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*General Article*____ *Chapter – 8*

BIOINTENSIVE APPROACHES FOR THE MANAGEMENT OF PHYTONEMATODES

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Abstract

One of the most important objectives of the goals of Millennium Development Goals is to eradicate extreme poverty and hunger. Sufficient nourishment for the whole population of the world is one of the challenges of the present era. Future agricultural growth must come from productivity growth to address the persistent problems of poverty, food insecurity and malnutrition. Disease is one of the most important factor in maintaining plant health. Diseases are caused by either biotic or abiotic causes. Among them nematodes are biotic causes of plant diseases.

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Introduction

One of the most important objectives of the goals of Millennium Development Goals is to eradicate extreme poverty and hunger. Sufficient nourishment for the whole population of the world is one of the challenges of the present era. Future agricultural growth must come from productivity growth to address the persistent problems of poverty, food insecurity and malnutrition (Singh *et al.,* 2015). Disease is one of the most important factor in maintaining plant health. Diseases are caused by either biotic or abiotic causes. Among them nematodes are biotic causes of plant diseases.

Genera of The Most Common Plant Parasitic Nematodes:

Root – knot nematode	*Meloidogyne* sp.	Pin nematode	*Paratylenchus* sp.
Cyst nematode	*Globodera* sp. *and Heterodera* sp.	Reniform nematode	*Rotylenchulus* sp.
Awl nematode	*Dolichodorus* sp.	Ring nematode	*Criconemella* sp.
Dagger nematode	*Xiphinema* sp.	Sheath nematode	*Hemicycliophora* sp.
Foliar nematode	*Aphelechoides* sp.	Spiral nematode	*Helicotylenchus* sp.
Lance nematode	*Hoplolaimus* sp.	Sting nematode	*Belonolaimus* sp.
Lesion nematode	*Pratylenchus* sp.	Stubby – root nematode	*Paratrichodorus* sp. *and Trichodorus* sp.
Needle nematode	*Longidorus* sp.	Stunt nematode	*Tylenchorhynchus* sp.

How Nematode Cause Injury to Plant?

- Direct damage.
- Alter host physiology.
- Removal of host tissue.
- Allow to infection by another organism.
- Transmit other pathogens.
- Interact with other pathogens, synergisti
- Increase susceptibility of host to environmental stress.
- It may also interfere with rhizobial nodulation in legumes leading to decrease in nodule number, size and therefore nitrogen fixation.

Why Nematode Management?

According to an estimate plant parasitic nematodes are causing much more damage annually compared to insect pests. They caused projected yield loss of 12.3 % ($157 billion dollars) worldwide. Out of which $40.3 million is reported from India. Farmers/growers identified insect pests, and other constraints as production problems but overlooked plant parasitic nematodes. Nematode diseases are difficult to control because of their hidden nature and hence, more often overlooked. Plant parasitic nematodes not only cause damage individually but form disease-complexes with other micro-organism and increased the crop loss (Singh *et al.,* 2015).

Estimated Annual Yield Losses Due to Damage by Plant-Parasitic Nematodes Worldwide Ravichandra (2008)

Life-sustaining crops**	**Loss (%)**	**Economically important crops**	**Loss (%)**
Banana	19.7	Cacao	10.5
Barley	6.3	Citrus	14.2
Cassava	8.4	Coffee	15.0
Chickpea	13.7	Cotton	10.7
Coconut	17.1	Cowpea	15.1
Corn	10.2	Eggplant	16.9
Field bean	10.9	Forages	8.2
Millet	11.8	Grape	12.5
Oat	4.2	Guava	10.8
Peanut	12.0	Melons	13.8
Pigeon pea	13.2	**Misc. other*****	17.3
Potato	12.2	Okra	20.4
Rice	10.0	Ornamentals	11.1
Rye	3.3	Papaya	15.1
Sorghum	6.9	Pepper	12.2
Soybean	10.6	Pineapple	14.9
Sugar beet	10.9	Tea	8.2
Sugar cane	15.3	Tobacco	14.7
Sweet potato	10.2	Tomato	20.6
Wheat	7.0	Yam	17.7
Average	10.7%	Average	14.0%

What is Biointensive Agriculture?

