)	3,620.0
II (n = 7)	2,527.0
III (n = 9)	6,747.2
IV (n = 7)	6,840.1

Natural farming region	P. zeae/10.0 grams roots
I (n = 3)	1,077.0
II (n = 14)	3,690.4
III (n = 8)	3,113.9
IV (n = 34)	2,205.9
V (n = 1)	340.0

but S. magniphasmum and S. unum were mainly prevalent in natural region IV. Helicotylenchus spp. were equally prevalent in all the five natural regions and Criconemella spp. were more prevalent in natural region IV only. Rotylenchulus spp. were more prevalent in natural regions IV and V.

The mean population densities of P. zeae which were recovered from maize roots were a function of the total rainfall which had been received in the farm and rainfall regimes of >1,000, 800-1,000, 600-799, 400-599 and < 400mm per year, had mean P. zeae population densities of 2,138.5; 4,615.8; 6,767.7; 1,747.0 and 651.3 per 10.0 grams of roots respectively. The relationship between annual rainfall and Pratylenchus spp. population densities can be fitted by the quadratic equation:

$$Log_e(P.\ zeae\ in\ 10.0\ grams\ roots) = (2.619 \pm 1.973) + (0.0092 \pm 0.0047)\ (rainfall\ amount\ in\ mm) - (5.28 \times 10^{-6} \pm 2.77 \times 10^{-6})\ (rainfall\ amount\ in\ mm)^2$$

There were significant differences (P = 0.01) in the mean population densities of P. zeae which were recovered in the roots of maize plants growing in farms with rainfall regimes >1,000 and 800-1,000, 800-1,000 and 400-599, 600-799 and < 400, and 400-599 and < 400mm per annum (Appendix 5.1.5). There were, however, no significant differences in the mean population densities of P. zeae which were recovered in roots of maize plants growing in farms with rainfall regimes of >1 000 and 600-799 mm per annum. Low population densities of P. zeae were recovered in roots of maize plants growing in farms with either very high rainfall or very low rainfall per annum.

Mean population densities of P. zeae which were recovered from maize roots were also a function of the average temperatures for February and March and average temperature regimes of 20.0-22.5, 22.6 -25.0, 25.1-27.5, 27.6-30.1, 30.1-32.5 and > 32.5°C had mean P. zeae population densities of 595.0, 10,352.5, 4,871.5, 3,170.6, 705.0 and 0; and 595.0, 8,113.0, 6,786.5, 3,580.5, 363.6, and 0 per 10.0 grams of roots for February and March, respectively. The relationship between average February and March temperatures and P. zeae population densities can be fitted by quadratic equations:

a) Log_e (P. zeae in 10.0 grams roots) = (-58.62 ± 27.89) + (4.88 ± 2.04) February temp. -(0.09 ± 0.037) (February temp.)^2

b) Log_e (P. zeae on 10.0 grams roots) = (-59.16 ± 29.13) + (4.89 ± 2.11) March temp. -(0.091 ± 0.038) (March temp.)^2

The highest population densities of P. zeae were recovered in roots of maize plants growing in farms with temperature regimes of 22.5-29.9°C for both February and March average temperatures. There were significant

differences (P = 0.05) in the mean population densities of P. zeae which were recovered in roots of maize plants growing in farms with February and March mean temperature regimes of 20.0-22.4 and 22.5-24.9, 27.5-29.9 and 30.0-32.5, and 30.0-32.5 and > 32.5°C (Appendices 5.1.6-5.1.7). There were no significant differences (P = 0.05) in the mean population densities of P. zeae which were recovered in roots of maize plants growing in farms with February and March mean temperature regimes of 22.5-24.9 and 25.0-27.4. P. zeae was not recovered in roots of maize plants that were sampled from farms with temperature regimes > 32.5 °C and very low population densities of P. zeae, were recovered from farms with mean February and March temperature regimes of 20.0-22.4 and 30.1-32.5°C.

Soil texture influenced the population densities of P. zeae which were recovered in roots of maize plants growing in farms with different soil textures. In Manicaland province, a mean of 1,512.5, 1,587.3, 2,592.0 and 2,664.3 P. zeae per 10.0 grams of roots were recovered in roots of maize plants growing in sandy clay loam, sandy loam, loamy sand and sand soil, respectively. There were significant differences (P = 0.01) in the mean population densities of P. zeae which were recovered in roots of maize plants growing in farms with sand and sandy clay loam, sand and loamy sand, loamy sand and sandy loam, and sandy loam and sandy clay loam soil texture (Appendix 5.1.8).

The mean population densities of P. zeae which were recovered in roots of maize plants growing in soil with pH ranges 4.2-4.7, 4.8-5.3, 5.4-5.9 and 6.0-6.8 were 1,080.2, 2,701.5, 2,605.5 and 4,037.6 per 10.0 grams of roots, respectively. Comparisons of mean population densities of P. zeae recovered in roots of maize plants growing in farms with pH ranges of 4.2-4.7 and 4.8-5.3, and 5.4-5.9 and 6.0-6.8 had significant differences (P = 0.05) but there

Table 3.1.4. Relationships observed between manure, ammonium nitrate and Compound D fertilizer application and Pratylenchus zeae population densities, and subsequent maize yield in Manicaland province.

Nutrients	P. zeae/10.0 grams roots	Maize yield (tons/ha)
+ Manure (n = 10)	630.0	2.86
- Manure (n = 24)	2,631.8	1.81
+ Ammonium nitrate (n = 22)	2,210.1	2.20
- Ammonium nitrate (n = 12)	1,646.8	1.88
+ Compound D (n = 16)	1,111.9	2.52
- Compound D (n = 18)	2,786.9	1.89

were no significant differences in the mean population densities of P. zeae which were recovered in roots of maize plants which were growing in farms with pH ranges 4.2-4.7 and 6.0-6.8, and 4.8-5.3 and 5.4-5.9 (Appendix 5.1.9).

Communal farms in which manure was applied had a significantly lower ($P = 0.01$) mean population density of P. zeae in maize roots compared to farms in which manure had not been applied (Table 3.1.4) and the nematode control subsequently increased ($P = 0.01$) the mean maize yield (Appendix 5.1.10). The other nutrients, ammonium nitrate and compound D fertilizers, did not influence the mean population densities of P. zeae and subsequent mean maize yields.

Maize plants that were infected with high population densities of P. zeae (>1,000 per 10.0 grams of roots) had a significantly lower ($P = 0.01$) grain yield. There was a linear decrease in maize grain yield with increase in P. zeae population densities in maize roots (Fig. 3.1.3) and maize plants which were infected with <1,000 P. zeae per 10.0 grams of roots had a 2-fold higher mean yield.

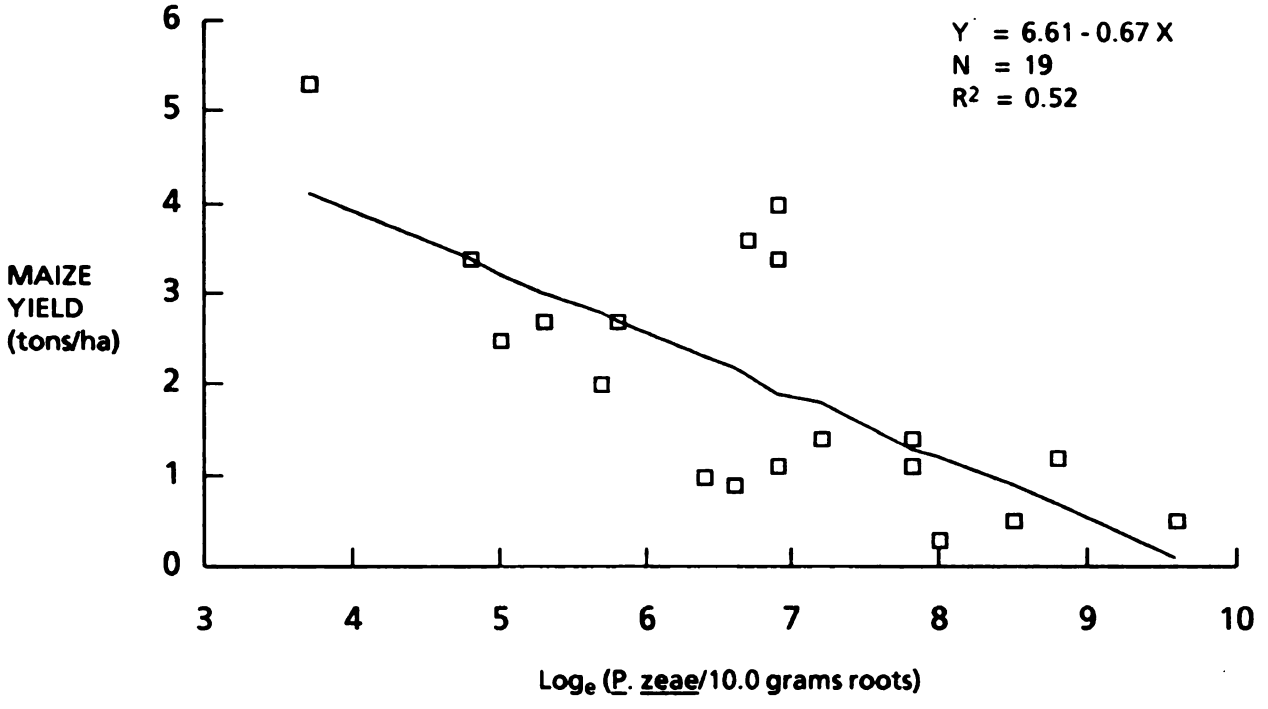

Figure 3.1.3. Relationships which were observed between maize grain yield and Pratylenchus zeae population densities in Manicaland province.

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3.1.4 Discussion

The survey indicates that the major nematode pests of maize in Zimbabwe communal areas are P. brachyurus and P. zeae and these two nematode species reduced maize grain yield by up to 48%. These two plant-parasitic nematode species have also been reported as major nematode pests of maize in North Carolina, South Africa and Nigeria (Chevres-Roman et al., 1973; Endo, 1959; Louw, 1982; Olowe and Corbett, 1976).

P. zeae, however, occurs more frequently in maize roots than P. brachyurus. The higher incidence of P. zeae in maize roots compared to P. brachyurus was similar to that reported in Nigeria, South Africa and Zimbabwe (Olowe and Corbett, 1976; Louw, 1982; Martin et al., 1975) where the incidences were reported as 51 and 29%, respectively. The competitive advantage of P. zeae over P. brachyurus in maize roots appears to be a function of shorter life cycle, faster reproductive rate, faster migration and tolerance to a wider range of temperatures and gravimetric soil moistures (Olowe and Corbett, 1976; Martin et al., 1975). Consequently, P. zeae which is more tolerant to a wider range of soil temperatures, textures and moistures occurs in all the five natural regions of Zimbabwe, whereas P. brachyurus is mainly restricted to natural regions II to IV.

The diversity and population densities of plant-parasitic nematodes that were recovered in maize roots during the survey were affected by natural regions. Natural regions I and V had the least diversity and lowest population densities of plant-parasitic nematodes and this appears to be a result of heavy soil texture, high soil moisture and low soil temperature in natural region I and the converse in natural region V.

Low population densities of Pratylenchus spp. which were recovered in areas with sub-optimal gravimetric soil moisture compared favorably with reports from Georgia, New York and South Africa (Good and Stansell, 1965; Kabel and Mai, 1968; Koen, 1967). The low population densities of Pratylenchus spp. in area with very high gravimetric soil moistures, especially in soils that do not drain well, appear to be a function of expended energy reserves in movement and maintenance of osmotic balance, toxin production by anaerobic bacteria and/or limited oxygen supply (Kabel and Mai, 1968) whereas in soil with very low gravimetric soil moisture, it appears the low population densities of Pratylenchus spp. are primarily due to desiccation. However, P. zeae which has been reported to survive in air-dried soil (2% gravimetric soil moisture) for longer than two years (Martin et al., 1975) was also recovered even in areas which receive less than 400mm of rainfall per year.

Low population densities of Pratylenchus spp. in natural regions V appear to be a result of very high soil temperatures in these areas. High soil temperatures $\geq$ 35°C inhibits development of Pratylenchus spp. and this has been reported in California, Japan, New York and Nigeria (Radewald et al., 1971; Mamiya, 1971; Kabel and Mai, 1968; Olowe and Corbett, 1976). These high temperatures primarily inhibit the hatching of eggs (Mamiya, 1971). On the other hand, low population densities of Pratylenchus spp. in natural region I were due to low soil temperatures and cropping patterns in these areas. Low population densities of Pratylenchus spp. (mainly P. brachyurus and P. zeae) in cool environments have also been reported in California, Nigeria, South Africa and South Carolina (Radewald et al., 1971; Olowe and Corbett, 1976; Koen, 1967; Graham, 1951). Low soil temperatures increase the time that is required to complete a life cycle because development will be

slow and if the soil temperature is very low, the life cycle might not be completed in a season (Olowe and Corbett, 1976; Mamiya, 1971).

Data on population densities of Pratylenchus spp. in natural region I indicate that heavy soil textures in this region could have contributed to the low population densities of Pratylenchus spp. Heavy soil textures have also been shown to impede rapid buildup of Pratylenchus spp. in Canada, Nigeria, North Carolina and South Africa (Townshend, 1972; Olowe and Corbett, 1976; Endo, 1959; Walters, 1979). The reproduction of Pratylenchus spp. is influenced by soil aeration and nematode motility and the optimum soil texture for P. brachyurus and P. zeae migration are sandy soils (Fortuner, 1976; Olowe and Corbett, 1976).

The population density of P. zeae was also affected by soil pH and low soil pH adversely impacted the population density of P. zeae. The adverse impact of low pH on the population density of P. zeae spp. compares favorably with reports in Canada and Iowa (Morgan and Maclean, 1968; Willis, 1972; Burns, 1971) where optimum pH range for P. zeae was reported as 5.2-6.4. Low pH appears to inhibit the hatching of P. zeae eggs (Willis, 1972).

The survey results also indicate that fields in which manure was applied had significantly lower population densities of P. zeae and higher maize yields. Control of plant-parasitic nematodes (mainly Meloidogyne spp. and Pratylenchus spp.) by use of organic amendments has been reported in Alabama, Connecticut, Egypt, New York and Nigeria (Mian and Rodriquez-Kabana, 1982 a-c; Miller, 1978; Badra and Mohamed, 1979; Walker, 1969; Egunjobi and Larinde, 1975). Organic amendments are effective in controlling plant-parasitic nematodes because they release ammonical nitrogen during their decomposition in the soil (Egunjobi and Larinde, 1975;

Mian and Rodriquez-Kabana, 1982 b; Muller and Gooch, 1982), increase microfauna inimical to plant-parasitic nematodes (Badra and Mohamed, 1979; Egunjobi and Larinde, 1975; Mankau and Das, 1974), create unfavorable environmental conditions for the nematode in the soil (Mankau and Das, 1974) and increase host vigor (Mankau and Das, 1974).

Use of organic amendments can be a viable plant-parasitic nematode control strategy to most communal farmers who generally keep 4.08 ± 0.285 cattle per household (Zimbabwe National Household Survey Capability Program, 1985/86). The study also indicates that maize yield can be increased by use of inorganic fertilizers in plants infected with P. zeae but the inorganic fertilizer will not adversely impact the population density of the nematodes at the recommended fertilizer application rates.

The survey results highlight the importance of P. zeae as a major potential constraint of maize production and this subsequently affects the living standards of communal farmers. The relationships which were observed between P. zeae population densities and maize yield are important in the development of regional crop loss assessment programs and P. zeae maize simulation models. The data presented in this study also demonstrate the importance of soil moisture, temperature and texture on Pratylenchus spp. reproduction and subsequent pathogenicity on maize growth. This information is well suited for the development and/or validation of P. zeae-maize simulation models. Also the abiotic and biotic relationships which were reported in this study can be utilized for within-year crop management decisions to optimize maize yields.

3.2 OVERWINTERING AND VERTICAL DISTRIBUTION OF P. ZEAE UNDER CLEAN FALLOW

3.2.1 Introduction

Information on the overwintering of P. zeae is important in the development and initialization of predictive computer simulation models and for recommending appropriate P. zeae control strategies to farmers. The objectives of this study were to: (a) assess the reduction of P. zeae population density achieved by leaving a piece of land fallow for one year, (b) evaluate whether P. zeae migrates to deeper depths if soil temperature and/or moisture conditions were sub-optimal in the upper layers and (c) assess life stages of P. zeae which are prevalent during the overwintering period.

3.2.2 Materials and Methods

The site for this study was in Chinamora communal area (Grid ref. 30 25' East and 17 30' South). Soil texture on this site was loamy sand (6% clay, 5% silt, 25.2% fine sand, 38.4% medium sand and 25.9% coarse sand), sandy loam (12% clay, 5% silt, 21.2% fine sand, 33.6% medium sand and 28.7% coarse sand), sandy clay loam (22% clay, 3% silt, 24.5% fine sand, 28.8% medium sand and 22.2% coarse sand), sandy clay loam (32% clay, 7% silt, 20.3% fine sand, 21.2% medium sand and 19.8% coarse sand) and sandy clay (36% clay, 6% silt, 19.7% fine sand, 17.1% medium sand and 21.3% coarse sand) for depths 0-10, 10-20, 20-30, 30-40 and 40-50 cm, respectively. The respective depths had soil at pH 4.4, 4.3, 4.6, 5.1 and 4.7; bulk density of 1.42, 1.46, 1.53, 1.61 and 1.57 grams/cm^3; and volumetric moisture content of 5.3, 8.9, 16.2, 23.2 and 26.2%. The soil was naturally infested with P. zeae and a plot 10x10m was marked out on 21st July, 1986. The plot was cleared of weeds using a hoe and randomly sampled 10 times at monthly intervals.

Sampling Procedure

On each sampling date, soil was collected at depths of 0-10, 10-20, 20-30, 30-40 and 40-50 cm. The diameter of the soil core was 20 cm. The soil was dug using a crow bar and soil from each cylinder was thoroughly mixed in a plastic bucket, and a sub-sample (ca 1,500 cm^3) was put in a labeled plastic bag. The plastic bags were closed to prevent any loss of moisture from the soil. The samples were put into cooler boxes and taken to the laboratory. The following parameters were evaluated from the samples:

i) Gravimetric moisture content:

Labeled crucibles (capacity = 10cm^3) were put in an oven at 105^oC for about 12 hours and then cooled in a dessicator for 1 hour. When the crucible had cooled to room temperature, they were put on a balance with an accuracy of ±0.001 grams using tongs to determine the weight of the crucible. After the second weight had been recorded, the crucibles were put into the oven at 105^oC for about 24 hours. After the 24 hours, the crucibles were put into a dessicator for about 1 hour. When the contents had cooled to room temperature, the crucibles were reweighed. This procedure was repeated whenever soil moisture content was determined. The soil moisture content was calculated using the following equation:

$$\%\ soil\ moisture = \frac{weight\ of\ soil - weight\ of\ oven\ dry\ soil}{weight\ of\ oven\ dry\ soil} * 100$$

ii) Distribution of P. zeae:

Soil was thoroughly mixed in a tray and 100cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 1964) and observed under

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a stereoscopic microscope to enumerate P. zeae second, third to fourth stage juveniles and mature females in the soil.

iii) P. zeae and soil moisture data in this experiment were transformed (square root transformation) during analysis because it exhibited a Poisson distribution. Two way analysis of variance between P. zeae stages in the soil, time and depth of sampling was carried out. For the different time and depth of sampling; linear, quadratic and cubic orthogonal polynomials were fitted in trend analysis. Also regression analysis was carried out between P. zeae stages recovered in the soil and gravimetric soil moisture content. After the analysis of variance, least significant difference (LSD), standard error (SE) and coefficient by variation (CV) were calculated.

3.2.3 Results

The population density of P. zeae second stage juveniles in the soil was very low and it did not change (P = 0.05) throughout the sampling period. There was, however, a significant linear decrease (P = 0.05) of P. zeae second stage juveniles in the soil with depth (Table 3.2.1). The population density also had a significant linear decrease (P = 0.05) with increase in gravimetric soil moisture content, which increased with depth:

$$\underline{P.\ zeae}\ J_2\ in\ 100cm^3\ soil = (0.967 \pm 0.097)\text{-}(0.028 \pm 0.014)^{*}$$

$$sq.\ rt.\ (\%\ soil\ moisture)$$

Despite the low population density of P. zeae second stage juveniles in soil, there was considerable variability (c.v.% = 25.1) in the numbers recovered from the soil.

The population density of P. zeae third to fourth stage juveniles in the soil significantly changed (P = 0.05) with time (Fig. 3.2.1). The population

density fluctuated in a linear (P = 0.05) and quadratic (P = 0.01) manner. The population density of P. zeae third to fourth stage juveniles was initially high at the beginning of the sampling period (July and August) then it decreased by 74%, possibly in a quadratic manner in about five months. From February to June, the population density of P. zeae third to fourth stage juveniles increased by 41%, possibly in a linear manner. The population density of P. zeae third to fourth stage juveniles in the soil had a significant linear decrease (P = 0.01) with depth and the population density at depth 0-10 cm was 3.4 x greater than the population density at depth 40-50 cm (Table 3.2.1). In July and August, P. zeae third to fourth stage juveniles were more abundant at depth 20-40 cm. In November and December, the population density of P. zeae third to fourth stage juveniles was high at 0-10 cm. From January to June, the population density of P. zeae third to fourth stage juveniles was generally very low. The population density of P. zeae third to

Table 3.2.1. Influence of the depth of sampling on the population density of Pratylenchus zeae recovered from 100 cm^3 of soil in Chinamora communal area.

Parameters / Sampling depth (cm)	P. zeae stages			
	J_2	J_3-J_4	Mature females	Total
0-10	1.0[1]	7.9	12.2	21.1
10-20	0.2	4.2	3.6	8.6
20-30	0.1	4.9	0.9	5.9
30-40	0.0	2.3	1.4	3.7
40-50	0.0	0.2	0.0	0.2

Key

[1]Mean of 10 different sampling times.
Analysis in Appendix 5.2.2-5.2.3.

fourth stage juveniles also had a significant linear decrease (P = 0.01) with increase in gravimetric soil moisture content which increased with depth:

$$\underline{P.\ zeae}\ J_3\text{-}J_4\ in\ 100\ cm^3\ soil = (3.188 \pm 0.532)\text{-}(0.229 \pm 0.076)^{*}$$

$$sq.\ rt.\ (\%\ soil\ moisture)$$

There was, however, considerable variability (C.V.% = 62.5) in the number of P. zeae third to fourth stage juveniles recovered from soil despite the square root transformation of the raw data to normalize it.

The population density of P. zeae mature females in the soil significantly fluctuated (P = 0.05) with time (Fig. 3.2.1). The fluctuations in the population density of P. zeae mature females with time were linear (P = 0.05). The population density was high in July and August, then it decreased by 54.3% in three months. In December, the population density increased by 61% then decreased by 66.5% in January and thereafter, the population density increased by 25.4% in three months. The population density of P. zeae mature females in the soil had a significant linear decrease (P = 0.01) with depth and the population density at depth 0-10 cm was 4.2 x greater than the population at depth 40-50 cm (Table 3.2.1). In July and August, P. zeae mature females were more prevalent at depth 0-10 cm and from September to November, the population density was uniform up to a depth of 0-20 cm. In December, P. zeae mature females were again more abundant at depth 0-10 cm and thereafter, the population density was very low. The population density of P. zeae mature females also had a significant linear decrease (P = 0.01) with increase in gravimetric soil moisture content, which increased with depth:

P. zeae mature females in 100 cm^3 *soil* = (3.348 ± 0.545)-(0.267 ± 0.078) $^{\sqrt{\text{sq. rt. (\% soil moisture)}}}$

There was also considerable variability (C.V.% = 62.2) in the population density of P. zeae mature females recovered from soil despite the transformation of the raw data.

The total population density of P. zeae in the soil fluctuated (P = 0.05) with time (Fig. 3.2.1). The fluctuation of the total population density of P. zeae with time was linear (P = 0.01) and it followed the same trend as P. zeae mature females in the soil. Similarly, the total population density of P. zeae had a significant linear decrease (P = 0.01) with depth and the population density at depth 0-10 cm was 5.1 x greater than the population density at depth 40-50 cm (Table 3.2.1). The population density also followed a similar trend to that outlined for P. zeae third to fourth stage juveniles and mature females. The total population density of P. zeae in the soil had a significant linear decrease (P = 0.01) with increase in gravimetric soil moisture content:

P. zeae in 100cm^3 soil = (4.807 ± 0.741)-(0.390 ± 0.106) $^{\sqrt{\text{sq. rt. (\% soil moisture)}}}$

3.2.4 Discussion

Data presented in this study show that P. zeae mainly overwinter as third to fourth stage juveniles and mature females and these life stages constitute 51.9 and 46.3% of the total population of vermiform stages, respectively. Similar results have also been reported from California where 56 and 41% of P. coffeae population density was reported to overwinter as third

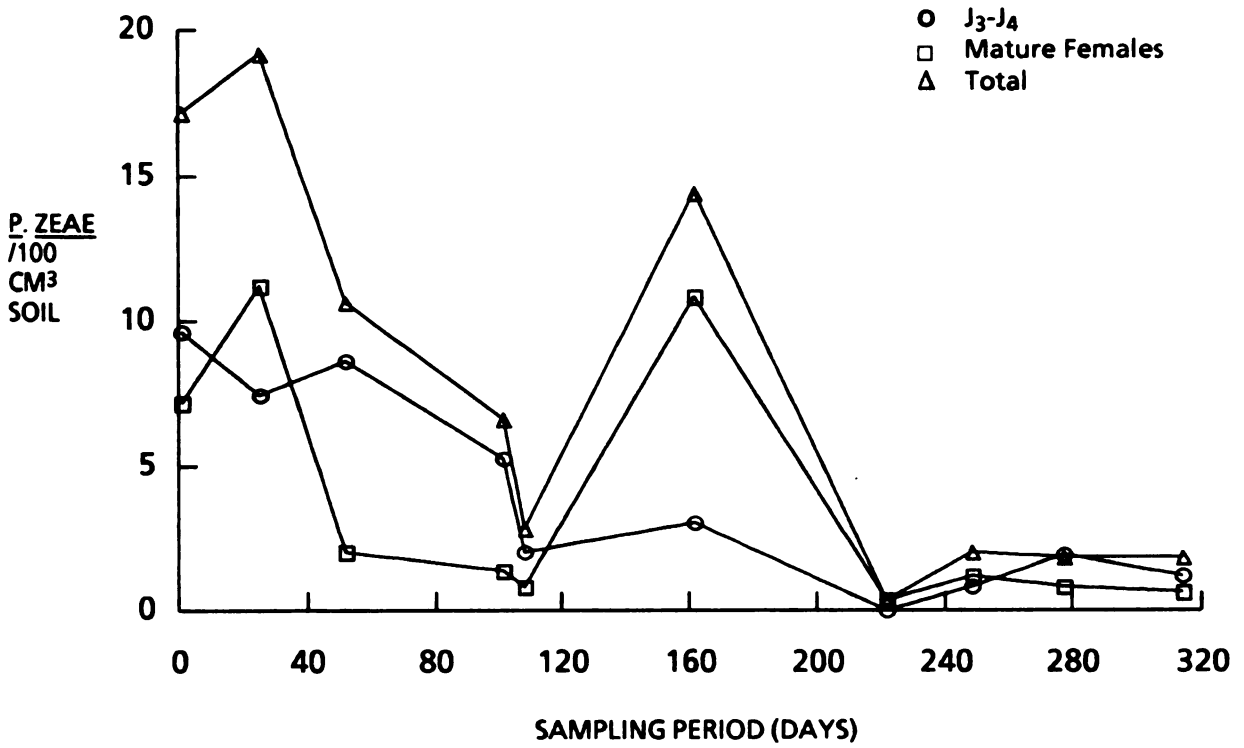

Figure 3.2.1. Influence of the time of sampling on the population density of Prtatylenchus zeae recovered from 100 cm3 of soil in Chinamora communal area.

to fourth stage juveniles and mature females, respectively. It appears during development, Pratylenchus spp. spent the least amount of time in the second juvenile stage in the soil and perhaps this is the reason why this developmental stage has a very low incidence when samples are processed. The low population densities of P. zeae second stage juveniles in the soil may be a function of the extraction method which was used. It is possible that a greater number of P. zeae second stage juveniles passed through the 400-mesh (30-µm) sieve. Viglierchio & Schmitt (1983) reported a relative efficiency of 17-29% for extracting Pratylenchus spp. with the centrifugal-flotation technique. The field which was used for this study was also infested with other plant-parasitic nematodes, therefore, it was not possible to differentiate P. zeae eggs from eggs of other plant-parasitic nematodes. It was, however, apparent that some P. zeae eggs hatched after the rainfall in November and the population density of third to fourth stage juveniles and mature females increased in December. In Nigeria, it has been reported that rainfall and low temperatures favor the hatch of Pratylenchus spp. eggs (Egunjobi and Bolaji, 1979).

Data presented in this study also show that the population density of P. zeae in the soil decreased with time when the land was left clean fallow for about a year. The decrease of P. zeae population density was mainly during the hot and dry months possibly through desiccation. The decrease of Pratylenchus spp. to very low population densities was similar to that reported in Nigeria and South Africa (Egunjobi, 1974; Koen, 1967). In spite of this decrease in the population density with time, the resistance of P. zeae to adverse conditions, especially desiccation, has been noted as remarkable (Olowe and Corbett, 1976; Louw, 1982) and P. zeae can survive in air dried soil for longer than two years (Martin et al., 1975). This investigation,

however, demonstrates the importance of removing old maize roots and weeds as an important condition to any cultural sanitation program for the maize crop in communal farms. It should, however, be noted that the population density of P. zeae builds up very rapidly when a susceptible host has been planted during the growing season. Rapid build up of Pratylenchus spp. after planting maize has been reported in Nigeria (Egunjobi, 1974; Egunjobi and Bolaji, 1979; Olowe and Corbett, 1976), North Carolina (Endo, 1959), South Africa (Koen, 1967), Tennessee (Southards, 1971) and Zimbabwe (Martin et al., 1975; Muchena et al., 1987).

This research also shows that the highest population density of P. zeae was mainly confined at a depth of 0-20 cm and the population density of P. zeae at this depth constituted about 78.2% of the total population density of P. zeae that was recovered from a depth of 0-50 cm. It appears P. zeae was mainly confined at a depth of 0-20 cm because the maize crop which was previously growing on this land had most of its root system restricted to the same depth. In general, the distribution of the root system of the host crop, dictates the distribution of the nematode pests. Higher population densities of Pratylenchus spp. associated with maize, at a depth of 0-20 cm have also been reported in Nigeria, North Carolina, and South Africa (Egunjobi, 1974; Barker, 1968; Koen, 1967). The data also show evidence of P. zeae migration to deeper depths (20-40 cm) especially during the hot and dry months of September and October. It appears P. zeae migrates to deeper depths to avoid adverse soil temperature and moisture conditions especially at a depth of 0-10 cm. The vertical migration of Pratylenchus spp. as a means of avoiding the adverse effects of the dry season was similar to what has been reported in Nigeria and South Africa (Egunjobi, 1974; Koen, 1967).

The research confirms the hypothesis that the population density of P. zeae in the soil can be adversely impacted if the land is left clean fallow for about a year, despite the migration of P. zeae to deeper depths to avoid the adverse effects of the dry season. The data also illustrate that third to fourth stage juveniles and mature females are the important stages in the overwintering of P. zeae. The data from this experiment should be well suited for initialization of P. zeae computer simulation models and development of a simulation model that predicts the overwintering of P. zeae in the soil without a host crop.

3.3 SPATIAL AND TEMPORAL DISTRIBUTION OF GRAVIMETRIC SOIL MOISTURE, MAIZE ROOT SYSTEM AND P. ZEAE WITH SPECIAL REFERENCE TO P. ZEAE SAMPLING SCHEMES

3.3.1 Introduction

Accurate estimation of Pratylenchus spp. in soil or roots is important in the development of integrated pest management strategies and computer simulation models. Very few studies, however, have been addressed to evaluate the accuracy of sampling schemes of Pratylenchus spp. associated with annual crops. The objectives of this study were to assess the a) temporal and spatial distribution of maize roots and P. zeae, b) impact of gravimetric soil moisture on the population density of P. zeae and c) optimal sampling schemes of P. zeae in soil or maize roots.

