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Management of potato nematodes: An overview

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ABSTRACT

Root-knot nematodes and cyst nematodes are important constraints that reduce potato yields in India. Three species of *Meloidogyne* cause root-knots on the crop throughout the country, of which, *M. incognita* is more wide-spread. Infected tubers also result in marketable-yield-loss particularly in the seed potatoes. The cyst nematodes include two species of *Globodera* restricted to the hilly regions of Tamil Nadu and are of quarantine importance, inhibiting seed-potato production. Potato produce from these hills is used only for consumption. The endoparasitic nature of their life cycle, deposition of eggs into a gelatinous egg mass in root knot and the female turning in to a hard cyst encompassing the eggs within them in cyst nematode makes them difficult organisms to manage. Both these nematodes exhibit physiologic variation, hence, their management is not absolute with host-resistance. Therefore, an Integrated Nematode Management (INM) is adopted in both the cases. Root-knot nematode in North India is managed using nematode-free seed tubers, crop rotation with maize or wheat and application of 1-2 kg ai /ha Carbofuran 3% G at the time of potato planting. Cyst nematode in Tamil Nadu hills is managed by crop rotation with vegetables, particularly cabbage and carrot, intercropping potato with beans or wheat, alternating nematode resistant potato variety 'Kufri Swarna' and application of 2 kg ai /ha Carbofuran 3% G at planting. A two-year adoption of INM for root-knot and a three-year INM practice for cyst nematodes gives efficient and economical production system. Potato farmers in Himachal Pradesh and Tamil Nadu hills follow practices standardized at the Central Potato Research Institute, Shimla and it's sub-station in the Nilgiri hills.

Key words: Root-knot nematodes, cyst nematodes, late blight disease, pathotypes, virulent strains, host resistance, crop rotation, cropping sequence, integrated management

INTRODUCTION

Cultivated potato *Solanum tuberosum* Linn., originated in the Andes mountains in South America, was introduced in the 16th century to Europe and was subsequently distributed throughout the world (Pushkarnath, 1976). Now, it is grown in almost all countries and is recognized as the world's most important tuber crop playing a vital role, meeting food requirement of people, particularly, in the developing countries (Swaminathan and Sawyer, 1983). Being one of the top high-value crops, its importance is highlighted by the United Nations by naming the year 2008 as the 'International Year of Potato' (FAO, 2007). Its global production is about 320 million tones, of which China (72 million tonnes) Russian Federation (35 million tonnes) and India (26 million tonnes) are the major producers.

In our country, potato is cultivated in almost all States under varying ecological situations. Basically, potato is cultivated in colder regions, but the adaptability of this crop to varied climates has been well-exploited indigenously by developing varieties suitable to different agro-climatic zones in India (Pushkarnath, 1976). Thus, the crop is grown under long-day conditions of summer months in the mid-hills of Himalayas, short-day conditions of winter months in the North-West plains of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal, in the equinox conditions of Deccan Plateau during rainy seasons, and, almost round-the-year in equable climate of Tamil Nadu hills (Grewal *et al*, 1992). It now serves as a major food source next only to rice, wheat and maize in our country (Pandey and Sarkar, 2005).

Major constraints in potato production are insect pests, nematodes and diseases which account for nearly 37% yield loss throughout the globe, of which the share of

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diseases and nematode parasites alone is 23% (Sasser and Freckman, 1987). Late blight (*Phytophthora infestans*), bacterial wilt (*Ralstonia solanacearum*), tuber moth (*Phthoremia operculella*), root-knot nematodes (*Meloidogyne* spp.) and cyst nematodes (*Globodera* spp.) are major pests, especially in India. But, unlike the infestation or incidence of an insect pest or disease, nematode infections are difficult to recognize or diagnose, as, these are often mistaken for nutrient deficiency. Primarily, the root-knot nematode (RKN) and potato cyst nematode (PCN) are important among 90 parasitic nematodes (Table 1) associated with the potato rhizhospere in India (Krishna Prasad, 1993). Both these nematodes are highly-adapted, obligate plant parasites exhibiting endoparasitic life cycle.

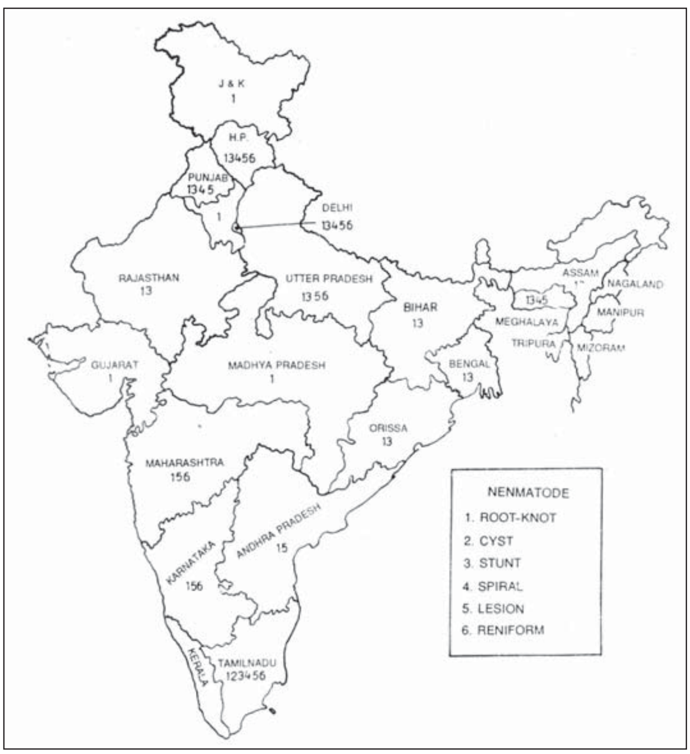

Fig 1. Major parasitic nematodes associated with potato in India

Other important nematode parasites (Fig.1) that occur in the potato rhizoshere are spiral (*Helicotylenchus* spp), stunt (*Tylenchorhynchus* spp; *Quinsulcius* spp.), lesion (*Pratylenchus* spp.), reniform (*Rotylenchulus reniformis*) and pin (*Paratylenchus* spp.) nematodes, that feed on potato roots, causing appreciable yield-reduction (Krishna Prasad and Sharma, 1985; Krishna Prasad and Rajendran, 1990).

Economic importance

The earliest record of a plant parasitic nematode (PPN) infection on potato was that of PCN by Julius Kuhn in 1881 at Rostoch, Germany, followed by occurrence of RKN by Neal in 1889 at Florida, USA. Since then, at least 150 species of PPN have been encountered in the rhizosphere of potato throughout the world (Jensen *et al*, 1979). Among these, the RKN (*Meloidogyne* spp. - basically tropical, polyphagous and prevalent in all regions) and PCN (temperate, host-specific and mainly restricted to potato-growing localities in mild climates) are the most important nematode parasites of potato (Jones *et al*, 1981). The endoparasitic nature of life cycle and protection of eggs in an egg-mass, or a cyst, make these organisms difficult to manage (Sethi and Gaur, 1986). Between these two, the PCN, popularly called '*The Golden Nematode*', is important throughout the world and is considered as the number one quarantine pest (Trudgill, 1985). Most of the countries free of PCN have quarantine regulations on import of potato that might endanger introduction of cysts into their country (Stone, 1985). Domestic quarantine regulations are strictly followed in the USA, Canada and India to prevent further spread of PCN (Brodie *et al*,1993).

Crop loss

Nematodes are mostly root feeders living in soil and cause gradual yield reduction, in addition to predisposing plants to infection by other microorganisms. The degree of damage depends on crop husbandry, nematode density and environmental conditions (Evans, 1993).The estimated yield-loss in potato by PPN around the world is 12.2% (Sasser, 1989). Under Indian conditions, an initial level of even two larvae of RKN per gram of soil results in overall yield reduction of 42.5% while, PCN accounts for 65% loss (Krishna Prasad, 1993). RKN infection on tubers manifests, as pimple-like blisters. Mere presence of two infected tubers per bag of 80 kg seed potato is sufficient to reject for export from Himachal Pradesh, a state which follows potato seed certification (Krishna Prasad, 1986).