Biointensive agriculture is an organic agricultural system that focuses on achieving maximum yields from a minimum area of land, while simultaneously increasing biodiversity and sustaining the fertility of the soil. Rajbhandari (2002) has defined bio-intensive farming system (BIFS) as a biologically intensive mixed farming system, which relies on the intensive engagement of the farmers; optimization of organic recycling through crop rotations; integrated plant nutrient management (IPNM); and integrated organic pest management (IOPM) with the use of bio-pesticides, botanical pesticides and biotagents.

During the past 50 years the use of pesticides has increased dramatically worldwide and now amounts to some 2.6 million tons of pesticides per year with an annual value in the global market of more than US$ 25 billion (Rajbhandari 2017).

Bio-intensive IDM strategies described as a minimal use of pesticides, as a last resort and giving preference to other non- chemical control methods such as sanitation, crop rotation, fallowing, resistance, bio agents, solarization *etc.*

Estimated Crop Losses Due to Major Plant-Parasitic Nematodes In India. Ravichandra (2008)

Crops	Nematode	loss	Crops	Nematode	loss
Barley	*Heterodera avenae*	Rs. 30 million	French bean	*Meloidogyne incognita*	43.5%
Black gram	*Meloidogyne incognita*	8.7%	Ground nut	*Meloidogyne arenaria*	51%
Brinjal	*Meloidogyne incognita*	33.7%	Maize	*Rotylenchulus reniformis*	6%
Citrus	*Tylenchulus semipenetrans*	15%	Okra	*Meloidogyne incognita*	28.1%
Coffee	*Pratylenchus coffeae*	Rs. 20 million	Pigeon pea	*Heterodera cajani*	14.2%
Cotton	*Meloidogyne incognita*	17.7-19.9%	Pea	*Meloidogyne incognita*	20%
Cowpea	*Meloidogyne incognita*	28.6%	**Potato**	***Globodera rostochiensis***	**99.98 %**
Finger millet	*Meloidogyne incognita*	4.8%	Rice	*Hirschmaniella oryzae/ Aphelenchoides besseyi*	30-87% 12.2%
Tobacco	*Meloidogyne incognita*	50%	Wheat	*Heterodera avenae*	Rs. 40 million

Plant Quarantine

The quarantine measures are of almost relevance to a country like India whose economy is largely Agriculture based. Quarantine can be defined "as a legal restriction to prevent the entrance and establishment of a plant disease or insect pest in an area where the pest or disease does not exist". In India plant quarantine is regulated under the destructive insect and pest act, 1914 (Reddy, 2010). The Destructive Insects and Pests Act, 1914 (DIPA) was passed by the Government of India which restricts introduction of exotic pests and disease into the country from abroad. Strict regulations have been made against *G. rostochiensis*, the potato cyst nematode and *Rhadinaphelenchus cocophilus*, the red ring nematode of coconut. Domestic quarantine regulations have also been imposed to restrict the movement of potato both for seed and table purposes in order to present the spread of potato cyst nematode from Tamil Nadu to other states in India (Prasad, 2008).

Bio Intensive Approaches

Method of management	**Specific practice**
Biosecurity	Plant quarantine
Selection of healthy planting material /field	Nematode free seed / seedlings
Cultural practices Nematode suppressive crops	Fallowing, Flooding, Summer ploughing, Green manuring, Trap crops, Crop rotation. Soil amendments, field sanitation. Bio-fumigation plants, Antagonistic crops. Cover crops, Trap crops
Physical Methods	Soil solarization, Steam sterilization, Hot water treatment
Biological Methods	Nematode trapping fungi, endoparasitic fungi, obligate parasitic fungi, PGPR
Botanicals	Neem based products
Resistant cultivars	Resistant varieties, Tolerant crops/varieties, Genetic Engineering.
Nematicides	Carbofuran

Healthy Planting Material

- In plants, propagated by vegetative means we can eliminate nematodes by selecting the vegetative part from healthy plants.
- The golden nematode of potato, the burrowing, spiral and lesion nematodes of banana can be eliminated by selecting nematode free plant materials.
- The wheat seed gall nematode and rice white tip nematode can be controlled by using nematode free seeds.

