STUDIES ON RENIFORM NEMATODE,
Rotylenchulus reniformis LINFORD AND
OLIVEIRA, 1940, ON CASTOR

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ABSTRACT
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STUDIES ON RENIFORM NEMATODE, ROTYLENCHULUS RENIFORMIS LINFORD AND OLIVEIRA, 1940, ON CASTOR

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Studies pertaining to the effects of reniform nematode, R. reniformis, on castor cvs. GAUCH 1 and GCH 4 with respect to i, interaction between R. reniformis and Fusarium oxysporum f. ricini on castor cv. GAUCH 1 and GCH 4; ii, interaction between R. reniformis and Macrophomina phaseolina on castor cv. GCH 4; iii, assessment of quantitative and qualitative losses due to R. reniformis in castor cv. GCH 4 and iv, determination of susceptible crop stage for R. reniformis infection on castor were carried out during 1992-93 and 1993-94. The salient findings are:

A. i, Study on interaction between R. reniformis (N) and F. oxysporum f. ricini (Fo) on castor cv. GAUCH 1 indicated that plant height was significantly reduced in N - Fo treatment, whereas fresh shoot and root weight of plant were minimum in N + Fo treatment followed by N - Fo and Fo - N treatments. The
treatment of N alone produced maximum (469 times) reproduction rate as compared to other treatments.

ii, Wilt disease appeared three weeks earlier in different combinations of N and Fo than Fo alone. Among the combinations, N inoculated 4 wk prior to Fo inoculation (N - Fo) proved highly detrimental inducing 66.6 % wilt disease in castor cv. GAUCH 1.

B. i, Experiment on interaction between R. reniformis and F. oxysporum f. ricini on castor cv. GCH 4 indicated that plant height, fresh shoot and root weights were significantly less in N alone treatment followed by N + Fo and N - Fo treatments. This treatment also produced maximum nematodes population build up/plant and had higher reproduction rate of 523 times as well over other treatments.

ii, Castor wilt disease incited by F. oxysporum f. ricini was not observed in the treatment of Fo alone, because of resistance against wilt disease in castor cv. GCH 4. However, wilt disease appeared in the plants inoculated with nematodes 4 wk prior to fungus inoculated (N - Fo) and inoculation of both the pathogens together (N + Fo). This indicated that nematode played a vital role to break down the wilt resistance nature of castor cv. GCH 4.
C. i, Study on interaction between *R. reniformis* and *M. phaseolina* on castor cv. GCH 4 indicated that the plant height and fresh root weight were significantly reduced in the treatment of N+Mp followed by N-Mp, Mp-N, N alone and Mp alone treatments. With regards to fresh shoot weight, significantly less fresh shoot weight was observed in the treatment of N alone followed by N+Mp and N-Mp treatments. The treatment of N alone produced maximum nematode population build up/plant and had higher reproduction rate of 528 times over other treatments.

ii, The root-rot disease appeared earlier in different combinations of N and Mp over Mp alone. The maximum plant mortality of 41.7% was recorded in the treatment of plants inoculated with nematode and fungus concomitantly (N + Mp) over other treatments.

D. i, Experiment on assessment of quantitative and qualitative losses indicated significant reduction in plant height, fresh shoot and root weights due to *R. reniformis* inoculation over control treatment.

ii, Seed yield and test weight of castor seed reduced significantly at 1000 and 500 inoculum levels/kg soil over control. Nematode inoculated plants (both levels) had 20.08% reduced yields over uninoculated
plants. Nematode inoculation also affected the oil content of castor seeds. There were 3.14 and 6.60% reduction in oil contents of castor seeds due to nematodes infection at 500 and 1000 J4/kg soil respectively.

iii, Chlorophyll content was also significantly reduced due to nematode inoculations.

iv, Observations recorded on meteorological parameters revealed that nematodes infected plants had the 35.2 and 57.0% reduction in diffusion resistance and 52.3 and 42.0% increased in transpiration rate at the inoculum level of 500 and 1000 J4/kg soil respectively over control.

E. Determination of susceptible crop stage of castor cv. GCH 4 to R. reniformis infection indicated that maximum nematode females penetration was recorded on 150 days old plants followed by 135 days old plants. Penetration of nematode females in castor roots progressively increased with an increase in plant age, indicating positive correlation between nematode infection and plant age.
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CERTIFICATE

This is to certify that the thesis entitled  
"STUDIES ON RENIFORM NEMATODE, Rotylenchulus reniformis  
LINFORD AND OLIVEIRA, 1940, ON CASTOR" submitted in partial  
fulfilment of the requirements for the award of the degree  
of Ph.D. in Plant Nematology of the Gujarat Agricultural  
University, Sardar Krushinagar is a faithful record of the  
bonafide research work carried out by Shri D.B. Patel under  
my guidance and supervision. No part of the thesis has been  
submitted for the award of any degree or diploma.

The assistance and help received by him during the  
course of investigations has been fully acknowledged.

Place : Anand  
Date : April 15, 1995

( D. J. PATEL )  
Major Advisor
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INTRODUCTION
I INTRODUCTION

Castor (Ricinus communis L.) is an important industrial oilseed crop in the world. It is cultivated in about 30 different countries on commercial scale. Among these, Brazil, India, China, Russia, Thailand and Philippines are the principal castor growing countries accounting for 88% of the total world production (Fatteh, 1986).

India, being the largest castor producer in Asia ranks second in the world after Brazil occupying about 25% of the world's total acreage of castor and contributes about 30% of total output (George et al., 1985). India earns around Rs. 350 crores as foreign exchange by way of exporting castor oil, thus playing a vital role in the agricultural economy of our country (Anon., 1994). It is grown in about 0.88 million ha producing about 0.7 million tons of castor seed production (Anon., 1994). Among the principal castor growing states such as Gujarat, Andhra Pradesh, Karnataka and Orissa, Gujarat is the largest castor producing state contributing more than 54% of total production in the country. Castor seed contains about 50 to 60% of oil which is mainly used for domestic, medicinal and lubricant purposes. Its oil differs from other vegetable oils in the sense that it does not freeze even under adverse
temperature of -12 to -18 °C. It is, therefore, considered as best lubricating agent particularly for motor and aviation motors lubrications.

Among different castor hybrids/varieties such as GAUCH 1, 2 and 3, GCH 4, Aruna, GAUC 1, 48-1, etc. cultivated in different states of India, castor hybrids GAUCH 1 and GCH 4 are predominantly grown in Gujarat because of their higher yield production (Anon., 1991).

Such an important oilseed crop is attacked by several biotic and abiotic stresses. The important diseases attacking castor are wilt incited by Fusarium oxysporum f. ricini, root rot by Macrophomina phaseolina (Maubl.), seedling blight by Phytophthora parasitica (Dastur), leaf blight by Alternaria ricini (Yoshii) Hansf, and powdery mildew by Leveillula taurica (Lev.) (Rangaswamy, 1975). Besides these, diseases caused by plant parasitic nematodes are also of economic importance.

Plant parasitic nematodes are real threat in successful and profitable cultivation of castor crop. The key nematodes reported to be associated with castor are Meloidogyne arenaria (Martin, 1958); M. arenaria thamesi (Linde et al., 1959). M. hapla (Gaskin and Crittenden, 1956); M. incognita (Minz, 1956); M. incognita acrita (Linde, 1956); M. javanica (Tarjan, 1953); Pratylenchus
vulnus (Jensen, 1953); P. zeae (McBridge et al., 1961); Radopholus similis (Birchfield, 1956) and Rotylenchulus reniformis (Seshadri and Sivakumar, 1963).

These tiny microscopic creatures induce stupendous quantitative and qualitative losses by way of reducing yields and oil contents especially when plants are attacked in the early crop growth stage.

Of various plant parasitic nematodes mentioned earlier, reniform nematode, Rotylenchulus reniformis, first reported by Linford and Oliveira (1940) on cowpea, (Vigna unguiculata L.) from Ohio, Hawaii, causes huge damage leading to tremendous yield losses in castor crop. In India, it was first reported by Siddiqui and Basir in 1959 on coffee roots from southern India. But Seshadri and Sivakumar (1963) reported this nematode on castor for first time in India and observed die-back and stunting symptoms on plants in heavily nematode infested castor field. Hence, it has been considered as a major pest of castor cultivated in sandy and loamy soils of India. Nematode infection delayed crop maturity and reduced castor seed size (Sivakumar and Seshadri, 1971). It has been observed that castor plants attacked by R. reniformis are predisposed and more prone to the attack of other pathogenic organisms like fungi, especially soil forms (Fusarium spp. and Macrophomina spp.). Such combined affected plants show stunted growth leading to
complete plant wilting/drying at any stage during crop growth resulting in reduction of yield and quality of crop produce. Such phenomena is recurrently occurring in castor mainly grown in North Gujarat comprising Banaskantha, Sabarkantha and Mehsana districts of the state. This motivated the author to undertake the research work with respect to:

i) Interaction between \( R. \) reniformis and Fusarium oxysporum f. ricini on castor cv. GAUCH 1 and GCH 4,

ii) Interaction between \( R. \) reniformis and Macrophomina phaseolina on castor cv. GCH 4,

iii) Assessment of quantitative and qualitative losses due to \( R. \) reniformis in castor cv. GCH 4 and

iv) Determination of susceptible crop stage of castor to \( R. \) reniformis infection.
REVIEW
OF
LITERATURE
II REVIEW OF LITERATURE

2.1 Reniform nematode, *Rotylenchulus reniformis*, was first reported by Linford and Oliveira (1940) on cowpea (*Vigna unguiculata* L.) from Ohio, Hawaii. In India, it was first reported by Siddiqui and Basir (1959) on coffee roots from Southern India, while in Rajasthan, it was reported for the first time by Swarup and his co-workers in 1969 during survey work. Seshadri and Sivakumar (1963) recorded occurrence of reniform nematode on castor for the first time in India and reported die-back and stunting symptoms on plants grown in heavily *R. reniformis* infected castor fields.

Castor is a highly favoured host for *R. reniformis* and usually hibernates high nematode population resulting into poor plant growth (Sivakumar and Seshadri, 1971).

2.2 Interaction between *Rotylenchulus reniformis* and *Fusarium oxysporum* f. *ricini* on castor cvs. GAUCH 1 and GCH 4.

The plant parasitic nematodes interact with other pathogenic micro-organisms viz., fungi, bacteria and viruses and thereby act as an incitants, aggravators, carriers and/or vectors. They cause either additive, synergistic or antagonistic effects on disease production on the host.
plants. Virtually these effects are produced either by providing mechanical injuries to the roots for easy entry of other pathogenic micro-organisms or by providing suitable substrates for colonization of other micro-organisms or by weakening the plants for easy attack by other micro-organisms and so on (Khan, 1993).

Literature scanned did not reveal any research informations on interaction between wilt fungus and reniform nematode especially on castor crop and hence, review on fungus and nematode interactions on other related crops has been cited.

The first nematode fungus interaction between fungus, *Fusarium* Spp. and root-knot nematodes, *Meloidogyne* spp., on cotton was reported by Atkinson (1892), where he observed synergistic effect on incidence and severity of cotton wilt disease.

Minton et al. (1964) while observing the effect of nematodes species on the cotton species reported that each nematode species reduced crop yield, *Rotylenchulus reniformis* having the greatest effect. Seedling emergence was also slightly reduced by each species. *Fusarium* wilt incidence was significantly increased by *R. reniformis* infection and it was positively correlated with spring larval counts and varietal susceptibility. *Rotylenchulus*
_reniformis_ reduced plant height while crop maturity was hastened by infection of _R. reniformis_, _Rotylenchus brachyurus_, _Helicotylenchus nannus_ and _Trichodorus christei_.

Khadar _et al._ (1972) reported varietal susceptibility and significance of reniform nematode, _R. reniformis_ and Fusarium wilt of cotton. Among 16 Egyptian cotton varieties tested for their response to Fusarium wilt in the presence or absence of _R. reniformis_, variety Ashmoni was observed to be resistant to wilt infection under all conditions, but all other known wilt resistant varieties viz. Giza 66, 67 and 69 showed an increase in *Fusarium* infection in the presence of nematodes. The highest levels of wilt infection were recorded when both _R. reniformis_ and *Fusarium* fungus were present at seeding time.

While studying the effect of _R. reniformis_ and _Verticillium dahliae_ alone and in all possible combinations on *Verticillium* wilt of cotton, Tachtchoua and Sikora (1978) reported that reniform nematode alone caused significant reduction in fresh shoot weight at inoculum levels of 5,000 and 10,000 larvae/250 ml soil, when 5,000 and 10,000 larvae levels were combined with 60 and 90 x 10^6 fungus conidia, reduction in plant growth was enhanced than additive. This synergistic effect was detected in both growth reduction and wilt intensity. Per cent wilt was also found to be correlated with fresh shoot weight.
El-gindi et al. (1974) reported that *R. reniformis* is associated with *Fusarium oxysporum* f. *vasinfectum* in increasing the susceptibility of a few wilt resistant Egyptian cotton varieties.