Quarantine regulations

Occurrence of PCN in India on potato from Nilgiri hills during 1961 provided the trigger for organized nematological research in the country, as, this nematode had established itself as one of the most destructive pests of potato all over the world (Evans and Stone, 1977; Seshadri, 1978). Potential danger from this nematode to potato cultivation in the country was such that Government of Tamil Nadu amended the Destructive Insect Pest Act 1914 in 1971 to ensure inspection of seed potato for presence

Table 1. Parasitic nematodes associated with the potato crop in India

Nematode	Locality	State	Initial record
Anguina tritici	Kufri	Himachal Pradesh	CPRI, 1975
Aphelenchoides avenae	Kufri	Himachal Pradesh	CPRI, 1985
A. ritzemabosi	Kufri	Himachal Pradesh	CPRI, 1975
A. solani	Kufri	Himachal Pradesh	CPRI, 1965
Aphelenchus avenae	Hyderabad	Andhra Pradesh	Das, 1960
	Aligarh	Uttar Pradesh	Khan *et al*, 1964
	Jalandhar	Punjab	CPRI, 1974
	Shimla	Himachal Pradesh	CPRI, 1985
Criconemoides ornatus	Kufri	Himachal Pradesh	CPRI, 1960
Criconemoides spp.	Kufri	Himachal Pradesh	CPRI,1957
Ditylenchus destructor	Shillong	Meghalaya	CPRI, 1965
	Imported tubers		NBPGR, 1980
D. dipsaci	Imported tubers		NBPGR, 1980
D. solani	Hapur	Uttar Pradesh	Hussain and Khan, 1976
Ditylenchus spp.	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
Dorylaimus spp.	Shimla	Himachal Pradesh	CPRI, 1965
Ecphydophora goodeyi	Aligarh	Uttar Pradesh	Hussain and Khan, 1965a
Enchoderella mustafi	Aligarh	Uttar Pradesh	Hussain and Khan, 1965
Eudorylaimus monohystera	Aligarh	Uttar Pradesh	Jairajpuri, 1969
Globodera pallida	Ootacamund	Tamil Nadu	Howard, 1977
	Devikulam	Kerala	Ramana and Das, 1988
G. rostochiensis	Ootacamund	Tamil Nadu	Jones, 1961
	Kodaikanal	Tamil Nadu	Vijayarhagavan *et al*, 1975
Helicotylenchus caudatus	Almora	Uttaranchal	Sultan, 1985
H. crenatus	Bhakulty	Himachal Pradesh	CPRI, 1966
H. dihystera	Bhakulty,	Himachal Pradesh	CPRI, 1965
	Keylong	Himachal Pradesh	CPRI, 1985
H. nannus	Kufri	Himachal Pradesh	CPRI, 1960
H. willmottae	Ootacamund	Tamil Nadu	Siddiqui, 1972
Helicotylenchus spp.	Ootacamund	Tamil Nadu	Murthy, 1963
	Shillong	Meghalaya	CPRI, 1965
	Delhi	Delhi	Khan and Wadhwa, 1969
	Jalandhar	Punjab	CPRI, 1974
	Kufri	Himachal Pradesh	CPRI, 1976
	Imported tubers		NBPGR, 1980
Hemicriconemoides spp.	Aligargh	Uttar Pradesh	Fasahat *et al*,1973
	Shimla	Himachal Pradesh	CPRI, 1985
	Jalandhar	Punjab	CPRI, 1985
Hemicycliophora spp	Kufri	Himachal Pradesh	CPRI, 1960
	Imported tubers		NBPGR, 1980
Heterodera avenae	Shimla, MandiKulu,	Himachal Pradesh SirmourKinnaur and Lahaul-Spiti	Krishna Prasad, 1986
H. carotae		Himachal Pradesh	Swarup *et al*, 1964
H. punciata		Himachal Pradesh	CPRI, 1966
Hoplolaimus galetus	Patna	Bihar	CPRI, 1960
H. indicus	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
Hoplolaimus spp.	Allahabad	Uttar Pradesh	Edward *et al*, 1963
	Delhi	Delhi	Khan and Wadhwa, 1969
	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
	Jalandhar	Punjab	CPRI, 1974
	Imported tubers		NBPGR, 1980

Table 1. Continued

Nematode	Locality	State	Initial record
Indokochinema ekramullahi	Burdwan	West Bengal	Jana and Baqri, 1982
Lelenchus annulatus	Octacamund	Tamil Nadu	Saddiqui and Khan, 1983
Longidorella minitissima	Aligarh	Uttar Pradesh	Khan, 1972
Longidorus elongetus	Aligarh	Uttar Pradesh	Khan *et al*, 1964
L. nirulai	Shillong	Meghalaya	Siddiqui, 1965
Longidorus spp.	Shillong	Meghalaya	CPRI, 1965
	Kufri	Himachal Pradesh	CPRI, 1966
	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
	Jalandhar	Punjab	CPRI, 1975
Meloidogyne arenaria	Aligarh	Uttar Pradesh	Khan *et al*, 1964
*M. hapla**	Shimla	Himachal Pradesh	CPRI, 1975
*M. incognita**	Kufri	Himachal Pradesh	Thirumalchar, 1951
*M.javanica**	Patna	Bihar	Pushkarnath and Roy Choudhary, 1958
Meloidogyne spp.	Imported tubers		NBPGR, 1980
Michonchus digiturus	Rajgurunagar	Maharashtra	Jairajpuri, 1969
Nothotylenchus cylindricus	Almora	Uttaranchal	Khan and Siddiqi, 1968
N. geraerti	Aligarh	Uttar Pradesh	Khan and Siddiqi, 1968
N. hexaglyphus	Almora	Uttaranchal	Hussain and Khan, 1974
Ogma spp.	Srinagar	Jammu & Kashmir	
Paratrichodorus spp.	Almora	Uttaranchal	Khan, 1972
Paratylenchus spp.	Shimla	Himachal Pradesh	CPRI, 1973a
	Jalandhar	Punjab	CPRI, 1974
	Imported tubers		NBPGR, 1980
	Ootacamund	Tamil Nadu	Krishna Prasad, 1986
Pratylencuhus brachyurus	Kufri	Himachal Pradesh	CPRI, 1962
P. brevicauda	Hyderabad	Andhra Pradesh	Das, 1960
	Shillong	Meghalaya	CPRI, 1965
	Kufri	Himachal Pradesh	CPRI, 1966
P. coffeae	Allahabad	Uttar Pradesh	Edward, 1969
	Shimla	Himachal Pradesh	CPRI, 1985
P. indicus	Hyderabad	Andhra Pradesh	Das, 1960
	Shillong	Meghalaya	CPRI, 1965
	Kufri	Himachal Pradesh	CPRI, 1966
P. penetrans	Shimla	Himachal Pradesh	CPRI, 1962
P. pratenses	Shillong	Meghalaya	CPRI, 1965
	Kufri	Himachal Pradesh	CPRI, 1966
P. teres	Jallandhar	Punjab	Khan and Singh, 1975
	Allahabad	Uttar Pradesh	Edward *et al*, 1963
Pratylencuhus spp.	Ootacamund	Tamil Nadu	Murthy, 1963
	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
	Shimla	Himachal Pradesh	CPRI, 1974
	Madapur	Karnataka	Singh *et al*, 1979
Psillenchus spp.	Shimla	Himachal Pradesh	CPRI, 1985
Quinisulcius capitatus	Kufri,	Himachal Pradesh	CPRI, 1974
	Bhakhulty	Himachal Pradesh	CPRI, 1985
	Keylong	Himachal Pradesh	Krishnaprasad and Sukumaran, 1986
Q.acti	Shimla	Himachal Pradesh	Nagesh, 1993
Rotylenchulus reniformis	Ootacamund	Tamil Nadu	Murthy, 1963
	Delhi	Delhi	Verma and Prasad, 1969
	Solan	Himachal Pradesh	Swarup *et al*, 1967
	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973

