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**Research Article**

# Yield Gap Analysis in Fruit Orchard as a Function of Soil Physico-Biological and Chemical Indicators

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**ABSTRACT**

Fruit yield act as a function of soil-tree-climatic interaction. Productivity varies across different soil led management and climate led changes. Variability in yield of fruit orchards indicated that efforts should be done to reach the yield at least nearest to the potential level. Experimental results inferred that majority had <15 t $ha^{-1}$ mango cv. Dashehari yield and challenge is to enhance up to 30 to 40 t $ha^{-1}$. Distribution of soil parameters indicated the effects on yields. Tree nutrient constraints also add to the yield gap. Soil physical and biological indicators significantly bring out the possible reason for vast yield gap existed in fruit orchards. The present analysis will be helpful for policy planners/growers to reform existing barriers in technologies so that scientific breakthrough in advanced technologies can meet out the fruit demands in future.

**Key words:** Yield gap, Soil physical indicators, Soil biological indicators, Soil chemical indicators

## Introduction

To overcome the problems of malnutrition and hunger across global population, production of nutritious foods in sufficient quantity is to be ensured. On the present scenario, there was a vast gap between the actual yield and potential yield. This may be contributed by variable soil, atmosphere and water interactions and assessed by indicators. Even if the edaphic factors are problematic or deficient, it can be well managed up to a desirable level of production. However, atmospheric variables are known to influence the standing crop at any point of time. Apart from day to day variation, un-seasonality in flooding, drought, forest fire etc. tremendously reduced the scope of better quality production. Keeping the detrimental impact aside, soils that support life on the earth is the most precious material and should be treated as par the requirement. Physical, biological and chemical interactions of soil properties always do impact on the gap of such yield variation analysis (Cassman, 1999). The present paper deals with existing *vs* potential yield gap in fruit/food crops.Godfray *et al.*(2010) expressed the anxiety for food security of global population under diverse climate led effects on natural resources. Van Wart *et al.* (2013) made a detailed analysis for future course of action needed when the national yield potential of crops reached a plateau. Hazarika *et al.* (2015) suggested adoption of robust soil fertility management for reducing the vast yield gap that exited in banana across soil types and ecological region. Likewise, acclimatization of strawberry in subtropical condition is also challenging from view point of adaptability and stable production cum profitability to farmers (Costa *et al.*, 2015). Adak *et al.* (2016a) recommended adoption of advanced technological solutions for sustainability in Dashehari mango production

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under subtropics while Ganeshamurthy *et al.* (2019) opined to follow the proper nutrition for quality fruit production and thereby reduce the yield gap. Adak *et al.* (2020) experimentally proved to enhance the sustainable yield index in Guava under sandy loam soil. Not only for fruit tree, but yield variability of high value oil contents in Indian Sandalwood need to be addressed (Bisht *et al.*, 2019). Recently, Singh *et al.* (2019) experimentally proved that agro-geo-textiles in combination with conservation tillage practices ensure productivity and profitability as compared to sole practice of conservation tillage in India. For small holding farmers in South-Asia, Gathala *et al.* (2020) suggested technological interventions for enhancing yield cum water and energy productivity. Since, quantitative information on these aspects is lacking, the present study was performed to analyze key issues for yield gap.

## Materials and Methods

The study was conducted in the mango orchards of Rehmankhera farm, ICAR-CISH, mango orchards in Malihabad orchards and RB Road campus farm in Telibagh, Lucknow, U.P., India. Undisturbed core soil samples at different depths *viz*., 0 to 30 cm with 10 cm intervals and 30-60 and 60-90cm were also collected from mango orchards for estimation of water holding capacity, bulk density etc. Separate set of soil samples at 0-30 and 30-60 cm were collected for nutrient determination. Biologically active soils were also collected from mango orchards with the tree basin for analyzing the microbial activity in terms of enzymatic activities like dehydrogenase activity by Casida *et al.* (1964) and fluorescein diacetate activity by Adam and Duncan (2001). Chemical properties were analysed in the laboratory following standard protocol. Soil organic carbon by wet digestion method (Walkley and Black, 1934). Available P by the Olsen method (Olsen *et al*., 1954) using spectrophotometer and available K by neutral normal ammonium acetate in Atomic Absorption Spectrophotometer. Scattered diagram was developed to have a look on the vast variations and their contribution towards yield. Seasonal yield from the orchards was recorded and scattered plot indicated the extent of variability. The gap between the existing *vs* potential yield was discussed. Yield gap in other fruit crops was also included in the text to have a look on the existing system and future course of action needed to secure food/fruit availability to burgeoning population.

