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Soil fertility and soil healthcare in citrus: A review

A.K.SRIVASTAVA*, P.S SHIRGURE, SAROJ DESHMUKH AND PARESH BHOYAR

ICAR- Central Citrus Research Institute, Nagpur 440033, Maharashtra

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ABSTRACT

Citrus fruits are tagged as having strong carbon sink, their productivity depend essentially on the two premier facts, soil nutrient balance and the biological activity.The biggest constraint in making soil analysis more purposeful is the non-redressal of spatial variation in soil fertility. Conjoint use of geoinformatics (Geographical Information System, Global Positioning System, Remote Sensing) and site specific nutrient management strategy have offered an easier method of combating such pivotal factor driving into reduced fertilizer use efficiency. Sensor-based technology (called proximal sensing of nutrients on real time basis) has further added a new dimension in providing the nutrient supply as per canopy size (Normalised difference vegetation index) using programmable multi-channel fertigation. Application of open field hydroponics, using both INM and organic concepts is the starting point to adopt such improvised fertility management option.Development of microbial consortium (microbial reactor) exploiting the native and natural microbial synergisms (with twin role as growth promoter and antagonistic to soil borne pathogens) is one of the popular methods of managing multiple soil fertility constraints occurring within the rhizosphere. Such rhizosphere specific consortia (often called as crop-microbiome) could further engineer rhizosphere's nutrient demand and supply through loading with organic manures in a much value added form using a widely accepted concept like INM, in addition to exploiting the plant endophytic ability as a better option towards future soil healthcare issue.

Keywords: Soil fertility, nutrient diagnostics, fertigation, microbial consortium, soil health

INTRODUCTION

Perennial fruit crops represent hardly 1% of the global agricultural land area, but Mediterranean region covers maximum of 11% area, which are of great economic importance in world trade and tariff (FAO, 2011). Approximately 1.7 million (2.8%) of deaths worldwide are attributable to micronutrient deficiency induced through lesser consumption of fruits and vegetables and regarded as top 10 selected risk factors for global mortality (WHO, 2014). At least 60% of the world's arable lands have mineral deficiencies or elemental toxicity problems, and on such soils fertilizers and lime amendments are essential for achieving improved crop yields (Pathak and Nedwell, 2011). Soil function fertility refers to the ability of soil to support and sustain plant growth, which relates to making all the essential nutrients available for root uptake (Srivastava and Kohli, 1997., Srivastava and Malhotra, 2014). This is facilitated by their storage in soil organic matter, nutrient recycling from organic to plant available mineral forms, and physicochemical processes that control their fixation and release (Srivastava, 2013; Srivasatva and Singh, 2001b). On the other hand, managed soils are highly dynamic system that makes the soil work and supply ecosystem services to humans. Overall, the fertility and functioning of soils strongly depend on interactions between soil mineral matrix, plants and microbes (Srivastava and Singh, 2001a; 2001c).These are responsible for both building and decomposing soil organic matter, and therefore for the preservation and availability of nutrients in soils, cycling of nutrients in soils must be preserved (Shirgure etal; 2004a; 2004b; Srivastava *et al.* 2012).

Managing soil carbon for multiple benefits address to enhance a range of ecological services. Increasing the soil organic matter of degraded soils can boost crop productivity, sequester CO_2, enhance soil microbial growth andactivities and improve water capture and retention (Shirgure *et al*., 2001; Srivastava *et al*., 2000). Soil carbon stocks, highly vulnerable to human activities, decrease significantly in response to changes in land capability and land use such as deforestation and increased tillage continues. Decline in soil fertility is the major constraint limiting the productivity of fruit crops. Continuous reduction in nutrient density

