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Research Article

The conceptualisation of mycorrhizosphere of banana crop and it's benefits

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ABSTRACT

The top root soil around a banana plant, supplemented with organic carbon of soil conditioner, plant growth promoting organisms (consortium of biofertilisers) and native mycorrhizae cumulatively constituted its mycorrhizosphere. Drippers used for irrigation maintained requisite moisture level in this sphere. Exogenously introduced biofertilisers proliferated in the matrix provided by soil conditioner and helped the plant symbiotically to sustain its productivity and yield. They grew on the mycoplane as well as rhizoplane to interact with vesicular arbuscular mycrorrhizae (VAMs) and roots. VAMs produced extracellular hyphae, which extended several cm into the surrounding matrix and exuded organic secretions that were substrates to other soil microbes. These hyphae-associated microbes frequently produced sticky materials that caused soil aggregation that imparted texture to soil, allowing for improved aeration, water percolation and stability. Mycorrhization selectively altered pressure on the population of soil microbes, some of which engaged in controlling root borne pathogens

Keywords: Mycorrhizosphere, biofertilizers, PGPR, mycorrhizae, soil aggregation, pathogen control.

INTRODUCTION

Bananas, being grown on 45,000 hectares of Jalgaon district, Maharashtra State of India, produce 2.25 million MT annually, to serve as a major source of income for farmers in *Tapti* river basin. The last two decades witnessed a decline in banana yields as a result of traditional cultivation practices, such as improper nourishment and soil-borne diseases. As sword suckers were preferred as planting material, it provided a vector for root parasites and disabilities in pathogen-free healthy soils. It was worth exploring if these man-made evils could be rectified by application of mycorrhizae.

During the past two decades, an upsurge of interest in vesicular arbuscular mycorrhizae (VAM) due to their plant growth stimulation and protection against soil-borne pathogens [1,2] indicated that they probably have substantial impact on the present problem, since VAM are known to occur in Indian banana cropping eco-systems [3,4,5]. Further, a few VAM inoculation experiments conducted to date showed, (i) an increase in phosphate uptake and banana plant growth [6,7] and (ii) increased banana plant tolerance to nematodes [8]. Thus, survival of native VA-mycorrhizae in soil seemed to permit the maintenance of healthy, disease-free and robust orchard eco-system for banana cultivation.

To (i) demonstrate integrated plant nutrition management (IPNM) practices to farmers, (ii) minimise water consumption during irrigation, (iii) eradicate soil-borne pathogen(s) affecting plant productivity and (iv) cultivate banana sustainably in societal and environmental favour, semi-commercial R & D plantation trials were undertaken in July, 1998 to October, 2000 at North Maharashtra University (NMU) Research Farm and Bajirao Agro-Tech (BAT) Research Farm. The results of these field trials for the occurrence of native VA-mycorrhizal flora, its management and exploitation in banana orchard for recurring maximal benefits to soil fertility and yield are presented here.

For this purpose, the experimentation was designed and executed as described at Phirke (2014 a, b) [9,4] on the basis of Phirke *et al*., 1999 [10]. The observations from mycorrhizospheric point of view are presented in Table 1 and 2.

Comprehension and conceptualization from the review of literature and published data

Native vesicular arbuscular mycorrhizae (VAM) in banana farming systems

Mycorrhizae, a symbiotic association of soil fungi with plant roots, have attributes of penetrating along with a root system and providing an increased absorptive root surface for increased uptake of nutrients, especially by VAM fungi [11].

Non-septate zygomycetous fungi belonging to the genera *Glomus*, *Gigaspora*, *Acaulospora*, *Enterophospora*, *Scutellospora* and *Sclerocystis* form VA mycorrhizae; being obligate biotrophs, they do not grow on synthetic media and hence are classified according to morphological characteristics of their spores formed in the soil [12].

a. Occurrence and significance of VAM in banana eco-system

Maximum root colonisation and sporulation occurs in soils of low fertility, where available P and N contents are less. Mycorrhizae are also reported to tide over stress due to heavy cations/pesticidal toxicity.

