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Research Review Articles

INM in fruit crops: Sustaining quality production and soil health

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ABSTRACT

Sustainability in quality production and ensuring a tangible soil health, are the two most discerning challenges, which the fruit crops are likely to confront with in years to come. Integrated Nutrient Management (INM) is one such option, which exploits the synergy of divergent nutrient sources. As many as four modules of INM (T_2: RDF + VAM 500 g/plant + PSB 100g/plant + *Azospirillum* 50g/plant; T_3 : 100% RDF + VAM 500 g/plant + PSB 100g/plant + *Azospirillum* 100g/plant + *T. harzianum* 100g/plant; T_4 : 75% RDF + VAM 500 g/plant + PSB 100g/plant + *Azospirillum* 100g/plant and T_5 :50% RDF + VAM 500 g/plant + PSB g/plant + *Azospirillum* 100g/plant + *T.harzianum* 100g/plant) were tested against inorganic mineral fertilization T_1 (Recommended dose of fertilizers, RDF (900 N- 225 P_2O_5-225 K_2O g/plant for Nagpur mandarin, 450 N- 225 P_2O_5 – 450 K_2O g/plant for Khasi mandarin and 1125 N- 263 P_2O_5 - 300 K_2O g/plant for Sathgudi sweet orange) as control in 11-12 year-old Nagpur mandarin orchard established on Vertisols at Akola, Maharashtra (2009-15); Khasi mandarin on Alfisols at Tinsukia, Asom (2009-15) and Sathgudi sweet orange on Inceptisols at Tirupati, Andhra Pradesh (2006-19) under All India Coordinated Research Project on Fruits. Based on pooled data analysis, treatment T_4 with 75% RDF + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (100 g/plant) + *T. harzianum* (100 g/plant) produced by far the best response over T_1 control in Nagpur mandarin grown on Vertisol. Similarly, in Khasi mandarin, raised on Alfisol, T_4 was observed significantly superior over T_1 control. While in Sathgudi sweet orange on Alfisol, T_4 surpassed rest of the other treatments including T_1 control. Soil health parameters were significantly better with treatment T_4 exploiting the efficacy of INM module than treatment T_1 as control. The review on recommendations of INM on a variety of fruit crops (Guava, mango, banana, papaya, pomegranate, aonla, litchi, sapota, lemon) revealed similar combinations. These observations provided a countrywide database that INM module which consists of nutrient sources having three-tier nutrient release pattern, has far reaching consequences on soil and plant health translating into real guard production sustainability, nearer to climate resilient fruit crops.

Key words: Citrus, INM, Quality, Soil fertility, Soil health, Yield

A guesstimate proclaims over 900 million people in the world are under–nourished and malnutrition alone is responsible for 3.5 millon deaths annually (Srivastava 2010a, 2004b). On the other hand, citrus fruits are produced in many countries around the world, although production shows geographical concentration in certain areas, but still citrus fruits rank first in the international market (Srivastava and Shirgure 2018, Srivastava and Singh 2001a). In the backdrop of demography-driven diminishing per capita availability of land (more so in fruit crops), sustaining soil fertility management has gained a phenomenal significance in meeting the multipronged challenges of sustaining the quality production on one hand and ensuring the carrying capacity of soil health on the other hand (Srivastava and Singh 2003c). Malnutrition of citrus orchards in Asian countries like India, Pakistan, Sri Lanka, Thailand, China, Philippines, Nepal, Iran etc. is more or less a commonality (Ghosh and Singh 1993) with some exceptions. However, the situation by contrast is extremely different in frontline citrus growing countries like USA, Brazil, Israel, Spain etc. in terms of rootstock options as per soil conditions, micro-irrigation/fertigation technology, better refined diagnostic techniques, and larger proportion of orchards being regularly fertilized based on nutrient demand and supply analysis (Srivastava and Singh 2004a). Single or multiple nutrient deficiency linked decline in citrus orchard productivity is reported worldover (Table 1). Considering the economics of citrus production, fertilizers alone on an average, constitutes about 20-30% of total cost of citrus production which is a significant recurring expenditure, a grower needs to invest every year (Srivastava and Singh 2003a, 2005).

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The mechanistic steps involved in an efficient nutrition program are absorption, translocation, and utilization of applied nutrients (Srivastava and Singh 2013a). All three steps being entirely different but equally dependent to each other (Srivastava 2009).

Citrus requires 16 essential elements for normal growth, production, and quality irrespective of the source (Zekri 1995, Srivastava 2011, 2013b). Renewed and intensified efforts are in progress during the past 10-15 years to grow citrus organically ever since the depleting soil fertility has attained a serious concern with the practice of high density orcharding coupled with heavy use of chemical fertilizers that were immediately available to the plants for nutrient uptake (Kohli *et al.* 1998, Srivastava 2013c,) bringing unprecedented reduction in soil organic matter (Intrigliolo and Stagno 2001).

Fertilizers act in exactly the same way as nutrient from organic resources in the soil, since they are chemically the same (Srivastava and Kohli 1997). The plant itself cannot differentiate where the nutrient is coming from (Srivastava *et al*. 2014). A debate with extreme postures on the subject is totally futile and absurd. Crops can be raised purely on either resources, if they are not compared against yields, economics, nutritional quality, and environmental damages all frequently integrated on the index of sustainability (Srivastava *et al.* 2015a).

The advent of synthetic chemical fertilizers decreased organic fertilizer use such that it makes up only about 0.1% of all fertilizers applied to citrus today (Srivastava and Malhotra 2014). However, interest in applying organic amendments to citrus is rising because of increased supplies and reduced cost of non-hazardous organic wastes (Srivastava and Singh 2001b, 2001c). Citrus growers apply these materials for perceived or real improvements in soil physical, chemical, and biological properties, but the main benefits appear to be the increased nutrient availability (Srivastava and Ngullie 2009). The use of organic materials as an N source is being considered as a best management practice (BMP)

Table 1 Global distribution of nutrient deficiencies in citrus orchards

Citrus region	Nutrient deficiency	References
Argentina (Tucuman)	N, Cu, Fe, Mg, Zn	Aso and Dantur (1970)
Australia (New South Wales, Riverland, Sunrayasia)	N, P, Cu, Mn, Zn, B	Halase (1963), Duncan (1969)
Brazil (Sao Paulo, Parana)	Ca, Mg, P, K, Zn, B	Caetano *et al.* (1984), Fidalski and Auler (1997)
Chile (Azapa, Elqui, Limari, Cachapoal)	N, Zn, Mn, P, S	Veregara *et al.* (1973)
China (Fujian, Sichuan)	Ca, P, Fe, Mn, Zn, Mo	Li *et al*. (1998), Yin *et al.* (1998)
Costa Rica (Atlantic zone)	N, P, K, Ca, Mg, Mn, Zn	Bornemisza *et al.* (1985), Alvardo *et al*. (1994), Araya *et al.* (1994)
Egypt (Aswan, Beheira, Tahrir)	N, P, Fe, Mn, Zn	El-Fouly *et al.* (1984), Salem *et al.* (1995)
India (northwest, northeast, south, central region)	N, P, Ca, Mg, Fe, Mn, Zn	Awasthi *et al*. (1984), Dhatt (1989), Srivastava and Singh (2004b, 2004c, 2006b, 2008a)
Iran (Jiroff valley)	Zn, Mn, Cu	Rao (1993)
Israel (Negev, Sinai, Jordan valley)	Ca, Mg, Fe, Zn	Shaked and Ashkenazy (1984), Horesh *et al.* (1986)
Italy (Sicily, Calabria, Barasilicata)	N, K, Mg, Cu	Pennisi (1975)
Japan (Shizuoka, Ehime, Kanagawa)	N, P, K, Mg, Zn	Takatsuji and Ishihara (1980), Kozaki (1981), Wada *et al.* (1981)
Kenya (Rift valley)	N, P, B, Fe, Zn, Cu, Mn, Mo	Kimani (1984)
Korea (Jeju Island)	N, P, K, Ca, Mg, S, Cu, Zn	Kim *et al.* (1969), Moon *et al*. (1980)
Morocco (Sou valley)	Fe, Mn, Zn	Penkov *et al.* (1979)
Nepal (Dhankuta, Lamjung, Gorkha),	B, Mg, Cu, Ca, Zn	Gupta *et al.* (1989), Tripathi and Harding (2001)
Pakistan (Punjab)	K, Zn, B	Haq *et al.* (1995)
Sierra Lone (Sierra)	N, P, K, Ca, Mg, Zn	Haque and Godfrey (1976)
Spain (Valencia, Seville, Murcia, Catania)	N, P, K, Ca, Mg, Fe, Mn, Zn	Majorana (1960), Hellin *et al.* (1988)
Thailand (Korat Plateau)	Ca, Mg, P, Zn	McCall (1965)
Trinidad (Caribbean area)	Mg, Zn, Mn	Weir (1969, 1971)
Turkey (Izmir, Aegean region)	Ca, Mg, Fe, Zn	Ercivan (1974), Saatci and Mur (2000)
USA (Florida, California, Texas)	N, P, K, Fe, Mg, Zn, Mn, Cu, B, Mo	Koo (1982), Zhou and Alva (1993), Tucker *et al.* (1995), Zhang *et al.* (1997)
Venezuela (Carabobo)	N, P, Ca, Mg, Zn	Pinto and Leal (1974)

Organic manuring is often considered amongst one of the sustainable agricultural practices, if used appropriately, promises to offer rich dividends on a long term basis (Ferguson 1990b).

for N management because organic sources release N to the plant more gradually than water-soluble, inorganic fertilizer sources. Current organic amendments applied to citrus groves (biosolids, poultry waste, and composts) differ substantially from those applied in the past. The Florida Department of Agriculture and Consumer Services (FDACS) interim BMP rule for citrus stated that the contribution of plant-available N from natural organic N sources for the 1st year after application shall be 50% of the total N application. Application rates are determined by a process design that takes into account the crop N requirement and the N mineralization rate. Mineralization rate studies are being, therefore, conducted to refine this figure for accurate nutrient management planning under Florida conditions (Obreza and Ozores-Hampton 2000).

