Causes of citrus decline and its management practices adopted in Myagdi district, Nepal

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ARTICLE INFO

Keywords:
Citrus decline
Management practices
Orchard
Productivity
Rejuvenation

ABSTRACT

Citrus decline has been the major constraint faced by citrus growers in Nepal. Survey research was conducted in Beni municipality and Malika rural municipality of Myagdi district to study the cause of citrus decline and their management practices. A total of 94 mandarin growing farmers were selected randomly and interviewed with a semi-structured questionnaire. Analytical tools like logistic regression, multiple linear regression, and t-test were used to derive the inferences needed. The study showed that 72.3% of the mandarin growing farmers had experienced citrus decline problems in their orchards. Disease and pest incidence, climatic extremities, poor fertility status of soil, low-quality planting materials, and poor orchard management were found to be positively influencing citrus decline. Insect infestation was 52 percent more likely to cause citrus decline as compared to insect non-infested conditions. The study revealed that 75.5% of the farmers use farmyard manure (FYM) of more than 30 kg per plant per year, 44.7% of the farmers use chemical fertilizers, 85.1% of the farmers irrigate their orchard, 98.94% of farmers practice weeding, 33% of the farmers practice mulching, 84% of the farmers practice pruning, 50% of the farmers use Bordeaux mixture and 61.7% of the farmers manage insects. Moreover, effective orchard management practices like manuring, irrigation, pruning, Bordeaux application, and insect management were significantly associated with a higher percentage of rejuvenation of declining orchards. The productivity of mandarin orchards, in addition, was significantly enhanced by FYM application, chemical fertilizers, irrigation, weeding, and Bordeaux application. This study elucidated that citrus decline has been the major constraint of mandarin farming, and improved management practices are pivotal for combating the citrus decline.

1. Introduction

Citrus is amongst the most important commercially grown fruit crop of Nepal. It has been grown in 62 districts of Nepal covering 46,715 ha of land with the production and productivity of 274,140 Mt (metric tons) and 10.03 Mt/ha respectively (MoALD, 2019). The mid-hill region of Nepal: 900–1400 m above sea level (masl) - due to its affirmative climates-has a comparative advantage in citrus cultivation (Acharya et al., 2019). Syangja, Sindhuli, Myagdi, Solukhumbu, Udaypur, Gulmi, Jajarkot, Gorkha, and Dailekh are some of the major citrus-growing districts in the mid-hill region of Nepal. Nepal, due to its felicitous soil and climatic conditions, has immense potential for citrus farming. Mandarin, sweet orange, lime, and lemon are the major citrus fruits produced in Nepal (Budathoki et al., 2004). With the vision of increasing the commercial production of citrus fruit, the government of Nepal has executed 10 zones and a superzone under the Prime Minister Agriculture Modernization Project (PMAMP) in 11 districts of Nepal (PMAMP, 2019).

Mandarin (Citrus reticulata Blanco) is a subtropical fruit grown in a wide range of soil with optimum pH between 5.5 and 6.5, receiving an average annual rainfall of 125 cm–180 cm, and having mild (frost-free) winter (Acharya et al., 2019). Mandarin is an indigenous fruit of Nepal that has been grown traditionally from times immemorial. Mandarin production had been prioritized in the Agricultural Perspective Plan (APP) (1995–2015) and its priority has been carried by the Agriculture Development Strategy (ADS) (2015–2035). In Nepal, mandarin is grown in 26,591 ha of land with the production of 156,179.68 Mt; it has national average productivity of 10.73 Mt/ha (MoALD, 2019). Though the area under cultivation and production of mandarin is continuously waxing, its productivity has been waning over the years (NFDP, 2019).

