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Effect of nutrient management practices on yield and quality of Mandarin (*Citrus reticulata* Blanco) production in Sankhuwasabha district, Eastern Nepal

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ABSTRACT

This study assessed the effect of nutrient management practices on the yield and quality of mandarin (*Citrus reticulata* Blanco) grown by commercial orchardists in Sankhuwasabha district, Eastern Nepal, comparing farmer practices before and after an intervention led by the National Agricultural Modernization Project (NAMP). A descriptive survey was conducted among 60 purposively selected mandarin growers using a structured questionnaire, key-informant interviews and field observation. Before the intervention, nutrient supply in all orchards depended entirely on farmyard manure (FYM), supplemented only marginally by poultry manure (5% of farmers) and chemical fertilizer (10%). Following NAMP promotion, all 60 growers adopted bone meal (mean rate 395.89 g plant^{-1}) and micronutrient mixtures (mean rate 146.29 g plant^{-1}, applied mostly at 1-250 g plant^{-1} by 91.67% of respondents), with bone meal commonly incorporated with FYM (55%) rather than applied alone. Growers reported visible improvement in fruit shape and yield (100% of respondents), vegetative growth (63.33%) and leaf colour (21.67%) after adopting the new practices. Mean fruit yield increased from 105.58 ± 48.60 kg plant^{-1} before nutrient management to 141.17 ± 58.43 kg plant^{-1} afterward, a gain of 35.58 kg plant^{-1} (54.14%). A paired-samples t-test confirmed that the increase was highly significant ($t = -11.20$, $p < 0.001$), and yield before and after the intervention were strongly correlated ($R^2 = 0.829$), with low-yield categories (< 90 kg plant^{-1}) disappearing entirely after adoption of the improved practices. These findings indicate that moving away from sole reliance on farmyard manure toward balanced nutrition, particularly bone meal and micronutrient supplementation, can substantially raise mandarin productivity and support more sustainable, income-generating citrus farming in Nepal's mid-hill districts.

KEY WORDS: *Mandarin*; *Citrus reticulata*; *Nutrient management*; *Bone meal*; *Micronutrients*

1. Introduction

Agriculture underpins the Nepalese economy, contributing roughly one-sixth of national Gross Domestic Product and providing the principal livelihood for close to two-thirds of the population (Central Bureau of Statistics, 2021); within this sector, fruit, nut, beverage and spice crops alone account for more than one percent of GDP, and horticulture as a whole continues to expand as

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farmers shift from subsistence toward market-oriented production (Ministry of Agriculture and Livestock Development [MoALD], 2021). Citrus is among the most important cash crops for hill farmers (Regmi *et al.*, 2020; Shrestha, 2015; Sharma & Upadhayaya, 2020; Dahal *et al*., 2023), and mandarin (*Citrus reticulata* Blanco) is by far the dominant citrus species grown in the country, occupying roughly two-thirds of the citrus area and production (MoALD, 2021). The crop is cultivated across some 60 districts, mainly in mid-hill pockets between 800 and 1,400 m above sea level, where deep, well-drained loamy soils, moderate rainfall and frost-free winters favour its growth (Bishnu & Shiva, 2019).

Sankhuwasabha district, in Koshi Province, is recognized as one of the leading commercial mandarin-producing pockets of eastern Nepal, yet orchard productivity in the district remains far below its potential (Timsina *et al.*, 2025). A recurring constraint identified by growers and extension workers alike is nutrient management: most orchards have historically relied on farmyard manure (FYM) as the sole nutrient source, with negligible use of supplementary organic inputs such as bone meal or balanced micronutrient formulations (Adhikari *et al*., 2021; Poudel *et al.*, 2020). Because nutrient supply directly governs vegetative vigour, flowering, fruit set and fruit quality (Gogoi *et al*., 2018; Parent *et al*., 2025), this near-total dependence on a single, often nutrient-poor input is widely regarded as a major factor limiting yield and market quality in the district's orchards (Bishnu & Shiva, 2019).