Concerns about improving nitrogen use efficiency, reducing nitrate pollution, contamination due to byproducts of various chemical pesticides in use, and continued gradual loss of soil organic matter have always been the major core issues, and more so, citrus raised through organic manuring (Ferguson 1994, Srivastava *et al.* 2003). But, the organic manuring has yet not received the priority it deserves, was a result, soil physical, chemical, and microbiological health have not been so favouring consistently high yield (Dahama 1994, Paroda 1999, Ghosh 2000). In addition to changes in land use pattern, unfavourable climatic conditions have further enhanced the rate of decomposition of soil organic matter and its further depletion (Velayutham *et al.* 1999). These problems warrant revision of ongoing agricultural practices, and adaptation of some alternative strategies whose origin is presumed to be age old, popularly known as organic farming or natural farming. Traditional organic manuring with special reference to rotation, use of green manures and rural agricultural waste as compost, tank silt application would all help to build soil organic matter base, a reliable index of fertility. This is long-term endeavour but once attained all parameters, physical, chemical, and biological work at optimum. Use of microbial biofertilizers on one hand, and the utilization of AM fungi as bioprotectors, bioregulators and biofertilizers in citrus (Manjunath *et al.*1983, Ishii and Kadoya 1996) on the other hand is likely to bring a desirable changes in the quality production, besides beneficial impact on soil health.

Alteration of heavy with light crop is a common feature in many fruit crops (Reuther 1973, Moss *et al.* 1981, Monselise and Goldschmidt 1982, Kihara *et al.*1995, Haggag *et al.* 1995). Alternate bearing is more pronounced from tree to tree basis in Kinnow mandarin, without any significant difference in feeder root density compared between on and off year trees (Jones *et al.* 1975). The present citrus production trends are characterized by either frequent crop failure or recurrence of alternate on and off year setting a substantial monetary loss to the industry (Jones *et al.*1975, Smith 1976, Rojas 1998, Dass *et al.* 1998). In the recent years, the nutrient additions have been exclusively in favour of mineral fertilizers due to demographic pressure, of demands related to life styles and trade involvement. While, the quick and substantial response to fruit yield due to mineral fertilizers eclipsed the use of organic manures, the inadequate supply of the latter sources exacerbated this change (Ghosh 2000). Integrated nutrient management (INM) with emphasis on the use of bio-organics is a comparatively recent concept which needs to be vigorously pursued to achieve the sustainability in citrus production trend spaced over the years. Additionally crop nutrition, therefore, must respect the prescriptions of INM (Srivastava and Ngullie 2009). The merits of INM based practices also takes into account the mobilization of unavailable nutrients could also be effected by speeding up the rate of mineralization of various organic substrates.

INM as a dynamic concept of nutrient management is looked upon the economic yield in terms of fruit yield coupled with quality on one hand, and soil physico-chemical and microbiological health on other hand as a marker of resistance against the nutrient mining that arises because of failure to strike a balance between annual nutrient demand versus quantum of nutrients applied (Srivastava and Singh 2008a). Soils under citrus differ from other cultivated soils, that remain fallow for 3-6 months every year forcing depletion of soil organic matter (Bhargava 2002). On the contrary, biological oxidation of existing C continues in soil covered under citrus (Srivastava *et al*. 2002). Multiple nutrient deficiencies are considered to have triggering effect on potential source of atmospheric CO_2. Soil carbon stock is, hence, considered as an important criterion of determining the impact of INM in the longer version of impact assessment (He *et al.* 1997b, Joa *et al.* 2006). The amount of accumulated C within the rhizosphere soil does not continue to increase with time with increasing C outputs. An upper limit of C saturation level occurs, which governs the ultimate limit of soil C sink and rate of C sequestration in mineral soils, independent of C input rate. An understanding of mechanism involved in C stabilization in soils is needed for controlling and enhancing soil C sequestration (Goh 2004).

Recognition of the importance of soil microorganisms has led to increased interest in measuring the quantum of nutrients held in their biomass (Srivastava *et al.* 2002). An increase in the microbial biomass often goes along with increased nutrient immobilization. Over the years, the concepts of integrated nutrient management (INM) and integrated soil management (ISM) have been gaining acceptance, moving away from a more sectoral and inputs driven approach (Srivastava *et al.* 2012). INM advocates the careful management of nutrient stocks and flows in a way that leads to profitable and sustained production. ISM emphasizes the management of nutrient flows, but also highlights other important aspects of soil complex such as maintaining organic matter content, soil structure, moisture, and microbial biodiversity (Srivastava *et al.* 2015b). Still more attention is needed towards integrated soil biological management as a crucial aspect of soil fertility management since providing protection to citrus rhizosphere against the nutrient depletion is of utmost importance for sustained orchard production in which the objectivity of INM could have far reaching consequences (Srivastava *et al.* 2008). Exploring microbial diversity perspectives in citrus crop is, therefore, important and equally useful to arrive at measures that can act as indicators of soil quality and sustainable orchard productivity using biological soil management to be intimately integrated with INM (Srivastava *et al.* 2015b). Diagnosis of nutrient constraints and their efficient management has, therefore, now shifted in favour of INM through collective use of organic manures, inorganic fertilizers and beneficial microorganisms becomes all the more difficult.

Long term evaluation of INM in citrus

The trial was laid out using bio-fertilizers, viz. VAM, PSB, *Azospirillum* and bio-control agent *T. harzianum* in combination with RDF in RBD replicated four times in Nagpur mandarin (Vertisol), Khansi mandarin (Alfisol) and Sathgudi sweet orange (Alfisol) with five treatments, comprising T_1, Recommended dose of NPK-100% RDF as (Control); T_2, 100% RDF + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (50 g/plant*);* T_3, 100% RDF + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (100 g/plant*)* + *T. harzianum* (100 g/plant); T_4, 75% RDF + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (100 g/plant*)* + *T. harzianum* (100 g/plant) and T_5, 50% RDF + VAM (500 g/plant) + PSB - (100 g/plant) + *Azospirillum* (100 g/plant*)* + *T. harzianum* (100 g/plant).

Response of INM treatments in khasi mandarin

At Tinsukia, significantly higher plant height (6.44 m), canopy volume (41.51 m^3) and fruit yield (39.60 t/ha) were recorded under the treatment T_4, having 75% recommended dose of NPK (450 g N, 225 g P_2O_5, 450 g K_2O and 5.62 kg neem oil cake) + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (100 g/plant) + *T. harzianum* (100 g/plant). The fruits were also significantly superior in different quality parameters as evident from highest juice content (48.95%), TSS (13.77°B) and lowest acidity (0.37%). The time taken for maturity was the lowest (244 days) while shelf life was the highest (18 days) though not significant. Significantly higher soil fertility status and superior N, P, K content on leaf were also observed in T_4 treatment. Similarly, maximum B: C ratio (4.7) was also observed under this treatment (T_4) (Tables 2, 3).

Response of INM treatments in Nagpur mandarin

Growth of Nagpur mandarin was influenced with application of bio-fertilizers. Significantly higher plant height (4.72 m) and canopy volume (57.16 m^3) were observed with an application of 100% RDF + VAM 500 g + PSB 100 g + *Azospirillum* 100 g + *T. harzianum* 100 g per plant compared to other treatments. Application of 100% RDF +VAM 500 g + PSB 100 g + *Azospirillum* 100 g + *T. harzianum* 100 g per plant also recorded significantly highest number of fruits (770), yield (106.81 kg/plant and 29.59 t/ha) as well as fruit weight (146 g). Same treatment produced best quality fruit with high juice percentage (42.50%), ascorbic acid content, i.e. 41.10 mg/100 ml and TSS (11.27°B) and minimum acidity (0.67%). Treatment T_3 also recorded significantly lower deadwood percentage. Also, leaf and soil nutrient status improved with incorporation of bio-fertilizers (Tables 2, 3).