Corresponding author: E-mail: aksrivas2007@gmail.com
** Principal Scientist, ICAR-CCRI, Nagpur, Maharashtra*

of different fruit crops is an indication of nutrient mining induced decline in fruit crop productivity (Srivastava and Singh, 2003a; 2003b). Microbes are considered gateway to improved use efficiency of applied fertilizers. A still bigger question emerges, whether rhizosphere competent microbes could collectively contribute towards improved resilience of plant's rhizosphere (Wang *et al.*, 2014) and hence better soil healthcare (Srivastava and Singh, 2004c; 2004d). And if those microbes are so successful in promoting growth response, addition of starter nutrients in such combination may further magnify the magnitude of response called nutrient-microbe synergy. A sound understanding of nutrient- microbe synergy could possibly lay a solid foundation in unlocking the productivity potential of perennial fruit crops, besides safeguarding the soil health, both physic-chemically as well as biologically (Srivastava *et al.*, 2014a). In this background the present review highlights the various core issues of soil fertility management with emphasis on soil healthcare.

PERENNIAL FRUITS: A BETTER CARBON SINK

Fruit crops by the virtue of their perennial nature of woody framework (Nutrients locked therein), extended physiological stages of growth, differential root distribution pattern (root volume distribution), growth stages from the point of view of nutrient requirement and preferential requirement of some nutrients by specific fruit crop, collectively make them nutritionally more efficient than the annual crops (Srivastava and Singh, 2008a; Scholberg and Morgan, 2012). Perennial fruit trees act as strong carbon sink by sequestering the atmospheric carbon. Studies in the past have shown increase in yield of fruit crops like apple, grape, Japanese pears, mango, citrus etc. in response to elevated CO_2 concentration. It remains to be investigated through available but hugely unexpected germplasm diversity, how nutrient-microbe association could bring better dividends to accurate estimation of orchard C budget vis-a-vis time scale and feedback mechanisms of changes in soil carbon pool and steady state level under specific fruit crop in order to expand potential of C credits through perennial fruit crops. Perennial fruit trees play an important role in carbon cycle of terrestrial ecosystems and sequestering atmospheric CO_2 (Guimaraes *et al.*, 2014). According to Wu *et al.* (2012), net C sink and C storage in biomass of apple orchard ranged from 19 to 32 Tg C, respectively, and from 230 to 475 Tg C in 20 years period, amounting to 4.5% of total net C sink in the terrestrial ecosystems in China. In an estimate, Lakso (2010) observed that an acre of apple orchard fixed about 20 tons of CO_2 from the air each season, and provided over 15 tons of O_2, equivalent to over 5 billion BTU's of cooling power. While Mwamba (2013) showed that citrus trees carbon sequestration in biomass ranged from 23.9 tons CO_2 ha^{-1} for young trees to 109 tons CO_2 ha^{-1} for mature trees.With the availability of more technical know-how on combined use of organic manures, prolonged shelf life of microbial bio-fertilizers, and inorganic chemical fertilizers, an understanding on nutrient acquisition and regulating the water relations would help switch orchards to CO_2 sink (expanding carbon capturing capacity of rhizosphere) so that a more sustainable fruit-based integrated crop production system under biotic and abiotic stress could be evolved.

LEAF NUTRIENT DIAGNOSTICS: LINKAGE TO PRODUCTIVITY

Plant nutritionists across the globe are on their toes to find ways and means to identify nutrient constraints as early in standing crop season as possible while dealing with perennial crops. Exciting progress has been made over the years, and accordingly, the basis of nutrient management strategy has experienced many paradigm shifts. While doing so, it is being increasingly felt to have some diagnostic tool to identify nutrient constraint as and when it originates by capturing the signals released at subcellular level. On the other hand, conventionally used diagnostic tools of identifying nutrient constraints such as leaf analysis, soil analysis, juice analysis, and to some extent, metalloenzyme-based biochemical analysis, all have been under continuous use and refinement. There are definite limitations with conventional leaf analysis application which is largely dependent upon composition of index leaves or any other plant parts. On the other hand, overlapping phenotypic symptoms of plants deficient in N, S or Fe accompanied by lowered chlorophyll concentration makes the distinction between nutrients most often very difficult. In the light of these information, an integrative physiological approach was suggested. For example, the use of the peroxidase in the diagnosis of Fe- and Mn-deficiencies prompted checking the utility of the method for citrus cultivars grown on differentially fertile soils. Parallel to what was observed with peroxidase, catalase, and aconitase reduced their levels of activity with Fe-deficiency and increased with Mn-deficiency, facilitated to establish the possibility of using the latter enzyme as an alternative mean of diagnosing Fe- and Mn- deficiencies (Srivastava and Singh, 2006).Many studies suggested that the levels of enzymatic activity could be effectively used as an alternative diagnostic tool to leaf analysis. Since functional analysis of the nutrients is, thus, based on the examination of certain molecular compounds linked with their functional activity (Srivastava and Singh 2008a).