They increased banana plant tolerance to nematode, *Radopholus similis* and killing effect on soil borne pathogens [6,8,1]. Apparently, it may be due to availability of more nutrition/plant protection and in turn more vitality as observed by DeClerck *et al*. (1994) [13] who found significant increase in uptake of not only in P, but also K content in mycorrhiza treated banana plants. These functions seem to have made substantial impact, since VAM fungi are reported to occur in banana cropping eco-systems, although only a few experiments have been conducted to date [3].

b. VAM for nutrient solubilisation, absorption, mobilisation and plant growth

Growth of plants as a result of management of mycorrhizal fungi, apparently depends on available P in the soil. However, increased growth of plants inoculated with VA mycorrhizal fungi is not attributed to merely increased phosphate uptake, but also to more availability of other elements like N, S, K, Fe, Zn, Cu, Mn etc [14]. Simultaneously, Linn and Fox (1992) [7] demonstrated that intensity of VAM infection on root decreased with an increase in available phosphorus. Long term fertiliser application experiments revealed that application of half the recommended level of fertilisers together with soil conditioner (SC) favours the build up of native VAM fungal population in soils [15]. In *Raver*, *Yawal* and *Jamner Tehsils*, banana crop was found to be attacked by *Radopholus* sp., apparently due to lack of proper mycorrhizal management [16].

Therefore, proper management of native VAM population appeared to afford more uptake of nutrition/moisture and robust banana plant growth.

c. Beneficial effects of VAM colonisation

Allen *et al.* (1996) [17] have illustrated that VA mycorrhizae directly affect the levels of cytokinins and gibberellin-like substances in soil. They also absorb moisture from soil, supply to plants and thereby tolerate a wide range of soil regimes by improving water relations of many plants.

Anatomical and physiological studies have brought out that mycorrhizal plants exhibit changes in their root exudation and altered rhizospheric microbial population (which affects plant growth) [18]. They have (i) more number of chloroplasts, mitochondria, xylem vessels and motor cells, (ii) increased rate of photosynthesis and respiration and (iii) increased pool of RNA, sugars and amino acids.

d. Interaction with other rhizospheric organisms

Mycorrhizal colonisation also allows maintenance of inoculated population of beneficial soil organisms like *Azotobacter*, *Azospirillum* and phosphate solubilising micro-organisms (PSMs) in larger numbers than around non-mycorrhizal plants. They, in turn, exhibit synergistic effect(s) on plant growth [19,12]. It is apparent from the investigations on plant-pathogen interactions that VAM usually (though not always) deter or reduce the severity of disease caused by soil-borne pathogens [21,21]. All these studies have brought out that VA mycorrhizal colonisation helps host plants in more than one way.

e. Fertilisation by optimal management of native VAM

An average fertility index for available P_2O_5 was 1.10 and for available K_2O 2.98 during 1981-97 for Jalgaon district. This illustrated scarcity of available P and more availability of K than required (Soil Testing Laboratory, Jalgaon). Exploitation of native VAM and PSMs resulted in (a) about 25% saving of super phosphate and (ii) 20% higher yield of banana [22,23,15,10].

Azotobacter species grow and function mutualistically with other groups of mycorrhizospheric organisms, including phosphate solubilising microbes, vesicular arbuscular mycorrhizae, saprophytes, heterotrophs and autotrophs. This has been evident from (i) enhanced *Azotobacter* population by co-inoculation of PSMs in the rhizosphere [24], (ii) maintenance of *Azotobacter* population in larger numbers by mycorrhizal colonisation than around non-mycorrhizal plants [19], (iii) synergistic effect on plant growth [12] and (iv) significant increase in the crop yields after single inoculation and pronounced effect after co-inoculation in the presence of farm yard manure or SC [25].

f. The concept of mycorrhizosphere for IPNM system for banana cultivation

The major substrate for microbial activity in the rhizosphere is exogenously supplemented organic carbon or endogenously introduced rhizospheric secretions by the microbes/plant roots. The organic carbon varies from simple to complex molecules and cell debris sloughed off during root growth [26]. The simple, low molecular weight compounds mainly consist of sugars, amino acids, organic acids, plant hormones, plant growth regulators, plant protectants and phenolics.