Fallowing

Leaving the field without cultivation, preferably after ploughing helps to expose the nematodes to sunlight and the nematodes are die due to starvation without host plant. This method is not economical. With fallowing the concept is that an area of ground is left unplanted for a season or more in an effort to limit food available to nematodes. Existing and newly hatched nematodes will starve, reducing the population enough to permit planting of a susceptible crop. A fallow period of two years with no susceptible plants (including weeds) can decreases nematode populations. This host free period can be achieved in one season rather than two years by disking every 10 days all summer (Anwar, 2007). One of the earliest cropping systems specifically designed for nematode management involved 6–8-year rotations and fallows to avoid low yields in the presence of potato cyst nematodes, *Globodera* spp. (Bridge, 1996). For attempted eradication of root-knot nematodes in chickpea, it was suggested some innovative ideas like dry fallowing, moist fallow during warm weather etc (Alphei *et al.,*1996). In many experiments, rotation crops were not more effective than fallow in reducing root-knot nematode population levels or galling (McSorley, 2011).

Trap Crops

For trapping the nematodes, two crops are grown, first grow highly susceptible crop followed by main crop. Grow susceptible crop first and destroy crop before nematode become mature. Later, grow main crop which escape nematode damage ex: cowpea – highly susceptible to Root knot nematodes.

The Trap Crop *Solanum sisymbriifolium*

Trap crops, which are non-host crops that stimulate egg hatching but do not support nematode reproduction, provide one potential mechanism to control PCN, since hatched juveniles have limited food reserves and will die if they do not successfully parasitize plant roots within days. Otherwise, cyst nematode population decline in the absence of a host and host root recognition factors is typically fairly low (Evans, 1993). *Solanum sisymbriifolium* has been shown to be nearly as effective as potato at inducing egg hatching, but is resistant to subsequent nematode development and reproduction (Scholte, 2000). It has been investigated as a trap crop for both *G. pallida* and *G. rostochiensis* (golden nematode) (Timmeimans *et al.,* 1998). Knudsen *et al.,* (2005) observed that PCN cyst numbers were significantly reduced in potato following *S. sisymbriifolium*, compared to either potato-following-fallow or potato-following-potato. Not only was a comparative reduction in cyst numbers observed, but also a decrease in nematode fecundity (numbers of eggs per cyst). However, while nematode hatching typically increases in the presence of a trap crop, it is rare to have a high percentage of juveniles hatch from cysts in a single year, so that population carry-over typically necessitates additional years of rotation with a non-host or trap crop.

Effect of crop rotation sequence on reniform nematode populations at planting, midseason, and harvest from 2000 to 2003 in Stoneville, MS. Within each sampling interval and year, means with the same letter are not significantly different from each other (differences of least squares means, $P \leq 0.05$). *Nematode* counts were subjected to log10 transformation prior to analysis; values presented are geometric means (back transformed values) of eight replications averaged across four cotton cultivars or four corn hybrids. At fourth year result showed that the monocropping of cotton increases nematode population while in rotation with corn it reduced nematode population as compare to monocropping (Stetina *et al*., 2007). Average nematodes per gram of root and nematodes per 100 cm^3 soil after the species recommended for the succession planting in soil naturally infested with *Pratylenchus brachyurus* in two separate experiments.

Diego *et al.,* in the year 2014 at Brazil recorded the average nematodes per gram of root and nematodes per 100 cm^3 soil after the species recommended for the succession planting in soil naturally infested with *Pratylenchus brachyurus* in two separate experiments. In experiment 1 minimum number of nematode per gram of root showed in fallow treatment while in soil fallow, stylosanthes and crotalaria showed no nematode population, in second experimnet fallowi treatment showed overall significant superior result. Juvenile populations (J_2) of *Rotylenchulus reniformis* on the ground before and after culture with the species of green winter fertilizer in naturally infested soil under cotton cultivation and reproduction factor (RF). Original averages of six replications. Transformed values: starting and ending pop to $\sqrt{x}$; 3 RF = Pf / Pi; Transformed values $\sqrt{(x + 0.01)}$. RF <1.0 (R = Resistant) and RF> = 1.0 (S = Susceptible). Gardiano *et al.* in 2014 at Brazil recorded juvenile populations (J_2) of *Rotylenchulus reniformis* on the ground before and after culture with the species of green winter fertilizer in naturally infested soil under cotton cultivation and reproduction factor (RF). Except hairy vetch all tested crops shows resistance reaction as compare to control.