Again Tachatchoua and Sikora in 1979 reported the effect of *R. reniformis* and *Verticillium dahaliae*, either singly or together, in unsterilized and sterilized field soils. They observed that level of damage caused by each organism singly was less in unsterilized soil (containing micro-organisms) than in sterilized one. But there was a significant increase in wilt intensity and numbers of plants killed in the unsterilized soil, exhibiting that rhizosphere micro-organisms may increase damage level induced by interaction of plant parasitic nematodes and fungal pathogen.

The fairly heavy incidence of *Verticillium* wilt ranging from 25 to 50% was observed on different cotton varieties during the months of October and November, 1974 at the Agricultural Research Station, Dharwar (Krishnaprasad and Padaganur, 1980). Heavy reniform nematode populations were observed from the rhizosphere of nematode infected plants harbouring more nematode populations compared to healthy plants.

Salem (1980) reported that simultaneous inoculation of wilt susceptible and resistant cotton
cultivars with *M. incognita* and *F. oxysporum f. vasinfectum* resulted in an increase in wilt symptoms, particularly in the wilt resistant cultivars. The presence of *Fusarium* negatively affected the reproduction of *M. incognita* and gall formation.

2.3 Interaction between *Rotylenchulus reniformis* and *Macrophomina phaseolina* on castor cv. GCH 4.

Sharma and Gill (1979) reported that potato inoculated with *M. incognita* (2000 J2/500 g soil) and/or *Rhizoctonia solani* (1 g fungus/500 g soil) had significantly reduced shoot weight. *Meloidogyne incognita* alone also reduced root weight. Total nematode multiplication was highest where *M. incognita* was inoculated singly. Maximum reduction (66.72 %) in nematode multiplication occurred when *R. solani* was inoculated 10 days preceding *M. incognita*.

Carter (1980) reported that the incidence and severity of charcoal-rot caused by *Macrophomina phaseolina* were significantly greater when cantoloup (*Cucumis melonis* L.) was parasitized by *R. reniformis*. Charcoal rot incidence and numbers of dead plants increased by 53 and 15 % respectively, when *M. phaseolina* was combined with *R. reniformis* compared to *M. phaseolina* alone. Both *R.*
reniformis and M. phaseolina together significantly reduced top fresh weight but not root weight than that of uninoculated plants.

Okra (Abelmoschus esculentus L.) plants succumbed to wilt disease at an early stage when both R. reniformis and R. solani were present (Kumar and Sivakumar, 1981). However, when plants were inoculated with nematodes preceding the fungus, wilting occurred earlier than the plants inoculated with fungus preceding nematodes. The fungus induced wilt at 45–60 DAG in the absence of nematodes depending upon the inoculum level and plant age while initial injury by the nematode shortened the wilt appearance period to 34–43 DAG. However, when both the pathogens were concomitantly inoculated with high densities at 15 DAG, wilt occurred at 23 DAG. Even low initial nematode inoculum of preceding the fungal inoculum also caused early wilting irrespective of density of latter.

AL-Hazmi (1985) reported that the severity of Macrophomina root-rot of bean (Phaseolus vulgaris L.) increased when M. incognita was introduced 2 WK earlier to fungus than that of fungus alone. Nematode infection and reproduction were reduced when fungus was introduced prior to nematode inoculation. Inoculation with either pathogen or with both generally reduced root weight of both the
cultivars under test. There was significant reduction in pod weight in bean cv. Romano Italian but not in bean cv. Harvester. Harvester was more tolerant to both the pathogens than Romano Italian.

Studies conducted by Patel (1989) on interaction between reniform nematode, *R. reniformis* and fungus, *R. bataticola*, virulent and nonvirulent strains on cotton cv. Hybrid 6 indicated that nonvirulent fungus acted more or less in a similar fashion as virulent one in causing seedling root-rot in nematode presence. When virulent fungus was combined with nematodes, the mortality due to root-rot began one WK earlier than fungus alone.

Suhail Anver et al. (1991) observed interactive effects of reniform nematode, *R. reniformis* and root-rot fungus, *M. phaseolina*, on lentil. Both the pathogens caused significant reduction in shoot and root length as well as weights, number of pods and root nodules when inoculated singly, simultaneously as well as sequentially. However, the reduction in plant growth parameters was more pronounced in simultaneous inoculation over sequential one. It was further reported that fungus had an antagonistic effect on nematode multiplication but root-rot disease intensity increased in the presence of nematodes.
2.4 Assessment of quantitative and qualitative losses due to *R. reniformis* in castor cv. GCH 4.

Majority of phytophagous nematodes are ectoparasites. However, some species are either sedentary or migratary endoparasites or semi-endoparasites. Their feeding behaviour also varies according to their habits of parasitism. Ectoparasitic nematodes are mostly surface feeders while endoparasitic ones are either cortex or phloem or xylem vessels feeders, whereas others are in between (Zuckerman *et al.*, 1971). Due to these variations in nematode parasitism on host plant, intensity of damage to the host varies with the types of nematodes involved. The losses in terms of plant growth, yield, chlorophyll content and oil percentage due to reniform nematode studied by different researchers with different host plants are summarised here.

Minton *et al.* (1964) investigated effects of nematode species on cotton species and selections. They found that each nematode species reduced yield, *R. reniformis* having the greatest effect. Seed emergence was also slightly reduced by each species. *Rotylenchulus reniformis* reduced plant height and enhanced crop maturity.

Sivakumar and Seshadri (1971) considered *R. reniformis* to be pathogenic to castor and it caused growth reduction, leaf shedding, early flowering and malformation.
and discolouration of castor seeds. While correlating the growth and yield of castor with initial nematode population, they found that nematode infected plants produced inferior quality seeds containing lesser amount of oil. The quality of castor oil was also affected by nematode infestation.

Singh (1975) while studying the effect of inoculum levels and plant age on pathogenicity of M. incognita and R. reniformis on tomato observed that shoot and root growth of 18 days old tomato plants were significantly reduced at $2 \times 10^3$ concentration of R. reniformis.

Four potato (Solanum tuberosum L.) cultivars were found to be susceptible to R. reniformis under green house conditions by Rebois, et al. (1978). Soil nematode populations built up 3 to 19 folds depending on the cultivar in a period of 3.5 months. Tuber yield and quality, but not the dry weight of plant shoots and roots, were significantly reduced by nematode parasitism. Reniform nematode development was noticed on roots but not on tubers.

Heald (1978) conducted the study on effect of reniform nematode, R. reniformis, on yields of various vegetables in fumigated and non fumigated plots. Fumigation was perfected with 92 % 1, 3, dichloropropene (1,3-D) @ 47 l/ha to a 25 cm soil depth. In 1975, crop yields from
fumigated plots of okra, tomatoes, cowpea and lettuce were 19 %, 20 %, 15 % and 52 % higher than yields obtained from nonfumigated plots respectively. While in 1976, fumigated plots of okra, tomatoes, lettuce and squash yielded 19 %, 13 %, 57 % and 69 % higher than corresponding nonfumigated plots respectively.

Study on effect of castor plant densities on the rate of *R. reniformis* multiplication was carried out by Mukhopadhyay and Haque (1979). Each pot contained 1, 2, or 3 castor seedlings and was inoculated with 7000 nematodes. Results indicated that nematode multiplication as well as plant growth/unit area was maximum in the treatment of 2 plants/pot and was minimum in 3 plants/pot treatment. Final nematode population increased by 10, 16 and 8 times in the treatment having 1, 2 or 3 plants/pot respectively.

Mahapatra and Padhi (1986) observed chickpea plants exhibiting symptoms of yellowing, stunting, poor development and browning of roots at 500 *R. reniformis* nematodes/kg soil. Plant growth was negatively correlated with nematode inoculum levels. There was generally a trend of decrease in rate of nematode multiplication with an increase in the level of infestation.

Different pigeonpea varieties showed variable reactions to *M. incognita* and *R. reniformis*. Losses in
plant weight, number of pods/plant, chlorophyll content of leaves and bulk density of stem parts were directly correlated with nematodes multiplication, the maximum being in susceptible varieties and minimum or no change in resistant ones by Anver and Alam (1989).

2.5 Determination of susceptible crop stage for *R. reniformis* infection on castor cv. GCH 4.

Reniform nematode has a wide host range and is distributed in almost all the subtropical and tropical countries including India. It causes severe damage to many crops including castor. Though pathogenicity, biology and control have been well studied, no much attempt has been made to investigate the role of crop age to nematode infection. Research work was not traceable on castor but on other crops with respect to this aspect by various researchers is summarised here.

Haque and Padmavathy (1985) reported that penetration of *R. reniformis* during 48 to 72 hrs was significantly different on two tomato cvs. Pusa Ruby and Patriot. The highest number of juveniles in roots was invariably observed after 96 hrs. Number of juveniles in 3, 4 and 5 WK old seedlings of varieties Pusa Ruby and Patriot at 96 hrs were 18.0, 10.0 and 5.75 and 35.5, 19.25 and 7.25 respectively. Obviously, the intensity of nematode...
penetration decreased with the seedling age in both the varieties. Similarly, they also observed that the number of *R. reniformis* juveniles penetrating the cowpea roots increased with time. The seedling age appeared to have an influence on penetration. This was markedly reflected in 3 WK old seedlings of both the cowpea varieties viz. Pusa Do Phasali and C 152.
MATERIALS
&
METHODS
III MATERIALS AND METHODS

3.1 Introduction.

Studies pertaining to the effects of reniform nematode, *Rotylenchulus reniformis*, on castor cvs. GAUCH 1 and GCH 4 with respect to (i) Interaction between *R. reniformis* and *Fusarium oxysporum f. ricini* on castor cv. GAUCH 1 and GCH 4; (ii) Interaction between *R. reniformis* and *Macrophomina phaseolina* on castor cv. GCH 4; (iii) Assessment of quantitative and qualitative losses due to *R. reniformis* in castor cv. GCH 4 and (iv) Determination of susceptible crop stage for *R. reniformis* infection on castor were carried out at the Department of Nematology, B. A. College of Agriculture, Gujarat Agricultural University, Anand Campus, Anand during 1992-93 through 1993-94.

3.2 Maintenance of pure culture of nematode.

*Rotylenchulus reniformis* culture maintained in 2.0 m x 1.0 m x 0.5 m size microplots at the Department of Nematology, B. A. College of Agriculture, Anand was multiplied by continuously providing nematode susceptible castor cv. GAUCH 1. Regular watering and after cares were taken from time to time. The nematode culture, thus, maintained on host crop in the microplots was used for conducting various research studies on castor cvs. GAUCH 1 and GCH 4.
3.3 Maintenance of pure cultures of fungi, *Fusarium oxysporum* f. *ricini* and *Macrophomina phaseolina*.

Plants affected by castor wilt and root-rot diseases caused by *Fusarium oxysporum* f. *ricini* and *Macrophomina phaseolina* respectively were collected from the castor fields at Castor Research Station, Gujarat Agricultural University, Sardar Krushinagar, Dist. Banaskantha and isolation of fungi was carried out on Potato Dextrose Agar (PDA) medium at the Department of Nematology, B.A. College of Agriculture, Gujarat Agricultural University, Anand. After getting these fungi in pure forms, pathogenicity tests were conducted on castor cv. GAUCH 1. Then after, both the fungi were subcultured and maintained on PDA regularly. For the purpose of inoculations in various studies conducted, both the fungi were multiplied on Potato Dextrose Broth (PDB) for 15 days in 250 ml erlenmeyer flasks.

3.4 Soil sterilization.

Sandy loam soil (Coarse sand 1.3 %, fine sand 63 %, silt 15 % and clay 20 %) was collected from the nearby fields of the Department of Nematology and sieved through 25 mesh sieve to remove bigger size stones and other matters. Then, it was filled in an aluminium tray of 45 cm x 30 cm x 15 cm size and steam sterilized at 1.4 kg/cm² pressure for three hours consecutively in mini soil
sterilizer (boiler) at Bidi Tobacco Research Station (BTRS), Gujarat Agricultural University, Anand Campus, Anand. This sterilized soil was used for conducting various research experiments.

3.5 Disinfestation of pots.

Earthen pots of 11, 18 and 21 cm diameters to accommodate 0.8, 4 and 8 kg soils respectively were washed with tap water and disinfested with 4% formaldehyde (formalin 40 EC) solution. Then pots were exposed for 15 minutes to evaporate formalin before they were being used for experimentation.

3.6 Extraction of nematodes.

To obtain Rotylenchulus reniformis J4 (preadult/immature stage), soil from the nematode maintained pure culture microplots was collected from the rhizosphere of susceptible crops and processed using Petri Dish Assembly Method (Chawla and Prasad, 1974). Nematodes, thus, obtained were used for inoculations in different studies.

3.7 Experiments.

3.7.1 Interaction between R. reniformis and wilt and root-rot causing fungi on castor cvs. GAUCH 1 and GCH 4.
3.7.1.1 Interaction between *R. reniformis* and *Fusarium oxysporum* f. *ricini* on castor cv. GAUCH 1.

3.7.1.1.1 Experimentation.

Experiment was conducted to study the effect of interaction between *R. reniformis* and *F. oxysporum* f. *ricini* using castor cv. GAUCH 1 (susceptible to wilt disease) during 1992-93 and 1993-94. The treatment consisted of *R. reniformis* alone (N); *Fusarium oxysporum* f. *ricini* alone (Fo); *R. reniformis* + *F. oxysporum* f. *ricini* simultaneously (N + Fo); *R. reniformis* followed by *F. oxysporum* f. *ricini* by four Wks (N-Fo); *F. oxysporum* f. *ricini* followed by *R. reniformis* by four Wks (Fo-N) and control - no nematode or fungus inoculation for comparison purpose, thus making total six treatments. These treatments were attempted in completely randomized design with six repetitions in net house at 22 to 36 °C temperature.