The concept of mycorrhizosphere [2] implies that mycorrhizae significantly influence the microflora of the rhizosphere by altering root physiology and exudation(s) in the colonised plants. In addition, hyphae of mycorrhizal fungi provide nutrition for bacteria. This leads to both qualitative and quantitative changes in the mycorrhizospheric soil of the mycorrhized plants, compared to the rhizospheric soil of non-mycorrhized plants. These microbial shifts were clearly time-dependent and dynamic, changing as the plants developed [27,17]. The total population of microbes in the mycorrhizospheric soil of mycorrhized plants was greater than in the rhizospheric soil of non-mycorrhized plants. The effect of mycorrhizae on other microbial groups (such as nitrogen fixers, phosphate solubilisers, heterotrophs and autotrophs, Gram-positive and negative bacteria, spore formers, urea hydrolysers, saprophytes and starch hydrolysers) was positive and varied qualitatively and quantitatively as a function of mycorrhizae.

g. Interactions in mycorrhizosphere

The interactions that occur between mycorrhizae and plant growth promoting organisms, either in the soil or at the root surface are well established. Besides long distance interactions (molecular signals), direct cell-to-cell interactions are important in the soil. The cell walls of mycorrhizal fungi provide a suitable surface for bacterial attachment and colonisation. For example, *Azotobacter chroococcum* are capable of adhering to VAM fungal structures. However, the number of bacteria found on the fungal hyphae and spores differ depending on the strain used [28,5].

h. Mycorrhizosphere of banana

The top 25 cm root zone, 100-150 cm around a banana plant, supplemented with organic carbon (SC), plant growth promoting organisms (consortium of biofertilisers), PGR and native mycorrhizae cumulatively constitute its mycorrhizosphere [5,2,10]. Drippers maintain requisite moisture level in this sphere. Exogenously introduced biofertilisers are expected to proliferate in the matrix provided by SC and help the plant symbiotically in a number of ways. They grow on the mycoplane as well as rhizoplane to interact with VAMs and roots. VAMs produce extracellular hyphae [29], which extend several cm into the surrounding matrix and exude organic secretions that are substrates for other soil microbes. These hyphae-associated microbes frequently produce sticky materials that cause soil particles to adhere, creating small aggregates that impart structure to soil, allowing for improved aeration, water percolation and stability [30,31]. Mycorrhization selectively alters pressure on the population of soil microbes, some of which engage in controlling root pathogens [32,33].

i. VAM infection permitted more uptake of nutrition

P uptake was highest in severely VAM infected IPNM treatment, so also nitrogen uptake as compared to control treatments, while K uptake increased with an increase in nitrogen [15]. These findings correlated with those of Linn and Fox (1992) [7]who demonstrated that in banana orchard, intensity of mycorrhization decreased with an elevated P level. Earlier, DeClerck *et al*. (1994)[13] also found significant rise not only in P content, but also in K content in mycorrhizae infected banana plants. Average bunch weight was also highest in IPNM treatment. This is in accordance with the findings that VAM fungi infestation was responsible for increasing the uptake of nutrients from the root surface, primarily by diffusion [11].

j. Diversified indigenous VAM population for possible role in detoxification

Table 1, has summarised the profiles of VAM population in soil.

Table 1 : Exploration of VA-mycorrhizae in banana mycorrhizosphere

Sr. No	*Glomus*	*Gigaspora*	*Sclerocystis*	*Scutellospora*
1.	*G. mosseae*	*G. margarita* *G. decipiens*	*S.* sp.	*S.* sp.
2.	*G. fasciculatum*			
3.	*G. intraradices*			
4.	*G. macrocarpum*			
5.	*G. fuegianum*			
6.	*G. geosporum*			

Accordingly, ten species of VAM fungi were found in all the treatments and their replicates at NMU and BAT farm, representing the typical soil type of Jalgaon district (Table 1) [4,5]. They were, therefore, anticipated to be well adapted to its humid (large tracts of soil under banana cultivation being irrigated) and sub-tropical climate. That such a diversified group of VAM species exists must be having some relevance to nature. It may be particularly related to toxicity of heavy metals, unavoidably augmented through the application of high doses of phosphatic and potassic fertilisers [22].

k. Diversified VAM population for possible role in combating nematode infection

Among the two treatments, (a) chemical treatment (receiving the nutrient dose totally through chemical fertilisers, recommended by Pawar *et al.*, 1997; Souvenir, 1999) [34,35], served as a positive control for traditional Indian banana cultivation and (b) IPNM treatment (receiving the balanced nutrition, predetermined by site-specific nutrient budgeting through well optimised cultural practices; [10]), served as a test for comparison.