The citrus decline has been a major and contemporary shortcoming in citrus cultivation in Nepal. Many trees in the citrus orchards have either turned into dried skeletons or are dying back (Panth and Dhakal, 2019). The citrus decline is not a specific disease but is a symptomatic expression of many causes (Paudel and Shrestha, 1995). Incidence of disease and...
pests, poor planting materials, poor soil status, and climatic variability associated with poor management practices have lowered the productivity of the orchard (FAO, 2011; Panth and Dhakal, 2019). Although the citrus decline has been seen throughout Nepal, it is reported to be severe in the western region (NARDF, 2015). Declining citrus trees do not usually die for several years but remain unproductive; they generally appear on bearing trees aged 15–20 years (FAO, 2011). Diseases like root rot, stem rot, huanglongbing (HLB), canker, gummosis, pink disease, etc. have affected the citrus orchards of the country. The citrus greening disease has been a major mishap of citrus decline in Nepal, and its severity is higher in lower belts (up to 900 m altitude) (Roistacher, 1996). Moreover, this disease is rapidly spreading and poses a great threat to citrus orchards (Regmi and Yadav, 2007; Knorr et al., 1970). Phytophthora species, additionally, cause foot rot, root rot, crown rot, gummosis, leaf fall, and brown rot disease in citrus (Paudel and Shrestha, 1995). Similarly, different insect pests cause damage to citrus leading to their decline. Insects like citrus psylla, fruit fly, scale insect, stem borer, and leaf miner are serious threats to citrus cultivation (Budathoki and Pradhanang, 1990; Nath and Sikha, 2019). The Chinese fruit fly, Bactrocera minax has been the most devastating pest and causes severe damage to the plants (Sharma et al., 2015). Likewise, citrus psylla is the vector of greening disease and is now highly reported in Nepal (Regmi and Yadav, 2007). Several factors have consorted to citrus decline and the declining production has led to dissatisfaction among the citrus growers and ignorance of the orchards.

Most of the citrus orchards, in Nepal, are either mismanaged or neglected leading to poor orchard hygiene. Planting trees at the edges of the terraces and with less spacing, poor and uncertified seedlings, poor nutrition, excessive intercropping with exhaustive crops, lack of specific training and pruning practices, and lack of effective disease and pest control are major factors for the decline in productivity of citrus in Nepal (FAO, 2011). Climatic uncertainties like a long spell of drought and strong hailstorms during flowering and fruiting cause blossom and fruit drops in citrus (Dhakal et al., 2002).

Improved management practices, however, can be a good panacea to rejuvenate the declined orchard (Ansari et al., 2011). Farmyard manure is the most common form of organic manure applied in the mid-hills of Nepal since ancient times. Fertilizer application increases the yield, fruit quality, and resilience (Obreza et al., 1993). Water management has a direct impact on tree health as well as fruit yield, size, and quality (Dorji et al., 2016). Regular weeding, and intercropping with shallow-rooted, short-duration, and restorative crops provide higher income potential (Gauchan et al., 1994). Similarly, pruning the trees just after harvest and giving an ideal shape like a low head with a dome-like crown, and treating with a Bordeaux mixture will benefit the tree health (FAO, 2011; Tucker et al., 1994). Lime should be applied if the soil is acidic and if the orchard is in slopppy land where the leaching of cation is higher (Natal et al., 2012). Likewise, mulching citrus orchard helps to retain moisture, and the best time for mulching in Nepal is Sept.–Oct (Rai, 2004). The use of effective bio-control and IPM measures to control disease and pests, further, promotes tree health and increases tree production (Astraf et al., 2014).

Despite the fact that citrus decline is a symptomatic expression of many causes, and since no single measure can manage the problem, good agricultural practices would sustain the health of orchards and enhance productivity (Paudel and Shrestha, 1995). Provided technical assistance and extension services to the farmers, improved management practices would rejuvenate the orchard and augment productivity. This research, at the end, will help to assess the prevailing factors leading to a decline in production and highlight effective management practices to remediate the declining orchard.

2. Objectives

2.1. Broad objective

To know the different factors associated with the citrus decline in Nepal and prevailing management practices to remediate them.

2.2. Specific objectives

To assess the extent and causes of citrus decline in the study area.