3.7.1.1.2 Procedure.

The earthen pots of 18 cm diameter were disinfested as mentioned under section 3.5 and filled with steam sterilized soil (4.0 kg/pot). Three seeds of castor cv. GAUCH 1 were seeded in the centre of each pot. On germination (2-3 cm height), plants were thinned down to one/pot.
Nematodes were extracted as mentioned under section 3.6 and were inoculated with 4,000 *R. reniformis* J4/pot as per the treatment details mentioned under section 3.7.1.1.1. Nematodes were inoculated in the rhizosphere of respective plant by making ring around plant stem.

The fungus, *F. oxysporum f. ricini*, grown on PDB as per section 3.3 was collected, dried at room temperature and suspended in 0.1 % tween solution prepared in distilled water (Vyas, 1988). Then the suspension was vigorously shaken manually for 15-20 minutes for fungal spores separations. Afterwards spore count was taken by Haemocytometer (Tuite, 1969). For fungus inoculation, the soil around plant collar region was removed carefully and fungus @ 1.8 x 10^8 spore concentration was inoculated in the rhizosphere of the respective plants as per the treatments. After fungus inoculation, soil removed earlier was again put back to the rhizosphere of each inoculated plant. This was carried out carefully without disturbing plant roots. For simultaneous inoculation of fungus and nematode, the soil around plant collar region was removed carefully and nematode and fungus inoculation was done. Uniform regular watering and cares were taken throughout the experimentation.

One hundred fifty days following inoculation, plants were carefully depotted, washed free of soil and used for recording observations.
3.7.1.1.3 Observations.

Observations were recorded on

(i) Plant height, cm,
(ii) fresh shoot and root weights, g,
(iii) numbers of females penetrated in the roots and numbers of eggmasses and eggs/plant root after staining roots in 0.1 % acid fuchsin lactophenol (Franklin, 1949),
(iv) soil nematode population/plant,
(v) total nematode population build up/plant and reproduction rate (pf/pi) and
(vi) number of wilted plants at weekly intervals.

Finally data were tabulated and subjected to statistical analysis using Duncan's New Multiple Range Test (DNMRT).

3.7.1.2 Interaction between *R. reniformis* and *Fusarium oxysporum f. ricini* on castor cv. GCH 4.

3.7.1.2.1 Experimentation.

The experimentation mentioned under section 3.7.1.1.1 was followed in this experiment also but castor cv. GCH 4 (resistant to wilt disease) was used.
3.7.1.2.2 Procedure.

The procedure mentioned under section 3.7.1.1.2 was totally followed in this experiment also.

3.7.1.2.3 Observations.

Observations listed under section 3.7.1.1.3 were recorded in this experiment also.

Finally data were tabulated and subjected to statistical analysis using Duncan's New Multiple Range Test (DNMRT).

3.7.1.3 Interaction between R. reniformis and Macrophomina phaseolina on castor cv. GCH 4.

3.7.1.3.1 Experimentation.

Experiment was carried out to study the interaction between R. reniformis and M. phaseolina using castor cv. GCH 4 during 1992-93 and 1993-94. The treatments consisted of R. reniformis alone (N); M. phaseolina alone (MP); R. reniformis + M. phaseolina simultaneously (N + MP); R. reniformis followed by M. phaseolina by four Wks (N - MP); M. phaseolina followed by R. reniformis by four Wks (MP-N); and control - no nematode and no fungus for comparison purpose, thus making total six treatments. The treatments were tried in completely randomized design with six repetitions in net house at 22 to 36°C temperature. This
study was conducted only with castor cv. GCH 4 and not with castor cv. GAUCH 1 separately as both the cultivars were susceptible to *Macrophomina phaseolina*.

### 3.7.1.3.2 Procedure.

The earthen pots of 18 cm diameter were disinfested as mentioned under section 3.5 and filled with steam sterilized soil (4.0 kg/pot). Three seeds of castor cv. GCH 4 were seeded in the centre of each pot. Upon seed germination (2-3 cm height), plants were thinned down to one/pot.

Nematodes after extracting from the soil as per procedure mentioned under section 3.6 were inoculated @ 4,000 *R. reniformis* J4/pot as per the treatments details under section 3.7.1.3.1. The nematodes were inoculated in the rhizosphere of respective plant by making ring around plant stem.

The *M. phaseolina* mat grown on PDB as per section 3.3 was collected separately from each culture flask and was passed through blotting paper to remove excess broth. In case of fungus inoculation, the soil around the plant collar region was taken out carefully without disturbing the roots and was mixed uniformly with 8 g mycelium fungus mat (4 x 10^3 sclerotia/2 g mat). This mixture was put back in the same rhizosphere of the respective plant. Then after, plants
were slightly watered. For concomitant inoculation of both nematode and fungus, the soil around plant collar region was removed carefully and nematode inoculation was done. The removed soil was mixed with 8 g mycelium mat uniformly and put back in the respective pots. Uniform regular watering and after cares were followed during the experimentation.

One hundred fifty days following inoculation, plants were carefully depotted, washed free of soil and used for recording observations.

3.7.1.3.3 Observations.

The observations mentioned under section 3.7.1.1.3 were recorded in this experiment also.

Finally data were tabulated and subjected to statistical analysis using Duncan's New Multiple Range Test (DNMRT).

3.7.2 Assessment of quantitative and qualitative losses due to \textit{R. reniformis} in castor cv. GCH 4.

3.7.2.1 Experimentation.

An experiment was conducted to study the yield losses induced by \textit{R. reniformis} (Rr.) infection separately in terms of plant growth characters, seed yield, oil percentage, chlorophyll content and alterations in
meteorological parameters in castor cv. GCH 4. The nematode inoculum levels tried were 500 and 1,000 Rr J₄/kg soil (4,000 J₄ and 8,000 J₄/kg soil/pot). Uninoculated plants served as control for comparison purpose. Thus, total three treatments were experimented in completely randomized design with six repetitions.

3.7.2.2 Procedure.

The earthen pots of 21 cm dia. were disinfested as mentioned under section 3.5 and filled with steam sterilized soil (8 kg/pot). Three seeds of reniform susceptible castor cv. GCH 4 were seeded in the centre of each pot. On seed germination (2-3 cm height), plants were thinned down to one/pot. Nematodes extracted (as per section 3.6) were carefully depipetted in each plant rhizosphere after making a ring around the stem as per treatments under section 3.7.2.1. Rings lateron were sealed with required steam sterilized soils. Plants were watered regularly and protected from insect-pests damage by spraying recommended insecticides as and when needed. Pots were subjected on cement concrete platform in net house at 22 to 36 °C temperature. After 150 days following nematode inoculation, mature capsules were harvested. Then plants were carefully depotted and washed free of soil with water in each treatment and used for recording observations.
3.7.2.3 Observations.

Observations were recorded on

(i) Plant height, cm,
(ii) fresh shoot and root weights, g,
(iii) numbers of females penetrated in the roots and numbers of eggs/plant root (Franklin, 1949),
(iv) soil nematode population/plant,
(v) total nematode population build up and reproduction rate (pf/pi),
(vi) yield, g/plant,
(vii) oil percentage (estimated through NMR),
(viii) estimation of chlorophyll a, b and total chlorophyll contents from leaf (Hicox and Israel stam, 1979) and
(ix) meteorological parameters using steady state porometer.

Finally, data were tabulated and subjected to statistical analysis using Duncan's New Multiple Range Test (DNMRT).

3.7.3 Determination of susceptible crop stage for R. reniformis infection on castor cv. GCH 4.
3.7.3.1 Experimentation.

Study was planned to find out most susceptible/vulnerable crop stage to *R. reniformis* infection in castor during 1992-93 and 1993-94 seasons. The nematodes were inoculated @ 500 J₄/plant/pot to castor plants of 15, 30, 45, 60, 75, 90, 105, 120, 135 and 150 days age. Total 10 different treatments of time durations were studied in completely randomized design repeated three times.

3.7.3.2 Procedure.

The earthen pots of 11 cm dia. were disinfested as mentioned under section 3.5 and filled with steam sterilized soil (0.8 kg/pot). Three seeds of reniform susceptible castor cv. GCH 4 were seeded in the centre of each pot upto 150 days at an increment of 15 days. On getting seed germination (2-3 cm height), plants were thinned down to one/pot. Plants were watered regularly and protected from insect-pests damage by spraying recommended insecticides as and when needed. On germination of last sowing interval i.e. at 150 days, nematodes extracted (as per section 3.6) were carefully depipetted in each plant rhizosphere after making a ring around the plant steam as per treatments under section 3.7.3.1. Rings later on were
sealed with sterilized soils. Ten days after nematode inoculation, plants were carefully depotted and washed free of soils with water in each treatment and then used for recording observations.

3.7.3.3 Observations.

Observation was recorded on numbers of females penetrated in the root tissues after staining roots in 0.1% acid fuchsin lactophenol (Franklin, 1949) in each treatment.
RESULTS & DISCUSSION
IV RESULTS AND DISCUSSION

Studies on reniform nematode, *Rotylenchulus reniformis*, affecting castor cvs. GAUCH 1 and GCH 4 with respect to i, interaction between *R. reniformis* and *Fusarium oxysporum* f. *ricini* on castor cvs. GAUCH 1 and GCH 4, ii, interaction between *R. reniformis* and *Macrophomina phaseolina* on castor cv. GCH 4, iii, assessment of quantitative and qualitative losses due to *R. reniformis* in castor cv. GCH 4 and iv, determination of susceptible crop stage of castor to *R. reniformis* infection were conducted at the Department of Nematology, B.A. College of Agriculture, Gujarat Agricultural University, Anand during 1992-93 through 1993-94. Results obtained from these studies are presented and discussed in the subsequent sections.

4.1 EXPERIMENTS.

4.1.1 Interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on castor cvs. GAUCH 1 and GCH 4.

4.1.1.1 Interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on castor cv. GAUCH 1.

Significant differences were obtained due to different treatments for all the characters under study viz. plant height, fresh shoot and root weights during 1992-93 and 1993-94 (Table 1, Plate 1 A & B).
PLATE 1 : EFFECT OF INTERACTION BETWEEN R. RENIFORMIS AND F. OXYSPORUM F. RICINII ON SHOOT (A) AND ROOT (B) DEVELOPMENT OF CASTOR CV. GAUCH 1
During 1992-93, plant height was significantly less in plants inoculated with *R. reniformis* (N) @ 4,000 J4/plant followed by 4 wks inoculation of *F. oxysporum f. ricini* (Fo) @ 1.8 x 10^8 fungal spores/plant (N-Fo) and nematode and fungus inoculated simultaneously (N + Fo), there being no significant differences between them (Table 1). Plants inoculated with either nematode (N) or fungus (Fo) alone or fungus inoculation followed by 4 wk inoculation of nematode (Fo-N) had mediocre effect on plant height. Control (uninoculated) plants had significantly more plant height over other treatments.

Almost similar trend as observed during 1992-93 was observed for plant height barring Fo treatment which was at par with control-uninoculated plants during 1993-94 (Table 1).

Data pooled for two years also indicated similar trend for plant height as observed during 1993-94. (Fig. 1).

All the treatments under study gave significantly less fresh shoot weight over control treatment during 1992-93 and 1993-94. During 1992-93, fresh shoot weight was minimum in N-Fo treatment followed by N + Fo, N and Fo - N treatments, being not differing statistically from each other. The treatment of fungus alone (Fo) had mediocre effect on fresh shoot weight. Control plants had
Table 1: Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on growth and development of castor cv. GAUCH 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant height, cm</th>
<th>Fresh weight, g/plant</th>
<th>Shoot</th>
<th>Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>39.97&lt;sup&gt;b&lt;/sup&gt;</td>
<td>53.23&lt;sup&gt;b&lt;/sup&gt;</td>
<td>46.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.32&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>F&lt;sub&gt;0&lt;/sub&gt;</td>
<td>44.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>59.99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.87&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>N + F&lt;sub&gt;0&lt;/sub&gt;</td>
<td>28.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>46.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>17.91&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>N - F&lt;sub&gt;0&lt;/sub&gt;</td>
<td>28.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>38.52&lt;sup&gt;c&lt;/sup&gt;</td>
<td>33.28&lt;sup&gt;c&lt;/sup&gt;</td>
<td>17.34&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>F&lt;sub&gt;0&lt;/sub&gt; - N</td>
<td>38.95&lt;sup&gt;b&lt;/sup&gt;</td>
<td>54.88&lt;sup&gt;b&lt;/sup&gt;</td>
<td>46.92&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.18&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>60.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>88.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>74.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>50.77&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

S. Em. 3.93 8.98 5.27 4.76 5.32 5.62 3.73 2.14 2.27  
Year - - ns - - ns - - ns  
Y x T - - ns - - S - - ns  
C.V. % 24.1 36.9 34.1 42.0 30.6 35.1 37.9 20.8 30.1  

*N = Rotylenchulus reniformis; F<sub>0</sub> = Fusarium oxysporum f. ricini*

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.
Fig. 1 Effect of interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on growth and development of castor cv. GAUCH 1

Height, cm.; Weight, g.