In response, the National Agricultural Modernization Project (NAMP), the successor to the earlier Prime Minister Agriculture Modernization Project, has been promoting supplementary nutrient inputs - principally bone meal and micronutrient mixtures - together with complementary orchard management practices such as moderate pruning, Bordeaux paste application and mineral oil spraying, among commercial mandarin growers in Sankhuwasabha (Kandel & Chhetri, 2019). While the rationale for such interventions is well established in the wider citrus nutrition literature (Nasir *et al*., 2016; Gogoi *et al*., 2018), farm-level evidence on the extent of adoption and the resulting effect on yield in this specific district has not previously been documented systematically, with existing work on Sankhuwasabha having examined the socio-economic determinants of adoption rather than yield outcomes (Timsina *et al*., 2025).

This study therefore examined nutrient management practices among commercial mandarin growers of Sankhuwasabha district before and after the NAMP intervention, with three specific objectives: (i) to characterize the nutrient sources used by farmers prior to the intervention; (ii) to assess the adoption rate, application rate, method and duration of the additional nutrients (bone meal and micronutrients) promoted under the intervention; and (iii) to evaluate the effect of this additional nutrient application on plant health, fruit yield and perceived fruit quality of mandarin. The findings are intended to provide field-based evidence to guide extension planning and to support wider adoption of balanced nutrient management in Nepal's mid-hill citrus belt.

2. Material and Methods

2.1 Study area

The study was carried out among mandarin-growing communities of Sankhuwasabha district, Koshi Province, Nepal, located approximately between 27.06°-27.55° N latitude and 86.57°-87.40° E longitude. The district has hilly terrain and a subtropical-to-temperate climate with comparatively high rainfall, conditions that are favourable for commercial mandarin cultivation. Within the district, mandarin is grown on about 450 ha, of which roughly 207 ha are currently in production, yielding an estimated 2,000 metric tonnes annually (about 9.66 t ha^{-1}) (MoALD, 2021).

2.2 Research design

A descriptive survey design was adopted, being a non-experimental quantitative approach suited to capturing the characteristics, practices and perceptions of a defined farmer population at a given point in time through structured tools such as questionnaires and interviews.

2.3 Sampling technique and sample size

Mandarin-growing wards of Sankhuwasabha district were first selected purposively on the basis of commercial orchard concentration and exposure to the NAMP intervention. From these wards, 60 commercial mandarin growers were then selected for the survey.

2.4 Data collection

Primary data were collected through structured questionnaire-based interviews with individual farmers and through direct field observation of orchard practices. Secondary data on citrus area, production and productivity were obtained from published reports, journal articles and records maintained by district agriculture offices.

2.5 Data analysis

Data were coded, tabulated and analysed in Microsoft Excel and SPSS. Descriptive statistics - frequency, percentage, mean and standard deviation together with bar charts, box plots and scatter plots, were used to summarize the socio-demographic profile of respondents and their nutrient management practices before and after the NAMP intervention. A paired-samples t-test was used to determine whether the difference between fruit yield per plant before and after the intervention was statistically significant, and the coefficient of determination (R^2) was calculated to examine the strength of the linear relationship between pre- and post-intervention yield. Results are presented according to the specific objectives of the study.

3. Results and Discussion

3.1 Socio-demographic characteristics of respondents

Of the 60 mandarin growers surveyed, 51.68% were male and 48.31% female, indicating that mandarin cultivation in Sankhuwasabha engages both genders in comparable proportion (**Table 1**). By ethnicity, the sample was dominated by Chhetri (46.66%) and Janajati (26.66%) households, with smaller shares of Brahmin (20%) and Dalit (6.66%) growers, while by religion Hindu households predominated (70%), followed by Kirat (15%), Christian (8.33%) and Buddhist (6.66%) households. Literacy was comparatively high, with 68.33% of respondents reported as literate against 31.66% illiterate. This relatively literate farmer base is favourable for the uptake of extension messages and new input technologies, and is consistent with the high adoption rates for bone meal and micronutrients recorded after the

NAMP intervention, echoing earlier findings that literacy and extension contact are key determinants of adoption of improved mandarin management practices in Nepal (Poudel *et al.*, 2020; Timsina *et al.*, 2025).