3.3.2 Materials and Methods

This study was carried out in four pits 3.0 m long, 1.0 m wide and 0.75 m deep at the Harare Research Center (Grid ref. 30° 25' East and 17° 22' South). The pits were filled with loamy sand (6% clay, 5% silt, 25.2% fine sand, 38.4% medium sand and 25.9% coarse sand) naturally infested with

30.0 P. zeae per 100 cm^3 soil. The soil had a pH of 4.4, bulk density of 1.42 grams/cm^3 and volumetric moisture content of 5.3%. Basal fertilizer, compound D (8% N, 14% P_2O_5, 7% K_2O, 6.5% S) was applied at a rate of 300kg/ha to all the pits on 21st January, 1987. After basal fertilizer application, maize variety R 215 seeds were planted into the pits on the same date. The seeds were planted in one row at the center of the pit with an intra-row spacing of 80 cm. After planting the seeds, all the pits were gently watered. Emergence of the maize seed occurred 7-10 days after seeding and the maize plants were sampled biweekly for 20 weeks.

Sampling Procedure

On each sampling date, soil and maize roots were collected from one plant at depths 0-10, 10-20, 20-30, 30-40 and 40-50 cm and radii of 0-10, 10-20 and 20-30 cm. The soil was dug using a sharpened trowel which cuts roots and soil and roots from each cylinder was sieved using a 25 mesh sieve and all the maize roots which were caught on the sieve were put into a labeled plastic bag. Also a sub-sample (ca 1,500 cm^3) of the sieved soil was put into a labeled plastic bag. All the plastic bags were closed to prevent any loss of moisture from the soil or roots. The samples were put into cooler boxes and then taken back to the laboratory. The following parameters were evaluated from the samples:

i) Fresh weights of the root system were obtained by weighing on a balance with an accuracy of ±0.001 grams.

ii) Gravimetric soil moisture content:

Labeled crucibles (capacity = 10 cm^3) were put into an oven at 105°C for about 12 hours and then cooled in a dessicator for one hour. When the crucibles had cooled to room temperature, they were put on a balance with an accuracy of ±0.001 grams using

tongs to determine the weight of the empty crucible. After the weight had been recorded, about 5.0 cm^3 of soil was put into the crucible using a spatula and the weight of the crucible with soil was determined. It was important to note that the tongs were not in contact with the soil when lifting the crucible. After the second weight had been recorded, the crucibles were put into the oven at 105°C for about 24 hours. After the 24 hours, the crucibles were put into a dessicator for about one hour. When the contents had cooled to room temperature, the crucible were reweighed. This procedure was repeated whenever soil moisture content was determined. The soil moisture content was calculated using the following equation:

$$\%\ soil\ moisture = \frac{Weight\ of\ soil - weight\ of\ oven\ dry\ soil}{weight\ of\ oven\ dry\ soil} * 100$$

iii) Distribution of P. zeae :

a) Soil was thoroughly mixed in a tray and 100cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 1964) and observed under a stereoscopic microscope to enumerate P. zeae second, third to fourth stage juveniles and mature females in the soil.

b) The whole root system from each cylinder was chopped into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random if the weight of the root system in a cylinder was greater than 10.0 grams but if the weight of the root system was less than 10.0 grams, the whole root system was processed using

the maceration-centrifugal-flotation technique (Southey, 1985 p. 54) and observed under a stereoscopic microscope to enumerate P. zeae second, third to fourth stage juveniles and mature females in the roots using the examination of nematode suspensions technique (Southey, 1985 p.59-60).

iv) Sampling schemes:

The total number of potential sampling schemes for P. zeae in the soil or roots are: 10 sampling times x 5 depths x 3 radii = 150 different sampling schemes. After determining the number of P. zeae in 150 soil samples and 150 root samples, the mean number of P. zeae either in the soil ($\bar{X}_s$) or roots ($\bar{X}_r$) were determined. Then the number of P. zeae in the soil (X_s) or in the roots (X_r) were substracted from the respective means:

a) Percent error for sampling soil = $$\frac{X_s - \bar{X}_s}{\bar{X}_s} * 100$$

b) Percent error for sampling roots = $$\frac{X_r - \bar{X}_r}{\bar{X}_r} * 100$$

The magnitude of percent errors which were generated from the above two steps were ranked separately for soil or roots. Rank 1 was assigned to the sampling scheme with the least percent error and the rank 150 was assigned to the sampling scheme with the highest percent error. After ranking all the sampling schemes, the ranks were adjusted to compensate for energy and time expended when sampling at deeper depths. In the adjusted ranks, 0, 1, 2, 3 or

4 was added to the rank if the sampling depth was 0-10, 10-20, 20-30, 30-40 or 40-50 cm, respectively.

v. Three way analysis of variance between P. zeae stages in the soil or maize roots; time, depth and radius of sampling was carried out. For the different time, depth and radius of sampling; linear and quadratic orthogonal polynomials were fitted in trend analysis. After the analysis of variance, least significant difference (LSD) and standard error (SE) were calculated.

3.3.3 Results

Weight of maize root system was significantly (P = 0.01) influenced by the time of sampling (Table 3.3.2) and at the beginning of the growing season, maize root weight had a significant (P = 0.01) linear increase but at the end of the season, the weight of the root system fluctuated in a quadratic manner (P = 0.01). The weight of the root system was also significantly (P = 0.01) different for different depths of sampling and the weight of the root system had a linear (P = 0.01) decrease with increase in depth (Table 3.3.4). Between depths of 30-50 cm, the weight of the root system fluctuated in a quadratic manner (P = 0.05). Weight of maize root system was also significantly (P = 0.01) different for different radii of sampling and the weight of the root system had a significant (P = 0.01) linear decrease with increase in sampling radius (Table 3.3.6).

The population densities of P. zeae second stage juveniles (J_2) in soil or maize roots significantly (P = 0.01) fluctuated with time (Tables 3.3.1-3.3.2). The population density of P. zeae J_2 in soil had a significant (P = 0.01) linear increase with time and P. zeae J_2 roots initially had a significant (P = 0.01) linear increase but later fluctuated in a quadratic manner (P = 0.01). P. zeae J_2 in soil and maize roots were also significantly (P = 0.01) affected by the

Table 3.3.1. Effect of the time of sampling on the population density of Pratylenchus zeae recovered from 100 cm^3 of soil around maize roots.

Parameters Sampling time (weeks)	P. zeae stages				Gravimetric soil moisture (%)
	J_2	$J_3 - J_4$	Mature females	Total	
2	0.00[1]	33.6	1.88	35.38	6.876
4	0.00	59.8	5.14	64.94	6.291
6	1.93	45.7	2.51	50.14	5.904
8	10.47	5.5	1.46	17.43	4.602
10	7.07	0.3	5.49	12.86	3.987
12	0.07	6.6	1.24	7.91	4.623
14	0.20	5.3	1.71	7.21	6.312
16	0.00	29.8	2.35	32.15	6.069
18	3.00	22.2	3.93	29.13	5.157
20	10.07	56.2	9.51	75.78	4.470
L.S.D. 0.05	3.54	15.44	2.53	2.56	0.390
S.E.	1.808	7.88	1.292	1.307	0.199

[1]Mean of 5 different depths x 3 radii.

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[1]Mean

Table 3.3.2. Influence of the time of sampling on maize root weight and the population density of Pratylenchus zeae recovered in 10.0 grams of roots.

Parameters Sampling time (weeks)	Root weight (grams)	P. zeae stages			
		J_2	J_3 - J_4	Mature females	Total
2	0.05[1]	0.00	10.0	9.0	19.00
4	0.09	0.00	2.0	11.0	13.00
6	0.04	0.00	334.0	59.0	393.00
8	3.55	2.83	143.0	131.0	276.83
10	5.87	5.10	321.0	547.0	873.10
12	10.19	10.70	415.0	35.0	460.70
14	6.09	10.59	421.0	60.0	491.59
16	10.10	2.94	1558.0	110.0	1670.94
18	5.88	20.09	1370.0	110.0	1500.09
20	4.81	210.61	4346.0	462.0	5018.61
L.S.D. 0.05	5.70	3.26	727.2	223.1	853.8
S.E.	2.909	1.665	371.0	113.8	435.6

[1]Mean of 5 different depths x 3 radii.

Table 3.3.3. Impact of the depth of sampling on gravimetric soil moisture and the population density of Pratylenchus zeae recovered from 100 cm^3 of soil.

Parameter Sampling depth (cm)	P. zeae stages				Gravimetric soil moisture (%)
	J_2	J_3 - J_4	Mature females	Total	
0-10	1.23[1]	12.5	2.52	16.25	5.157
10-20	4.47	35.9	3.14	43.51	5.440
20-30	3.03	21.4	2.56	26.99	5.424
30-40	2.83	30.7	2.26	35.79	5.625
40-50	4.83	31.9	2.06	38.79	5.493
L.S.D. 0.05	2.51	10.92	2.35	2.37	0.28
S.E.	1.28	5.57	1.20	1.21	0.141

[1]Mean of 10 different depths x 3 radii.

Table 3.3.4. Influence of the depth of sampling on maize root weight and the population density of Pratylenchus zeae recovered in 10.0 grams of roots.

Parameters Sampling depth (cm)	Root weight (grams)	P. zeae stages			
		J_2	J_3 - J_4	Mature females	Total
0-10	12.70[1]	12.18	1039.0	1420.0	2471.18
10-20	5.64	20.08	1270.0	1605.0	2895.08
20-30	3.03	6.36	788.0	961.0	1755.36
30-40	1.26	1.36	698.0	794.0	1493.36
40-50	0.70	1.76	665.0	761.0	1427.76
L.S.D. 0.05	4.04	2.80	514.1	157.8	603.7
S.E.	2.06	1.43	262.3	80.5	308.0

[1]Mean of 10 different depths x 3 radii.

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Table 3.3.5. Effect of the radius of sampling on the population density of Pratylenchus zeae recovered from 100 cm^3 of soil.

Parameters Sampling radius (cm)	P. zeae stages			
	J_2	J_3-J_4	Mature females	Total
0-10	2.74[1]	22.9	2.65	28.29
10-20	3.40	27.3	2.58	33.38
20-30	3.70	29.3	2.26	35.26
L.S.D. 0.05	1.94	8.47	2.25	2.27
S.E.	0.99	4.32	1.15	1.16

[1]Mean of 10 different sampling times x 5 depths.

Table 3.3.6. Influence of the radius of sampling on maize root weight and the population density of Pratylenchus zeae recovered in 10.0 grams of roots.

Parameters Sampling radius (cm)	Root weight (grams)	P. zeae stages			
		J_2	J_3 - J_4	Mature females	Total
0-10	7.68[1]	3.90	564.0	84.0	651.9
10-20	3.92	6.00	754.0	145.0	905.0
20-30	2.40	6.69	1358.0	231.0	1595.7
L.S.D. 0.05	3.14	2.59	398.3	122.1	467.7
S.E.	1.60	1.32	203.2	62.3	238.6

[1]Mean of 10 different sampling times x 5 depths.

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depth of sampling (Tables 3.3.3-3.3.4). P. zeae J_2 in roots had a linear (P = 0.01) decrease with increase in depth and P. zeae J_2 in soil also had a linear (P = 0.05) decrease with increase in depth. The population densities of P. zeae J_2 at radii 0-10, 10-20 and 20-30 cm were equal (P = 0.01) for both soil and maize roots. The population density of P. zeae J_2 was generally very low throughout the whole growing period and it constituted 2.5% of the total population of P. zeae that were recovered.

The population densities of P. zeae third to fourth stage juveniles (J_3-J_4) in soil and maize roots were significantly (P = 0.01) influenced by the time of sampling during the growing period (Tables 3.3.1-3.3.2). The population density of P. zeae J_3-J_4 in the soil fluctuated in a quadratic manner (P = 0.05). P. zeae J_3-J_4 in the soil started with a high population density which decreased for 10 weeks then increased from the tenth week until the end of the growing period. The population density of P. zeae J_3-J_4 in roots had a much more complex fluctuation with significant (P = 0.01) linear, quadratic and cubic variations. There were four distinct peaks in the population density of P. zeae J_3-J_4 in roots during the 20 weeks growing period which might imply four generations were completed during the growing period. The population densities of P. zeae J_3-J_4 in soil or maize roots were also significantly (P = 0.01) affected by the depth of sampling (Tables 3.3.3-3.3.4). The population density of P. zeae J_3-J_4 in soil had a significant (P = 0.01) linear increase with depth and P. zeae J_3-J_4 in roots had a significant (P = 0.01) linear decrease with increase in depth. The population density of P. zeae J_3-J_4 in the soil was not significantly (P = 0.05) influenced by the radii of sampling (Table 3.3.5). But the population density of P. zeae J_3-J_4 in roots was significantly (P = 0.01) affected by the radii of sampling (Table 3.3.6). The population density of P. zeae J_3-J_4 in roots had a significant (P = 0.01)

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linear increase with increase in the radii of sampling. The population density of P. zeae J_3-J_4 constituted 83.2% of the total population of P. zeae that were recovered in the experiment.

The population densities of P. zeae mature females in soil and maize roots were significantly (P = 0.01) influenced by the time of sampling (Tables 3.3.1-3.3.2). The population density of P. zeae mature females in the soil had a significant (P = 0.001) quadratic fluctuation. There were three distinct peaks in the population density during the growing season. On the other hand, the population density of P. zeae mature females in roots had s significant (P = 0.01) linear increase during the early part of the growing season, then the population density decreased during midseason and then the population density increased again at the end of the growing period. The population density of P. zeae mature females in roots was significantly (P = 0.01) influenced by the sampling depth (Table 3.3.4) but the population density of P. zeae mature females in soil was not significantly (P = 0.05) influenced by the sampling depth (Table 3.3.3). However, there was a significant (P = 0.05) linear decrease of the population density of P. zeae mature females in soil with increase in sampling depth. There was also a significant (P = 0.01) linear decrease of the population density of P. zeae mature females in roots with increase in sampling depth. The population density of P. zeae mature females in soil was not significantly (P = 0.05) influenced by the sampling radius and was equal (P = 0.05) for the three different sampling radii (Table 3.3.5). On the other hand, the population density of P. zeae mature females in roots was significantly (P = 0.05) influenced by the radius of sampling (Table 3.3.6). The population density of P. zeae mature females in roots had a significant (P = 0.05) linear increase with increase in sampling radius.

The total population density of P. zeae in soil and maize roots was significantly (P = 0.01) influenced by the time of sampling (Tables 3.3.1-3.3.2). The population density of P. zeae in the soil fluctuated in a quadratic (P = 0.001) manner and it started fairly high and the population decreased during midseason then it increased at the end of the growing season. The population density of P. zeae in maize roots had a much more complex pattern with significant linear (P = 0.001), quadratic (P = 0.01) and cubic (P = 0.01) variations. The fluctuation in the population density of P. zeae had four distinct peaks during the growing season. The total population of P. zeae in soil and maize roots was also significantly (P = 0.01) influenced by the depth of sampling (Tables 3.3.3-3.3.4). The population density of P. zeae in soil had significant (P = 0.01) linear, quadratic and cubic variations). The population density was lowest at depth 0-10 cm then it increased at depth 10-20 cm then decreased at depth 20-30 cm and it increased at depth 30-50 cm. The population density of P. zeae in roots had a significant (P = 0.01) linear decrease with increase in sampling depth. The population density of P. zeae in soil was not significantly (P = 0.05) influenced by the sampling radius but the population had a significant (P = 0.01) linear increase with increase in sampling radius (Table 3.3.5). The population density of P. zeae in maize roots was significantly (P = 0.01) influenced by the sampling radius and the population also had a significant (P = 0.01) linear increase with increase in sampling radius (Table 3.3.6).

The sampling schemes of P. zeae in soil around maize plants were ranked in order of accuracy and the best sampling scheme had an error of 0.46% and the worst sampling scheme had an error of 300.14% (Table 3.3.7). The adjusted sampling schemes for energy and time which can be expended digging samples showed that the most practical and accurate sampling

Table 3.3.7. Sampling schemes of Pratylenchus zeae in soil around maize roots.

Sampling schemes			Rank	% error[1]
Time (weeks)	Radius (cm)	Depth (cm)		
12	0-10	30-40	1	0.46
2	10-20	10-20	2	0.98
10	0-10	30-40	3	1.92
16	20-30	0-10	4	1.95
6	0-10	40-50	5	2.16
4	10-20	20-30	6	2.26
12	0-10	40-50	7	2.66
8	20-30	20-30	8	2.77
8	20-30	0-10	9	2.87
14	0-10	10-20	10	3.19
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
20	0-10	40-50	141	127.82
4	0-10	40-50	142	143.88
20	10-20	40-50	143	144.69
20	10-20	10-20	144	149.62
20	10-20	0-10	145	151.22
6	10-20	10-20	146	167.56
6	10-20	30-40	147	191.97
20	20-30	10-20	148	202.45
6	20-30	40-50	149	258.32
18	10-20	10-20	150	300.14

[1]Percent deviation from a mean of 31.80.

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scheme of P. zeae in soil was 2 weeks after planting at radius 10-20 cm from the maize plant and at depth 10-20 cm (Table 3.3.9). The sampling schemes of P. zeae in maize roots were also ranked in order of accuracy and the best sampling scheme had no error from the grand mean and the worst sampling scheme had an error of 548.01% from the grand mean (Table 3.3.8). The adjusted sampling schemes for energy and time which can be expended in digging samples showed that the most practical and accurate sampling scheme of P. zeae in maize roots was 4 weeks after planting at radius 0-10 cm from the plant and depth 10-20 cm (Table 3.3.9).

3.3.4 Discussion

Data presented in this study show that 80.0% of the maize root system was confined to a depth of 0-20 cm. Berger (1962) also reported that root system of maize plants is restricted in the topsoil but under adverse soil moisture conditions, individual roots can reach a depth of up to 250 cm and radius 100 cm. In general, however, the growth of maize roots occur almost equally outwards and downwards and branch out in all directions (Berger, 1962). The rate of maize root growth which was observed in this study was less than what has been reported in the literature (Berger, 1962). The slow maize root growth may have been in part a result of inadequate soil nutrients and moisture and the P. zeae infection. Maize root weights at the end of the growing season were lower than previously recorded root weights and this could have been a result of senescence and increased P. zeae stress on the root system as the nematodes continued to reproduce and cause more damage.

The data presented in this study show that P. zeae mainly thrives as third to fourth stage juveniles and mature females and these life stages constituted 83.2 and 14.3% of the total population of vermiform stages that

Table 3.3.8. Sampling schemes of Pratylenchus zeae in maize roots.

Sampling schemes			Rank	% error[1]
Time (weeks)	Radius (cm)	Depth (cm)		
6	20-30	40-50	1	0.00
6	10-20	30-40	2	0.51
12	10-20	40-50	3	1.26
4	0-10	10-20	4	1.32
14	10-20	40-50	5	1.41
8	10-20	20-30	6	1.56
12	10-20	10-20	7	1.66
12	20-30	20-30	8	1.77
14	20-30	20-30	9	3.34
6	10-20	40-50	10	3.44
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
20	20-30	10-20	141	197.65
20	10-20	0-10	142	214.71
10	10-20	0-10	143	217.78
16	20-30	10-20	144	228.34
20	20-30	40-50	145	245.01
20	0-10	20-30	146	246.11
20	0-10	10-20	147	294.31
20	0-10	0-10	148	409.02
20	20-30	30-40	149	433.94
20	20-30	0-10	150	548.01

[1]Percent deviation from a mean of 1,108.00.

Table 3.3.9. Adjusted[1] sampling schemes of Pratylenchus zeae in maize roots and soil around the roots.

a) Soil

Sampling schemes			Rank	% error[2]
Time (weeks)	Radius (cm)	Depth (cm)		
2	10-20	10-20	1	0.98
16	20-30	0-10	2	1.95
12	0-10	30-40	3	0.46
10	0-10	30-40	4	1.92
4	10-20	20-30	5	2.26
6	0-10	40-50	6	2.16
8	20-30	0-10	7	2.87
8	20-30	20-30	8	2.77
12	0-10	40-50	9	2.66
14	0-10	10-20	10	3.19

b) Roots

Sampling schemes			Rank	% error[3]
Time (weeks)	Radius (cm)	Depth (cm)		
4	0-10	10-20	1	1.32
6	10-20	30-40	2	0.51
6	20-30	40-50	3	0.00
12	10-20	40-50	4	1.26
8	10-20	20-30	5	1.56
12	10-20	10-20	6	1.66
14	10-20	40-50	7	1.41
12	20-30	20-30	8	1.77
14	20-30	20-30	9	3.34
6	10-20	40-50	10	3.44

[1]To compensate for energy used to sample at deeper depths, 0, 1, 2, 3 or 4 is added to the rank of the sampling scheme (adjusted rank) if the sampling depth is 0-10, 10-20, 20-30, 30-40 or 40-50 cm, respectively.

[2]Percent deviation from a mean of 31.80.

[3]Percent deviation from a mean of 1,108.00.

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were recovered, respectively. Comparable results have also been reported in California (Radewald et al., 1971) where 56 and 41% of P. coffeae population density was reported to overwinter as third to fourth stage juveniles and mature females, respectively. It appears during development in the root system or soil, Pratylenchus spp. spent a very limited amount of time in the second stage juvenile and this may in part explain the low incidence of second stage juveniles in samples. The low population densities of P. zeae second stage juveniles in the soil or maize roots may be a function of the extraction method which was used. It is possible that a greater number of P. zeae second stage juveniles passed through the 400-mesh (38-µm) sieve. Viglierchio and Schmitt (1983) reported a relative efficiency of 17-29% for extracting Pratylenchus spp. with the centrifugal-flotation technique. The culture which was used for this study was also infected with other plant-parasitic nematodes namely Helicotylenchus spp. and Scutellonema spp., therefore it was not feasible to differentiate P. zeae eggs from eggs of other plant-parasitic nematodes.

This research shows that 54.5% of the population density of P. zeae in maize roots was mainly confined to a depth of 0-20 cm. Aggregation of Pratylenchus spp. associated with maize at depth 0-20 cm was similar to that reported in Nigeria, North Carolina and South Africa (Egunjobi and Bolaji, 1979; Barker, 1968; Koen, 1967). The high population density of P. zeae at this sampling depth was in part a function of the available root tissue for P. zeae to penetrate and develop. This phenomenon is analogous to fields or treatment with higher maize root weights which end up with higher population densities of Pratylenchus spp. in the roots. The increase in the population density of P. zeae which was observed as a result of the higher

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maize root weight was similar to that reported in Nigeria (Egunjobi and Larinde, 1975).

The data also showed that the population density of P. zeae in the soil was highest at depth 10-20 cm and lowest at depth 0-10 cm. The high population density of P. zeae at depth 10-20 cm was similar to what has been reported in Nigeria, North Carolina and South Africa (Egunjobi and Bolaji, 1979; Barker, 1968; Koen, 1967). At this depth, soil moisture, temperature and texture and root system availability for P. zeae penetration and development were optimal. At shallow depths, population densities of P. zeae were low as a result of very low soil moisture and very high soil temperatures. Low population densities of Pratylenchus spp. in soil with very high temperatures above 34 C have also been reported in California, Japan and Nigeria (Radewald et al., 1971; Mamiya, 1971; Olowe and Corbett, 1976). Similarly, low population densities of Pratylenchus spp. in soil with very low moisture have been reported in Canada, Nigeria, South Africa and Zimbabwe (Townshend, 1972; Egunjobi and Bolaji, 1979; Koen, 1967; Louw, 1982; Martin et al., 1975). At depths greater than 20 cm, population densities of P. zeae were sub-optimal possibly because of heavy soil textures and limited root system for P. zeae penetration and development. Low population densities of Pratylenchus spp. in heavy textured soils have also been reported in Canada and North Carolina (Townshend, 1972; Endo 1959).

Data presented in this study show that the population density of P. zeae in soil and maize roots increased with increase in sampling radius. The data suggest that in order to collect a representative sample of P. zeae in roots, the sample should be collected at a radius of 10-20 cm from the stem. This sampling radius compares favorably with 5-12 cm. that was recommended for row crops in the USA (Barker, 1985; Barker, et al., 1978). The distribution of

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P. zeae in maize appeared to be in part a function of the distribution of maize root system attackable sites and the number of attackable sites per root weight depend on the age of the root system. Young roots have more attackable sites per unit weight compared to old roots. The distribution of P. zeae in roots will in turn influence the distribution of P. zeae in the soil.

The data presented in this research show that the population density of P. zeae increased very rapidly during the growing season. The population had P_f/P_i and P_m/P_i ratios of 170.0 and 29.5, respectively. High reproductive rates of P. zeae have also been reported in Nigeria and Zimbabwe (Egunjobi and Bolaji, 1979; Martin et al., 1975) where P_f / P_i ratios of P. zeae associated with maize were recorded as 86.0 and 54.2, respectively. The reproductive rate of P. zeae is influenced by host suitability and several edaphic factors that include soil moisture, temperature, texture and pH. This study illustrates that the edaphic factors under which the study was conducted were suitable for P. zeae reproduction. Also the research demonstrates that maize variety R 215 is very susceptible to P. zeae infection.

This study shows that very large errors (as high as 548.0%) can be encountered if P. zeae sampling in maize roots or soil is not properly timed and carried out at the correct depth and distance from the plant. Data presented in this research show that the optimal time of sampling maize roots for P. zeae population density assessment in loamy sand soil is 4 weeks after planting at depth 10-20 cm and radius of 0-10 cm. The optimal time of sampling soil surrounding maize roots for P. zeae population density assessment is 2 weeks after planting at depth 10-20 cm and radius 10-20 cm. The findings compare favorably with the recommendations in the USA (Barker, 1985; Barker and Campbell, 1981; Barker et al., 1978) where they

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advocated sampling annual plants for plant-parasitic nematodes at depth 10-20 cm with cores coming from the root zone 5-12 cm from the stems.

3.4 INFLUENCE OF GRAVIMETRIC SOIL MOISTURE ON PRATYLENCHUS ZEAE AND MAIZE ROOT SYSTEM DEVELOPMENT

3.4.1 Introduction

Constant soil moisture is difficult to maintain and thus there are few direct observations on the effect of soil moisture on nematode populations (Norton, 1979). The few studies that have been conducted, inconsistent results have been reported on the impact of soil moisture on nematode populations and this is because volumetric and gravimetric soil moisture contents have been measured without complete specification of the soil texture which will in turn determine the amount of available moisture to the nematode. Information on the impact of soil moisture on the population density of P. zeae is important in the development of P. zeae predictive simulation models, design of P. zeae cultural control strategies and in understanding the overwintering of P. zeae during the dry season. The specific objectives of this study were to evaluate the (a) impact of gravimetric soil moisture on the population density of P. zeae both in soil and roots and maize root system development and (b) gravimetric soil moisture content for the permanent wilting point of maize (variety R 215).

3.4.2 Materials and Methods

P. zeae was maintained for 8 months on maize plants in sandy loam soil (17% clay, 5% silt, 17% fine sand, 25% medium sand, 35% coarse sand and 0.9% organic matter), in cement built tubs (1.0 m long, 0.75 m wide and 0.75 m deep) in a greenhouse at the Harare Research Center (Grid ref. 30°25' East

and 17°22' South). The culture contained about 100 P. zeae per 100 cm^3 of soil when used as inoculum for the research and the soil had a pH of 5.0.

Eighteen clay pots (30cm diameter and 45cm deep) were filled with the P. zeae infested soil on 27th April, 1987. The pots were arranged on a greenhouse bench in a completely randomized block design of three treatments and six replications. The greenhouse had maximum day and minimum night temperatures of 32 and 20°C respectively. Immediately after arranging the pots, each pot received an application of 150 kg/ha of compound D fertilizer (8% N, 14% P_2O_5, 7% K_2O, 6.5% S). After basal fertilizer application, two maize seeds (variety R 215) were planted into each pot. All the pots were gently watered and emergence occurred as early as 5 days after planting and was complete 9 days after planting. Maize plants in each pot were thinned to one plant per pot 10 days after planting.

All the pots were maintained at the same moisture level (daily watering) for three weeks. After three weeks, watering was terminated for six pots which constituted treatment three, the second treatment, the pots were watered twice a week on Monday and Thursday. The pots which constituted treatment one were watered daily until the end of the experiment. The experiment was terminated 8 weeks after planting when maize plants in treatment three were at the permanent wilting point. The maize plants were sampled at the end of the experiment and on the sampling date, the whole plant was removed from the pot and the whole root system was cut into a labeled plastic bag. Soil from the pot was thoroughly mixed and a sub-sample (ca 1 500 cm^3) of the soil was put into a labeled plastic bag. All the plastic bags with samples were closed immediately after putting in the sample to prevent any loss of moisture from the soil or roots. The samples

were put into cooler boxes and then taken back to the laboratory. The following parameters were evaluated form the samples:

i) Fresh weights of the root system were obtained by weighing on a balance with an accuracy of ± 0.001 grams.

ii) Gravimetric soil moisture content:

Labeled crucibles (capacity = 10 cm^3) were put in an oven at 105 C for about 12 hours and then cooled in a dessicator for 1 hour. When the crucibles had cooled to room temperature, they were put on a balance with an accuracy of ± 0.001 grams using tongs to determine the weight of the empty crucible. After the weight had been recorded, about 5.0 cm^3 of soil was put into the crucible using a spatula and the weight of the crucible with soil was determined. It was important to note that the tongs were not in contact with the soil when lifting the crucible. After the second weight had been recorded, the crucibles with the soil were put into the oven at 105 C for about 24 hours. After the 24 hours, the crucibles with the soil were put into a dessicator for about 1 hour. When the contents had cooled to room temperature, the crucible with the oven dried soil were reweighed. This procedure was repeated whenever soil moisture content was being determined. The soil moisture content was calculated using the following equation:

$$\%\ soil\ moisture = \frac{weight\ of\ soil - weight\ of\ oven\ dry\ soil}{weight\ of\ oven\ dry\ soil} * 100$$

iii) Soil was thoroughly mixed in a tray and 100 cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 1964)

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and observed under a stereoscopic microscope to enumerate P. zeae in the soil.

iv) The whole root system from each pot was cut into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the maceration-centrifugal-flotation technique (Southey, 1985 p. 54) and observed under a stereoscopic microscope to enumerate P. zeae in the roots using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).

v) P. zeae and maize root weight data presented in this study were transformed (square root transformation) during analysis because it exhibited a Poisson distribution. One way analysis of variance between P. zeae in the soil and maize roots and gravimetric soil moisture content was carried out. After the analysis of variance, least significant difference (LSD), standard error (SE) and coefficient of variation (CV) were calculated.

3.4.3 Results

Eight weeks after planting, maize plants that were grown in soil which was maintained at medium and low gravimetric soil moisture contents had significantly ($P = 0.05$) lower root weights compared to maize plants that were grown in soil which was maintained at high gravimetric moisture content. The maize root weights of plants that were grown in soil which was maintained at medium (11.7%) and low (5.0%) gravimetric moisture contents were 21.1 and 55.9% lower compared to root weight of maize plants grown in soil which was maintained at 16.5% gravimetric moisture content (Table 3.4.1). Also, there was a significant ($P = 0.01$) difference in the root weights of maize plants grown in medium and low gravimetric soil moisture contents, at the end of the experiment.

Table 3.4.1. Influence of gravimetric soil moisture on Pratylenchus zeae and maize root system development.

Parameters Treatments	Gravimetric soil moisture (%)	Root weight (grams)	P. zeae in soil and roots 8 weeks after planting	
			100 cm^3 soil	10.0 grams roots
High moisture	16.5[1]	32.4	15.0	927.5
Medium moisture	11.7	19.8	8.5	916.2
Low moisture	5.0	5.5	15.4	523.8

[1]Mean of 6 replications.
Analysis in appendix 5.4.2.

The population density of P. zeae in soil surrounding maize plants was equal (P = 0.05) for the three treatments eight weeks after planting maize (Table 3.4.1). The population density of P. zeae in the soil was generally very low and it constituted 1.67% of the total population density of P. zeae recovered from soil plus roots. However, the population density of P. zeae in roots of maize plants grown in soil maintained at a gravimetric moisture content of 5.0% was significantly (P = 0.05) lower compared to the population density of P. zeae in roots of maize plants grown in soil which was maintained at a gravimetric moisture content of 16.5%. There were no significant (P = 0.05) differences in the population densities of P. zeae in roots of maize plants that were grown in soil which was maintained at 16.5 and 11.7% or 11.7 and 5.0% gravimetric moisture contents.

3.4.4 Discussion

Low gravimetric soil moisture adversely impacted the growth of maize root system and the population density of P. zeae in the roots. The data show that the maize root system was more sensitive to low gravimetric soil moisture compared to the population density of P. zeae in the roots or soil. P.