- **Fresh root wt.**
- **Fresh shoot wt.**
- **Plant ht.**

N : *R. reniformis* @ 4000 J4/4 kg soil/plant

Fo : *F. oxysporum* f. *ricini* @ 1.8x10^8 spores/4 kg soil/plant
significantly more fresh shoot weight (Table 1), while in 1993-94, fresh shoot weight of plants was minimum in N + Fo treatment followed by N - Fo and Fo - N treatments, being statistically at par with each other over control. However, N and Fo - N treatments remained statistically at par with each other. But Fo treatment had mediocre effect. Control plants had significantly more fresh shoot weight (Table 1).

However, pooled data for fresh shoot weight for two years indicated almost similar trend as observed during 1992-93 season (Fig. 1).

For fresh root weight recorded during 1992-93, the treatment differences were significant among various treatments. It was significantly more in control-uninoculated treatment over other treatments. Significantly less fresh root weight was recorded in N - Fo treatment followed by N + Fo, Fo - N and N treatments, being not differing statistically from each other over control. However, Fo, N and Fo - N treatment had mediocre effects on fresh root weight and did not differ statistically from each other. Almost same trend of observations was noticed in fresh root weight among various treatments during 1993-94 (Table 1).

Two years pooled data also indicated that fresh root weight was significantly less in the treatment of N + Fo followed by N - Fo, N and Fo - N treatments, there
being no significant differences between them. However, the $F_o$ treatment had mediocre effects, but did not differ significantly with $F_o - N$ treatment. Control (uninoculated) plants had significantly maximum fresh root weight over other treatments (Table 1, Fig. 1, Plate 1 B). Hence, overall findings indicated that $N + F_o$ and $N - F_o$ treatments had significantly more depressing effects on plant growth and development of castor cv. GAUCH 1 than that of $N$ or $F_o$ or $F_o - N$ treatment. Control (uninoculated) plants had significantly more plant growth over other treatments.

With regard to reproduction of *R. reniformis* (Table 2) during 1992-93, 1993-94 and pooled data, nematode ($N$) alone treatment produced maximum numbers of females, eggs soil and total population build up/plant as expected followed by $N + F_o$ and $N - F_o$ treatments. While $F_o - N$ treatment had lowest numbers of females, eggs and soil as well as total population build up/plant. The possible existence of nematoxic antimetabolites produced by the fungus could be responsible for reduced reproductive units for $F_o - N$ treatment. Similar findings were also recorded by Mani and Sethi (1984), and Sakhuja and Sethi (1986) in cotton crop.
Table 2: Effect of interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on nematode reproduction on castor cv. GAUCH 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Root (Females + Eggs)</th>
<th>Soil larvae</th>
<th>Total</th>
<th>Reproduction rate</th>
<th>% decrease over nematode alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>23,456</td>
<td>25,705</td>
<td>24,581</td>
<td>16,62,233</td>
<td>20,42,400</td>
</tr>
<tr>
<td>Fo</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>N + Fo</td>
<td>18,441</td>
<td>22,269</td>
<td>20,355</td>
<td>14,67,333</td>
<td>17,37,000</td>
</tr>
<tr>
<td>N - Fo</td>
<td>18,867</td>
<td>21,888</td>
<td>20,378</td>
<td>11,11,333</td>
<td>16,94,000</td>
</tr>
<tr>
<td>Fo - N</td>
<td>8,338</td>
<td>10,728</td>
<td>9,533</td>
<td>3,13,333</td>
<td>8,12,907</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*N = Rotylenchulus reniformis; Fo = Fusarium oxysporum f. ricini*
There was maximum (469 times) *R. reniformis* multiplication on plants inoculated with N alone, next in order being N + Fo treatment (406 times) followed by N - Fo treatment (356 times). Treatment Fo - N recorded lowest nematode reproduction rate (143 times).

Based on the total nematode population build up/plant in different treatments, it was observed that Fo - N treatment had 69.49 % less nematode reproduction followed by N - Fo (24.18 %) and N + Fo (13.55 %) over nematode alone. Here also, it is quite clear that antitoxins produced by fungus had played a major role in suppressing nematode population and hence, there was maximum of 69.49 % reduction in nematode reproduction on castor cv. GAUCH 1 (Table 2, Fig. 2).

For per cent wilted castor plant due to various treatments under study during 1992-93, it was observed that Fo treatment alone induced plant mortality from 4\textsuperscript{th} wk and it continued further giving a total of 33.3 % plant mortality upto 16\textsuperscript{th} wk of fungus inoculation (Table 3). This proved that Fo used for inoculation is sufficiently virulent to cause wilt disease in castor cv. GAUCH 1. However, plant mortality started from 4\textsuperscript{th} wk of fungus inoculation, three weeks earlier than Fo alone, in N + Fo and N - Fo treatments which gave total plant mortality of 50 %. Time for first disease appearance did not vary between
Fig. 2 Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on nematode reproduction on castor cv. GAUCH 1

Nematode population/plant (Millions)

- Root (Females & Eggs)
- Soil larvae
- Total

N: *R. reniformis* @ 4000 J4/4 kg soil/plant
Fo: *F. oxysporum f. ricini* @ 1.8x10^a spores/4 kg soil/plant
Fo alone and Fo - N treatments. However, disease intensity varied and it was 33.3 and 50.0 % in Fo and Fo - N treatments respectively. With an increase in time duration, the plant mortality also invariably increased, maximum plant mortality of 50.0 % being recorded uniformly in N + Fo, N - Fo and Fo - N treatments over Fo treatment which had 33.3 % plant mortality (Table 3).

During 1993-94 also, it was observed that Fo alone induced plant mortality from 4th wk and continued further giving a total of 33.3 % plant mortality upto 16th wk of fungus inoculation. The plant mortality started from 1st wk following fungus inoculation, three weeks earlier than Fo alone, in N + Fo, N - Fo and Fo - N treatments which had total plant mortality of 66.6, 50.0 and 50.0 % respectively (Table 3).

As observed during 1993-94, it was also noticed that with an increase in time duration, plant mortality also invariably increased (Table 3). The maximum plant mortality of 66.6 % was recorded in N + Fo treatment over other treatments.

Pooled data of 1992-93 and 1993-94 depicted in Table 4 also indicated that maximum plant mortality of 58.3% was recorded in N + Fo treatment followed by 50.0 % in each of the N - Fo and Fo - N treatments. This clearly indicated that R. reniformis might have certainly favoured the entry.
Table 3: Effect of interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on occurrence of wilt disease in castor cv. GAUCH 1

<table>
<thead>
<tr>
<th>Treatment</th>
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<tr>
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(1992-93)

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(1993-94)

N = *Rotylenchulus reniformis*; F0 = *Fusarium oxysporum* f. *ricini*
Table 4: Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on occurrence of wilt disease in castor cv. GAUCH 1 during 1992-93 and 1993-94

(Summary)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total plant mortality (%)</th>
<th>% increase over fungus alone</th>
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<tr>
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<td>1992-93</td>
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<tr>
<td>N</td>
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</tr>
<tr>
<td>Control</td>
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<td>00.0</td>
</tr>
</tbody>
</table>

N = *Rotylenchulus reniformis*;
Fo = *Fusarium oxysporum f. ricini*
of fungus easily and profusely due to nematode injury on the roots, which has resulted 75% increased in plant mortality over fungus inoculation alone (Table 4). Whereas, there was 50% increase in plant mortality in each of N - Fo and Fo - N treatments. When both the pathogens were inoculated simultaneously and one after another, fungus could have fully penetrated in the roots because of avenues created by nematode feeding on the roots. This authentically proved that R. reniformis had played a positive role in aggravating F. oxysporum f. ricini for early production of wilt disease in castor.

Present findings of the study indicated that uninoculated control plants had maximum plant height, fresh shoot and root weights over other treatments. Plant height was significantly less in N - Fo treatment followed by N + Fo treatment. While fresh shoot and root weights were minimum in N + Fo treatment followed by N - Fo, Fo - N and N treatments, there being no significant differences between them. Similar findings could not be traced in the literature on castor. However, Tachatchoua and Sikora (1978) observed reduction in cotton plant growth due to combined effects of Verticillium dahliae and R. reniformis. With regard to R. reniformis reproduction, N alone treatment produced maximum numbers of females, eggs, soil and total nematode population.
build up/plant followed by N + F₀ treatment. The treatment of N - F₀ had third highest nematode population. While F₀ - N treatment had lowest numbers of females, eggs, soil and total population of *R.* reniformis. Salem (1980) also observed reduction in *M.* incognita reproduction and gall formation on cotton in the presence of *Fusarium* fungus.

For per cent castor (GAUCH 1) wilted plants due to various treatments under study, findings indicated that F₀ alone treatment induced plant mortality from 4ᵗʰ wk and continued further giving a total of 33.3 % plant mortality upto 16ᵗʰ wk of fungus inoculation. However, plant mortality started from 1ˢᵗ wk of fungus inoculation, three weeks earlier than F₀ alone, in the treatments of N + F₀ and N - F₀. The maximum plant mortality of 58.3 % was recorded in the treatment of N + F₀ over other treatments and there was 75 % increase in plant mortality over fungus inoculation alone. While there was 50 % increase in plant mortality in each of N - F₀ and F₀ - N treatments. Tachatchoua and Sikora (1978) reported synergistic effect on wilt intensity due to interaction of *Verticillium* dahliae and *R.* reniformis in cotton. Krishnaprasad and Padaganur (1980) also observed the higher *Verticillium* wilt disease intensity in the presence of *R.* reniformis on cotton crop.
4.1.1.2 Interaction between R. reniformis and F. oxysporum f. ricini on castor cv. GCH 4.

Significant differences were obtained due to different treatments for all the characters viz. plant height, fresh shoot and root weights (Table 5 plate 2 A & B). Plant height was significantly less in the treatment of plants inoculated with R. reniformis alone (N) @ 4,000 J4/plant followed by R. reniformis (N) @ 4,000 J4/plant and F. oxysporum f. ricini (Fo) @ 1.8 x 10^8 spores/plant inoculated simultaneously (N + Fo) and R. reniformis (N) followed by 4 wk inoculation of F. oxysporum f. ricini (Fo) treatment (N - Fo), both being at par with each other. Fungus inoculation followed by 4th wk inoculation of R. reniformis treatment (Fo - N) had mediocre effect on plant height. Control (uninoculated) plants had maximum plant height followed by F. oxysporum f. ricini alone (Fo) over other treatments during 1992-93. For 1993-94, plant height was also significantly less in the treatment of N alone followed by N - Fo and N + Fo treatments, there being no significant differences between them. The Fo - N treatment had mediocre effect on plant height and was statistically at par with N + Fo and N - Fo treatments. Control plants had maximum plant height over other treatments. However, it was statistically at par with Fo alone treatment (Table 5).
PLATE 2: EFFECT OF INTERACTION BETWEEN

R. RENIFORMIS AND F. OXYSPORUM

F. RICINI ON SHOOT (A) AND ROOT (B)

DEVELOPMENT OF CASTOR CV. GCH 4
Pooled data for 1992-93 and 1993-94 (Table 5, Fig. 3) also indicated that plant height was significantly less in N treatment alone, followed by N - F₀ and N + F₀ treatments, there being no significant differences between them. Treatment of F₀ - N had mediocre effect on plant height and did not differ statistically from N + F₀ treatment. Control (uninoculated) plants recorded maximum plant height over other treatments and was statistically at par with F₀ treatment.

In case of fresh shoot weight recorded during 1992-93, N treatment alone had minimum weight followed by N - F₀ and N + F₀ treatments, being not differing statistically from each other. Treatment of F₀ - N had mediocre effect and was at par with the treatments of N + F₀ and F₀ including control (uninoculated) plants. As expected control plants had maximum fresh shoot weight over other treatments (Table 5).

For shoot weight also, it was minimum in case of N treatment followed by N - F₀ treatment, both being at par with each other during 1993-94. The treatments of N + F₀, N - F₀ and F₀ - N had mediocre effect and did not differ statistically from each other. Plants under control treatment had maximum fresh shoot weight followed by the treatments of F₀, N + F₀ and F₀ - N, there being no significant differences between them (Table 5).
Pooled data for 1992-93 and 1993-94 also indicated that minimum shoot weight was recorded in N treatment followed by the treatments of N - Fo and N + Fo, there being no significant differences between them. The treatments of N - Fo, N + Fo, Fo - N and Fo alone had mediocre effect and were statistically at par with each other. Control plants as expected recorded maximum shoot weight over other treatments and were at par with Fo alone, N + Fo and Fo - N treatments (Table 5, Fig. 3).

With regard to fresh root weight, it was minimum in N treatment followed by N + Fo and N - Fo treatments, there being no significant differences between them. The treatment of Fo - N had mediocre effect on fresh root weight and was statistically at par with N - Fo treatment. Maximum fresh root weight was recorded in control plants which were at par with Fo treatment during 1992-93.

Almost same trend as observed during 1992-93 was recorded for fresh root weight during 1993-94 as well except for N + Fo treatment which had mediocre effect (Table 5).

