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Asian Citrus: A Meta-Analysis on Soil Fertility and Plant Nutrition Constraints

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ABSTRACT

Citrus is one of the most researched fruit crops (grown in 153 countries) and known for creating a niche for international trade and tariff. Asian citrus (occupying an area of 5.33 million ha with a production of 80.0 million tons) has paved the way to proliferation of citrus in those parts of the world, presently known as globally leading citrus producers. Predominantly citrus being grown on acidic soils under tropical/subtropical climate, faces multiple nutrient deficiencies (phosphorous, calcium, magnesium, zinc, boron, molybdenum) cutting down the crop carrying capacity of citrus orchards. The coarse texture (sandy loam /loamy sand) of soils coupled high nutrient and water percolation rate and dominance of exchangeable aluminum, collectively account for depleted water-and nutrient-use-efficiency. While, citrus orchards established on alkaline and calcareous soils (clay/clay loam/sandy clay loam) pose altogether a different set of soil fertility constraints, namely clogging of subsurface due to colloidal nature of calcium carbonate particles hampering water and nutrient movements, besides acute shortage of nitrogen, phosphorous, potassium, iron, manganese, zinc and boron deficiencies. There is absolutely no soil health card available for monitoring soil health on a long term basis for any of the commercially grown citrus cultivars, resultantly nutrient mining linked decline in citrus productivity is more or less a common feature in Asian citrus. These soil fertility constraints warrant different management strategies, which comprise of crop phenology based fertigation , integrated nutrient management (utilizing nutrient release kinetics of organic manures, biofertilizers and inorganic fertilizers on a limited scale) and exclusive use of bio-inoculants in form of microbial concoction (called microbial consortium) exploiting the native and natural microbial synergisms (with twin role as growth promoter and antagonistic to soil borne pathogens), all slated to address multiple soil fertility constraints occurring within the citrus rhizosphere. Such rhizosphere specific consortia (often called as phytomicrobiome) in combination with 4R principles of nutrient stewardship could further pave the way to balanced citrus nutrition program for citrus orchards in Asia.

Keywords: Asian citrus, nutrient mining, soil fertility constraints, soil health card, microbial inoculants. Constraints

A statistical analysis

The enormity of significance of citrus can be easily gauzed, considering citrus as one of the most popular fruit commodities as the worlds 210th most traded product with total trade of 16.3 billion US dollars (trade of 3.6 billion US dollars through Asian citrus industry). The total grower's value of citrus fruits stretches over 1090 billion US dollars with fruit processing and fresh consumption valued at 986 and 103 million US dollars, respectively. World citrus (production of 158.9 million tons from an area of 10.17 million ha with a productivity of 15.7 tons/ha) has always been dominated by the richness and diversity of Asian citrus (production of 80.0 million tons from an area of 5.33 million ha with a productivity of 14.8 tons/ha), with nearly 50% share emerging through Asian citrus industry (FAO Stat, 2022). Production analysis Citrus on inter-continental basis further strengthens these facts in million tons (80 .0 by Asia followed by 27.7 by South America, 15.6 by Africa, 15.0 by North America, 10.5 by Europe, 9.7 by Central America in decreasing order) about another glittering hallmark feature of loose- skinned mandarins- dominated citrus industry of Asia (NHB Stat , 2022).

Comparing world (predominantly sweet orange-based industry, as many 153 countries engaged in growing citrus) citrus vis-à-vis Asian citrus (predominantly mandarins/tangerines-based industry as many 30 countries engaged in citrus growing) put forth hardly any significant difference between average citrus productivity, another very interesting feature of Asian citrus competing so close with global industry. On the other hand, with Asia, major citrus producers are China (44.1 million tons from 2.97 million ha area with a productivity of 14.8 tons/ha), India