To know the different orchard management practices adopted by farmers

To study the rejuvenation of declined orchards in association with different management practices.

3. Research methodology

3.1. Site selection and sampling technique

The research was conducted in Beni municipality (28.37° N, 83.54° E) and Malikha Rural municipality (28.41° N, 83.38° E) of Myagdi district, Nepal (Figure 1). Geographically, the district is situated in the hilly region of Nepal, extending from 28°20’ to 28°47’ North and 83°08’ to 83°53’ East, and is elevated from 792 masl to as high as 8,167 masl. The total mandarin growing farmers of the citrus zone command area were taken as a sampling frame. The sample size was determined using Raosoft software by Raosoft, Inc. and a total of 94 Mandarin growing farmers were selected as samples using a simple random sampling technique.

3.2. Sources of data collection and survey design

A semi-structured questionnaire was prepared and pre-tested on 10 percent of respondents near the study area to check its reliability and validity and then a final interview schedule with necessary adjustments, as per the requirements, was administered to the respondents. Primary data were procured through household surveys, focus group discussions, and key informant interviews after informed consent was obtained from all participants of the experiment. Additional information on actual field conditions was obtained from direct field observations. The secondary information was acquired through reviewing different publications like the reports of the Ministry of Agriculture and Livestock Development (MoALD), Nepal Agricultural Research Council (NARC), Agriculture Knowledge Center (AKC) Myagdi, etc.

3.3. Methods and techniques of data collection and analysis

The information collected from the field was first coded and entered into the computer; data entry and analysis, in the same way, were done by using computer software packages like the Statistical Package for Social Science (SPSS), MS Excel, and STATA. Qualitative data were analyzed using Frequency and Percentage, while quantitative data were analyzed by using both descriptive and analytical statistics. Analytical tools like indexing/scaling technique, logistic regression, and t-test were used to derive different inferences needed.

3.3.1. Indexing

Indexing was done for the quantification of qualitative phenomena regarding the ranking of major insect pests and major diseases seen in the mandarin orchard. Scaling techniques, which provide the direction and extremity attitude of the respondent towards any proposition was used to construct the index (Miah, 1993). The ensuing equation (Eq. 1) was used to index and rank the most prevailing insects and diseases in the study area.

\[
I_{\text{prob}} = \sum \frac{S_iF_i}{N}
\]

Where,

\[
I_{\text{prob}} = \text{Index value for intensity.}
\]

\[
\Sigma = \text{Summation.}
\]

\[
S_i = \text{Scale value of } i^{th} \text{ intensity.}
\]

\[
F_i = \text{Frequency of } i^{th} \text{ response.}
\]

\[
N = \text{Total number of respondents.}
\]
3.3.2. Logistic regression

Different factors causing citrus decline were computed using a binary logistic regression model. It has a dependent variable \( Y \) with two possible values (For example, \( 1 = \text{declined} \) and \( 0 = \text{not declined} \)) and independent variable/predictors \( X_1, X_2, \ldots, X_m \) (For instance, various decline causing factors). The linear relationship between predictor variables and log-odds of probability/event that \( Y = 1 \) can be written as Eq. (2).

\[
\ln \frac{p}{1-p} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_m
\]

Where \( \ln = \log \)-odds.

\[ \beta = \text{parameters of model and probability that } Y = 1 \text{ is given as (Eq. 3)} \]

\[
p = \frac{1}{1 + e^{-\beta_0 - \beta_1 X_1 - \beta_2 X_2 - \ldots - \beta_m X_m}}
\]

3.3.3. T-test

Two sample t-test was performed to compare the means of rejuvenated percentage using group variables of adoption and non-adoption of management practices. The t-test is computed as shown in Eq. (4).

\[
t = \frac{(\bar{X}_1 - \bar{X}_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}
\]

Where, \( \bar{X}_1, s_1, n_1 \) are mean, variance, and number of observations for the first group and \( \bar{X}_2, s_2, n_2 \) are mean, variance, and number of observations for the second group.

