Statistical basis of production sustainability of citrus orchards

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Reduced longevity coupled with poor efficiency of commercial 'Nagpur' mandarin orchards collectively render the economics of cultivation non-remunerative more often quite untimely due to unsustainability in production. Quadratic regression of orchards age with fruit yield and tree efficiency revealed an increase in fruit yield from 37.7 to 66.3 kg tree^{-1} and tree efficiency 8.6 to 11.0 % within 6 to 17 years, and beyond that, both parameters declined invariably. Other biometric relations viz., orchard age versus tree volume and tree volume versus fruit yield followed a similar curvilinear quadratic pattern with peak fruit yield coinciding with the orchard age of 17 to 20 years. Such statistical basis can be effectively applied for yield forecasting of citrus orchards on a long term basis.

Keywords: C*itrus reticulata* Blanco, quadratic relation, orchard efficiency, and central India

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Citrus is globally considered to be a premium fruit crop. The future growth of citrus industry will be marked not only by a simple increase in yield, but sustainability in the production pattern has to be viewed as a major challenging task in the light of many newly emerging problems. In citrus belts of countries like Japan, China, Philippines, Thailand including India (Srivastava and Singh 2002, 329-346) where loose jacket mandarin has a characteristic feature of expressing an alternation of 'on' and 'off' year cycle, the consistency in production assumes a much greater significance. 'Nagpur' mandarin (*Citrus reticulata* Blanco), a commercial citrus cultivar par excellence to any of the world's other commercial mandarin cultivars, is widely cultivated in central India predominantly on alkaline, calcareous basalt derived black clay soils under hot sub-humid tropical climate. There is hardly any information available regarding attempts made so far through use of a statistical model to arrive at sustainable orchard age from production point of view so that, depending upon the unsustainable period, contingency efforts could be formulated to sustain production for a longer period. In the past, various types of non-linear regression models were observed to be effective in predicting fruit yield in relation to various soil properties (Srivastava and Singh 2007, 2077-2099) in both monocropped and intercropped 'Nagpur' mandarin orchards (Srivastava et al. 2007, 67-70).

With this background information, studies were therefore carried out to establish the upper limit of various production determining variables viz., orchard age, tree canopy volume and fruit yield in relation to tree efficiency using Nagpur mandarin (*Citrus reticulata* Blanco) as a test crop based on various statistical computations. The information on these lines could well be used to determine the orchard age at which sustainability in production of citrus orchards can be obtained.

Material and Methods

Experimental setup

A total of 178 Nagpur mandarin orchards representing an area of 178 km^2 (26.6% of total citrus cultivation in Vidarbha region of Maharashtra) covering Kalmeshwar, Katol, Narkhed, Ramtek, Saoner and Hingna subdivisions were surveyed during 1992-98. Subsequently, these orchards were surveyed during 1999-2001 and 2001-02 to obtain the cumulative effect of three seasons so that the influence of temporal variability on fruit field variation is minimised. The earmarked orchards were predominantly established on three soil orders viz., Entisols, Inceptisols, and Vertisols,

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derived from basalt type of parent material having smectite mineralogy.

Climatic features of the area surveyed are characterized by an annual rainfall of 750-1350 mm, mostly concentrated during the months of June-September. Mean summer (April, May, and June) and mean winter (December, January, and February) temperature varies from 35 to $45^{O}C$ and from 15 to $22^{O}C$, respectively. Maximum peak summer temperatures are 42 to $47^{O}C$ and minimum winter temperatures 8 to $12^{O}C$ respectively. The pH of the soils varied from7.2 to 7.8, EC 0.12 to 0.28 dSm^{-1}, and texture from sandy clay loam to clay.

Observations and statistical analysis

All the orchards comprised plants of Nagpur mandarin as scion on rough lemon *(Citrus jambhiri*, Lush) rootstock. The source of irrigation was dug wells with very poor irrigation capacity during severe summer months of April-May.

The soil samples were analysed for pH, $CaCO_{3,}$ and particle size distribution as per procedures suggested by Page et al. (1982, 159-164). Soils were taxonomically classified as per Soil Survey Staff (1994) to downsize the data according to soil types at great group level. Data on orchard age, tree height, tree spread (E-W x N-S), and fruit yield were simultaneously recorded. Tree volume (Tree volume: 0.5236 D^2h where D and h stand for diameter of canopy and plant height, respectively) and tree efficiency (tree efficiency = yield / canopy volume x 100) were calculated using the formulae as suggested by Castle 1983, 23-25. Cultural practices followed by the orchardists were almost uniform. Quadratic equations ($Y=a+bx-cx^2$ where Y, a, and x are dependent variable, intercept, and independent variable, respectively, with b and c as regression coefficients) were developed using different components of production sustainability viz., fruit yield versus orchard age, tree canopy volume versus orchard age, and fruit yield versus tree canopy volume to determine the orchard age associated with peak production efficiency of orchards under the conventional cultural practices. Critical difference (CD) coefficient of variation (CV), linear correlation (r), and quadratic correlation (R^2) were computed as per procedures suggested by Gomez and Gomez 1984, 357-423.

