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Management of root-knot nematodes (*Meloidogyne* spp.) in pulses by crop rotation

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Abstract
Root-knot nematodes multiply very fast due to continuous cultivation of susceptible crops. Various technologies are being used for their management. Among them, crop rotation is the oldest and effective method. Root-knot susceptible cow pea variety Gujarat Dantiwada Vegetable Cowpea 2 (GDVC 2) and resistant variety Anand Vegetable Cowpea 1 (AVCP 1) were rotated with susceptible, resistant, non host and poor host crops for three years during *Kharif*, *Rabi* and summer seasons in root-knot nematode infested field and okra was also grown as a test crop in *Kharif* of fourth year. Cowpea (R) – onion– cowpea (R) rotation was found most effective rotation in which minimum nematode population, root-knot index and highest yield was recorded availing maximum income benefits. Cow pea, chickpea and mung were susceptible to root-knot nematodes therefore; nematode population and root-knot index were maximum in cowpea (S) – chickpea - mung rotation.

Keywords: Root-knot nematode, cowpea, crop rotation, economics

Introduction
Root-knot nematodes (*Meloidogyne incognita & M. javanica*) are an important pest of field crops causing heavy losses to pulses (Gupta and Verma, 1990) [5]. The nematode infestation results in gall formation on the root system resulting into yellowish leaves and poor plant growth. Avoidable losses up to 40-44% in pulses due to *M. incognita & M. javanica* have been reported (Kalitha and Phukan, 1993) [8]. Although several management strategies such as application of organic amendments, growing of resistant varieties, summer ploughing, application of nematicides *etc*. have been advocated for the control of nematodes in different field crops, all may not be feasible to use under field conditions. In multiple cropping systems, crop rotation with non-host crop can maintain the nematode population below economic threshold levels.

Continuous cropping of susceptible crops leads to the buildup of nematode; hence it would be difficult and expensive to control. Various methods are in practice to manage nematodes of them chemical application is more popular but in absence of true nematicide in the country, farmers have to relay on alternative management options. Crop rotation is among the oldest and most important method for managing nematodes in annual crops but development of crop rotation programs is often constrained by specialized cropping practices, local climate and the market value of the crops (Thomason and Caswell, 1987) [20]. In an optimum crop rotation system, the preceding crop prevents damage to the following crop by suppressing the target nematode population without increasing other species of nematode that may be parasitic to the future crop (Johnson, 1985) [7].

Inclusion of crops in rotation with different susceptibility to root-knot nematodes can give dramatic results (Noe, 1986; Kanwar and Bhatti, 1992) [14, 9] and is a low cost, low input technology (Noe, 1988) [15]. The present study was undertaken to workout effective and economical crop rotation with non host crop**,** resistant crop and poor host crop variety to manage root-knot nematodes for cowpea crop.

Materials and Methods

A field experiment was conducted at Nematology farm, Department of Nematology, B.A. College of Agriculture, Anand Agricultural University, Anand, Gujarat (India) during *Kharif*, *Rabi* and summer seasons for three consecutive years. An experiment was started during *Kharif* season in 2016 in soil having initial nematode population of 247 J_2/ 200 cm^3 soil and loamy sand texture (sand 81%, silt 12%, clay 4% with organic matter 0.70 and PH 8.15).

Root-knot susceptible cow pea variety Gujarat Dantiwada vegetable cowpea 2 (GDVC 2) and resistant variety Anand Vegetable Cowpea 1 (AVCP 1) were rotated with susceptible, resistant, non host and poor host crops for 3 years in root-knot nematode infested field during *Kharif*, *Rabi* and summer seasons, respectively in fixed plots. Crops were grown in 3.15 x 6.00 m sized plots in randomized block design with six replications and okra was also grown as a test crop in *Kharif* of 4^{th} year. The mung, chickpea, groundnut, cluster bean and cowpea crops were sown directly, where as garlic, onion, cabbage were transplanted. Details on various crop rotations, crop variety along with agronomical practices followed are mentioned in Table 1 and 2. The experiment was maintained for three years to observe effect of crop rotation on nematode population buildup and income of each rotation.