Table 2 has clearly indicated that mycorrhizal spore density and percent infection was the highest in IPNM treatments at NMU and BAT farms and it was superior to that of control. On the contrary, all the three control treatments (T-1 to T-3) adversely affected the mycorrhizal spore density and infection, resulting into varied degree of positive effect(s) on vigour, nutrient uptake, biomass and banana yield.

Table 2 : Mycorrhizospheric profiles of banana plants as a function of treatments

Tr.	Description	Rhizospheric count (x 10^6 cfug^{-1})	Rhizospheric count (x 10^6 cfug^{-1})	VAM spores (g^{-1})	VAM spores (g^{-1})	VAM infect. (%)	VAM infect. (%)	Siderophore unit (%)	Siderophore unit (%)
		NMU	BAT	NMU	BAT	NMU	BAT	NMU	BAT
T-1	50 % Chem. Fert.	5.9	68	52.4	54.4	60.8	58.8	09.5	07.1
T-2	100 % Chem. Fert.	4.7	60	45.9	45.9	49.2	41.4	02.0	18.4
T-3	150 % Chem. Fert.	3.8	54	28.6	32.8	36.5	36.2	03.4	12.5
T-4	BF	8.5	78	52.9	55.7	62.4	62.3	27.5	64.7
T-5	FA 5 MTha^{-1}	4.3	53	60.1	62.1	62.7	64.7	48.0	38.0
T-6	FA + BF	5.6	82	64.9	60.3	63.8	65.6	36.1	32.7
T-7	SC 10 MTha^{-1}	91,000	78	73.4	55.6	71.5	59.2	19.8	68.2
T-8	SC + BF	98,000	25,000	73.8	69.8	72.4	69.2	72.8	58.2
T-9	SC + FA	220	34,000	67.4	70.2	76.5	68.2	08.6	68.7
T-10	SC + FA + BF	97,000	20,000	68.7	67.3	78.4	65.3	35.4	48.4
T-11	PGR	36	33	60.5	63.4	59.0	65.8	45.0	38.6
T-12	SC + FA + BF + PGR	61,000	37,000	70.2	68.0	79.3	70.4	40.7	52.6
	S. E. $\pm$	NS	NS	3.7	1.68	2.2	0.80	1.6	1.48
	C. D. (p 0.05)	--	--	7.7	3.50	4.6	1.67	3.4	3.07

Tr. = Treatments; Chem. Fert. = Chemical fertilisers; BF = Biofertilisers; S.E. = Standard error; C.D. = Critical difference; NS = Non-significant

On this background, a considerable decrease in the nematode population found in IPNM plots is worth noting. Mycorrhizae have attributes of penetrating along with the root system and thereby, providing an increased absorptive surface. Their ramification with the root system permitted enhanced nutrient uptake from the soil rhizosphere and thereby spared the healthy plants from nematode attack [18]. Furthermore, increased VAM spore density and decreased nematode population in IPNM (T-4 to T-12 treatments) has shown that it is combatible by IPNM in spite of such infection being spread in the neighbouring farms. This dual effect (more nutrition, better combating) resulted in an increased per cent plant survival and enhanced growth in IPNM system.

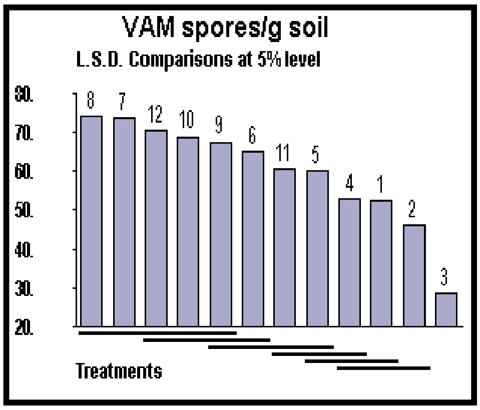
l. VAM infection affording higher productivity of banana

Soil Testing Laboratory, Jalgaon has reported an average fertility index for the district for available P_2O_5 as 1.10 and available K_2O as 2.98, for 1981-97. This illustrated the scarcity of available P and higher content of available K. To alleviate these constraints, banana cultivation in Jalgaon district has ample scope for optimal exploitation of native VAM flora for maximal benefit through IPNM system.