## Results and Discussion

### *Soil physical indicators for yield gap attenuation*

Soil physical parameters do vary and significantly contribute to yield gap. Such yield gap may also be attributed by the variations in physical component of soil under vast management regime. Fig. 1 exhibits the scatteredness of physical indicators (water holding capacity) in dominantly mango grown soils. Soils of Dashehari, Langra planted at normal distance, high density Dashehari plantations, Mallika plantations etc. undergoes changes over time and space. Soil compaction tends to reduce the water-nutrient flow and other fluxes in a way to lower attainable yield. Aggregate stability tends to impact on physical environment and thereby fruit size, fruit drop, maturing and ultimately harvested yield. Mango grown on problematic soils tried very hard to establish and more often to produce yield of desirable level. Under such condition, entire physical environment of soil plays crucial role in soil-yield gap analysis. Adak *et al.* (2018c) critically analysed the soil condition in Langra mango orchards of farmers' field to indicate the yield gap. Stefanou *et al.* (2018) examined the soil factors for problematic growth of olive while Rafaela *et al.* (2017) quantified soil compressibility to show the differences in soil condition *vis-a-vis* yield variations. *In-situ* soil and water conservation techniques improved yield from 4.8 to 6.6 t ha$^{-1}$ in Cashew (Rejani and Yadukumar, 2010) whereas mulching effects on reducing the yield gap through soil moisture conservation in Jujube (Jin *et al.,* 2018). In fact, soil physical condition particularly drainage condition (up to 1 m depth with increment of 25 cm; 0-25, 25-50, 50-75 and 75-100 cm) showed

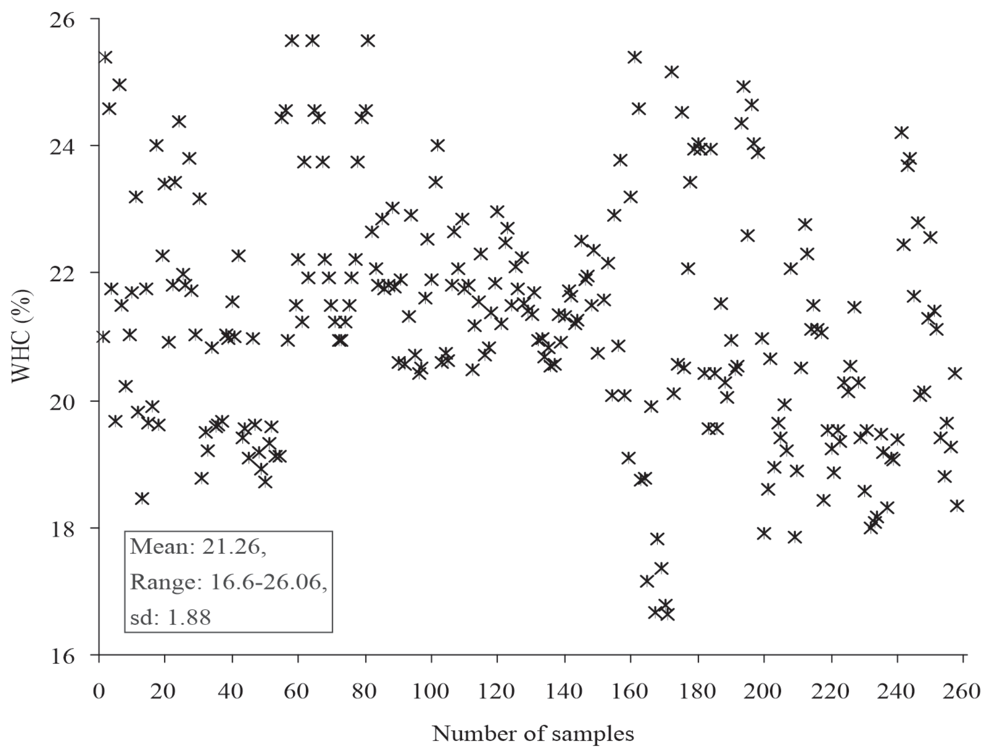



**Fig. 1.** Scattered distribution of water holding capacity (%) across orchard soils of different age, depths, management and climatic actions in ICAR-CISH Experimental Research Farm, Lucknow, UP, India