Root-knot nematode galling was accessed before maturity on 10 plants randomly selected by following index scale of 1 to 5 (Heald *et al.* 1989) [6]. To assess nematode population from soil at harvest of each crop, ten soil cores were taken from root zone from each plot and mixed well to make one composite sample. From this soil sample, 200 cm^3 soil was processed by Cobb's Sieving and Decanting method (Cobb, 1981) [2] followed by Modified Baermann's funnel technique (Southey, 1986) [17].

For recording nematode population in roots, roots were carefully dugout from the soil and washed under running water to make free from soil particles. Then roots were cut into small pieces, mixed well and 5g root stained in 0.05% acid fuchsine lactophenol (Franklin, 1949) [3]. After staining, roots were washed in running water to remove excess stain. The roots were kept overnight in plain lactophenol for removing excess stain. Observations on number of nematodes penetrated in roots were recorded. Periodical harvesting was done in cabbage, cluster bean and cowpea (veg. purpose) while mung, chickpea, garlic, onion, ground nut were harvested at crop maturity and recorded weight. On fourth year during *Kharif* season, okra was taken as a test crop. Crop yield harvested from entire plot was extrapolated on a hectare basis and crop yield was converted into income by multiplying yield with current market price of the crop. Income of nine seasons of three years from each rotation was averaged and compared. After completion of experiment for three years, okra cv. GAO 5 as an indicator host was sown during *kharif* season of forth year to assess the comparative effectiveness of different cropping rotations.

Results and Discussion

Root-knot Index

In crop rotation of cowpea (seed) - onion – cowpea (veg.) root-knot index at harvest for three years was 1.82, 1.37 and 1.10 (Table 3). Whereas, root-knot nematode susceptible crops were grown during *Kharif*, *Rabi* and summer, root-knot index was increased. Minimum root-knot index (1.42) recorded in the rotation of cowpea (seed)-onion-cowpea [veg. (Table 7)].

During fourth year, okra was taken as a test crop in which maximum root- knot index was recorded in the rotation where root-knot nematode susceptible crops cowpea (seed) (in *Kharif*) - chickpea (in *Rabi*) and mung (in summer) were taken. Minimum root-knot index found in rotation No. 3 followed by rotation with cowpea (seed)-cabbage- groundnut (Table 7).

This study has established that some crops have potential of suppressing root-knot nematodes when incorporated in rotational cycles with susceptible crops like cow pea. Green gram and chick pea both are susceptible to root-knot nematode (Greco, *et al.,* 1984; Ali and Askary, 2001; Rehman *et al*., 2012; Mayuri and Patel, 2017; Tariq *et al.;* 2017) [4, 1, 16, 10, 18] hence, cow pea - chick pea - green gram rotation supports multiplication of root-knot nematode (Table 1) therefore root knot index is also more in the above said crops.

Final nematode population

Nematode population at harvest increases when root-knot susceptible crops were grown during *Kharif*, *Rabi*, summer 2016 and *Kharif* 2017. In rotation No. 2 root-knot nematode susceptible crop cowpea grown during *Kharif*, nematode population at harvest increases but due to garlic (R) in *Rabi* and cluster bean (NH) in summer, population decreases and it again multiply in *Kharif* due to root-knot nematode susceptible cowpea. In rotation No.3 where root-knot nematode resistant cowpea grown in *Kharif*, onion in rabi and cowpea (vegetable) found effective to keep nematode population at very low level. In *Kharif*, root-knot nematodes susceptible cowpea taken, population of nematodes at harvest increases but due to cabbage in *Rabi* and groundnut in summer nematode population decline but it again increases in *Kharif* due to root-knot susceptible cowpea (Table 4).

After three years of experiment, okra was taken as a test crop. Final nematode population was reduced in the rotation of cow pea - onion- cow pea (veg. purpose).

Cabbage is also reported least susceptible or poor host of root-knot nematode (McSocley and Frederick; 1995; Waceke, 2007) [11, 21]. Reduction in root-knot index and nematode population was observed after cluster bean and it is due to its poor host status. Similar results were also reported by Mweke *et al.* (2008) [13]. Suppression of root-knot nematode by cluster bean is a finding which is in agreement with earlier studies (Wang *et al*., 2001; Morris and Walker, 2002; Wang *et al*., 2003) [2, 12, 23].

