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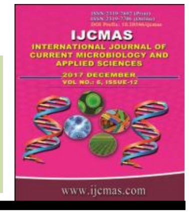

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Integrated Nutrient Management of Peppers (*Capsicum annuum* L.) in 21st Century - A Review

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The increased use of chemicals under intensive cultivation has not only contaminated the ground and surface water but has also disturbed the harmony existing among the soil, plant and microbial population. On the other hand, the traditional organic inputs viz. crop residues and animal manures at their own, cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials, and the high labor demands for processing and application. Several nutrient managements have been practiced; however, current studies on long term experiments indicated that integrated nutrient management proved to be the best approach for sustainable crop production as well as reducing environmental pollution. This review paper therefore, present review on various aspects of INM use to enhance capsicum yield and quality along with improvement in soil environment.

Introduction

India is bestowed with vast diversity of flora, fauna, and soil and agro climatic conditions. This makes it feasible to grow the largest number of vegetable crops in the world and is regarded as a horticultural paradise (Saravaiya and Patel, 2005).

Capsicum sp. is an important commercial spice and vegetable crop for small and marginal farmers in Asia, Africa and South America. Among the five cultivated species of the genus *Capsicum*, *Capsicum annuum* is the most widely cultivated in India for its pungent (chilli *syn.* hot pepper) fruits that are dried for spicy powders, paprika for pickles and non-pungent (capsicum *syn.* bell pepper, sweet pepper, Shimla mirch) fruits which are cooked as vegetables or used as stuffing in fast food preparations like pizza and burgers.

According to an estimate for 2016, in India, chillies (fresh-green fruits) were cultivated on 238 thousand hectares area and 2392 thousand metric tonnes production with states of Andhra Pradesh, Karnataka, Maharashtra, Orissa and Tamil Nadu accounting for more than 75% of the area and total production. Similarly, sweet pepper occupies an area of 32.15 thousand hectares with a production of 182.50 thousand metric tonnes (Anonymous, 2016). It is commercially grown in Himachal Pradesh, Jammu and Kashmir, Uttarakhand, Arunachal Pradesh and Darjeeling district of West Bengal during summer months and as an autumn crop in Maharashtra, Karnataka, Tamil Nadu and Bihar. The continuous use of high level of chemical fertilizers leads to decrease the nutrient uptake efficiency of plants, resulting in either stagnation or decrease in yield and also causing environmental pollution (Singh and Kalloo, 2000).

In recent times, the concept of integrated nutrient management has been receiving increasing attention worldwide obviously for reasons of economization of fertilizer usage, safeguarding and ensuring scientific management of soil health for optimum growth, yield and quality of crops in an integrated manner in a specific agro-ecological situations, through balanced use of organic and inorganic plant nutrients; so that one can harvest good yield without deteriorating soil health. All the relevant and important published work during 21st century on capsicum has been reviewed and presented here under the following heads:

Effect of INM on growth, yield attributes and yield of peppers

Effect of INM on quality of peppers

Effect INM on incidence of diseases in peppers

Effect of INM on physico-chemical and microbiological properties of the soil

Effect of INM on growth, yield attributes and yield of peppers

Sharu and Meerabai (2001) reported that among the three organic manures (poultry manure, vermicompost and neem cake), the highest chilli fruit yield (9.66 t/ha) was found when poultry manure and chemical fertilizers were applied in the ratio of 1:1 on N equivalent basis among the various treatments. Working with chilli cv. 'Byadgi' under Vertisols of Dharwad (Karnataka), Patil and Biradar (2001) recorded the highest fruit yield (19.12 q/ha) with the application of 200 % RDF + FYM (10 t/ha) + VC (2.5 t/ha).