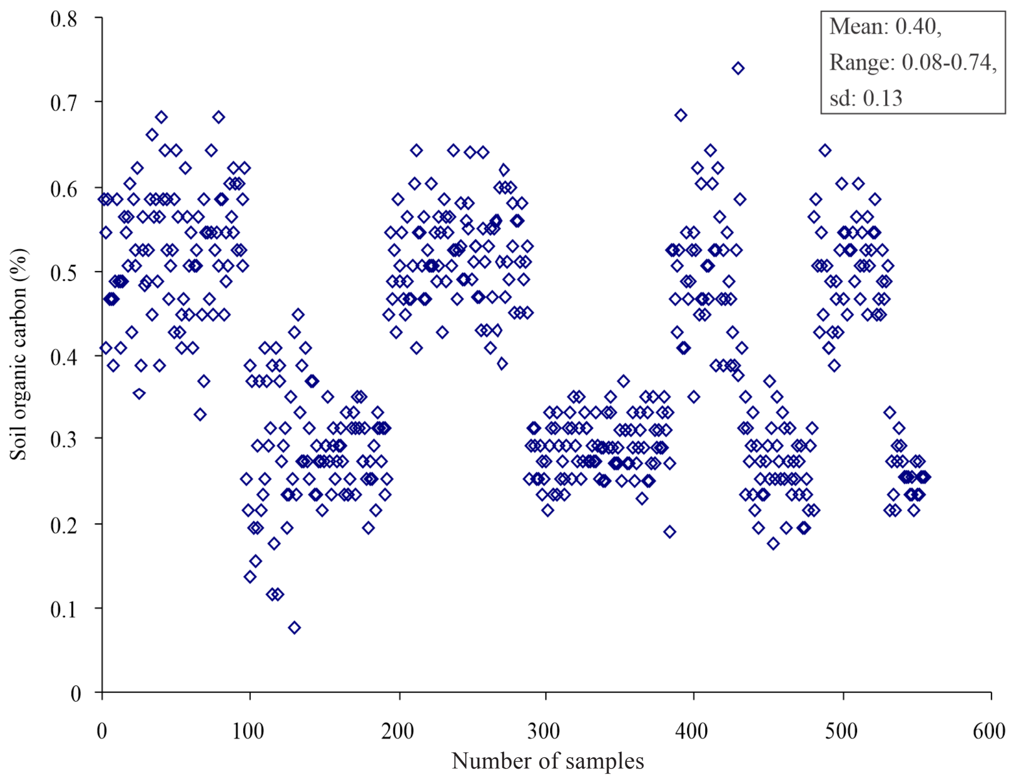
that root growth in fruit tree like Kiwi was less or nil in vertical soil distribution of medium and large roots. The dry weight of large Kiwifruit roots in well-drained soil is estimated as 6.53 in contrast to 0.58 kg tree$^{-1}$ in poor drained soil (Hughes and Wilde, 1989). Impacts of high density plantations of Dashehari mango on soil properties indicate yield variations as a result of soil condition (Adak *et al.,* 2016c). Schulze *et al.* (2013) recommended adoption of advanced irrigation than traditional led to 31 per cent increase in class I fruits. Land use history also plays dominant role in quantifying the impactson soil condition *vis-a-vis* yield record.Acín Carrera *et al.* (2013) inferred that with the reduction of soil use intensity bulk density may improve from 1.2 to 1.4 g cm$^{-3}$ and there is increase in water holding capacity and soil organic carbon as well. Changing hydraulic properties on top soil (0-30 cm) under saline environment enhanced water repellency index (56 and 134 per cent in 8 and 15 years of drip saline irrigation) in pomegranate orchard than control was responsible for yield gap (Tadayonnejad *et al.,* 2017). Even, draught stress is critical issue in attaining a desirable yield in Coffee; choice of cultivars is utmost critical issue with Dawairi>Tufahi and Tessawi> Kholani (Tounekti *et al.,* 2018). Thus, post-harvest irrigation management many a timeplays significant role in attaining the desired yield with other resource conservation benefits like in sweet cherry (Carrasco-Benavides *et al.,* 2020). Therefore, improvement in soil physical properties is crucial for reduction in yield gaps and critical analysis is needed to understand gaps under subtropics (Hochman *et al.,* 2012; Oliveira and Merwin, 2001).

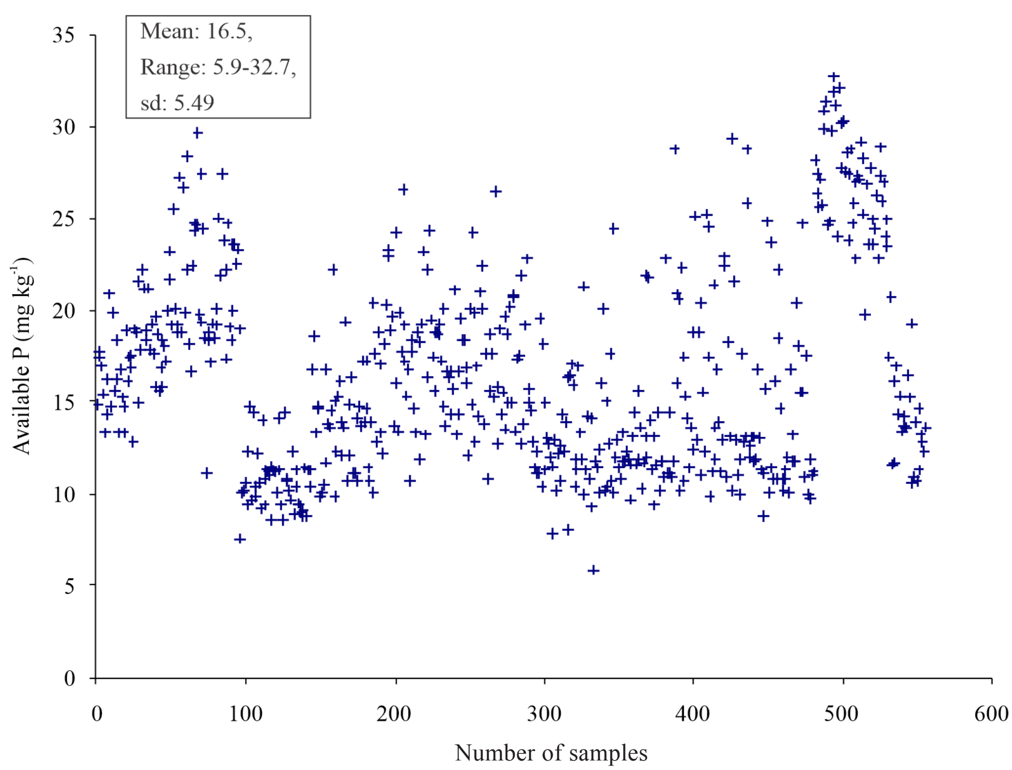
### ***Soil biological indicators for yield gap attenuation***