Crop Rotation

Some Non/Poor Hosts to Include In Crop Rotation

Target Nematode	Poor / Non host
Globodera rostochienesis (Potato cyst nematode)	Wheat, cabbage, cauliflower, peas, mize, beans,
Heterodera avenae (Cereal root nematode)	Pea, maize, carrot, gram, mustard
Meloidogyne, Pratylenchus, Tylenchorynchus, Rotylenchulus, Radopholus, Heterodera	*Tagetes spp, Crotalaria spectabilis, C. striata*
M. hapla- Northern RKN	Cotton, wheat
M. incognita, M javanica	Peanut, mustard, marigold, onion, garlic, lucerne
Radopholus similis	Vegetables, cereals, cotton, castor,
M. graminicola Rice RKN	Potato, groundnut, blackgram, wheat, sunflower, soybean, onion, cauliflower, cowpea
Anguina tritici – seed gall nema	Rice

Soil Amendments

Effect of organic amendments on plant growth of okra hybrid MHOK 10 infected with reniform nematode, *Rotylenchulus reniformis* race A. Effect of organic amendments on plant growth of okra hybrid MHOK 10 infected with reniform nematode, *Rotylenchulus reniformis* race A. Each data represents average of three replications Figures in parenthesis are (X+0.5)1/2 transformed value. Within a column; data followed by same letter are not significantly different (DMRT at 5%). Jagadeeswaran in 2010 at new Delhi recorded effect of organic amendments on plant growth of okra hybrid MHOK 10 infected with reniform nematode, *Rotylenchulus reniformis* race A. among all treatment neem cake shows minimum female per plant which was at par with treated control while sunflower cake at their minimum dose found least effective. Neem cake at their higher dose was found overall significant as compare to other treatments except in no of eggs per egg mass. Figure 2 also illustrated the same resultes. Root morphology of 14-day-old rice seedlings grown in sterile culture on agar in Petri dishes supplied with three different forms of N supply and 1% sucrose and infected with *Meloidogyne graminicola*. There are nematode galls when 2.85 mM $Ca(NO_3)_2$ was added, but no galls were found with 2.85 mM NH_4NO_3 and NH_4Cl (Hertfordshire, UK, Patil, 2013). Effect of soil amendments with dry meal of *Artemisia annua* biomass on the infestation of the root-knot nematode *M. incognita* and plant growth of tomato (cv. San Marzano). Effect of soil amendments with dry meal of Artemisia annua biomass on the infestation of the root-knot nematode *M. hapla* and plant growth of tomato (cv. San Marzano). D'Addabbo *et al.* in 2017 at Italy reported the effect of soil amendments with dry meal of *Artemisia annua* biomass on the infestation of the root-knot nematode *M. incognita, M. hapla* and plant growth of tomato (cv. San Marzano). In both the experiment population reduced by all treatments compare with control and experiment follows dose-response relationship with *A. annua* meal. Baheti in year 2005 at Udaipur recorded efficacy of different oil-cakes as soil amendment for the management of root-knot nematode, *Meloidogyne incognita* infecting okra. Neem, mustard and karanj cake evaluated with three different concentrations among them neem cake at their higher dose found significant superior and mustard cake at their lowest dose found least effective. Efficacy of different oil-cakes as soil amendment for the management of root-knot nematode, *Meloidogyne incognita* infecting okra. Ganaie in 2014 at Aligarh recorded effect of chopped leaves of some plants on the disease development in *Pseuderanthemum atropurpureum* infected with *Meloidogyne incognita* Race-3 (Mi). Among tested plant leaves *Parthenium hysterophorus* leaves was found effective in all tested parameters during experiment while different treatments found least effective in different parameters. Effect of chopped leaves of some plants on the disease development in *Pseuderanthemum atropurpureum* infected with *Meloidogyne incognita* Race-3 (Mi). Comparative effects of different organic materials on the means of gall index and *Meloidogyne incognita* reproduction on sweet potato. Osunlola and Fawole in 2015 at Nigeria noted comparative effects of different organic materials on the means of gall index and *Meloidogyne incognita* reproduction on sweet potato. Among all testes organic materials poultry manure at 20q per hectare found superior in gall index, j_2 population in soil as well as on root while horse manure at lower dose found less effective.