Leaf nutrient levels of N, P and K were observed more in treatment T_3 as compared to other treatments. Also, treatment T_3 recorded maximum level of available soil N (250.28 kg/ha) and P_2O_5 (18.03 kg/ha), however treatment T_2 recorded maximum level of soil K_2O (392.72 kg/ha). Highest net return (₹ 3.97 Lakhs) and maximum B:C ratio (5.29) were obtained with treatment T_3. Treatments T_3 and T_4 has given incremental benefit of ₹ 1.23 and ₹ 1.12, respectively over control. These results suggested treatment T_3 plant was superior and recorded highest growth, yield and quality parameters for Nagpur mandarin as compared to the other remaining treatments under Akola conditions in addition to highest net return with maximum B:C ratio. However, B:C ratio of treatment T_4 was at par with treatment T_3. Treatment T_4 saved 25% fertilizer over T_3 which became more visible on the cost of fertilizer to be saved. Hence, application of 75% RDF (900g:300g:300g) +VAM 500 g/plant + PSB 100 g/plant + *Azospirillum* 100 g/plant + *T. harzianum* 100 g/plant is recommended for better growth, yield, quality and for getting maximum profit from Nagpur mandarin (Tables 4, 5).

Table 2 Effect of INM on growth and yield performance of Nagpur mandarin, Khasi mandarin and Sathgudi sweet orange

Treatment	Akola (Nagpur mandarin)		Tinsukia (Khasi mandarin)		Tirupati (Sathgudi sweet orange)	
	Canopy volume (m^3)	Fruit yield (t/ha)	Canopy volume (m^3)	Fruit yield (t/ha)	Canopy volume (m^3)	Fruit yield (t/ha)
T_1	13.80	20.18	32.29	32.34	22.24	16.15^{c}
T_2	26.79	23.35	34.64	29.58	21.62	21.81^{ab}
T_3	30.10	25.84	39.38	32.63	21.39	23.92^{ab}
T_4	23.26	22.49	41.51	39.60	23.04	28.14^{a}
T_5	18.20	19.02	34.80	30.55	20.32	20.16^{bc}
CD (P=0.05)	2.96	1.93			NS	0.63

Pooled data of 2009-15 for Akola and Tinsukia centres; Pooled data of 2006-14 for Tirupati Centre

Table 3 Effect of INM on quality traits of Nagpur mandarin, Khasi mandarin and Sathgudi sweet orange

Treatment	Akola (Nagpur mandarin)			Tinsukia (Khasi mandarin)			Tirupati (Sathgudi sweet orange)		
	Juice (%)	Acidity (%)	TSS (^{0}Brix)	Juice (%)	Acidity (%)	TSS (^{0}Brix)	Juice (%)	Acidity (%)	TSS (^{0}Brix)
T_1	50.98	0.79	11.61	43.02	0.46	10.60	41.24^a	0.99	9.84^c
T_2	51.25	0.75	12.17	43.33	0.45	11.43	36.73^b	0.95	9.89^{bc}
T_3	51.83	0.74	12.38	46.58	0.42	11.60	37.27^b	1.07	10.00^{ab}
T_4	51.03	0.77	11.95	48.95	0.37	13.77	40.51^a	0.98	10.11^a
T_5	49.88	0.73	11.53	41.01	0.45	10.25	40.70^a	1.03	9.90^{bc}
CD (P=0.05)	0.41	0.18	0.169	6.34	NS	1.98	1.56	NS	0.15

Pooled data of 2009-15 for Akola and Tinsukia centres; Pooled data of 2006-14 for Tirupati Centre

Response of INM treatments in Sathgudi sweet orange

At Tirupati, there was no significant difference with respect to the vegetative growth parameters (plant height and canopy volume) with different bio-fertilizers (Tables 2, 3, 4 and 5). However, number of fruits per plant (425 fruits/plant) and fruit yield (28.14 t/ha) recorded were highest with the inclusion of bio-fertilizers VAM at 500 g/plant PSB at 100 g/plant + *Azospirillum* at 100 g/plant + *T. harzianum* at 100 g/plant along with 75% RDF followed by application of VAM at 500 g/plant + PSB at 100 g/plant + *Azospirillum* at 100 g/plant + *T. harzianum* 100 g/plant along with complete dose of RDF (398 fruits/plant and 23.92 t/ha). The lowest number of fruits/plant (330 fruits/plant) and fruit yield (16.15 t/ha) was with soil application of 1500g N: 350g P_2O_5: 400 g K_2O/plant/year (100% RDF). Soil application of 75% RDF + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (100 g/plant) + *T. harzianum* (100 g/plant) also recorded the best quality fruits (Juice 40.51%, TSS 10.11^{o}Brix and acidity 0.98%) due to higher soil fertility status (165, 193.13 and 448.75 N, P_2O_5 and K_2O kg/ha) and superior N, P, K and zinc levels in the leaf. The results clearly indicated that the bio-fertilizers are essential for higher yields and good quality in sweet orange cv. Sathgudi along with 75% RDF.

The benefit cost ratio was higher under 75% RDF + VAM (500 g/plant)+ PSB (100 g/plant) + *Azospirillum* (100 g/plant) + *T. harzianum* (100 g/plant), which could be attributed to increased number of fruits/plant. But the treatment 50% RDF + VAM (500 g/plant) + PSB (100 g/plant) + *Azospirillum* (100 g/plant) + *T. harzianum* (100 g/plant) (2.21) also recorded the same benefit cost ratio which is particularly attributed to reduced quantity of fertilizers (50% RDF). Sweet orange grower can get higher income per rupee invested by adopting 75% RDF + VAM (500 g/plant)+ PSB (100 g/plant) + *Azospirillum* (100 g/plant) + *T. harzianum* (100 g/plant) treatment at field level. Leaf and soil nutrient status was improved with incorporation of biofertilizers, but not significantly.

Table 4 Effect of INM on leaf and soil fertility status of Nagpur mandarin, Khasi mandarin and Sathgudi sweet orange

Treatment	Akola (Nagpur mandarin)			Tinsukia (Khasi mandarin)			Tirupati (Sathgudi sweet orange)		
	N	P	K	N	P	K	N	P	K
				Leaf nutrient status (%)					
T_1	2.42	0.32	1.63	2.24	0.16	1.17	2.53	0.42	1.38
T_2	2.48	0.36	1.69	2.26	0.22	1.20	2.91	0.54	1.94
T_3	2.52	0.38	1.72	2.51	0.27	1.32	2.93	0.55	2.26
T_4	2.32	0.28	1.57	2.64	0.30	1.49	3.04	0.59	1.97
T_5	2.25	0.24	1.46	1.99	0.17	1.07	2.96	0.53	1.85
CD (P=0.05)	0.008	0.045	0.049	0.25	0.17	1.14	NS	0.41	NS
				Soil fertility status (kg/ha)					
T_1	221.02	14.46	346.90	298	26.9	132.5	167	138.75	393.75
T_2	239.49	16.76	393.72	318	28.6	158.4	163	132.5	428.75
T_3	250.28	18.03	384.61	327	32.8	155.1	160	161.25	405.00
T_4	232.29	15.69	369.65	360	33.9	175.3	165	193.13	448.75
T_5	225.14	15.55	289.00	302	24.3	134.2	168	157.50	392.50
CD (P=0.05)	12.65	1.82	20.98	18.9	5.4	7.8	NS	NS	NS

Pooled data of 2009-15 for Akola and Tinsukia centres, Pooled data of 2006-14 for Tirupati Centre (Unpublished)

Table 5 Effect of INM on soil microbial population in Nagpur mandarin, Khasi mandarin and Sweet orange

Treatment	Soil microbial count (cfu/g soil)								
	Akola (Nagpur mandarin)			Tinsukia (Khasi mandarin)			Tirupati (Sathgudi sweet orange)		
	Fungi ($\times 10^3$)	Bacteria ($\times 10^6$)	Actinomycetes ($\times 10^2$)	Fungi ($\times 10^4$)	Bacteria ($\times 10^7$)	Actinomycetes ($\times 10^5$)	Fungi ($\times 10^4$)	Bacteria ($\times 10^7$)	Actinomycetes ($\times 10^5$)
T_1	32.7	21.7	13.7	19.6	27.4	5.6	25.00	35.00	9.00
T_2	34.5	23.5	17.7	18.3	29.8	9.7	26.30	35.30	9.50
T_3	37.0	25.7	19.7	21.8	31.5	10.3	27.60	36.00	10.00
T_4	34.7	24.2	18.0	24.6	36.2	14.9	29.40	37.20	11.00
T_5	29.2	18.2	10.2	17.7	25.8	8.5	29.90	37.50	11.20
CD (P=0.05)	5.20	4.24	5.46						

Pooled data of 2009-15 for Akola and Tinsukia centres; Pooled data of 2006-14 for Tirupati Centre

Treatment T_4 recorded maximum level of available soil N (165 kg/ha), P_2O_5 (193.13 kg/ha) and K_20 (448.75 kg/ha). Leaf nutrient levels of P and Zn were significantly highest in treatment T_4, as compared to other treatments (Tables 2, 3, 4 and 5). These results showed T_3 as the most effective treatment at Akola and T_4 at Tinsukia and Tirupati centres on the basis of responses on fruit yield, quality, leaf nutrient composition and soil microbial properties.