Table 1. Continued

Nematode	Locality	State	Initial record
R. stajnabu	Aligarh	Uttar Pradesh	Hussain and Khan, 1965b
Rotylenchulus spp.	Delhi	Delhi	Khan and Wadhwa,1969
	Imported tubers		NBPGR, 1980
Rotylenchus ranpoi	Rajgurunagar	Maharashtra	Darekar and Khan, 1982
Rotylenchus spp.	Aligarh	Uttar Pradesh	Khan *et al*, 1964
Scutellonema spp	Aligarh	Uttar Pradesh	Khan *et al*, 1964
Thornedia solani	Aligarh	Uttar Pradesh	Hussain and Khan, 1965c
Trichodorus christei	Kolar	Karnataka	CPRI, 1965
T. minor	Shimla	Himachal Pradesh	Siddiqi, 1960
T. nannus	Jalandhar	Punjab	CPRI, 1974
T. pachydermus	Jalandhar	Punjab	CPRI, 1965
T. similes	Aligarh	Uttar Pradesh	Khan *et al*, 1964
Trichodorus spp.	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
	Jalandhar	Punjab	CPRI, 1974
	Kufri	Himachal Pradesh	CPRI, 1984
Tylenchorhynchus brevidens	Soil samples	Delhi	Sethi and Swarup, 1968
		Punjab	Sethi and Swarup, 1968
		Rajasthan	Sethi and Swarup, 1968
T. claytoni	Shimla	Himachal Pradesh	CPRI, 1985
	Jalandhar	Punjab	CPRI, 1985
T. cuticaudatus	Bhubaneswar	Orissa	Roy and Das, 1983
T. dubius	Shimla	Himachal Pradesh	CPRI, 1975
T. martini	ShimlaPatna	Himachal PradeshBihar	CPRI, 1960
T. mashoodi	Aligarh	Uttar Pradesh	Khan *et al*, 1964
T.neoclavicaudatus	Soil adhering totubers	Uttar Pradesh	Khan *et al*, 1964
	Imported potato tubers		Mathur *et al*, 1978
T. swarupi	Burdwan	West Bengal	Singh and Khera, 1978
Tylenchorhynchus spp.	Shillong	Meghalaya	CPRI, 1965
	Kufri	Himachal Pradesh	CPRI, 1966
	Delhi	Delhi	Khan and Wadhwa, 1969
	Aligarh	Uttar Pradesh	Fasahat *et al*, 1973
	Imported tubers		NBPGR, 1978
Tylenchus spp.	Shillong	Meghalaya	CPRI, 1965
	Kufri	Himachal Pradesh	CPRI, 1966
Xiphinema americanum	Kufri	Himachal Pradesh	CPRI, 1966
X. index	Kufri	Himachal Pradesh	CPRI, 1962
X. indicum	Kufri	Himachal Pradesh	CPRI, 1966
X. radicicola	Kufri	Himachal Pradesh	CPRI, 1966
Xiphinema spp.	Shillong	Meghalaya	CPRI, 1964
	Jalandhar	Punjab	CPRI, 1974
	Madapur	Karnataka	Singh *et al*, 1979
	Ootacamund	Tamil Nadu	Krishna Prasad, 1986

*Refer Table 2 for detailed, State-wise prevalence of root-knot nematodes

of cyst nematode and check its spread to other parts of the country. Large-scale inspection of potato fields around the country revealed that this nematode was restricted to the hills in Tamil Nadu (Logiswaran and Menon, 1965). Therefore, seed movement of potato from these hills is banned and the entire produce is used for consumption purposes only. However, detection of PCN from the neighboring states of Tamil Nadu such as Karnataka (Singh and Krishna Prasad, 1986) and Kerala (Ramana and Mohandas, 1988) calls for strengthening of domestic quarantine. The other nematode pests of potato that merit quarantine importance and are not yet found in the country are the potato rot nematode, *Ditylenchus destructor* and potato false root-knot nematode, *Naccobus aberrans* (Renjhen, 1973).

Distribution

RKN, with about 65 species of *Meloidogyne*, is widely distributed throughout the world causing typical root-galls on crop plants (Brodie *et al*, 1993). At least ten of these infest potatoes, though, *M. incognita*, *M. javanica* and *M. hapla* are predominant. In India, RKN was first reported on potato in 1951 from Shimla (Thirumalachar, 1951) and is prevalent in all the potato growing regions of the country (Nirula and Roy Choudhary, 1957). *Meloidogyne incognita* is the dominant RKN species causing galls on roots and tubers, followed by *M. javanica*. Infestation of *M. hapla* on potato roots is recorded at higher altitudes of 2000m (above) MSL from hilly tracts of Himachal Pradesh, Jammu & Kashmir, Uttaranchal and Tamil Nadu (Table 2). Detailed surveys undertaken in Himachal Pradesh (Fig 2) and Uttaranchal shows that all these three species affect potato with varying intensity. *Meloidogyne incognita* is occurring either alone or with the other two species, at altitudes ranging 760-2900 m MSL. Infestation of *M. javanica* was observed at lower altitudes of 410 to 1100 m MSL while *M. hapla* was restricted to higher altitudes of 1950 to 3300 m MSL and its presence could be ascertained by indicator plant reaction (Krishna Prasad, 1986). Tuber infection manifests as blisters and is invariably associated with *M. incognita* and *M. javanica* wherever bacterial wilt is endemic (Nirula and Paharia, 1970; Krishna Prasad and Sukumaran, 1986; Nagesh and Shekhawat, 1997).

Table 2. Species of *Meloidogyne* causing root-knots on potato in India

State / Union Territory	Species	Initial record
Andhra Pradesh	*M. javanica*	Das, 1960
Arunachal Pradesh	*M. incognita*	Mishra and Jaya Prakash, 1980
Assam	*M. incognita*	CPRI, 1957, 1965
Bihar	*M. incognita*	CPRI, 1957, Lal and
	M. javanica	Das, 1957
Delhi	*M. javanica*	Prasad *et al*, 1964
Gujarat	*M. incognita*	Desai *et al*, 1970
Haryana	*M. incognita*	CPRI, 1971
	M. javanica	
Himachal Pradesh	*M. hapla*	CPRI, 1974
	M. incognita	Mukhopadhyaya,1970
	M. javanica	CPRI, 1957
Jammu & Kashmir	*M. hapla*	CPRI, 1977
Karnataka	*M. incognita*	CPRI, 1957
	M. javanica	CPRI, 1965
Maharashtra	*M. incognita*	CPRI, 1965
	M. javanica	Manjrekar and Talgeri, 1969
Meghalaya	*M. incognita*	Pushkarnath and Roy Choudhary, 1958
Orissa	*M. incognita*	CPRI, 1977
Punjab	*M. incognita*	CPRI, 1963
	M. javanica	CPRI, 1974
Rajasthan	*M. incognita*	CPRI, 1972
	M. javanica	CPRI, 1974
Tamil Nadu	*M. hapla,*	Gill, 1974
	M. incognita	Singh *et al*, 1979
	M. javanica	Singh *et al*, 1979
Uttar Pradesh	*M. incognita*	CPRI, 1957
	M. javanica	Gill, 1974
Uttaranchal	*M. hapla*	Krishna Prasad, 1993
	M. incognita	CPRI, 1957
West Bengal	*M. incognita*	CPRI, 1971