Economics

Crop rotation of cow pea (R) in *Kharif*- onion in *Rabi*-cow pea (R) for veg. purpose in summer found more economic. It gave Rs. 95,660/- which was 180.28 percent higher (Table 6) income than the rotation where root- knot nematode susceptible crops were grown for three years.

Cow pea (S)-cabbage-garlic was found second best rotation from which Rs. 81,540/- income was generated which was 138.91 percent higher (Table 6) followed by cowpea (S) - garlic (R) - cluster bean (NH) rotation.

Crop rotation of cow pea (S)-chickpea-green gram in which all crops are highly susceptible to root-knot nematode, they support nematode multiplication. Due to high nematode population, crop yield is less which resulted in lowest income as compared to rest of the rotations (Table 6).

When okra was taken as a test crop, maximum reduction in root-knot index and final nematode population and increase in yield was recorded in cow pea (R) in *Kharif*- onion in rabi-cow pea (R) veg. purpose rotation followed by cow pea – cabbage – garlic rotation.

Table 1: Different crop rotation

Rotations	*Kharif*	*Rabi*	Summer
R_1	Cowpea (Seed) (S)	Chickpea (S)	Mung (S)
R_2	Cowpea (Seed) (S)	Garlic (R)	Cluster bean (NH)
R_3	Cowpea (Seed) (R)	Onion (R)	Cowpea (R)Vegetable
R_4	Cowpea (Seed) (S)	Cabbage (R)	Groundnut (P)

S- Susceptible; R= Resistant; NH- Non host; P- Poor

Table 2: Experimental detail

Crop	Variety	Seed rate (kg/ha)	Plot size (M)	Spacing (cm)	Fertilizer, kg NPK/ha
Mung	GAM 5	20	3.15 x 6.0	30 between rows	25:50:0
Chickpea	Guj. Gram 1	60	-- do--	30 between rows	25:50:0
Garlic	Gujarat Anand Garlic 6	500-700 cloves	-- do--	15 x 10	Basal: 25:50:50 Top: 25:0:0
Onion	As per market availability/GAWO 2	10	-- do--	15 x 10	Basal: 37.5:75:50 Top: 37.5:0:0
Cabbage	Local	40,000 – 50,000 seedlings	-- do--	45 x 45	Basal:100: 75:0 Top: 100:0:0
Groundnut	TG 37 A	120	-- do--	30 between row	Basal:25:50:50
Cluster bean	Pusa Navbahar	10-12	-- do--	45 x 15	20:40:0
Cowpea	Anand Vegetable Cowpea 1	12-15	-- do--	45 x 15	20:40:0
	GDVC-2	12-15	-- do--	45 x 15	20:40:0

Table 3: Effect of crop rotation on root-knot index for management of root-knot nematodes in pulses

Treatments		RKI (1-5)												
		Kharif				*Rabi*				Summer				Test crop okra
		2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled	
1.	C-C-M (S-S-S)	2.06 (4.23)	2.18 (4.75)	2.20 (4.84)	2.15 (4.62)	2.04 (4.14)	2.04 (4.16)	2.00 (4.07)	2.03 (4.12)	2.03 (4.10)	2.08 (4.33)	1.99 (3.98)	2.03 (4.12)	2.13 (4.53)
2.	C-Ga-Cl (S-R-NH)	2.10 (4.40)	2.03 (4.13)	2.10 (4.41)	2.08 (4.33)	1.54 (2.38)	1.49 (2.22)	1.21 (1.47)	1.42 (2.01)	1.08 (1.16)	1.14 (4.41)	1.05 (1.12)	1.09 (1.19)	1.56 (2.57)
3.	C-O-C (R-R-R)	1.38 (1.90)	1.33 (1.75)	1.34 (1.80)	1.35 (1.82)	1.12 (1.26)	1.12 (1.25)	1.25 (1.62)	1.17 (1.37)	1.07 (1.14)	1.06 (1.80)	1.01 (1.03)	1.05 (1.10)	1.03 (1.07)
4.	C-Ca-Gr (S-R-PH)	2.18 (4.74)	1.71 (2.93)	2.16 (4.67)	2.00 (4.00)	1.35 (1.82)	1.35 (1.82)	1.66 (2.82)	1.46 (2.13)	1.01 (1.03)	1.05 (4.67)	1.04 (1.08)	1.03 (1.06)	1.56 (2.52)
S. Em. ±	T	0.06	0.06	0.04	0.08	0.04	0.05	0.09	0.09	0.02	0.03	0.05	0.02	0.10
	Y	-	-	-	0.03	-	-	-	0.03	-	-	-	0.02	-
	T*Y	-	-	-	0.06	-	-	-	0.06	-	-	-	0.03	-
C.D. 0.05%	T	0.18	0.19	0.13	0.27	0.11	0.15	0.28	0.30	0.06	0.09	0.14	0.05	0.31
	Y	-		-	0.08	-	-	-	0.09	-	-	-	0.05	-
	T*Y	-	-	-	0.16	-	-	-	0.18	-	-	-	NS	-
CV %		7.69	8.50	5.65	7.32	5.89	7.93	14.76	10.32	3.94	5.41	8.78	6.30	15.89