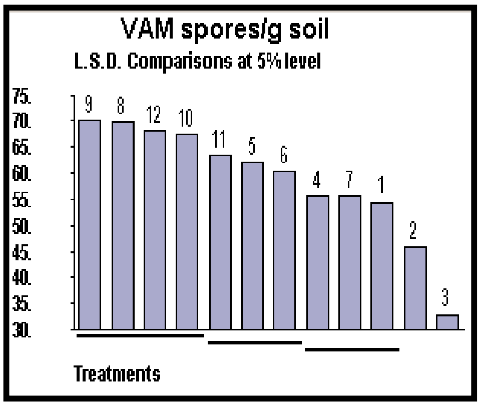
m. Profiles of VAM spores per g soil

From Fig. 1 (a & b), it is clear that T-8, T-9, T-10 and T-12 treatments have provided highest and comparable number of VAM spores in both the soils. All these treatments have a common denominator by way of SC input (Table 1). Least number of VAM spores in T-1, T-2 and T-3 treatments in the decreasing order (where SC is not added) and their highest number in T-8, T-9, T-10 and T-12 treatments in both the soils has conclusively demonstrated that input of SC is highly desirable for ensuring highest spore count in rhizosphere and in turn guarantying the multiple services offered by VAM for the crop. To our knowledge, this is the first report correlating the number of spores with the presence of SC and their deteriorated number with the fortification of chemical fertilisers (Table 2). Further, T-9, T-10 and T-12 have simultaneous soil amendment by fly ash (FA) and yet have the highest number of VAM spores (Table 2).

This has implied that toxic elements in FA do not forbid multiplication of VAM spores, providing a hope for increased use of FA in future to meet micro-nutrient requirements in agriculture. Sizeable number of spores in soil in T-11 treatment in two trials has demonstrated a facilitating role of PGR in the multiplication of spores as well as striking out the myth that VAM spores arise by FA amendment in response to its toxicity. These observations may herald far reaching implications.

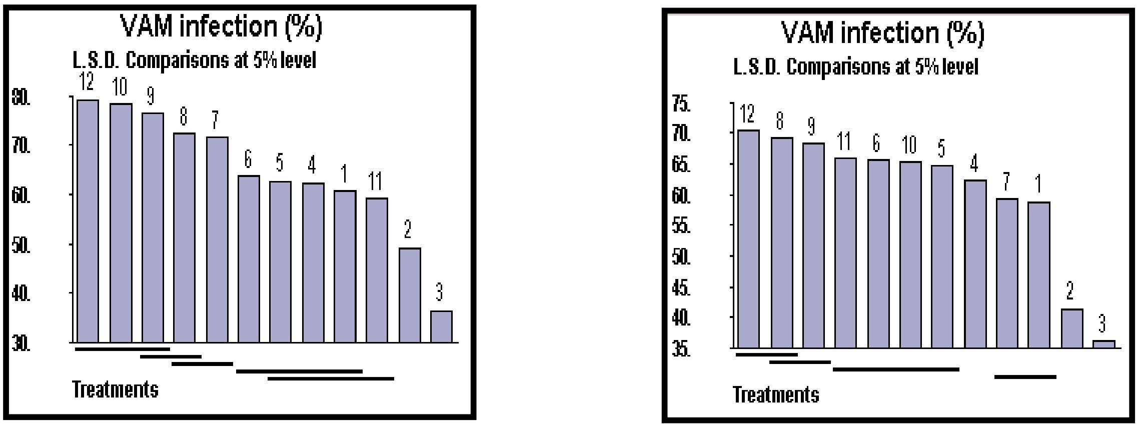


a. At NMU farm



b. At BAT farm

Fig. 1 : LSD comparative profile of VAM spores g^{-1} soil as a function of traditional and biotech inputs