Not surprisingly, proximal sensing through spectral signatures of crop canopies in the field are more complex and often quite dissimilar from those of single green leaves measured under carefully controlled conditions. Even when leaf spectral properties remain relatively constant throughout the season, canopy spectra change dynamically depending upon variation in soil type, vegetation, and architectural arrangement of plant components. Vegetation indices provide a very simple yet elegant method for extracting the green plant quantity signal from complex canopy spectra (Adams *et al*., 2000).Narrower band indices such as the photochemical reflectance index, water band index, and normalized pigment chlorophyll ratio index are examples of reflectance indices that are correlated with certain physiological plant responses, and have promise for diagnosing water and nutrient stress (Srivastava *et al.*, 1994; 1998; 2003). Such studies hold promise for nutrient like nitrogen. Ironically, micronutrient deficiencies are diagnosed through specific pattern of chlorosis, e.g., Fe versus Mn or Fe/Mn versus Zn backed up by nutrient concentration, capturing symptomatic pattern of chlorosis via spectral norms (signatures) irrespective of crop species further limit this concept towards more wider application (Adams *et al.*, 2000; Srivastava and Singh, 2004c).

Specific nutrient-signalling pathways have made it feasible to enhance the uptake and use efficiency of applied nutrient. Nutrient mobility in the phloem from the leaves to the fruits and from the older to the younger fruits is reported in perennial crop like banana. Considering the thumping success of trunk nutrition, won't it be more advisable to analyse the xylem sap or phloem tissue for chemical and microbial constituents since the signal transduction for various nutrients functioning mediate through these tissues only. Such attempts could provide some meaningful clues about the presence or absence of those signals to be later utilized in understanding the underlying principles of nutrient stress induced warning mechanism. These studies could lay the solid foundation for developing some probe linked to transpiration stream of plant to act as early warning system for identifying deficiencies of various nutrients (Srivastava and Singh, 2007).

EXPLOITING SPATIAL VARIABILITY IN SOIL FERTILITY

Characterizing spatial variability of soil physico-chemical properties is a fundamental element of soil fertility management, which is nowadays oriented towards tailoring fertilizer requirement. However, success of precision fruit growing largely depends upon the correctness to which, the spatial variability in soil fertility is addressed as a major production constraint. Redressal of such spatial variability in soil is, therefore, important to identify the nutrient constraint zones vis-à-vis production zones to rationalize the nutrient use and optimize the factor productivity. Attempts were made to address these issues with the help of spatial technology like geographical information system. (GIS). An extensive exploration of 'Khasi' mandarin (Citrus reticulata Blanco) (geographical indicator) growing belts across seven sister states of northeast India, Sikkim and West Bengal was carried out covering 108 orchards from georeferenced 52 sites (grid points) of different geographical origins.The data, hence produced, were subjected to analysis through two diverse kinds of software-based decision support systems in two tiers of interpretation. These included: i. analysis through diagnosis and recommendation integrated system (DRIS) to determine leaf nutrient optima and ii. mapping of spatial variability in nutrient constraints nutrient wise and production wise using the nutrient optima. The nutrient wise spatial soil fertility maps produced were superimposed over each other to identify different production zones displaying high fruit yield and lowest frequency of nutrient constraint (Srivastava and Singh, 2005).