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zeae has also been reported to be tolerant to low gravimetric soil moisture in Nigeria and Zimbabwe (Olowe and Corbett, 1976; Martin et al., 1975). Also it appears the low population density of P. zeae in the roots of maize plants which were maintained at low gravimetric soil moisture may have been in part a function of the low root weight in these plants. Low population densities of Pratylenchus spp. in maize plants with smaller root weight has also been reported in Nigeria (Egunjobi and Larinde, 1975).

Data presented in this study confirm the hypothesis by Norton (1979) that optimum plant growth occurs between 100 and 75% of the field capacity since at 70% and 30% of the field capacity, growth of maize root system was adversely affected. This research illustrates that P. zeae can reach high population densities under soil moisture conditions which are sub-optimal for maize growth. Thus P. zeae can be expected to cause higher maize yield losses during seasons of unfavorable rainfall since P. zeae can reach high population densities on plants which are already under moisture stress. This research, therefore, demonstrates the importance of controlling P. zeae associated with maize especially during seasons of unfavorable rainfall.

This research also illustrates that it is extremely difficult to effectively control P. zeae by cultural practices which reduce gravimetric soil moisture since P. zeae is tolerant to very low gravimetric soil moisture contents. Data presented in this study is well suited for adjusting the development of P. zeae associated with maize under varying gravimetric soil moisture contents in P. zeae predictive simulation models.

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3.5 EVALUATION OF MAIZE VARIETIES AND INBREEDS AGAINST P. ZEAE INFECTION

3.5.1 Introduction

There are several P. zeae control strategies that can be adopted in maize production. The specific tactic that is adopted will depend on the population density of P. zeae in the soil at the beginning of the growing season, the socio-economic status of the farmer, size of the farm, soil texture, soil temperature and soil moisture. In Zimbabwe communal farms, where farmers have land resources of limited sizes, minimal financial resources and edaphic factors are favorable for P. zeae development, most control strategies of P. zeae in maize are not viable. Availability of maize varieties that are resistant to P. zeae infection and pathogenicity would be a viable nematode control option for most small scale farmers.

Information on the resistance of maize varieties to P. zeae infection is important in the development of appropriate control strategies against P. zeae infection, for communal farmers who can not afford to use expensive and very toxic nematicides and in identifying resistant lines (genes) which can be incorporated into maize breeding programs. The objective of this study was to evaluate whether major maize varieties and inbreeds commonly grown in Zimbabwe are resistant to P. zeae infection.

3.5.2 Methods and Materials

P. zeae was maintained for 6 months on maize plants in loamy sand soil (6% clay, 5% silt, 25.2% fine sand, 38.4% medium sand, 25.9% coarse sand and 0.3% organic matter), in cement built pits (3.0 m long, 1.0 m wide and 0.75 m deep) at the Harare Research Center (Grid ref. 30^{o} 25' East and 17^{o} 22' South). The culture contained about 30 P. zeae per 100 cm^3 of soil when used as inoculum for the research.

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Fifty clay pots (15 cm in diameter and 18 cm deep) were filled with the P. zeae infested soil on 27th March, 1987. The clay pots were arranged in a field at the Harare Research Center in a completely randomized block design of 10 treatments and 5 replications per treatment. Immediately after arranging the pots, each pot received applications of 150 kg/ha of compound D fertilizer (8% N, 14% P_2O_5, 7% K_2O, 6.5% S) and 100 kg/ha of agricultural lime (4.5% Mg). After basal fertilizer application, seeds of seven maize varieties (R 201, R 215, SR 52, ZS 107, ZS 206, and ZS 225) and three inbreeds (83 3WH 59, 83 3WH 27 and 86 3WH 12) were planted into the pots, two maize seeds per pot. The pots were gently watered and emergence occurred as early as 5 days after planting and was complete 9 days after planting.

The maize plants were sampled 8 weeks after planting. On the sampling date, the whole plant was removed from the pot and the following parameters were measured:

i) Fresh weights of the root system were determined on a mettler balance which can measure one hundredth of a gram.

ii) The whole root system from each pot was chopped into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the maceration-centrifugal-flotation technique (Southey, 1985 p.54) and observed under a stereoscopic microscope to enumerate P. zeae in the roots using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).

iii) Soil was thoroughly mixed in a tray and 100 cm^3 of soil was processed using the centrifugal-flotation technique. (Jenkins, 1964) and observed under a stereoscopic microscope to enumerate P. zeae in the soil.

iv) P. zeae and maize root weight data presented in this study were transformed (square root transformation) during analysis because it exhibited a Poisson distribution. One way analysis of variance between P. zeae in the soil and maize roots and the different maize varieties and inbreeds was carried out. After the analysis of variance, least significant differences (LSD), standard error (SE) and coefficient of variation (CV) were calculated.

3.5.3 Results

Eight weeks after planting, all the maize varieties and inbreeds had an equal (P = 0.05) root weight (Table 3.5.1). P. zeae infected the root system of all the maize varieties and inbreeds that were tested in this experiment. Varieties R 215, ZS 206 and ZS 225 had a slightly lower population density of P. zeae in the roots compared to varieties R 201 and ZS 107 (Table 3.5.1). Varieties R215, SR 52, ZS 202, ZS 206, ZS 225 and inbreeds 83 3WH 59, 83 3WH 27 and 86 3WH 12 had an equal (P = 0.05) population density of P. zeae in the roots at the end of the experiment. Similarly, varieties R 201 and ZS 107 had an equal (P = 0.05) population density of P. zeae in the roots. The population density of P. zeae in the soil was equal (P = 0.05) for all the treatments, eight weeks after planting.

3.5.4 Discussion

All the maize varieties and inbreeds were susceptible to P. zeae infection. Maize varieties ASA 80, ASA 81, SR 52 and R 215 have also been reported to be very susceptible to P. zeae infection and pathogenicity (Martin et al., 1975; Muchena et al., 1987). The population density of P. zeae in this study did not build up rapidly possibly because of sub-optimal temperature conditions during the growing period. This study illustrates that resistance

Table 3.5.1. Evaluation of maize varieties and inbreeds against Pratylenchus zeae infection.

Parameters / Varieties	Root weight (grams)	P. zeae in soil and roots 8 weeks after planting	
		100 cm^3 soil	10.0 grams roots
R 201	45.2[1]	12.2	24.0
R 215	45.8	11.0	9.2
SR 52	39.6	12.8	18.4
ZS 107	53.9	13.4	23.8
ZS 202	40.3	16.4	14.2
ZS 206	44.5	15.2	10.4
ZS 225	37.4	10.6	8.8
83 3WH 59	38.8	7.8	14.4
83 3WH 27	38.5	12.2	15.8
86 3WH 12	39.0	14.0	14.6

[1]Mean of 5 replications.
Analysis in appendix 5.5.2

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to major root-lesion nematode parasites of maize has not been incorporated in maize breeding programs.

3.6 INFLUENCE OF NUTRIENTS ON P. ZEAE POPULATION DENSITY AND MAIZE GROWTH PARAMETERS

3.6.1 Introduction

In the USA, maize yield increased from 780 to 6,000 kg/ha between 1895 and 1962 and in Zimbabwe commercial farms, maize yield increased from 1,320 to 1,970 kg/ha between 1934 and 1960 (Berger, 1962) and during the 1985/86 growing season, maize yield was 5,668 kg/ha in Zimbabwe commercial farms. Most of the maize yield increase can be attributed to new high yielding hybrids and varieties. However, the productive and quick-growing hybrids and varieties require an adequate supply of nutrients for full development of the inherited productivity (Berger, 1962). The nutrients can be applied as organic or inorganic fertilizer and apart from stimulating maize growth, the nutrients can adversely or favorably influence population densities of plant-parasitic nematodes in the soil.

Information on the influence of nutrients on the population density of P. zeae and maize growth parameters is important in the development of predictive computer simulation models and cultural control strategies and in understanding the interactions between nutrients, P. zeae population densities and maize growth parameters. The specific objective of this study was to evaluate the impact of organic and inorganic nutrients on the population density of P. zeae and maize growth.

3.6.2 Materials and Methods

P. zeae was maintained for 6 months on maize plants in loamy sand soil (6% clay, 5% silt, 25.2% fine sand, 38.4% medium sand, 25.9% coarse sand,

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0.3% organic matter and pH 4.4) in cement built pits (3.0 m long, 1.0 m wide and 0.75 m deep) at the Harare Research Center (Grid ref. 30^{o} 25' East and 17^{o} 22' South). The culture contained about 30 P. zeae per 100 cm^3 of soil when used as inoculum for the research.

Forty eight clay pots (30 cm long, 30 cm wide and 30 cm deep) were filled with the P. zeae infested soil on 26th March, 1987. The clay pots were arranged in a field at the Harare Research Center in a completely randomized block design of 8 treatments, 3 replications and 2 sampling times per treatment. Immediately after arranging the pots, six pots per treatment receive the following treatments:

1. untreated
2. compound D fertilizer (8% N, 14% P_2O_5, 7% K_2O, 6.5%S) at a rate of 150 kg/ha on the planting date.
3. ammonium nitrate (34.5% N) at a rate of 150 kg/ha 8 weeks after planting.
4. cattle manure at a rate of 12 tons/ha on the planting date.
5. compound D fertilizer at a rate of 150 kg/ha on the planting date + ammonium nitrate fertilizer at a rate of 150 kg/ha 8 weeks after planting.
6. compound D fertilizer at a rate of 150 kg/ha + cattle manure at a rate of 12 tons/ha on the planting date.
7. cattle manure at a rate of 12 tons/ha on the planting date + ammonium nitrate fertilizer at a rate of 150 kg/ha 8 weeks after planting.
8. compound D fertilizer at a rate of 150 kg/ha + cattle manure at a rate of 12 tons/ha on the planting date + ammonium nitrate at a rate of 150 kg/ha 8 weeks after planting.

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After the treatments, 100 kg/ha of agricultural lime (4.5% Mg) was applied to all the pots to increase the soil pH and maize seed (variety R 215) was planted at the center of the pot, two seeds per pot. The pots were gently watered and emergence occurred as early as 5 days after planting and was complete 9 days after planting. The plants were thinned to one plant per pot two weeks after planting. The maize plants were watered daily for six weeks and thereafter, the plants were only watered when there were signs of water stress.

The maize plants were sampled 8 and 16 weeks after planting. On the sampling date, the whole plant was removed from the pot and the following parameters were evaluated:

i) Fresh weights of the root and shoot systems were determined on a Mettler balance which can measure one-hundredth of a gram.

ii) The root system from the plant was chopped into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the maceration-centrifugal-flotation technique (Southey, 1985 p. 54) and observed under a stereoscopic microscope to enumerate P. zeae in the roots using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).

iii) Soil was thoroughly mixed in a tray and 100 cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 1964) and observed under a stereoscopic microscope to enumerate P. zeae in the soil.

iv) One way analysis of variance between P. zeae in the soil and maize roots and different nutrient levels was carried out. After the analysis of variance, least significant difference (LSD), standard error (SE) and coefficient of variation (CV) were calculated.

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3.7.3 Results

Maize root and shoot weights were significantly (P = 0.01) influenced by application of nutrients 8 and 16 weeks after planting (Tables 3.6.1-3.6.2). Eight weeks after planting, treatments in which nutrients had not been applied had the lowest (P = 0.01) shoot weight compared to all the other treatments. Treatments in which manure had been applied, had significantly (P = 0.05) lower shoot weight compared to treatments in which compound D fertilizer had been applied. Treatments in which compound D fertilizer plus manure had been applied, had significantly (P = 0.01) higher shoot weight compared to treatments which had only received compound D fertilizer. Treatments in which nutrients had not been applied had the lowest (P = 0.05) root weight eight weeks after planting. Treatments in which manure had been applied, one treatment in which compound D fertilizer and one treatment in which compound D fertilizer plus manure had been applied had equal root weight and the root weight was significantly (P = 0.05) greater compared to treatments which had not received any nutrients. One treatment in which compound D fertilizer plus manure had been applied had a significantly (P = 0.05) higher root weight compared to all the other treatments except one treatment where manure had been applied.

Sixteen weeks after planting maize, the treatment which had not received any nutrients had the lowest (P = 0.01) shoot weight compared to all the other treatments. Treatments in which manure and ammonium nitrate fertilizer had been applied, had a significantly (P = 0.05) higher shoot weight compared to the treatment which had not received any nutrients. Treatments which had compound D fertilizer, compound D fertilizer plus manure and ammonium nitrate fertilizer plus manure had significantly (P = 0.01) higher shoot weight compared to treatments which had just received

Table 3.6.1. Impact of nutrients on Pratylenchus zeae population density and maize growth parameters 8 weeks after seeding.

Parameters / Nutrients	No. of P. zeae		Weight (grams)	
	100 cm^3 soil	10.0 grams	Root	Shoot
Nontreated	4.3[1]	20.0	31.5	39.5
Compound D	3.0	45.0	74.0	160.7
Ammonium Nitrate	31.7	32.3	21.7	30.7
Manure	14.3	21.3	61.4	95.5
Compound D + Amm. nitrate	5.7	18.0	62.6	131.4
Compound D + Manure	3.0	11.3	68.6	200.0
Amm. nitrate + Manure	4.3	14.7	96.0	109.3
Amm. nitrate + Manure + Compound D	4.0	21.0	112.9	278.3

Key

[1]Mean of 3 replications.
Analysis in Appendix 5.6.3.

Table 3.6.2. Influence of nutrients on Pratylenchus zeae population density and maize growth parameters 16 weeks after seeding.

Parameters / Nutrients	No. of P. zeae		Weight (grams)	
	100 cm^3 soil	10.0 grams	Root	Shoot
Nontreated	20.0[1]	116.7	59.2	102.2
Compound D	18.7	83.3	180.5	450.4
Ammonium Nitrate	18.3	88.3	60.1	210.0
Manure	30.3	149.3	99.5	162.8
Compound D + Amm. nitrate	12.0	70.7	214.3	440.7
Compound D + Manure	25.0	117.0	163.3	350.3
Amm. nitrate + Manure	9.0	182.7	93.9	295.8
Amm. nitrate + Manure + Compound D	14.3	78.3	200.5	491.8

Key

[1]Mean of 3 replications.
Analysis in Appendix 5.6.4.

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either ammonium nitrate or manure. Treatments which received compound D fertilizer plus ammonium nitrate fertilizer and compound D fertilizer plus ammonium nitrate plus manure, had significantly (P = 0.05) higher shoot weight compared to all the other treatments. Also sixteen weeks after planting, the treatment which had not received any nutrients and a treatment in which ammonium nitrate fertilizer had been applied had the lowest (P = 0.05) root weight compared to all the other treatments. Treatments where manure and ammonium nitrate fertilizer plus manure had been applied, had significantly (P = 0.01) higher root weight compared to the treatments which had not received any nutrients or where ammonium nitrate fertilizer had been applied. Treatments in which compound D fertilizer, compound D fertilizer plus ammonium nitrate fertilizer, compound D fertilizer plus manure and compound D fertilizer plus ammonium nitrate fertilizer plus manure had been applied, had significantly (P = 0.01) higher root weight compared to all the other treatments.

The population density of P. zeae in soil and maize roots was significantly (P = 0.05) influenced by the application of nutrients 8 and 16 weeks after planting (Tables 3.6.1-3.6.2). Eight weeks after planting, the population density of P. zeae in the soil was equal (P = 0.05) except for one treatment which had not received any nutrients. The population density of P. zeae in the roots was also equal (P = 0.05) except for two treatments, one had received compound D fertilizer and the other had not received any nutrients.

Sixteen weeks after planting, the population density of P. zeae in the soil from pots which had not received any nutrients was equal (P = 0.05) to population densities of P. zeae in the soil from pots which had received compound D fertilizer, ammonium nitrate fertilizer, manure plus ammonium

nitrate fertilizer, compound D fertilizer plus manure, compound D plus ammonium nitrate and compound D plus manure. The treatments which had received manure had the highest (P = 0.05) population density of P. zeae in the soil. During the same sampling period, the population density of P. zeae in roots of maize plants growing in pots which had not received any nutrients was equal (P = 0.05) to population densities of P. zeae in roots of maize plants growing in pots which had received compound D fertilizer, ammonium nitrate fertilizer, manure,compound D plus ammonium nitrate fertilizer, compound D fertilizer plus manure, ammonium nitrate fertilizer plus manure and compound D plus ammonium nitrate fertilizer plus manure. Treatments which had received manure and ammonium nitrate fertilizer plus manure had the highest (P = 0.05) population densities of P. zeae in maize roots compared to treatments which and received compound D plus ammonium nitrate fertilizer and compound D plus ammonium nitrate fertilizer plus manure.

3.6.4 Discussion

Data presented in this study show that the application of nutrients significantly reduced the population density of P. zeae in the soil eight weeks after planting. However, the population density of P. zeae in the soil sixteen weeks after planting was greater in treatments where manure had been applied. The reduced population density of P. zeae eight weeks after planting was similar to that reported in Alabama, Egypt, Florida and Nigeria with other plant-parasitic nematodes (Mian and Rodriguez-Kabana, 1982a-b; Badra and Mohamed, 1979; Tarjan, 1977; Egunjobi and Larinde, 1975). The reduction of P. zeae in soil with manure may be a function of released ammoniacal nitrogen during decomposition of manure, increased microfauna inimical to P. zeae and unfavorable environmental conditions for

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P. zeae created by the application of manure. The high population densities of P. zeae in the soil sixteen weeks after planting, especially in manured soil, compares favorably with data which was reported for Rotylenchulus reniformis associated with tomatoes growing in sheep dung manured soil in Egypt (Badra and Mohamed, 1979). It appears after sixteen weeks, plants growing in soil with manure had higher root weight which allowed P. zeae to reproduce more rapidly and the P. zeae subsequently ended up in the soil. The number of P. zeae in the soil eight weeks after planting was very low and the data had high variability, therefore, the validity of these findings may be of limited scope.

The data show that roots from soil which was not treated and roots from soil where compound D fertilizer had been applied had higher population densities of P. zeae eight weeks after planting. The high population density of P. zeae in roots from soil which was not treated despite the low root weight indicate that P. zeae in this soil was not impaired in its ability to penetrate and develop in maize roots relative to other treatments whereas the high population density of P. zeae in roots from soil where compound D fertilizer was applied may be in part a function of greater root weight which enabled the population density to build up more rapidly. The greater root weight as a result of applying compound D fertilizer compares favorably with the faster root growth that has been reported after application of fertilizers with a high content of phosphates (Berger, 1962). The high population density of P. zeae in roots from soil where compound D fertilizer was applied was analogous to high population densities of plant-parasitic nematodes that result in plant roots after a nematicide in soil is no longer effective (Muchena and Bird, 1987).

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This study shows that the population density of P. zeae did not reproduce rapidly as what has been recorded in previous studies in Zimbabwe (Martin et al., 1975; Muchena et al., 1987). The low population density of P. zeae in this study may have been in part a function of low soil temperature during the growing period. As a result of the low population densities of P. zeae during the growing period, it is possible that trends from some treatments may have been masked, therefore it is essential for this study to be repeated to evaluate the consistency of the data.

Data from this study also show that maize root and shoot systems were increased by the application of organic and inorganic fertilizers into the soil. Increased plant growth after application of nutrients that was recorded, compares favorably with that reported in Alabama, Egypt, England, Florida, Nigeria and Zimbabwe (Mian and Rodriguez-Kabana, 1982a-b; Badra and Mohamed, 1979; Arnon, 1974; Cooke, 1975; Tarjan, 1977; Egunjobi and Larinde, 1975; Mugwira, 1984). The nutrients increase plant growth especially by increasing the availability of essential nutrients (N, P, K) and secondary nutrients (Ca, Mg, S, Fe, Zn, Cu, Mn) in the soil (Mugwira, 1984).

3.7 EFFECT OF GRANULAR NEMATICIDES ON P. ZEAE ASSOCIATED WITH MAIZE

3.7.1 Introduction

In Zimbabwe, the incidence of Pratylenchus spp. was 97% in maize fields sampled during the national survey of pests and diseases in communal areas during the 1985/86 growing season. Population densities of Pratylenchus spp. in 54.5% of the fields that were infested were above the damage threshold, the damage threshold was estimated to be 1,000 Pratylenchus spp. per 10.0 grams of roots, 8 ± 2 weeks after planting.

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Pratylenchus spp. were especially a major constraint of maize production in sandy soils where farmers were not practicing crop rotation because they have limited land resources. The main Pratylenchus spp. which were found associated with maize are Pratylenchus brachyurus and P. zeae and had absolute frequencies of 21.1 and 52.6%, respectively. There are, however, several strategies that can be adopted for control of Pratylenchus spp. in maize and they include organic amendments, early land preparation, crop rotation, use of resistant maize varieties and application of nematicides. When population densities of Pratylenchus spp. in the soil are very high, as was detected in some of the communal farms, use of nematicides is perhaps the most reliable method for a quick and effective control of Pratylenchus spp. in maize (Egunjobi and Larinde, 1975; Muller and Gooch, 1982). The objectives of this study were to : (a) evaluate the effects of organophosphate and organocarbamate nematicides in controlling population densities of P. zeae associated with maize in a communal farm and (b) assess the subsequent maize yield increase associated with the P. zeae control.

3.7.2 Materials and Methods

The site for this study was in Zvimba communal area (Grid ref. 30° 5' East and 17° 50' South). The soil was sandy loam (12% clay, 5% silt, 21.2% fine sand, 33.6% medium sand, 28.7% coarse sand and 1.2% organic matter) with a pH of 5.3 and was naturally infested with P. zeae . The land was plowed using an ox drawn plow by the farmer after the first effective rainfall on 25th November, 1986. The land was leveled using hoes and plots (9 x 2.7m) with guard rows of 1.0 m marked out in a completely randomized block design with five treatments and four replications on 5th December, 1986. Basal fertilizer, compound D (8% N, 14% P_2O_5, 7% K_2O, 6.5% S) was applied at a rate of 300 kg/ha to all the plots immediately after laying out the trial.

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Then furrows 5 cm deep, 10 cm wide and 90 cm apart, in which the seed was to be planted using planting chains, were made to all the plots using hoes. After making the furrows, nematicides were applied into sixteen plots in furrow and incorporated with a hoe. The nematicides which were applied are carbofuran 10G, fenamiphos 10G and isazofos 10G at a rate of 20 kg/ha and terbufos 10G at a rate of 10 kg/ha. Four plots were not treated with the nematicides. After all the treatments had been applied, maize seed (variety R 215) was planted on the same date with inter-row spacing of 90 cm and intra-row spacing of 40 cm.

Soil samples composed of five sub-samples collected at random using a 5 cm diameter auger were collected from each plot on the planting date before the nematicides had been applied. The soil auger was pushed to a depth of 15-20 cm and then moist soil was put into labeled plastic bags and sealed. Also soil and root samples composed of five sub-samples collected at random were collected from each plot four and eight weeks after planting. Root samples were collected by digging the root system of the plant and then soil was shaken off the root system and part of the root system was cut into a labeled plastic bag. The samples were put into cooler boxes and then taken back to the laboratory. The following parameters were evaluated from the samples:

1. The root system was chopped into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the maceration-centrifugal-flotation technique (Southey, 1985 p. 54) and observed under a stereoscopic microscope to enumerate P. zeae in the roots using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).

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2. Soil was thoroughly mixed in a tray and 100 cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 11964) and observed under a stereoscopic microscope to quantify P. zeae in the soil using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).

During the growing season, all the plots were hand weeded using hoes on 5th January, 1987 and 2nd February, 1987. Ammonium nitrate fertilizer (34.5% N) was applied on 2nd, February, 1987 at a rate of 150 kg/ha. After the crop had reached physiological maturity on 28th April, 1987, maize ears were removed from the stalks and put into bags. The ears were further dried while they were in the bags using an electric dryer for 7 days. The maize was hand shelled and the weight of seed per plot was determined. A small sample of the dried seed was used to determine the percentage of moisture in the seed using a moisture meter MM250.

Maize dried to a moisture level of 12.5% can be sold to the Grain Marketing Board (GMB). The controlled price for selling maize to the GMB was Z$180.00 per ton at the end of 1985/86 growing season. During the same period, the estimated basic cost, excluding labor, for growing 1.0 ha of maize was Z$303.00. The basic cost for maize production included: seed, fertilizer, bags for packing the maize and transportation of the maize to the GMB from the nearest main road. If a nematicide was used in the maize production, the cost of the nematicide, Z$193.40 or Z$130.40, was added to the basic cost if the nematicide was carbofuran or fenamiphos, respectively. To evaluate the return for the farmer after growing maize, the cost of production should be subtracted from the gross income:

a) Gross income/ha = Yield (tons/ha) * Z$180.00

b) Cost of production/ha = Z$303.00 + cost of nematicide

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c) Net income/ha = Gross income - Cost of production

P. zeae data in this experiment were transformed (square root transformation) because it exhibited a Poisson distribution. One way analysis of variance between P. zeae in the soil and maize roots and different nematicide treatments was carried out. After the analysis of variance, least significant difference (LSD), standard error (SE) and coefficient of variation (CV) were calculated.

3.7.3 Results

On the planting date, all the plots had an equal (P = 0.05) population density of P. zeae in the soil (Table 3.7.1). Four weeks after planting, plots which were treated with nematicides had a significantly lower (P = 0.05) population density of P. zeae in roots and soil compared to the nontreated plots. Plots that were treated with carbofuran, isazofos, terbufos and fenamiphos had population densities of P. zeae which were 68.61, 63.10, 56.90 and 53.37% lower than the population density of P. zeae in nontreated plots, respectively. There were, however, no significant differenced in the population densities of P. zeae in roots and soil from nematicide treated plots. The population densities of P. zeae in roots and soil four weeks after planting (Pm) compared to the initial population density in the soil (Pi) had ratios of 3.3, 4.6, 5.2, 8.3 and 16.6 for plots that were treated with carbofuran, fenamiphos, isazofos, terbufos and nontreated plots, respectively.

Eight weeks after planting, plots which were treated with nematicides had a significantly lower (P = 0.01) population density of P. zeae in roots and soil compared to the nontreated plots. Plots that were treated with carbofuran, isazofos, terbufos and fenamiphos had population densities of P. zeae which were 94.81, 95.11, 93.14 and 95.97% lower than the population

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density of P. zeae in the nontreated plots, respectively. There were, however, no significant differences (P = 0.05) in the population densities of P. zeae in roots and soil from nematicide treated plots. The population densities of P. zeae in roots and soil eight weeks after planting (Pf) compared to the initial population density in the soil (Pi) had ratios of 0.96, 1.27, 1.23, 1.32 and 29.64 for plots that were treated with carbofuran, fenamiphos, isazofos, terbufos and nontreated plots, respectively. The ratio of Pm/Pf was 0.3, 0.15, 0.24, 0.28 and 1.78 for plots that were treated with carbofuran, fenamiphos, isazofos, terbufos and nontreated plots, respectively. There was considerable variability (c.v.% = 46.60) in the number of P. zeae that were recovered from maize roots in some treatments.

All the nematicides that were applied, significantly increased (P = 0.05) maize yield compared to the nontreated plots (Table 3.7.1). Carbofuran, terbufos, fenamiphos and isazofos increased maize yield by 67.4, 66.0, 54.7 and 36.7% compared to the nontreated plots, respectively. Plots that were treated with carbofuran, fenamiphos and terbufos, had an equal (P = 0.05) maize yield and the yield of maize in fenamiphos treated plots was also equal (P = 0.05) to the maize yield in isazofos treated plots. Plots that were treated with isazofos had a significantly lower (P = 0.05) maize yield compared to plots that were treated with carbofuran or terbufos.

Use of nematicides to control P. zeae in maize, resulted in loss of revenue used to buy inputs despite the maize yield increase (Table 3.7.2). The cost of isazofos and terbufos is currently not available in the country because the nematicides are not registered in Zimbabwe but it is quite apparent that the maize yields that were obtained, will not be able to pay for the inputs. Also the maize yield that was obtained in the nontreated plots, resulted in loss of revenue used to buy seed, fertilizer and packing material.

Table 3.7.1. Effect of several granular nematicides on Pratylenchus zeae associated with maize in Zvimba communal areas.

Parameters Treatments	P. zeae in soil[1] on treating date	P. zeae in roots and soil[2] 4 weeks after	P. zeae in roots and soil[2] 8 wks after	Maize yield (tons/ha)
carbofuran 10g	48.3[3]	184.3	50.0	1.94
fenamiphos 10g	30.3	283.8	37.8	1.79
isazofos 10g	36.0	196.0	53.0	1.58
terbufos 10g	45.5	229.3	67.0	1.92
nontreated	33.8	502.3	944.5	1.16

Key
[1]Soil = 100 cm^3.
[2]Roots and soil = 100 cm^3 soil + 10.0 grams roots.
[3]Mean of 4 replications.
Analysis in appendix 5.7.2

Table 3.7.2. Comparative economic analysis for using nematicides in controlling Pratylenchus zeae in maize.

Parameters Treatments	Maize yield (kg/ha)	Total cost of inputs (Z$)	Gross[1] income (Z$)	Net[2] Income (Z$)
carbofuran 10 g	1937.00	496.40	348.66	-147.74
fenamiphos 10 g	1790.00	433.40	322.20	-111.20
isazofos 10 g	1582.00	*	284.76	--
terbufos 10 g	1921.00	*	345.78	--
nontreated	1157.00	303.00	208.26	-94.74

*Cost of nematicide currently not available.
[1]Gross income = tons/ha x Z$180.00
[2]Net income = gross income - total cost of inputs.

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3.7.4 Discussion

All the nematicides significantly controlled P. zeae for eight weeks and subsequently increased maize yield. The nematicides equally controlled P. zeae and the magnitude of control was similar to that reported in Georgia, Indiana and Zimbabwe (Johnson and Chalfant, 1973, 1973; Bergeson, 1978; Martin et al., 1975). The population density of P. zeae in maize roots (P. zeae in the soil was negligible and it constituted about 0.4% of the total population recovered from roots and soil) was 3 x lower compared to the population density of P. zeae that was recovered in maize roots during the 1985/86 growing season (Muchena et al., 1987). The lower population densities of P. zeae in maize roots during the 1986/87 growing season appear to be a result of the relatively low rainfall that was received during the season. Also because of the drought, the nematicides had a higher reduction of the population density of P. zeae in roots and soil, 94.8% compared to 79.8% during the 1985/86 season (Muchena et al., 1987). The growing season with higher rainfall had lower P. zeae control because the rainfall will flush out the nematicides, hence reduce the efficacy of the nematicides. Reduced nematicide efficacy because of high rainfall and/or irrigation has also been observed in California and Michigan (Hough et al., 1975; Muchena and Bird, 1987).

Also because of the drought, maize yields in this study, were 3.7 x lower compared to the maize yields that were obtained during the 1985/86 growing season on the same site (Muchena et al., 1987). The low maize yields could not generate enough revenue to pay for the nematicides and other agricultural inputs that had been purchased. Studies that have been carried out in Nigeria have also shown that increases in maize yields obtained by use of nematicides may not be sufficient to cover costs (Egunjobi and Larinde,

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1975). The drought, however, appears to be responsible for the greater differences in maize yields between nematicide treated plots and nontreated plots compared to an average of 48.85% maize yield increase which was achieved during the 1985/86 growing season (Muchena et al., 1987). Maize yield data presented in this study suggest that P. zeae is more limiting to maize growth and development when there is a stress of low soil moisture and/or soil nutrients.

Plots that were treated with isazofos had a lower maize yield compared to the other nematicide treatments despite comparable P. zeae control with the other nematicide treatments. The low maize yield in isazofos treated plots appear to be a result of slightly lower maize germination which was observed in this treatment. It appears isazofos was phytotoxic to some maize seedlings. It is, therefore, important to ensure thorough incorporation of isazofos with soil before planting the seed, particularly during seasons with low rainfall.

Data presented in this study illustrate the importance of controlling P. zeae associated with maize in communal farms infested with P. zeae to avoid substantial maize yield losses. The data also illustrate the importance of judiciously evaluating growing seasons when nematicides can be used to control P. zeae in maize with resultant terminal benefits to the farmer. Comparisons of the data from this experiment and the data from the 1985/86 growing season experiment, demonstrate the impact of rainfall on maize yields and P. zeae population densities. This information should be well suited for validation of P. zeae computer simulation models.

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3.8 INFLUENCE OF ORGANIC AMENDMENTS AND EARLY PLOWING ON P. ZEAE PATHOGENICITY ON MAIZE

3.8.1 Introduction

The use of nematicides is perhaps the most reliable method for a quick and effective control of plant-parasitic nematodes infecting crops (Egunjobi and Larinde, 1975; Muller and Gooch, 1982). However, in Zimbabwe communal farms, it is unrealistic to recommend such pesticides to farmers because most nematicides are extremely toxic to humans and require skilled labor for a successful application; they are also expensive and the increases in yields obtained by their use may not be sufficient to cover costs. Other plant-parasitic nematode control strategies which are compatible with communal farmers socio-economic considerations must, therefore, be found to ensure increased maize yields in communal farms which are commonly infested with high population densities of root-lesion nematodes especially P. zeae.