Table 1: Socio-demographic characteristics of the mandarin-growing respondents (n = 60) in Sankhuwasabha district.

Characteristic	Category	Respondents (%)
Gender	Male	51.68
	Female	48.31
Ethnicity	Chhetri	46.66
	Janajati	26.66
	Brahmin	20.00
	Dalit	6.66
Religion	Hindu	70.00
	Kirat	15.00
	Christian	8.33
	Buddhist	6.66
Literacy	Literate	68.33
	Illiterate	31.66

Source: Field survey.

3.2 Nutrient management practices before the NAMP intervention

Prior to the NAMP intervention, nutrient supply in the surveyed orchards was overwhelmingly dependent on a single organic source. All 60 growers (100%) applied FYM as their nutrient base, while only 3 farmers (5%) additionally used poultry manure and 6 farmers (10%) used chemical fertilizer (**Table 2**). This pattern reflects the traditional, low-input orchard management typical of Nepal's hill districts (Adhikari *et al.*, 2021), where nutrient supply is generally drawn from locally available organic resources rather than from balanced, recommendation-based fertilization. Because FYM alone, particularly when produced and stored under farm conditions with variable composting practices, often supplies inadequate levels of phosphorus, calcium and micronutrients relative to citrus requirements (Gogoi *et al.*, 2018; Kandel & Chhetri, 2019), this near-exclusive reliance on FYM is a plausible explanation for the comparatively low pre-intervention yields recorded in this study.

Table 2: Nutrient sources used by mandarin growers before the NAMP intervention (n = 60; multiple responses).

Type of nutrient source	Farmers using (n)	Farmers using (%)
Farmyard manure (FYM)	60	100.00
Poultry manure	3	5.00
Chemical fertilizer	6	10.00

Source: Field survey, 2026.

3.3 Adoption of additional nutrient inputs after the intervention

Following promotion by NAMP, adoption of the two additional nutrient inputs was complete: all 60 growers (100%) reported using both bone meal and micronutrient mixtures, while none used oil cake or chemical fertilizer as a supplementary source (**Fig. 1**). This universal, near-simultaneous adoption of two previously unused inputs indicates strong farmer acceptance of the intervention package, likely reflecting both the visible, relatively rapid effect of bone meal and micronutrients on fruit development and the accompanying extension support provided through the project. Bone meal, as a source of phosphorus and calcium, is expected to support root development, flower initiation and fruit set (Gogoi *et al.*, 2018; Nasir *et al.*, 2016), while balanced micronutrient application addresses deficiencies - commonly of zinc, boron and manganese - that are frequently reported in mandarin orchards of Nepal's mid-hills and that otherwise constrain metabolic activity and fruit quality (Kandel & Chhetri, 2019; Pun & Shrestha, 2023; Parent *et al*., 2025).

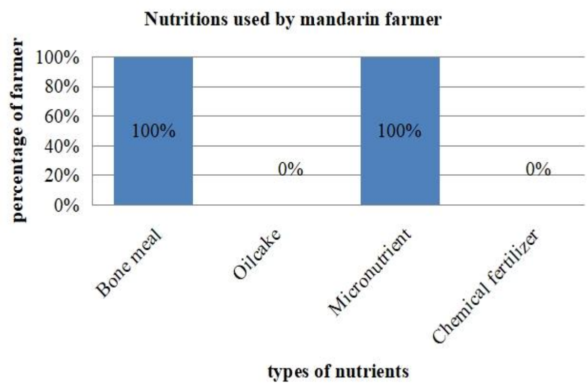

Fig. 1: Additional nutrient inputs adopted by mandarin growers after the NAMP intervention.