a. At NMU farm b. At BAT farm

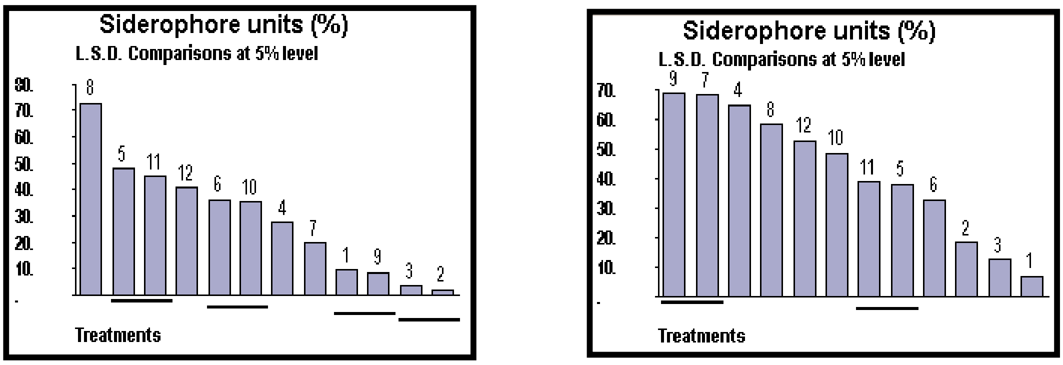
Fig. 2 : LSD comparative profiles of per cent VAM infection as a function of traditional and biotech inputs

c. Profiles of VAM infection

From Fig. 2 (a & b), it is clear that T-8, T-9, T-10 and T-12 treatments also promoted between 70-80% VAM infection in the root system of banana (Table 2). This augurs well for efficient utilisation of endogenous nutrients and moisture available in the soil and exogenously fortified nutrients through SC, FA and PGR. Reducing degree of per cent VAM infection with an increasing degree of chemical fertilisers fortification (T-1 to T-3) has corroborated the view that chemical fertilisers are rendering soil infertile. As a logical corollary, jointly both the scenario provide a hope for further reduction in the use of chemical fertilisers, thereby reducing the cost of cultivation and at the same time improving fertility of soil and reducing the pollution arising out of indiscriminate use of chemical fertilisers.

d. Profiles of siderophore units

From Fig. 3 (a & b), it is clear that chemical fertiliser treatments (T-1 to T-3) are injurious to soil's potential to synthesise siderophore units for combating a potential pathogen, while the biotech treatments induce secretion of siderophore units. However, no distinct trend in siderophore units is seen as a function of individual treatments in both soils, except a common thread that wherever SC and/or biofertilisers (BF) have been fortified in soil, 40-70% siderophore units are present [36]. Talegaonkar (1998) [37] made a similar observation. Genesis of siderophore units being a function of iron stress (Chincholkar *et al.*, 2000)[38], a detailed analysis of each soil may be necessary to shed some light on siderophore content.



a. At NMU farm b. At BAT farm

Fig. 3 : LSD comparative profiles of per cent siderophore units as a function of traditional and biotech inputs

e. Significance of mycorrhizospheric profiles

Table 1 has summarised rhizospheric count as well as VAM spores per g soil, percent VAM infection and percent siderophore units from the soil of T-1 to T-12 treatments at NMU and BAT farm. Accordingly, while S.E. of rhizospheric count is regarded as non-significant, a striking difference does point out that all single treatments (T-1 to T-5 and T-11) are individually ineffective in improving the microbial count in soil, but together, these treatments (barring T-6) have improved the microbial count, T-9 being least efficacious, by about 10,000 fold. In all of them (T-7, T-8, T-10 and T-12), a common denominator was SC. This observation is repeated at two trials (NMU and BAT) and in two crop years (1998-99 and 1999-2000). This has demonstrated that SC incorporation in the soil is a corner-stone of IPNM treatment to be sustainable. In the case of other parameters (VAM spores/infection and siderophore units), S.E. and C.D. values themselves validate their significance and eventual multiplier effect in providing the plants more nutrition (VAM spores and infection) and more protection (percent siderophore units), thereby more vigour and more productivity too.

At this juncture, it would be interesting to look at the root system, its ramification and infestation by VAM. Development of a root system in control vis-à-vis IPNM is remarkably different as could be unequivocally assessed from Photoplate 3.4 a, c and e vis-à-vis 3.4 b, d and f. More surface area of well ramified root system in IPNM augments capacity of plants to be more self reliant in nutrition and moisture procurement, thereby sparing them from the vagaries of nature, heat stress in summer, extra cost of frequent irrigation and implied soil salinisation.

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