Research on organic amendments for control of plant-parasitic nematodes has, however, concentrated on addition of large quantities of material in the soil and up to 84 metric tons/ha (Egunjobi and Larinde, 1975; Mian and Rodriguez-Kabana, 1982; Muller and Gooch, 1982). Addition of such large quantities of organic material especially for field crops such as maize is unrealistic for most communal farmers.

Early land preparation prior to the dry season or winter is also known to reduce the population densities of plant-parasitic nematodes in the soil. During the dry season, soil and roots in the plowed field will be exposed to solar radiation and drying such that at planting, seeds are placed in upper layers with low plant-parasitic nematode populations. This study was, therefore, set up to evaluate P. zeae control and subsequent maize yield response obtained by three cultural practices commonly used by communal

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farmers. It was also of interest to compare the effectiveness of the cultural practices with a registered nematicide on maize.

3.8.2 Materials and Methods

The site for this study was in Chinamora communal area (Grid ref. 30° 25' East and 17° 30' South). The soil was loamy sand (9% clay, 5% silt, 23.2% fine sand, 36% medium sand, 27.3% coarse sand and 0.64% organic matter) with a pH of 4.4 and bulk density of 1.46 grams/cm^3 and was naturally infested with P. zeae. Plots 9 x 4.5m with guard rows of 1.8m were marked out in a completely randomized block design with five treatments and four replications on 2nd September, 1986. Four plots which required early land preparation were dug using hoes on the same date. This early land preparation procedure was repeated to the same plots twice at monthly intervals. After the first effective rainfall on 25th November, 1986, the rest of the plots were plowed using an ox-drawn plow. The land was leveled using hoes and all the remaining treatments including basal fertilizer application were carried out on 2nd December, 1986. The basal fertilizer, compound D (8% N, 14% P_2O_5, 7% K_2O, 6.5% S) was broadcasted at a rate of 300kg/ha to all the plots immediately after leveling. Then eight plots were applied with manure, four with cattle manure and the other four with compost manure at a rate of 12 tons/ha. The manure was broadcasted into the respective plots and incorporated with a hoe. After the manure application, furrows 5 cm deep, 10 cm wide and 0.9 m apart, in which the seed was to be planted using planting chains, were made to all the plots using hoes. Carbofuran 10G was applied in furrows at a rate of 20 kg/ha to four plots and incorporated with a hoe. The remaining four plots out of the twenty plots were not treated.. After all the treatments had been applied, maize seeds (variety R 215) were planted with inter-row spacing of 90 cm and intra-row spacing of 40 cm.

Soil samples composed of five sub-samples collected at random using a 5 cm diameter auger were collected from each plot on the planting date before the nematicide and the manure had been applied. The soil auger was pushed to a depth of 15-20 cm and then the moist soil was put into labeled plastic bags and sealed. Also soil and root samples composed of five sub-samples collected at random were collected from each plot 4, 8, 12 and 16 weeks after planting. Root samples were collected by digging the root system of the plant then soil was shaken off the root system and part of the root system was cut into a labeled plastic bag. The following parameters were evaluated from the samples:

1. The root system was chopped into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the maceration-centrifugal-flotation technique (Southey, 1985 p.54) and observed under a stereoscopic microscope to enumerate P. zeae in the roots using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).
2. Soil was thoroughly mixed in a tray and 100 cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 1964) and observed under a stereoscopic microscope to quantify P. zeae in the soil using the examination of nematode suspension technique (Southey, 1985 p. 59-60).

During the growing season, all the plots were hand weeded using hoes on 2nd January, 1987 and 30th January, 1987. Ammonium nitrate fertilizer (34.5% N) was also applied twice on 16th January, 1987 and 13th February, 1987 at a rate of 150 kg/ha. After the crop had reached physiological maturity on 22nd May, 1987, maize ears were removed from the stalks and put into bags. The ears were further dried while they were in the bags using

an electric dryer for 5 days. Then the maize was hand shelled and the weight of the seed per plot was determined. A small sample of the dried seed was used to determine the percentage of moisture in the seed using a moisture meter MM 250.

P. zeae and maize yield data in this experiment were transformed (square root transformation) during analysis because it exhibited a Poisson distribution. One way analysis of variance between P. zeae in the soil and maize roots and different treatments was carried out. After the analysis of variance, least significant difference (LSD), standard error (SE) and coefficient of variation were calculated.

3.8.3 Results

On the planting day, all the treatments had an equal (P = 0.05) population density of P. zeae in the soil (Table 3.8.1). Four weeks after planting, plots which were early plowed had a significantly higher (P = 0.05) population density of P. zeae in soil and roots compared to plots which were treated with carbofuran. There were, however, no significant differences (P = 0.05) in the population densities of P. zeae in the soil and roots between nontreated plots, manured plots and early plowed plots. Also on this sampling date, only carbofuran treatment had reduced the population density of P. zeae in soil and roots by 39.17% compared to the nontreated plots but in all the other treatments, the population density of P. zeae in soil and roots had increased compared to the nontreated plots.

Eight weeks after planting, manured, early plowed and nontreated plots had an equal (P = 0.05) population density of P. zeae in soil and roots (Table 3.8.1). Plots which were treated with carbofuran had a significantly lower (P = 0.05) population density of P. zeae compared to all other treatments. the population density of P. zeae in soil and roots in the

Table 3.8.1. Impact of several management practices on Pratylenchus zeae associated with maize in Chinamora.

Table 3.8.1. Impact of several management practices on Pratylenchus zeae associated with maize in Chinamora.

Parameters Treatments	P. zeae in soil[1] on treating date	P. zeae in soil and roots[2] 4 wks after	P. zeae in soil and roots[2] 8 wks after	P. zeae in soil and roots[2] 12 wks after	P. zeae in soil and roots[2] 16 wks after	Maize yield (tons/ha)
carbofuran 10g	16.3[3]	78.5	8.0	141.5	39.0	2.34
cattle manure	17.3	197.3	116.8	2,014.8	888.5	2.63
compost manure	18.8	203.3	144.3	795.5	396.0	2.28
early plowing	16.0	150.3	166.0	518.8	303.0	1.95
nontreated	31.5	135.8	135.0	977.5	992.3	1.07

Key

[1]Soil = 100cm^3

[2]Soil and roots = 100 cm^3 soil + 10.0 grams roots.

[3]Mean of 4 replications.

Analysis in appendix 5.8.2

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carbofuran treated plots was 93.7% lower compared to the nontreated plots. Plots in which cattle manure had been incorporated, the population density of P. zeae was 4.7% lower than in the nontreated plots; the compost manure and early plowing treatments, still had a higher population density of P. zeae in soil and roots compared to the nontreated plots.

After an additional four weeks, still carbofuran treatment provided adequate control of P. zeae in soil and roots and the population density was significantly lower (P = 0.05) compared to all the other treatments. All the other treatments including the control, had an equal (P = 0.05) population density of P. zeae in soil and roots (Table 3.8.1). The population densities of P. zeae in soil and roots of carbofuran treated and compost manured plots were 85.0 and 29.6% lower than in the nontreated plots. Cattle manured and early plowed plots had higher population densities of P. zeae in soil and roots compared to the nontreated plots. It is also noteworthy that there were considerable variations in the number of P. zeae recovered from similar treatments in different replications as reflected by the high coefficient of variations (51.8%).

Sixteen weeks after planting, carbofuran treated, early plowed and compost manured plots had a significantly lower (P = 0.05) population density of P. zeae in soil and roots compared to the nontreated plots. The population density of P. zeae in soil and roots of the respective treatments were 96, 70 and 70% lower than that of the nontreated plots. The population density of P. zeae in soil and roots in the cattle manured plots was not significantly different (P = 0.05) from that of the nontreated plots even though it was 18.5% lower.

Maize yield was evaluated when the maize seed was at 9.0% moisture. All the treatments significantly increased (P = 0.05) maize yield compared to

the control (Table 3.8.1). There were, however, no significant differences (P = 0.05) in maize yield between all the treated plots. Cattle manure, carbofuran, compost manure and early plowing increased maize yield by 145.7, 118.8, 113.0 and 82.0%, respectively, compared to the control. There were, however, considerable variations in the maize yield obtained from similar treatments in different replications as indicated by the considerably high coefficient of variation.

3.8.4 Discussion

Carbofuran, a nematicide which was used as a standard in this study, significantly controlled the population density of P. zeae for sixteen weeks and subsequently increased maize yield. The magnitude of P. zeae control which was observed in this study, compares favorably with reports from Georgia, Indiana and Zimbabwe (Johnson and Chalfant, 1973; Bergeson, 1978; Martin et al., 1975; Muchena et al., 1987). The nematicide, however, protected the maize plants from P. zeae infection for a considerably longer period than three months that has been reported in the literature (Bergeson, 1978; Johnson and Chalfant, 1973). The longer persistence of the nematicide in the soil appears to be a function of very little rainfall that was received during the growing season. High rainfall and/or irrigation can flush out carbofuran, hence efficacy of the nematicide is reduced. Reduced nematicide efficacy because of high rainfall and/or irrigation has been reported to occur in California and Michigan (Hough et al., 1975; Muchena and Bird, 1987).

Also because of the drought, maize yield was generally very low compared to 4.5-6.8 tons/ha which were harvested in the 1985/86 season (Muchena et al., 1987). The low rainfall, however, appears to have caused a greater difference in maize yield between carbofuran treated and nontreated plots (Muchena et al., 1987). Maize yield data in this study

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suggest that P. zeae is more limiting to maize growth and development under stress of low soil moisture and/or soil nutrients.

Early land preparation did not reduce the population density of P. zeae in the soil at the planting time and this can be attributed to the high tolerance of P. zeae to very low gravimetric soil moisture content of up to less than 2.0% for two years (Martin et al., 1975) and wide range of temperature regimes (Olowe and Corbett, 1976). In Tennessee, early land preparation was also failed to reduce the population density of P. zeae in the soil (Southards, 1971). In Nigeria, however, early land preparation has been shown to reduce the population density of Pratylenchus spp. by 90% (Egunjobi and Bolaji, 1979). It appears, for early land preparation to have a significant impact on the population density of Pratylenchus spp. in the soil, the population density of Pratylenchus spp. in the soil must be very high (ca 600/100 cm^3 soil) and if the population density is low (30-50/100 cm^3 soil) as was recorded in this study, early land preparation might not have significant impact on the population density. It should, however, be noted that the low population density of P. zeae that remains in the soil at the end of the dry season quickly builds up when a susceptible host like maize is planted during the growing season. The rapid build up of very low population densities of Pratylenchus spp. that remain in the soil after the dry season when a susceptible host has been introduced during the growing season has also been reported in Nigeria, South Africa, Tennessee and Zimbabwe (Egunjobi , 1974; Koen, 1967; Southards, 1971; Martin et al., 1975; Muchena et al., 1987). At the end of the growing period, the population density of P. zeae in early plowed plots was adversely impacted by organic debris that was plowed in and and started decomposing during the rain season and/or some organisms that are inimical to P. zeae, their population density increased as a result of the early plowing.

Early land preparation significantly increased maize yield. Increase of crop yield in early plowed fields has also been reported in Ontario (Thames, 1982). The higher maize yield in early prepared plots appears to be a function of improved soil moisture content and soil tilth from plowed in organic debris rather than P. zeae control.

Organic amendments initially increased the population of P.zeae in maize roots (P. zeae in the soil was negligible and it constituted about 0.54% of the total population recovered from roots and soil) but at the end of the growing period, the population density of P. zeae was adversely impacted by organic amendments especially compost manure. Higher population densities of Pratylenchus spp. in maize roots growing in manured plots compared to nontreated plots has also been reported in Egypt and Nigeria (Badra and Mohamed, 1979; Egunjobi and Larinde, 1975). The higher root population densities of P. zeae in manured plots appear to be a function of greater available root tissue for P. zeae to penetrate since maize plants in manured plots will have greater root tissue compared to plants in nontreated plots which have sub-optimal root growth. The low population density of P. zeae in roots of maize plants growing in manured plots at the end of the growing period compared to nontreated plots might be attributed to by-products of manure decomposition. It is unlikely that the by-products of manure decomposition killed P. zeae but rather impaired the reproduction capacity of P. zeae.

Organic amendments significantly increased maize yield despite the higher root population densities of P. zeae in manured plots. The higher maize yield in manured plots appear to be a result of altered host physiology such that the host is more resistant to the nematode infection and/or improved root growth which enhances better utilization of nutrients thus

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neutralizing the effect of nematode damage (Badra and Mohamed, 1979; Egunjobi and Larinde, 1975).

Data in this study show that communal farmers with P. zeae problems in their farms especially in sandy soils can derive maize yield increase by adopting cultural practices such as early land preparation and organic amendments. The mechanism of how these cultural practices impact the population density of P. zeae and subsequently increase maize yield, however, requires further research.

3.9 EFFECT OF ORGANIC AMENDMENTS AND THE TIME OF APPLICATION ON P. ZEAE PATHOGENICITY ON MAIZE

3.9.1 Introduction

There are very few studies on organic amendments that have been conducted with field crops (Egunjobi and Larinde, 1975; Muller and Gooch, 1982) and no studies have been conducted to evaluate the optimal time for application of the organic matter into the soil. This information is important to broaden the scope of organic amendments in small-scale farming. The information is also important to improve the effectiveness of organic amendments and subsequently this will lower the rates of application. The objectives of this study were to (a) evaluate P.zeae control and subsequent maize growth response derived by using organic amendments and (b) evaluate the optimal time for applying organic amendments in maize production.

3.9.2 Materials and Methods

P. zeae was maintained for 7 months on maize plants in sandy loam soil (15% clay, 3% silt, 13% fine sand, 25% medium sand, 44% coarse sand, 0.64% organic matter and pH 5.4), in cement built tubs (1.0 m long, 0.75 m

wide and 0.75 m deep) in a greenhouse at the Harare Research Center (Grid ref. 30°25' East and 17°22' South). The culture contained about 100 P. zeae per 100 cm^3 of soil when used as inoculum for the research.

Twenty clay pots (30 cm diameter and 45 cm deep) were filled with the P. zeae infested soil on 2nd April, 1987. The pots were arranged on a greenhouse bench in a completely randomized block design of five treatments and four replications. The greenhouse had maximum day and minimum night temperatures of 32 and 20° C, respectively. After arranging the pots, four pots per treatment received the following treatments:

1. cattle manure applied 12 weeks before planting at a rate of 12 tons/ha and incorporated into the soil.
2. cattle manure applied 8 weeks before planting at a rate of 12 tons/ha and incorporated into the soil.
3. cattle manure applied 4 weeks before planting at a rate of 12 tons/ha and incorporated into the soil.
4. cattle manure applied on the planting date at a rate of 12 tons/ha and incorporated into the soil.
5. nontreated

All the pots were watered once a week throughout the preplanting period to facilitate the decomposition of manure. Two maize seeds (variety R 215) were planted into each pot on 26th June, 1987. All the pots were gently watered on the planting date and emergence occurred as early as 5 days after planting and was complete 9 days after planting. Maize plants in each pot were thinned to one plant per pot 14 days after planting.

All the pots were maintained at the same moisture level (daily watering) for four weeks. After four weeks, the plants were watered once a week. The experiment was terminated after 8 weeks. The plants were sampled at the

end of the experiment and on the sampling date, the whole plant was removed from the pot and the root and shoot systems were cut and put into separate labeled plastic bags. Soil from the pot was thoroughly mixed and a sub-sample (ca 1,500 cm^3) of the soil was put into a labeled plastic bag. All the plastic bags with samples were closed immediately to prevent any loss of moisture from the sample. The following parameters were evaluated from the samples:

i) Fresh weights of the shoot and root systems were obtained by weighing on a balance with an accuracy of ± 0.01 grams.

ii) Soil was thoroughly mixed in a tray and 100 cm^3 of soil was processed using the centrifugal-flotation technique (Jenkins, 1964) and observed under a stereoscopic microscope to enumerate P. zeae and other nematodes in the soil.

iii) The whole root system from each pot was cut into small pieces about 0.1-0.5 cm long and 10.0 grams were selected at random and processed using the maceration-centrifugal-flotation technique (Southey, 1985 p. 54) and observed under a stereoscopic microscope to enumerate P. zeae in the roots using the examination of nematode suspensions technique (Southey, 1985 p. 59-60).

iv) The data in this study were transformed (square root transformation) during analysis because the data exhibited a Poisson distribution. One way analysis of variance between P. zeae in soil and roots and maize growth parameters and different treatments was carried out. After the analysis of variance, least significant difference (LSD), standard error (SE) and coefficient of variation were calculated.

3.9.3 Results

Eight weeks after planting, maize plants that were grown in nontreated soil and soil which was treated with manure at planting had an equal (P = 0.05) root weight (Table 3.9.1). The roots weight was significantly (P = 0.05) lower compared to root weight in pots which had received manure 4, 8 and 12 weeks before planting. There were, however, no significant (P = 0.05) differences in the root weights of the latter three treatments. The latter three treatments increased the root weight of maize by 53.5, 49.7 and 47.8% compared to the control, respectively. Shoot weight of maize plants in nontreated soil was significantly (P = 0.05) lower compared to all the other treatments. (Table 3.9.1). The next lowest shoot weight was derived from pots which were treated with manure at planting and the shoot weight was 68.7% greater compared to that for the nontreated plots. Shoot weight of maize plants grown in soil which was treated with manure 8 and 12 weeks before planting was equal (P = 0.05) and it was significantly (P = 0.05) greater compared to the treatment which received manure at planting. The shoot weights in the latter two treatments were 138.0 and 119.6% greater compared to that for the control. Maize plants from pots which received manure 4 weeks before planting had the highest (P = 0.05) shoot weight compared to all the other treatments. The shoot weight was 220.9% greater compared to that for the control (Table 3.9.2).

Treatments in which manure was applied 8 and 12 weeks before planting had an equal (P = 0.05) population density of *P. zeae* in the soil eight weeks after planting. The population density of *P. zeae* in these two treatments was significantly (P = 0.05) lower compared to that of the control (Table 3.9.1). These two treatments decreased the population density of *P. zeae* in the soil by 29.0% compared to that for the control (Table 3.9.2). The

Table 3.9.1. Influence of the time of applying manure on the population density of Pratylenchus zeae *and maize growth.*

Parameters	P. zeae in soil1	P. zeae in roots2	Other		

Table 3.9.1. Influence of the time of applying manure on the population density of Pratylenchus zeae and maize growth.

Parameters / Treatments	P. zeae in soil[1] 8 wks after planting	P. zeae in roots[2] 8 wks after planting	Other nematodes in soil[1] 8 wks after planting	Root weight (grams) 8 wks after planting	Shoot weight (grams) 8 wks after planting
Manure applied 12 wks before planting	1.5[3]	221.0	0.75	76.6	218.9
Manure applied 8 wks before planting	1.3	209.5	4.5	78.2	256.0
Manure applied 4 wks before planting	2.0	206.3	3.5	83.1	365.9
Manure applied on planting day	2.0	347.0	6.8	39.6	130.1
Untreated	3.5	964.0	5.3	35.7	46.4

Key

[1]Soil = 100cm[3]

[2]Roots = 100 cm[3] soil + 10.0 grams roots.

[3]Mean of 4 replications.

Analysis in appendix 5.9.2

Table 3.9.2. Percent reduction of Pratylenchus zeae and subsequent maize growth increase after applying manure.

Parameters Treatment	P. zeae reduction in soil[1] 8 wks after planting (%)	P. zeae reduction in roots[2] 8 wks after planting (%)	Root weight increase 8 wks after planting (%)	Shoot weight increase 8 wks. after planting (%)
Manure applied 12 wks. before planting	29.03	47.60	47.81	119.55
Manure applied 8 wks before planting	28.99	47.60	49.66	138.03
Manure applied 4 wks before planting	11.31	49.81	53.53	220.87
Manure applied on the planting day	18.25	39.11	6.22	68.66

Key

[1]Soil = 100 cm3

[2]Roots = 10.0 grams

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population densities of P. zeae in the soil in treatments which received manure 4 weeks before planting and at planting were equal (P = 0.05) to that of the control. The population densities of other nematodes (mainly Dorylaimoid and Scutellonema spp.) that were recovered in the soil were equal (P = 0.05) and the population densities were generally very low. Also there was considerable variability (C.V% = 31.8) in the population densities of other nematodes in the soil despite the transformation.

The population densities of P. zeae in the roots from plants which were manured at planting and from plants in nontreated soil were equal (P = 0.05) 8 weeks after planting (Table 3.9.1). The population density of P. zeae in roots from plants which were manured at planting was also equal (P = 0.05) to the population densities of P. zeae in roots from plants which were growing in soil which was manured 4, 8 and 12 weeks before planting. The manure treatments reduced the population densities of P. zeae in the roots by up to 49.8% (Table 3.9.1). There was, however, considerable variability (C.V.% = 42.1) in the population densities of P. zeae in the roots.

3.9.4 Discussion

Data presented in this study show that organic amendments reduced the population density of P. zeae in the soil. The decrease of the population density of P. zeae in the amended soil by 29% compares favorably with a decrease of 30-35% that was reported in Egypt and Nigeria (Badra and Mohamed, 1979; Egunjobi and Larinde, 1975). The decrease of P. zeae in amended soil appeared to be in part a function of increased inimical organisms in the soil since replications in which high population densities of Dorylaimoid nematodes were recovered had the lowest population densities of P. zeae in the roots.

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This study also shows that organic amendments in the soil subsequently lowered the population densities of P. zeae in maize roots. The decrease in the population density of P. zeae in maize roots when manure was applied at planting was similar to that reported in Egypt after applying poultry droppings in soil infested with Rotylenchus reniformis (Badra and Mohamed, 1979). Better control of P. zeae in maize roots was, however, obtained by applying the manure several weeks before planting. This implies that a period for the decomposition of the manure in the soil before planting is essential to attain optimal control of P. zeae.

The data also illustrate that organic amendments subsequently increased maize growth as measured by root and shoot weights. The increased maize growth when manure was applied at planting compares favorably with that reported in Nigeria (Egunjobi and Larinde, 1975). The data also show that the optimal time for manure application to obtain high maize growth in P. zeae infested soil was 4 weeks before planting. If the manure was applied 8-12 weeks before planting, good P. zeae control was maintained but sub-optimal maize growth was recorded possibly because some nutrients had been leached from the manure. On the other hand, when manure was applied into the soil at planting, poor P. zeae control was obtained hence the sub-optimal maize growth was in part a function of P. zeae infection and possibly 'unavailable nutrients' which require a period of decomposition before they are released from the manure.

The study demonstrates that proper application of organic amendments in P. zeae infested soil may be a viable nematode control option for some small scale farmers if the population density of P. zeae is below a certain threshold. The study also demonstrates the importance of applying the manure at the right time but the timing should, however, be adjusted

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depending on the rainfall pattern in the area. The decomposition duration of 4 weeks should be increased if the area is dry to ensure complete decomposition of the manure and the duration should be reduced if the area is very wet and hot to minimize leaching of the nutrients.

3.10 SIMULATION MODEL OF PRATYLENCHUS ZEAE ASSOCIATED WITH MAIZE

3.10.1 Introduction

Many mathematical models have been developed in recent years to predict changes in the population densities of pests in agroecosystems, especially in the field of entomology (McSorley and Ferris, 1979). Such models can prove invaluable if properly integrated into an on-line pest management system. Modeling efforts for simulations of nematodes are few, however. Some important simulation models in nematology include: a simulation model of Heterodera schachtii Schmidt infecting sugar beets (Caswell et al., 1986), detailed model for the simulation of the Meloidogyne - grapevine system based on population dynamics data for Meloidogyne (Ferris, 1976), computer simulation and population dynamics for cyst-nematodes (Jones et al., 1978), simulated changes in Globodera rostocheinsis (Wollenweber) Mulvey and Stone population caused by growth of potato varieties having various degrees of resistance (Jones et al., 1967), combinations of environmental factors to estimate population levels of Pratylenchus hexincisus Taylor and Jenkins on maize roots (McSorley et al., 1977). These computer simulation models have helped advance our understanding of nematode-host plant interactions (Duncan and McSorley, 1987; Ferris, 1978).

There are no simulation models that have been developed to summarize data on P. zeae population dynamics and its pathogenicity on maize. P. zeae is, however, widespread in maize fields in Zimbabwe communal farms and yield losses caused by P. zeae on maize are substantial (Martin et al., 1975; Muchena et al., 1987). A P. zeae - maize simulation model will be useful in: (1) predicting the population levels of this nematode species in maize roots throughout the growing season, (2) assessing the impact of soil moisture and temperature on the population dynamics of P. zeae in different seasons and fields and (3) predicting the pathogenicity of P. zeae on maize root system and subsequent maize yield.

3.10.2 Model development

A model that simulates population dynamics of P. zeae was interfaced with an existing CERES - maize simulation model to establish a P. zeae - maize simulation model. The overall model has six basic components: nematode model, maize model, soil nematode data, agronomic data, weather data, and soil water data (Fig. 3.10.1). Dyke et al. (1986) outlined the details of the CERES - maize simulation model and how the model runs and these details will not be outlined in this study. The P. zeae simulation model is a subroutine **NEMPOP** in the CERES - maize simulation model and the subroutine flow is depicted in Fig. 3.10.2. **NEMPOP** subroutine reads weather data **CLIMT**, calender information **DATEC**, soil data **SOILI**, soil water data **WATER**, and agronomic data **PARAM** from the main program. Data which determine the length of the life cycle, birth rates, and mortality factors of P. zeae depending with the temperature are provided in arrays **VALT**, **VALB** and **VALD**, respectively (Table 3.10.1). The length of the life cycle is variable because time spent in a given developmental stage **DEL** in poikilothermic organisms is variable and depends on ambient temperature. The population density of P.

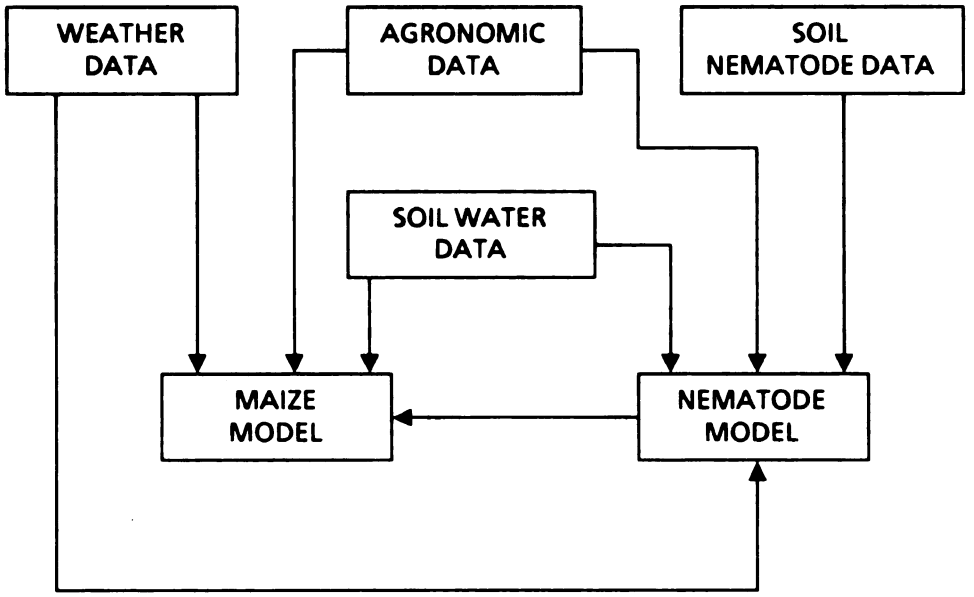


Figure 3.10.1. Simplified flowchart for the Pratylenchus zeae-maize simulation model.

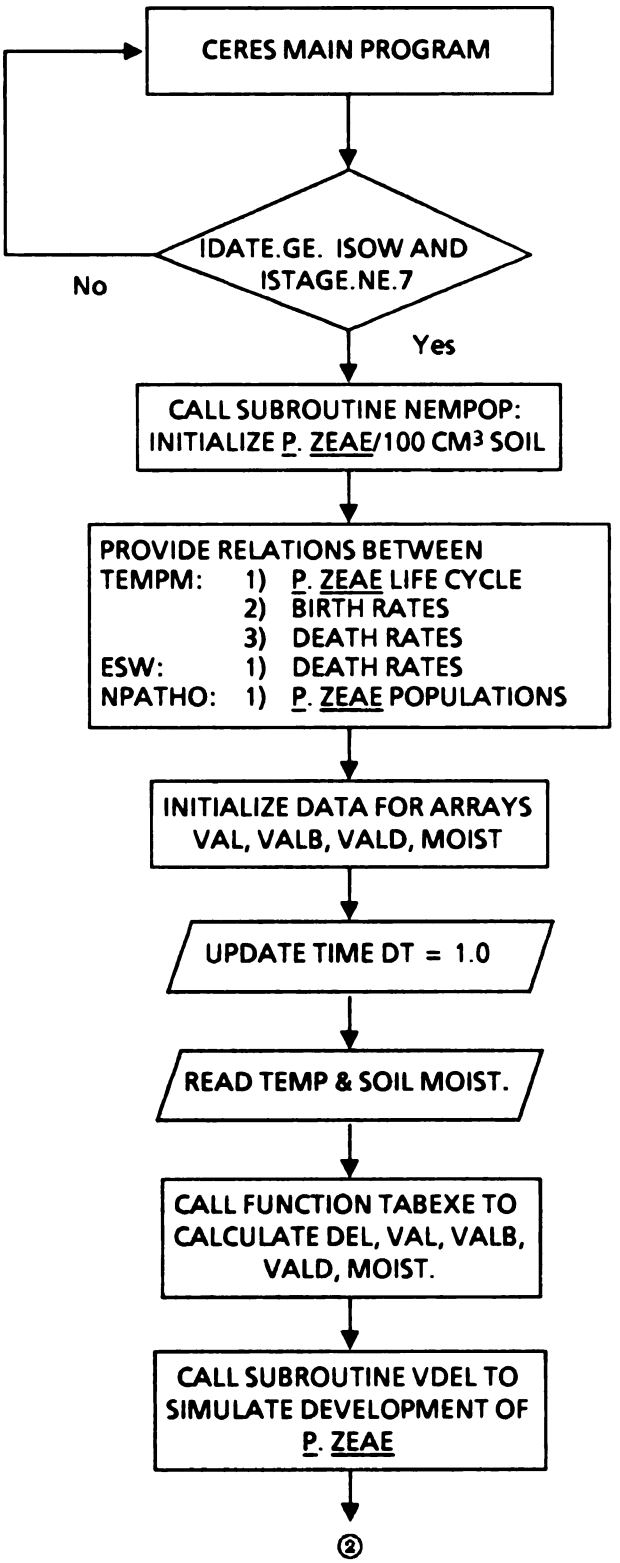
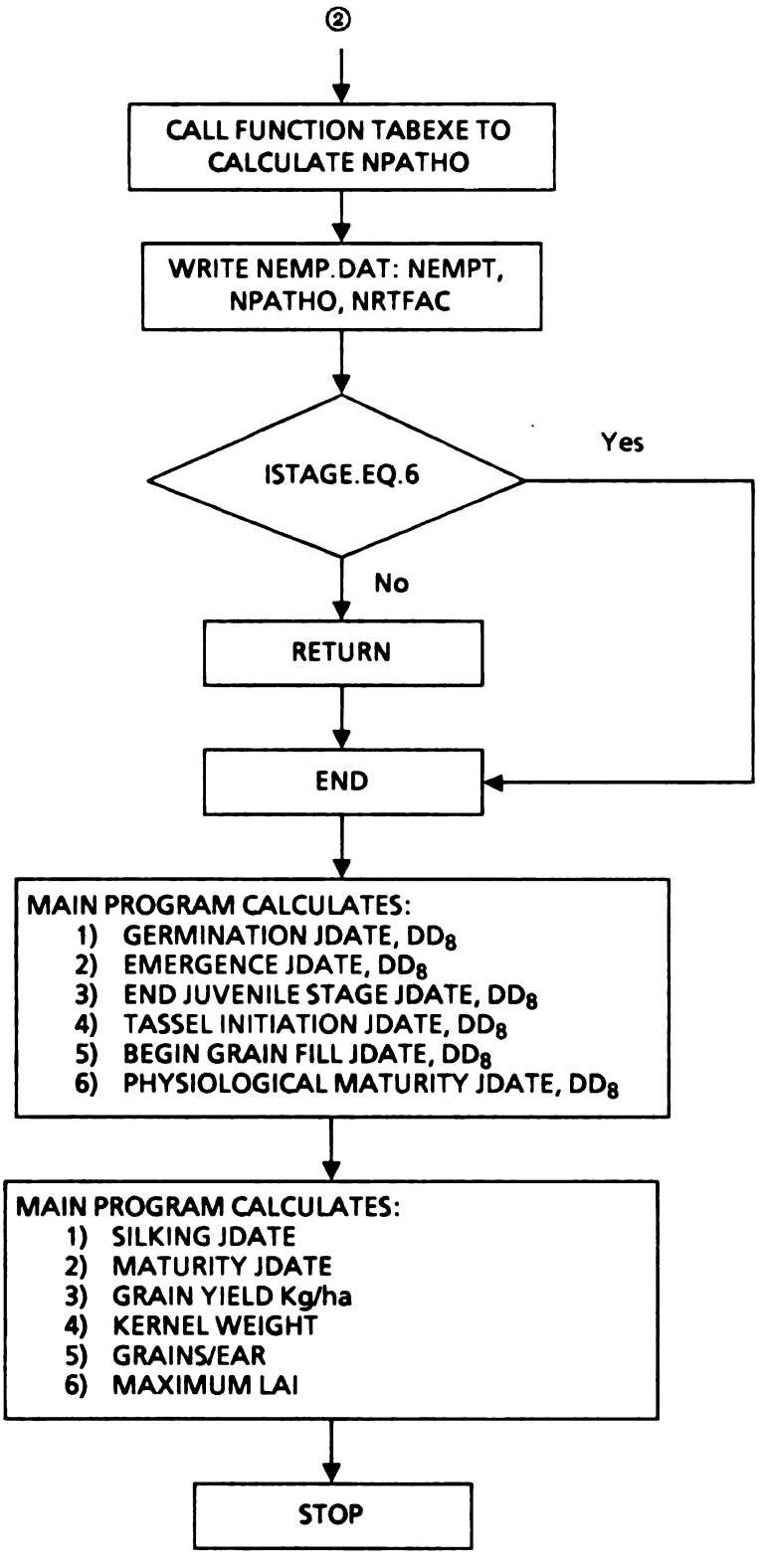


Figure 3.10.2. Flowchart of the subroutine NEMPOP which simulates the development of Pratylenchus zeae in maize roots.