3.4 Application rate, method and duration of bone meal and micronutrients

Among the 60 bone-meal users, the majority (47 farmers, 78.3%) applied 250-500 g plant^{-1}, six farmers (10%) applied 750-1,000 g plant^{-1}, and seven farmers (11.7%) applied only 1-250 g plant^{-1}, giving an overall mean application rate of 395.89 g plant^{-1}. For micronutrients, application rates were markedly lower and more tightly clustered: 55 farmers (91.67%) applied only 1-250 g plant^{-1} and five farmers (8.33%) applied 250-500 g plant^{-1}, giving a mean rate of 146.29 g plant^{-1} (**Table 3**), consistent with the standard practice of applying micronutrient mixtures in small, foliar-oriented doses rather than as bulk soil amendments (Nasir *et al*., 2016).

Regarding application method, more than half of bone-meal users (55%) mixed the material with FYM before application, while the remainder (45%) applied it directly to the basin around the tree; broadcasting was not practiced by any respondent. Mixing bone meal with FYM likely improves the gradual release and soil incorporation of nutrients and may explain the relatively consistent uptake of the practice across the sample. In terms of duration, the largest group of farmers (41.67%) had been applying bone meal for two years and 33.33% for three years, with a mean duration of 2.48 years, indicating that although the intervention is comparatively recent, farmers have already accumulated two to three growing seasons of experience with the new inputs.

3.5 Complementary orchard management practices

Alongside the two nutrient inputs, several complementary practices promoted under the intervention were also widely taken up. Bordeaux

Table 3: Application rate of bone meal and micronutrients per mandarin plant (n = 60).

Input	Application rate class	Farmers (n)	Farmers (%)	Mean rate (g plant^{-1})
Bone meal	1-250 g	7	11.67	
	250-500 g	47	78.33	
	750-1,000 g	6	10.00	
	Overall mean	60	100.00	395.89
Micronutrients	1-250 g	55	91.67	
	250-500 g	5	8.33	
	Overall mean	60	100.00	146.29

Source: Field survey.

paste was applied mainly for disease prevention (41.67% of respondents) and wound treatment (33.33%), with most applications timed either just after pruning (41.67%) or during the winter season (38.33%). Pruning was practiced predominantly for pest and disease control (61.67%) and canopy management (38.33%), carried out mostly after harvest (60%), with a moderate pruning intensity favoured by 70% of growers. Mineral oil sprays were used mainly against aphids (33.33%) and mites (20%), applied twice per season by 48.33% of users, and 56.67% of those who applied mineral oil reported a noticeable reduction in subsequent pest incidence. Although these practices were not the primary focus of the present study, their concurrent adoption alongside bone meal and micronutrient application means that the yield improvement reported below reflects the combined effect of a broader package of improved orchard management rather than nutrient supplementation in complete isolation.

3.6 Farmer-perceived changes in plant health and fruit characteristics

Nearly all respondents attributed a visible improvement in fruit shape and fruit yield to the new nutrient regime, with both indicators reported by 100% of the 60 growers (**Table 4**). A majority also reported improved vegetative growth (63.33%), while smaller proportions observed changes in leaf colour (21.67%) and flowering behaviour (15%).

The consistency with which fruit shape and yield were singled out suggests that the additional phosphorus, calcium and micronutrients supplied through bone meal and the micronutrient mixture had their most pronounced, and most readily observable, effect on reproductive rather than purely vegetative growth parameters.

Table 4: Farmer-perceived changes in mandarin plant health and fruit characteristics after adoption of additional nutrients (n = 60; multiple responses)

Observed change	Farmers reporting (n)	Farmers reporting (%)
Fruit shape	60	100.00
Fruit yield	60	100.00
Vegetative growth	38	63.33
Leaf colour	13	21.67
Flowering	9	15.00

Source: Field survey, 2026.