INM and nutrient dynamics (Soil health and CO_2 emission)

In recent years, nutrient additions have been exclusively in favour of inorganic fertilizers (IF) due to demographic pressure and demands related to life styles and trade involvement. While the quick and substantial response to fruit yield due to IF eclipsed the use of organic manures (OM), the inadequate supply of the latter sources exacerbated this change (Srivastava 2009). Although, differential efficacy of two conventional methods of fertilization (soil versus foliar application) has helped in improving the quality production of citrus (Srivastava and Singh 2008a) and other fruits (Singh and Banik 2011, Singh *et al*. 2012).

In recent years, continuous fertilization has failed to sustain the yield expectancy on a long term basis due to depletion of soil carbon and consequently, multiple nutrient deficiencies have emerged irrespective of soil type (Srivastava *et al.* 2010). The menace of multiple nutrient deficiencies has further been triggered through increase in air temperature via changes in microbial communities and activities within the rhizosphere in the light of climate change (Wu and Srivastava 2012). Such changes will adversely dictate on the orchard's productive life in long run. Gradual shift from purely IF to OM started gaining wide scale application for enhanced nutrient cycling (Srivastava *et al*. 2002).

Integrated nutrient management (INM) as a dynamic concept of nutrient management (Srivastava and Ngullie 2009) considers the economic yield in terms of fruit yield coupled with quality on one hand, and soil physico-chemical and microbial prospects on other hand as a marker of resistance against the nutrient mining (arises because of failure to strike a balance between annual nutrient demand and quantity of nutrients applied). Soils under citrus differ from other cultivated soils, with respect to fallow period of 3–6 months every year forcing depletion of soil organic matter in latter case (Bhargava 2002). In contrast, biological oxidation of existing carbon (C) continues in soil covered under citrus (Srivastava *et al.* 2002). Multiple nutrient deficiencies are considered to have a profound effect on potential source of atmospheric carbon dioxide (CO_2). Soil carbon stock is, hence, considered as an important criterion to determine the impact of INM in the longer version of impact assessment (He *et al.* 1997). The amount of accumulated C within the rhizosphere soil does not continue to increase with time with increasing C outputs. An understanding of the mechanism involved in C stabilization in soils is needed for controlling and enhancing soil C sequestration (Goh 2004) under different modes of nutrient management. with this background, studies were carried out with objectives, viz. of response of INM on canopy growth, fruit yield and quality indices;. soil carbon dynamics related fertility changes in response to INM, and INM-induced changes in plant nutrition (Srivastava *et al.* 2007a). These objectives are anticipated to collectively provide a strong database support for suitability of INM module versus sole application either inorganic fertilizers or green manure.An array of fruit crops have been reported to respond to the synergies originated through combination of organic nutrient-microbe-inorganics (Table 6). And such associations have invariably witnessed substantially higher productivity than any single component alone. However, there is a greater need to expand such plant response advantages using more rhizocompetent microbes preferably in consortium mode, plant response as well as soil health response both have to be sustained on a long term basis (Srivastava *et al.* 2003a, Srivastava and Singh 2002).

Our long term study entitled "Integrated nutrient management in relation of sustained quality production of Nagpur mandarin (*Citrus reticulata* Blanco)" was initiated in 2007 with a total of five treatments, viz. T_1, 100% RDF (600 g N – 200 g P – 300 g K - 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$ /tree/year); T_2, 75% RDF + 25% vermicompost; T_3, 75% RDF + 25% vermicompost + microbial consortium; T_4, 50% RDF + 50% vermicompost, and T_5, 50% RDF +

50% vermicompost + microbial consortium. The response of various treatments was evaluated in terms of growth parameters, fruit yield, fruit quality (including micronutrient composition of fruit juice), available pool of nutrients in soil, soil on a smectite rich black clay soil (Typic Ustochrept) carbon stock, soil microbial communities, leaf nutrient composition, CO_2 emission rate and spectral properties of soil.

Growth response

All the INM-based treatments displayed significant response on changes in canopy volume (Table 7). Maximum increase in canopy volume was observed with T_3 (18.67 m^3) followed by T_4 (17.16), T_5 (16.93 m^3), on part with T_2 (16.70 m^3) and T_1 (11.50 m^3). Incorporation of microbial consortium either with T_3 or with T_5 invariably induced higher canopy volume suggesting better response on canopy

Table 6 Different components of integrated nutrient management recommended for different fruit crops

Crop	Nutrient-microbe combination	Reference
Guava (*Psidium guajava* L.)	FYM 50 kg/plant – *Azotobacter* sp 50 g/plant - *Azospirillum* sp 50 g/plant – *Sesbania* sp as green manure	Ram and Rajput (2000)
Pomegranate (*Punica granatum* L.)	400 g N- 100 g P_2O_5 – 300 g K_2O/plant – FYM 20 kg/plant	Ghosh *et al*. (2012)
Papaya (*Caria papaya* L.)	Vermicompost 20 kg/plant – rhizosphere culture 50 g/plant - 150 N – 200 P_2O_5 – 200 K_2O g/plant (75% RDF)	Kirad *et al*. (2010)
Banana (*Musa acuminata* L.)	FYM 12 kg/plant – *Azospirillum* sp 50 g/plant - Phosphate Solubilising Bacteria 50 g/plant– *T. harzianum* 50 g/plant	Hazarika and Ansari (2010)
Banana	50% RDF- FYM 20 kg/plant – *Azotobacter* sp 50 g/plant – Phosphate solubilising bacteria 50 g/plant –VAM 250 g/plant	Patil and Shinde (2013)
Guava	488 g N – 244 g P_2O_5 - 281 g K_2O/plant – FYM 50 kg/plant – *Azotobacter* 250 g/plant – phosphate solubilising bacteria 25 g/plant	Barne *et al*. (2011)
Strawberry (*Fragaria ananassa* Duches)	75% N as RDF – 25% N as FYM – *Azotobacter* sp	Umer *et al*. (2009)
Pomegranate	300 g N/plant – neem cake 1 kg/plant	Ray *et al.* (2014)
Banana	100% RDF – 40% Wellgrow organic manure	Kuttimani *et al*. (2013)
Peach (*Prunus persica* (L.) Stokes)	75% RDF - 25% N equivalent FYM	Shah *et al*. (2014)
Lemon (*Citrus limon* (L.) Burm. f.)	N 525 g/plant – FYM 150 kg/plant – *Azotobacter* sp 18 g/plant	Khehra and Bal (2014)
Apricot (*Prunus armeniaca* (L.))	75% RDF – 25% FYM	Shah *et al*. (2014)
Papaya	50% RDF (100 N – 100 P_2O_5 – 125 K_2O g/plant)- *Azotobacter* sp 50 g/plant – Phosphate solubilising bacteria 2.5 g/m^2	Singh and Varu (2013)
Guava	50% RDF (250 g N – 100 g P_2O_5 - 250 K_2O g/plant) - FYM 25 kg/ plant – vermicompost 5 kg/plant	Dwivedi (2013)
Sapota (*Achras zapota* L.)	75% RDF + 25% RDF equivalent vermicompost	Hebbarai *et al.* (2006)
Mango (*Mangifera indica* L.)	500 g N - 250 g P_2O_5 – 250 K_2O g/plant – 50 kg FYM/plant – *Azospirillum* sp 250 g/plant	Singh and Banik (2011)
Mango	250 N – 425 P_2O_5 – 1000 K_2O – *Azospirillum* sp 250 g/plant – PSB – 250 g/plant – $ZnSO_4$ 100 g/plant – Borax 100 g/plant	Hasan *et al*. (2012)
Banana	100% RDF – FYM 10 kg/plant – *Azospirillum* sp 25 g/plant-Phosphate solubilising bacteria 250 g/plant	Bhalerao *et al*. (2009)
Guava	236 g N – 66 g P_2O_5 – *Azospirillum* sp 30 g/plant – VAM 30 g/plant	Dutta *et al*. (2009)
Mosambi (*Citrus sinensis* Osbeck)	300 g N – 250 g P_2O_5 – 300 g K_2O – AMF 10 g/plant – *Azospirillum* sp 25 g/plant	Patel *et al*. (2009)
Guava	250 g N – 100 g P – 250 g K_2O/plant – *Azotobacter sp* 250 g/plant	Shukla *et al.* (2009)
Litchi (*Litchi chinensis* Sonn.)	500 g N – 250 g P_2O_5 – 500 g K_2O /plant – FYM 50 kg/plant – *Azotobacter* sp 150 g/plant – VAM 100 g/plant	Dutta *et al*. (2010)
Aonla (*Emblica officinalis* Gaertn.)	50% NPKS (105 kg N – 7.20 kg P_2O_5 – 125.25 kg K_2O/ha) – Biofertilizers (*Azotobacter* sp – *Azospirillum* sp – Phosphate solubilising bacteria) – FYM (2 t/ha)	Yadav *et al.* (2007)
Aonla	100 g N – 25 g P_2O_5 – 150 g K_2O/plant – FYM 10 kg/plant – Phosphate solubilising bacteria 50 g/plant	Mandal *et al*. (2013)
Sapota	1500 g N – 1000 P_2O_5 – 500 g K_2O/plant – 75 kg FYM – 12.5 g/ plant PSB	Dalal *et al*. (2004)
Guava	50% RDF (225 g N – 195 g P_2O_5 – 150 g K_2O/plant)- FYM 50 kg/ plant – *Azospirillum* 250 g/plant	Goswami *et al*. (2012).

volume with either T_3 or T_5 which were better than either T_2 or T_4 compared to T_1 which comprised only inorganic fertilizers.