1= Free from infection, 5= maximum galling intensity, Figures in parentheses are retransformed value of √x transformation.

	Kharif	*Rabi*	Summer
1	Cowpea (Seed) (S)	Chickpea (S)	Mung (S)
2	Cowpea (Seed) (S)	Garlic (R)	Cluster bean (NH)
3	Cowpea (Seed) (R)	Onion (R)	Cowpea (R)Vegetable
4	Cowpea (Seed) (S)	Cabbage (R)	Groundnut (P)

Table 4: Effect of crop rotation on final nematode population for management of root-knot nematodes in pulses

Initial nematode population=247J_2/200 cc soil														
Treatments		**FNP (200 cm^3 soil + 5 g root)**												
		Kharif				***Rabi***				**Summer**				**Test crop okra**
		2016-17	**2017-18**	**2018-19**	**Pooled**	**2016-17**	**2017-18**	**2018-19**	**Pooled**	**2016-17**	**2017-18**	**2018-19**	**Pooled**	
1.	C-C-M (S-S-S)	2.88 (758)	3.15 (1412)	3.20 (1584)	3.08 (1201)	3.38 (2512)	3.39 (2455)	3.27 (2443)	3.33 (2137)	3.06 (1148)	3.09 (1230)	2.51 (333)	2.89 (775)	2.57 (371)
2.	C-Ga-Cl (S-R-NH)	2.87 (744)	2.94 (871)	2.96 (871)	2.92 (831)	2.12 (178)	2.27 (186)	2.15 (148)	2.18 (150)	0.51 (2)	0.30 (1)	0.196 (1)	0.34 (1)	2.26 (181)
3.	C-O-C (R-R-R)	2.17 (147)	2.02 (105)	2.11 (129)	2.10 (125)	0.28 (1)	0.90 (6)	1.21 (33)	0.80 (5)	0.98 (7)	0.79 (4)	0.71 (26)	0.83 (6)	1.87 (73)
4.	C-Ca-Gr (S-R-PH)	2.81 (650)	2.96 (912)	3.08 (1202)	2.95 (890)	2.26 (229)	2.38 (240)	2.35 (225)	2.33 (213)	0.01 (2)	0.01 (2)	0.12 (1)	0.04 (0)	2.18 (150)
S. Em. ±	T	0.02	0.08	0.06	0.06	0.16	0.22	0.17	0.11	0.23	0.22	0.17	0.12	0.08
	Y	-	-	-	0.03	-	-	-	0.09	-	-	-	0.10	-
	T*Y	-	-	-	0.06	-	-	-	0.19	-	-	-	0.21	-
C.D. 0.05%	T	0.06	0.23	0.17	0.20	0.48	0.68	0.51	0.32	0.68	0.66	0.51	0.33	0.27
	Y	-	-	-	0.08	-	-	-	0.26	-	-	-	0.30	-
	T*Y	-	-	-	0.16	-	-	-	NS	-	-	-	NS	-
CV %		1.97	6.69	4.95	4.97	19.44	24.61	18.59	21.18	49.77	51.17	47.27	49.92	9.21

Figures in parentheses are retransformed value of Log x+1 transformation.