②
CALL FUNCTION TABEXE TO CALCULATE NPATHO
WRITE NEMP.DAT: NEMPT, NPATHO, NRTFAC
ISTAGE.EQ.6
Yes
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RETURN
END
MAIN PROGRAM CALCULATES:
1) GERMINATION JDATE, DD8
2) EMERGENCE JDATE, DD8
3) END JUVENILE STAGE JDATE, DD8
4) TASSEL INITIATION JDATE, DD8
5) BEGIN GRAIN FILL JDATE, DD8
6) PHYSIOLOGICAL MATURITY JDATE, DD8
MAIN PROGRAM CALCULATES:
1) SILKING JDATE
2) MATURITY JDATE
3) GRAIN YIELD Kg/ha
4) KERNEL WEIGHT
5) GRAINS/EAR
6) MAXIMUM LAI
STOP

zeae is also influenced by the soil water content and the data is in **MOIST** (Table 3.10.2). Pathogenicity of P. zeae on maize roots is determined by the population density of P. zeae in roots and the data is defined in **VALL** (Table 3.10.4). The number of P. zeae mature females that survive and produce eggs are influenced by the population density of P. zeae in the roots **TLOFF** and if the population density is high, the density dependent mortality is high (Table 3.10.3).

NEMPOP subroutine utilizes a table look up function **TABEXE** to calculate daily time delay **DEL**, birth rate **BREGG** and density dependent mortality **TLOFF**. The same function is also used to calculate death rates **DRATE** depending on the average daily temperature **TEMPM** and **DRATEM** depending on available extractable soil water content **ESW**. The minimum and maximum temperatures are read in the main program from a weather input file **WETZIM** and the mean temperature is calculated in the subroutine **NEMPOP**:

```
TEMPM = (TEMPMN + TEMPMX)/2
DEL = TABEXE(VALT,SMALLP,DIFFP,KP,TEMPM)
BREGG = TABEXE(VALB,SMALLP,DIFFP,KP,TEMPM)
DRATE = TABEXE(VALD,SMALLP,DIFFP,KP,TEMPM)
TLOFF = TABEXE(DDMOT,SMALLPP,DIFFDM,KD,NEMPT)
```

The extractable soil water content is calculated in the main program and the values are passed through a COMMON statement to subroutine **NEMPOP**:

```
DRATEM = TABEXE(MOIST,SMALLM,DIFFM,KM,ESW)
```

The calculated rates are utilized to estimate the number of P. zeae eggs laid daily by mature females **R(6)**, second stage juveniles **R(2)** and developing females that die daily:

Table 3.10.1. Influence of temperature on P. zeae life cycle, fecundity and mortality factors (Mamiya, 1971; Olowe and Corbett, 1976).

Temp. (C)	Days for a life cycle **VAL**	No. of eggs/female/day **VALB**	No. of J_2 that die per day **VALD**
<15	84	0.056	0.035
20	42	1.100	0.102
25	28	6.662	0.645
30	21	9.500	0.905
>35	20	0.614	0.155

Table 3.10.2. Effect of soil water on the number of P. zeae J_2 that die per day (Egunjobi and Bolaji, 1979; Koen, 1967; Martin et al., 1975; Norton 1979; Townshend, 1972; Trivedi et al., 1978).

Extractable soil water (cm/cm)	.00	.04	.08	.120	.160
No. P. zeae J_2 that die/day **(MOIST)**	.55	.50	.10	.059	.104

Table 3.10.3. Impact of P. zeae population density in maize roots on P. zeae fecundity (McSorley and Ferris, 1979).

Population/gram dry root weight	0	500	1000	1500	2000	2500
Fecundity factor **DDMOT**	1	0.91	0.85	0.81	0.77	0.73

Table 3.10.4. Influence of P. zeae population density on new root growth of maize (Martin et al., 1975; Muchena et al., 1987; Tarte, 1971).

Population/dry gram root	0	500	1000	1500	2000	2500
Pathogenicity factor **VALL**	0	.635	.9860	.900	.955	.962
New root factor **NRTFAC**	1	.365	.140	.100	.045	.038

BRFEM = BREGG * R(6)

DVFEM = DRATE * R(6) * 0.2

DREJ2 = DRATE * R(2) + DRATEM * R(2)

The number of P. zeae second stage juveniles, developing females and mature females that die daily are subtracted from the number of P. zeae in the respective stages:

R(2) = R(2) - DREJ2

R(5) = R(5) - DVFEM

R(6) = R(6) * TLOFF

The remaining P. zeae will undergo a developmental process. **NEMPOP** subroutine utilizes a time - varying distributed delay **VDEL** (Manetsch, 1976) to calculate the developmental process of P. zeae depending on **DEL**:

VDEL(BRFEM,VOUT,R,DEL,DELP,DT,K)

The total number of P. zeae in 1.0 gram dry root weight is the summation of second stage juveniles **R(2)**, third stage juveniles **R(3)**, fourth stage juveniles **R(4)**, developing females **R(5)**, and mature females **R(6)**:

NEMPT = NEMPT + R(2,6)

The pathogenicity of P. zeae on the root system **NPATHO** is calculated using a table look up function **TABEXE**:

NPATHO = TABEXE(VALL,SMALLPP,DIFFPP,KPP,NEMPT)

NRTFAC = 1.0 - NPATHO

The value of **NRTFAC** is transferred into the main program to influence new root growth.

The program was written in **FORTRAN** and it requires the user to interactively input the initial population densities of P. zeae eggs, second stage juveniles, third stage juveniles, fourth stage juveniles, developing female, and mature females in 100 cm^3 of soil. The program calculates daily

values of all the state variables (Table 3.10.5) from the sowing date of maize until the crop reaches physiological maturity:

IF(JDATE .GE. ISOW .AND. ISTAGE. NE. 7) CALL NEMPOP

The program does not calculate the fixed initializing arrays used in the extrapolation function **TABEXE**.

To execute the program, the user will have to enter **'PZCORN1'**. The program will return with a list of 24 variables about weather, soil type, maize variety, sowing date etc. and if the user does not want to change any of the variables, the user should enter **'0'**. The program will request for the title of the run. After the name of the run has been entered, the program will ask the user whether this is a multiple year run. The answer to this question should be no **'N'** because this has not been incorporated in the nematode subroutine **NEMPOP**. The subroutine **NEMPOP** simulates the population dynamics of P. zeae during the growing season only.

After each run, daily simulated values of the total P. zeae population densities per 1.0 gram dry root weight **NEMPT**,nematode pathogenicity factor **NPATHO**, and the new root growth factor **NRTFAC** are stored in the file **NEMP.DAT**. This file can accessed by entering 'type **NEMP.DAT**', if the data is to be viewed on the screen or 'print **NEMP.DAT**' if a print out of the data is required.

Parameters which were also required in the initialization of the CERES - maize program were **CGENET, CLIMT, SOIL,** and **WATER**. These parameters were initialized with specific information for Zimbabwe which was derived from several field and laboratory experiments. Most of the field studies were conducted in Chinamora communal area.

Weather data (daily maximum and minimum air temperatures, rainfall and solar radiation) for the 1985/85 growing season was recorded at the

Table 3.10.5 State variables used in the subroutine **NEMPOP.**

Variable	Definition	Initial value
BRFEM	Total no. of eggs laid/day	compute
DIFFM	Difference between adjacent ESW (cm/cm) in MOIST	0.04
DIFFP	Difference between adjacent temp. in VALT, VALB, VALD	5.00
DIFFPP	Difference between adjacent P. zeae population densities/1.o dry gram of roots in VALL	500.0
DREJ2	No. of second stage juveniles of P. zeae that die/day	compute
DT	Time increments being used in the simulation (days)	1.00
ESW(L)	Extractable soil water content for soil layer (L)	compute
ISOW	Day of year for sowing	compute
JDATE	Day of the year	compute
K	No. of stages in P. zeae life cycle	6
KM	The no. of intervals between extractable soil moisture contents MOIST	4
KP	The no. of intervals between tempts. for VALT, VALB	4
KD	The no. of intervals for P. zeae population densities	4
KPP	The no. of intervals between P. zeae population for VALL	5
NEMPO	P. zeae population densities in 100 cc soil by life stage	input
NEMPT	Total P. zeae in 1.0 dry gram of roots excluding eggs	0
NPATHO	P. zeae pathogenicity on maize roots (scale 0-1.0)	0
NRTFAC	P. zeae root factor (scale 1.0-0)	1
R(1)	Eggs per 100 cc soil	input
R(2)	Second stage juveniles per 100 cc soil or 1.0 gram dry root weight	input
R(3)	Third stage juveniles per 100 cc soil or 1.0 gram dry root weight	input
R(4)	Fourth stage juveniles per 100 cc soil or 1.0 gram dry root weight	input
R(5)	Developing females per 100 cc soil or 1.0 gram dry root weight	input
R(6)	Mature females per 100 cc soil or 1.0 gram dry root weight	input
SMALLM	The smallest element of the array MOIST (cm/cm)	0.0
SMALLP	The smallest element of the arrays VALT, VALB, VALD (C)	15.0
SMALLPP	The smallest element of the array VALL (P. zeae/1.0 gram root weight)	0.0
TEMPM	Mean air temperature (C)	compute
TEMPMN	Minimum air temperature (C)	compute
TEMPMX	Maximum air temperature (C)	compute
TLOFF	Population density dependent mortality of P. zeae	compute

Harare research center. Maize growth parameters for variety **R 215** (root and shoot weights, number of leaves, number of days to 50% tassel and silk emergence and leaf length and width) were measured in plants which were grown at Harare research center. Also genetic inputs for maize variety R 215 which were estimated for the simulation model are:

P1 (growing degree days base 8 C (GDD8) from seedling emergence to the end of the juvenile phase). This value was estimated to be similar to values for the southern USA and tropical regions with a range of 260 to 350. A value of 311 was used in the simulation.

P2 (photoperiod sensitivity coefficient) which ranges from 0 to 0.8 (Dyke et al., 1986) was estimated to be similar with that for the southern USA which is 0.75.

G2 (potential kernel number) was reported to vary from about 560 to 834 kernels per plant (Dyke et al., 1986). In this study, a mean of 588 kernels per plant was obtained.

G5 (potential kernel growth rate), Dyke et al. (1986) reported this parameter to vary from approximately 6 to 11 mg/kernel day). This was estimated to be 7.5 mg/kernel day in this study.

Soil data which was used in the simulation was measured in Chinamora communal area. The data which was measured include the number of soil layers **NLAYR** to reach bedrock, thickness of each layer **DLAYR**, bulk density **BD** of each layer, textural analysis of each layer and amount of organic matter in each layer. The following parameters were calculated from the data:

Porosity of each layer **PO** was calculated from bulk density **BD** (Dyke at al., 1986):

PO(I) = 1.0 - BD(I)/2.65

where 2.65 was mineral particle density. Next a correction factor **XC** for the lower density of organic matter was calculated:

XC = OC(I) * 0.0172

where OC was the organic carbon concentration (%) of the layer. The maximum bulk density to which the layer could be compacted **BDM** was then calculated:

BDM(I) = (1.0 - XZ) / (1.0 / BD(I) - XZ / 0.224

where **BDM(I)** was not allowed to exceed 2.5.

The effects of soil texture on lower limit of plant extractable water for the layer **LL(I)** and the drained upper limit for the layer **DUL(I)** were estimated with the variables **W1** and **W2** (Dyke at al., 1986), respectively. When sand content **SAN(I)** was greater than 75%:

W1 = 0.19 - 0.0017 * SAN(I),

W2 = 0.429 - 0.00388 * SAN(I).

When silt content **SIL(I)** was greater than 70%:

W1 = 0.16

W2 = 0.1079 + 0.000504 * SIL(I)

LL(I) and **DUL(I)** were calculated:

LL(I) = W1*(1.0-XZ)*(1.0 + BDM(I)-BD(I)) + 0.23*XZ

DUL(I) = LL(I) + W2*(1.0-XZ)-(BDM(I))*0.2 + .55*XZ

SAT(I)was then calculated with the following equation:

SAT(I) = K(PO(I) - DUL(I)) + DUL(I)

where **K** = 0.5 for sandy and coarse loamy soils and 0.4 for other soils. The root distribution factor **WR** was estimated for any soil layer by the equation:

WR(I) = exp(-4.0 * Z(I) / 200.0)

where **Z(I)** was the depth (cm) to the center of the layer I. In the top soil layer **WR** was set to 1.0.

Soil reflectivity or albedo **SLAB** was estimated from a table of soil albedo (Dyke et al., 1986). The coefficient for the upper limit of stage 1 soil evaporation **U** was estimated as 6 mm because the soil of the top layer was sandy. The whole profile drainage rate coefficient **SWCON** was calculated for each soil layer **L** from the porosity **PO(I)** and drain upper limit **DUL(L)** for each layer:

$$PO(I) = 1.0 - BD(L) / 2.65$$

$$SWCON(L) = PO(L) - DUL(L) / PO(L)$$

where **BD(L)** was the moist bulk density of the layer and 2.65 was the approximate particle density. The runoff curve number **CN2** of 78 was chosen from a USDA Soil Conservation Service, 1972 table (Dyke et al., 1986).

3.10.3 Model Evaluation

The output of the P. zeae - maize simulation model was compared with data of P. zeae population dynamics and maize growth parameters which were measured at the Harare Research Station during the 1986/87 growing season.

P. zeae Population Dynamics

Accurate simulation of the fecundity and mortality factors of P. zeae as influenced by temperature, soil moisture, host suitability and the carrying capacity of the root system are important for accurate simulation of the population densities of P. zeae in the root system. Simulated and measured population densities of P. zeae (initial population density of P. zeae = 30/100 cc soil) were similar during an entire growing period (Fig. 3.10.3). The mean error of the simulated values for the nine sampling dates was 7% of the measured values.

Sensitivity of the simulation model was evaluated by running the model with different initial population densities of P. zeae in the soil. The output

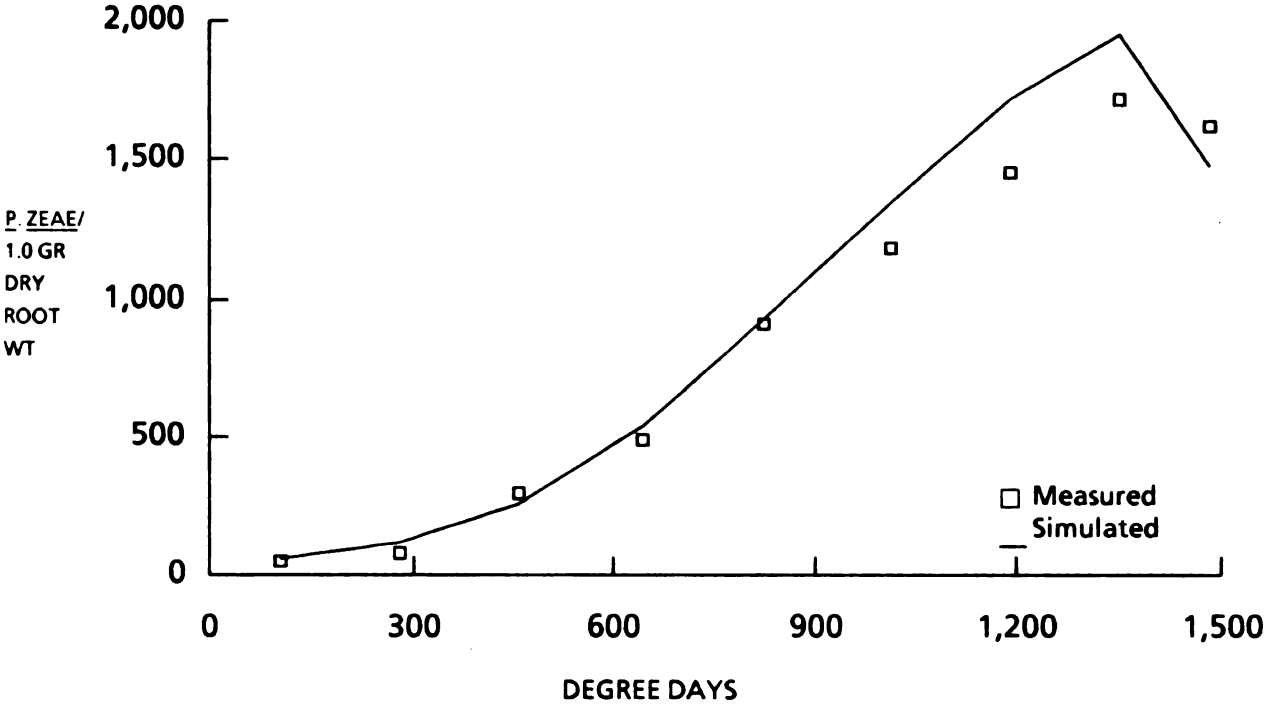

Figure 3.10.3. Simulated and measured population densities of P. zeae in 1.0 gram dry root weight of maize variety R 215 during the 1987 growing season.

from the runs, showed that the model was sensitive to the initial population density of P. zeae in the soil (Fig. 3.10.4). The magnitidue of the increase in the population density was a function of the initial population density. The increase of P. zeae population densities in different treatments followed the same trend with a slow build up of the population density at the beginning of the season followed by a rapid buildup during the middle of the growing season and a decline in the population density at the end of the season. McSorley and Ferris (1979) also reported declining population densities of root lesion nematodes infecting maize roots at the end of the growing period, in Indiana. The decline in the population density of root-lesion nematodes at the end of the growing season was attributed to senescing and decaying roots which would harbor lower Pratylenchus populations, as Pratylenchus migrate back into the soil.

The sensitivity of the model was also evaluated by running the model with different temperature regimes. Weather data for Zimbabwe and Michigan growing seasons were used to run the model (Fig. 3.10.5). At the beginning of the growing season, when the accumulated degree days for Zimbabwe and Michigan were about the same, the population densities of P. zeae in roots for the two sites were equal (Fig. 3.10.6). During the middle of the growing period, the simulated population density of P. zeae in roots was higher in the run where Michigan weather data had been used because the average temperatures were higher in Michigan. At the end of the growing period, the temperature in Michigan decreased faster than the temperature in Zimbabwe (Fig. 3.10.5). The low temperature which was experienced in Michigan caused a rapid decrease in the population density of P. zeae in roots at the end of the growing season. These results indicate that the model is sensitive to very small temperature fluctuations which might be experienced

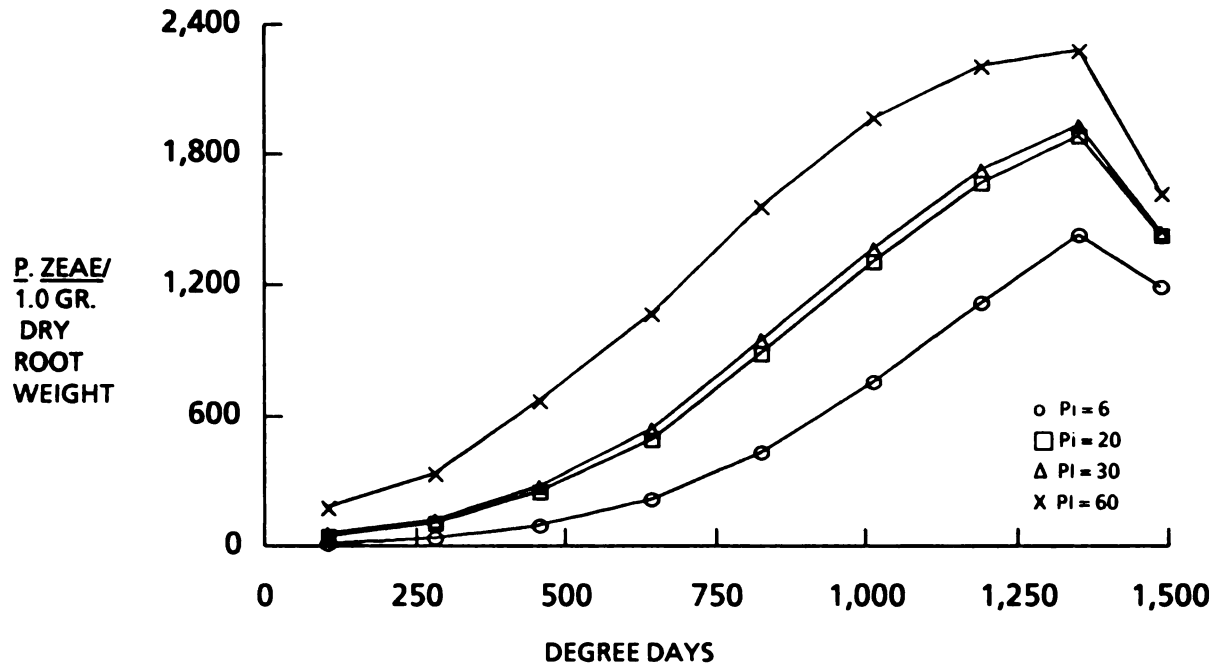

Figure 3.10.4. Simulated influence of the initial population density of P. zeae in the soil on the population dynamics of P. zeae in 1.0 gram dry root weight of maize variety R 215 during the 1987 growing season.

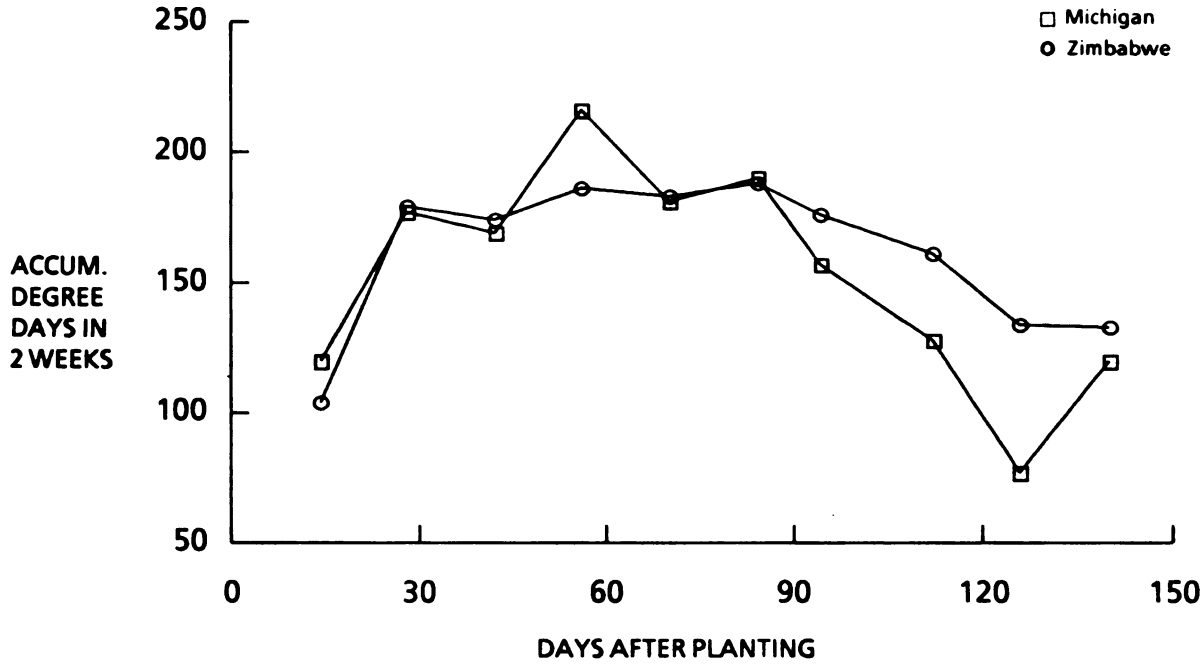

Figure 3.10.5. Measured degree days (base 8°C) accumulated in two-week intervals for Zimbabwe 1986/87 growing season and for Michigan 1985 growing season.

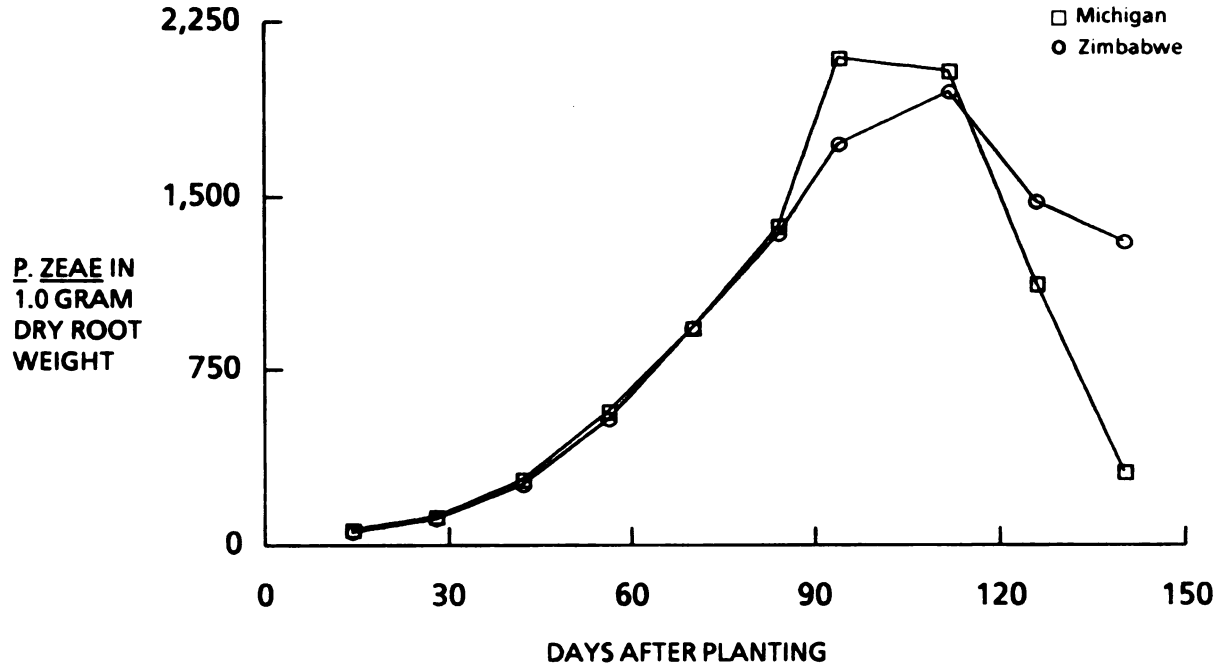

Figure 3.10.6. Simulated population dynamics of P. zeae in 1.0 gram dry root weight of maize R 215 using Zimbabwe 1986/87 and Michigan 1985 weather data.

at different sites. It is however, important that the simulation model be validated by a minimum of two data sets from different growing seasons.

Maize Growth Parameters

(a) Silking date

Accurate prediction of silking date requires accurate weather data and correct adjustment of the genotype - specific coefficients **P1** and **P2** (Dyke et al., 1986). The predicted and measured silking dates for maize variety R 215 were equal and 50% of the silking occurred 70 days after sowing. Dyke et al (1986) reported a mean error of one tenth of a day between predicted and measured silking dates for maize hybrid Pioneer 3780 grown in Pennsylvania, Nebraska and Texas. The silking date of the hybrid B73 x Mo 17 has been more extensively tested in four states in the USA and five countries in Europe. The mean error for the silking date of this hybrid was reported as -2.3 days (Dyke et al., 1986).

(b) Physiological maturity

Accurate prediction of the date for physiological maturity requires accurate air temperatures and correct adjustment of the genotype - specific coefficient **P5** (Dyke et al., 1986). The predicted and measured dates for physiological maturity for maize variety R 215 differed by 4 days. For the hybrid B73 X Mo17, Dyke et al. (1986) reported a mean error of 2.5 days for the difference between silking and physiological maturity dates.

(c) Leaf number

Simulated leaf numbers were higher than observed leaf numbers throughout the growing period (Fig. 3.10.7). The difference can be attributed to the fact that the model was simulating leaf tip emergence; whereas, the measured data is leaf collar emergence. However, the simulated plants continued to produce leaves after the plants grown at

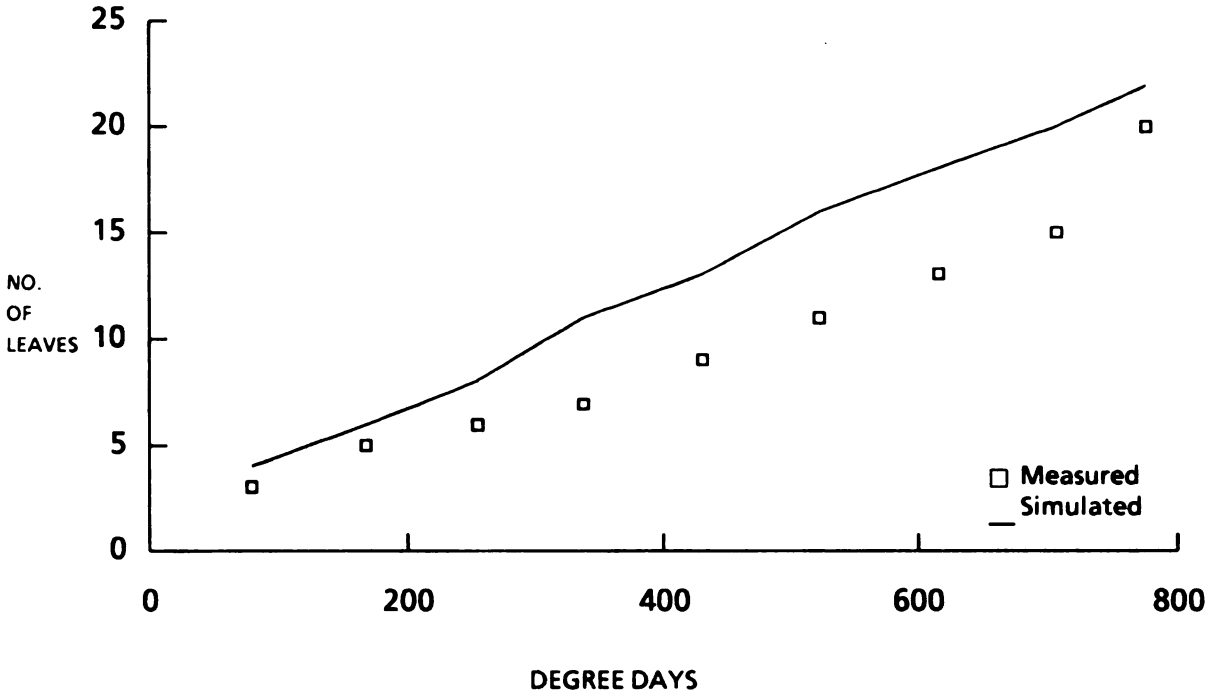

Figure 3.10.7. Simulated and measured number of leaves of maize variety R 215 during the 1987 growing season.