Looking to the pooled data for 1992-93 and 1993-94, the fresh root weight was minimum in N treatment alone followed by the treatments of N + Fo, N - Fo and Fo - N which had mediocre effects and were statistically at par with each other. Here also as expected, control plants
Table 5: Effect of interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on growth and development of castor cv. GCH 4

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant height, cm</th>
<th>Fresh weight, g/plant</th>
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</thead>
<tbody>
<tr>
<td>N</td>
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<td>60.83&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>F&lt;sub&gt;0&lt;/sub&gt;</td>
<td>62.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100.02&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>N + F&lt;sub&gt;0&lt;/sub&gt;</td>
<td>41.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>74.02&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
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<td>N - F&lt;sub&gt;0&lt;/sub&gt;</td>
<td>40.77&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
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<td>51.90&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80.18&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>64.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100.45&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

S.E.m.  | 2.63  | 5.01  | 3.09  | 2.43  | 6.92  | 6.61  | 2.96  | 3.49  | 2.55  |
Year     | -     | -     | ns    | -     | -     | ns    | -     | -     | ns    |
Y x T    | -     | -     | ns    | -     | s     | -     | ns    | -     | -     |
C.V. %   | 12.9  | 15.3  | 15.1  | 21.6  | 26.8  | 28.0  | 22.7  | 23.0  | 22.9  |

N = *Rotylenchulus reniformis*; F<sub>0</sub> = *Fusarium oxysporum* f. *ricini*

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.
Fig. 3 Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on growth and development of castor cv. GCH 4

Height, cm.; Weight, g.

- Fresh root wt.
- Fresh shoot wt.
- Plant ht.

N: *R. reniformis* @ 4000 J4/4 kg soil/plant

Fo: *F. oxysporum f. ricini* @ 1.8x10^8 spores/4 kg soil/plant
had maximum fresh root weight followed by Fo treatment, there being no significant differences between them (Table 5, Fig. 3).

With regard to *R. reniformis* reproduction on castor cv. GCH 4 (Table 6) during 1992-93, 1993-94 and in pooled data, N treatment produced maximum numbers of females, eggs, soil and total nematode population build up/plant followed by N + Fo treatment, whereas Fo - N treatment had lowest numbers of females, eggs, soil and total nematode population build up/plant.

Nematodes reproduced maximum (523 times) in the treatment of N alone. Next in order was N + Fo treatment (450 times) followed by N - Fo treatment (435 times). Reproduction rate was least in Fo - N treatment (100 times) where perhaps nematodes might have been reduced by the effect of mycotoxins produced by fungus. Hence, Fo - N treatment recorded highest nematode reduction of 80.89 % over N treatment alone. Whereas other treatments of N + Fo and N - Fo had 13.83 and 16.80 % reduction in nematode reproduction rate respectively (Table 6, Fig. 4).

With regard to per cent wilted plants due to various treatments under study, it was observed that Fo alone treatment did not produce the disease and hence did not give any plant mortality even at the end of the
Table 6: Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on nematode reproduction on castor cv. GCH 4

<table>
<thead>
<tr>
<th>Treatment</th>
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<th>Reproduction rate</th>
<th>% decrease over nematode alone</th>
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<td>Root (Females + Eggs)</td>
<td>Soil larvae</td>
<td>Total</td>
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<td>19,453 34,502 26,978</td>
<td>17,46,067 23,82,000</td>
<td>20,64,034</td>
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<td>0 0 0 0</td>
<td>0 0</td>
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</table>

N = *Rotylenchulus reniformis*; Fo = *Fusarium oxysporum f. ricini*
Fig. 4 Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on nematode reproduction on castor cv. GCH 4

Nematode population/plant (Millions)

- Root (Females & Eggs)
- Soil larvae
- Total

N : *R. reniformis* @ 4000 J4/4 kg soil/plant
Fo : *F. oxysporum f. ricini* @ $1.8 \times 10^8$ spores/4 kg soil/plant
experiment. This may be due to the fact that GCH 4 variety reported to be resistant to *F. oxysporum f. ricini* maintained its resistance in the present study also. While inoculation of nematode and fungus together (N + F₀) produced the disease and thereby had plant mortality started from 6ᵗʰ wk and continued further giving a total of 33.3% plant mortality upto 16ᵗʰ wk following fungus inoculation. Whereas in case of N - F₀ treatment, plant mortality started from 5ᵗʰ wk of fungus inoculation, one week earlier than N + F₀ treatment and it was also 33.3 % upto 16ᵗʰ wk of fungus inoculation indicating no differences in per cent plant mortality in both the treatments. But wilt disease in plants under F₀ - N treatment started from 9ᵗʰ wk, four weeks later than N - F₀ treatment and it was to the extent of 16.7 %. With an increase in time duration the plant mortality also invariably increased (Table 7).

In 1993-94 also, wilt disease started in the treatments of N + F₀, N - F₀ and F₀ - N from 7ᵗʰ, 6ᵗʰ and 10ᵗʰ wks after fungus inoculation giving 16.7, 33.3 and 16.7% plant mortality respectively (Table 7).

The data averaged for two years (1992-93 and 1993-94) indicated maximum plant mortality of 33.3 % in N - F₀ treatment. This indicated that *R. reniformis* inoculated four weeks preceding *F. oxysporum f. ricini* inoculation might have favoured the fungus entry freely and profusely.
Table 7: Effect of interaction between *R. reniformis* and *F. oxysporum f. ricini* on occurrence of wilt disease in castor cv. GCH 4

| Treatment | Weeks after fungus inoculation | Total plant mortality (%)
<table>
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<tr>
<th></th>
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<tbody>
<tr>
<td></td>
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<td>(1992-93)</td>
</tr>
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<td>N</td>
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<td>100.0</td>
</tr>
<tr>
<td>Fo</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0</td>
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<tr>
<td>N + Fo</td>
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<tr>
<td>N - Fo</td>
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<tr>
<td>Fo - N</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 16.7 16.7 16.7 16.7 16.7 16.7 16.7 16.7</td>
<td>16.7</td>
</tr>
<tr>
<td>Control</td>
<td>0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

|           | 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 | (1993-94)                |
| N         | 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 | 100.0                   |
| Fo        | 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 | 0.0                     |
| N + Fo    | 0.0 0.0 0.0 0.0 0.0 16.7 16.7 16.7 16.7 16.7 16.7 16.7 16.7 16.7 16.7 | 16.7                   |
| N - Fo    | 0.0 0.0 0.0 0.0 16.7 33.3 33.3 33.3 33.3 33.3 33.3 33.3 33.3 33.3 33.3 | 33.3                   |
| Fo - N    | 0.0 0.0 0.0 0.0 0.0 0.0 0.0 16.7 16.7 16.7 16.7 16.7 16.7 16.7 16.7 | 16.7                   |
| Control   | 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 | 0.0                     |

*N* = *Rotylenchulus reniformis*; *Fo* = *Fusarium oxysporum f. ricini*
Table 8: Effect of interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on occurrence of wilt disease in castor cv. GCH 4 during 1992-93 and 1993-94 (Summary)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total plant mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1992-93</td>
</tr>
<tr>
<td>N</td>
<td>00.0</td>
</tr>
<tr>
<td>Fo</td>
<td>00.0</td>
</tr>
<tr>
<td>N + Fo</td>
<td>33.3</td>
</tr>
<tr>
<td>N - Fo</td>
<td>33.3</td>
</tr>
<tr>
<td>Fo - N</td>
<td>16.7</td>
</tr>
<tr>
<td>Control</td>
<td>00.0</td>
</tr>
</tbody>
</table>

N = *Rotylenchulus reniformis*;
Fo = *Fusarium oxysporum* f. *ricini*
due to injury caused by nematode feeding on crop roots. While, N + Fo and Fo-N treatments also recorded plant mortality to the tune of 25.0 and 16.7 % respectively. But there was no plant mortality at all in the treatment of F. oxysporum f. ricini alone due to wilt resistance in GCH 4 variety as mentioned earlier (Table 8).

Pooled data (Table 5) indicated that control (uninoculated) plants had maximum plant height over other treatments. While it was significantly less in the treatment of N followed by N - Fo and N + Fo treatments, there being no significant differences between them. Efficacywise, Fo - N treatment had mediocre effect on plant height but did not differ statistically from N + Fo treatment. For fresh shoot weight also, N treatment alone had minimum shoot weight followed by N + Fo and N - Fo treatments, both being statistically at par with each other. The treatments of N - Fo, N + Fo, Fo - N and Fo alone had mediocre effect. Plants under control treatment had maximum shoot weight over other treatments. The maximum fresh root weight was observed in control plants followed by Fo treatment, there being no significant differences between them. However, minimum fresh root weight was observed in N treatment alone followed by the treatments of N + Fo, N - Fo and Fo - N, there being no significant differences between them due to castor cv. GCH 4 which is resistant to F. oxysporum f. ricini, causal agent.
of castor wilt disease and hence, fungus did not induce wilt disease in GCH 4 cultivar. Similar observations were recorded by Tachatchoua and Sikora (1978) who reported reduction in plant growth because of combined infection of 5,000 and 10,000 *R. reniformis* larvae with 60 and 90 x 10^6 concentrations of *Verticillium dahliae* Conidia in cotton crop.

For nematode reproduction, it was observed that N alone treatment produced maximum numbers of soil and total nematodes populations build up/plant followed by N + Fo treatment. But the numbers of females and eggs were maximum in N + Fo treatment followed by N - Fo treatment. This perhaps might be due to the wilt resistance nature of GCH 4 variety. Treatment of Fo - N had lowest numbers of females, eggs, soil and total nematodes population of *R. reniformis* due to toxic effect of fungus on nematode reproduction. As a result, there was 80.89 % decrease in nematode reproduction rate over nematode alone. The nematode reproduction rate was decreased by 13.83 and 16.80 % in N + Fo and N - Fo treatments respectively over nematode alone. Salem (1980) also reported that the presence of *Fusarium* has negatively affected *M. incognita* reproduction and its gall formation. For per cent wilted plants, it was observed that Fo treatment alone did not produce wilt disease in plants because of wilt resistant nature of GCH 4 variety. But the
fungus, *F. oxysporum f. ricini*, when inoculated with *R. reniformis* either simultaneously or sequentially easily produced wilt disease. This may be due to fact that fungus alone did not produce disease but nematode injury might have favoured the fungus entry to produce wilt disease. Plants in *N - Fo* treatment started mortality symptoms from 5th and 6th wk and continued further giving a total of 33.3 % plant mortality upto 16th wk of fungus inoculation during 1992-93 and 1993-94 respectively, one week earlier than *N + Fo* treatment during both the years. However in *Fo - N* treatment, plant mortality was recorded at later stage and disease intensity was also comparatively less as compared to *N - Fo* and *N + Fo* treatments. Two years average data also indicated that the highest wilt disease of 33.3 % was recorded in *N - Fo* treatment followed by 25.0 % wilt disease in *N + Fo* treatment. It was lowest in *Fo - N* treatment. Similar trend was noticed by Minton et al. (1964) who reported that *Fusarium* wilt disease incidence was significantly increased by *R. reniformis* infection on cotton crop. Khadar et al. (1972) also reported that wilt resistant cotton varieties such as Giza 66, 67 and 69 showed an increase in *Fusarium* infection in the presence of *R. reniformis*. Such findings were also observed by EL-Gindi et al. (1974) who reported *R. reniformis* associated with *F. oxysporum f. vas Infectum* increased susceptibility of a few wilt resistant Egyptian cotton varieties.
4.2. Interaction between *R. reniformis* and *Macrophomina phaseolina* on castor cv. GCH 4.

Significant differences were obtained for all the growth characters such as plant height, fresh shoot and root weights during 1992-93 (Table 9, Plate 3 A & B). Plant height was significantly less in the plants inoculated with *R. reniformis* alone (N) @ 4000 J4/plant followed by the plants inoculated with *R. reniformis* (N) @ 4000 J4/plant preceding 4 wks inoculation of *M. phaseolina* (Mp) @ 8 g mycelial mat/plant (N - Mp), nematode and fungus inoculated simultaneously (N + Mp), *M. phaseolina* inoculation 4 wks preceding to *R. reniformis* inoculation (Mp - N) and inoculation of *M. phaseolina* alone (Mp), all treatments being statistically at par with each other. Control (uninoculated) plants gave significantly more plant height over other treatments barring Mp alone and Mp - N treatments.

But during 1993-94, the plant height was significantly less in N + Mp treatment followed by the treatments of N - Mp, N alone and Mp - N, being not differing significantly from each other. However Mp - N, Mp alone and N alone treatments had mediocre effects on plant height and did not differ significantly from each other. Plants under control treatment had significantly more plant height over other treatments.
PLATE 3: EFFECT OF INTERACTION BETWEEN

*R. reniformis* AND *MACROPHOMINA PHASEOLINA* ON SHOOT (A) AND ROOT (B)

DEVELOPMENT OF CASTOR CV. GCH 4
Results when pooled for 1992-93 and 1993-94 had similar trend of treatment efficacy as indicated for plant height character observed during 1992-93 (Table 9, Fig. 5).