4. Results and discussion

4.1. Socio-economic characteristics

The study showed that the majority of the respondents were male (76.40%), whereas only 23.40% of the respondent farmers were female. The mean age of the respondents in the study area was found to be 47.82. Likewise, the preponderance of the respondent households in the study area belonged to Janajati ethnic community (57.40%) followed by Chhetri (21.30%), Brahmin (14.90%), and Dalit (6.40%). Further, the majority of the respondents had a Secondary level of education (23.4%), followed by illiterate respondents (22.3%) and then by respondents having a lower secondary level of education (21.3%). Respondents having higher secondary level and primary level of education were 12.8% each. Only 7.4% of the respondents had a bachelor’s and above degree of education. The study, moreover, revealed that the bulk part of the respondent’s family members was under the economically active age group (56.55%) after that the younger age group (29.83%) and then the older age group (13.62%). Similarly, the study indicated that the primary source of income of the generality of respondent households was agriculture (52.1%), trailed by remittance (24.5%), service (8.5%), wage labor (7.4%), and business (7.4%). Interestingly, mandarin growing farmers in the study area had integrated livestock as a pivotal component of their farming as they provide manure together with the additional farm income. The study outlined that the average figure of buffalo, cow, goat, and poultry in the study area were 1.84, 0.59, 2.91, and 5.44, respectively.

Furthermore, the average time involved in mandarin orchard management and regular supervision of the farm in the study area were found to be 2.01 h per day. Besides, the study manifested that the entanglement of male members (63.48%) of the family in mandarin farming was higher than female members (36.52%) of the family. It indicates that males are actively involved and have greater knowledge in orchard management than females. The study reported that the average area per household under mandarin farming was 7.49 ropani (0.38 ha), and 54.37% of mandarin trees in the study area were at the bearing stage. The total production of mandarin in the study area, however, has reduced from 391.04 Mt in the year 2019/020 to 340.61 Mt in the year 2020/021. Similarly, productivity has declined from 12.39 Mt/ha in the year 2019/020 to 10.82 Mt/ha in the year 2020/021, which might be due to several factors including climatic factors, insect and disease incidence. The average variable cost per tree per annum in the study area was found to
be NPR (Nepalese Rupee) 140.01 and the average income per fruit-bearing tree per annum was found to be NPR 1230.98. This indicates that mandarin farming is a highly profitable business in the study area. Over and above, the study revealed that 73.4% of the farmers had institutional support for input services like saplings, CuSO4, pesticides, etc. from AKC, Myagdi and Citrus zone, PMAMP, Myagdi, whereas 26.6% of the farmers had not got any of the input services support. Similarly, 53.2% of the farmers had got training and extension services on orchard management while 46.8% of the farmers did not have access to such training and extension services.

4.2. Citrus decline

4.2.1. Status of citrus decline in the study area

The study showed that 72.3% of the orchards in the study area were affected by the decline. Of the 185.93 trees (on average) per orchard in the study area, 6.50 trees per orchard were affected by the citrus decline. 27.7% of the orchards in the study area, however, were free from citrus decline.

Furthermore, the majority (35.3%) of farmers with a declined orchard reported that declined trees were aged above 20; 19.12% of the farmers proclaimed that decline is more seen in trees aged between 10 to 15 years of age and 17.6% of farmers found decline mostly in trees aging 15–20 years of age. Only 14.7% and 13.2% of the farmers with declined orchards reported that the declined trees were aged between 0 to 5 years of age and 5–10 years of age, respectively. This reflects that citrus decline is inordinately seen in older aged trees above 20 years of age.

4.2.2. Factors causing citrus decline

4.2.2.1. Biological factors

4.2.2.1.1. Insect incidence. As reported by the farmers, the mandarin orchard had been highly infested by insects in the study area. While ranking the insect incidence by indexing technique, the fruit fly was the most problematic insect in the study area followed by the stem borer (Table 1). The utmost insects prevalent in the study area are shown in Table 1.