Harare Research Station plants had stopped producing leaves. These differences may, in part, account for the difference in the total number of leaves between the simulated and counted number of leaves. Dyke et al. (1986) also reported overprediction of leaf area index of maize hybrid Pioneer 3780 at silking in Pennsylvania.

(d) Above-ground dry biomass

Accurate above-ground biomass is important for accurate simulation of the nutrient and carbon cycling (Dyke et al., 1986). Simulated and measured total above-ground biomass development were similar for R 215 grown at the Harare Research Station. For the first three dates of measurement, simulated and measured values were equal. The last five measurements, the difference between simulated and measured above-ground dry biomass increased with time (Fig. 3.10.8). The mean error of the simulated values for the eight measurement dates was 17.7% of the measured values. The higher weights in the above-ground dry biomass for the simulated maize plants can, in part be explained by the higher number of leaves on the simulated plants.

(e) Below-ground dry biomass

Simulated below-ground biomass of maize variety R 215 had a mean error of 11.1% from the measured values (Fig. 3.10.9). The measured dry root system was higher than the simulated dry root system, whereas, the measured above-ground biomass was smaller than the simulated above-ground biomass. The differences between the simulated and measured below and above-ground dry biomass might be a result of how the researchers separate above and below biomass.

(f) Grain yield

Grain yield prediction represents the integration of virtually every system operative in the model. Field studies which were extensively carried

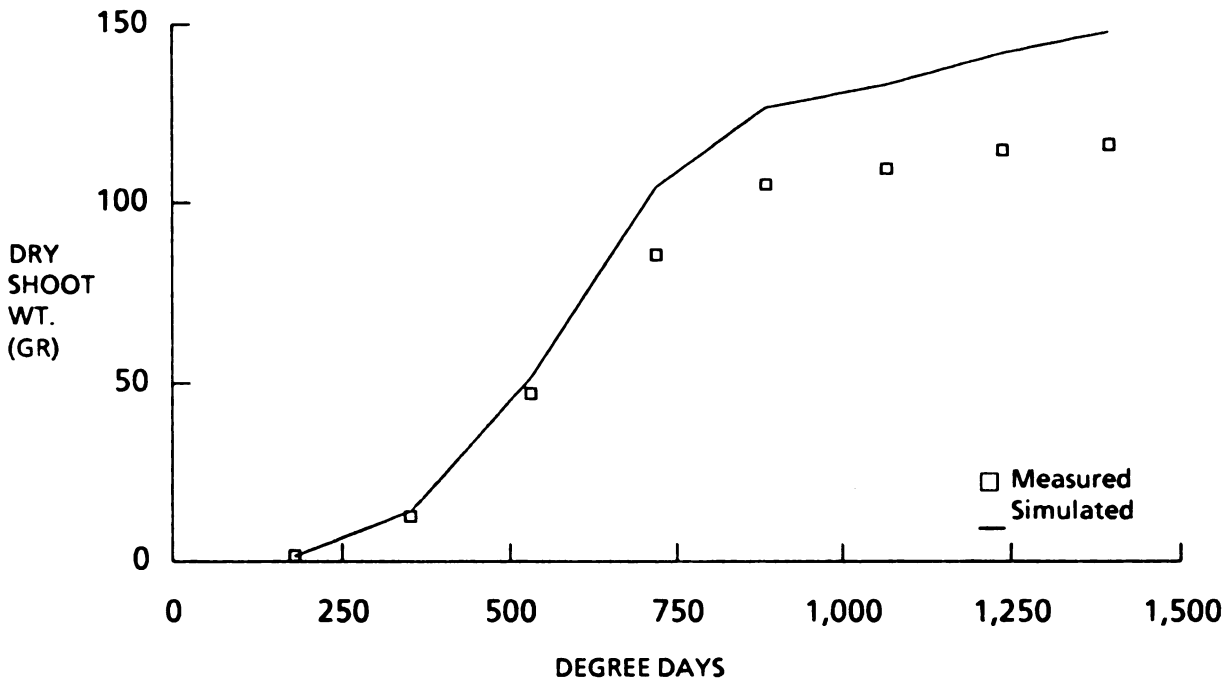

Figure 3.10.8. Simulated and measured maize dry shoot weight of maize variety R 215 during the 1987 growing season.

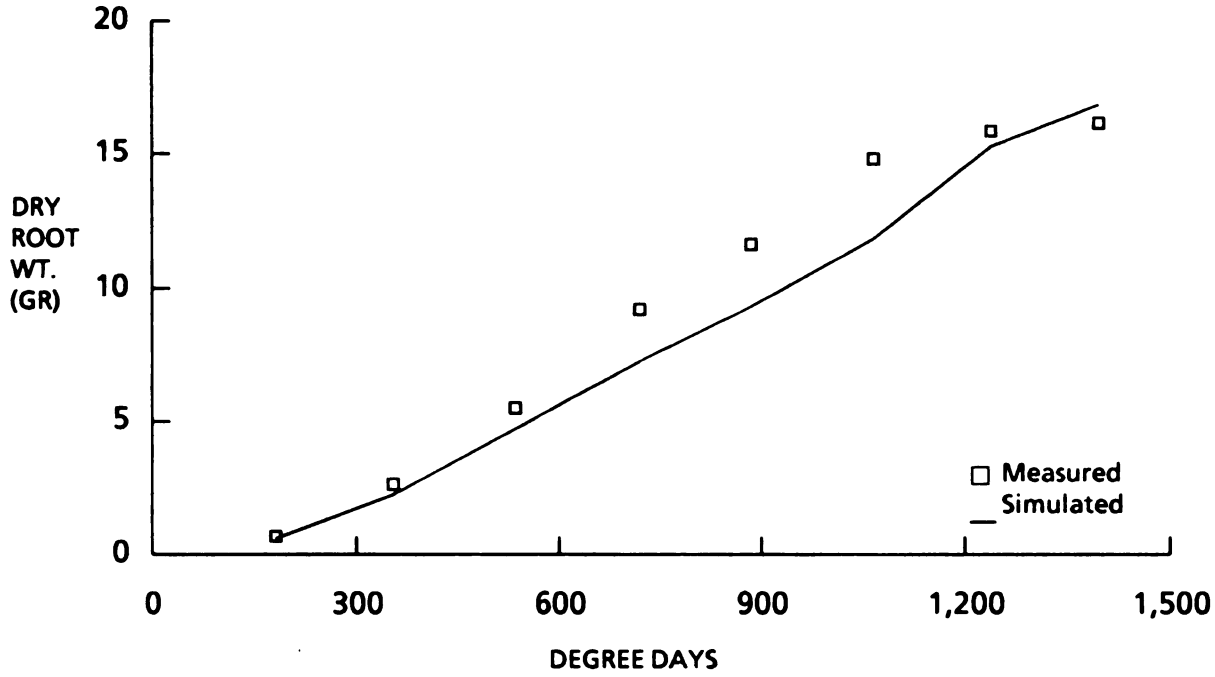

Figure 3.10.9. Simulated and measured dry root weight of maize variety R 215 during the 1987 growing season.

out by the Crop Breeding Institute in 31 communal farms in Zimbabwe had a mean grain yield of 6736 kg/ha for maize variety R 215. The measured maize grain yield compares favorably with the simulated maize grain yield of 6907 kg/ha. Inaccurate estimates of initial soil water, plant-extractable soil water, or soil depth could produce large errors in simulated grain yields (Dyke et al., 1986). In addition, genetic coefficients used in the model are often unavailable from independent studies and have to be estimated. It appears the genetic coefficients which were estimated for maize variety R 215 are approximately equal to the actual values, however, the validation process should be repeated with maize growth parameters obtained from a second growing season.

Pathogenicity of P. zeae on Maize Plants

P. zeae has been reported to reduce maize yield by up to 25% (Martin et al., 1975) and 50% (Muchena et al., 1987). The magnitude of maize yield reduction is dependent on the initial population density of P. zeae in the soil. Simulated maize yield reductions were 20% and 47.5% with P. zeae initial population densities of 30 and 60 per 100 cc of soil. The simulated maize yield reductions compare favorably with the measured maize yield reductions. Other maize growth parameters which were reduced by P. zeae infection include maximum leaf area index, total dry biomass, and number of grains per ear (Table 3.10.6).

The simulation showed that at the beginning of the season, both infected and non-infected maize plants had equal dry biomass (Fig. 3.10.10). Differences in the amount of dry biomass were detected five weeks after planting between non-infected plants and plant growth which was simulated in soil infested with the highest population density of P. zeae (Pi = 60). Six weeks after planting, differences were detected between maize plant

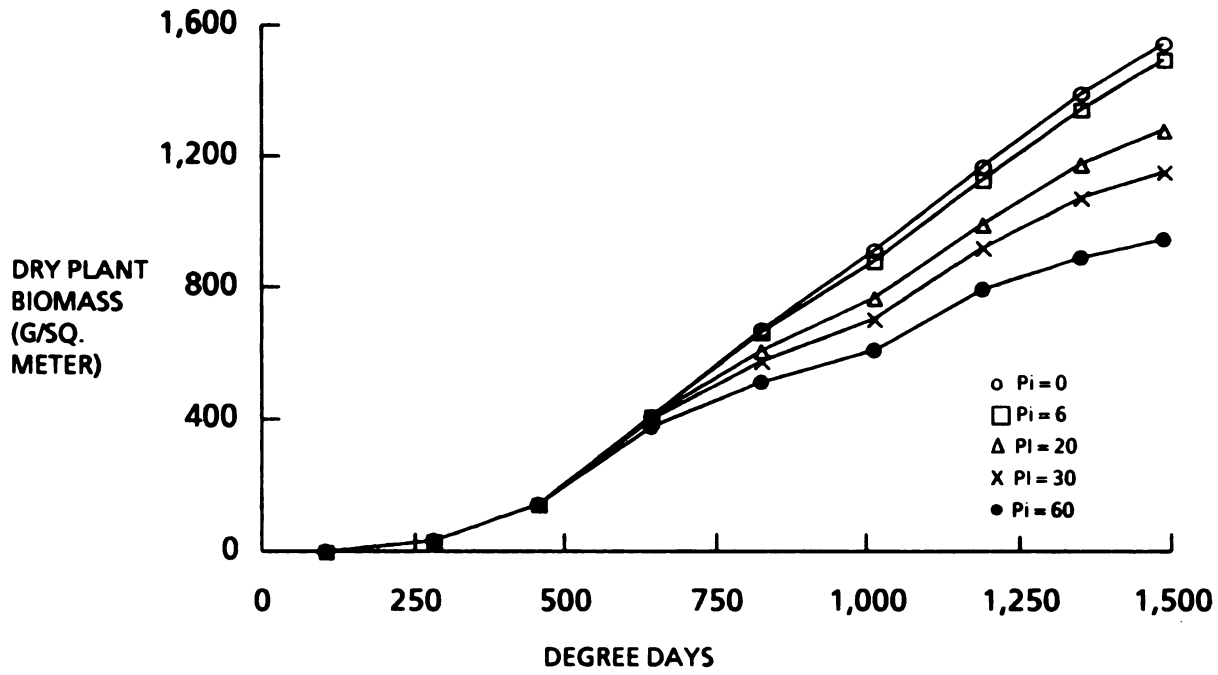

Figure 3.10.10. Simulated dry plant biomass of maize variety R 215 growing in soil infested with different initial population densities of P. zeae per 100 cm^3 of soil during the 1987 growing season.

growth simulated in non-infested soil and soil infested with P. zeae (Pi = 20 or 30). Simulated growth in non-infested soil and soil infested with P. zeae (Pi = 6) had detectable differences eight weeks after planting.

Further research is required on how P. zeae impacts maize new root growth. This aspect requires further investigation and validation for at least two growing seasons. Also further development of the simulation model could incorporate some of the management strategies outlined in this dissertation to reduce the population densities of P. zeae infecting maize roots and subsequently increase maize yield.

Table 3.10.6. Maize growth parameters which were influenced by P. zeae infection in the simulation model.

P. zeae/100 cc	Grain yield (kg/ha)	Grains/ear	Maximum LAI	Biomass (grams/sq meter)
0	6907.0	413	3.69	1544.0
6	6874.0	411	3.60	1494.0
20	6295.0	376	3.09	1278.0
30	5540.0	331	2.74	1114.0
60	3625.0	285	2.35	941.0

4. SUMMARY AND CONCLUSIONS

4.1 RESEARCH PROGRAM OVERVIEW

The research that has been addressed in this dissertation on plant-parasitic nematode problems of maize in Zimbabwe communal farms was divided into four components: (a) problem identification, (b) ecology of the pest, (c) management of the pest, and (d) simulation model of the pest.

4.2 PROBLEM IDENTIFICATION

The national survey of plant-parasitic nematodes associated with maize in communal farms which was conducted during the 1985/86 growing season, found thirteen plant-parasitic nematode genera associated with maize. The major nematode pests of maize were identified as Pratylenchus zeae and Pratylenchus brachyurus with relative densities of 50.0 and 38.5% and absolute frequencies of 52.6 and 21.9%, respectively. Other plant-parasitic nematodes which were found associated with maize are: Aphelenchoides sp., Aphelenchus avenae, Aphelenchus sp., Criconemella sphaerocephala, Criconemella sp., Helicotylenchus sp., Hoplolaimus sp., Meloidogyne sp., Paratrichodorus minor, Pratylenchus sp., Pratylenchus goodeyi, Rotylenchulus sp., Rotylenchulus parvus, Rotylenchus brevicaudatus, Scutellonema sp., Scutellonema brachyurum, Scutellonema labiatum, Scutellonema magniphasmum, Scutellonema unum, Trichodorus sp., and Tylenchorhynchus sp.

In Manicaland province, maize plants which were infected with > 1,000 P. zeae per 10.0 grams of fresh root weight during the survey, were estimated to have mean maize yield of 1 392 kg/ha. Maize plants which were infected with < 1,000 P. zeae per 10.0 grams of fresh root weight were estimated to have a mean grain yield of 2 659 kg/ha. The findings in this research clearly demonstrated that P. zeae is a major limiting factor in communal area maize production. On the basis of these results, P. zeae was selected as the target pest for further research.

4.3 ECOLOGY OF THE PEST

The ecology of the target pest was approached in two phases: (a) survey and (b) controlled experiments.

4.3.1 Analysis of Survey Results

Different natural farming regions of Zimbabwe, influenced the diversity and population densities of plant-parasitic nematodes recovered from maize roots. P. brachyurus and P. zeae were equally prevalent in natural regions II to IV but in natural regions I and V, P. zeae was more prevalent than P. brachyurus. This showed that P. zeae has a competitive advantage over P. brachyurus. The mean population densities of P. zeae per 10.0 grams of fresh root weight + 100 cc of soil were 1, 773, 4, 794, 3, 915, 1, 937 and 150 for natural regions I, II, III, IV and V, respectively. The results demonstrated that natural regions II to IV had the ideal conditions for P. zeae high rate of reproduction. Some of the edaphic factors that influenced the population dynamics of P. zeae are:

(a) Rainfall

Mean population densities of 2, 138.5, 4, 615.8, 6, 767.7, 1, 747.0 and 651.3 P. zeae per 10.0 grams of fresh root weight were recovered from maize

plants growing in rainfall regimes of > 1, 000, 800-1, 000, 600-799, 400-599 and < 400 mm per year, respectively. The results showed that annual rainfall of 600-1, 000 mm is the optimum range for P. zeae high population densities in maize roots. However, it should be noted that P. zeae was recovered in maize roots from farms with very low or high soil moisture. The results showed that P. zeae was tolerant to a very wide range of soil moisture conditions. Since rainfall is probably the most important abiotic parameter in Zimbabwe communal area maize production, the adverse effects of rainfall on maize growth in fields that are infested with P. zeae are compounded because P. zeae has a wider optimum soil moisture tolerance than maize.

(b) Temperature

Mean population densities of 595.0, 8, 113.0, 6, 786.5, 3, 580.5, 363.6 and 0; and 595.0, 10, 352.5, 4, 871.5, 3, 170.6, 705.0 and 0 P. zeae per 10.0 grams of fresh root weight were recovered from maize plants growing in fields with March and February air temperature regimes of 20.0-22.5, 22.6-25.0, 25.1-27.5, 27.6-30.1, 30.1-32.5 and > 32.5 C, respectively. The results demonstrated that the optimum air temperature for P. zeae multiplication ranged from 22.6 to 30.1 C. Since the summer temperature conditions in Zimbabwe communal farms are ideal for P. zeae reproduction, it is conceivable that P. zeae population densities reach very high levels and cause extensive reduction in maize growth.

(c) Soil texture

Mean population densities of 1, 512.5, 1, 587.3, 2, 592.0 and 2, 664.3 P zeae per 10.0 grams of fresh root weight were recovered in maize plants growing in fields with sandy clay loam, sandy loam, loamy sand and sandy soil textures, respectively. The results showed that the reproduction of P. zeae was faster in light textured soils. The research demonstrated that P. zeae is a

major limiting factor in maize production in most communal areas since most communal farms have sandy soils which are ideal for P. zeae reproduction.

(d) Soil pH

Mean population densities of 1, 080.2, 2, 701.5, 2, 650.5 and 4, 037.6 P. zeae per 10.0 grams of fresh root weight were recovered in maize roots of plants growing in soil with pH ranges of 4.2-4.7, 4.8-5.3, 5.4-5.9 and 6.0-6.8, respectively. The study showed that the fecundity of P. zeae was higher in soil with high soil pH.

(e) Soil nutrients

Communal farms where nutrients (manure, ammonium nitrate or compound D fertilizer) had been applied, especially manure, had a lower population density of P. zeae in 10.0 grams of fresh root weight and this subsequently increased maize yields in the respective fields at the end of the growing season. The research demonstrated that soil nutrients were a major limiting factor in communal area maize production especially in sandy soils infested with high population densities of P. zeae. Therefore, cropping systems that can increase the amount of available soil nutrients and at the same time reduce the population densities of P. zeae in the soil may enhance maize yield optimization in the communal farms. Possible cropping systems may include crop rotation of maize with bean varieties that are tolerant and/or resistant to P. zeae.

4.3.2 Controlled Field and Greenhouse Studies

(a) Overwintering mechanism of P. zeae

A field observation experiment showed that P. zeae vermiform stages in the soil overwintered mainly as third to fourth stage juveniles and mature females and these stages constituted 51.9 and 46.3% of the total population of vermiform stages, respectively. An increase in the population densities of

P. zeae vermiform stages in December appeared to be a result of hatching eggs.

The study also showed that the highest population densities of P. zeae were at depth 0-20 cm but the highest population density was at depth 20-30 cm during the hot and dry months of September and October. The latter confirms the hypothesis that P. zeae migrates to deeper layers to escape adverse soil moisture and temperature conditions in the upper layer during the hot and dry months of the year.

The research also showed that clean fallow for one year can reduce the population density of P. zeae in the soil by up to 87.5%. The P. zeae control which was obtained from clean fallow can be incorporated into integrated pest management with other cultural practices to minimize maize yield reduction caused by P. zeae. The major set-back of clean fallow in communal farms is that most farmers have land resources of limited sizes.

(b) Temporal and spatial distribution of P. zeae and maize roots

The study showed that maize root weight increased with time and 81.0% of the root weight was within a depth of 0-20 cm and 82.8% of the root weight was within a radius of 0-20 cm. The study showed that maize root system was aggregated in the top soil.

The population density of P. zeae also increased with time and had a Pf/Pi ratio of 170. This showed that maize variety R 215 was very susceptible to P. zeae infection and that the edaphic factors in this study were suitable for a rapid multiplication of P. zeae. This study also demonstrated that P. zeae mainly thrived as third to fourth stage juveniles and mature females and these life stages constituted 83.2 and 14.3% of the total population of vermiform stages.

The research also showed that 54.5% of the total population of P. zeae in the roots was within a depth of 0-20 cm. The high population density of P. zeae within a depth of 0-20 cm appears to be dictated by the amount of root tissue within this depth. The population density of P. zeae in the soil was highest at depth 10-20 cm and lowest at depth 0-10 cm. The high population density of P. zeae in the soil at depth 10-20 cm appears to be a function of optimal soil moisture, temperature and root tissue availability at this depth. The low population density of P. zeae in the soil at depth 0-10 cm appears to be a function of adverse soil moisture and temperature at this depth. Data presented in this study also showed that the population density of P. zeae in the soil or roots increased with increasing sampling radius.

The study showed that very large errors (as high as 548.0%) can be encountered if P. zeae sampling in maize roots or soil is not properly timed and carried out at the right depth and distance from the plant. Data presented in this study showed that the optimal time of sampling maize roots for P. zeae population density assessment in loamy sand soil was 4 weeks after planting at depth 10-20 cm and radius of 0-10 cm. The optimal time of sampling soil surrounding maize roots for P. zeae population density assessment was 2 weeks after planting at depth 10-20 cm and radius 10-20 cm.

(c) Influence of soil moisture on P. zeae and maize root system development

A greenhouse study showed that maize root system was adversely impacted at 11.7% gravimetric soil moisture in loamy sand soil but P. zeae population density was only slightly adversely impacted at 5.0% gravimetric soil moisture. The study demonstrated that P. zeae was more tolerant to low soil moisture than maize. This phenomenonappears to account for the higher

pathogenicity of P. zeae on maize during growing seasons with inadequate rainfall.

(d) Influence of soil nutrients on P. zeae and maize growth

This study showed that various combinations of soil nutrients increased maize growth (above and below biomass). The highest maize growth after applying nutrients was attained by applying compound D + ammonium nitrate fertilizer + manure and the lowest maize growth was attained by applying ammonium nitrate fertilizer. This study underlines the importance of applying adequate soil nutrients especially in P. zeae infected maize plants to compensate for the inadequate nutrient and water uptake by infected maize roots.

The population densities of P. zeae in this study did not increase as expected possibly because of sub-optimal temperature conditions. Treatments which included manure application had slightly lower population densities of P. zeae in roots 8 weeks after planting. However, the trend was not maintained 16 weeks after planting and there were no significant differences in the population densities of P. zeae in roots or soil.

4.4 Management of the Pest

Two strategies were evaluated in the management of P. zeae associated with maize production: (a) nematicide control and (b) cultural control.

(a) Nematicide control

Carbofuran, fenamiphos, isazofos and terbufos reduced the population densities of P. zeae in maize roots by 94.81, 95.97, 95.11 and 93.14% and subsequently increased maize yield by 67.41, 54.71, 36.73 and 66.03%, respectively. The research also showed that under sub-optimal moisture conditions, a farmer may not obtain a financial return after applying nematicides to control P. zeae in maize production. This instability in financial

returns is likely to act as a deterrent in the adoption of nematicides by most communal farmers. Also communal farmers are unlikely to adopt use of nematicides in maize production because of socio-economic reasons.

(b) Cultural control

A study to evaluate whether major maize varieties grown in Zimbabwe are resistant to P. zeae infection showed that all the varieties were susceptible to P. zeae infection. It is likely that resistance for P. zeae infection has not been incorporated in the maize breeding programs. However, there is need for this work to be incorporated into future maize breeding programs in order to optimize maize yields in the communal farms.

A greenhouse and a field study on organic amendments in maize production showed that manure can reduce the population density of P. zeae in roots and subsequently increase maize growth and yield. The greenhouse study also demonstrated the importance of timing the application of the manure in order to get optimal P. zeae control and subsequent maize growth. Most communal farmers keep some livestock, therefore, this technology is likely, in part, to assist communal farmers in reducing population densities of P. zeae in maize fields and subsequently increase maize yields.

4.5 SIMULATION MODEL OF THE PEST

A P. zeae simulation model was developed to summarize data from the research and literature review. The P. zeae simulation model was incorporated into an existing CERES-MAIZE simulation model. The P. zeae - maize simulation model predicted the population density of P. zeae in maize roots with a mean error of 7%. The simulation model was sensitive to different initial population densities of P. zeae in the soil and weather data.

The simulation model also predicted the correct silking date of maize variety R 215 and above and below-ground dry biomass with mean errors of 17.7 and 11.1%, respectively. Simulated values of P. zeae pathogenicity on maize and measured values were comparable. This research showed the simulation model could be incorporated in future predictive P. zeae maize yield and crop loss assessments. However, most of the parameters which were predicted using the simulation model requires further validation. Also further development of the simulation model could incorporate management strategies of P. zeae associated with maize.

5. APPENDICES

Appendix 5.1.1. Plant-parasitic nematodes found associated with maize during the 1986/86 national survey of pests and diseases in Zimbabwe.

a. Manicaland Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
I	Holdenby	Peresa	Pratylenchus zeae Graham, 1951	1,566	4
			Scutellonema sp. (juv)	0	3
		Muchena	P. zeae	1,110	184
			Scutellonema sp. (juv)	0	19
		Mutambara	Pratylenchus brachyurus (Godfrey 1929) Filipjev & Stekhoven, 1941	3,620	56
			Helicotylenchus sp. (juv)	28	40
			Scutellonema sp. (juv)	0	10
	Nyamaropa	Mubvuta	P. zeae	555	3
			Scutellonema sp. (juv)	1	15
II	Chiduku	Mukamha	P. zeae	2,510	0
			Rotylenchulus sp. (juv)	0	100
			Helicotylenchus sp. (juv)	7	15
			Scutellonema sp. (juv)	0	13
		Makoni	P. brachyurus	125	0
			Rotylenchulus sp. (juv)	10	115
			Meloidogyne sp. (juv)	15	15
		Samatende	P. zeae	1,250	17
			Rotylenchulus sp. (juv)	0	301
			Scutellonema unum Sher, 1964	0	18
		Tanhuki	P. zeae	1,100	134
			Rotylenchulus sp. (juv)	0	111
			Scutellonema unum	0	18
		Zembe	Pratylenchus sp. (juv)	5	0
			Rotylenchulus sp. (juv)	0	141
			Scutellonema sp. (juv)	0	3
	Mutasa North	Chademwiri	P. zeae	2,286	52
			Helicotylenchus sp. (juv)	0	1
			Scutellonema sp. (juv)	0	1
		Mukwindidza	P. zeae	6,350	0
			Scutellonema sp. (juv)	0	18
	Nyanga	Ndau	Pratylenchus sp. (juv)	10	0
			Helicotylenchus sp. (juv)	1	0
		Kangoni	P. zeae	595	3
			Helicotylenchus sp. (juv)	0	2

a. Manicaland Province, continued.

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
II	Manyika	Masvikeni	P. zeae	11,200	2
			Rotylenchulus parvus (Williams, 1960) Sher, 1961	400	100
			Criconemella sphaerocephala (Taylor, 1936) Luc & Raski, 1981	0	11
			Helicotylenchus sp. (juv)	9	50
			Scutellonema sp. (juv)	23	30
		Mutasa	Pratylenchus goodeyi Sher & Allen, 1953	804	11
			Criconemella sp. (juv)	0	3
			Helicotylenchus sp. (juv)	0	12
			Rotylenchulus sp. (juv)	8	1
			Scutellonema sp. (juv)	0	23
		Nyadore	P. zeae	491	25
			Helicotylenchus sp. (juv)	5	7
			Scutellonema sp. (juv)	5	10
III	Matizi	Mapara	P. zeae	1,870	0
			Scutellonema sp. (juv)	0	25
		Muromo-wenyoka	Pratylenchus sp. (juv)	26	0
			Scutellonema sp. (juv)	0	3
	Mutasa	Haukozi	P. zeae	2,290	5
			Helicotylenchus sp. (juv)	0	5
			Scutellonema sp. (juv)	0	25
		Pfachi	Pratylenchus sp. (juv)	5	0
			Rotylenchulus sp. (juv)	0	23
			Scutellonema sp. (juv)	0	32
	St. Swithins	Makura	Pratylenchus sp. (juv)	306	1
			Helicotylenchus sp. (juv)	0	3
			Scutellonema sp. (juv)	2	2
		Kawundo	P. zeae	1,007	0
			Scutellonema sp. (juv)	1	20
		Satumba	Pratylenchus sp. (juv)	609	0
		Tsikayi	Pratylenchus sp. (juv)	4	0
			Helicotylenchus sp. (juv)	1	5
			Scutellonema sp. (juv)	1	5

a. Manicaland Province, continued.

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
III	Zimunya	Musiyanga	P. zeae	1,165	81
			Helicotylenchus sp. (juv)	0	11
			Scutellonema sp. (juv)	0	4
		Muzarwetu	P. zeae	1,200	0
			Scutellonema brachyurum (Steiner, 1938) Andrassy, 1958	0	51
			Helicotylenchus sp. (juv)	0	7
			Criconemella sp. (juv)	0	3
		Waziweyi	Pratylenchus sp. (juv)	735	8
			Helicotylenchus sp. (juv)	0	58
			C. sphaerocephala	0	3
IV	Chinyauwhera	Hwenzira	P. zeae	5,040	0
			Helicotylenchus sp. (juv)	0	15
			Scutellonema sp. (juv)	0	7
		Musabayana	P. zeae	3,105	108
			Criconemella sp. (juv)	0	3
			S. brachyurum	0	60
		Musona	P. zeae	338	0
			Helicotylenchus sp. (juv)	0	76
			S. brachyurum	0	31
			Criconemella sp. (juv)	0	3
		Musukutwa	P. zeae	1,330	21
			Helicotylenchus sp. (juv)	5	183
			Scutellonema sp. (juv)	0	18
			Criconemella sp. (juv)	0	9
	Marange	Chinoera	P. zeae	2,560	39
			Rotylenchulus sp. (juv)	8	25
			Scutellonema sp. (juv)	0	6
		Jera	P. zeae	1,009	4
			Rotylenchus sp. (juv)	0	71
			Scutellonema sp. (juv)	0	12
			Criconemella sp. (juv)	0	3
		Katsidzira	P. zeae	1,015	11
			Rotylenchulus sp. (juv)	0	170
			Scutellonema sp. (juv)	0	13
			Criconemella sp. (juv)	0	3
		Muzii	P. zeae	201	3
			Rotylenchulus sp. (juv)	11	50
			Scutellonema magniphasmum Sher, 1964	4	43
			Scutellonema unum Sher, 1964	1	29

a. Manicaland Province, continued.