During 1992-93, fresh shoot weight was significantly less in N alone treatment followed by the treatments of N - Mp and N + Mp, there being no significant differences between them (Table 9). However, treatments of N + Mp and Mp - N had mediocre effects on fresh shoot weight and were statistically at par with each other. While Mp alone and Mp - N treatments were statistically at par and ranked in third category according to the reduction of fresh shoot weight, significantly more fresh shoot weight was obtained in control plants over other treatments followed by Mp alone treatment, both being at par with each other.

In 1993-94, fresh shoot weight was significantly less in N alone treatment followed by N + Mp, N - Mp and Mp - N treatments, there being no significant differences between them. The treatment of Mp - N had mediocre effect on fresh shoot weight and was at par with Mp alone treatment. As expected, control (uninoculated) plants gave maximum shoot weight over other treatments and remained statistically at par with Mp alone treatment.

Pooled data of 1992-93 and 1993-94 for fresh shoot weight also indicated that minimum fresh shoot weight was
recorded in N alone treatment followed by N + Mp and N - Mp treatments there being no significant differences between them. The Mp - N treatment had mediocre effect on shoot weight but was at par with Mp alone treatment. Control plants had significantly more fresh shoot weight as compared to other treatments (Table 9, Fig. 5).

Looking to the fresh root weight recorded during 1992-93, it was observed that significantly less fresh root weight was obtained in N - Mp treatment followed by the treatments of N alone, N + Mp, Mp - N and Mp alone, there being no significant differences between them. Like other characters here also, control plants had similarly more fresh root weight over other treatments and was at par with Mp alone treatment (Table 9).

For 1993-94, it was significantly less in N + Mp treatment followed by N - Mp, N alone and Mp - N treatments, being not differing significantly from each other. The Mp alone treatment had mediocre effect on fresh root weight and was at par with Mp - N treatment. As expected control plants recorded significantly more fresh root weight as compared to other treatments barring Mp alone treatment (Table 9).

Pooled data also indicated that fresh root weight was significantly less in N + Mp treatment followed by N - Mp, N alone, Mp alone and Mp - N treatments, all being at
Table 9: Effect of interaction between *R. reniformis* and *M. phaseolina* on growth and development of castor cv. GCH 4

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant height, cm</th>
<th>Fresh weight, g/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>30.30^b</td>
<td>63.63^bc</td>
</tr>
<tr>
<td>MP</td>
<td>42.08^ab</td>
<td>82.82^b</td>
</tr>
<tr>
<td>N + MP</td>
<td>32.42^b</td>
<td>51.23^c</td>
</tr>
<tr>
<td>N - MP</td>
<td>30.60^b</td>
<td>57.23^c</td>
</tr>
<tr>
<td>MP - N</td>
<td>35.62^ab</td>
<td>71.82^bc</td>
</tr>
<tr>
<td>Control</td>
<td>47.68^a</td>
<td>106.00^a</td>
</tr>
</tbody>
</table>

| S.Em. | 3.31 | 5.77 | 6.75 | 3.14 | 6.06 | 3.84 | 1.86 | 3.21 | 4.03 |
| Year  | -    | -    | ns   | -    | -    | ns   | -    | -    | ns   |
| Y x T | -    | -    | s    | -    | -    | ns   | -    | -    | s    |
| C.V. %| 22.2 | 19.6 | 21.2 | 26.0 | 30.8 | 33.4 | 28.0 | 28.3 | 29.1 |

N = *Rotylenchulus reniformis*; MP = *Macrophomina phaseolina*

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.
Fig. 5 Effect of interaction between *R. reniformis* and *M. phaseolina* on growth and development of castor cv. GCH 4

Height, cm.; Weight, g.

- Fresh root wt.
- Fresh shoot wt.
- Plant ht.

N : *R. reniformis* @ 4000 J4/4 kg soil/plant
Mp : *M. phaseolina* @ 8 g mycelium mat/4 kg soil/plant
par statistically with each other (Table 9). As usual, control plants recorded maximum fresh root weight and was at par with Mp - N and Mp alone treatments (Fig. 5).

With regard to *R. reniformis* reproduction for individual and two years average data (Table 10), it was observed that N alone treatment produced maximum numbers of females, eggs, soil and total nematode population build up/plant closely followed by N + Mp treatment. The treatment of N - Mp ranked third in nematode reproduction rate. Whereas Mp - N treatment recorded minimum numbers of females, eggs, soil and total nematode population/plant (Table 10, Fig. 6).

There was maximum of 528 times *R. reniformis* reproduction in the plants inoculated with *R. reniformis* alone. Next in order was N + Mp treatment (484 times) followed by N - Mp treatments (401 times). The treatment of Mp - N had lowest (168 times) reproduction rate as compared to other treatments where perhaps nematode population might have been reduced due to the toxins produced by fungus (Table 10).

In terms of per cent decrease of nematode reproduction rate, it was observed that highest of 68.25 % was noticed in Mp - N treatment over nematode alone. The N + Mp and N - Mp treatments had 8.32 and 24.09 % decrease in nematode reproduction rate respectively (Table 10).
Table 10: Effect of interaction between *R. reniformis* and *M. phaseolina* on nematode reproduction on castor cv. GCH 4

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Root (Females + Eggs)</th>
<th>Soil larvae</th>
<th>Total</th>
<th>Reproduction rate</th>
<th>% decrease over nematode alone</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>18,267</td>
<td>22,090</td>
<td>20,179</td>
<td>16,23,533</td>
<td>26,58,267</td>
</tr>
<tr>
<td>MP</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>N + MP</td>
<td>14,702</td>
<td>21,249</td>
<td>17,976</td>
<td>12,28,300</td>
<td>26,06,800</td>
</tr>
<tr>
<td>N - MP</td>
<td>11,192</td>
<td>16,742</td>
<td>13,967</td>
<td>11,00,100</td>
<td>20,76,800</td>
</tr>
<tr>
<td>MP - N</td>
<td>12,442</td>
<td>8,630</td>
<td>10,536</td>
<td>3,70,251</td>
<td>9,48,800</td>
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<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*N = Rotylenchulus reniformis; MP = Macrophomina phaseolina*
Fig. 6 Effect of interaction between *R. reniformis* and *M. phaseolina* on nematode reproduction on castor cv. GCH 4

Nematode population/plant (Millions)

- Root (Females & Eggs)
- Soil larvae
- Total

N : *R. reniformis* @ 4000 J4/4 kg soil/plant

Mp : *M. phaseolina* @ 8 g mycelium mat/4 kg soil/plant
For percentage of root-rot diseased plants in castor cv. GCH 4 among various treatments during 1992-93 under study, it was observed that Mp alone treatment induced plant mortality from 15th wk and continued further giving a total of 33.3% plant mortality up to 16th wk of fungus inoculation (Table 11). This gave a clue that fungus used for inoculation was sufficiently virulent to cause root-rot disease in castor cv. GCH 4. However, plant mortality started from 12th wk of fungus inoculation, three weeks earlier than Mp alone treatment, in N + Mp and N - Mp treatments, both recorded total plant mortality of 33.3%. But in case of Mp - N treatment, plant mortality started two weeks later than N + Mp and N - Mp treatments (Table 11).

During 1993-94, the disease appeared earlier than that of 1992-93. This may be due to the rise in temperature earlier than 1993-94. The Mp alone treatment induced plant mortality from 9th wk and continued further giving a total of 33.3% plant mortality up to 16th wk of fungus inoculation. However, plant mortality started from 6th wk of fungus inoculation, four weeks earlier than Mp alone treatment, in N + Mp and N - Mp treatments, which had total plant mortality of 50.0 and 33.3% respectively. But in case of Mp - N treatment, the plant mortality started in a similar fashion as in case of Mp alone treatment from disease appearance and plant mortality view points (Table 11).
Table 11: Effect of interaction between *R. reniformis* and *M. phaseolina* on occurrence of root-rot disease in castor cv. GCH 4

| Treatment  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | (1992-93) | Total % increase over fungus alone (%)
<table>
<thead>
<tr>
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<th></th>
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<tbody>
<tr>
<td>N</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>00.0</td>
<td></td>
</tr>
<tr>
<td>MP</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>16.7 33.3 33.3</td>
<td></td>
</tr>
<tr>
<td>N + MP</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>16.7 33.3 33.3 33.3</td>
<td></td>
</tr>
<tr>
<td>N - MP</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>16.7 33.3 33.3 33.3</td>
<td></td>
</tr>
<tr>
<td>MP - N</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>00.0</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>00.0</td>
<td></td>
</tr>
</tbody>
</table>

(1993-94)

| N          | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 00.0       |
| MP         | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 16.7 33.3 33.3  |
| N + MP     | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 16.7 33.3 33.3 33.3  |
| N - MP     | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 16.7 33.3 33.3 33.3  |
| MP - N     | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 00.0       |
| Control    | 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 0.0| 00.0       |

N = *Rotylenchulus reniformis*; MP = *Macrophomina phaseolina*
Two years average data indicated that with an increase in time duration, the plant mortality also invariably increased. The maximum plant mortality of 41.7% was recorded in N + Mp treatment over other treatments. The N + Mp and N - Mp treatments had recorded root rot disease earlier due to the fact that nematode injury to the roots would have predisposed the entry of fungus easily and profusely and hence there was 25% increase in plant mortality in N + Mp treatment (Table 12). This clearly indicated that R. reniformis played a very positive role in easy entry of M. phaseolina fungus resulting into aggravation of root rot disease in castor crop.

Plant height and fresh root weights were significantly less in N + Mp treatment followed by N -Mp, Mp - N, N alone and Mp alone treatments, there being no significant differences between them. Control plants had maximum plant height and fresh root weight over other treatments. Looking to the fresh shoot weight, it was minimum in the N alone treatment followed by N + Mp and N - Mp treatments, there being no significant differences between them. The treatment of Mp - N had mediocre effect on plant growth characters. While Mp alone ranked third. Control plants had maximum fresh shoot weight. The N + Mp treatment had minimum plant height and root weight because of the synergistic effects of combined inoculation of M.
Table 12: Effect of interaction between *R. reniformis* and *M. phaseolina* on occurrence of root-rot disease in castor cv. GCH 4 during 1992-93 and 1993-94 (Summary)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total plant mortality (%)</th>
<th>% increase over fungus alone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1992-93</td>
<td>1993-94</td>
</tr>
<tr>
<td>N</td>
<td>00.0</td>
<td>00.0</td>
</tr>
<tr>
<td>MP</td>
<td>33.3</td>
<td>33.3</td>
</tr>
<tr>
<td>N + MP</td>
<td>33.3</td>
<td>50.0</td>
</tr>
<tr>
<td>N - MP</td>
<td>33.3</td>
<td>33.3</td>
</tr>
<tr>
<td>MP - N</td>
<td>33.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Control</td>
<td>00.0</td>
<td>00.0</td>
</tr>
</tbody>
</table>

*N = Rotylenchulus reniformis; MP = Macrophomina phaseolina*
phaseolina and *R. reniformis*. Sharma and Gill (1979) also reported that inoculation of *Meloidogyne incognita* and *Rhizoctonia solani* reduced shoot weight in potato. Similarly Carter (1980) reported that both *M. phaseolina* and *R. reniformis* inoculated together significantly reduced top fresh weight in Cantoloup crop. The reduction in bean root weight was recorded when fungus was introduced prior to nematode inoculation by Al-Hazmi (1985). Likewise Patel (1989) reported the reduction in growth parameters in cotton crop due to inoculation of *M. phaseolina* and *R. reniformis* separately and together with each other. Suhail Anver et al. (1991) also observed interactive effects of reniform nematode, *R. reniformis* and root-rot fungus, *M. phaseolina*, on lentil where significant reduction in length and weight of shoot and root was recorded due to individual, together and sequential inoculations of both the pathogens.

For *R. reniformis* reproduction, it was observed that N alone treatment produced 528 times more numbers of females, eggs, soil and total nematodes build up/plant followed by 484 times in N + Mp treatment. Whereas N - Mp and Mp - N treatments had 401 and 168 times nematodes reproduction respectively. This may perhaps be due to the toxic effects produced by fungus. Similar trend was observed by Sharma and Gill (1979) who also reported total nematode multiplication to be highest in the *M. incognita* inoculation.
alone. Maximum reduction of 66.77% in nematode multiplication occurred when *Rhizoctonia solani* was inoculated prior to *M. incognita* on potato crop. Similarly AL-Hazmi (1985) also noted that nematode infection and reproduction were reduced when the fungus was introduced prior to nematode inoculation on bean. Suhail Anver et al. (1991) observed *M. phaseolina* fungus to have an antagonistic effect on *R. reniformis* multiplication. For percentage of castor root-rot plants due to various treatments under study, it was observed that Mp alone treatment induced plant mortality from 15<sup>th</sup> wk and 9<sup>th</sup> wk during 1992-93 and 1993-94 respectively and continued further giving a total of 33.3% plant mortality up to 16<sup>th</sup> wk of fungus inoculation during both the years. However, N + Mp and N - Mp treatments had three and four weeks earlier disease appearance than Mp alone during 1992-93 and 1993-94 respectively. Two years average data also indicated that the maximum plant mortality of 41.7% was recorded in N + Mp treatment and there was 25% increase in plant mortality in the treatment where both the nematodes and fungus were inoculated concomitantly. Almost same trend was recorded by Patel (1989) who reported that root-rot disease on cotton appeared one week earlier in different combinations of nematodes, *R. reniformis* and fungus, *R. bataticola*. The incidence and severity of charcoal rot caused by *M. phaseolina* was combined with *R. reniformis* as compared to *M. phaseolina* alone (Carter,
1980). Even low initial R. reniformis inoculum preceding the fungal, M. phaseolina inoculum also produced early wilting of okra crop (Kumar and Sivakumar, 1981). Suhail Anver et al. (1991) also observed increase in root rot disease intensity in the presence of R. reniformis on lentil.