Fig 2. Root- Knot Nematode Intensity on Potato in Himachal Pradesh

PCN is restricted to the potato growing localities of about 60 countries, with two species that are characterized by colour of the developing female (Evans and Stone, 1977). *Globodera pallida* (white or cream-coloured females) is prevalent in 25 countries and *G. rostochiensis* (yellow cyst nematode) is reported from 57 countries (Brodie *et al*, 1993). Dr. F. G. W. Jones, Head, Nematology Department, Rothamsted Experimental Station, Harpenden, U.K., on a personal trip to Ootacamund, first detected this nematode in India from a field situated at an elevation of 2125m MSL. Realizing the importance of this problem in potato, the Indian Council of Agricultural Research (ICAR) and the Government of Tamil Nadu launched the *'Golden Nematode Scheme'* at Ootacamund in 1963 (Seshadri and Sivakumar, 1962). Large-scale inspection of potatoes in the marketing mandies at Mettupalayam (trading centre and rail-head at the foothills of Nilgiris) and field-to-field surveys were undertaken (Seshadri, 1970). These studies indicated presence of cysts in potato consignments meant for transportation to Bombay, Calcutta, Cuttack and Poona (Seshadri, 1978). Detailed surveys conducted in other major potato growing areas of Assam, Himachal Pradesh, Karnataka, Punjab, Tamil Nadu and Uttar Pradesh indicated this nematode to be restricted to the Nilgiri hills (Gill, 1974) and Kodaikanal hills (Thangaraju, 1983) of Tamil Nadu.

Presence of cysts of PCN in several potato-growing villages was recorded in Karnataka (Singh and Krishna Prasad, 1986) although the species could not be determined, as, the eggs in the cysts were non-viable. Later, G. *pallida* was observed to be associated with potato at the Devikulam locality in Idukki district of Kerala (Ramana and Mohandas, 1988). Species composition, distribution and intensity (Fig 3) indicated 57% PCN population in the Nilgiris to be that of *G. pallida* and 43% was that of *G.*

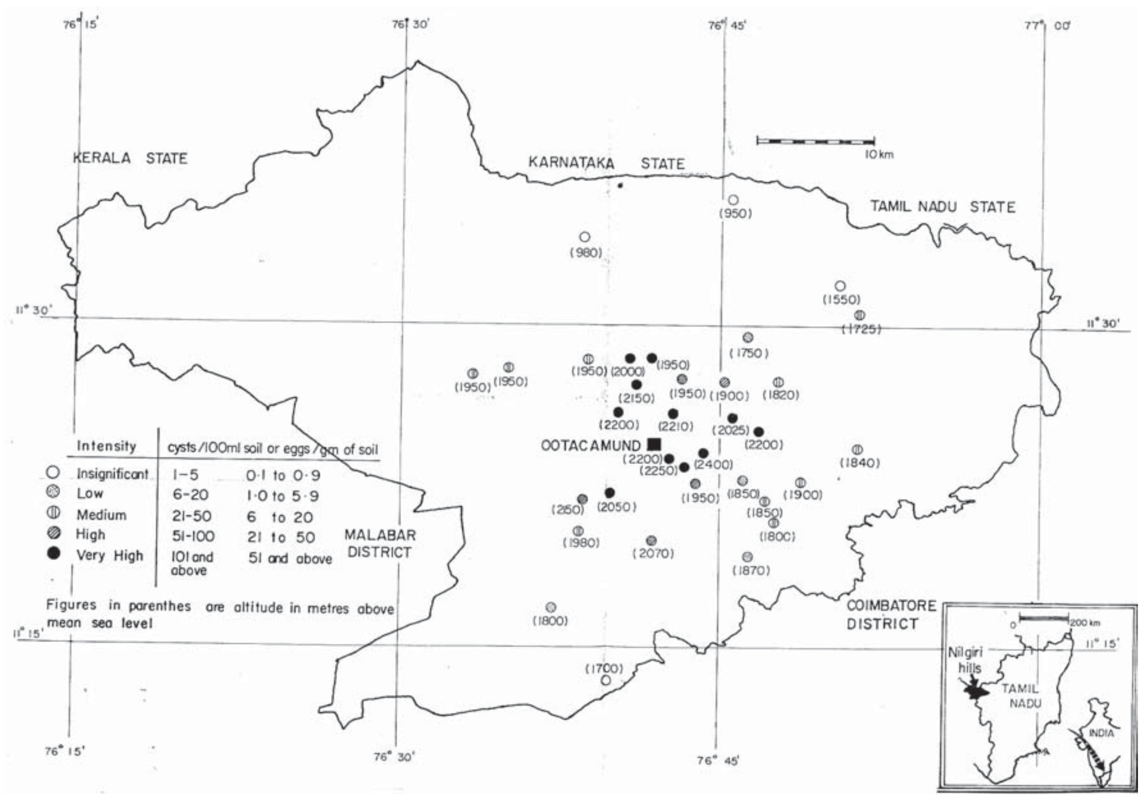

Fig 3. Intensity of Potato Cyst Nematodes in Nilgiri Hills.

Table 3. Distribution of PCN species in major potato growing localities of Nilgiri hills

Locality	MSL-Climate	No. of potato crops /year	Occurrence% *G. pallida*	Occurrence% *G. rostochiensis*
Nanjanadu	2250-Cool	Two	0.0	100.0
Mynala	2250-Cool	Two	15.0	85.0
Vijayanagaram	2175-Cool	Two	28.5	71.5
Kavaratty	2175-Cool	Two	0.0	100.0
Thalaiattumandu	2150-Cool	Two	25.0	86.0
Fern hill	2150-Ambient cool	Two	49.0	51.0
Hullahatty	2100- Ambient cool	One	51.0	49.0
Finger post	2100 -Ambient cool	Two	26.0	74.0
Adigaratty	2070 -Ambient warm	One	94.0	6.0
Kallahatty	1950 -Ambient warm	Three	92.5	7.5
Sholur	1950 -Ambient warm	Two	81.0	19.5
Thummanatty	1920 -Warm	Two	100.0	0.0
Thummanada	1920 -Warm	Two	100.0	0.0
Jegathala	1875 -Warm	One	100.0	0.0
Milidhen	1850 -Warm	One	100.0	0.0

rostochiensis. Nematode intensity was high (Table 3) in localities where invariably two potato crops were taken in a calendar year (Krishna Prasad, 2003). Both species differed in their preference for infecting and developing on potato, with the former preferring altitudes of 1550 to 2100 m MSL and the latter preferring localities above 2100m MSL (Krishna Prasad, 2004c).

Physiologic specialisation

Initially it was thought that PCN populations at the Nilgiris comprised *G. rostochiensis* pathotype A (Hari Kishore *et al*,1969). Breeding and screening potato for resistance to cyst nematodes brought to light occurrence of Ro1 and Pa 2 in both species (Howard, 1977). Cultivation of nematode-resistant potato 'Kufri Swarna' (derived from *Solanum vernei*) at different localities in the Nilgiris indicated the presence of other pathotypes (Krishna Prasad, 1996). Differential host-reaction studies have shown that three pathotypes occur in each species at the Nilgiris (Krishna Prasad, 2004). Pathotype Ro1 of *G .rostochiensis* and Pa 2 of *G. pallida* are the most prevalent and constitute 75% of total population. Other pathtoype Pa 1 accounted for 15%, followed by Ro2, at 7%. The least prevalent pathotypes Pa3 and Ro5 accounted for only 3% but were able to develop distinctly on some of the differential hosts, indicating their virulence (Krishna Prasad, 2006). PCN populations from Kodaikanal constituted pathotypes Ro1 of *G. rostochiensis* and Pa 2 *of G. pallida.*

Field symptoms

Generally, nematode infestations are not easy to recognize and may be suspected when yellowing of foliage, coupled with stunted growth of the plants in patches (Fig 4) is observed which is often mistaken for nutrient deficiency symptoms. Yield-reduction due to nematode damage is progressive and increases year after year. RKN juveniles, on entry into the root, cause typical root galls and affect uptake of nutrients. Similarly, PCN juveniles also enter feeder roots, establish and obstruct uptake of minerals and nutrients, impeding the overall plant growth, but without forming root knots.