Fruit yield response

Fruit yield was observed to be significantly affected by different INM-based treatments (Table 8). However, these responses were of variable magnitude. The maximum fruit yield of 88.8 kg/tree was observed with treatment T_5 which was better than 83.2 kg/tree with T_4 or 80.5 kg/tree with T_3 than 71.0 kg/tree with treatment T_2. However, all these treatments were far superior in magnitude of response when compared with 100% RDF as T_1 (67.7 kg/tree). Hence, different INM-based treatments (71.0-88.8 kg/tree) were much better than exclusive inorganic fertilizer treatment like T_1 (67.7 kg/tree).

Fruit quality response

Different fruit quality parameters, except peel thickness (Table 8) displayed significant response in relation to different treatments. There was much high fruit weight with different INM-based treatments T_2-T_5 (104.1-114.6 g) compared to inorganic RDF treatment T_1 (101.4), showing that incorporation of both organic manure as well as microbial cultures improved the efficiency of organic fertilizers. Similar observations were obtained with respect to other three fruit quality related parameters such as juice content, acidity and TSS. In treatments which involved microbial consortium alongside inorganic fertilizers plus vermicompost, e.g. T_3 (41.5% and 9.5%) and T_5 (44.2% and 9.3%), both juice content as well as TSS were significantly higher than T_2 (39.6% and 8.6%) and T_4 (42.7% and 8.4%), all of them were better than T_1 (40.2% and 8.4%). On the other hand, acidity observed a significant reduction with those superior treatment, e.g. T_3 (0.86%) and T_5 (0.80%) compared to T_2 (0.93%) and T_4 (0.91%) highlighting the favorable changes in different fruit quality changes in response to different INM-based treatments.

Response on soil fertility changes

Changes in soil fertility indices with regard to available macro- as well as micronutrients were observed highly significant, but of variable nature in response to different treatments (Table 9). Amongst macronutrients, $KMnO_4$-N

Table 7 Growth attributing parameters in response to different vermicompost-based INM treatments (Pooled data 2007-16)

Treatment	Plant height (m)	Tree spread (m)		Canopy volume (m^3)	Cumulative increase in canopy volume over 2007-08 (m^3)
		E-W	N-S		
T_1 - 100% RDF	3.82 (2.02)	2.52 (1.27)	2.50 (1.20)	13.04 (1.54)	11.50
T_2 - 75% RDF + 25% Vm	5.09 (2.10)	2.98 (1.39)	2.89 (1.25)	18.51 (1.81)	16.70
T_3 - 75% RDF + 25% Vm + MC	3.87 (2.13)	3.00 (1.27)	3.22 (1.23)	20.28 (1.61)	18.67
T_4 - 50% RDF + 50% Vm	3.76 (2.10)	3.73 (1.30)	2.93 (1.30)	19.78 (1.62)	17.16
T_5 - 50% RDF + 50% Vm + MC	3.86 (1.87)	2.97 (1.18)	2.96 (1.22)	18.33 (1.40)	16.93
CD (P=0.05)	0.49	0.38	0.51	1.18	0.80

RDF stands for recommended doses of fertilizer (600 g N – 200 g P – 300 g K – 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$/tree/year). Vm stands for vermicompost (Nutrient composition: 2.38% N, 0.09% P, 1.42% K, 1072 ppm Fe, 116 ppm Mn, 39 ppm Cu and 46 ppm Zn). MC stands for microbial consortium developed by isolating the native microbes (mixture of *Bacillus pseudomycoides, Acinetobacter radioresistens, Micrococcus yunnanensis, Paenibacillus alvei* and *Aspergillus flavus*). Figures in parenthesis indicates the value obtained in 2007-2008. *Source*: Srivastava *et al* (2015b).

Table 8 Fruit yield and quality parameter in response to different vermicompost based INM-treatments (Pooled data 2007-16)

Treatment	Yield (kg/tree)	Fruit weight (g/fruit)	Peel thickness (mm)	Fruit quality parameters			
				Juice content (%)	TSS (^{0}Brix)	Acidity (%)	TSS/Acid
T_1 - 100% RDF	67.7	101.4	4.1	40.2	8.4	0.96	8.92
T_2 - 75% RDF + 25% Vm	71.0	104.1	3.0	39.6	8.6	0.93	9.23
T_3 - 75% RDF + 25% Vm + MC	80.5	106.2	3.4	41.5	9.5	0.86	10.05
T_4 - 50% RDF + 50% Vm	83.2	109.1	3.4	42.7	8.4	0.91	9.56
T_5 - 50% RDF + 50% Vm + MC	88.8	114.6	3.0	44.2	9.3	0.80	11.62
CD (P=0.05)	2.1	1.4	NS	1.1	0.20	NS	

RDF stands for recommended doses of fertilizer (600 g N – 200 g P – 300 g K - 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$/tree/year). Vm stands for vermicompost (Nutrient composition: 2.38% N, 0.09% P, 1.42% K, 1072 ppm Fe, 116 ppm Mn, 39 ppm Cu and 46 ppm Zn). MC stands for microbial consortium developed by isolating the native microbes (mixture of *Bacillus pseudomycoides* (MF113272), *Acinetobacter radioresistens* (MF113273), *Micrococcus yunnanensis* (MF113274), *Paenibacillus alvei* (MF113275) and *Aspergillus flavus* (MF113270) *Source*: Srivastava and Malhotra (2014), Srivastava *et al.* (2015b).

and Olsen-P showed significant responses, without any significant response on NH_4OAc-K. The treatments such as T_3 (155.7 and 203.6 mg/kg $KMnO_4$-N and Olsen-P, respectively) and T_5 (178.5 and 212.6 mg/kg $KMnO_4$-N and Olsen-P, respectively) were comparatively higher than T_2 (193.5 and 196.6 mg/kg $KMnO_4$-N and Olsen-P, respectively) and T_4 (161.0 and 209.2 mg/kg $KMnO_4$-N and NH_4OAc-K, respectively). These observations suggested that superiority of INM-based treatments than those treatments without microbial consortium.

Amongst all the four micronutrients, except DTPA-Cu other DTPA extractable micronutrients such as DTPA-Fe, DTPA-Mn and DTPA-Zn showed significant response, vis-a-vis different INM-based treatments (Table 9). The treatment like T_1 involving exclusive inorganic fertilizers (10.35 mg/kg DTPA-Fe, 10.54 mg/kg DTPA-Mn and 0.98 mg/kg DTPA-Zn), registered lowest test values as against treatment like T_5 (19.50 mg/kg DTPA-Fe, 12.93 mg/kg DTPA-Mn and 1.32 mg/kg DTPA-Zn) registering maximum values, validating the supremacy of those treatments which carry all the three components of INM.

Changes in soil carbon fractions and soil C:N ratio

The soil properties such as soil pH and soil EC were not affected by any of the INM-based treatments (Table 10). While, amongst different fractions of soil carbon, viz. organic-C (SOC), inorganic-C (SiC) and total-C (TC) only SOC and TC were significantly affected. These observations showed that changes in soil carbon stock are more governed by organic fraction than inorganic fraction. Maximum SOC and TC of 7.43 g/kg and 9.14 g/kg were observed with T_5. Likewise, treatment T_3 (7.02 mg/kg and 8.76 mg/kg) registered much SOC and TOC than T_2(6.70 mg/kg and 8.4 g/kg), displaying the significant role of microbial consortium in improving the carbon sink capacity of soil. Different INM-based treatments were also observed to aid in improving the total soil N stock, being maximum with treatment like T_3-T_5 (0.741-0.748%) compared to rest of the treatments like T_1, T_2 or T_4 (0.721-0.738%). However, soil C:N ratio in the range of 12.00-12.32, without displaying significant changes in response to different treatments. While minimum SOC of 6.61 g/kg was observed with treatment T_1. Incorporation of microbial consortium in treatments like T_3 or T_5 invariably helped in improving SOC of soil compared to other treatments like T_2 or T_4 without the microbial consortium.