4.3 Assessment of quantitative and qualitative losses due to R. reniformis in castor cv. GCH 4.

Significant differences were obtained for all the characters viz., plant height, fresh shoot and root weights (Plate 4 A & B), seed yield, chlorophyll content and meteorological parameters due to inoculations of 500 and 1,000 J₄/kg soil during 1992-93 and 1993-94 (Table 13). Plant height, fresh shoot and root weights were reduced significantly due to 500 and 1,000 J₄ inoculum levels than control (uninoculated) plants. On the contrary, the minimum plant height was recorded in 1,000 inoculum level followed by 500 inoculum level, both the levels being statistically at par with each other. Control plants had significantly more plant height (Table 13).

During 1993-94, significantly less plant height, fresh shoot and root weights were observed in 1,000 inoculum level treatment followed by 500 inoculum level, both being at par with each other barring fresh root weight. Control plants gave significantly more plant height and fresh shoot as well as root weight (Table 13).
PLATE 4: INFLUENCE OF *R. RENIFORMIS* ON SHOOT (A) 
AND ROOT (B) DEVELOPMENT OF CASTOR CV. 
GCH 4 IN LOSS ASSESSMENT STUDY
Table 13: Growth and development of castor cv. GCH 4 affected by R. reniformis inoculation

<table>
<thead>
<tr>
<th>Nematode level / kg soil</th>
<th>Plant height, cm</th>
<th>Fresh weight, g/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>76.37&lt;sup&gt;c&lt;/sup&gt; 83.00&lt;sup&gt;b&lt;/sup&gt; 79.88&lt;sup&gt;b&lt;/sup&gt;</td>
<td>110.15&lt;sup&gt;c&lt;/sup&gt; 54.75&lt;sup&gt;b&lt;/sup&gt; 82.45&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>500</td>
<td>82.53&lt;sup&gt;b&lt;/sup&gt; 90.93&lt;sup&gt;b&lt;/sup&gt; 86.33&lt;sup&gt;b&lt;/sup&gt;</td>
<td>126.22&lt;sup&gt;b&lt;/sup&gt; 70.32&lt;sup&gt;b&lt;/sup&gt; 98.27&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>107.85&lt;sup&gt;a&lt;/sup&gt; 131.05&lt;sup&gt;a&lt;/sup&gt; 119.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>174.58&lt;sup&gt;a&lt;/sup&gt; 132.55&lt;sup&gt;a&lt;/sup&gt; 153.47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

S.Em. 1.78 3.90 4.55 2.06 3.35 3.88 1.15 1.95 1.39
Year - - ns - - ns - - ns
Y x T - - ns - - s - - ns
C.V. % 4.9 9.4 7.8 3.7 10.0 6.1 3.6 9.3 6.0

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.
Fig. 7 Growth and development of castor cv. GCH 4 affected by *Rotylenchulus reniformis*

Height, cm.; Weight, g.

- Fresh root wt.
- Fresh shoot wt.
- Plant ht.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh root wt.</th>
<th>Fresh shoot wt.</th>
<th>Plant ht.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 J4/Kg. soil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 J4/Kg. soil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pooled data for two years also indicated that the minimum plant height and fresh shoot and root weights were recorded in 1,000 inoculum level treatment followed by 500 inoculum level treatment, both being not differing significantly from each other, except for fresh root weight. Of course, control plants recorded significantly more plant height, fresh shoot and root weights (Table 13, Fig. 7).

Seed yield and test weight of 100 seeds recorded during 1992-93 and 1993-94 were also reduced significantly due to 1,000 and 500 inoculum level treatments over control. However, there were no significant differences between 500 and 1,000 inoculum levels (Table 14).

Pooled data also indicated significant reduction in seed yield and test weight due to 500 and 1,000 inoculum levels than control treatment. Seed yield was reduced by 20.08 % due to both 500 and 1,000 inoculum levels (Table 14, Fig. 8).

The nematode infection also reduced castor seed oil content. It was reduced by 6.60 % and 3.14 % in the inoculum levels of 1,000 and 500 J4/kg soil, respectively over control, uninoculated plants (Table 14, Fig. 8).

With regard to *R. reniformis* reproduction in different inoculum levels on castor cv. GCH 4 (Table 15), it was observed that nematode reproduction (729 times) was
Table 14: Effect of *R. reniformis* on yield and quality of castor cv. GCH 4.

<table>
<thead>
<tr>
<th>Nematode level / kg soil</th>
<th>Seed yield, g</th>
<th>Test weight, g</th>
<th>Per cent oil content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>15.34&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.43&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>500</td>
<td>16.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>22.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.43&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>20.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.29&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

S. Em. 0.52 0.97 0.68 0.40 0.18 0.26 ns  
Year - - ns - - ns -  
Y x T - - ns - - ns -  
C.V. % 7.4 9.6 9.0 5.9 2.6 4.5 6.3  

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.  
Figures in parentheses indicate per cent decrease (-) over control.
Fig. 8 Yield and quality of castor cv. GCH 4 affected by Rotylenchulus reniformis

Weight, g; Oil content, %

- Test wt.
- Yield
- Oil content

1000 J4/Kg.soil  500 J4/Kg.soil  Control
Table 15: Effect of inoculum level on nematode reproduction on castor cv. GCH 4

<table>
<thead>
<tr>
<th>Nematode level/kg soil</th>
<th>Reproduction rate (FR/PF)</th>
<th>Reproduction rate (FR/PF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: FR = Fertility Rate; PF = Productivity Factor.
recorded in plants inoculated with 500 nematodes followed by 1,000 nematodes (373 times). Control plants having no nematode inoculation did not have nematode population as expected.

Data presented in Table 16 indicated significant differences in castor leaf chlorophyll content due to nematode infection. The inoculum levels of 500 and 1,000 J4/kg soil significantly reduced chlorophyll content of leaves. Chlorophyll a, b and total chlorophyll contents were highest in uninoculated control plants (Fig. 9).

For various meteorological parameters, significant differences were obtained for all the attributes except for leaf temperature and relative humidity of plant leaves, (Table 17). Plants inoculated with 1,000 nematodes had significantly less diffusion resistance followed by 500 inoculum level, both being statistically at par with each other. Control plants had highest diffusion resistance. Transpiration rate increased progressively with an increase in nematode inoculum level and it was significantly higher in both the levels than control plants. However, 500 and 1,000 inoculum levels did not differ significantly from each other (Fig. 10).

Treatment differences were significant for plant height, fresh shoot and root weights. These plant growth
Table 16: Effect of *R. reniformis* on chlorophyll a, b and total chlorophyll content/gm of leaf tissue on castor cv. GCH 4

<table>
<thead>
<tr>
<th>Nematode level/kg soil</th>
<th>Chlorophyll 'a'</th>
<th>Chlorophyll 'b'</th>
<th>Total chlorophyll</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1.258&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.255&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.582&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>500</td>
<td>1.387&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>0.337&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.801&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>1.452&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.703&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.236&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>S.Em.</td>
<td>0.06</td>
<td>0.07</td>
<td>0.81</td>
</tr>
<tr>
<td>C.V. %</td>
<td>9.3</td>
<td>38.2</td>
<td>9.7</td>
</tr>
</tbody>
</table>

Figures indicating *. common letters do not differ significantly from each other at 5 % level of significance according to DNMRT.
Fig. 9 Chlorophyll content of leaf tissue of castor cv. GCH 4 affected by *Rotylenchulus reniformis*

Chlorophyll content/g. leaf tissue

- Chlorophyll a
- Chlorophyll b
- Total chlorophyll

1000 J4/Kg.soil  500 J4/Kg.soil  Control
Table 17: Effect of *R. reniformis* on meteorological parameters of castor cv. GCH 4

<table>
<thead>
<tr>
<th>Nematode level / kg soil</th>
<th>Leaf Temperature, °C (LT)</th>
<th>Relative humidity, % (Rh)</th>
<th>Diffusion Resistance, s.cm.⁻¹ (DR)</th>
<th>Transpiration rate, mg.cm⁻² sec.⁻¹ (TRA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>29.82ᵃ</td>
<td>58.08ᵃ</td>
<td>0.90ᶜ</td>
<td>7.87ᵃᵇ</td>
</tr>
<tr>
<td>500</td>
<td>30.82ᵃ</td>
<td>53.32ᵃ</td>
<td>1.34ᵇ</td>
<td>8.44ᵃ</td>
</tr>
<tr>
<td>Control</td>
<td>30.66ᵃ</td>
<td>52.08ᵃ</td>
<td>2.07ᵃ</td>
<td>5.54ᵇ</td>
</tr>
<tr>
<td>S.Em.</td>
<td>ns</td>
<td>ns</td>
<td>0.07</td>
<td>0.43</td>
</tr>
<tr>
<td>C.V. %</td>
<td>1.9</td>
<td>9.1</td>
<td>10.4</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.
Fig. 10  Effect of *R. reniformis* on meteorological parameters of castor cv. GCH 4

- LT: Leaf temperature
- Rh: Relative humidity
- DR: Diffusion resistance
- TRA: Transpiration rate
attributes were significantly reduced in 1,000 inoculum level followed by 500 inoculum level of *R. reniformis*, being not differing statistically from each other except for fresh root weight. Control plants has significantly more growth and development of castor plants. Similar trend was also observed by Sivakumar and Seshadri (1971) who reported *R. reniformis* to be pathogenic to castor and caused growth reduction of castor crop. Significant reduction in tomato shoot and root growth was recorded at $2 \times 10^3$ concentration of *R. reniformis* by Singh (1975). Seed yield and test weight of castor seed were reduced significantly due to 1,000 and 500 inoculum levels. There was 20.08% reduction in seed yield in both 500 and 1,000 nematodes inoculum levels as compared to control plants. Nematode infection in castor also reduced castor seed oil content reduction was highest of 6.60% in 1,000 inoculum level over control. While 500 inoculum level recorded 3.14% reduction in oil contents. Findings obtained in present study were in agreement with those of Sivakumar and Seshadri (1971) who reported reduction in castor yield with inferior quality seeds containing lesser amount of oil. The quality of castor oil is also affected by nematode infection. Potato tuber yield and its quality were significantly reduced by *R. reniformis* parasitism (Rebois, et al. 1978). Likewise, Anver and Alam (1989) while working on effect of *R. reniformis* on
pigeonpea, recorded the losses in plant height, numbers of pods/plant, chlorophyll content of leaves which were directly correlated with nematodes multiplication.

The reproduction rate of 1,000 and 500 inoculum levels indicated that higher reproduction rate was observed in 500 inoculum level (729 times). While 1,000 inoculum level had 373 times reproduction rate which may perhaps be due to more nematode competition for feeding on limited host roots. Such observations were recorded by Mahapatra and Padhi (1986) on chickpea with *R. reniformis* where nematode multiplication rate decreased drastically with increase in the inoculation levels. Sahoo and Padhi (1985) also observed decrease in nematode multiplication rate with an increase in initial inoculum level of *R. reniformis* on okra.

Chlorophyll content also varied significantly in different nematode inoculum levels. The levels of 500 and 1,000 nematodes/kg soil significantly reduced chlorophyll content of leaves. Chlorophyll a, b and total chlorophyll contents were higher in uninoculated control plants. Similar trend was observed by Anver and Alam (1989) on pigeonpea where chlorophyll contents of pigeonpea leaves were directly correlated with *R. reniformis* nematodes multiplication.

Observations on meteorological parameters revealed significant differences in transpiration rate and diffusion resistance between control and nematodes inoculum levels of
500 and 1,000 J/kg soil on castor plants. Significant increase in transpiration rate and decrease in diffusion resistance was recorded in nematode inoculated plants than control plants. However, leaf temperature and relative humidity between inoculated and control plants were not altered. Joshi and Patel (1989) also observed significant increase in transpiration rate and decrease in diffusion resistance due to M. javanica infection in groundnut.

4.4 Determination of susceptible crop stage for *R. reniformis* infection on castor cv. GCH 4.

Results (Table 18) showed significant differences in penetration of *R. reniformis* females in castor cv. GCH 4 roots during different crop period. The highest number of penetrating females in roots was observed in 150 days old plant followed by 135 days old plant. However, nematode penetration in 105, 120, 135 and 150 days old plants did not vary significantly during 1992-93. The treatment of 90 and 75 days old plants had mediocre effect on nematode penetration, whereas 15, 30, 45, 60 and 75 days old plants had less number of females penetration and did not differ significantly from each other during 1992-93.

During 1993-94 also, the highest female root penetration was observed in 150 days old plants followed by 135 days old plants, there being no significant differences
between them (Table 18). However, nematode penetration did not vary in the treatments of 105, 120 and 135 days old plants. Similarly 90 and 105 days old plants ranked third and 30, 45, 60 and 75 days old plants ranked fourth for nematode penetration. Finally, there was minimum nematode female penetration in 15 days old plants over other treatments.