In the light of these soil fertility variations using GIS tool, there is strong possibility of establishing a databank of millions of alternative soil fertility analogous in relation to fruit yield. The soil test value at given site can be effectively be worked out (what is done in case of genomics to match the genome with global genomic library) with these analogues to quantify the level to which different soil test values need to be elevated in order to accomplish the target fruit yield, and consequently, the amount of fertilizer to be applied. Such novel possibilities lie in an entirely new field right now, however, this concept is in a nascent stage. Emergence of site specific nutrient management (SSNM) exploiting the spatial variability in soil fertility, indigenous nutrient supply of soil and crop phenology-based nutrient demand has started sensitizing the researchers as well as practitioners both, to tailor fertilizer requirement either based on soil test value in annual crops or based on plant canopy size in perennial crops, for example citrus (Srivastava and Singh, 2008b). The success of SSNM during the last 10 years has been prominently realized on a number of perennial crops like coconut, avocado, olive, citrus to cite few perennial fruit crop-based success stories.

There could be still a better response anticipated provided, SSNM is linked to fertigation in a variable rate application mode in time domain so that fertilizer requirements are tailored as per crop phenophase demand instead of splitting the fertilizer dose without demand- driven. (Fare *et al.*2012; Srivastava, 2013) recently introduced a model to answer three questions pertaining to SSNM in production of perennial crops viz., which input factors of crop production are limiting yield; what action should be taken to remove limiting factor and what is the potential gain in revenue from taking the actions, spatial variation in leaf nutrient composition within an orchard in relation to different production zones can also be demarcated for rationalized fertilizer use. Preparing simplified ready reckoner for SSNM using diverse crop and agro-pedological analogues in form Nutrient Expert as a development strategy in years to come on the principles of 4R Nutrient Stewardship would be the most benign research and development strategies with regard to precision-based soil fertility management.

NUTRIENT AND WATER USE PARTITIONING vis-a-vis CROP PHENOLOGY

Tailoring the nutrient and water application as per crop phonological stages is a pre-requisite to elevated nutrient use efficiency (Shirgure, 2013; Shirgure and Srivastava, 2014; 2016; Srivastava *et al.*, 2009; 2014b). And occurrence of nutrient constraint or water stress at any - phenological growth stage in any perennial fruit crop e.g. citrus, could jeopardize the incentive accruing through other management practices. Studies on dynamics of different nutrients and water application (ER-based) across all six growth stages (January-February as Stage I, March-April as Stage II, May-June as Stage III, July-August as Stage IV, September-October as Stage V and November - December as Stage VI) of Nagpur mandarin trees grown on alkaline calcareous Haplustert, have shown some interesting observations. These treatments having varying schedules of fertilization as well as irrigation based on evaporation rate influenced both the production oriented parameters viz., canopy volume, fruit yield and fruit quality parametersthrough application of 30% N , 40% P and 10% K out of total requirement at fruit set stage ; 30% N , 35% P and 10% K at marble size stage; 30% N , 25% P and 55% K during fruit development stage and remaining 10% N and 25% K during fruit maturity colour break stage. While, irrigation requirement across crop phenophases showed 9%, 18%, 45%, 20% and 8% out of total water requirement needs to be given to corresponding stages of flowering, fruit set, fruit development, harvesting and colour break stage(Srivatava *et al.*, 2014c). Thus, such studies on partitioning nutrient and water requirement across crop phonological stages would lay a sound research and development strategy for scheduling fertigation for any perennial fruit crop with improved demand-driven nutrient use and better soil healthcare as well. Such attempt on nutrient and water partitioning has been attempted in other fruit crops like apple, banana, grapes, mango crops but distinctly lacking in other perennial fruit crops to develop crop demand oriented fertigation scheduling including variable rate fertigation technique.