Mulching

Das *et al.* in 2017 at Nadia recorded effect of organic mulches and scaffolding on nematode infestation in pointed gourd. Among different mulching and scaffolding, scaffolding was found effective in reduction of nematode population in both years because due to scaffolding root contact with soil is reduced which ultimately reduce the nematode population.

Antagonistic /Enemy crops

Mortality of *Meloidogyne incognita* and *Globodera rostochiensis* juveniles and of adult females of *Xiphinema index* after exposure to aqueous extract of *Artemisia annua* over time. Data followed by the same letters on the same column are not significantly different (P=0.05) according to Least Significant Difference's Test. Trifone *et al.* in 2013 at Italy counted mortality of *Meloidogyne incognita* and *Globodera rostochiensis* juveniles and of adult females of *Xiphinema index* after exposure to aqueous extract of *Artemisia annua* over time. Maximum mortality was found at maximum concentration with 24 hours of exposure in all three tested nematode species.

Sanitation /Eradication

- Eradicate weed hosts
- Clean tools and equipment
- Remove infected plant roots
- Avoid moving plants and soil from infested field
- Don`t allow irrigation water from around infested plants to run off

The reniform nematode (*Rotylenchulus reniformis*) is the primary economical nematode pest of cotton (*Gossypium hirsutum*). Corn (*Zea mays*), a non-host to *R. reniformis*, is the principal crop rotated with cotton to reduce *R. reniformis* populations. The important role played by 43 weed species in sustaining reniform nematode populations in cotton-corn rotation system was confirmed in greenhouse, microplot and field experiments. In the greenhouse, the majority of dicotyledonous weed species tested served as hosts for *R. reniformis* , while the monocots did not. In field microplot studies, individual weed species (*Ipomoea hederacea*, *I. lacunosa*, *I. purpurea* and *Senna obtusifolia)* growing in association with corn increased *R. reniformis* nematode populations. In field trials where corn plots were treated with only a pre-emergence herbicide, non-controlled weed species sustained *R. reniformis* populations as compared to the weed-free treatments. Season long weed management during the corn rotation system is an essential agronomic practice to obtain the full benefit of the rotation, and to effectively suppress *R. reniformis* populations (Lawrenc *et al.,* 2008). Weeds can be hosts of root-lesion nematode (*Pratylenchus spp.),* maintaining or increasing their population in the soil. Bellé, *et al.,* (2017) evaluate the reaction of 25 weeds species to the nematode *Pratylenchus zeae.* The weed plants were individually inoculated with 1,000 individuals of *P. zeae and* maintained in a greenhouse for 90 days. After this period, eggs and nematodes were extracted, quantified, and the reproduction factor (RF = final population/initial population) was calculated. All tested weeds were susceptible (RF>1) to *P. zeae, and* the species *Brachiaria decumbens, Rhynchelytrum repens, Digitaria insularis, D. horizontalis, B. brizantha* were the most susceptible to this parasite (Bellé, *et al.,* 2017).

Green Manure

Resistant and Tolerant Varieties

Disadvantages of Plant Resistance: Not available for all nematodes, level of control may not be sufficient, preventative in nature, discovery and development is slow, breakdown of resistance, may not be agronomically acceptable. Kipkorir in 2015 at Kenya classified some sugarcane cultivars based on their resistance to lesion nematode. Among tested cultivar KEN83-737 was found resistant against lesion nematode while Co421 found highly susceptible cultivar. Kipkorir in 2015 at Kenya recorded effect of plant parasitic nematodes on sugarcane intercropped with different crops. Spider plant with KEN 83-737 cultivar shows minimum number of nematode during. Karuri *et al.* in 2017 at Kenya tested resistance level of 74 sweet potato varieties infected with *Meloidogyne incognita*. Among tested varieties 11 were found moderately resistance, 9 were susceptible, 4 were slightly resistance and 50 were found very resistance.

Biological control

What is Biological Control?

"Biological control is defined as the reduction of inoculum density or disease producing activities of a pathogen or parasite in its active or dormant state, by one or more organisms, accomplished naturally or through manipulation of the environment, host or antagonist or by mass introduction of one or more antagonist" (Baker and Cook, 1974).