4.2.2.1.2. Disease incidence. Several diseases were reported to cause a citrus decline in the study area. The ranking of the diseases through the indexing/scaling method manifested that twig blight/wither tip was the most rampant disease in the study area followed by sooty mold and powdery mildew (Table 2). Though the general symptoms of HLB disease were seen in some of the orchards, almost all farmers (100%) reported that the orchard was not tested for greening disease. Table 2 presents the major diseases prevalent in the study area.

4.2.2.1.3. Phanerogamic parasites. Parasitic plants like Loranthus had plagued the branches of aging trees in most of the orchards (63.8%). Loranthus appropriates water and minerals from mandarin plants as well as occludes sunlight in encroached places causing the decline of the tree ((Kumari et al., 2020).

4.2.2.1.4. Grazing of cattle and goats in the orchard. The data evinced that 26.6% of the orchard was reachable by cattle and goats. The browsing animals may impair younger tree growth and can deflate the bark of trees leading to stressful conditions for the plant (Wilson and Hardestry, 2006).

4.2.2.2. Climatic factors. From the study, 27.7%, 23.4%, and 8.5% of farmers reported that their orchard was highly affected by hailstorms, erratic rainfall, and drought/moisture stress, respectively. Similarly, 43.6%, 42.6%, and 22.3% of the respondent farmers in the study area reported that their orchard was moderately distressed by hailstorms, erratic rainfall, and drought/moisture stress, respectively. Hailstones and heavy rain at flowering and fruit sets are highly responsible for flower and fruit drops. Likewise, the unavailability of moisture during the critical period (flowering and fruit setting) of the plant is greatly associated with the decline in production (Fereres et al., 2003).

4.2.2.3. Soil and nutritional factors. From the study, it was observed that 76.6 % of the farmers had not tested the soil for pH and nutritional status; neither have they practiced liming on their orchards. Acidic soil is strongly associated with deficient levels of exchangeable bases (principally calcium, magnesium, potassium, and sodium) and hampers crop yield (Natale et al., 2012). Some of the orchards (22.3%) were established in rugged soil, which encumbers proper penetration of roots resulting in poor establishment. Nevertheless, almost all orchards in the study area had proper drainage. Stagnant water would impair root growth and their function leading to declining of the tree (Lewis and Work, 1931). Unfortunately, the study revealed that 47.9% of the orchard in the study area had a primary nutrient deficiency, and 60.6% of the orchard had micronutrient deficiency. Nutrient deficiency hampers physiological functions and biochemical processes causing the decline of the orchard (Srivastava, 2013).

4.2.2.4. Planting materials related-factors. The study exhibited that 81.9% of the planting materials were purchased from private nurseries, 12.8% of the planting materials were self-prepared by the mandarin growers, and 5.3% of the planting materials were procured from governmental nurseries. From the study, it was discovered that 84% of the mandarin grower's orchards were established using seed propagated saplings, while 16% of the farmer's orchards were established using both seeds propagated as well grafted saplings. Similarly, most of the farmers (97.9%) in the study area have been using uncertified saplings. Farmer's preference for seed propagated plants might be due to their hardiness (even though they have a long juvenile phase), whilst grafted plants are

| Table 1. Ranking of the insects that occurred in the study area. |
|------------------|---------|-----|
| Insect infestation | Index   | Ranking |
| Citrus leaf miner | 0.53    | VII   |
| Fruit fly         | 0.94    | I     |
| Aphid             | 0.54    | VI    |
| Citrus Green bug  | 0.56    | IV    |
| Citrus scale      | 0.36    | IX    |
| Whitefly          | 0.31    | X     |
| Citrus butterfly  | 0.36    | VIII  |
| White grub        | 0.55    | V     |
| Stem Borer        | 0.63    | II    |
| Red ant           | 0.59    | III   |
| Source: Field Survey, 2021 |