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
IV	Mutambara	Chiremba	P. zeae	246	0
			Helicotylenchus sp. (juv)	0	18
		Mangure	P. zeae	511	0
			Helicotylenchus sp. (juv)	0	5
			Rotylenchulus sp. (juv)	0	15
	Muwushu	Matsikinyire	P. brachyurus	1,311	62
			S. magniphasmum	10	72
			Criconemella sp. (juv)	0	8
			Helicotylenchus sp. (juv)	0	56
		Muzvuzvu	Criconemella sp. (juv)	0	2
			Meloidogyne sp. (juv)	2	0
			Scutellonema sp. (juv)	0	2
	Ndowoyo	Makumbe	Hoplolaimus sp.	1,113	78
			S. unum	0	6
	Nyanga North	Mavungire (1)	P. zeae and P. brachyurus	731	0
			S. unum	0	6
			Helicotylenchus sp. (juv)	0	1
		Mavungire (2)	P. zeae and P. brachyurus	465	0
			S. unum	0	5
	Sabi	Kanda	Pratylenchus sp. (juv)	40	0
			Rotylenchulus sp. (juv)	0	62
			S. unum	0	70
		Makure	P. zeae	15,210	214
			Helicotylenchus sp. (juv)	0	28
			Scutellonema sp. (juv)	5	14
		Shonhiwa	P. zeae	150	0
			R. parvus	0	205
			S. unum	0	52
	Tanda	Dzikiti	P. zeae	1,880	0
			Meloidogyne sp. (juv)	55	0
		Murienge	P. zeae	2,145	0
			Helicotylenchus sp. (juv)	0	21
			Rotylenchulus sp. (juv)	0	9
			Scutellonema sp. (juv)	0	11

b. Mashonaland East Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm^3 soil
II	Chinamora	Gotora	P. zeae	114	0
			Helicotylenchus sp. (juv)	0	4
			Scutellonema sp. (juv)	0	2
		Mazvirongwa	Pratylenchus sp. (juv)	47	6
			Scutellonema sp. (juv)	0	32
			Tylenchorynchus sp. (juv)	0	3
		Shongedza (1)	P. zeae	502	0
			Meloidogyne sp. (juv)	10	0
			Scutellonema sp. (juv)	0	4
		Shongedza (2)	P. zeae	561	0
			Helicotylenchus sp. (juv)	0	5
			Scutellonema sp. (juv)	0	7
	Chiota	Chakadona	P. brachyurus	710	10
			R. parvus	165	45
			Scutellonema sp. (juv)	0	30
		Munemo	P. brachyurus	5,362	147
			R. parvus	42	30
			Scutellonema sp.	0	21
			Trichodorus sp. (juv)	0	49
	Kunzwi	Mutero	P. zeae	14,805	0
			Rotylenchulus sp. (juv)	5	140
		Muzawazi	P. brachyurus	3,647	14
			Rotylenchulus sp. (juv)	26	221
		Zambezi	P. brachyurus and P. zeae	5,900	0
			Scutellonema sp. (juv)	0	21
	Mangwende	Kamundirira	P. brachyurus	380	0
			S. unum	0	172
		Nhende	P. brachyurus	1,570	0
			Criconemella sp. (juv)	0	44
			S. unum	0	256
			Trichodorus sp. (juv)	0	44
IV	Chimanda	Makasa	P. zeae	1,920	55
			Helicotylenchus sp. (juv)	0	11
			Scutellonema sp. (juv)	0	13
	Maramba	Chibanda	P. brachyurus	12,660	30
			Criconemella sp. (juv)	0	31
			Helicotylenchus sp. (juv)	0	10
			R. parvus	20	165
			S. unum	0	90
		Hukuimwe	Pratylenchus sp. (juv)	180	0
			Helicotylenchus sp. (juv)	0	3
			Scutellonema sp. (juv)	0	9
		Muchaparara	P. zeae	1,603	36
			Scutellonema labiatum Siddiqi, 1972 and S. magniphasmum	0	48
			Trichodorus sp. (juv)	0	3
	Mkota	Chingaubare	P. zeae	1,045	20
			Rotylenchulus sp. (juv)	5	5
			Scutellonema sp. (juv)	0	25

c. Mashonaland Central Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm³ soil
II	Bushu	Chinyangiwe	P. zeae	4,001	0
			Helicotylenchus sp. (juv)	0	56
			Scutellonema sp. (juv)	0	3
III		Mutiwekuziva	Pratylenchus sp. cf goodeyi Sher & Allen, 1953	846	0
			Criconemella sp. (juv)	0	4
			Helicotylenchus sp. (juv)	0	13
			Scutellonema sp. (juv)	0	113

d. Mashonaland West Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm³ soil
II	Hurungwe Zvimba	Masamba Mereki	Scutellonema sp. (juv)	0	286
			P. zeae	46,130	125
			Rotylenchus cf. brevicaudatus Colbran, 1970	0	340
			Criconemella sp. (juv)	0	4
		Neushe	P. brachyurus	13,650	55
			Meloidogyne sp. (juv)	30	20
			Rotylenchulus sp. (juv)	0	165
		Sakanda	P. brachyurus	3,150	40
			Meloidogyne sp. (juv)	50	75
			Scutellonema sp. (juv)	0	30
III	Umfuli	Jenga	Pratylenchus sp. (juv)	10	0
			Tylenchorhynchus sp. (juv)	0	2
		Kasenga	Pratylenchus sp. (juv)	4	0
IV	Omay	Masham-bakaru	Pratylenchus sp. (juv)	7	0
			Helicotylenchus sp. (juv)	0	26
			S. unum	0	27

e. Masvingo Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
III	Serima	Bere	P. brachyurus	1,360	18
			R. parvus	45	75
		Kwashira	P. brachyurus	1,680	12
			R. parvus	34	132
			Trichodorus sp. (juv)	0	12
		Varibo	P. brachyurus	2,555	85
			R. parvus	55	252
IV	Gutu	Chinyaure	P zeae	13,520	85
			R. parvus	15	30
			S. unum	0	10
		Mangezi	P. zeae	1,330	145
			R. parvus	42	100
		Nyamande	P. zeae	3,700	10
			R. parvus	220	250
			S. unum	0	11
	Nyajena	Mangwadi	P. zeae	2,250	0
			R. parvus	16	80
			S. unum	0	8
			Criconemella sp. (juv)	0	12
			Trichodorus sp. (juv)	0	4
		Mutsikwa	P. zeae	20	0
			R. parvus	27	30
			S. unum	0	52
			Meloidogyne sp. (juv)	40	0
V	Matibi 2	Dzviriri	Rotylenchulus sp. (juv)	5	125

f. Midlands Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm^3 soil
III	Chiwundura	Khumalo	Aphelenchus avenae Bastian, 1865	13,310	5
			Criconemella sp. (juv)	0	3
			Scutellonema sp. (juv)	0	25
	Ngezi	Kureva	P. brachyurus	5,280	20
			Paratrichodorus minor (Colbran, 1956) Siddiqi, 1974	0	600
		Mupanda-wana	P. brachyurus	5,320	0
			P. minor	0	196
			R. parvus	36	106
		Midzi	P. brachyurus	14,840	63
			P. minor	1	161
	Sanyati	Dhiwiera	P. brachyurus and P. zeae	15,940	220
			Scutellonema sp. (juv)	0	35
		Mandaka	P. brachyurus	7,100	50
			Scutellonema sp. (juv)	0	10
		Nhendere	P. brachyurus	6,650	38
IV	Mberengwa	Dube	Helicotylenchus sp. (juv)	0	4
			Scutellonema sp. (juv)	0	28
		Mawela	R. parvus	20	86
			Scutellonema sp. (juv)	0	60
		Sama	P. zeae	170	0
			Rotylenchulus sp. (juv)	30	204
			Scutellonema sp. (juv)	0	24
		Tshuma	P. zeae	260	0
	Gokwe	Bhora	Pratylenchus sp. (juv)	2	0
			Rotylenchulus sp. (juv)	0	61
			Scutellonema sp. (juv)	0	2
		Mhazo	Pratylenchus sp. (juv)	9	0
V	Mazvihwa	Tshuma	P. zeae	340	0
			Rotylenchulus sp. (juv)	16	125

g. Matebeleland North Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
III	Mzola	Ncube	P. zeae	720	20
			R. brevicaudatus	0	10
			Scutellonema sp. (juv)	0	35
IV	Lupane	Silandu	P. zeae	1,940	130
			R. parvus	45	110
			Scutellonema sp. (juv)	0	15
	Nkai	Sipepa	Rotylenchulus sp. (juv)	20	270
		M'nongo	P. zeae	1,226	0
			R. parvus	42	130
			Scutellonema sp. (juv)	0	24
		Moyo	P. zeae	250	0
		Nkomo	Pratylenchus sp. (juv)	18	8
	Ntabazin-duna		Scutellonema sp. (juv)	0	18
		Majelimana	P. zeae	1,300	1
			Helicotylenchus sp. (juv)	10	20
			Rotylenchulus sp. (juv)	0	24
			Scutellonema sp. (juv)	4	10
		Ncube	Aphelenchus sp. (juv)	78	0
			Criconemella sp. (juv)	0	9
			Rotylenchulus sp. (juv)	0	83
		Ndhlovu	P. zeae	200	0
			Rotylenchulus sp. (juv)	10	712
		Sithubeni	Pratylenchus sp. (juv)	158	0
			Helicotylenchus sp. (juv)	0	8
			Rotylenchulus sp. (juv)	9	200
			Scutellonema sp. (juv)	0	3

h. Matebeleland South Province

Natural Region	Communal Area	Farmer's Name	Nematode found associated with maize	No./10.0 grams roots	No./ 100 cm3 soil
IV	Godlwayo	Manasa	Pratylenchus sp. (juv)	41	0
			Criconemella sp. (juv)	0	2
			Rotylenchulus sp. (juv)	0	29
			Scutellonema sp. (juv)	0	12
		Ncube	Pratylenchus sp. (juv)	114	10
			Criconemella sp. (juv)	0	3
			Rotylenchulus sp. (juv)	4	15
			Scutellonema sp. (juv)	0	8
			Tylenchorhynchus sp.	0	8
		Sibanda	P. zeae	2,115	14
			Helicotylenchus sp. (juv)	0	4
			Meloidogyne sp. (juv)	20	0
			Scutellonema sp. (juv)	0	9
	Mpande	Magama	P. zeae	3,806	263
			Helicotylenchus sp. (juv)	0	254
			Rotylenchulus sp. (juv)	16	250
			Scutellonema sp. (juv)	0	16
		Mpofu	Aphelenchoides sp. (juv)	0	42
			Pratylenchus sp. (juv)	2	0
	Nswazi	Madhuma	Rotylenchulus sp. (juv)	0	276
			S. unum	0	20
		Tshuma	P. zeae	200	0
			R. parvus	10	764
			Scutellonema sp. (juv)	0	2
V	Gwaran-yemba	Chithe	Pratylenchus sp. (juv)	16	0
			Helicotylenchus sp. (juv)	0	39
		Dzingai	Criconemella sp. (juv)	0	9
			Helicotylenchus sp. (juv)	1	4
			Pratylenchus sp. (juv)	14	0
			Scutellonema sp. (juv)	0	14
			Tylenchorhynchus sp. (juv)	0	1
	Mphoenghs	Moyo	Pratylenchus sp. (juv)	198	0
			Rotylenchulus sp. (juv)	0	64

Appendix 5.1.2. Results for parameters which were assessed during 1985/86 maize surveys in Manicaland Province.

Natural Region	Communal Area	Farmer's Name	Soil Texture	Soil pH	Maize Yield Estimate	Actual Yield	Pratylenchus spp. 10.0 g roots	Manure	Compound D Fertilizer	Ammonium Nitrate	Farm Size (Ha)	Family Size	Self Sufficient
I	Holdenby	Peresa	Sandy loam	4.3	0.45	0.90	1,566	No	No	No	1.0	12	No
		Muchena	Sandy loam	4.7	2.52	2.88	1,110	Yes	No	Yes	1.4	5	Yes
		Mutambara	Sandy loam	4.2	0.72	0.90	3,620	No	No	No	1.2	3	Yes
	Nyamaropa	Mubvuta	Loamy sand	4.6	6.75	7.76	550	No	Yes	No	3.0	7	Yes
II	Chiduku	Mukamba	Sand	4.9	0.45	1.41	2,510	No	Yes	Yes	2.4	7	Yes
		Makoni	Sand	5.2	2.64	3.38	125	Yes	Yes	Yes	2.4	10	Yes
		Zembe	Loamy sand	6.5	3.15	3.86	5	No	No	Yes	3.6	10	Yes
		Samatende	Sand	—	0.72	—	1,250	No	Yes	Yes	1.8	—	Yes
		Tanhuki	Sand	—	0.27	—	1,100	No	No	No	1.2	—	No
	Mutasa North	Chademwiri	Sandy loam	5.5	1.80	2.24	2,286	No	Yes	Yes	5.0	12	Yes
		Mukwindidza	Sand	4.9	1.62	1.23	6,350	No	Yes	Yes	4.8	6	Yes
	Nyanga	Ndou	Sand	4.4	2.25	3.00	10	No	Yes	Yes	3.6	10	Yes
		Kangoni	Sand	—	0.90	1.10	595	No	Yes	No	1.0	14	No
	Manyika	Masvikeni	Loamy sand	5.8	2.23	2.81	11,200	No	No	Yes	2.4	3	Yes
		Mautsa	Sand		2.35	3.60	804	No	Yes	Yes	3.6	7	Yes
		Nyadore	Sandy loam	5.7	1.85	2.25	941	Yes	No	Yes	2.0	7	Yes
III	Matizi	Mapara	Loamy sand	—	2.25	—	1,870	No	Yes	Yes	1.4	—	Yes
		Muromowenyoka	Sand	—	1.35	—	26	No	Yes	No	2.8	—	Yes
	Mutasa South	Haukozi	Sandy clay loam	4.6	0.92	1.35	2,290	No	Yes	Yes	4.0	11	Yes
		Pfachi	Loamy sand	5.5	1.44	2.70	5	Yes	No	Yes	2.4	8	Yes
	St. Swithins	Makura	Sand	6.6	0.90	1.97	306	No	No	No	3.6	5	Yes
		Kawando	Sand	6.0	0.94	1.08	1,007	No	Yes	Yes	2.3	10	Yes
		Satumba	Sand	—	0.45	—	609	No	No	No	0.6	7	No
		Tsikayi	Sandy loam	5.7	0.81	0.90	1	No	Yes	Yes	1.6	9	Yes
	Zimunya	Musiyanga	Sand	5.2	0.45	—	1,165	No	Yes	Yes	6.0	15	Yes
		Muzaruwetu	Loamy sand	5.5	0.45	1.13	1,200	No	No	No	2.0	6	Yes
		Wazwegu	Sandy clay loam	4.4	1.80	2.70	735	Yes	Yes	Yes	1.0	5	Yes
IV	Chinyauwhera	Hwenzwa	Sand	5.2	0.28	0.45	5,050	No	No	No	2.0	11	No
		Musabayana	Sand	6.4	0.18	0.28	3,105	No	No	No	5.0	4	Yes
		Musona	Sand	6.1	1.76	2.70	338	No	Yes	Yes	3.6	5	Yes
		Musukutwa	Sand	6.6	0.45	1.35	1,330	Yes	No	Yes	2.4	6	Yes
	Marange	Chinoera	Sand	—	0.64	1.13	2,560	No	No	No	1.6	4	Yes
		Jera	Sand	5.3	0.73	3.38	1,009	Yes	No	No	6.4	7	Yes
		Katsidzira	Sand	6.8	1.88	3.96	1,015	Yes	No	Yes	1.6	4	Yes
		Muzvi	Sand	—	0.45	2.70	201	No	No	No	3.2	5	Yes
	Mutambara	Chiremba	Sand	—	1.49	—	246	No	No	No	1.2	—	Yes
		Mangure	Sand	—	1.13	—	511	No	Yes	No	1.0	—	Yes
	Muwushu	Matsikinyire	Sand loam	—	2.25	—	1,311	No	Yes	Yes	4.0	—	Yes
	Nyanga North	Mavungire	Sand	4.2	0.54	0.90	731	No	No	No	3.5	6	Yes
	Sabi	Kanda	Sand	4.2	4.32	5.31	40	Yes	Yes	Yes	2.4	5	Yes
		Makure	Sand	6.6	0.72	0.54	15,210	No	No	Yes	1.2	3	No
		Shonwe	Sand	4.4	2.25	2.48	150	Yes	Yes	Yes	3.2	5	Yes
	Tanda	Dzikiri	Sand	-	5.15	—	1,880	Yes	Yes	Yes	2.0	—	Yes
		Marenge	Sand	-	1.35	—	2,145	No	Yes	Yes	1.0	—	Yes

Appendix 5.1.3. Monthly rainfall during the 1985/86 national survey of pests and diseases in Zimbabwe.

Communal Area	Sites	Monthly rainfall (mm) season 1985/86								
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Year
Nyanga North	Mavhungire	0	4.1	142.9	215.3	280.3	140.5	67.8	15.0	865.9
Nyanga	Kangoni	2.5	75.4	135.4	289.3	491.8	250.9	118.5	42.7	1416.5
Nyamaropa	Mubvuta	0	36.9	153.4	364.5	455.1	100.3	52.3	57.8	1220.3
Matizi	Marapa	0	4.5	78.0	354.7	133.8	130.0	41.5	0	742.5
Tanda	Dzikiti	0	9.0	63.0	252.5	314.0	50.0	43.5	49.0	781.0
Mutasa North	Mukwindiza	1.5	32.5	110.0	171.0	481.8	161.0	107.0	104.5	1197.8
Holdenby	Mutambara	42.2	70.4	198.7	464.2	1024.0	326.8	163.0	240.3	2597.7
Mutasa South	Pfachi	2.5	33.0	44.5	211.3	241.5	50.7	35.0	33.0	652.6
Mutasa South	Haukozi	0	0	176.0	116.0	246.3	134.3	184.0	109.0	976.6
Manyika	Masvikeni	14.4	58.1	62.4	197.3	307.2	121.1	93.5	62.6	936.6
Chinyauwhera	Hwenzira	6.5	53.2	171.3	76.0	309.5	162.0	98.12	56.5	968.2
Zimunya	Muzaruwetu	34.0	86.3	122.7	114.5	260.5	28.2	186.1	68.8	900.9
Marange South	Chimoera	3.0	39.4	85.5	156.0	125.0	68.8	60.2	77.9	615.8
Marange North	Katsidzira	0	22.5	72.0	82.6	245.1	95.0	51.0	49.0	629.1
Mutambara	Mangure	4.0	28.0	80.5	143.0	241.5	77.9	49.0	135.7	676.2
Mutema	Mtisi	34.0	57.2	49.0	109.6	134.3	60.9	85.8	156.8	687.6
Sabi North	Makure	10.0	37.3	22.0	204.5	231.8	157.0	96.0	140.5	911.1
Chiduku	Tanhuki	13.0	30.4	68.7	182.3	160.5	97.0	79.3	5.5	636.7
Chiduku	Makoni	15.1	39.4	546.7	240.7	209.8	189.6	148.8	93.8	993.9
Zvimba	Mereki	0	23.0	9.0	143.9	214.0	171.2	54.5	98.5	714.1
Umfuli	Jenga	0	0	74.5	303.5	209.4	272.5	143.0	108.5	1111.4
Hurungwe North	Masamba	0	25.0	56.4	195.4	117.4	157.2	92.1	167.8	811.2
Kandeya	Mutiwekuziva	0	2.3	27.3	268.6	266.5	171.8	19.4	88.9	844.8
Bushu	Chinyangwe	0	5.0	76.5	349.5	234.5	119.0	62.5	103.4	950.4
Chinamora	Gotora	0	22.3	58.1	327.8	556.6	284.9	77.2	151.2	1496.8
Chinamora	Shongedza	1.5	19.0	34.4	233.5	396.0	184.1	73.0	98.5	1047.6
Chiota	Munemo	1.8	30.4	79.9	232.4	382.3	191.9	97.6	106.2	1122.5
Kunzwi	Mutero	0	22.5	40.5	383.0	284.3	145.5	74.0	86.5	950.4
Mangwende	Kumundirira	0	13.1	41.4	262.8	262.2	174.2	88.5	118.5	960.7
Chimanda	Makasa	0	0	37.3	282.3	241.5	171.0	24.5	89.8	846.4
Gutu	Chinyaure	18.0	19.1	27.5	141.5	116.5	124.5	72.5	78.0	600.6
Nyajena	Mangwadi	22.5	59.8	30.3	121.5	90.7	96.5	80.4	76.4	578.1
Matibi 2	Dzviriri	36.1	1.7	52.5	1.5	45.0	23.0	28.6	55.5	316.3
Chiwundura	Khumalo	2.5	6.5	26.4	309.2	120.8	32.6	35.0	94.2	627.3
Ngezi	Mupandawana	9.0	9.4	7.0	234.5	31.5	30.0	73.5	118.0	520.1
Sanyati	Dhiwiera	0	0	23.0	241.0	206.0	179.0	96.0	167.0	912.0
Belingwe	Sama	117.0	22.0	1.0	89.0	352.0	112.0	128.5	222.5	1098.5
Gokwe	Bhora	0	0.5	2.5	161.0	206.5	172.0	108.5	222.0	878.0
Mazvihwa	Tshuma	4.3	13.0	48.0	139.9	112.4	41.7	45.8	131.6	543.8
Mzola	Ncube	9.4	7.0	234.5	31.5	30.0	73.5	118.0	7.0	520.1
Lupane	Silandu	0	0	47.0	157.0	96.0	10.9	26.0	13.2	350.1
Nkayi	M'nongo	0	24.0	0	177.9	60.2	52.7	93.5	106.5	514.8
Ntabazinduna	Majelimana	0.6	8.7	22.2	139.9	52.7	36.4	35.5	180.6	496.2
Godlwayo	Sibanda	7.0	22.0	41.0	89.0	69.0	42.0	158.5	122.8	561.3
Mpande	Magama	0.1	27.0	4.5	136.8	46.4	68.8	60.0	151.3	520.9
Nswazi	Tshuma	6.1	46.7	50.1	118.2	57.0	31.8	41.1	153.6	523.3
Gwaranyemba	Dzingai	10.1	25.4	9.9	83.4	52.2	13.6	67.9	94.4	369.9
Mphoenghs	Moyo	92.9	58.6	23.3	26.7	37.4	34.9	14.3	119.3	430.8

Appendix 5.1.4. Average monthly maximum and minimum temperature during the 1985/86 national survey of pests and diseases in Zimbabwe.

Communal Area	Maximum and Minimum Temperatures (°C)											
	November 1985		December 1985		January 1986		February 1986		March 1986		April 1986	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Mtetengwe	32.6	19.1	33.7	17.6	33.7	21.9	34.4	21.5	34.8	20.9	30.3	18.5
Matibi No. 2	32.6	19.1	33.7	17.6	33.7	21.9	34.4	21.5	34.8	20.9	30.3	18.5
Maranda	32.6	19.1	33.7	17.6	33.7	21.9	34.4	21.5	34.8	20.9	30.3	18.5
Ndowoyo	32.2	18.8	32.4	20.3	30.7	20.5	32.5	20.5	33.1	18.9	29.5	17.7
Sabi	28.3	14.6	27.3	16.3	26.8	16.4	27.5	15.2	27.1	14.0	25.1	13.7
Ntabazinduna	29.9	15.6	27.8	17.2	27.8	17.1	28.7	16.6	29.0	16.2	25.2	14.5
Zvimba	29.0	14.8	26.7	17.0	26.3	16.0	27.2	14.7	27.3	13.6	25.7	13.2
Mutema	32.3	18.5	31.8	19.9	30.3	19.6	31.3	19.2	31.8	17.5	29.0	17.2
Muwushu	32.3	18.5	31.8	19.9	30.3	19.6	31.3	19.2	31.8	17.5	29.0	17.2
Ngezi	28.1	13.8	25.9	15.8	26.2	15.6	25.9	14.6	26.8	13.7	24.5	13.6
Gokwe	30.0	17.0	26.8	17.0	26.1	17.1	26.3	16.5	26.7	16.1	24.6	14.8
Guruve	28.8	17.0	26.1	17.9	25.8	17.4	26.1	17.1	26.7	16.4	25.5	15.0
Chiwundura	28.4	13.1	26.1	15.5	25.4	15.1	26.3	14.3	26.4	13.2	23.8	12.8
Hwange	32.8	18.0	29.8	18.8	28.9	18.2	28.9	17.3	28.9	16.7	27.0	14.0
Sanyati	30.9	16.9	28.0	18.0	27.3	17.5	28.2	16.7	28.6	15.8	26.6	15.1
Omay	33.9	23.0	31.1	22.6	30.5	21.6	30.5	21.3	31.3	20.8	29.2	19.1
Hurungwe	26.9	15.9	24.9	17.1	24.9	16.7	25.2	16.7	25.9	15.8	23.9	14.4
Gutu	28.2	14.7	27.4	16.8	26.7	16.6	27.7	15.9	27.8	15.0	25.0	14.1
Kunzwi	24.7	12.8	23.7	15.0	23.1	14.6	24.2	14.1	24.1	13.0	22.2	12.8
Nswazi	29.2	14.6	27.9	16.3	27.6	15.9	28.4	15.0	28.9	14.2	24.5	13.0
Kandeya	30.9	17.9	27.4	18.8	27.0	18.7	27.8	18.3	28.2	17.1	27.0	15.8
Mtoko	27.2	16.3	25.5	17.3	25.7	17.1	26.2	17.0	26.7	16.1	25.7	15.1
Chiweshe	25.9	14.2	23.9	15.7	24.3	15.5	24.6	15.4	25.2	14.9	23.4	13.6
Nyanga	21.2	11.5	20.7	12.7	20.9	13.2	20.8	12.7	21.2	11.9	20.2	11.1
Mpande	29.9	16.2	28.0	17.1	28.2	16.8	26.6	16.6	29.1	16.1	24.6	14.2
Chiduku	25.6	13.3	24.9	15.7	24.2	15.0	25.0	14.2	24.7	13.3	23.6	13.0
Chiota	26.5	14.4	25.7	16.2	24.9	16.0	25.0	15.2	25.7	14.4	24.3	14.0
Gwaranyemba	32.1	16.9	31.2	18.9	30.2	18.5	32.5	18.7	32.4	17.4	27.3	15.5
Nyajena	29.7	17.2	29.4	18.9	27.8	19.0	29.2	18.6	29.9	17.4	27.3	16.1
Mberengwa	30.7	17.2	29.7	18.7	28.2	18.4	29.6	18.1	30.6	16.8	26.1	15.5
Zimunya	26.4	15.7	26.0	17.0	25.7	17.3	27.4	17.0	26.4	15.4	25.0	15.5
Chinyauhwera	26.4	15.7	26.0	17.0	25.7	17.3	27.4	17.0	26.4	15.4	25.0	15.5
Chinamora	28.5	13.4	25.8	16.5	26.0	16.0	26.6	15.3	27.1	13.6	25.2	12.5
Bushu	31.1	17.3	27.7	18.9	28.0	18.5	28.6	18.4	28.8	17.1	27.6	15.1
Mzola	33.0	17.4	29.8	17.0	28.2	16.5	28.6	16.0	29.0	15.4	27.2	14.1
Goldwayo	30.5	14.2	28.9	17.5	28.3	16.9	30.1	16.5	30.0	15.2	25.6	14.4

Appendix 5.1.5. Influence of rainfall on the population density of P. zeae recovered from maize roots during the national survey of pests and diseases.

Annual rainfall (mm)		P. zeae / 10.0 grams roots	
		Transformed[1]	Detransformed
> 1000	(n = 15)	6.10	445.85
800-1000	(n = 21)	6.82	915.99
600-799	(n = 10)	6.58	720.53
400-599	(n = 8)	6.87	962.95
< 400	(n = 3)	3.40	30.06
SE		2.759	
CV %		46.50	
F ratio		1.228 ns	
Contrasts		**F ratio**	
> 1000 vs 800 - 1000 mm		9.76 **	
> 1000 vs 600 - 799 mm		3.47 ns	
800 - 1000 vs 400-599 mm		35.29 ns	
600-799 vs < 400 mm		128.66 **	
400-599 vs < 400 mm		143.00 **	

Key

[1]Logarithmic transformation ($y = \log_e x$)
* = significance level (P = 0.05)
** = significance level (P = 0.01)
ns = not significant (P > 0.05)

Appendix 5.1.6. Influence of February temperature on the population density of P. zeae recovered from maize roots during the national survey of pests and diseases.

Average temperature (°C) in February, 1986		P. zeae /10.0 grams roots	
		Transformed	Detransformed
> 32.5	(n = 1)	0.00	0.00
30.0-32.5	(n = 3)	3.44	31.19
27.5-29.9	(n = 17)	5.76	317.34
25.0-27.4	(n = 14)	6.21	497.70
22.5-24.9	(n = 2)	8.83	6,836.28
20.0-22.4	(n = 1)	4.39	80.64
SE		3.002	
CV %		53.00	
F ratio		2.648 ns	
Contrasts of Feb. temperature groupings		**F ratio**	
20.0-22.4	vs 22.5-24.9°C	6.960 *	
25.0-27.4	vs 27.5-29.9°C	9.063 **	
27.5-29.9	vs 30.0-32.5°C	33.185 **	
30.0-32.5	vs >32.5°C	10.283 **	
20.0-22.4	vs >32.5°C	2.850 ns	

Key

[1]Logarithmic transformation ($y = \log_e x$)
* = significance level (P = 0.05)
** = significance level (P = 0.01)
ns = not significant (P > 0.05)

Appendix 5.1.7. Influence of March temperature on the population density of P. zeae recovered from maize roots during the national survey of pests and diseases.

Average temperature (°C)		P. zeae / 10.0 grams roots	
		Transformed[1]	Detransformed
> 32.5	(n = 1)	0.00	0.00
30.0-32.5	(n = 7)	3.44	31.19
27.5-29.9	(n = 12)	5.76	317.34
25.0-27.4	(n = 11)	6.30	544.57
22.5-24.9	(n = 5)	6.88	972.62
20.0-22.4	(n = 1)	4.39	80.64
SE		3.046	
CV %		53.70	
F ratio		2.211 ns	
Contrasts of March temperature groupings		**F ratio**	
20.0-22.4	vs 22.5-24.9°C	23.05 **	
25.0-27.4	vs 27.5-29.9°C	3.09 ns	
27.5-29.9	vs 30.0-32.5°C	32.22 **	
30.0-32.5	vs > 32.5°C	9.89 **	
20.0-22.4	vs > 32.5°C	2.77 ns	

Key

[1]Logarithmic transformation ($y = \log_e x$)
* = significance level (P = 0.05)
** = significance level (P = 0.01)
ns = not significant (P > 0.05)

Appendix 5.1.8. Influence of soil texture on the population density of P. zeae associated with maize in Manicaland province.

Soil Texture		P. zeae / 10.0 grams roots	
		Transformed[1]	Detransformed
Sandy clay loam	(n = 2)	7.17	1299.84
Sandy loam	(n = 7)	6.43	620.17
Loamy sand	(n = 5)	5.26	192.48
Sand	(n = 30)	6.55	699.24
SE		1.995	
CV %		31.11	
F ratio		0.698 ns	
Contrasts		**F ratio**	
Sand vs sandy clay loam		25.958 **	
Sand vs loamy sand		7.329 **	
Loamy sand vs sandy loam		707.814 **	
Sandy loam vs sandy clay loam		260.440 **	

Key

[1]Logarithmic transformation ($y = \log_e x$)
* = significance level (P = 0.05)
** = significance level (P = 0.01)
ns = not significant (P > 0.05)

Appendix 5.1.9. Influence of soil pH on the population density of P. zeae associated with maize in Manicaland province.

Soil pH	P. zeae /10.0 grams roots	
	Transformed[1]	Detransformed
4.2-4.7 (n = 11)	6.12	454.86
4.8-5.3 (n = 6)	7.32	1,510.20
5.4-5.9 (n = 7)	5.74	311.74
6.0-6.8 (n = 10)	6.52	678.58
SE	2.177	
CV %	34.20	
F ratio	0.642 ns	
Contrasts of soil pH groupings	**F ratio**	
4.2-4.7 vs 4.8-5.3	6.798 *	
4.2-4.7 vs 6.0-6.8	0.033 ns	
4.8-5.3 vs 5.4-5.9	0.227 ns	
5.4-5.9 vs 6.0-6.8	7.972 **	

Key

[1]Logarithmic transformation ($y = \log_e x$)
* = significance level (P = 0.05)
** = significance level (P = 0.01)
ns = not significant (P > 0.05)

Appendix 5.1.10. Influence of manure, ammonium nitrate and compound D fertilizer on the population density of P. zeae associated with maize on Manicaland province.

Nutrient		P. zeae / 10.0 grams roots	
		Transformed[1]	Detransformed
+ Manure	(n = 10)	5.38	217.02
– Manure	(n = 24)	6.78	880.06
SE		2.07	
CV %		32.50	
F ratio		3.24*	
+ Ammonium nitrate	(n = 22)	6.01	407.48
– Ammonium nitrate	(n = 12)	7.03	1,130.03
SE		2.12	
CV %		33.20	
F ratio		1.77ns	
+ Compound D	(n = 16)	5.91	368.71
– Compound D	(n = 18)	6.68	880.06
SE		2.13	
CV %		33.40	
F ratio		1.44ns	

Key

[1]Logarithmic transformation ($y = \log_e x$)
ns = not significant (P > 0.1)
* = significance level (P = 0.1)

Appendix 5.1.11. Relationships observed between manure, ammonium nitrate and compound D fertilizer and maize yield in Manicaland province.

Nutrients		P. zeae/ 10.0 grams roots	
		Transformed[1]	Detransformed
+ Manure	(n = 10)	1.375	2.955
– Manure	(n = 24)	0.946	1.575
SE		0.400	
CV %		37.300	
F ratio		8.118**	
+ Ammonium nitrate	(n = 22)	1.164	2.203
– Ammonium nitrate	(n = 12)	0.094	1.450
SE		0.429	
CV %		40.000	
F ratio		2.868 ns	
+ Compound D	(n = 16)	1.180	2.254
– Compound D	(n = 18)	0.977	1.656
SE		0.436	
CV %		40.600	
F ratio		1.846 ns	

Key

[1]Logarithmic transformation ($y = \log_e x + 1$)
** = significance level (P >0.05)
ns = not significant (P = 0.01)

Appendix 5.1.12. Relationships observed between population densities of P. zeae and maize yield in Manicaland province.

P. zeae / 10.0 grams roots		Maize yield (tons/ha)	
		Transformed[1]	Detransformed
<1000	(n = 16)	1.297	2.659
>1000	(n = 18)	0.872	1.392
SE		0.391	
CV %		36.5000	
LSD 0.05		0.274	
LSD 0.01		0.406	
F ratio		9.978**	

Key

[1]Logarithmic transformation ($y = \log_e x + 1$)

** = significance level (P = 0.01)

Appendix 5.2.1. Temporal and spatial distribution of P. zeae under clean fallow in Chinamora communal area.