TAILORING NUTRIENT USE THROUGH FERTIGATION

Fertigation is considered synonymous to Nutrient-Use-Efficiency(Shirgure *et al.*, 2001; 2004b) which can further be fine tuned with nitrification inhibitors (restrict the microbial conversion of ammonium to nitrate that it is mobile in soils) or plant growth-promoting bio-effectors (microorganisms and active natural compounds involved in plant growth). Open hydroponics (OH), a concept synonymous to fertigation is a management practice to address low fertility gravel base soils and saline water. The nutrient uptake is maximized, if the ratio of ions in the solution matches with scion/stock requirements. In Spain, the performance of ‘Nova’, ‘Marisol’, and ‘Dalite’ mandarins at density of 1000 plantsha^{-1} under OH system was evaluated (Krugger *et al.*, 2000). In South Africa where OH system increased the yield of ‘Valencia’ orange and ‘Clementine’ orange by 19% and 25%, respectively, using 16% less water with 25-31% higher returns compared to micro-irrigation with broadcast method of fertilizer application as control (Martinez and Fernandez, 2004). More information on critical issues like capability of manipulate the soil solution as a restricted root zone versus conventional drip irrigation root zone, buffering capacity of soil manipulating specific nutrient ratios at different physiological stages, evaluating orchard productivity-energy relationship through ionic balanced nutrient solution, planting density etc. are further required before OH system under citrus is adopted on a commercially large scale(Srivastava and Singh, 2005).

Large number of studies have, however, demonstrated much better NUE with fertigation in crops like guava , banana, apple, kiwifruit, sweet cherry, litchi, sapota, mango, Banana, citrus, papaya, pomegranate etc. using various bases of drip irrigation scheduling and NPK-based fertilizers, but without much success with micronutrient fertigation. These studies have provided a wealth of information with unanimous result that fertigation reduced both irrigation and nutrient requirement by 30-50% compared to conventional split application within plant basin. Open hydroponics (Krugger *et al.*, 2000; Martinez and Fernandez, 2004) and variable rate fertilizer linked site specific nutrient management (Zaman and Schumann, 2006; Johnston *et al.*, 2009; Srivastava *et al.*, 2014a) in fruit crops like citrus, olive, avocado, coconut etc. have also started showing their utility in improving fertilizers use efficiency to various dimensions.Possibility of integrating liquid biofertilizers (broth using native isolates) as a starter with nutrients in order to further hasten the bioavailablity of nutrients within plant rhizosphere needs to be looked afresh (Srivastava and Singh 2004a; Shirgure *et al.*, 2014). Concept of rhizosphere hybridization triggering the nutrient dynamics across crop phenophases then finds its candid way into the curriculum of fertigation oriented research (Srivastava and Singh, 2004b) Thus, in addition to all these, precise soil sampling, whether to take samples from below drippers or in between drippers or mixing soil samples from both the sites and finally, drawing a representative soil samples, find a greater intervention while evaluating nutrient-water interaction in citrus. Another prominent concern is often raised with regard to threshold values of leaf nutrient diagnostics. Whether or not, optimum leaf nutrient values hold some application efficacy when compared with basin irrigation coupled with basal fertilizer application.

MICROBIAL CONSORTIUM AND SUBSTRATE DYNAMICS

Exploiting microbial synergisms is one of the popular methods of substrate dynamics and associated changes in nutrient environment of rhizosphere. Rhizo-competent microbes viz., *Azotobacter chroococcum* (asymbiotic N-form), *Bacillus mycoides* (K-solubilizer), *Pseudomonas fluorescens* (P-solubilizer),*Paenibacillus polymyxa* (P-solubilizer) and *Trichoderma harzianum* (P-solubilizer) were isolated from rhizosphere of high yielding Nagpur mandarin trees, out of large microbial accessions isolated from various orchards. Their complementarity test and synergism with chemical fertilizers were later carried out to further judge the suitability of developed microbial consortium. A liquid culture of so developed microbial consortium having 10^8-10^{10} cfu/ml displayed an excellent promise to improve the plant growth and soil health, in addition to quality of compost upon loading as microbially enriched compost. The developed microbial consortium not only improved the assimilable nutrient pool, but improved the microbial load of the soil, thereby, aided in reducing the respiration of the rhizosphere. The microbial consortium produced a good response in both nursery plants as well as in grown-up trees, when applied in integrated nutrient management mode cutting the inorganic fertilizers by anticipated 10-15% (Srivastava and Singh 2009). Of late, efforts are being made to develop consortium of endophytic microbes.