Fig 4. Initial nematode infection

In both the cases, field symptoms appear after the nematode population in the soil builds up to about 10 eggs and larvae (propagules) per 100 ml of soil. Initially, small patches of poorly growing, pale yellow plants are observed. A closer examination of the root system of such plants show galls of RKN (Fig 5) while, in PCN, one can observe yellow or white, small, mustard-size female nematodes sticking to the roots (Fig 6). Temporary wilting of plants occurs around mid-noon and late evening, while, in heavily infested fields, plants remain stunted, show premature yellowing and poor root development. Reduction in size and number of tubers is also observed. Pimple-like blisters appear on tubers due to RKN, which reduces the marketable value of the produce (Fig 7) especially, the seed tubers. Well-grown cysts on tubers are often seen in fields

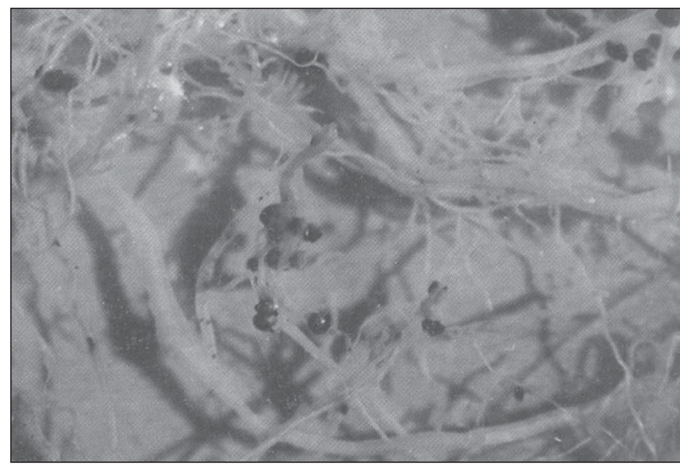

Fig 5. Root knot nematode on potato roots with egg masses

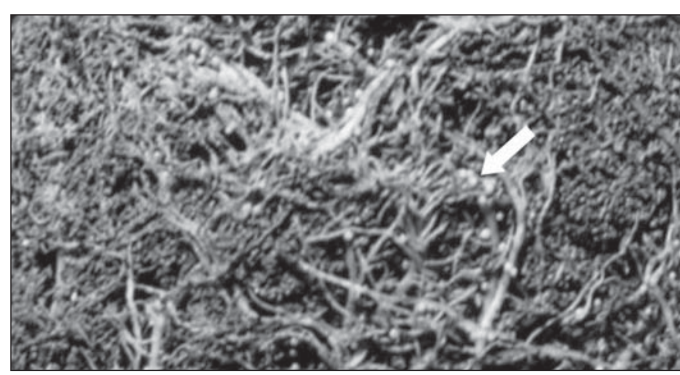

Fig 6. Female Cyst Nematodes on potato roots

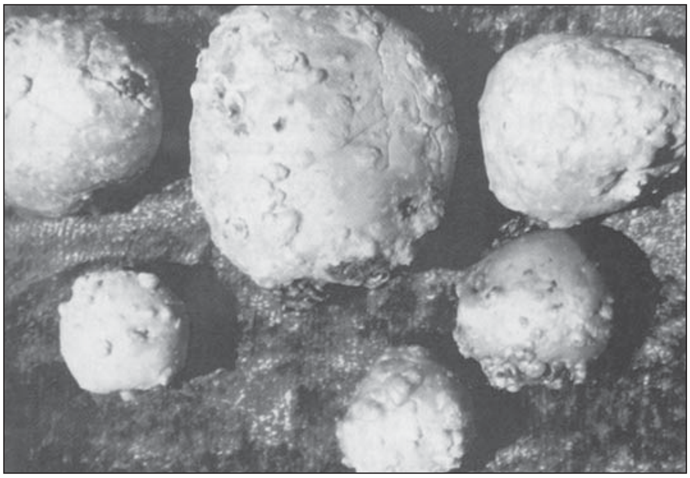

Fig 7. Tubers infected by RKN

heavily infested with PCN (Fig 8) and cause gradual reduction in yield year after year, with poor quality seed tubers despite good crop-management practices (Ravichandran *et al*, 2001).

Fig 8. Potato field heavily infected by nematodes

Nematode biology

Lifecycle and biology of RKN and PCN are similar, with only subtle differences. Since RKN is polyphagous, the larvae readily hatch in soil without presence of any stimulant, while, in the oligophagous PCN, hatching of cysts is initiated by root diffusates. Solanine and alfa-chaconine are glycoalkaloids released by potato roots, which act as PCN hatching stimulants. Absence of potato root exudates is known to force PCN eggs to remain unhatched for 15-20 years. The 2nd stage larvae emerging out of the egg-mass or cyst move actively in soil, to invade roots, and lie parallel to the vascular system. This infection results in formation of giant cells from which nematodes extract nourishment. Female larvae undergo successive molts, increasing each time in size to attain a spheri-cal shape. Adult females remain attached to the roots by their neck, are pear-shaped and measure 0.7 -0.8 mm in diameter and are white or yellow in colour. RKN eggs are laid into a gelatinous matrix (Fig 9) while, in PCN, females turn brown and become hard

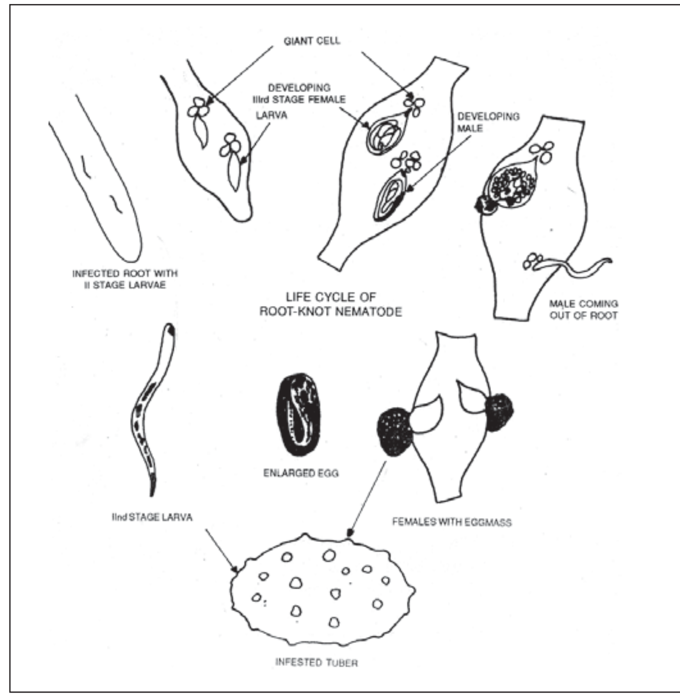

Fig 9. Life cycle of root-knot nematode in potato

cysts. Male nematodes are thread-like and come out freely from the root system. Approximately 25 to 30 days are required for completion of life cycle in both the cases (Fig 10). However, in winter months at Shimla, RKN took about 65 days to complete its lifecycle, due to snowfall that decrease the soil temparatures (Nirula and Raj, 1969).