Why Biological Control?

The discovery of the nematicidal properties of DD, EBD and DBCP during the 1940s and 1950s heralded a new era in plant pathology. For the first time, nematicide were available at price which made them economical to use for nematode control on agricultural and horticultural crops. The period from 1955 to 1975 might be termed the 'golden years' for nematicide But**,** This situation changed dramatically and it is now recognized that nematicide have adverse effect on the environment and on human health. The finding that DBCP was carcinogenic and that it depressed sperm counts of worker who associated with manufacturing units. Subsequent studies in the USA and elsewhere showed that groundwater was contaminated with many organic chemicals including the nematicide DBCP, EBD, 1,2-dichloropropane component of DD. So, Biological control is one such alternative.

Huang *et al.* in 2016 at china recorded mean population of Root Knot Nematode *M. incognita* treated with different bioagents in the pot experiment. Among all treatment combination of *Syncephalastrum racemosum* and *Paecilomyces lilacinus* found significant superior while *Bacillus cereus* was found least effective. Kar *et al*. in 2018 at Bengal tested comparative efficacy of different bioagents against population of root knot nematode (*M. incognita*) in cowpea. Among all tested bioagents combination of *P. fluorescens* and neem cake shows minimum nematode population in soil while in case of root population all treatment found non-significant. Hashem and Abo-Elyousr in 2011 at Egypt recorded effect of different biocontrol agents alone or in combination on number of nematodes, gall index in tomato plants under greenhouse condition. Combination of all tested bio agents found superior among all treatments while combination of *Calothrix parietina* and *Paecilomyces lilacinus* found least effective. Sankaranarayanan and Hari in 2013 at Coimbatore recorded effect of AMF, nematophagous fungi on root galling and *Meloidogyne javanica* population in sugarcane. Among all treatments combination of *Glomus fasciculatum* and *Paecilomyces lilacinus* was found effective in both the tested parameters which were at par with several other treatments. Solo application of *Arthrobotrys oligospora* was found least effective.

Recommendation for the Farmers of Saurashtra Agro-Climatic Zone, Gujarat

- The farmers of South Saurashtra Agro-climatic Zone are advised to sow groundnut with castor as relay crop (Row ratio of 2:1) along with soil application of carbofuran 3 G @ 1 kg a.i./ha (Furadan 3G @ 33 kg/ha) to reduce the root knot nematode disease (Meloidogyne arenaria)and to get higher yield (CBR 1: 2.35) (2006-07).

- The farmers of South Saurashtra Agro-climatic Zone cultivating groundnut are advised to treat the seed with talc based *Pseudomonas fluorescens* @ 20 g/kg seeds followed by the application of *Pseudomonas fluorescens* in furrow @ 2.5 kg/ha for effective management of root knot nematode and stem rot diseases (2009-10).
- The groundnut growing farmers of South Saurashtra Agro-climatic Zone are advised to apply talc based *Paecilomyces lilacinus* (cfu $1x10^6$ /g) as seed treatment @ 10 g/kg seed or soil application of *Paecilomyces lilacinus* (cfu $1x10^6$ /g) @ 2.5 kg/ha for effective and economical management of root knot nematode (2012-13) (Main Oilseeds Research Station, JAU, Junagadh).

Conclusion

Plant parasitic nematode cause huge losses in agricultural crop yield. The management of nematode through only chemicals is not economically viable and also environmental hazardous. Bio-intensive approaches helps long lasting management of phytonematodes and it is also economically viable. Bio-intensive approaches *viz.,* Quarantine (*G. rostochiensis*), Healthy Planting Material (burrowing, spiral and lesion nematodes of banana), Fallowing (RKN in Chickpea), Trap crop (*Solanum sisymbriifolium*-PCN), Crop Rotation (Corn-Cotton), Soil amendments (Neem, Castor, Karanj), Mulching (Black polythene), Plant Extract (*Artemisia annua*), Sanitation /Eradication (*Ipomoea hederacea*), Inter crop (Spider Plant), Antagonistic crops (Marigold), Green manure (Cowpea), Resistant and tolerant varieties (KEN83-737 - Sugarcane), Biological control (*Paecilomyces lilacinus, Bacillus cereus*) used in compatible manner reduced nematode population and damage caused by them.

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