Changes in soil microbial population

Changes in soil microbial population (Bacterial count, *Bacillus* count, iron bacteria and fungal count) were observed to be significantly affected by different INM-based treatments. Soil bacterial count of 86 × 10^3 cfu/g soil was observed with treatment T_5 which was significantly higher than bacterial count of 44 × 10^3 cfu/g soil with treatment T_4. Similar treatment T_3 (54 × 10^3 cfu/g soil) registered significantly higher bacterial count than treatment T_2 (36 × 10^3 cfu/g), suggesting role of microbial consortium in improving the soil health. Treatment T_1 carrying inorganic fertilizers, however, recorded minimum bacterial count (28 × 10^3 cfu/g). On the other hand, *Bacillus* count and iron bacteria were also followed the similar pattern of response, being maximum with T_5 (48 × 10^3 cfu/g soil *Bacillus* count and 27 × 10^3 cfu/g soil iron bacteria) and minimum with T_1 (26 × 10^3 cfu/g soil *Bacillus* count and 05 × 10^3 cfu/g soil iron bacteria). Likewise, treatment T_3 showed significantly higher count on *Bacillus* and iron bacteria compared to treatment T_2 carrying no microbial consortium.

These treatments also influenced the fungal count of the soil to varying proportions (Table 11). Treatment T_1 showed lowest fungal count (12 × 10^3 cfu/g soil) carrying inorganic fertilizers. On the other hand, treatment T_5 carrying microbial consortium registered highest fungal count of 42 × 10^3 cfu/g soil being significantly superior over fungal count of 26 × 10^3 cfu/g soil treatment T_4. Likewise, treatment T_3 registering fungal count of 22 × 10^3 cfu/g soil was superior over fungal count of 18 × 10^3 cfu/g soil with treatment T_2, suggesting the significant role played by microbial consortium in improving the efficacy

Table 9 Changes in soil fertility status in response to different INM-based treatments (Pooled data 2007-16)

Treatment	Available nutrients (mg/kg)						
	Macronutrients			DTPA-Micronutrients			
	$KMnO_4$-N	Olsen-P	NH_4OAc-K	Fe	Mn	Cu	Zn
T_1 - 100% RDF	140.0	9.32	185.2	10.35	10.54	2.2	0.98
T_2 - 75% RDF + 25% Vm	1435	9.27	196.6	12.57	11.54	2.3	1.00
T_3 - 75% RDF + 25% Vm + MC	155.7	9.15	203.6	15.18	12.45	2.7	1.10
T_4 - 50% RDF + 50% Vm	161.0	9.57	209.2	16.56	11.67	2.8	1.18
T_5 - 50% RDF + 50% Vm + MC	178.5	9.55	212.6	19.50	12.93	2.5	1.32
CD (P=0.05)	2.2	NS	1.3	1.32	1.01	NS	0.9

RDF stands for recommended doses of fertilizer (600 g N – 200 g P – 300 g K – 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$/tree/year). Vm stands for vermicompost (Nutrient composition: 2.38% N, 0.09% P, 1.42% K, 1072 ppm Fe, 116 ppm Mn, 39 ppm Cu and 46 ppm Zn). MC stands for microbial consortium developed by isolating the native microbes (mixture of *Bacillus seudomycoides* (MF113272), *Acinetobacter radioresistens* (MF113273), *Micrococcus yunnanensis* (MF113274), *Paenibacillus alvei* (MF113275) and *Aspergillus flavus* (MF113270). Source: Srivastava (2010a), Srivastava *et al.* (2015b).

Table 10 Soil carbon fractions and C:N ratio in response to different vermicompost-based INM treatments (Pooled data 2007-16)

Treatment	pH	EC (dS/m)	Soil carbon (g/kg) SOC	SiC	TC	Soil total N (g/kg)	Soil C:N ratio
T_1 -100% RDF	7.7	0.168	6.61	1.71	8.32	0.721	11.54
T_2 - 75% RDF + 25% Vm	7.8	0.174	6.70	1.71	8.41	0.732	11.48
T_3- 75% RDF + 25% Vm + MC	7.7	0.163	7.02	1.74	8.76	0.741	11.82
T_4 - 50% RDF + 50% Vm	7.6	0.173	7.11	1.75	8.86	0.738	12.00
T_5 - 50% RDF + 50% Vm + MC	7.8	0.174	7.43	1.81	9.24	0.748	12.32
CD (P=0.05)	NS	NS	0.08	NS	0.09	0.006	NS

RDF stands for recommended doses of fertilizer (600 g N – 200 g P – 300 g K - 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$/tree/year). Vm stands for vermicompost (Nutrient composition: 2.38% N, 0.09% P, 1.42% K, 1072 ppm Fe, 116 ppm Mn, 39 ppm Cu and 46 ppm Zn). MC stands for microbial consortium developed by isolating the native microbes (mixture of *Bacillus pseudomycoides* (MF113272), *Acinetobacter radioresistens* (MF113273), *Micrococcus yunnanensis* (MF113274), *Paenibacillus alvei* (MF113275) and *Aspergillus flavus* (MF113270)). SOC, SiC and TC stand for soil organic carbon, soil inorganic carbon and total carbon, respectively. *Source*: (Unpublished, A K Srivastava).

of combination of vermicompost and inorganic fertilizers in varying combinations.

Leaf nutrient composition

The nutrient composition of index leaves in terms of both macronutrients as well as micronutrients was significantly affected by different INM-based treatments (Table 12). Leaf N, P and K concentrations were highest with treatment T_5 (2.49% N, 0.157% P and 1.40% K) better than either T_4 (2.39% N, 0.136% P and 1.24% K) or T_3 (2.42% N, 0.139% P and 1.32% K). While treatment T_1 registered the lowest nutrient concentration of 2.21% N, 0.16% P and 0.196% K, far inferior to rest of the other treatments. Concentration of micronutrients in index leaves except Cu showed responses of varying proportions. The treatment T_5 by far proved to be the most effective treatment (124.4 ppm Fe, 82.4 ppm Mn and 25.1 ppm Zn) which was superior to either T_4 (110.6 ppm Fe, 76.6 ppm Mn and 22.8 ppm Zn) or T_3 (102.0 ppm Fe, 73.9 ppm Mn and 23.3 ppm Zn), showing the better effectiveness of those treatments carrying microbial consortium compared to those one without microbial consortium. On the other hand, treatments carrying inorganic fertilizers like T_1 registered the lowest concentration of leaf Fe (97.9 ppm), Mn (67.3 ppm) and Zn (20.0 ppm). These observations suggested that the efficacy of same inorganic fertilizers was improved when combined with vermicompost and microbial consortium.

Changes in rhizosphere CO_2 emission

All the INM-based treatments influenced the CO_2 emission to varying proportions across various seasons in a year (Table 13). The appraisal on CO_2 emission rate in response to differential treatments showed comparatively higher CO_2 emission in the morning was observed over evening time, irrespective of the season. While, much higher CO_2 emission was observed during summer season (3127.2-4530.6 mg C/m^2 hr^1) compared to either rainy season (1858.9-2371.4 mg C/m/hr) or winter season (1212.1-2052.9 mg C/m/hr) with treatment T_1 involving exclusive use of inorganic fertilizers.With replacement of 25% of RDF with vermicompost (T_2), CO_2 emission rate was slowed down to 1297.0 – 1959.7 mg C/m/hr, 1381.7-2075.8 mg C/m/hr and 746.3-1189.8 mg C/m/hr during summer, rainy and winter season, respectively, irrespective of time of sampling. Incorporation of microbial brought down the CO_2 emission rate to 980.5-1030.6 mg C/m/hr, 408.6-528.8 mg C/m/hr and 988.3-1061.6 mg C/m/hr, respectively during summer, rainy and winter season, respectively, irrespective of time of

Table 11 Changes in soil microbial count (× 10^3 cfu/g) in response to different INM-based treatments

Treatment	Bacterial count	Bacillus count	Iron bacteria	Fungal count
T_1 - 100% RDF	28	26	05	12
T_2 - 75% RDF + 25% Vm	36	24	17	18
T_3 - 75% RDF + 25% Vm + MC	54	32	23	22
T_4 50% RDF + 50% Vm	44	38	25	26
T_5 50% RDF + 50% Vm+ MC	86	48	27	42
CD (P=0.05)	4.2	1.8	2.8	3.2

RDF stands for recommended doses of fertilizer (600 g N – 200 g P – 300 g K – 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$/tree/year). Vm stands for vermicompost (Nutrient composition: 2.38% N, 0.09% P, 1.42% K, 1072 ppm Fe, 116 ppm Mn, 39 ppm Cu and 46 ppm Zn). MC stands for microbial consortium developed by isolating the native microbes (mixture of *Bacillus pseudomycoides* (MF113272), *Acinetobacter radioresistens* (MF113273), *Micrococcus yunnanensis* (MF113274), *Paenibacillus alvei* (MF113275) and *Aspergillus flavus* (MF113270)). BC and FC stand for bacterial count and fungal count, respectively. *Source*: (Unpublished A K Srivastava).