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(14.1 million tons from 1.12 million ha area with a productivity of 14.1 tons/ha), Turkey (4.34 million tons from 0.16 million ha area with a productivity of 27.5 tons/ha), Iran (4.0 million tons from 0.14 million ha area with a productivity of 29.4 tons/ha). On export front, Asian citrus is involved with meager 3.5 million tons of annual export (2.1 million tons as mandarins/tangerines as major share coming from Turkey with 1.5 million tons followed by 0.77 million ton by China and 0.44 million ton by Pakistan), which account to just 5% of Asian citrus basket, suggesting preference of Asian consumers towards fresh fruits rather than processed or value added products. Likewise, import figures of 4.2 million tons by Asian countries, where countries like Saudi Arabia (0.60 million ton), China (0.55 million ton), Pakistan, United Arab Emirates (0.43 million ton), Hong Kong (0.41 million ton) are major players of citrus imports in Asia compared to global imports scenario (FAO, 2022).

Upfront Indian citrus industry in relation to world citrus as globally third most important citrus growing country, sharing a contribution of 8.9% and 10.1% in terms of area and production, respectively. While, the south Asian countries (including India, Pakistan, Bangladesh, Nepal, Bhutan and Sri Lanka) produce 16.90 million tons of citrus fruits from an area of 1.62 million ha coupled with abysmally low productivity of 7.9 tons/ha (major cause of concern as well), thus, contributing to 10.5% and 10.6 %, respectively, out of world citrus production, distinctively signify the astounding role of south Asian citrus vis-à-vis either Asian citrus (amidst 30 countries) or world citrus (amidst 153 citrus growing countries). Incidently, Asian countries like China (44.1 million tons), India (14.1 million tons), Turkey (4.34 million tons), Iran (4.0 million tons), Pakistan (2.29 million tons) figure so prominently towards global basket of citrus with Indian citrus perched at second spot after China has always posed a choicest export destination by most of the other frontline citrus producing countries, resultantly citrus fruits now remained no longer the fruits of seasonal availability (Srivastava and Singh, 2008 c) .

Historical viewpoints

Citrus plants are considered native to subtropical and tropical regions of Asia, Island Southeast Asia, near Oceania and Northeast Australia, inhabiting the planet earth much before the dawn of human civilization. Although, lot of uncertainty still exists about when and where domestication of citrus species first happened through hybridization and introgression (Wu *et al.,* 2018). The history of citrus in Asia (amongst the top three fruits in the region) is quite intriguing and a myriad of learning expedition to any citrus scholar (Srivastava and Singh, 2008c). A genomic, phylogenic, and biogeographically analysis has established the southeast foothills of Himalayas (region stretching from eastern Assam, northern Myanmar, to western Yunnan) as the center of origin of genus Citrus, diverging from a common ancestor with *Poncirus trifoliata*. Following change in climatic conditions during Miocene period resulted a sudden speciation event, leading to development of many edible ancestral citrus species like citrons (*Citrus medica*), pomelos (*C. maxima*), mandarins (*Citrus reticulata*) of southeast Asia; kumquats (C*itrus japonica*), mangshanyegan *Citrus mangshanensis*), and ichang papedas (C*itrus cavaleriei*) of southeastern China; Kaffir limes (C*itrus hystrix*) of island southeast Asia and biasing and samuyao (*Citrus micrantha*) of Philippines. Many citrus taxonomists still believe citron originated in northern India and spread later to China, and that the sweet orange originated in southern China, where both mandarins and pumelos were planted together, spreading later to India (Srivastava, 2014). Such divergence of these citrus species added a strong alternative to options of nutritional security , considering citrus fruits a good source of value added dietary nutrients for human health, in addition to role of citrus fruits in cosmetics, food, beverage, and pharmaceutical industries, including the use of wild citrus species like *Citrus latipes*, *Citrus indica*, *Citrus megalaxicarpa*, *Citrus ichagenesis*, *Citrus medica*, *Citrus wilsonii* and *Atalantiabauxifolia* in developing traditional herbal medicine, all originating via Asian citrus diversity, yet another dimension of contribution towards diversified use of world citrus (Srivastava and Hota, 2020).