Gowda *et al.,* (2002) reported that when the capsicum plants inoculated with *Azotobacter*, *Azospirillum*, PSB and VAM were further supplied with 75 % N & P plus 100 % K, the plant height, number of branches per plant, leaf area and dry matter production increased significantly. Similarly, Sajan *et al.,* (2002) observed that the plants of chilli cv. Byadagi Dabba when inoculated with *Azotobacter*, *Azospirillum*, PSB, and VAM in combination with 75 % N, P plus 100 % K, produced more number of fruits per plant and higher yield compared to the application of chemical fertilizers or bio-fertilizers alone. Chattoo *et al.,* (2003) found bacterial inoculation of capsicum plant with *Azospirillum* superior to *Azotobacter* while, Mondal *et al.,* (2003) concluded that *Azotobacter* seed treatment improved all growth and yield characters of chilli cv. Bona Lanka, and resulted in the highest fruit yield (3.34 t/ha). Guillen *et al.,* (2006) also reported that inoculation with *Bacillus* sp. in capsicum resulted in increased height by 20 % and yields by 270 % as compared to check.

Siddesh (2006) observed that application of *Azospirillum* to chilli plants with 70 kg N per ha produced the higher plant height (101.1 cm) and branches (11.2/plant) as compared to 70 kg N per ha applied singly, with plant height and number of branches (92.2 cm and 8.3, respectively).

Dass *et al.,* (2008) illustrated the use of vermicompost with 50 % RDF producing significantly higher yield of bell pepper over 100 % chemical fertilization with a net return increase of 29.8 per cent. The use of inoculants (*Azotobacter*, *Azospirillum*) in conjunction with 75 % recommended nitrogen increased growth characters and yield of chilli as compared to control. Khan *et al.,* (2008) also showed that *Azotobacter* and *Azospirillum* in conjunction with 75 % recommended nitrogen recorded significant increase in growth characters and yield as compared to control and concluded that N-fixing bio-fertilizers could reduce the use of inorganic nitrogen by 25-50 per cent.

Shetty *et al.,* (2008) concluded that the integrated application of 25 % of nitrogen through Pongamia cake + 75 % of recommended dose of fertilizers + FYM @ 25 t/ha + *Azotobacter* @ 5 g/plant significantly increased the fruit set (29.10 %), number of fruits/plant (15.07), fruit yield/plant (2.8 kg), yield/m^2 (11.76 kg) and yield/hectare (117.6 t/ha) in capsicum cv. Orobelle under protected condition.

Bhattarai (2009) recorded the maximum plant height (10.26 cm), number of primary branches (7.65), fruit yield (24.21 kg per plot), seed yield/plot (243.6 g), 1000-seed weight (7.29 g), seed germination (91.33%) and vigour index (1262.74) with application of *Azotobacter* + boron + vermicompost + 75 % NPK in chilli. Similarly, Kondapa *et al.,* (2009) observed significantly highest number of branches (33.98/plant), dry weight of 100 fruits (139.50 g) and highest benefit: cost ratio (1.78) in chilli with 50 % RDN + 50 % N through FYM + bio-fertilizer + Panchagavya as compared to other treatments. Singh *et al.,* (2009) also demonstrated that application of FYM @ 50 t/ha + 75 % RDN (94 kg/ha) + VAM gave capsicum fruit yield at par with that was obtained with FYM @ 50 t/ha + 100 % RDN (125 kg N/ha) under poly house conditions.

Talukder and Jana (2009) found maximum growth and yield (7.43 t/ha) in chilli with dual inoculation (*Azotobacte*r and *Azospirillum*) with the biological nitrogen fixers, 100 % recommended dose of N-fertilizer @ 80 kg N/ha and farmyard manure @ 15 t/ha but no significant differences were observed when N-fertilizer level was reduced to 75 per cent.

Deshpande *et al.,* (2010) revealed that the treatment N 125 kg / ha + FYM @ 10 t/ha + *Azospirillum* reported more plant height, number of braches per plant, days to first 50 % flowering, days to first harvest, number of fruits per plant, weight of individual fruit, fruit length, fruit diameter, yield of fresh red fruits, while least values for all above characters were recorded in control (N 150 kg/ha + FYM @ 10 t/ha).

Jaipaul *et al.,* (2011) studied the effect of different organic manures in comparison to inorganic inputs on growth, yield and quality attributes of capsicum (*Capsicum annuum* L.) and garden pea (*Pisum sativum* L.). Application of poultry manure (5 t/ha) + bio-fertilizer produced capsicum plant biomass and yield at par with integrated nutrient (recommended NPK + FYM @10 tonnes/ha + bio-fertilizer). Highest B: C ratio was recorded with poultry manure + bio-fertilizer for capsicum.