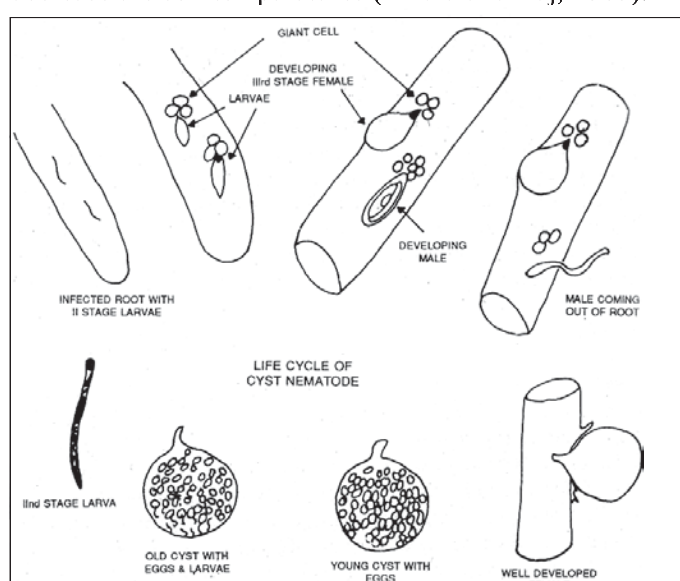

Fig 10. Life cycle of cyst nematode in potato

Generally, one nematode generation is completed in a crop season as potato itself is grown as a sandwitch crop at most places, particularly, in the Indian plains. Evidence of the 2nd generation being completed in both RKN and PCN is available. As there is no distinct dormancy in RKN prior to hatching, larvae from the first generation can infect stolons and tubers, while PCN exhibits specific dormancy. *Globodera rostochiensis*, with a shorter dormancy of 45 to 60 days can complete its second generation in the Nilgiri hills (Krishna Prasad, 2004b) on potato in the long-duration varieties that complete a crop cycle in 130 days. *Globodeva pallida* generally has one life cycle, with 60 to 75 days' dormancy. Multiplication rate of both the nematodes ranges from 7 to 13 times the initial population in one crop cycle on potato (Krishna Prasad, 2004c). Studies have shown that *G. pallida* is able to develop and reproduce in the foothills of Nilgiris at 300 to 350 m MSL from October to February, when ambient temperatures ranges from 14° to 19°C (minimum) and 22^{o} to 30°C (maximum). However *G. rostochiensis* could develop into females only at 1400m MSL and above, where maximum day temperature is not more than 24°C during the above months (Krishna Prasad, 2004a).

Nematode spread

At the time of harvest, egg-masses or the brown cysts containing eggs are easily dislodged into the soil (Fig 11). Nematode infection by either the egg mass or cysts with eggs within usually spreads with soil adhering to the farm implements, harvested tubers, gunny bags, etc. Other major means of spread is through contaminated compost, laborers feet, and, by seed potatoes. During monsoon months, water running down slopes also facilitates transmittance or spread of cysts. (Logiswaran and Menon, 1965).

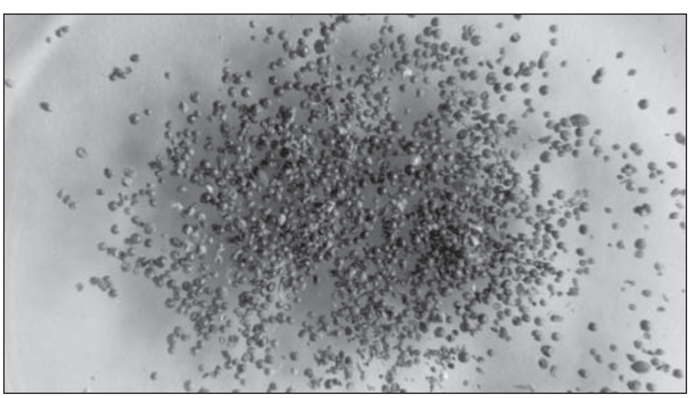

Fig 11. Mature cysts in soil debris

Nematode management

Nematode management is practiced using seeds obtained from nematode-free areas and by following several cultural practices like deep ploughing and exposing soil to summer heat, trap cropping, rotation with non-host crops, intercropping in potato based cropping system, nematicide treatment to reduce the initial nematode population, breeding nematode-resistant potato varieties, addition of organic amendments to increase the activity of antagonistic microorganisms, and by use of biological-control agents (Sethi and Gaur, 1986). However, the endoparasitic nature of the nematode, deposition of eggs into a gelatinous eggs mass (in RKN) and the female turning into a hard cyst encompassing eggs within (in PCN) makes them difficult organisms to manage. Occurrence of physiologic variations (Krishna Prasad, 1996; Mathur and Krishna Prasad, 1998; Wajid Khan and Khan, 1998) complicates the use of resistant varieties. Experience shows that these nematodes need to be managed by adopting several plant protection strategies.

Cultural practices

Cultural management basically involves all crop-husbandry practices that deprive the nematodes from infesting potato thereby reducing their population (Evans and Stone, 1977; Evans, 1993). The most common practice is use of healthy seed, crop rotation and intercropping with antagonistic plants. Surveys conducted to document species-complex, distribution and subsequent mapping of nematode intensity, have helped identify nematode-free zones for seed-potato production in India (Fig 2 and 3). This has helped in obtaining healthy seed potatoes and thus potato from North-West plains of Punjab and Haryana States and the high hilly districts of Kullu, Kinnaur and Lahual & Spiti in Himachal Pradesh are more favored as a source for reducing RKN infection. On the other hand, potato from Nilgiris and Kodaikanal hills is avoided, to restrict the movement of PCN.

Growing non-host crops such as maize, wheat and the trap-crop, marigold helps minimize RKN in northern India (Gill, 1974; Deshraj, 1983). A two-year crop rotation and application of nematicide (carbofuran @ 2 kg ai /ha in two equal splits, once at planting and the other at earthing-up) increased potato yields by 45% and brought down RKN tuber-infection by 96% in Shimla hills (Krishna Prasad, 1986).

Crop rotation with non-solanaceous vegetables (beetroot, cabbage, carrot, cauliflower, french bean, garlic, radish, turnip, etc.) between September-November reduced PCN cysts and its propagules in South Indian hills, ranging from 24 and 76% respectively (Table 4). A three and four year rotational sequence with a nematode susceptible and resistant potato brought down PCN by 98 to 99% and increased yields by 65% in Nilgiri hills (Krishna Prasad, 2000). These crop rotations and inter-cropping of potato with French bean or wheat reduced nematode infestation by 35%, while, nutritive value of the soil increased (Manorama *et al*, 2003). Exposing soil to summer heat, fallowing, mulching, trap-cropping, addition of organic amendments to increase the activity of antagonistic organisms in the soil are other methods of nematode management in potato.

Table 4. Effect of growing potato and other crops on cysts and propogules of PCN

Initial population : Cysts 250/100 ml soil
Eggs and larvae : 85 /cyst

Crop	Build-up index * of cysts	Build up index* of eggs and larvae	Calculated CPR** value	Per cent reduction over susceptible potato var. at harvest
Susceptible potato var.	4.982	2.551	12.71*	
Resistant potato var.	0.582	0.454	0.26	97.9
French bean	0.612	0.752	0.46	96.4
Cabbage	0.514	0.385	0.22	98.4
Carrot	0.537	0.392	0.19	98.3
Garlic	0.628	0.422	0.26	97.9
Maize	0.734	0.704	0.51	95.9
Wheat	0.716	0.795	0.57	95.5
Oat	0.695	0.681	0.47	96.3
Fallow	0.915	0.860	0.76	93.9

*Build-up index calculated as the ratio of final population over initial population

** CPR Calculated as Cumulative Percent Reduction over initial population

Breeding for resistance

Use of host-resistance is the most sustainable nematode management strategy and has been exploited in potato nematode management (Stone and Turner, 1983). Research on breeding for nematode resistance in India started for RKN in 1961 and for PCN in 1968 at the Central Potato Research Institute, Shimla and its sub-station at Ootacamund. High degree of resistance in several tuber-bearing *Solanum* species is available (Table 5) both for RKN and PCN (Birhman *et al*, 1998; Gaur *et al*, 1999). Continuous breeding and selection of resistant lines of potato brought to light existence of variations within the species of RKN and PCN which were designated as biotypes and pathotypes. Pathotype-specific, major genes control resistance to PCN (Kort *et al*, 1977) and non-specific