Results and Discussion

Nagpur mandarin orchards under investigation varied from 6 to 30 years in age, 17.1 to 81.4 m^3 in tree volume and from 143 to 1210 fruits $tree^{-1}$ (4-40 tonnes ha^{-1}) in fruit yield having tree efficiency of 7.3 to 16.0% (Table 1). Different components of production sustainability viz., fruit yield vs orchard age, tree efficiency vs orchard age, tree volume vs orchard age, and fruit yield vs tree volume showed significantly higher determination coefficient (R^2) under quadratic fit than linear fit (Table 2). In earlier studies (Srivastava and Singh 2007), quadratic models (measuring 82.1% orchard efficiency as optimum) were nearly as good as best fit models (predicting 86.4% orchard efficiency as optimum) in defining the soil property optima compared to conventionally used mean orchard yield (65.1% orchard efficiency as optimum). Bivariate quadratic regression between fruit yield as a resultant effect of all the inputs and orchard age, showed that fruit yield increased from 352 fruits $tree^{-1}$ (37.7 kg $tree^{-1}$) at 6 years of age to 620 fruits $tree^{-1}$ (66.3 kg $tree^{-1}$) at an orchard age of 18 years, and thereafter the yield declined regularly to as low as 227 fruits $tree^{-1}$ (24.2 kg $tree^{-1}$) up to an orchard age of 30 years (Table 3), loosing the productivity potential beyond a certain orchard age. Lal et al. (1990, 186) suggested that sustainability can be expressed in terms of output-input relationship as a function of time or as an output per unit consumptive use of the most limited manageable resources. Considering the first five pre-bearing (non-productive) years, the non-negative trend in fruit yield (or no decline in output-input ratio over a period of time) was observed for 13 years as a production sustainable period. Similarly, the tree efficiency increased from 8.6 to 11.0% within the orchard age of 6 to 17 years, and the efficiency beyond followed a declining trend (Table 3). These observations in other words showed that the production potential of 'Nagpur' mandarin in Central India could be harnessed only up to 18 years of orchard age.

Table 1: Variation in components of sustainability of Nagpur mandarin cultivation in central India (Pooled data)

Subdivisions	No. of orchards	Orchard age (Years)	Tree volume (m^3)	Fruit yield		Tree efficiency (%)
				(No.tree^{-1})	(kg tree^{-1})	
Kalmeshwar	22	7-23	28.5-81.4	241-788	34-109	8.6-14.9
Katol	30	7-23	24.2-64.0	240-620	33-84	9.9-16.0
Narkhed	35	6-24	18.0-68.3	143-1174	21-160	7.3-14.0
Ramtek	26	6-30	17.0-78.8	290-1210	40-156	8.4-12.0
Saoner	34	6-22	23.8-57.0	426-527	58-73	7.4-14.1
Hingna	31	6-20	25.7-52.2	484-761	64-103	8.2-14.1
Mean	-	21	38.2	836	89.3	11.6
CV(%)	-	53.2	28.6	46.1	42.2	28.4

CV: Coefficient of variation

Table 2: Correlation between different components of production sustainability of Nagpur mandarin orchards under linear versus quadratic fit

Sr.No.	Components of sustainability	Linear (r)	Quadratic (R^2)
1.	Fruit yield vs. orchard age	0.431**	0.621**
2.	Tree efficiency vs. orchard age	0.328*	0.469**
3.	Tree volume vs. orchard age	0.411*	0.582**
4.	Fruit yield vs. tree volume	0.489**	0.611**

* Significant at ($P < 0.05$), ** Significant at ($P<0.01$)

Table 3: Quadratic regression equations between different components of production sustainability of Nagpur mandarin orchards

Sr. no.	Components of sustainability	Bivariate quadratic equation
1.	Fruit yield vs. orchard age	Fruit yield (Y) = -30.77 + 77.57 x (orchard age) – 2.32 x^2
2.	Tree efficiency vs. orchard age	Tree efficiency (Y) = 7.24 + 0.25 x (orchard age) – 0.004 x^2
3.	Tree volume vs. orchard age	Tree volume (Y) = 11.44 + 3.97 x (orchard age) – 0.11 x^2
4.	Fruit yield vs. tree volume	Fruit yield (Y) = –163.89 +24.61 x (tree volume) – 0.20x^2

Table 4: Variation in tree efficiency parameters in relation to soil types (Pooled data)

Soil types	Tree canopy volume (m^3)	Fruit yield (kg tree^{-1})	Tree efficiency (%)
Entisols (Ustorthent)	17.0-28.6	21-40	7.4-8.6
Inceptisols (Ustochrept)	52.2-64.0	109-160	14.2-16.1
Vertisols(Haplustert)	68.3-78.3	73-84	8.5-12.1
CD ($P = 0.05$)	5.3	6.4	1.0

Table 5: Soil series identified from citrus growing areas (Pooled data)