NUTRIOMICS AND NUTRIENT USE EFFICIENCY

Biomass or yield selections based soil fertility are not only costly but also subject to confounding environmental interactions and spatial heterogeneity. Therefore, it would be preferable to identify and select specific traits that are directly related to a specific nutrient efficiency on both nutrient depleted and fertile soils. The fact that many of the molecular and biochemical changes in response to nutrient deficiency occur in synchrony suggests that the genes involved are coordinately expressed and share a common regulatory system. Therefore, systematic studies are needed to understand the genomics, transcriptomics, proteomics and metabolomics aspects of nutrient efficiency in response to varying soil fertility. This area of study is termed plant nutriomics, a new frontier of plant biology that is attracting more and more attention by the researchers worldover.Improving nutrient-use-efficiency in perennial fruit crops has to be viewed by classifying system approaches, one relying on soil-based processes, while other on crop growth and yield (Srivastava and Singh 2008a).

Better understanding on mechanisms involving genotype variability of fruit crops to different nutrient regime; physiological basis of fruit crop responses to nutrient application during the growth; and the morpho-physiological and molecular traits (at development, growth and metabolic levels) controlling NUE under nutrient limiting conditions to develop through molecular breeding and genetic engineering, will lead to better performance of perennial fruit crops, irrespective of any nutrient or hydric stress.

Table 1: Growth response of acid lime seedlings in response to different microbial inoculations (Period: 120 days)

Treatments	Shoot parameters				Root parameters	
	Shoot length (cm)	Shoot weight (g)	No. of leaves/plant	Girth (mm)	Root length (cm)	Root weight (g)
Seed inoculation						
T_0 (Control)	18.6	1.60	14	1.87	10.5	0.40
T_1 (Th)	21.5	1.72	16	2.03	11.1	0.43
T_2(Th+Bm)	22.7	2.53	19	2.32	13.6	0.67
T_3(Th+Bm+Pp)	23.9	2.64	19	2.38	8.6	0.71
T_4(Th+Bm+Pp+Ac)	24.9	2.60	22	2.21	11.1	0.78
T_5(Th+Bm+Pp+Ac+Pf)	23.4	2.81	26	3.09	19.4	0.89
CD($P=0.05$)	1.2	0.10	1.8	0.11	0.40	0.06
Soil inoculation						
T_0 (Control)	16.6	1.61	19	1.96	9.6	0.38
T_1 (Th)	17.5	2.12	21	1.99	10.7	0.43
T_2(Th+Bm)	22.5	2.26	28	2.16	15.3	0.51
T_3(Th+Bm+Pp)	20.1	2.56	32	2.46	15.5	0.64
T_4(Th+Bm+Pp+Ac)	21.4	3.25	33	2.92	17.1	0.77
T_5(Th+Bm+Pp+Ac+Pf)	23.3	3.48	38	3.17	19.1	1.01
CD(P=0.05)	0.50	0.20	3	0.18	0.82	0.22

Th, Bm, Pp, Ac and *Pf* stand for *Trichoderma harzianum, Bacillus mycoides, Paenibacillus polymyxa*, *Azotobacter chroococcum* and *Pseudomonas fluorescens,* respectively.Source: Srivastava *et al.* (2015a)