Table 5: Effect of crop rotation on the yield of different crops

Rotation	**Yield, kg/ha**									**Total**	**Av.**	**Test crop okra**
	Kharif			***Rabi***			**Summer**					
	2016-17	**2017-18**	**2018-19**	**2016-17**	**2017-18**	**2018-19**	**2016-17**	**2017-18**	**2018-19**			
1. C-C-M (S-S-S)	519	236	255	1744	2053	755	125	128	344	6159	684	1328
2. C-Ga-Cl (S-R-NH)	512	494	305	1535	1715	1943	5001	6513	3848	21866	2430	2111
3. C-O-C (R-R-R)	706	425	468	15206	17907	21022	3709	4291	4675	68409	7601	2501
4. C-Ca-Gr (S-R-PH)	498	417	299	16411	16605	16728	1054	1879	1456	55347	6150	2228

	Kharif	*Rabi*	Summer
1	Cowpea (Seed) (S)	Chickpea (S)	Mung (S)
2	Cowpea (Seed) (S)	Garlic (R)	Cluster bean (NH)
3	Cowpea (Seed) (R)	Onion (R)	Cowpea (R)Vegetable
4	Cowpea (Seed) (S)	Cabbage (R)	Groundnut (P)

Table 6: Economics of various crops evaluated against root knot nematodes

Treatments		**Income (Rs./ha)**											
		Kharif			***Rabi***			**Summer**			**Total**	**Average**	**Test crop okra**
		2016-17	**2017-18**	**2018-19**	**2016-17**	**2017-18**	**2018-19**	**2016-17**	**2017-18**	**2018-19**			
1	C-C-M (S-S-S)	33767	8202	15320	87200	102625	30194	6250	6392	17213	307163	34129	26552
2	C-Ga-Cl (S-R-NH)	33312	32110	18320	46050	51460	48576	150030	130263	115452	625573	69508 (+103.66)	42217
3	C-O-C (R-R-R)	45912	27625	28060	121648	179067	168176	111270	85690	93495	860943	95660 (+180.28)	50011
4	C-Ca-Gr (S-R-PH)	32359	27123	17960	164110	166052	167277	47430	75140	36411	733862	81540 (+138.91)	44563

Selling price of various crops:

Season	**Crops**	**Rs./kg**		
		2016	**2017**	**2018**
Kharif	Cow pea	60	65	60
	Okra	20		
Rabi	Chick pea	50	50	40
	Garlic	30	30	25
	Onion	8	10	8
	cabbage	10	10	10
Summer	Mung	50	50	50
	Cluster bean	30	20	30
	Cow pea (veg.)	30	20	20
	Groundnut	45	40	25

Table 7: Management of root-knot nematodes (*Meloidogyne* spp.) in pulses by crop rotation

Treatments		Pooled over season and year (9 seasons and 3 years)					
		RKI (1-5)		FNP (200 cm^3 soil + 5 g root)		Income (Rs./ha)	
		Treatments	Test crop okra	Treatments	Test crop okra	Treatments	Test crop okra
1.	C-C-M (S-S-S)	2.07 (4.29)	2.13 (4.53)	3.10 (1258)	2.21 (166)	34129	26552
2.	C-Ga-Cl (S-R-NH)	1.53 (2.34)	1.56 (2.57)	1.81 (64)	2.08 (144)	69508	42217
3.	C-O-C (R-R-R)	1.19 (1.42)	1.03 (1.07)	1.24 (16)	1.10 (32)	95660	50011
4.	C-Ca-Gr (S-R-PH)	1.50 (2.25)	1.56 (2.52)	1.77 (58)	1.98 (109)	81540	44563
S. Em	T	0.07	0.10	0.22	0.18		
	Y	0.03	-	0.08	-		
	T*Y	0.05	-	0.17	-		
C.D. 0.05%	T	0.22	0.31	0.63	0.55		
	Y	0.07	-	0.23	-		
	T*Y	0.15	-	0.46	-		
CV %		8.26	15.89	20.36	23.91		

1= Free from infection, 5= maximum galling intensity, Figures in parentheses are retransformed value of √x trans. and Log x+1 transformation.

Conclusion

Cowpea (R) – onion– cowpea (R) rotation was found most effective rotation in which minimum nematode population, root-knot index and highest yield was recorded availing maximum income benefits. Cow pea, chickpea and mung were susceptible to root-knot nematodes therefore; nematode population and root-knot index were maximum in cowpea (S) – chickpea - mung rotation.

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