Asian Citrus, snapshot of problems

Amid Asian citrus industry placed at a comparatively comfortable position, there lies a number of challenges to be coped up, right from nursery to post-harvest, processing and value addition coupled with marketing operandi, covering an entire value-chain management of citrus vis-a-vis well organized research and development sector of citrus growing countries like Brazil, USA, Spain, Mexico, including the accessibility to problem –based research grants. The much desired budwood certification coupled with certified mother stock as the foundation of prolonged orchard life loaded with export quality fruits is perhaps the most missing link of Asian citrus. And resultantly of late, citrus greening disease (HLB, Huanglongbing, though first spotted in China way back in the year 1900) has made heavy in-roads in more than 58 citrus growing nations affecting 21 commercial citrus cultivars (noticeably mediterranean citrus is still free from HLB), in the tropics, subtropics of Africa and Asia including India and Bangladesh, setting an alarm bell to citrus researchers of Asia (Dong *et al.,* 2021; 2023) for developing a multipronged strategy (including field diagnostics) to address this global issue setting up a new order of citrus research, the world is however still clueless. The onset of changing climate in relation to host –pathogen-psyllids vector interaction further turn this issue a more complex, jeopardizing potential trade opportunities and posing economic challenges for Asian citrus (just imagine, over the past 5 years amounts to over $1 billion with loss of 5000 jobs annually in Florida, USA alone; US$39.2 million for Brazillin industry, which could touch the figure of US$ 127 million in next 15 years, if the greening spread invades East Africa).

Wealth of germplasm diversity within Asian citrus is likely to foresee the possible solution, provided researchers find some definitive clues about genomic changes taking place during their domestication process from their ancestral wild relatives of citrus. Rootstock research with emphasis on high density planting (with an exception of Satsuma mandarin on trifoliate rootstock) fitted with sensor-based fertigation (including citrus under protected system) and natural resource conservation structures is still far from reality for Asian citrus to compete with global citrus industry (Poudel *et al.,* 2022; Ahmad *et al.,* 2022). Precision forescasting of pests and disease outbreaks coupled with enabling techniques of population dynamics –based management involving minimum use of agrochemicals, paving the way for phase-wise use of biopesicides (preferably formulations using microbial bioagents, secondary metabolites as synthetic microbes, and entomopathogens), need renewed emphasis in the context of Asian citrus (Noorizadeh *et al.,* 2022). Secondary agriculture has remained neglected in Asia, especially in Southeast Asia due to dominance of fresh fruit market over processed products, still a long way to go to catch up with international excellence (Siddique and Garnevska, 2016). Role of microbial bioagents coatings as a part of post-harvest disease management, cold storages (for example cellar stores used in Nepal and Bhutan) for off-season outlet and smart-packaging are likely to cater to consumers demand of citrus during off-season, despite the fact that clementines arrive in the citrus market much earlier than any other citrus fruits (Rokaya *et al.,* 2016). And above all, most importantly, we also need to devise ways and means of rewarding citrus growers for production –linked incentives on farm-gate prices of citrus fruits. These issues deserve to be addressed sooner than leaving them simply unattended.

Soil fertility and plant nutrition issues

Unfortunately , the concept of balanced citrus nutrition is still far for reality in the pretext that citrus orchards are plagued with number of nutritional disorders (Srivastava, 2013), depending upon nature and properties of soil (Srivastava *et al.,* 2014), rootstock-scion combination (Srivastava and Malhotra, 2017), ratio of nutrients removed versus annual addition of nutrients in relation to annual productivity level Poudel *et al.,* 2022), method of irrigation (basin irrigation versus fertigation) to name few important ones. Nutrition can stake strong claim to intervene in sustaining the quality citrus production (Shirgure *et al.,* 2001a; 2001b; Jeyabaskaran *et al.,* 2021). Unfortunately, in(India, not too many options are available with regard to rootstock-scion combinations (Srivastava and Singh, 2008c), with an exception of citrus industry of northeast India where majority of citrus is even today raised on seedlings (Srangthem *et al.,* 2014). While in other citrus producing countries like China, Japan, Nepal, Thailand, Bangladesh, the rootstock trifoliate (*Poncirus trifoliata*) dominates with Satsuma as scion raised predominantly on coarse textured acidic soils (taxonomically classified as Entisols, Inceptisols, Alfisols, Ultisols) .