Chetri *et al.,* (2012) investigated influence of INM on growth and yield of capsicum and revealed that crop fertilized with 50 % NPK (60:30:30 kg/ha) + 50 % poultry manure (5 t/ha) produced significantly taller plants (44.7 cm), more number of leaves (94.80) and branches (8.1), maximum number of fruits per plant (11.17), fruit length (8.46 cm), fruit girth (7.16 cm) and fruit yield (232.59 q/ha). Application of 50 % NPK + 50 % FYM was found next best treatment which produced a yield of 195.18 q/ha, while the minimum yield was recorded with control (74.94 q/ha).

Vimera *et al.*, (2012) obtained maximum pod yield (11.05 t per ha), vitamin C (117 mg per 100g) and capsaicin content (847 thousand SHU) in king chilli under foothill condition (sandy loam Alfisol) of Nagaland with conjoint application of 50 % NPK+50 % FYM + bio-fertilizers along with highest net return of Rs. 571,000 and benefit: cost ratio of 6.19:1. Similarly, Lal and Kanaujia (2013) recorded maximum plant height (54.46 cm), number of leaves per plant (38.89), leaf area (54.60 cm^2), number of fruit per plant (10.48), average fruit weight (85.06 g), fruit length (8.56 cm), fruit diameter (5.63 cm), fruit yield (29.70 t/ha), along with highest net return of Rs.7, 93,858.00 and benefit: cost ratio of 8.16: 1.

Pariari and Khan (2013) applied six organic manures namely cow dung, neem cake, poultry manure, mustard cake, phosphor-compost and vermicompost in different combinations with inorganic nitrogenous fertilizer (urea) at three levels (25, 50, and 75 %) and found maximum plant growth and fruit yield of chilli with the combination of vermicompost and urea at 50 percent as compared to without nitrogen. Abu-Zhara (2014) compared the four fermented organic matter sources (cow, poultry, sheep manure in addition to compost) @ 4 kg/m^2 each with that of the chemical fertilizers (50 kg/ha/week of 20 N: 20 P: 20 K as fertigation and 118 kg/ha of ammonium nitrate as side dressing) under plasticulture on yield and fruit quality of red pepper "Barotte" and found biggest size pepper fruit (190.5 cm^2) and highest total yield per replicate (48.22 kg) and highest water content, lycopene and titratable acidity. However, quality attributes were better under organic supplementation. Addition of animal manures gave increased total soluble solids content, ascorbic acid, total phenols, and crude fibre intensity of red color in comparison to conventional chemical treatment.

Tariq *et al.,* (2014) applied various formulations of PGPR's (*Klebsiella* sp. + *Burkholderia* sp. + *Panibacillus* sp. + *Bacillus* sp.) after every 20-30 days interval in the field of bell pepper and recorded higher yield per treatment and yield per acre at 6-litre/acre application of PGPR formulation. They concluded that use of PGPR could be helpful to improve the health of crop with increased yield.

Tuti *et al.*, (2014) demonstrated that 20 t/ha FYM along with 125 % of recommended NPK (125, 27.5, and 52.1 kg /ha NPK) increased fruits/plant, average fruit weight, plant height, fruit length, and fruit diameter and resulted in significantly higher fruit yield (33.9 t/ha) along with net return and energy ratio of 1.29.

Rani *et al.*, (2015) conducted a study with 9 treatment combinations including recommended dose of inorganic fertilizer/RDNF (200:60:80 kg NPK/ha), 150 % of RDNF, 200 % of RDNF, 250 % of RDNF, complete organic N through FYM (25 %) and neem cake (25 %) as basal and vermicompost as top dressing (50 %), 50 % organic + 50 % RDNF, 75 % organic + 75 % RDNF, 100 % organic + 100 % RDNF, 125 % organic + 125 % RDNF) in randomized block design with 3 replications.