Table 5. Nematode resistance available in tuber-bearing *Solanum* species (compiled from CPRI Annual Reports)

Species	Number of accessions resistant to RKN	Number of accessions resistant to PCN
Solanum acaule	3	2
S. acroscopicum	1	—
S. agrimonifolium	1	—
S. ajanhurri	1	—
S. bolviense	2	—
S. brevicaule	1	—
S. bulbocastanum	1	1
S. cardiophyllum	3	—
S. chacoense	14	2
S. chrenbergii	—	1
S. chaucha	1	—
S. curtilobum	3	—
S. demissum	7	2
S. famatinae	1	1
S. fendleri	—	1
S. hougasii	1	—
S. infundibuliforme	1	—
S. jamesil	1	—
S. gourlayi	—	1
S. grandarillasii	1	—
S. kurtzianum	2	3
S. leptophyes	2	—
S. lignicaule	1	—
S. maglla	2	—
S. microdontum	1	3
S. multidissectum	1	2
S. ochranthum	1	—
S. oplocense	—	2
S. phureja	2	2
S. pinnatisectum	1	—
S. raphanifolium	4	—
S. recho	1	—
S. sanitaerosae	1	—
S. sparsipillum	2	3
S. spegazzinii	5	9
S. stenophyllidium	1	—
S. *stenotonum*	1	—
S. *stoloniferum*	8	—
S. *sucrense*	—	2
S. *tarifense*	—	1
S. *tuberosum* spp *andigena*	28	168
S. *tuberosum*	16	13
S. *vallis mexici*	1	—
S. *vernei*	2	5
Inter varietal Hybrids	161	287
Imported accessions	75	22

polygenes to RKN (Harikishore *et al*, 1977). An intervarietal hybrid HC-294 possessed resistance to *M. incognita* and several commercial potato varieties showed reduced development and reproduction (CPRI, 1986).

High degree of PCN resistance available in *S. vernei* (clone 62-33-3) has been used for developing a PCN resistant variety *'Kufri Swarna'* (Fig 12) at the Nilgiris (CPRI, 1986). This variety offers better management of PCN

Fig 12. PCN resistant variety Kufri Swarna

as it is resistant to pathotypes Ro 1 and Pa 2 (Maximum occurrence). Continuous cultivation of resistant varieties helps build up other pathotypes (Krishna Prasad, 1996). Therefore, it has to be alternated often with a susceptible potato variety. South Indian hills, which grow potato throughout the year, are also endemic to the late blight (LB) pathogen, *Phytopthora infestans* (Krishna Prasad and Latha, 1999), and hence, potato varieties should have combined resistance to PCN and LB (Fig13).

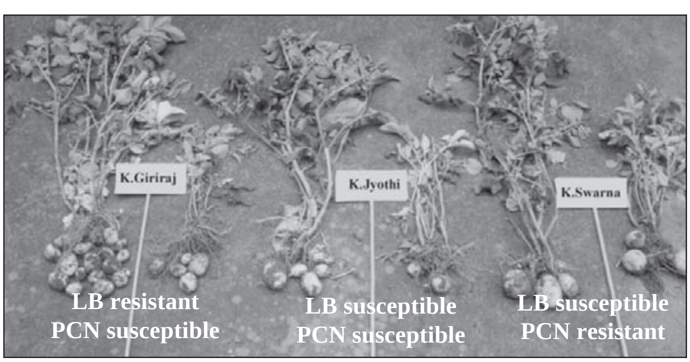

Fig 13. Growth comparison in potato varieties in healthy & nematode-sick plots

Potato breeding and evaluation resulted in developing 21 promising advance hybrids (Fig 14) with combined resistance to PCN and LB (Krishna Prasad *et al*, 2001; Joseph *et al*, 2003). Two advance hybrids OS/93-

Fig 14. View of promising advance hybrids with combined resistance to PCN and LB at CPRS, Ooty

D204 and OS/94-L956, have entered Adoptive Research Trials in farmers' fields (Fig 15; Joseph and KrishnaPrasad, 2005). One of the selections, E/79-42, has been registered with NBPGR as an excellent male source, with combined resistance to PCN and LB (Krishna Prasad, 2006).

Fig 15. Adoptive research trials in farmers' fields in the Nilgiris

Chemicals in nematode management

Initially, DD (1-3 Dichloropropane1-2 dichloropropene), EDB (Ethylene di bromide), MBr (Methyl bromide), DBCP (Dibromochloropropene), Dorlone (a mixture of DD and EDB) were used for controlling RKN and PCN. Massive chemical-control attempt was also made under the Indo-German Nilgiris Development Project during 1971-75 to check PCN. The treatment was made mandatory under the Tamil Nadu Pest Act 1971 and all the infested fields at that time in Nilgiris were treated with 30 kg ai/ha of Fensulfothion (Dasanit 10 % G) in the first year, followed by 15 kg ai/ha in the subsequent years.

Nearly 1000 tons of 10% Fensulfothion was used treating about 3100 hectares of annual cropped area, over a period of five years (Seshadri, 1978). Thus, each hectare, on average, received 325 kgs of the pesticide. In spite of this massive application of pesticides, PCN continued to be one of the limiting factors for potato production in the Nilgiris (Table 6; CPRI, 1985). At present, application of Carbofuran

Table 6. Quantity of Dasanit 10%G used in the Nilgiris for PCN control

Year	Hectares treated	Dasanit 10 % G used in kg
1970	1220	3,28,518
1971	1400	2,23,639
1972	1564	1,99,425
1973	1227	1,11,246
1974	1874	1,37,150
Total		9,99,978 kg (1000 tonnes)

at 2 kg ai/ha is recommended to keep nematodes at below the economic threshold levels of less than 10 eggs or larvae per 100 ml of soil at the time of planting potato (Krishna Prasad, 2000). This will help reduce the initial nematode inoculum in soil and also reduce build-up of pathotypes that multipliy on the resistant cv. 'Kufri Swarna'(Krishna Prasad, 2007b).

Biocontrol agents for nematode management

Nematode management in potato by bioagents has not been exploited to its full potential (Crump, 1989; Crump and Flynn, 1992). The fungus, *Paecilomyces lilacinus,* is effective against root knot nematodes on potato (Jatala, 1985) and was extensively used for RKN management in other crops under the International Meloidogyne Project (Sasser, 1989), while, the endomychorhhizal fungi, *Glomus fasciculatus* and *G. mossae,* offer possibilities for nematode management, especially RKN, in India (Krishna Prasad, 1993). Two bioagents, *Paecilomyces lilacinus* and *Pochonia chlamydosporia*, in talc formulations, were tested for PCN management under field conditions, with and without the nematicide (Krishna Prasad and Nagesh, 2007). Both these organisms (Fig 16) were able to reduce cysts and propagules by 46 to 49% while increasing marketable-potato yields by 40 to 70%. Similarly, *Pseudomonas flourencens*, in combination with *Paecilomyces lilacinus,* brought about substantial yield increase upto 70% while reducing PCN (Malavika *et al*, 2008).

The rapidity with which many of these nematode biocontrol agents have been used in the Indian agriculture for management of several parasitic nematodes like RKN, in vegetables (Rao *et al*, 1997, 1998; Rao, 2004), ornamentals (Rao *et al*, 2003) and reniform and burrowing nematodes in cotton (Shivakumar *et al*, 2004) and banana (Karuna *et al*, 2004) has shown that indigenously isolated and multiplied biocontrol agents will become an important component of nematode management in potato as well (Walia, 2004, Krishna Prasad, 2007a).