3.7 Effect of nutrient management on fruit yield

The quantitative yield data corroborated farmers' qualitative perceptions. Before the intervention, mean fruit yield was 105.58 ± 48.60 kg plant^{-1}, ranging from 15 to 200 kg plant^{-1}. After adoption of bone meal, micronutrients and the associated orchard management practices, mean yield rose to 141.17 ± 58.43 kg plant^{-1}, with a narrower minimum-to-maximum range of 80-250 kg plant^{-1} (**Fig. 2**). This represents a mean gain of 35.58 kg plant^{-1}, or 54.14%, per tree. The increase in the minimum recorded yield from 15 kg to 80 kg plant^{-1} is particularly notable, indicating that the intervention benefited even the district's lowest-performing orchards, and is consistent with the improved availability of phosphorus, calcium and micronutrients supporting photosynthesis, flower bud initiation and fruit retention across the sampled population (Gogoi *et al*., 2018; Nasir *et al*., 2016).

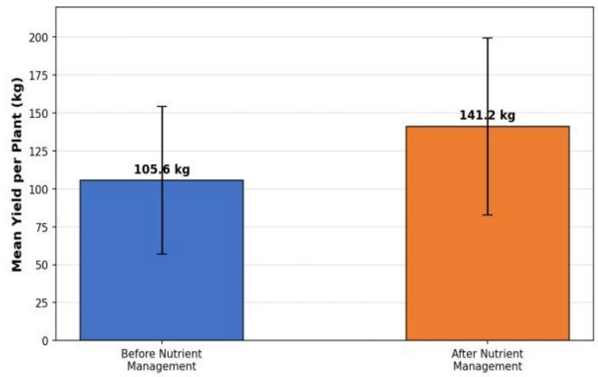

Fig. 2: Mean fruit yield per mandarin plant before and after adoption of additional nutrient management practices (n = 60)

3.8 Statistical validation of the yield improvement

A paired-samples t-test comparing yield per plant before and after the intervention returned t = -11.20 with $p < 0.001$, confirming that the observed gain in yield was highly statistically significant and not attributable to chance (**Table 5**). Yield before and after the intervention were also strongly and positively correlated, with a coefficient of determination of $R^2 = 0.829$ and a fitted regression of $Y = 1.094X + 25.617$, where X and Y denote yield before and after nutrient management, respectively. The positive slope indicates that farmers who already had comparatively high pre-intervention yields tended to record proportionally higher post-intervention yields as well, implying that nutrient management delivered a broadly consistent benefit across the sample rather than disproportionately favouring any single yield category.

This distributional shift is further illustrated by the box plot of yield values before and after the intervention (**Fig. 3**), in which the median yield rose from approximately 120 to 165 kg plant^{-1} and the overall spread of the data widened, showing that low, medium and high yielding growers alike benefited from the improved nutrient regime, with the widening interquartile range among higher-yielding plants suggesting that the best-managed orchards responded most vigorously to the additional nutrients.

Table 5: Descriptive statistics and paired t-test results for mandarin fruit yield per plant before and after nutrient management (n = 60)

Parameter	Yield before (kg plant^{-1})	Yield after (kg plant^{-1})
Minimum	15	80
Maximum	200	250
Mean	105.58	141.17
Standard deviation (±)	48.60	58.43
Mean increase (kg)	-	35.58
Mean increase (%)	-	54.14
Paired t-test	t = -11.20 ($p < 0.001$)	
Coefficient of determination (R^2)	0.829	

Source: Field survey, 2026. $p < 0.001$ = highly significant.

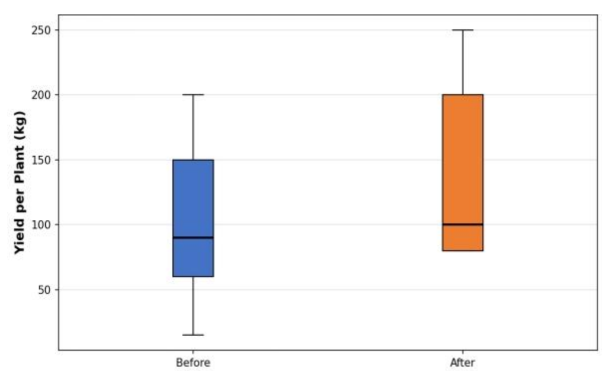

Fig. 3: Distribution of mandarin fruit yield per plant before and after nutrient management, shown as a box plot (n = 60).