It was revealed that during both the years, combined application of 150 kg N/ha along with 10 t FYM and 0.5 t neem cake/ha showed significant increase in plant height (59, 58 cm), canopy spread (40.7, 42.1 cm), number of branches/plant (23, 23), number of fruits/plant (194,164), yield/plant (410, 315 g) and total green chilli yield of 133.06 and 105.50 q/ha, respectively along with highest net returns (Rs. 79923/- and 52369/- ha) and B: C ratio (2.5 and 1.99) as compared to complete organic manure application. Shiva *et al.*, (2015) studied the influence of different

INM modules and concluded that integrated application of 75 % N (8 g /plant) + *Azospirillum* sp. (5 g/plant) + 75 % P (1.7 g/plant) + Phosphobacteria (5 g/plant) + 100 % K (2.5 g/plant) improved the growth, yield and quality parameters of paprika alike chillies as compared to recommended NPK indicating a saving 25 % of both inorganic N and P through biofertilizers.

Effect of INM quality parameters

According to Raj Narayan *et al.,* (2004), the integrated use of organic and inorganic fertilizers proved better in improving the yield in *Capsicum annuum* cv. Nishat-1 than using organic and inorganic fertilizers alone.

They found significant increase in ascorbic acid and chlorophyll content with the application 50 % PM + 50 % NPK. Similarly, Shehata *et al.,* (2004) observed an increase in flesh thickness as well as quality attributes such as ascorbic acid, acidity, carotenoids and total soluble solids (TSS) of pepper fruits through integration of NPK with chicken manure and compost. Bhattarai (2009) tested fifteen integrated combinations and concluded that *Azotobacter* + boron + vermicompost + 75 % NPK recorded the maximum vitamin C (295.42 mg/100 g) in chilli.

Jaipaul *et al.,* (2011) measured quality attributes of capsicum (*Capsicum annuum* L.) and garden pea (*Pisum sativum* L.) and recorded highest ascorbic acid content (25.23 mg/100 g) with integrated nutrition (recommended NPK + FYM @10 tonnes/ha + bio-fertilizer), followed by poultry manure + bio-fertilizer (19.26 mg/100 g) and combined application of farmyard manure + poultry manure + vermicompost + bio-fertilizer (18.83 mg/100 g).

Malik *et al.,* (2011) also observed highest fruit quality in terms of vitamin-C, total chlorophyll content, dry matter content, nitrogen, phosphorus and potassium in sweet pepper through integration of organic and inorganic sources of nutrition.

Chetri *et al.,* (2012) revealed that crop fertilized with 50 % NPK (60:30:30 kg/ha) + 50 % poultry manure (5 t/ha) produced significantly highest TSS(9.43^{0}B) and ascorbic acid content (130.50 mg/100 g).

Vimera *et al.,* (2012) obtained maximum vitamin C (117 mg per 100g) and capsaicin content (847 thousand SHU) in king chilli under foothill condition (sandy loam Alfisol) of Nagaland with conjoint application of 50 % NPK+50 % FYM + bio-fertilizers Similarly, Lal and Kanaujia (2013) recorded maximum TSS (9.55 ^{0}B) and vitamin C (126.31 mg/100g) with the conjoint application of 50 % NPK + 50 % FYM + biofertilizers.

Jayanthi *et al.,* (2014) concluded that combined application of vermi-fertilizer (5 t/ha) and recommended dose of chemical fertilizer(120:60:30 kg/ha NPK) was better for enhancing quality (Vitamin A, Vitamin C and Capsaicin content) of chilli than 100 % application of RDCF.

Effect of INM on incidence of diseases in peppers

Kolte *et al.,* (1994) dipped the seedlings in a suspension of *Azospirillum* sp. and found the best control of shoot dieback (mean incidence 16.94 %) compared with *Azotobacter* dip (17.14 %) and 22.39 % in the untreated seedlings.

Bharathi *et al.,* (2004) applied PGPR mixed bio-formulation + *B. Subtilis* + neem cake + chitin and found it to be the best for reducing the fruit rot incidence besides increasing the plant growth and yield parameters under both greenhouse and field conditions.

Burelle *et al.,* (2006) assessed the effects of applied PGPR and application methods on bacterial survival, rhizosphere colonization along with plant growth and yield and reported that aqueous application of PGPR increase plant growth as compared to the untreated control and also induced the systemic resistance. Jaipaul *et al.,* (2011) observed significantly higher incidence of leaf blight of capsicum in organic treatments in comparison to integrated nutrient management, while incidence of *Fusarium* root rot was lower in poultry manure + bio-fertilizer (11.42 %) and FYM treatments (12.06 %) compared to integrated nutrient management (46.75 %).