Emerging multiple nutrient deficiencies have necessitated renewed efforts to address nutrient management issue through integrated use of inorganic fertilizers (IF), organic manures (OM), and microbial consortium (MC). Accrued long term field experiment data on evaluation of integrated nutrient management (INM) in Nagpur mandarin (Citrus reticulata Blanco) carried out with the objective of working out an efficient INM module grown on Vertic Ustochrept showed much better effectiveness of MC when used in combination with IF fertilizers and OM, farmyard manure (FYM) or vermicompost (Vm). However, the latter could produce a much higher magnitude of response (Srivastava 2013). The net increase in canopy volume within four years (2007–2012) with 100% recommended dose of fertilizers (RDF) was much higher compared with 75% RDF plus 25% Vm plus MC, with significantly better fruit quality parameters. Soil quality parameters in terms of soil microbial biomass (SMB) and soil microbial biomass nutrients (SMBN) were much higher with 75% RDF plus 25% Vm plus MC as compared with exclusive use of IF as 100% RDF. These changes within rhizosphere were very well translated into consequent improvements in leaf nutrient composition, being significantly higher with 75% RDF plus 25% Vm plus MC over 100% RDF. These observations warranted strong support in favor of INM-based treatments than sole use of IF (Srivastava et.al 2015c).

Table 2: Response of microbial consortium loaded INM - treatments on canopy volume, fruit yield and soil fertility changes on Vertic Ustochrept (Pooled data 2010-16)

Treatments	Canopy volume (m^3)	Fruit yield (kg /tree)	Plant available nutrients in soil (mg /kg)						
			Macronutrients			DTPA-micronutrients			
			$KMnO_4$- N	Olsen-P	NH_4OAc-K	Fe	Mn	Cu	Zn
T_1 (100% RDF)	14.69 (13.04)*	58.07	145.6	9.22	184.5	10.40	10.54	2.13	0.96
T_2 (75% RDF + 25% Vm)	21.36 (18.51)	60.23	148.2	9.31	193.2	12.91	11.38	2.39	1.21
T_3 (75% RDF + 25% Vm +MC)	23.12 (20.28)	65.68	153.7	9.85	204.6	15.81	12.74	2.80	1.37
T_4 (50% RDF + 50% Vm)	25.20 (22.42)	72.66	160.6	10.38	221.5	17.22	11.93	2.88	1.47
T_5 (50% RDF + 50%Vm+ MC)	21.45 (18.33)	80.95	175.0	11.12	233.6	19.11	13.13	2.95	1.57
CD (*P=0.05*)		3.20	1.4	0.41	5.3	0.90	NS	NS	0.10

***Initial observations** RDF, Vm and MC stand for recommended doses of fertilizers, vermicompost and microbial consortium (*Paenibacillus polymyxa*, *Trichoderma harzianum*, *Bacillusmycoides*, *Azotobacter chroococcum* and *Pseudomonas fluorescens*), respectively. Source: Srivastava *et al.* (2012; 2015b)

CORE ISSUES

Until recently, research has focused on those organisms that are culturable. However a wealth of information is now being collected from both culturable and, as yet, unculturable organisms. Functions of the soil microbial population impact many processes and, therefore, productivity, if mechanisms involved in the plant-microbe interaction are better understood, since, a plant manufactures microbial communities according to its metabolic requirements. The genetic, functional and metabolic diversity of soil microorganisms within the rhizosphere of wide range of fruit crops is important, the capacity of soil microbial communities to maintain functional diversity of those critical soil processes could ultimately be more important to ecosystem productivity and stability than mere taxonomic diversity. In this context, it remains to be assessed how nutrient-microbe synergism is associated with productivity of perennial fruits. New research methods involving molecular techniques will extend our understanding of taxonomic and functional diversity in soil systems.

Delineation of production management zones linked with variable rate fertilizer application as per the crop phenology is expected to tailor the fertilizer requirement without altering the fertilizer requirement of a cropsoilfertilitybased spatial variogram would `further act as a decision support tool for precise fertilizer recommendation. Eventually, such attempts warrant for developing Nutrient Experts based on 4R nutrient Stewardship Concept whichhavedisplayed some definite yield advantages in cereal crops, but such serious efforts are direly needed in fruit crops, if nutrient management is to be linked with NUE.

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