The host crop is always at equilibrium with the soil micro and macroflora. The entire spectrum of biological activities, population and their distribution, action were in tandem with the yield. Higher the microbial activity better is the health indicator and thereby scope of quality fruit bearing ensured. Tropical, subtropical fruits like mango, guava, jackfruit etc. planted on harsh land, low biological activity contribute towards existing yield gap. The proliferation of one or more microbes, earthworm and other beneficial and symbiotic organisms are helpful in enhancing the yield. The role of mycorhizal infections, virulent strains of biofertilizers, VAM etc. are used to manage the biological health of orchard. In organic production, their role is obvious but contribution towards lowering the targeted yield is uncertain. Vermicompost, rhizospheric environment through mulching and other resources are known to supply the nutrient to fruit roots. In sodic or saline soils, or soils with low fertility status may yield better but still less than expected yield level. Thus, in order to reduce yield gap, we need to formulate integrated approach for satisfying potential yield harvest. Adak *et al.* (2018b) recorded biological activities and mostly low enzymatic activities (0.01 to 0.5, 0.46 to 0.99 and 1.01 to 2.71 μgTPFg$^{-1}$ h$^{-1}$ dehydrogenase in low, medium and high categories) in mango orchards and concluded that this might be responsible for lower yield (146.6 to 247.7, 202.2 to 252.1 and 250.6 to 388.4 mg fluorescein kg$^{-1}$ h$^{-1}$ in low, medium and high categories with low yield of <10 t ha$^{-1}$). Even, under temperate condition, soil enzymatic activities and microbial biomass contributes significantly to the soil biological health and overall yield performances in fruit trees (Debnath *et al.,* 2015). Not only that, organic farming statistically improves the enzymatic reactions and microbial abundances in soil (Lori *et al.,* 2017). Deakin *et al.* (2018) recorded significant positive differences in soil microbial community across orchards and even within the orchards due to vegetation and other management types in apple orchards in UK. The fact that the soil biota (FDA hydrolysis, Pratylenchus and free-living nematodes) was significantly active in young orchards (2.6 μg mL$^{-1}$ FDA hydrolysis) as compared to old one (1.5 μg mL$^{-1}$ FDA hydrolysis) in 18 cherry trees of varied soil types, age, types and land use history in Canada (Munro *et al.,* 2020). Even under bio-organic fertilization (pig manure compost) statistically ease and stabilized the network of soil microbial community networks in kiwifruit orchards in abetter way for ecological significance (Liu *et al.,* 2020) while Jiang *et al.* (2020) concluded soil properties, location (lat and long) and manure inputs in mango orchards are responsible for arbuscular mycorrhizal community distribution. Thus, it is evident that soil microbes plays critical role on soil-tree yield gap analysis.

### *Soil chemical indicators for yield gap attenuation*

Restriction in nutrient supply either as a function of physical constraints or lower biological actions ultimately leads to low yield. To ensure gap in bridging potential *vs* actual yield component, enhanced nutrient management is the key issue. Fig. 2 and 3 showed variability of soil chemical indicators both soil and tree foliage on the effect of yield gap in mango. Even if there is enough nutrition, sometimes G×E interaction may play vital role. Hidden hunger phenomenon may also be responsible for enhancing yield gap. Foliage treatments are also keys in fruit bearing. Soil and foliage nutrition should be well versed and responsible for observed fruit load. Deficiency may lead to existing gap scenario. Targeted yield of 30 to 40 t ha$^{-1}$ or even more till unattainable with the present practices at farmers field. Therefore we need to relook the entire gamut of strategy of fruit production to ensure at least 40 t ha$^{-1}$ mango fruit harvest. The situation may be much harsher with the decades to come and cope up with all limitations. Adak *et al.* (2019) nicely explained the soil and foliar nutrients *vis-a-vis* observed yield in Mango. Nutrient recommendations were thus opted for ensuring better orchard soils to support fruit production. In this connection, mango orchard soils from different mango growing villages were collected and 250 analyzed data suggested for precise soil fertility management in Malihabad region of Uttar Pradesh (Adak *et al.*, 2016b). Mali *et al.* (2016) quantified the spatial variability of soil chemical properties in mango orchards of Jharkhand for which a sum of 90 soils samples from 0-30, 30-60 and 60-90 cm soil depth were collected. Soil organic carbon (0.02 to 0.91%),