Effect of INM on physico-chemical and microbiological properties of the soil

Soil is the basic natural source that is fundamental to the ability of agriculture to meet basic human needs for food and fibre. Soil is also critical for supporting natural ecosystems and in the cycling of water and essential elements like carbon and nitrogen throughout the biosphere. Soil health is one of the key factors which decide the yield. Organic manures such as farmyard manure, vermicompost, farm waste compost and poultry manure as well as bio-inoculants are indispensable and are important components of INM system for maintaining soil fertility and yield stability. Application of organics including bio-fertilizers improved the physico-chemical and biological properties of the vegetable growing soils (Bhardwaj *et al.,* 2002) as Prabhu *et al.,* (2002) found the highest organic carbon content of the soil after manure application and *Azospirillum* inoculation in combination with PSB. According to Senthilkumaran and Vadivel (2002), organic acids released during decomposition of organic manure, controls certain fungal pathogens and nematode infestation.

Sharma (2002) reported that some of the secretions of worms and the associated microbes act as growth promoters along with other nutrients. He also stated that vermicompost releases the nutrients slowly and steadily into the soil which enhances the capability of plants to absorb these nutrients. The soil enriched with vermicompost provides additional substances that are not found in the chemical fertilizers.

Singh *et al.,* (2002) reported that available N, P and K were higher in soil that had received green manuring, FYM or *Azotobacter* along with 30 kg N/ha than those that were given chemical fertilizers only.

Anita and Prema (2003) reported that vermicompost is superior over farmyard manure in respect of available plant nutrients, improved physico-chemical conditions of the soil, microbial actions and plant growth regulating substances. Vermicompost, besides being a rich source of micronutrients also act as a chelating agent and regulates the availability of metabolic micronutrients to plants apart from increasing the plant growth and yield by providing nutrients in the available form.

Celik *et al.,* (2004) revealed that compost and manure-treated plots observed significantly decreased soil bulk density and increased soil organic matter concentration compared with other treatments. Compost and manure treatments increased available water content of soils by 86 and 56 per cent, respectively. Mycorrhizal inoculation + compost were more effective in improving soil physical properties than the inorganic treatment.

Selvi *et al.,* (2004) reported that application of FYM along with chemical fertilizers favoured the microbial population in the soil whereas; sole application of nitrogenous fertilizers had detrimental effect on soil micro flora. The same authors in 2005 showed a maximum increase in soil organic carbon with the application of FYM in combination with NPK when compared with NPK alone and the control.

Lee *et al.,* (2006) analyzed the effects of swine manure compost applied at low, medium and high rates vis-a-vis control (chemical fertilizers) on soil health indicators *viz*., bulk density, aggregate stability, organic carbon content, soil pH, available N, P, and K, extractable Cu and Zn, and microbial biomass and advocated that manure compost improved the soil quality.

Mandal *et al.,* (2007) also revealed that a balanced application of NPK + FYM gave the highest value for the Soil microbial biomass carbon (SMBC) and nitrogen (SMBN) as compared to control (no manure or fertilizer). Similarly, Manna *et al.,* (2007) reported that SMBC, SMBN and acid hydrolysable carbohydrates (HCH) were greater in NPK + FYM and NPK + lime as compared to other treatments. Manivannan *et al.,* (2007) recorded the reduction in porosity, organic carbon and microbial activity through the use of inorganic fertilizers.

Chan *et al.,* (2008) monitored the changes in soil P concentration under two compost treatments relative to conventional farmer's practice and observed increased soil organic carbon and soil quality including soil structural stability, exchangeable cations and soil biological properties through compost treatments. Importantly, the compost treatment was effective in reducing the rate of accumulation of extractable soil P compared with the conventional vegetable farming practice. Dass *et al.,* (2008) also noted improved status of organic carbon and available N and P due to treatment with cow manure and vermicompost. Ullah *et al.,* (2008) recorded higher organic matter content and availability of N, P, K and S in soils supplemented with organic matter whereas, soil pH was increased by chemical application than organic.