Sr. no.	Soil series	Description	Tree canopy volume (m^3)	Fruit yield (kg $tree^{-1}$)	Tree efficiency (%)
1.	Linga	Very deep, moderately well drained, clayey soils with slight erosion on slopes upto 1% (Piedmont plain landform)	71.3	70.4	10.2
2.	Kalra	Moderately shallow, well drained, clayey soils with slight to moderate erosion on 1-3 % slope (Plateau landform)	50.2	81.4	12.2
3.	Yenwa	Very shallow, excessively drained, gravelly clay loam soils with severe erosion on 3- 8% (Plateau landform)	38.2	36.4	8.1
4.	Muserkhapa	Shallow, well drained, clayey soils with moderate to severe erosion on 1–3% slope (Plateau landform)	41.4	44.2	8.3
5.	Bagbori	Deep, well drained, clayey soils with slight erosion on 1-3% slope (Valley landform)	52.8	93.6	15.1
6.	Sewadoli	Shallow, well drained, gravelly sandy loam soils with moderate erosion on 3–8% slope (Subdued hills landform)	42.4	42.3	9.4
7.	Devadipar	Shallow, well drained, sandy clay loam soils with moderate erosion on slopes upto 3% (Subdued hills landform)	42.6	40.4	9.8
8.	Ramtek	Very shallow, excessively drained, gravelly sandy loam soils with severe erosion on 8-15 % slope (Plateau landform)	40.2	32.7	8.4

Information on soil series was generated based on publication by Sehgal et al. (1994, 28).

Tree volume which provides total bearing area for fruits, recorded an increase from 31.3 to 47.3 m^3 as the orchard age increased from 6 to 18 years, and declined sharply thereafter to 31.5 m^3 up to an orchard age of 30 years, depending upon the potential of tree in a given set of agro-pedological conditions. This suggested a curvilinear relationship of tree volume and orchard age (Table 3). Similar relation was observed between tree volume and fruit yield, as evidenced by increase in fruit yield from 324.3 to 529.7 fruits $tree^{-1}$ (34.7 to 56.7 $tree^{-1}$) with increase in tree volume from 20.0 to 60.0 m^3, beyond which fruit yield dropped narrowly to 578.8 fruits $tree^{-1}$ (61.9 kg $tree^{-1}$) at a tree volume of 70.0 m^3 and further declined to 524.0 fruits $tree^{-1}$ (56.1 kg $tree^{-1}$) at tree volume of 80.0 m^3 (Table 3). Such a relationship could be suitably exploited for designing the high density planting and yield forecasting of different age groups of citrus orchards.

In the partitioning of sustainability parameters (Table 4) on the basis of predominant soil types, Ustochrepts were observed to have highest tree efficiency (14.2-16.1%), despite much less tree canopy volume (52.2-64.0 m^3). On the contrary, the tree canopy volume was highest (68.3-78.3 m^3) on Haplustert soil type with comparatively lower yield (73-84 kg tree^{-1}) and tree efficiency (8.5-12.1%). Presence of structurally well developed B-horizon in Ustochrept soil type proved to be a good source for constant supply of available nutrients. By the virtue of this quality, Reddy et al. 1992, 111-113 suggested Inceptisols as highly suitable for 'Sathgudi' sweet orange compared to either Entisols or Vertisols. Soil-water-deficit stress (a pre-requisite for induction of flowering) mediated flowering response in 'Nagpur' mandarin is by and large, the key factor to the success of Citriculture. The role of soil properties, therefore, holds a paramount importance in influencing the production pattern of 'Nagpur' mandarin orchards in central India (Srivastava and Singh 2007, 2077-2099) and the other parts of the world e.g. South Africa, Italy and Western Georgia etc. (Du Plessis 1977, 18-21; Gvaliya and Zonn 1990, 16-27; Proschnow and Boaretto 1995, 101-106).

Delineation of different production sustainability parameters (Table 5) based on soil series generated still a better interpretation. Linga soil series by the virtue of very deep soil profile with clayey texture, produced a higher canopy volume, but fruit yield was much lower than Bagbori and Kalra soil series. Bagbori soil series registered the highest fruit yield (93.6 kg tree^{-1}) with comparatively much lower canopy volume (52.8 m^3), but with much higher tree efficiency (15.1). Based on information on soil series, Bagbori, Kalra and Linga soil series were identified as highly productive soil series in the decreasing order.

Hence various quadratic regression analyses demonstrated that maximum tree efficiency through optimum tree volume *vis-à-vis* fruit yield could be achieved up to 18 years of orchard age under the cultural practices that are currently followed in central India. Such upper limit of orchard age from the standpoint of production was supported by our earlier observations that above this orchard age, trees responded to fertilization very slowly and most often visible response to fertilization was very difficult to ascertain (Srivastava and Singh 2007, 2077-2099), despite the fact that this orchard age limit is very low compared to average orchard life of citrus orchards in countries like USA, Spain, Brazil, Japan etc.

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