Mean: 0.40,
Range: 0.08-0.74,
sd: 0.13
Soil organic carbon (%)
Number of samples


Mean: 16.5,
Range: 5.9-32.7,
sd: 5.49
Available P (mg kg$^{-1}$)
Number of samples

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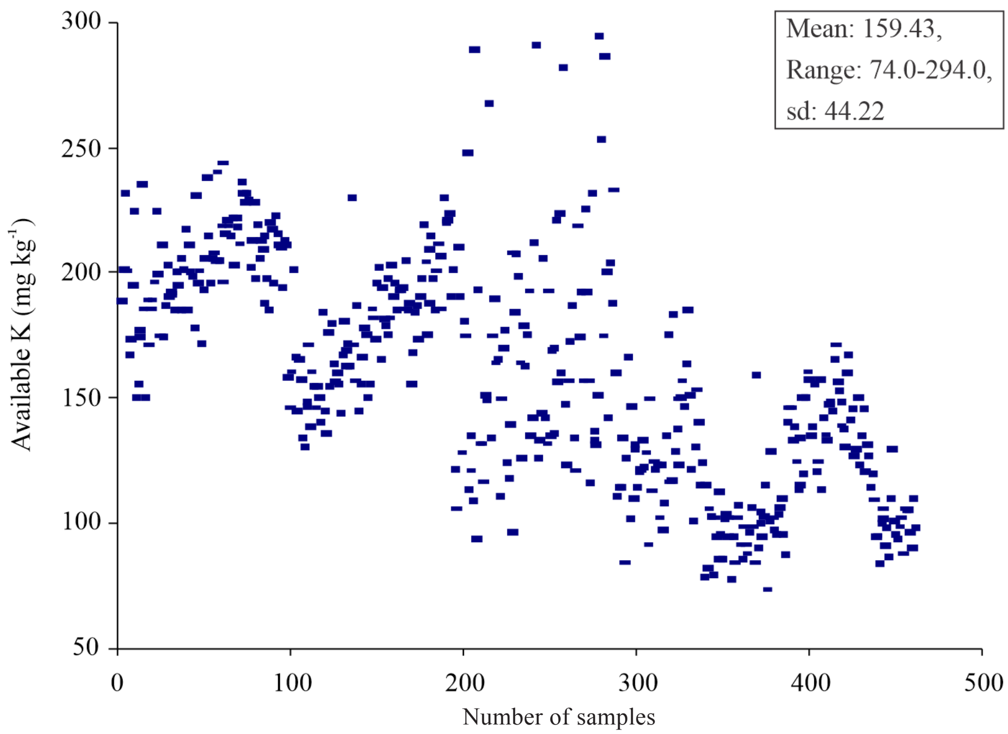
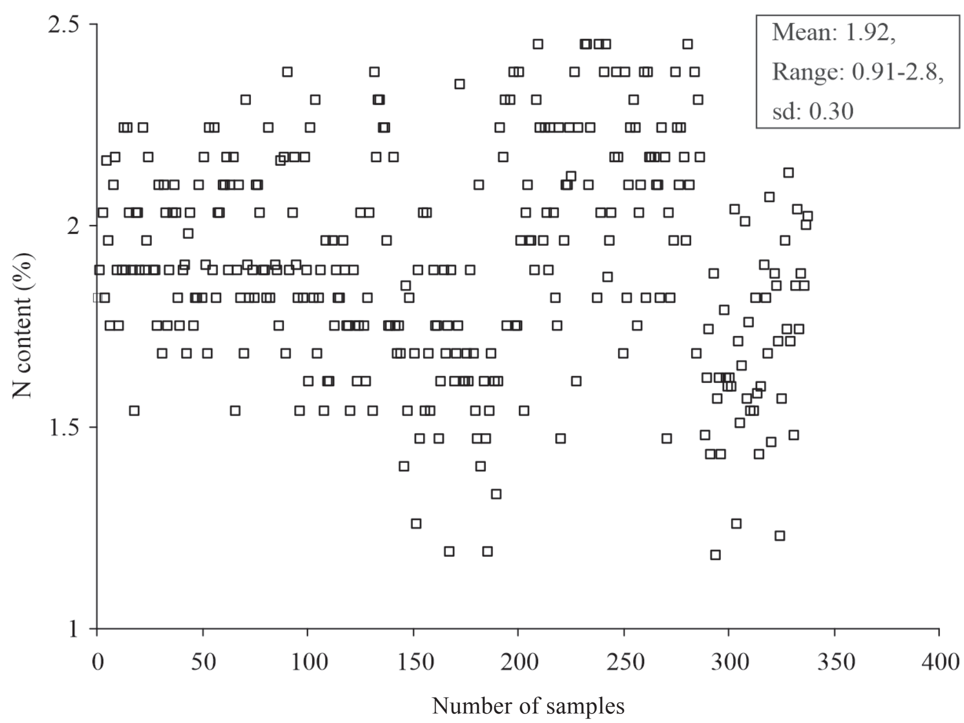