Table 1: Soil suitability criteria for Nagpur mandarin (*Citrus reticulate* Blanco) and sweet orange (Citrus *sinenesis* Osbeck) cultivar Mosambi grown in Marathwada region of Maharashtra -a case study for Asian citrus

Soil	Nagpur Mandarin		Mosambi Sweet orange	
Parameters	0-15	15-30	0-15	15-30
Soil pH	7.6-7.8	7.9-8.0	7.4-7.9	7.6-8.1
Soil EC (dS m^{-1})	0.12-0.24	0.21-0.28	0.22-0.34	0.26-0.44
Free $CaCO_3$ (%)	11.4-12.8	15.6-18.2	11.2-14.9	12.6-16.8
Particle size distribution (%)				
Sand	20.8-40.1	19.0-32.7	24.2-38.2	22.3-32.5
Silt	26.8-30.4	11.2-26.8	21.2-31.5	29.3-34.2
Clay	42.8-48.8	54.2-56.1	45.3-52.4	48.5-55.2
Water soluble cations (mg l^{-1})				
Ca^{2+}	168.3-182.3	192.50-212.45	182.1-216.8	192.6-248.3
Mg^{2+}	39.4-42.7	32.20-42.10	38.2-46.9	49.2-74.6
Na^{+}	0.98-1.1	0.68-1.23	0.62-0.98	0.58-0.82
K^{+}	12.1-28.2	11.40-12.8	11.4-21.2	11.6-18.3
Exchangeable cations [cmol(p^{+}) kg^{-1}]				
Ca^{2+}	31.9-32.3	38.1-41.2	35.8-40.2	34.2-44.8
Mg^{2+}	8.5-10.1	9.2-10.0	10.1-12.2	11.8-14.2
Na^{+}	0.68-1.23	0.8-1.1	0.42-1.06	0.46-0.98
K^{+}	3.2-4.1	4.5-4.6	4.3-5.8	3.8-4.9
Fertility status (mg kg^{-1})				
$KMnO_4$- N	118.4-121.2	92.8-110.2	130.1-142.2	120.4-128.6
Olsen- P	9.2-10.3	7.2-8.0	9.8-11.4	9.2-10.8
NH_4OAc K	178.4-232.5	204.2-228.1	182.4-210.3	192.2-222.2
DTPA - Fe	12.4-16.2	10.6-12.3	13.2-18.6	11.2-18.9
DTPA - Mn	8.6-12.2	7.2-9.1	14.6-22.6	15.2-21.8
DTPA - Cu	2.1-2.3	1.0-1.2	2.16-2.42	2.10-2.56
DTPA - Zn	0.98-1.10	0.72-0.78	0.98-1.21	0.81-0.92
Yield (tons/ha)	11-15	7-10	24.1-26.2	11.8-12.3

Source: Srivastava and Singh (2001; 2002; 2003a; 2004b; 2004c)

The soil suitability criteria were used as per the requirement of specific citrus cultivar and soil physic-chemical properties. The soil pH 8.2 EC 0.5 mmhos/cm and powdery form of free $CaCO_3$ 10% should be considered as critical limits for chemically delineating suitable soils from non-suitable ones. Minimum two feet depth, coarser texture with slightly heavier sub-surface, well drained, moderately level soil may be suitable for any commercial citrus cultivar grown in the country (Srivastava and Kohli, 1997). The soil may be suitable for any commercial citrus cultivar grown in the country (Nilangekar and Patil, 1982; Kalbande *et al.,* 1983; Chakravarty and Baruah, 1983; Brar *et al.,* 1986). The soils having clay content more than 60% beyond 30 cm soil depth should be avoided for cultivation of Nagpur mandarin in Central India (Srivastava and Singh, 2002). The depth of water table must be below six feet from the surface throughout the growing season. No hard-pan should be present within one meter of soil depth (Hernandez *et al.,* 1987; Srivastava and Singh, 2002). The presence of $CaCO_3$ concretions and Inceptisol type of soils were observed favourable for better quality of citrus fruits. The optimum available P, K and Zn were recorded as 4 to 10 ppm, 60-150 ppm and 0.6 to 1.0 ppm, respectively, while critical limit of Fe, Mn and Cu were suggested as 4.0 ppm, 2.8 ppm and 0.5 ppm(Srivastava and Singh, 2001). Respectively, for determining suitable soils for citrus. The different genotypic nutritional requirement further suggested that a soil suitable for a given cultivar may not hold promise for other cultivars. (Kohli *et al.,* 2000; Srivastava and Kohil, 1997). The soil suitability criteria for Nagpur mandarin grown in Vidharbha region and Marathwada region of Maharashtra have been developed (Table 1). Such an effort could be a template for future efforts to deal with other Asian citrus cultivars.