Table 12 Response of different vermicompost-based INM treatments on the leaf nutrient composition (Pooled data 2007-16)

Treatment	Macronutrients (%)			Micronutrients (ppm)			
	N	P	K	Fe	Mn	Cu	Zn
T_1 - 100% RDF	2.21	0.116	0.96	97.9	67.4	12.2	20.0
T_2 - 75% RDF + 25% Vm	2.33	0.124	1.12	102.3	71.9	12.9	21.3
T_3 - 75% RDF + 25% Vm + MC	2.42	0.139	1.32	102.0	73.9	13.1	23.3
T_4 - 50% RDF + 50% Vm	2.39	0.136	1.24	110.6	76.6	12.8	22.8
T_5 - 50% RDF + 50% Vm+ MC	2.49	0.157	1.40	124.4	82.4	13.3	25.1
CD (P=0.05)	0.07	0.11	0.11	3.1	2.4	NS	0.82

RDF stands for recommended doses of fertilizer (600 g N – 200 g P – 300 g K – 200 g $ZnSO_4$ – 200 g $FeSO_4$ – 200 g $MnSO_4$ tree/ year). Vm stands for vermicompost (Nutrient composition: 2.38% N, 0.09% P, 1.42% K, 1072 ppm Fe, 116 ppm Mn, 39 ppm Cu and 46 ppm Zn). MC stands for microbial consortium developed by isolating the native microbes (mixture of *Bacillus pseudomycoides* (MF113272), *Acinetobacter radioresistens* (MF113273), *Micrococcus yunnanensis* (MF113274), *Paenibacillus alvei* (MF113275) and *Aspergillus flavus* (MF113270)). *Source*: Srivastava *et al.* (2015b).

sampling. Combined use of 50% RDF + 50% vermicompost + microbial consortium (T_5) further brought down the CO_2 emission rate to 724.6-938.2 mg C/m/hr, 685.5-864.9 mg C/m/hr and 697.2-1007.1 mg C/m/hr, respectively during summer, rainy and winter season, respectively of time of sampling. On the other hand, treatment T_4 involving 50% RDF + 50% vermicompost showed comparatively higher CO_2 emission, 2205.0-2635.0 mg C/m/hr, 1108.4-1670.0 mg C/m/hr, and 831.3-1402.7 mg C/m/hr during summer, rainy and winter season, respectively. These observations showed better carbon accredition with those treatments having all the three components of INM.

Spectral behaviour of soil

The spectral properties of the soil were evaluated in response to different treatments (Fig 1). Although, pattern spectral response is same, but seggregation of various wavelength peaks seemed some marginal improvements in spectral properties of soil. These observations highlight the soils treated with INM-based treatments in improving the liveliness of the soil.

Stagewise nutrient dynamics

The changes in concentration of crunch nutrients like N, K, and Zn were started across crop critical growth stages in response to different treatments (Fig 2). Leaf nitrogen concentration was observed maximum as 1.01% at stage I, 1.56% at stage II, 1.61% at stage III, 2.30% at stage IV, 2.38% at stage V and 2.20% at stage VI, which significantly superior to T_4 (0.98% at stage I,1.16% at stage II,1.40% stage III,1.61% at stage IV, 2.18% at stage V and 1.98% at stage VI),T_3 (0.94% at stage I,1.06% at stage II, 1.28% at stage III, 1.38% at stage IV, 2.01% at stage V and 1.90% at stage VI), T_2 (0.92% at stage I, 1.16% at stage II, 1.20% at stage III, 1.28% at stage IV, 1.90% at stage V and 1.80% at stage VI) and T_1 (0.87% at stage I, 1.10% at stage II, 1.18% at stage III, 1.20% at stage IV, 1.70% at stage V and 1.58% at stage VI) in decreasing order of their effectiveness. The treatment T_5 maintained significantly maximum concentration of N at all the critical growth stages compared to rest of the treatments, especially by stage III onwards. This is the reason; fruit yield and quality were maximum with treatment T_5 (Fig 2).

The potassium concentration in index leaves varied from 0.38 to 0.70% with T_1, 0.40 to 0.78% with T_2, 0.42 to 0.81% with T_3, 0.48 to 1.040% with T_4 and 0.52 to 1.43% with T_5, considering all the six growth stages of sampling. Interestingly, the concentration K peaked during stages V only in all the treatments, with T_5 displaying maximum value of 1.43% followed by 1.04% with T_4, 0.81% with T_3, 0.78% with T_2 and 0.70% with T_1.However, treatments T_1-T_3 remained almost unchanged. It is more interesting to

Table 13 Response of different INM-based treatments on CO_2 emission rate (mg C/m/hr) (Pooled data 2007-16)

Treatment	Summer season (June)		Rainy season (september)		Winter season (February)	
	Morning (11.00 AM)	Evening (4.00 PM)	Morning (11.00 AM)	Evening (4.00 PM)	Morning (11.00 AM)	Evening (4.00 PM)
T_1	4530.6	2127.2	2371.4	1858.9	2052.9	1212.1
T_2	1297.0	959.7	2075.8	381.7	1189.9	746.3
T_3	1003.6	980.5	528.9	408.6	1061.6	988.3
T_4	2635.0	2205.0	1670.0	1108.4	1402.7	831.3
T_5	938.2	724.6	864.9	685.5	1007.1	697.2

T_1, 100% RDF; T_2, 75% RDF + 25% Vermicompost; T_3, 75% RDF + 25% Vermicompost + Microbial Consortium; T_4, 50% RDF + 50% Vermicompost; and T_5, 50% RDF + 50% Vermicompost + Microbial Consortium. *Source*: (Unpublished A K Srivastava).

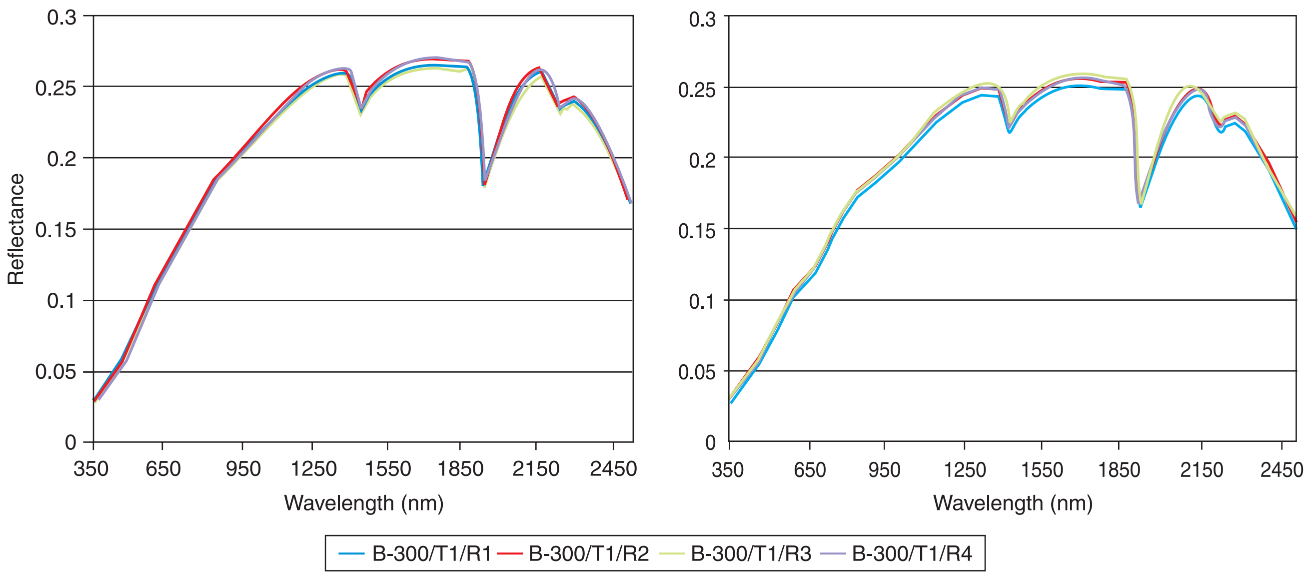

Fig 1 Comparision of spectral behaviour of soil treatment with 100% RDF (Recommended doses of fertilizer) and 75% RDF + 25% Vermicompost + MC under different replications (*Source*: Unpublished AK Srivastava).

observe at stage VI, treatment T_5 maintained the maximum K concentration 1.32%, 0.92%, 0.82%, 0.74% and 0.61%, respectively, with treatments T_5, T_4, T_3, T_2 and T_1. The treatment T_5 maintained almost optimum K-concentration from 0.68% at stage II to as high as 1.43% at stage V and 1.32% at stage VI, significantly superior to any of the other treatments including T_4. These observations suggested that a treatment is effective by a fair margin, maintains significantly higher concentration right from stages II and continues till stage V. And with still higher concentration to be effectively utilized in next crop as a carry forward stock of nutrient, popularly called residual K.