**Fig. 2.** Variability of soil organic carbon (%), available P and available K across Dashehari mango orchard soils of different age, depths, management and climatic actions in ICAR-CISH Experimental Research Farm, Lucknow, UP, India

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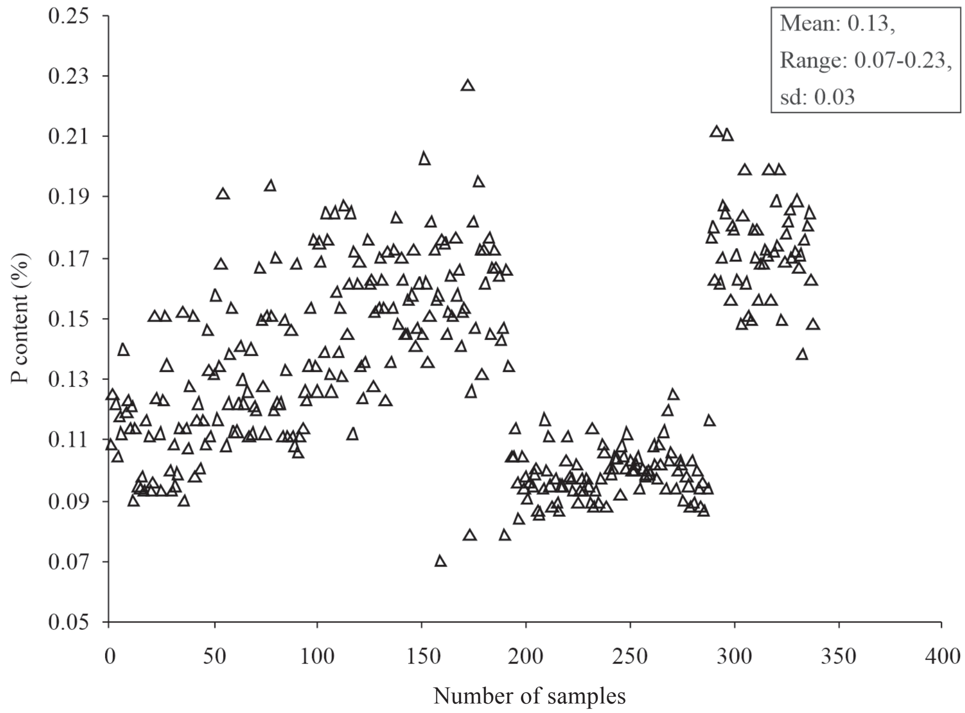


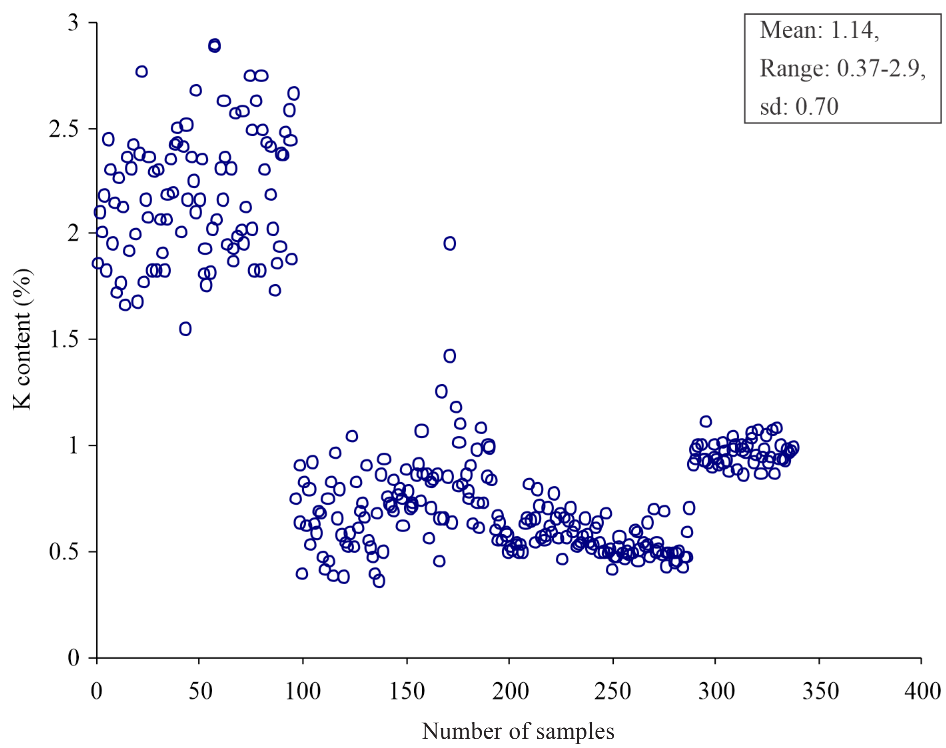


**Fig. 2.** Variability of soil organic carbon (%), available P and available K across Dashehari mango orchard soils of different age, depths, management and climatic actions in ICAR-CISH Experimental Research Farm, Lucknow, UP, India