Integrated management

Experience has shown that neither RKN nor PCN can be eradicated once these establish in a locality (Sethi and Gaur, 1986; Hamid and Alam, 1998). Their similarities in population dynamics, biology and life cycle facilitate integrated management of RKN and PCN in potato. Hence, these nematodes need to be managed by combining several plant-protection strategies (Kamra and Dhawan, 1998). RKN in the north Indian hills is being managed by application of Carbofuran 3G at 1 or 2 kg ai/ha at potato planting (Deshraj, 1983); two-year crop rotation with wheat or maize and seed certification after inspection for root knots on seed tubers (Krishna Prasad, 1986, 1993). This has helped keep juveniles of RKN at less than the threshold level of 10 to 20 larvae /100 g of soil sample.

Integrated PCN management practice was standardized in a nematode sick plot (Fig. 17) over a period of eight years involving crop rotation, intercropping, host resistance and nematicide treatment at potato planting

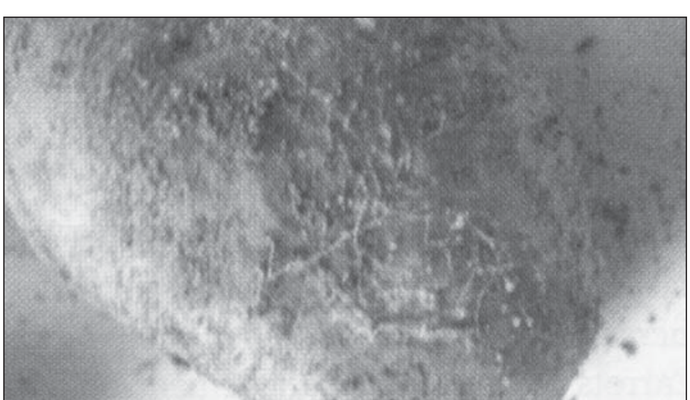

Fig 16. Bio-agent growing on potato cyst nematodes

Fig 17. Potato cyst mematode-sick plots at CPRS, Ooty

(Krishna Prasad, 2001). The treatments incorporated were potato cultivar *Kufri Swarna* resistant to PCN, potato cultivar *Kufri Jyothi*-PCN susceptible, locally grown vegetable cultivars of cabbage, carrot, French bean, garlic, pea, radish, and Carbofuran at 2 kg ai /ha. A PCN sick plot with initial population of 42 -50 cysts /100 soil harboring about 1500-2000 eggs and larvae was sub-divided into 72 sub-plots and the above crops were grown during April-August. The potato crop received nematicide treatment. Nematode build-up was monitored during the crop period and crops were alternated in the subsequent year. Each year, after the harvest of the main crop in sub-plots, wheat and fodder oat were planted. (Fig 18). This further reduced

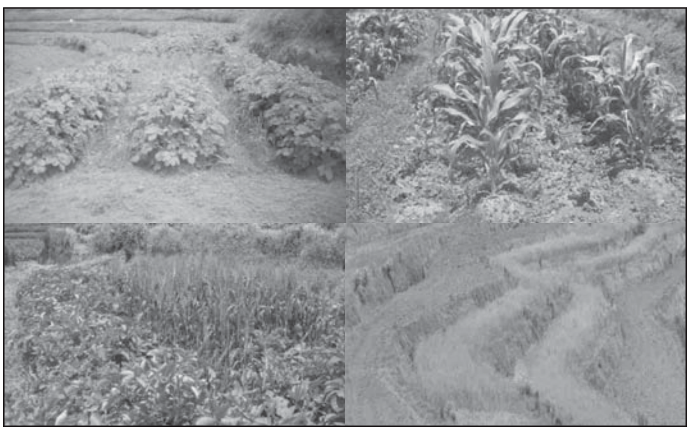

Fig 18. IPM practices for nematode management in potato

nematode populations by 20 to 24%, in addition to utilizing residual moisture in the soil.

Nematode resistant potato and other vegetables were able to bring down the nematode population by 82% in the very first year, with an accumulated reduction of upto 99.5% following pesticide treatment and crop rotation. At the same time, increase in nematode population in the susceptible potato variety was 3.2 times for cysts and 6.3 times for eggs and larvae, resulting in 65% yield-reduction. Cabbage and carrot grown after potato harvest reduced initial nematode populations and increased the potato yield the subsequent year. Studies indicated that even a three-year crop rotation of susceptible potato is sufficient to get economical yields when it is rotated with resistant potato or cabbage or carrot. However, there is a need to resort to minimum application of pesticide (2 kg ai/ha of Carbofuran) before the nematode-resistant potato can be grown, to keep the initial nematode population low and to avoid build-up of the less prevalent pathotypes. This cropping sequence has given 28 to 30 t/ha in PCN susceptible potatoes and 31 to 34 t /h in the resistant potatoes. Now, farmers in the

Fig 19. A view of farmers practising IPM in the Nilgiris

Nilgiris are following this crop management schedule (Fig 19).

Other nematodes

Several parasitic nematodes such as the lesion, spiral, stunt and reniform nematodes are constantly encountered in surveys on potato fields (Gill, 1974). Not much information was available hitherto on their role as pathogens in potato (Krishna Prasad, 1984), hence, their relative occurrence was quantified in potato based croping system at Nilgiris(Table 7).

Table 7. Build-up of ectoparasitic nematodes on different crops in the Nilgiris

Crop	Duration in days	Spiral nematode	Lesion nematode	Total EPN
Potato	110	7.82	5.35	6.58
Bean	75	3.45	2.85	3.15
Cabbage	115	6.45	4.85	5.65
Carrot	125	4.85	3.50	4.18
Garlic	105	4.50	3.30	3.90
Maize	135	7.60	5.20	6.40
Wheat	110	6.00	4.85	5.42
Oot	120	5.05	4.25	4.65
Mean Build-up Index*		5.71	4.27	4.99

* *Build-up index calculated as the ratio of final population over initial population

Pathogenicity of *Quinslcius capitatus,* a stunt nematode frequently occurring in the Himalayan mid-hills (Krishna Prasad and Sharma, 1985), and the spiral nematode (*Helicotylenchus dihystera*) prevalent in all the potato-growing tracts of India, was established on potato (Krishna Prasad and Rajendran,1990).The stunt nematode reduced 14 to 29% tuber yield, while, the spiral nematode accounted for 9 to 27% tuber yield reduction. Both these nematodes, polyphagous ectoparasites commonly encountered in all the potato-growing localities, are potential pests of potato, if

RKN or PCN are to be managed by host resistance alone. Studies on build-up of spiral and lesion nematodes in potato fields at Ootacamund showed that ectoparasitic nematodes preferred potato, followed by maize, cabbage and wheat in that order. Other parasitic nematodes of importance in potato are the pin (*Paratylenchus* spp.), reniform (*Rotylenchulus* spp.) and lesion (*Pratylenchus* spp.) nematodes. However, management practices followed for PCN or RKN reduce these pests (Krishna Prasad, 2007b).

Conclusion

Potato, an important crop grown in India, throughout the country, is associated with about 90 species of plant parasitic nematodes belonging to 38 genera. Among these, root-knot nematodes and cyst nematodes are important constraints in crop productivity. Root-knot nematodes are present throughout the country, while, cyst nematodes are restricted to the hilly regions of Tamil Nadu. The endoparasitic nature of life cycle in these nematodes poses difficulties in their management. Further, physiologic variation in these nematodes makes host resistance often a failure. Therefore, an integrated nematode management (INM) is adopted in both the cases. The root-knot nematode in North India is managed using nematode-free seed tubers, a two-year crop rotation with maize or wheat, and, with nematicide (carbofuran @ 2 kg ai/ha) application in split doses. The cyst nematode in Tamil Nadu hills is managed by following a three-year crop rotation with vegetables, intercropping with beans or wheat, using nematode resistant potatoes and by application of the nematicide in split doses. Adoption of INM for these nematodes has proved efficient and economical in Himachal Pradesh and Tamil Nadu hills. Few indigenously multiplied biocontrol agents like *Paecilomyces lilacinus*, *Pochonia chlamydosporia* and *Pseudomonas flourencens* offer excellent opportunity for incorporation into this nematode-management system.

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