| Table 2. Ranking of the diseases occurred in the study area. |
|------------------|---------|-----|
| Disease infestation | Index   | Rank |
| Sooty mold       | 0.70    | II   |
| Foot rot         | 0.364   | VIII |
| Citrus scab       | 0.359   | IX   |
| Citrus canker     | 0.367   | VII  |
| Pink Disease      | 0.44    | V    |
| Powdery mildew    | 0.66    | III  |
| Citrus gummosis   | 0.39    | VI   |
| Twig blight/Wither tip | 0.74 | I    |
| Root rot         | 0.34    | X    |
| Algal spot        | 0.62    | IV   |
| Source: Field Survey, 2021 |
short-lived and have a high risk of citrus decline (Ollitrault and Navarro, 2012). 18.1% of the farmers were exercising poor, unhealthy planting materials during the initiation of the plantation of mandarin. Poor planting material is highly conducive to citrus decline (FAO, 2011).

4.2.2.5. Planting position and land characteristics related-factors

4.2.2.5.1. Facing of the Mandarin field. While 53.2% of the mandarin growing fields in the study area were north-faced, 46.8% of the fields were facing south/east. South/East-faced slopes have more exposure to sunlight than north-facing slopes resulting in a higher loss of moisture that results in weak growth of citrus plants and fruit drop (Ekishana, 2021).

4.2.2.5.2. Planting position. The study revealed that 60.6% of the farmers had planted their mandarin in the mid-portion of the terraced field, while 39.4% of the farmers had planted their mandarin trees on the edges of the field. Trees planted on the edges of the terraced-field encounter stones in their root zone, suffer malnutrition and are more prone to decline (FAO, 2011).

4.2.2.6. Poor orchard management practice related-factors

4.2.2.6.1. Pit digging and pit filling. The study reflected that 75.5% of farmers established their orchards through pit preparation, whereas 24.5% planted mandarin trees directly on the field without pit preparation. Plantation without a pit causes bending of the roots and has improper aeration hence poor establishment (Telbirt, 1939). Similarly, 51.1% of the farmers in the study area used to plant trees by filling the pits just after pit digging, while 48.9% used to leave the pit open for about 1 month before plantation for solarization. Soil solarization -an eco-friendly soil disinfestation method using sunlight-helps to manage different soil-borne plant pathogens (Gill et al., 2017).

4.2.2.6.2. Intercropping. 74.5% of the farmers in the study area were practicing intercropping, of which 40.4% intercrop mostly exhausting crops (maize, millet, barley, and wheat), 24.5% intercrop mostly legumes (pea, bean, and cowpea), and 9.6% intercrop both exhaustive and legume crops in their orchard. Legume-based intercrop enhances the productivity of citrus, which might be attributed to the positive role of legumes in soil-fertility enrichment. Intercropping of the exhaustive crops, however, impairs the fruit yield of citrus, which might be due to tree-crop competition for nutrients, moisture, and space (Srivastava et al., 2007).

4.2.2.6.3. Ignorance of orchard. Ignorance of orchard is highly associated with a decline in citrus trees. Some farmers (3.19%) in the study area do not practice weeding, and some (16%) do not practice pruning of the mandarin trees. Trees with water sprouts, dead and dried twigs, phanerogamic parasites, and crowded conditions are prone to poor light exposure, and have low productivity with reduced size and quality than properly pruned trees (Tucker et al., 1994). Some farmers (7.4%) in the study area practice ineffective pruning techniques using sickle/axe. In addition, 37.2% of farmers in the study area use unsanitized equipment, which might be a seminal source of disease infection.

4.2.2.6.4. Intensive plowing. The study showed that 25.5% of the farmers in the study area have been practicing intensive plowing in the orchard. Intensive plowing in mandarin orchards disrupts feeder roots and makes the soil more prone to erosion (Gerdà et al., 2009).