Like other two nutrient (N and K), dynamics of Zn was also observed to follow the same physiological pattern of accumulation at various crop phenophases (Fig 2). Treatment T_5 registered the maximum Zn at all the critical growth stages (19.6 ppm at stage I, 20.9 ppm at stage II, 22.8 ppm at stage III, 24.5 ppm at stage IV, 26.2 ppm at stage V and 24.3 ppm at stage VI), significantly superior to either treatment T_4 with microbial consortium (19.4 ppm at stage I, 21.2 ppm at stage II, 21.8 ppm at stage III, 22.4 ppm at stage IV, 23.8 ppm at stage V and 22.1 ppm at stage VI) or treatment T_1 using only inorganic fertilizers (16.4 ppm at stages I, 17.2 ppm at stage II, 17.8 ppm at stage III, 18.9 ppm at stage IV, 20.0 ppm at stage V and 19.6 ppm at stage VI).These observations suggested that better nutrient dynamics is maintained across all critical growth stages by mobilising the both the nutrient fractions, applied nutrients as well as the native source of nutrients. And this is the reason for better effectiveness of treatments, comparatively higher nutrient concentration is maintained across all important growth stages, since our earlier findings advocated, it is not

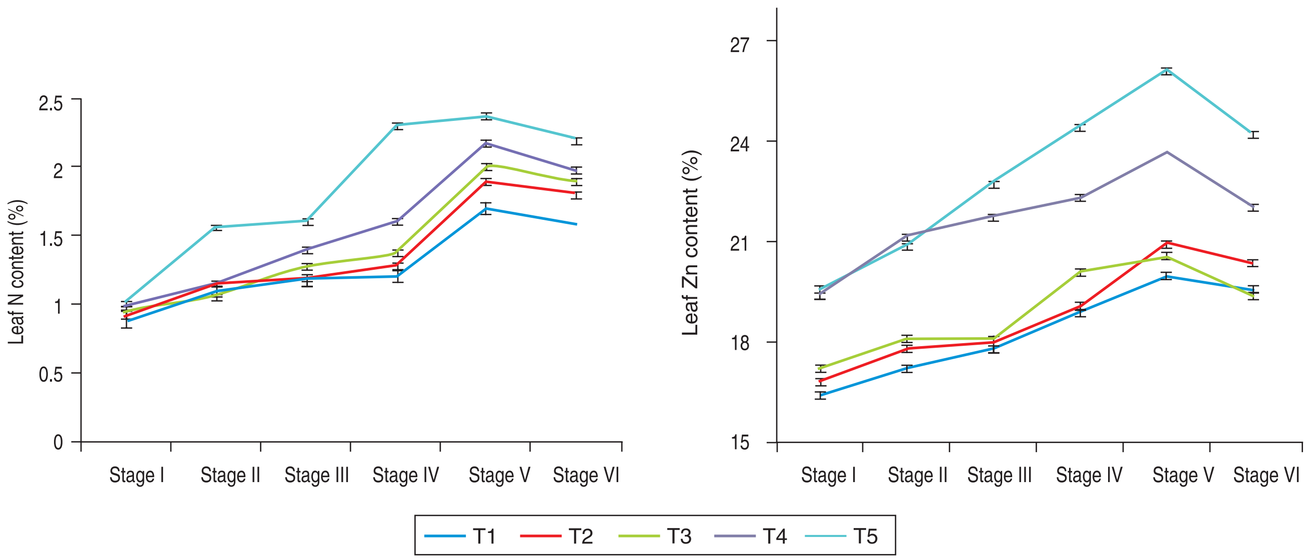

Fig 2 Response of different treatments on the N and Zn accumulation across critical growth stages of Nagpur mandarin. *Source*: Srivastava *et al*. (2012).

Table 14 Changes in fruit yield and soil fertility status at Selu, Kalmeshwar and Khapa Saoner (Pooled data 2015-17)

Treatment	Fruit yield (kg/tree)	pH (1:2)	EC (dS/m)	Available nutrients (mg/kg)					
				Macronutrients		DTPA-Micronutrients			
				$KMnO_4$-N	NH_4OAc-K	Fe	Mn	Cu	Zn
Selu, Kalmeshwar									
INM-treated	67.2	7.8	0.16	126.1	171.8	14.2	10.1	1.11	0.86
Control	51.8	7.6	0.18	120.8	161.2	10.8	0.1	1.18	0.76
t (*P=0.05*)	6.1	NS	NS	2.3	1.8	1.2	1.1	NS	0.05
Khapa, Saoner									
INM-treated	71.1	7.4	0.28	131.2	148.3	16.3	11.2	0.71	0.98
Control	61.3	7.6	0.21	121.1	136.1	13.1	9.2	0.89	0.84
t (P=0.05)	4.3	NS	NS	3.1	4.1	1.1	1.4	NS	0.06

Control means farmers package of practices. Source: (Unpublished AK Srivastava).

possible to forego the nutrient application at any growth stage considered critical to that crop (Srivastava and Singh 2007).

Demonstration trials on INM

Two demonstration trials using best INM module (50% RDF + 50% RDF equivalent vermicompost + microbial consortium) were carried out at two locations, viz. Selu, Kalmeshwar and Khapa, Saoner. Data presented amply suggest that the INM package has shown far better responses over farmers practices.

Future research

Despite many cutting edge technologies addressing a variety of core issues of nutrient management, many more issues are yet to be attempted with respect to INM-based citrus production *vis-à-vis* rhizosphere dynamics. Studies on biochemical response in relation to varying nutrient supply systems (through INM modules) especially under agropedological conditions facing multi-nutrient deficiencies and establishing the causal relationship between the physico-chemcial and microbiolgical changes within rhizosphere and to be able to coordinate changes in shoot system (changes in canopy size and fruit yield, i.e yield efficiency), are very much imperative that are seemingly most sensitive to various combinations of remediative treatment.

Nutrient dynamics is another virgin area where limited attempts have been made using citrus as test crop. Amongst different nutrients, Zn has attracted worldwide investigation from various angles (Srivastava and Singh 2009a). The changes in rhizosphere bring different simultaneous changes in microbial diversity *vis-a-vis* C_{mic}, N_{mic}, P_{mic} and nutrient regime especially for diffusion limited nutrients like P, Zn, Fe, Mn, etc. has to find serious considerations in any nutrient management program that involves INM-based corrective treatments (Srivastava *et al.* 2007a). Additionally, the conditions under which citrus trees are most likely to respond to corrective Zn-treatments are still not fully understood. The role of Zn in flowering, fruit set, fruit quality (external and internal) and juice shelf life; models defining the critical periods of Zn-supply to assure sustained response and its uptake for helping the management decision under different citrus-based cropping systems; and devising means for improved Zn-uptake efficiency need to be attempted to unravel many of the complexities involved with Zn-nutrition under INM-based production management (Srivastava *et al.* 2006a).

Out of different soil properties, the microbial biomass is the one biological property of soil that undergoes immediate change in response to fertilizer like input (Srivastava and Singh 2008b). Studies, therefore, need to be undertaken with a view to explore the possibility whether microbial properties could be used as a potential tool for finding out soil fertility constraint instead of available supply of nutrients in soil. Simultaneously, an eye should be kept on long term changes in total carbon pool of soil to arrive at the logistic conclusion that sequestration of carbon through improved production level could rejuvenate the lost productivity potential of nutritionally depleted soil (Srivastava and Singh 2015). However, it remains to be further established that any change in microbial diversity within the rhizosphere is brought about with different sources of substrate, and if there is any, how the nutrient dynamics is associated with orchard productivity.

Impacts due to environmental changes and anthropogenic activity are the potential threats to the conservation of soil quality, while expanding citriculture to marginal soils having a wide range of limitations. With the availability of more technical know-how on efficient use of bulky organic manures, prolonged shelf life of microbial bio-fertilizers, and better understanding on citrus - mycorrhiza symbiosis with regard to nutrient acquisition and regulating the water relations, a more effective integrated citrus production system could be evolved in future. The molecular approach to breeding of mineral deficiency resistance and mineral efficiency would facilitate to produce nutritionally efficient biotypes in order to maximise the quality production on sustained basis. Fertilizer applications are currently managed to protect environmentally sensitive areas by using controlled release fertilizers (use of organic manures, a befitting option), frequent low concentration fertigation, multiple applications, and variable rate application technology in order to improve fertilizer use efficiency. However, using newly emerging techniques of nutrient management and site specific management on the principles of INM could be worked out accommodating soil's nature and properties. Simultaneously, concerted efforts would be required to develop INM-based yield monitors and soil quality indicators in order to develop a comprehensive system, whereby the concept of soil security could be effectively brought into a reality with an emphasis on development of minimum data set to define Soil Health Card for different commercial citrus cultivars grown in India.

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