available N (37.6 to 175.6 kg ha$^{-1}$), available K (144.5 to 380.8), available P (0.16 to 16.66) with available Zn (0.15 to 0.71 g kg$^{-1}$) suggested for site specific nutrient recommendation. For 42 Oil palm plantations of Mysore, Mandya and Hassan districts of Karnataka, results from 82 analyzed soil samples at 0-20 and 20-40 cm depth recommends site specific fertility management for sustainable production (Behera *et al.,* 2015). In fact, for sustainable soil and agricultural productivity management, fertility classification is needed (Kalaiselvi *et al.,* 2019) and more often conservation and management of natural resources are essential particularly in Himalaya region in order to attain productivity potential and also for future ecosystem services (Mehta *et al.,* 2020). Future course of action remains more critical as nutrient dynamics undergo significant variations under climate change led abiotic stresses.

***Quantification of yield gap as a function of several factors***

Yield gap in different cash crops is to be analyzed for taking proper step to reduce the gap (Table 1). In case of mango variety Dashehari yielded maximum of 10 to 20 t ha$^{-1}$ in the Malihabad region of Lucknow, UP, India. Targeted yield of 30 to 40 t ha$^{-1}$ is far behind imagination. Fig. 4 showing scattered diagram of yield variations in mango. Old orchards, shifting of phenological events on account of weather, diseases and moreover pest attack in surplus, sometime unmanageable, enlarge the gaps.

**Table 1.** Yield gap in other fruit crops as a function of soil related problems

| Yield gap in concerned fruit orchard | Reason | Place/site | Reference | Potential yield |
|---|---|---|---|---|
| Mango | Soil health, majority of Dashehari trees having yield <15.0 t ha$^{-1}$ | Rehmankhera, Lucknow | Adak *et al.* (2018a) | 30-40 t ha$^{-1}$ (10×10m) |
| Guava | Soil-climate and canopy management. Guava cv. Sardar yielded max of 29.5 t ha$^{-1}$ at 1×2m spacing in third year. | Ranchi, Jharkhand | Das *et al.* (2018) | 60.0 t ha$^{-1}$ (2×1 m) |
| Pomegranate | Irrigation scheduling in loamy soil. 70% of cumulative pan evaporation yielded maximum of 6.79 kg tree$^{-1}$ in 3 yrs of tree. | Solapur, Maharashtra | Marathe and Dhinesh (2017) | 29.0 t ha$^{-1}$ |
| Rubber | Several reasons, yield gap of 21 to 30 and many a time>30 per cent | Kanyakumari, Tamil Nadu | Jergin and Somasundaram (2018) | 4284 kg from 450 trees |
| Coffee | Climate change severely impacting Arabica coffee yield | Wayanad, Kerala | Jayakumar *et al.* (2017) | 2.5 t ha$^{-1}$ |
| Coconut | Vast yield gap due to soil-irrigation, climate and varieties *viz*., 3000 to 27,000 nuts ha$^{-1}$ year$^{-1}$. | Southern India | Naresh Kumar *et al.* (2009) | 10 t copra/ha (7.5× 7.5 m) |
| Oil palm | Yield-limiting nutrients, soil fertility and leaf nutrient concentration. | Mizoram, North-Eastern India | Behera *et al.* (2017) | 50 t ha$^{-1}$ (18.5 t oil ha$^{-1}$ yr$^{-1}$) |
| Sapota | Low soil health, INM combinations can improve only upto 4.52 t ha$^{-1}$ | Vertisol, Chambal region in south-eastern Rajasthan | Meena *et al.* (2019) | 36 t ha$^{-1}$ (5× 5 m) |

Available reports indicate the yield gap in oil palm, coconut, rubber, coffee, guava, mango to contribute the need of century led practices. Such system needs to be relooked and readdressed for reducing the potential yield across various types of soil.