Esawy *et al.,* (2009) conducted experiment to evaluate the effect of three compost types (plant residues, animal residues and mixed) in combination with nitrogen fertilizers on soil properties. The study demonstrated that the nitrogen and phosphorus content of the soil significantly increased, as did the soil organic matter with the increase of organic nitrogen (plant compost, animal compost and mixed compost) applied. The experimental results confirmed that the combination of organic and inorganic fertilizers could increase soil fertility.

Gopinath *et al.,* (2009) found that both composted farm yard manure (FYMC) and FYMC + Poultry manure + Vermicompost + Biofertilizers enhanced soil pH (7.1) and oxidizable organic carbon (1.2-1.3 %) compared with (FYM + NPK) and un-amended control after a two-year transition period in capsicum.

Naidu *et al.,* (2009) reported that fertility status of soil including nutrient use efficiency, apparent nutrient recovery and the available nutrient status were improved along with the highest and sustainable crop yield of chilli as a consequence to highest uptake of major and micronutrients with the application of 50 % RDN + 50 % N through FYM + BF + Panchagavya as compared to the other treatments.

Adeleye *et al.,* (2010) reported that poultry manure application improved soil physical properties *viz.* it reduced soil bulk density and temperature while total porosity and soil moisture retention capacity were increased. It also improved soil organic matter, total N, available P, exchangeable Mg, Ca, K and lowered exchange acidity. Therefore, they recommended the use of poultry manure in crop production as it will ensure stability of soil structure; improve soil organic matter status and nutrients availability.

Liu *et al.,* (2010) conducted a long-term fertilizer and organic manures field experimentation and concluded that, compared with the unfertilized control, the average soil organic carbon and total nitrogen content were 2.0 and 3.1 %, 1.9 and 13.3 %, 32.7 and 24.5 %, 23.0 and 19.4 %, and 39.9 and 27.6 % higher, respectively, for treatments *viz.* nitrogen fertilizer annually, nitrogen and phosphorus fertilizers annually, straw plus nitrogen added annually and phosphorus fertilizer added every second year, farm yard manure added annually, and farm yard manure plus nitrogen and phosphorus fertilizers added annually.

Gopinath and Mina (2011) revealed that application of farmyard manure @ 20 t/ha + biofertilizers resulted in the lowest soil bulk density (1.19 mg/m^3) compared to other treatments. Similarly, soil organic carbon was significantly higher in all the treatments (1.21-1.30 %) except in poultry manure 5 t/ha + biofertilizers compared to control (1.06 %). Application of farmyard manure 10 t/ha + recommended NPK, however, recorded significantly higher available N than plots under organic manures. Application of farmyard manure 10 t/ha + recommended NPK being at par with application of farmyard manure 10 t/ha + poultry manure and vermicompost each 1.5 t/ha + biofertilizers registered significantly higher available P and K contents in soil compared to other treatments in garden pea.

Ganiger *et al.,* (2012) evaluated the effects of organic amendments on soil fertility in terms of physico-chemical properties in the process of organic production of capsicum and concluded that the soils of basal applications of N equivalent (150 kg/ha) through 50 % each FYM and poultry manure were found most superior in improving the physico-chemical properties of the soil.

Abu-Zhara *et al.,* (2013) compared the four fermented organic matter sources (cow, poultry, sheep manure in addition to compost) @ 4 kg/m^2 with that of the chemical fertilizers (50 kg/ha/week of 20 N:20 P:20 K as fertigation and 118 kg/ha of ammonium nitrate as side dressing) under plasticulture on soil properties by growing red pepper and observed significantly higher effect on soil pH, EC, N, P, K, Na along with 22 % higher yield through conventional (chemical) fertilization compared to organic manures.

Jayanthi *et al.,* (2014) conducted field experiments to evaluate the efficacy of vermin-fertilizer (VF) supplemented with recommended dose of chemical fertilizer (RDCF) on the soil quality characteristics, and on yield and quality characteristics of chilli (*Capsicum annuum* L.) in comparisons to inorganic fertilizers (NPK). VF (5 tons/ha) and VF supplemented with RDCF (120 N: 60 P: 30 K kg/ha) had significantly increased the pore space, water holding capacity, cation exchange capacity, organic carbon, available N, P, K, other micro-macro nutrients – Ca, Mg, Na, Fe, Mn, Zn, Cu and microbial activity and humic acid content, reduced particle and bulk density, pH and EC in the field soil.

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