The scatter plot of paired yield values (**Fig. 4**) similarly shows that the high R^2 of 0.829 reflects a consistent, near-proportional relationship across the full range of orchards sampled, so that roughly 83% of the variation in post-intervention yield can be statistically explained by the pre-intervention yield level. Together, the paired t-test, the coefficient of determination and the frequency-class analysis (where farmers yielding below 90 kg $plant^{-1}$ before the intervention were entirely absent from the lowest yield classes afterward) provide converging evidence that the adoption of bone meal, micronutrients and the accompanying orchard practices produced a robust, broadly distributed improvement in mandarin productivity in Sankhuwasabha district. These results are consistent with reports from other mid-hill citrus-growing areas of Nepal, where balanced fertilization and micronutrient correction have similarly been associated with substantial gains in citrus yield and fruit quality (Kandel & Chhetri, 2019; Pun & Shrestha, 2023; Dahal *et al.*, 2023; Regmi *et al.*, 2020).

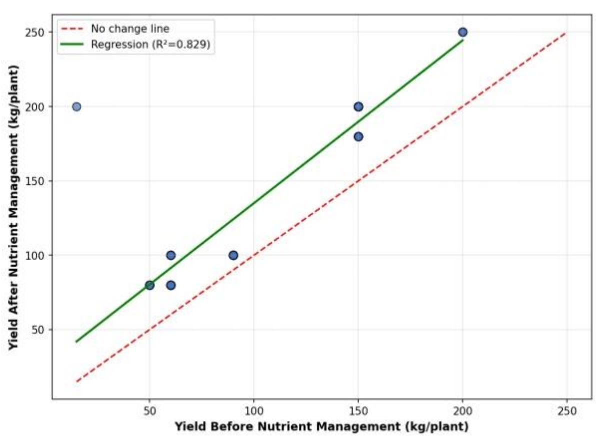

Fig. 4: Correlation between mandarin fruit yield per plant before and after nutrient management (R^2 = 0.829)

4. Conclusion

This study shows that, before the NAMP intervention, nutrient management in mandarin orchards of Sankhuwasabha district was almost entirely dependent on farmyard manure, with negligible use of complementary organic or chemical nutrient sources. Promotion of bone meal and balanced micronutrients achieved complete adoption among the surveyed growers and, together with complementary practices such as moderate pruning and Bordeaux paste application, was associated with a highly significant 54.14% increase in mean fruit yield per plant, from 105.58 to 141.17 kg, with the improvement statistically confirmed ($p < 0.001$) and consistently distributed across low, medium and high-yielding orchards (R^2 = 0.829). These findings indicate that transitioning from sole reliance on farmyard manure to balanced nutrient management focused on bone meal and micronutrient supplementation is an effective, farmer-acceptable pathway to raising mandarin productivity in Nepal's mid-hill districts, consistent with earlier evidence that adoption of improved orchard management is shaped by farmers' socio-economic circumstances and extension access (Poudel *et al.*, 2020; Timsina *et al.*, 2025). Continued extension support, training on correct dosage and timing, and integration of nutrient management with irrigation, pruning and plant protection are recommended to sustain and extend these gains, while future work should evaluate the longer-term and fruit-quality effects of these practices using laboratory-based quality parameters and multi-season yield monitoring, and should extend to post-harvest handling and value addition, given the demonstrated influence of these stages on marketable mandarin quality and returns (Paudel *et al*., 2019; Zaki & Krishnapal, 2020).

5. Conflict of Interest

The authors declare that they have no conflict of interest.

6. Acknowledgment

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