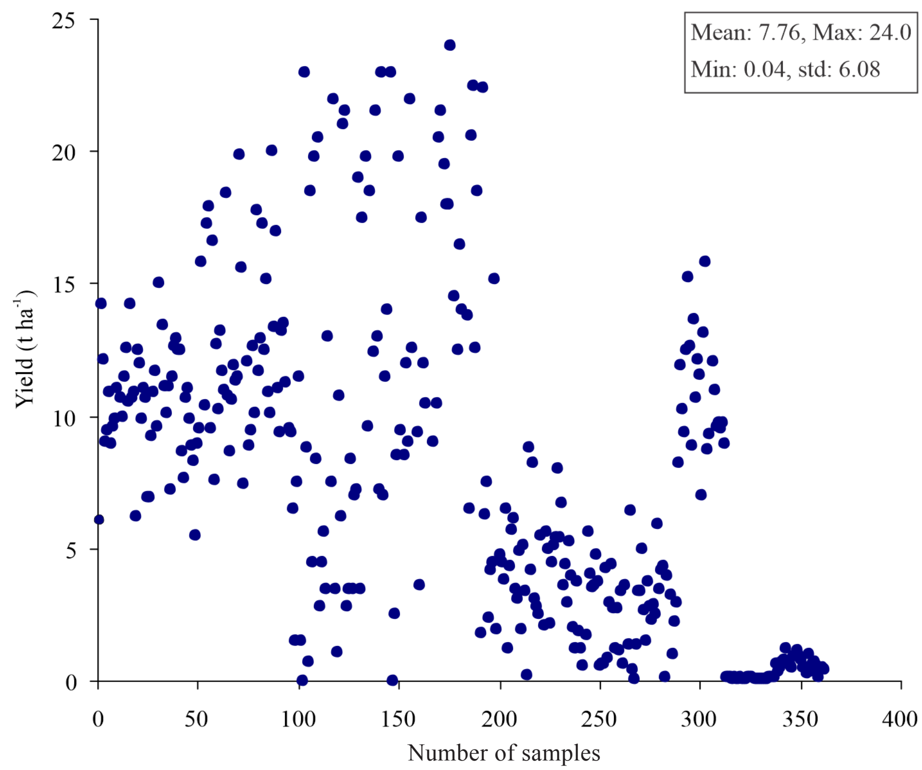


**Fig. 4.** Scattered distribution of yields across Dashehari mango trees of different age, management and climatic actions at ICAR-CISH Experimental Research Farm, Lucknow, UP, India

Langra, Chausa, Mallika, Amrapalli also yielded far less than targeted yields. It has been observed that the problem with these mango cultivars is that they were less planted at farmers' field. The commercial potential of Mallika, Amrapalli is still at bay. Since Dashehari was the choicest cultivar, there is immense scope of other varieties including early and late varieties so that availability of fruits should be maximum during April to August in the market and like those mentioned above to flourish in the market. The price was always higher for quality fruit as there was always demand for Langra, Chousa, Mallika, Amrapalli varieties. Marketing surplus of Dashehari was used for making jam, jelly, pulp business. Growers enjoy the Dashehari fruit even without doing anything but to reap a good harvest. In this situation, proper management procedures come into effect. Guava is another important crop which is always in demand in the market. But the price is often low Rs. 20 to 40 per kg of fruit. It was observed that maximum gap was there for guava production as farmers' shifts in cultivation of other fruit crops. Therefore, tough challenge lies in reducing the targeted yield gap of guava in market. In non-traditional areas, peoples are now cultivating banana fruit. With increasing cost of input use and labour costs, of course the crop may sustain initial profit making business to support the livelihood of growers. On long term basis, it should be productive enough to a level of farmers' satisfaction. Not only that, severe winter and frost attack had many a times caused havoc crop loss. Cultivation in sodic or highly saline soils, banana yields less with high costs of cultivation for initial years of establishments and stages. Under present situation, huge potential yield gap existed across soils and orchards in different parts of Uttar Pradesh and nearby Lucknow region. The role of jackfruit in nutritional security is well known but its availability round the year is unsecured. Therefore, to secure the potential availability in the market, efforts should be initiated at ground level (Pandey *et al*., 2018a,b). Thus, the potential yield gap of subtropical fruits existed to the tune

**Fig. 5.** Yield variation in Dashehari tree at same place under same management system and climatic condition

of unbearable and unimaginable level (Fig. 5). To attain trust of farmers, we need to work in a holistic manner and systematically with scientific temperament to ensure the food supply for hungry and deserved people. Kumar *et al.* (2016) recommended good agricultural practices of technological break through for small and marginal farmers for sustaining Dashehari mango while abiotic stresses plays dominant role in lowering banana yields (Wairegi *et al.*, 2010). Water availability is also another important issue for effective production system (Passioura, 2006; Wang *et al.,* 2014) and soil health parameters needs to be assessed through advanced technological use to support greater productivity (Adak *et al.,* 2018). Thus, exploring option for yield gap analysis in totality is the urgent need for policy planning.

## Conclusions

The present study exhaustively narrated the yield gap and role of soil physico-biological and chemical indicators. The targeted yield of 30 to 40 t ha$^{-1}$ or even more is still unattainable in orchards of Malihabad, Lucknow, U.P. Physical constraints along with poor biological health could be responsible for this. Site selection or suitability of establishing mango orchards is to be decided wisely to avoid any constraints in soil chemical transformations. Nutrient scattering depicted the variability but need more precise management to chalk out possible advancement protocol to reach nearby targeted yield. The achievement in attainable yield is possible only when we reconsider our existing technologies and relook the whole stratum of recommendations including G×E interaction.

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