Looking to two years pooled data, the highest females penetration was observed in 150 days old plants followed by 135 days old plants, both being statistically at par with each other. Next in order for nematode penetration was 105 and 120 days old plants. However, nematode penetration in 105, 120, 135 and 150 days old plants did not differ significantly (Table 18, Fig. 11). The 90 days old plants had mediocre effect on nematode penetration. While 45, 60 and 75 days old plants, being statistically at par, ranked third for nematode penetration. Nematode penetration was lower in 15 and 30 days old plants as compared to other treatments.

The females penetration in castor roots was found positively correlated with the plant age. With an increase in plant age, there was increase in nematode penetration because of increased root system of crop that had supported more number of nematodes. However, Haque and Padmavathy (1985) obtained contradictory results in tomato and observed
Table 18: Penetration of *R. reniformis* females in castor root at crop periods.

<table>
<thead>
<tr>
<th>Period, days</th>
<th>1992-93</th>
<th>1993-94</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>50.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>88.3&lt;sup&gt;e&lt;/sup&gt;</td>
<td>69.2&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>50.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>99.0&lt;sup&gt;d&lt;/sup&gt;</td>
<td>74.7&lt;sup&gt;de&lt;/sup&gt;</td>
</tr>
<tr>
<td>45</td>
<td>52.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>99.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>75.8&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>60</td>
<td>57.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>104.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>80.8&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>75</td>
<td>57.6&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>104.7&lt;sup&gt;d&lt;/sup&gt;</td>
<td>81.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>90</td>
<td>66.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>115.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>91.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>105</td>
<td>82.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>121.3&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>101.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>120</td>
<td>84.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>125.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>104.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>135</td>
<td>84.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>126.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>105.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>150</td>
<td>85.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>129.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>107.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

S.Em. | 2.53 | 2.08 | 1.79 |
Year | - | - | s |
Y x T | - | - | ns |
C.V. % | 6.5 | 3.2 | 4.5 |

Figures indicating common letters do not differ significantly from each other at 5% level of significance according to DNMRT.
Fig. 11 Penetration of *R. reniformis* females in castor root at different crop periods
decrease in *R. reniformis* penetration with an increase in seedling age of tomato cvs. Pusa ruby and Patriot. They also observed decrease in nematode penetration with an increase in age of cowpea crop.

4.5 GENERAL

Study conducted on interaction between nematode, *R. reniformis* and wilt fungus, *F. oxysporum f. ricini* and root-rot fungus, *M. phaseolina* on castor cvs. GAUCH 1 and GCH 4 revealed that both the pathogens, nematode, *R. reniformis* and fungus, *F. oxysporum f. ricini* when inoculated simultaneously or nematode inoculum prior to 4 wk fungi inoculation had more depressing effects on plant growth and development of castor cv. GAUCH 1 as well as GCH 4 and played major role in predisposing hosts to aggravate castor wilt and root-rot diseases. Even wilt resistant castor cv. GCH 4 became susceptible in the presence of *R. reniformis*.

Recently in castor growing areas of North Gujarat comprising Banaskantha, Sabarkantha and Mehsana districts, wilt and root-rot fungi in the presence of *R. reniformis* nematodes are major constraints in profitable castor cultivation. This complex nature of melady is increasing year after year. Hence, there is an urgent need to undertake
field studies on the combined effects of *R. reniformis* and wilt and root-rot causing organisms on plant growth characters, production and quality of castor seeds with respect to different castor cultivators in cultivation. Determination of appropriate crop stage at which the disease appears in field in presence of nematode needs to be studied.

Castor seed yield was also reduced by 20.08% at 500 and above J4/kg soil. Further, nematode infection deteriorated crop quality and reduced seed oil content of castor by 6.60% at 1000 and by 3.14% at 500 J4/kg soil over control-no infected plants. Studies should be planned to determine the effect of nematode infection on quality of oil such as Ricin sulfoxide, Ricin oxide, etc. and its industrial value. Results obtained in the present study also proposes to estimate avoidable castor yield losses due to nematode and fungi complex under field conditions.

Experiment on determination of suitable crop stage for *R. reniformis* infection on castor cv. GCH 4 indicated that number of nematode females penetrated in the host root increased with an increase in plant age. Hence, research work on reproduction rate or fecundity of reniform nematode during different crop stages should be contemplated.
As *R. reniformis* is new emerging out to be the key nematode limiting the profitable cultivation of castor crop especially in light soils, research work on practically feasible and economical viable management strategies through crop rotation, soil solarization, use of resistant varieties and bioagent, cultural practices, nematicides/fungicides etc. in a integrated way should be planned in future.
SUMMARY & CONCLUSIONS
SUMMARY AND CONCLUSION

Studies on reniform nematode, *R. reniformis*, affecting castor cvs. GAUCH 1 and GCH 4 were carried out with respect to i, interaction between *R. reniformis* and *F. oxysporum f. ricini* on castor cvs. GAUCH 1 and GCH 4, ii, interaction between *R. reniformis* and *M. phaseolina* on castor cv. GCH4, iii, assessment of quantitative and qualitative losses due to *R. reniformis* in castor cv. GCH 4, and iv, determination of susceptible crop stage of castor to *R. reniformis* infection.

Study on interaction between *R. reniformis* and *F. oxysporum f. ricini* on GAUCH 1 variety indicated that plant height was significantly less in the treatment of *N - F₀* followed by *N + F₀* treatment, there being no significant differences between them. However, the treatments of either nematode alone (*N*) or fungus alone (*F₀*) or *F₀ - N* treatment had mediocre effects on plant height, being not differing significantly from each other. Whereas fresh shoot and root weights of plants were minimum in *N + F₀* treatment followed by *N - F₀*, *F₀ - N* and *N* treatments but there were no significant differences between them. As expected, control plants had significantly more plant height, fresh shoot and root weights over other treatments. Hence, overall findings indicated that *N + F₀* and *N - F₀* treatments had significantly more depressing effects on plant growth and
development of castor cv. GAUCH 1 than N or Fo or Fo - N treatment. Control (uninoculated) plants had significantly more plant growth over other treatments.

With regard to *R. reniformis* reproduction, N alone treatment produced maximum numbers of females, eggs, soil and total nematode population (469 times) build up/plant followed by N + Fo (406 times) treatment. While N - Fo treatment had mediocre (356 times) nematode reproduction rate and Fo - N treatment had lowest (143 times) reproduction rate. The Fo - N treatment had 69.49 % less nematode reproduction followed by N - Fo (24.18 %) and N - Fo (13.55 %) treatments over nematode alone. This clearly indicated that antitoxins produced by the fungus had played a vital role in the reduction of nematode population. As a result, there was maximum of 69.49 % reduced nematode reproduction on castor cv. GAUCH 1.

For percentage of castor cv. GAUCH 1 wilted plants, the treatment of Fo alone induced plant mortality from fourth week and continued further giving a total of 33.3 % plant mortality up to sixteenth week of fungus inoculation. However, the mortality was started three weeks earlier than Fo alone in the treatments of N + Fo and N - Fo. The maximum plant mortality of 58.3 % was recorded in N + Fo treatment over other treatments, indicating 75.0 % increased plant mortality over fungus inoculation alone.
An experiment on interaction between *R. reniformis* and *F. oxysporum* f. *ricini* on castor cv. GCH 4 indicated that plant height was significantly less in the treatment of N alone followed by N - Fo and N + Fo treatments, there being no significant differences between them. However, the treatment of Fo - N had mediocre effect but did not differ statistically from N + Fo treatment. Control (uninoculated) plants had maximum plant height over other treatments. Whereas the minimum fresh shoot weight was observed in N treatment followed by N - Fo and N + Fo treatments, there being no significant differences between them. However, the treatments of N - Fo, N + Fo, Fo - N and Fo had mediocre effects and did not statistically differ from each other. Plants under control treatments had maximum shoot weight over other treatments. Looking to the fresh root weight, the minimum fresh root weight was recorded in N treatment followed by the treatments of N + Fo, N - Fo and Fo - N. However, there were no significant differences between them. There was maximum fresh root weight of plants in control treatment and it was at par with Fo treatment.

With regard to nematode reproduction, the maximum of 523 times reproduction of *R. reniformis* occurred on the plant inoculated with N alone, next in order was N + Fo treatment (450 times) followed by N - Fo treatment (435 times). The treatment of Fo - N had lowest of 100 times.
reproduction rate. For percentage of decrease over nematode alone, the highest of 80.89% decrease in nematode reproduction was recorded in Fo - N treatment. While other two treatments N + Fo and N - Fo had 13.83 and 16.80% reduction in nematode multiplication rate over nematode alone respectively.

For percentage of castor wilted plants, the Fo alone treatment had no plant mortality because of wilt resistant nature of castor cv. GCH 4. However, the treatment of N - Fo had highest plant mortality of 33.3% over other treatments and it was one week earlier than N + Fo treatment. Similarly N + Fo and Fo - N treatments also recorded 25.0 and 16.7% plant mortality respectively.

Study on interaction between R. reniformis and M. phaseolina on castor cv. GCH 4 indicated that plant height was significantly less in N + Mp treatment followed by N - Mp, Mp - N, N and Mp alone treatments, there being no significant differences between them. Plants under control treatment had maximum plant height over other treatments. Minimum fresh shoot weight was recorded in N alone treatment followed by N + Mp and N - Mp treatments, there being no significant differences between them. However, the treatment of Mp - N had mediocre effect on plant growth characters, but the treatments of N + Mp, N - Mp and Mp - N were statistically at par. Control plants had maximum fresh shoot
weight over other treatments. Likewise fresh root weight was also less in N + Mp treatment followed by N - Mp, N & Mp alone and Mp - N, treatments, there being no significant differences between them. Control plants had maximum fresh root weight but it was statistically at par with Mp - N and Mp alone treatments.

It clearly indicated that both nematode and fungus either inoculated together (N + Mp) or nematodes followed by fungus (N - Mp) had more depressing effects on plant growth and development than either of pathogen alone or fungus followed by nematode inoculation (Mp - N).

The maximum of 528 times *R. reniformis* multiplication was observed in the treatment of plants inoculated with N alone, next in order was N + Mp treatment with 484 times followed by N - Mp treatment with 401 times. While Mp - N treatment had lowest of 168 times reproduction rate recorded as compared to other treatments. Perhaps nematode population would have been reduced by toxic effect of fungus. Based on percentage reduction in nematode multiplication rate, the highest reduction of 68.25% was recorded in Mp - N treatment. While N + Mp and N - Mp treatments had 8.32 and 24.09 % reduction in nematode multiplication over nematode alone respectively.

For percentage of castor cv. GCH 4 dried plants due to various treatments during two years pooled
experimental data, it was observed that the maximum plant mortality of 41.7 % was recorded in N + Mp treatment over other treatments. Root-rot disease appeared earlier in case of nematodes inoculated with fungus simultaneously or nematodes prior to fungus inoculations. The *R. reniformis* might have favoured the entry of fungus easily and profusely. There was 25.0 % increased in plant mortality in N + Mp treatment over fungus alone treatment. This proved that *R. reniformis* played a major role in aggravating *M. phaseolina* fungus for producing root-rot disease in castor cv. GCH 4.

Trial on assessment of quantitative and qualitative losses due to *R. reniformis* indicated that plant height, fresh shoot and root weights, seed yield and chlorophyll contents were reduced significantly due to 500 and 1000 J4/kg soil over control. Plants under control treatment had significantly more plant height, fresh shoot and root weights. Seed yield and test weight were also significantly reduced due to both the levels of nematode inoculation over control. The inoculum levels of both 500 and 1000 J4/kg soil gave 20.08 % reduction in seed yield. Whereas oil content of castor seeds was reduced by 6.60 % in 1000 inoculum level and by 3.14 % in 500 inoculum level over control plants.
For nematode reproduction, it was observed that higher reproduction rate of 729 times was recorded in the treatment of 500 inoculum level. While it was 373 times in case of 1000 inoculum level.

Looking to the chlorophyll content, it was variable in two different nematode inoculum levels. The levels of 500 and 1000 nematodes/kg soil significantly reduced chlorophyll content of leaves. Chlorophyll a, b and total chlorophyll contents were higher in uninoculated control plants.

For meteorological parameters, significant differences for all the characters except for leaf temperature and relative humidity were obtained. However, diffusion resistance and transpiration rate differed significantly between control treatment and nematode inoculated with 500 and 1000 reniform nematodes/kg soil on castor plant. Significant increase in transpiration rate and decrease in diffusion resistance in inoculated plants were recorded over control.

Study on determination of suitable crop stage of castor cv. GCH 4 to the *R. reniformis* infection indicated significant differences in penetration of females during different crop periods. Two years pooled data revealed that highest number of females penetration was observed in the
roots of 150 days old castor plant followed by 135 days old plant, there being no significant differences between them. However, the plants of 120 and 105 days old had less females penetration but did not differ significantly from 135 and 150 days old plants. While 90 days old plants had mediocre effect on females penetration to the roots. The plants of 15 and 30 days old had significantly less number of females penetration in castor roots as compared to other treatments. In other words, the number of females penetration in castor root increased correspondingly with an increased plant age.
REFERENCES
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* Originals not seen.