Sampling date	Sampling depth (cm)	P. zeae stages			Gravimetric soil moisture
		J_2	J_3-J_4	Adult	
7/21/86	0-10	1	24	23	0.56
	10-20	0	19	10	2.72
	20-30	1	3	2	5.23
	30-40	0	2	1	6.39
	40-50	0	0	0	9.47
8/14/86	0-10	1	22	44	2.10
	10-20	1	12	7	3.60
	20-30	1	3	4	3.70
	30-40	0	0	1	7.60
	40-50	0	0	0	9.30
9/11/86	0-10	0	6	2	1.89
	10-20	0	4	2	3.21
	20-30	0	20	1	4.32
	30-40	0	13	5	5.34
	40-50	0	0	0	7.84
10/30/86	0-10	0	2	6	1.53
	10-20	0	4	0	2.94
	20-30	0	20	1	4.61
	30-40	0	0	0	5.81
	40-50	0	0	0	7.98
11/6/86	0-10	0	10	2	1.10
	10-20	0	0	2	2.46
	20-30	0	0	0	3.85
	30-40	0	0	0	5.04
	40-50	0	0	0	7.11
12/30/86	0-10	3	6	41	1.50
	10-20	0	0	4	4.52
	20-30	0	0	2	4.30
	30-40	0	8	7	7.41
	40-50	0	1	0	9.04
2/28/87	0-10	0	0	1	3.00
	10-20	0	0	1	2.84
	20-30	0	0	0	3.36
	30-40	0	0	0	5.90
	40-50	0	0	0	12.46
3/27/87	0-10	0	2	0	8.28
	10-20	0	1	6	6.51
	20-30	0	1	0	10.50
	30-40	0	0	0	8.31
	40-50	0	0	0	12.50
4/24/87	0-10	0	3	1	0.10
	10-20	0	1	3	1.16
	20-30	0	1	2	1.87
	30-40	0	8	7	2.98
	40-50	0	1	0	3.94
6/1/87	0-10	0	4	2	2.62
	10-20	0	1	1	3.00
	20-30	0	1	0	2.24
	30-40	0	0	0	5.92
	40-50	0	0	0	5.63

Appendix 5.2.2. Influence of the time of sampling on the population density of Pratylenchus zeae recovered from 100 cm^3 of soil in Chinamora Communal area.

Parameters Sampling date	P. zeae stages							
	J_2		J_3-J_4		Mature		Total	
	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans
7/21/86	0.914[2]	0.335	2.70	6.79	2.32	4.88	3.50	11.75
8/14/86	1.018	0.536	2.31	4.84	2.69	6.74	3.52	11.89
9/11/86	0.707	0.000	2.72	6.90	1.49	1.72	3.02	8.62
10/30/86	0.707	0.000	1.93	3.22	1.18	0.89	2.22	4.43
11/6/86	0.707	0.000	1.21	0.96	1.06	0.62	1.45	1.60
12/30/86	0.940	0.383	1.62	2.12	2.72	6.90	3.19	9.68
2/28/87	0.707	0.000	0.71	0.00	0.91	0.33	0.91	0.33
3/27/87	0.707	0.000	1.09	0.69	1.08	0.67	1.29	1.16
4/24/87	0.707	0.000	1.15	0.82	1.04	0.58	1.38	1.40
6/1/87	0.707	0.000	1.20	0.94	1.22	0.99	1.35	1.32
L.S.D. 0.05 L.S.D. 0.01	0.251 0.335		1.328 1.776		1.247 1.667		1.729 2.310	
S.E.	0.124		0.658		0.617		0.856	
C.V.%	25.12		62.50		62.17		62.00	

1. Square root transformation [y = sq. rt. (x + 0.05)].
2. Mean of 5 different sampling depths.

Appendix 5.2.3. Influence of the depth of sampling on the population density of Pratylenchus zeae recovered from 100 cm3 of soil in Chinamora communal area.

Parameters / Sampling depth (cm)	P. zeae stages							
	J_2		J_3-J_4		Mature females		Total	
	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans
0-10	0.927[2]	0.359	2.59	6.21	2.96	8.26	3.91	14.79
10-20	0.759	0.076	1.80	2.74	1.88	3.03	2.60	6.26
20-30	0.811	0.157	1.86	2.96	1.13	0.78	2.09	3.87
30-40	0.707	0.000	1.31	1.22	1.18	0.89	1.56	1.93
40-50	0.707	0.000	0.76	0.08	0.71	0.00	0.76	0.08
L.S.D. 0.05 L.S.D. 0.01	0.178 0.238		0.939 1.256		0.883 1.180		1.222 1.634	
S.E.	0.088		0.465		0.437		0.605	
C.V.%	25.12		62.50		62.17		62.00	

1. Square root transformation [y = sq. rt. (x + 0.5)].
2. Mean of 10 different sampling times.

Appendix 5.3.1. Temporal and spatial distribution of soil moisture and maize roots grown in pits filled with sandy soil.

Sampling date	Sampling depth (cm)	% Soil Moisture	Maize root weight (grams) Radius (cm)		
			0-10	10-20	20-30
1/28/86	0-10	9.25	0.70	0.00	0.00
	10-20	9.00	0.00	0.00	0.00
	20-30	10.16	0.00	0.00	0.00
	30-40	8.80	0.00	0.00	0.00
	40-50	7.60	0.00	0.00	0.00
2/10/87	0-10	6.40	0.50	0.00	0.00
	10-20	7.46	0.80	0.00	0.00
	20-30	6.75	0.00	0.00	0.00
	30-40	7.41	0.00	0.00	0.00
	40-50	7.77	0.00	0.00	0.00
2/24/86	0-10	4.92	1.60	1.90	1.00
	10-20	5.48	0.10	0.30	1.11
	20-30	5.90	0.00	0.10	0.70
	30-40	8.14	0.00	0.00	0.00
	40-50	6.75	0.00	0.00	0.00
3/10/87	0-10	3.73	9.00	6.70	3.60
	10-20	4.68	2.30	8.10	6.80
	20-30	3.03	3.00	3.50	4.50
	30-40	3.25	1.90	1.80	2.10
	40-50	3.66	0.00	0.00	0.00
3/24/87	0-10	2.64	27.00	11.50	7.00
	10-20	2.22	10.50	10.46	5.30
	20-30	3.25	5.00	9.90	0.50
	30-40	3.63	0.00	0.50	0.40
	40-50	2.33	0.00	0.00	0.00
4/7/87	0-10	2.88	33.40	17.80	8.60
	10-20	3.77	16.30	15.30	14.90
	20-30	4.01	7.50	13.70	11.10
	30-40	4.06	1.50	6.40	2.80
	40-50	3.72	0.40	0.50	2.60
4/23/87	0-10	6.27	49.90	6.70	3.40
	10-20	5.64	8.60	11.40	3.20
	20-30	7.64	1.50	0.50	0.90
	30-40	8.78	1.40	1.00	0.30
	40-50	8.09	1.00	0.90	0.60
5/6/87	0-10	4.90	70.40	5.80	3.50
	10-20	7.37	14.80	11.50	4.10
	20-30	8.33	4.00	8.70	3.00
	30-40	5.91	1.60	5.00	3.80
	40-50	6.77	2.00	4.80	8.50
5/19/87	0-10	6.81	54.90	7.10	10.10
	10-20	6.16	3.10	5.00	3.30
	20-30	4.40	0.80	1.60	1.00
	30-40	2.94	0.10	0.30	0.20
	40-50	3.46	0.10	0.30	0.30
6/10/87	0-10	1.90	35.10	2.50	1.10
	10-20	2.98	7.10	4.10	1.13
	20-30	2.24	3.20	4.50	2.30
	30-40	5.92	1.50	3.10	2.20
	40-50	5.63	1.40	1.50	1.40

Appendix 5.3.2. Temporal and spatial distribution of P. zeae in 100 cm³ of soil surrounding maize roots grown in pits.

Sampling date	Sampling depth (cm)	% Soil Moisture	Radius (cm)								
			0-10			10-20			20-30		
			J_2	J_3-J_4	adult	J_2	J_3-J_4	adult	J_2	J_3-J_4	adult
1/28/86	0-10	9.25	0	17	0	0	23	2	0	15	0
	10-20	9.00	0	52	2	0	46	0	0	28	4
	20-30	10.16	0	27	2	0	34	3	0	46	1
	30-40	8.80	0	69	0	0	51	0	0	33	0
	40-50	7.60	0	21	0	0	26	2	0	16	3
2/10/87	0-10	6.40	0	18	6	0	24	5	0	28	3
	10-20	7.46	0	89	12	0	74	6	0	106	3
	20-30	6.75	0	30	2	0	58	1	0	41	7
	30-40	7.41	0	43	3	0	69	10	0	83	4
	40-50	7.77	0	110	2	0	37	11	0	87	1
2/24/86	0-10	4.92	0	13	6	0	6	3	0	24	2
	10-20	5.48	0	34	13	13	80	4	0	5	1
	20-30	5.90	0	14	7	0	43	2	0	66	1
	30-40	8.14	2	32	1	6	103	2	0	71	0
	40-50	6.75	0	48	0	8	9	1	0	137	0
3/10/87	0-10	3.73	2	0	0	4	0	0	2	0	1
	10-20	4.68	0	0	1	19	2	0	16	3	0
	20-30	3.03	0	13	0	7	7	2	12	0	2
	30-40	3.25	19	10	0	4	7	7	15	6	0
	40-50	3.66	14	40	0	8	0	0	35	0	0
3/24/87	0-10	2.64	0	0	0	1	0	2	7	0	3
	10-20	2.22	2	0	1	1	0	0	11	0	1
	20-30	3.25	22	0	0	15	0	0	2	0	1
	30-40	3.63	0	5	3	1	0	0	19	0	0
	40-50	2.33	2	0	0	9	0	0	14	0	2
4/7/87	0-10	2.88	0	3	0	0	7	1	0	3	0
	10-20	3.77	0	6	0	0	3	0	0	17	1
	20-30	4.01	0	3	0	0	0	0	0	11	0
	30-40	4.06	0	7	0	0	0	0	0	10	0
	40-50	3.72	0	8	0	1	14	0	0	7	0
4/23/87	0-10	6.27	0	3	0	0	0	0	0	7	0
	10-20	5.64	3	7	2	0	11	3	0	15	3
	20-30	7.64	0	4	1	0	8	3	0	5	0
	30-40	8.78	0	3	1	0	4	1	0	4	0
	40-50	8.09	0	0	0	0	2	0	0	7	1
5/6/87	0-10	4.90	0	40	9	0	11	0	0	17	0
	10-20	7.37	0	12	1	0	21	0	0	18	0
	20-30	8.33	0	41	5	0	49	7	0	21	0
	30-40	5.91	0	45	5	0	18	0	0	22	3
	40-50	6.77	0	45	0	0	67	10	0	20	7
5/19/87	0-10	6.81	6	19	26	9	18	8	0	40	10
	10-20	6.16	0	9	3	20	107	10	0	30	7
	20-30	4.40	2	8	5	0	3	0	0	9	0
	30-40	2.94	0	4	0	3	17	7	0	15	0
	40-50	3.46	5	16	5	0	3	2	0	35	0
6/10/87	0-10	1.90	0	19	10	4	4	5	2	17	3
	10-20	2.98	21	68	34	8	115	12	20	119	16
	20-30	2.24	20	27	10	4	30	2	7	44	5
	30-40	5.92	6	43	12	2	56	9	8	98	9
	40-50	5.63	11	20	7	23	100	6	15	83	15

Appendix 5.3.3. Temporal and spatial distribution of P. zeae 10.0 grams of maize roots grown in pits filled with sandy soil.

Sampling date	depth (cm)	% Soil Moisture	Radius (cm)								
			0-10			10-20			20-30		
			J_2	J_3-J_4	Adult	J_2	J_3-J_4	Adult	J_2	J_3-J_4	Adult
1/28/86	0-10	9.25	0	157	128	0	0	0	0	0	0
	10-20	9.00	0	0	0	0	0	0	0	0	0
	20-30	10.16	0	0	0	0	0	0	0	0	0
	30-40	8.80	0	0	0	0	0	0	0	0	0
	40-50	7.60	0	0	0	0	0	0	0	0	0
2/10/87	0-10	6.40	0	0	100	0	0	0	0	0	0
	10-20	7.46	0	25	62	0	0	0	0	0	0
	20-30	6.75	0	0	0	0	0	0	0	0	0
	30-40	7.41	0	0	0	0	0	0	0	0	0
	40-50	7.77	0	0	0	0	0	0	0	0	0
2/24/86	0-10	4.92	0	1550	19	0	0	1046	0	1050	100
	10-20	5.48	0	600	400	0	0	0	0	145	18
	20-30	5.90	0	0	0	0	0	200	0	414	114
	30-40	8.14	0	0	0	0	0	0	0	0	0
	40-50	6.75	0	0	0	0	0	0	0	0	0
3/10/87	0-10	3.73	17	422	267	20	20	858	14	240	389
	10-20	4.68	21	318	217	8	8	120	4	144	225
	20-30	3.03	0	10	3	0	0	17	0	18	7
	30-40	3.25	0	0	0	0	0	0	0	0	0
	40-50	3.66	0	0	0	0	0	0	0	0	0
3/24/87	0-10	2.64	33	204	65	132	132	1012	94	644	1982
	10-20	2.22	22	343	369	99	99	594	43	1331	1746
	20-30	3.25	0	172	365	0	0	26	0	482	173
	30-40	3.63	0	0	0	0	0	0	0	0	0
	40-50	2.33	0	0	0	0	0	0	0	0	0
4/7/87	0-10	2.88	11	102	33	98	98	775	63	685	63
	10-20	3.77	93	122	47	101	101	730	103	1890	9048
	20-30	4.01	27	146	19	21	21	437	58	780	36
	30-40	4.06	0	7	0	0	0	119	0	225	4
	40-50	3.72	0	175	0	0	0	0	0	31	
4/23/87	0-10	6.27	18	37	10	35	745	27	426	697	124
	10-20	5.64	65	308	54	91	635	50	181	1825	265
	20-30	7.64	40	573	94	0	470	30	180	570	180
	30-40	8.78	0	47	13	0	50	0	0	267	33
	40-50	8.09	0	0	0	0	40	20	0	50	0
5/6/87	0-10	4.90	0	750	40	0	850	40	0	1250	25
	10-20	7.37	0	300	25	25	3075	250	225	5050	400
	20-30	8.33	30	822	77	55	1428	47	0	4107	214
	30-40	5.91	0	1312	181	0	1026	128	0	1749	89
	40-50	6.77	0	714	0	0	240	20	0	700	24
5/19/87	0-10	6.81	20	630	68	336	1046	240	447	2390	332
	10-20	6.16	312	2761	403	999	2266	230	331	2831	223
	20-30	4.40	0	1767	68	550	1050	50	200	1342	29
	30-40	2.94	0	1200	0	0	400	0	0	200	0
	40-50	3.46	0	1600	0	0	800	0	0	267	0
6/10/87	0-10	1.90	25	401	36	133	2416	341	600	11200	267
	10-20	2.98	92	1750	75	492	4237	240	357	6714	1299
	20-30	2.24	80	1752	172	455	3150	200	667	3906	1711
	30-40	5.92	100	2500	300	240	3480	320	111	8355	416
	40-50	5.63	167	4633	288	182	4364	191	967	6333	

Appendix 5.4.1. Influence of gravimetric soil moisture on Pratylenchus zeae and maize root system development.

Parameters / Treatments	Gravimetric soil moisture (%)	Root weight (grams)		P. zeae in soil and roots 8 weeks after planting			
				100 cm^3 soil		10.0 grams roots	
		Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans
High moisture	16.5[2]	5.74	32.95	3.90	15.21	30.2	912.04
Medium moisture	11.7	4.53	20.52	3.06	9.36	29.5	870.25
Low moisture	5.0	2.53	6.40	3.91	15.29	22.6	510.76
L.S.D. 0.05		0.673		1.025		7.456	
S.E.		0.523		0.797		5.34	
C.V. %		12.3		22.0		23.1	

[1]Square root transformation [y = sq. rt. (x)].
[2]Mean of 6 replications.

Appendix 5.4.2. Influence of gravimetric soil moisture on Pratylenchus zeae and maize root systems development for 8 weeks.

Parameters / Treatments	Gravimetric soil moisture %	Root weight (grams)						P. zeae in											
								100 cm^3 soil						10.0 grams roots					
		RI	RII	RIII	RIV	RV	RVI	RI	RII	RIII	RIV	RV	RVI	RI	RII	RIII	RIV	RV	RVI
High moisture	16.5	27.1	37.8	24.1	29.4	48.8	27.2	8	12	29	21	9	11	640	775	850	859	1056	1385
Medium moisture	11.7	15.9	26.1	13.1	22.7	22.1	18.7	6	6	13	10	9	7	543	915	1867	925	772	475
Low moisture	5.0	4.9	5.6	7.8	5.4	4.2	4.9	14	18	8	11	14	23	806	769	450	388	373	357

Appendix 5.5.1. Screening of maize varieties and inbreeds against Pratylenchus zeae infection for 8 weeks.

Parameters / Treatments	P. zeae in 100 cm^3 soil					P. zeae in 10.0 grams of roots					Root weight in grans				
	RI	RII	RIII	RIV	RV	RI	RII	RIII	RIV	RV	RI	RII	RIII	RIV	RV
R 201	4	7	16	14	20	34	18	24	21	23	56.6	56.5	37.9	38.7	36.6
R 215	2	10	4	17	22	10	8	12	16	0	65.5	52.4	41.9	26.3	42.9
SR 52	13	14	26	8	3	31	24	18	16	8	50.9	46.5	32.2	30.6	37.6
ZS 107	11	26	7	4	19	17	46	38	17	1	43.3	101.7	41.2	42.2	41.1
ZS 202	14	19	28	13	8	26	16	12	17	0	34.8	64.0	28.6	35.5	38.5
ZS 206	16	25	12	6	17	4	17	25	3	3	68.4	34.4	29.0	55.1	35.6
ZS 225	15	19	5	2	12	7	6	10	3	18	40.2	45.1	32.4	39.2	30.1
83 3WH 59	4	6	13	10	6	14	28	24	6	0	35.1	40.1	37.8	47.8	33.0
83 3WH 27	19	7	17	10	8	5	14	18	13	29	47.5	37.1	31.6	23.9	52.5
86 3WH 12	16	9	14	2	29	21	25	21	7	0	48.6	50.2	35.9	25.3	35.2

Appendix 5.5.2. Evaluation of maize varieties and inbreeds against Pratylenchus zeae infection.

Parameters / Varieties	P. zeae in soil and roots 8 weeks after planting				Root Weight (grams)	
	100 cm^3 soil		10.0 grams roots			
	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans
R 201	3.53[2]	12.46	4.97	24.70	6.81	46.38
R 215	3.26	10.63	3.01	9.06	6.77	45.83
SR 52	3.56	12.67	4.43	19.62	6.34	40.20
ZS 107	3.64	13.25	4.60	21.16	7.25	52.56
ZS 202	4.09	16.73	3.63	13.18	6.36	40.45
ZS 206	3.94	15.52	3.12	9.73	6.66	44.36
ZS 225	3.25	10.56	3.03	9.18	6.18	38.19
83 3WH 59	2.92	8.63	3.58	12.82	6.29	39.56
83 3WH 27	3.57	12.75	3.98	15.84	6.23	38.81
86 3WH 12	3.67	13.47	3.66	13.40	6.28	39.44
S.E.	1.048		1.209		0.799	
C.V.%	29.6		31.8		12.3	

[1]Square root transformation [y = sq. rt. (x)].
[2]Mean of 5 replications.

Appendix 5.6.1. Influence of nutrients in Pratylenchus zeae population density and maize growth parameters 8 weeks after planting.

Parameters / Nutrients	No. of P. zeae in 100 cm³						Weight					
	100 cm³ soil			10.0 grams			Roots			Shoot		
	RI	RII	RIII	RI	RII	RIII	RI	RII	RIII	RI	RII	RIII
Untreated	1	10	2	17	16	27	34.6	15.9	78.9	27.5	13.0	44.0
Compound D	4	4	1	65	28	42	70.3	70.3	81.4	115.0	187.0	180.0
Ammonium nitrate	16	34	45	60	14	23	27.4	20.3	17.3	11.5	21.5	57.5
Manure	1	5	37	21	13	30	60.6	96.4	34.2	53.5	85.5	147.5
Compound D + Amm. nitrate	1	6	10	12	10	32	53.6	41.7	31.1	115.0	154.0	126.3
Compound D + Manure	2	3	4	4	6	24	81.2	49.7	62.2	94.0	215.0	291.0
Amm. nitrate + Manure	1	6	6	17	22	5	49.9	97.5	140.6	105.0	71.0	152.0
Amm. nitrate + Compound D + Manuare	8	1	3	31	19	13	114.6	103.4	120.7	190.0	337.0	308.0

Appendix 5.6.2. Influence of nutrients on Pratylenchus zeae population density and maize growth parameters 16 weeks after planting.

Parameters / Nutrients	No. of P. zeae in 100 cm³						Weight					
	100 cm³ soil			10.0 grams			Roots			Shoot		
	RI	RII	RIII	RI	RII	RIII	RI	RII	RIII	RI	RII	RIII
Untreated	45	8	7	155	80	115	50.4	76.9	50.4	63.5	115.5	127.6
Compound D	26	16	24	92	51	107	176.7	158.3	206.5	202.0	308.0	390.8
Ammonium nitrate	23	3	49	60	88	117	54.1	99.5	26.7	350.0	227.3	52.7
Manure	38	28	25	108	92	253	124.4	76.1	98.1	163.5	152.0	172.8
Compound D + Amm. nitrate	11	12	13	33	148	31	158.7	233.5	250.6	410.0	446.0	466.2
Compound D + Manure	34	29	12	116	100	135	117.6	209.9	162.4	325.0	400.5	325.5
Amm. nitrate + Manure	14	7	6	192	265	91	57.9	73.3	150.5	196.5	300.2	390.6
Amm. nitrate + Compound D + Manuare	20	6	17	126	48	61	187.3	226.4	187.7	529.2	502.0	444.2

Appendix 5.6.3. Influence of nutrients on Pratylenchus zeae population density and maize growth parameters 8 weeks after planting.

Parameters / Nutrients	No. of P. zeae in				Weight (grams)			
	100 cm^3 soil		10.0 grams		Root		Shoot	
	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans
Untreated	1.86[2]	3.46	4.44	19.71	6.25	39.07	5.16	26.60
Compound D	1.33	1.78	6.61	43.71	8.56	73.40	12.61	158.89
Ammonium Nitrate	5.51	30.39	6.06	36.78	4.63	21.46	5.20	27.07
Manure	2.77	7.69	4.55	20.75	7.78	60.50	9.57	91.56
Compound D + Amm. nitrate	2.20	4.86	4.09	16.76	6.42	41.20	11.45	131.60
Compound D + Manure	1.72	2.96	3.12	9.73	7.98	63.68	16.29	265.36
Amm. nitrate + Manure	1.63	2.66	3.68	13.54	9.60	86.40	10.33	106.71
Amm. nitrate + Compound D + Manure	1.85	3.42	4.51	20.34	10.62	112.78	16.56	274.23
L.S.D. 0.05 L.S.D. 0.01	1.299 1.804		1.615 2.242		1.815 2.518		2.081 2.888	
S.E.	0.743		0.922		1.036		1.188	
C.V.%	74.10		39.50		21.30		16.70	

Key

[1]Square root transformation [y = sq. rt. (x)].

[2]Mean of 3 replications.

Appendix 5.6.4. Influence of nutrients on Pratylenchus zeae population density and maize growth parameters 16 weeks after planting.

Parameters / Nutrients	P. zeae in				Weight (grams)			
	100 cm^3 soil		10.0 grams		Root		Shoot	
	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans	Trans[1]	Detrans
Untreated	4.06	16.49	10.70	114.61	7.66	58.61	10.00	100.00
Compound D	4.66	21.77	9.03	81.46	13.35	178.35	17.18	195.05
Ammonium Nitrate	4.51	20.33	9.31	86.75	7.50	56.23	13.68	187.18
Manure	5.49	30.08	11.96	143.12	9.93	98.51	12.75	162.66
Compound D + Amm. nitrate	3.46	11.99	7.83	61.24	14.56	212.27	20.99	440.42
Compound D + Manure	4.89	23.31	10.80	116.64	12.69	161.04	18.69	349.32
Amm. nitrate + Compound D + Manure	3.68	13.54	8.65	74.82	14.14	199.94	22.16	491.07
L.S.D. 0.05 L.S.D. 0.01	1.276 1.771		2.966 4.117		2.003 2.781		2.495 3.462	
S.E.	0.728		1.694		1.143		1.424	
C.V.%	34.0		28.4		17.2		14.0	

Key

[1]Square root transformation [y = sq. rt. (x)].

[2]Mean of 3 replications.

Appendix 5.7.1. Influence of several granular nematicides on Pratylenchus zeae associated with maize in Zvimba communal area.

Parameters / Treatments	No. of P. zeae in soil[1] on treating date				No. of P. zeae in soil and roots[2] 4 weeks after				No. of P. zeae in soil and roots[2] 8 weeks after				Maize yield (kg/plot[3])			
	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV
carbofuran 10g	59	74	23	37	138	456	110	33	67	80	9	45	4.1	6.5	7.5	7.0
fenamiphos 10g	66	19	22	14	319	244	520	52	55	54	26	16	4.1	6.4	7.3	5.3
isazofos 10g	26	21	63	34	147	412	140	85	42	132	33	5	4.0	4.8	7.1	4.6
terbufos 10g	39	51	34	58	294	417	120	86	106	67	8	87	4.1	6.6	8.8	5.4
untreated	68	26	5	36	639	450	681	239	1146	743	1623	266	3.5	4.9	4.3	2.3

[1]Soil = 100 cm^3
[2]Soil and roots = 100cm^3 + 10 grams of roots
[3]Plot size = 9 x 2.7m

Appendix 5.7.2. Influence of several granular nematicides on Pratylenchus zeae associated with maize in Zvimba communal area.

Parameters / Treatments	P. zeae in soil[1] on treating date		P. zeae in roots and soil[2] 4 weeks after treating		P. zeae in roots and soil[2] 8 weeks after treating		Maize yield (kg/ha)
	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans	
carbofuran 10g	6.83[4]	46.65	12.33	152.03	6.7	44.89	1937.00
fenamiphos 10g	5.23	27.35	15.01	225.86	5.9	34.8	1790.00
isazofos 10g	5.86	34.34	13.37	178.76	6.5	42.25	1582.00
terbufos 10g	6.71	45.02	14.45	208.80	7.7	59.29	1921.00
untreated	5.40	29.16	22.01	484.40	29.40	864.36	1157.00
L.S.O. 0.05	2.711		6.065		8.066		401.774
L.S.D. 0.01	3.799		8.499		11.310		562.945
S.E.	1.759		3.935		5.24		260.6
C.V.%	29.30		25.20		46.60		15.5

Key

[1]Soil = 100 cm^3

[2]Roots and soil = 100 cm^3 + 10 grams of roots

[3]Square root transformation

[4]Mean of 4 replications

Appendix 5.8.1. Influence of several management practices on Pratylenchus zeae associated with maize in Chinamora communal area.

Parameters / Treatments	No of P zeae in soil[1] on treating day				No of P. zeae in soil and roots[2] 4 weeks after				No of P. zeae in soil and roots[2] 8 weeks after				No of P. zeae in soil and roots[2] 12 weeks after				No of P zeae in soil roots[2] 16 weeks after				Maize yield (kg/plot[3])			
	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV
carbofuran 10g	12	6	23	24	108	44	82	80	5	2	18	7	140	300	125	1	23	44	30	59	15.2	8.0	11.6	10.7
cattle manure	18	25	15	12	148	327	165	149	177	80	187	23	2110	4249	200	1500	1418	296	1521	319	11.1	14.5	16.5	9.0
compost manure	33	2	12	28	129	200	484	311	115	230	187	45	992	1210	384	596	451	540	437	156	9.4	10.6	16.5	7.5
early plowing	3	3	32	26	113	70	149	269	209	37	365	53	1050	200	625	200	311	203	313	385	5.7	10.7	15.0	6.5
untreated	52	13	20	41	234	53	161	95	309	53	158	20	3030	120	500	260	1088	457	1088	1336	3.0	5.0	7.3	5.5

Key

[1]Soil = 100 cm^3

[2]Soil and roots = 100 cm^3 + 10.0 grams roots

[3]Plot size = 9 x 4.5 m

Appendix 5.8.2. Influence of several management practices on Pratylenchus zeae associated with maize in Chinamora communal area.

Parameters / Treatments	P. zeae in soil[1] on treating date		P. zeae in roots and soil[2] 4 wks after treating		P. zeae in roots and soil[2] 8 wks after treating		P. zeae in roots and soil[2] 12 wks after treating		P. zeae in roots and soil[2] 16 wks after treating		Maize yield (kg/ha)
	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans	
carbofuran 10g	3.90[4]	15.21	8.79	77.26	2.63	6.92	10.10	102.01	6.10	37.21	2341.00
cattle manure	4.14	17.14	13.85	191.82	10.25	105.06	41.00	1681.00	27.90	778.41	2629.00
compost manure	3.98	15.84	12.06	145.44	11.59	134.32	28.00	784.00	19.50	380.25	2279.00
early plowing	3.55	12.60	16.35	267.32	11.79	139.00	21.90	479.61	17.40	289.00	1950.00
untreated	5.42	29.38	11.27	127.01	10.50	110.25	26.10	681.21	30.90	954.81	1070.00
L.S.D. 0.05	2.246		5.302		5.115		20.304		9.917		833.85
S.E.	1.457		3.440		3.318		13.170				540.90
C.V.%	34.70		27.60		35.50		51.80				26.30

Key

[1]Soil = 100 cm^3

[2]Roots and soil = 100cm^3 + 10 grams of roots

[3]Square root transformation

[4]Mean of 4 replications

Appendix 5.9.1. Influence of the time of applying manure on the population density of Pratylenchus zeae and maize growth.

Parameters / Treatments	No of P zeae in 100 cm^3 soil, 8 wks after planting				No of P. zeae in 10.0 grams roots 8 wks after planting				No of other nematodes in 100 cm^3 soil 8 wks after planting				Root weight (grams) 8 wks after planting				Shoot weight (grams) 8 wks after planting			
	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV	RI	RII	RIII	RIV
Manure applied 12 wks before planting	4	0	0	2	72	285	138	389	1	0	1	1	92.0	85.4	68.4	60.6	224.0	251.9	134.0	265.6
Manure applied 8 wks before planting	1	1	1	2	144	380	136	178	2	0	13	3	74.2	87.9	76.8	73.9	254.7	226.6	200.0	342.7
Manure applied 4 wks before planting	2	2	3	3	330	340	61	94	2	0	10	2	94.1	103.3	76.6	58.3	414.0	398.5	245.0	406.5
Manure applied on planting date	3	1	2	2	206	868	27	287	1	0	23	3	27.3	39.4	58.4	33.4	116.0	92.6	195.0	116.8
Untreated	5	4	2	3	528	1930	17	1381	1	0	16	4	27.1	34.1	60.5	21.0	44.0	32.3	84.8	24.4

Appendix 5.9.2. Influence of the time of applying manure on the population density of Pratylenchus zeae and maize growth.

Parameters / Treatments	P. zeae in soil[1] 8 wks after planting		P. zeae in roots[2] and soil 8 wks after planting		Other nematodes soil[1] 8 wks after treating		Root weight (grams) 8 wks after planting		Shoot weight (grams) 8 wks after planting	
	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans	Trans[3]	Detrans
Manure applied 12 wks. before planting	1.4924	1.228	14.20	200.64	1.31	0.716	8.78	76.09	14.71	215.38
Manure applied 8 wks. before planting	1.494	1.232	14.20	200.64	2.12	3.494	8.89	78.03	15.95	253.40
Manure applied 4 wks. before planting	1.866	2.482	13.60	183.96	1.95	2.802	9.12	82.17	19.06	362.28
Manure applied on planting day	1.720	1.958	16.50	271.25	2.33	4.429	6.31	38.82	11.34	127.59
untreated	2.104	3.427	27.10	733.41	2.19	3.796	5.94	34.28	6.70	43.89
L.S.D. 0.05	0.453		10.790		0.943		1.302		3.227	
S.E.	0.303		7.21		0.630		0.868		2.153	
C.V.%	17.4		42.1		31.80		11.10		15.90	

Key

[1]Soil = 100 cm^3

[2]Roots = 10.0 grams

[3]Square root transformation [y = sq. rt. (x + 1)]

[4]Mean of 4 replications

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