Future perspectives

Despite the fact that Asian citrus contributes nearly half of the world citrus , but still a number of issues need to be addressed to perch Asian citrus on par with some frontline citrus producers in the light some emerging diseases (Huanglongbing and *Phytophthora* induced foot and root rot as two major diseases), climate change-induced changes in plant metabolism , changing current periodicity of fruit drop, exploiting microbial niches towards developing a soil-plant health continuum (Srivastava *et al.,* 2003; 2016; 2022). These are some important areas where soil fertility and plant nutrition is supposed to play a pivotal role (Srivastava and Malhotra, 2014).

Nutrient dynamics is another virgin area where limited attempts have been made using citrus as test crop (Ngullie *et al.,* 2015). Amongst different nutrients, Zn has attracted worldwide investigation from various angles (Srivastava *et al.,* 2002; Srivastava and Singh 2009). The changes in rhizosphere bring different simultaneous changes in microbial diversity vis-a-vis Cmic, Nmic, Pmic 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 ISFM-based corrective treatments (Srivastava and Singh, 2005c; 2007). Additionally, the conditions under which citrus trees are most likely to respond to corrective Zn-treatments are still not fully understood (Srivastava and Singh, 2004a). 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 fruit crop-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 ISFM-based production management (Srivastava and Singh, 2005a; 2005b; 2006a; 2006b; 2006c ; Srivastava *et al.,* 2019).

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, 2007; 2008a; 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, besides a microbial species as nutrient deficiency or toxicity indicator (Srivastava and Singh, 2015; Hota *et al.,* 2020). While 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 (Srivastava *et al.,* 2015).

Role of AMF in providing an additional resilience to rhizosphere's ability of carbon accredition through within rhizosphere and associated development of plant's antioxidant profile as a defense mechanism should divert the research studying strong mycorrhizal dependency of fruit crops. Rhizosphere specific AMF-based microbial consortium would add a new dimension in providing newer options for raising the productivity potential of fruit crops (Wu *et al.,* 2013; Zou *et al.,* 2014). The framework on soil biodiversity effects from field to fork comprises: i. recognizing both direct and indirect mechanisms of soil biodiversity effects on crops properties, ii. Identifying postharvest processes that affect biodiversity legacy effects on crop properties; and iii. Pinpointing biodiversity-related crop properties that influence the efficacy and success of operations occurring in the agrifood chain (Sosa-Hernandez *et al.,* 2019).

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 and introduce a concept of Crop Nutrient Holiday. However, using newly emerging techniques of nutrient management and site specific management on the principles of Integrated Soil Fertility Management (Srivastava and Singh, 2003b; Srivastva *et al.,* 2015; Srivastava and Pandey, 2021; Srivastava *et al.,* 2021) could be worked out accommodating soil's nature and properties. Simultaneously, concerted efforts would be required to develop ISFM-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 crop-based Soil Health Card, the efforts on these lines are still in infancy (Srivastava *et al.,* 2006). Asian citrus, therefore, needs consolidated efforts to develop cultivar-based Soil Health Card to keep a constant vigil on current rate of nutrient mining/nutrient export from citrus orchards. These issues if addressed with precision are likely to transform the face of Asian citriculture far beyond the present level.

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