4.2.3. Influence of different factors on the citrus decline

The study revealed that citrus decline was positively influenced by insect infestation, disease incidence, Hailstorm damage, nutrient deficiency, plantation at the edge of the terrace, plantation without pit, and intercropping (Table 3). Meanwhile, the odds ratio of insect incidence is 22.99, which means that the likelihood of a citrus decline in insect-infested orchards is 22.99 times higher than in insect non-infested conditions, and is statistically significant at a 1% level of significance. Through marginal effect after logistic analysis, it is predicted that insect infestation is 52 percent more likely to cause citrus decline as compared to insect non-infested conditions, which is statistically significant at a 5% level of significance.

4.3. Management practices on combating citrus decline

4.3.1. Manuring and fertilization

75.5% of the farmers in the study area have been practicing the use of FYM on an average of more than 30 kg per plant per year, while 24.5% use less than 30 kg per plant per year. In addition to supplying nutrients gradually for a longer time, FYM has a salutary effect on soil health as it helps in ameliorating soil physical properties like water-holding capacity, soil aggregate stability, and mitigating soil erosion (Kumar et al., 2017). Similarly, 44.7% of the farmers in the study area use chemical fertilizers to supply primary nutrients, and 37.2% practice micronutrient application in their orchards. Nutrient ensures proper physiological functions and biochemical processes of plants enhancing better vegetative growth, fruit yield, and quality (Zekri and Obreza, 2003).

4.3.2. Irrigation

The study portrayed that 85.1% of the farmers in the study area irrigate their orchard, while 14.9% of the respondent's orchard depends on rainfall. The average annual rainfall in the study area is 1683.5 mm. Irrigation promotes better root development, canopy development, fruit yield, and quality and hence plays a vital role in combating citrus decline (Levy, 1998). At the same time, 55.3% of the households were practicing flooding irrigation, while 44.7% were using sprinkler irrigation. Sprinkler irrigation requires less water and is less prone to erosion and nutrient leaching than flooding irrigation (Carr, 2012).

4.3.3. Weeding

The average frequency of weeding in the mandarin orchards in the study area was 2.71 per year, and 98.94% of the farmers practice weeding. Weed management alleviates crop-weed competition and promotes better tree growth and yield (Froud-Williams, 2002).

Table 3. Logistic regression analysis and marginal effect after logistic analysis of citrus decline with different factors causing citrus decline.

| Causes of citrus decline | Odds Ratio | Std. Err. | Z | p>|z| | dy/dx | p>|z| |
|--------------------------|------------|-----------|---|-----|------|-----|
| Insect infestation       | 22.99      | 26.47     | 2.72 | 0.006*** | 0.52 | 0.045** |
| Disease incidence        | 2.38       | 2.27      | 0.91 | 0.37 | 0.10 | 0.41   |
| Hailstorm damage         | 1.26       | 0.77      | 0.38 | 0.71 | 0.02 | 0.70   |
| Primary Nutrient deficiency | 5.12     | 6.19      | 1.35 | 0.18 | 0.17 | 0.19   |
| Micronutrient deficiency | 2.04       | 2.14      | 0.68 | 0.50 | 0.08 | 0.53   |
| Edge planting position   | 1.75       | 2.40      | 0.41 | 0.68 | 0.06 | 0.66   |
| Plantation without pit   | 2.31       | 2.68      | 0.72 | 0.47 | 0.08 | 0.44   |
| Intercropping            | 1.41       | 1.72      | 0.28 | 0.78 | 0.04 | 0.80   |
| Poor packaging material  | 3.40       | 5.91      | 0.70 | 0.48 | 0.09 | 0.33   |

Source: Field Survey, 2021
4.3.4. Mulching

33% of the mandarin growing farmers in the study area have been practicing mulching with green/dried leaves and straw. Mulching abates the harmful effect of weeds; it also foreshortens extreme hydrological and temperature conditions in the citrus orchards (Liu et al., 2014).

4.3.5. Pruning

The data revealed that 84% of the farmers practice pruning activities. Pruning favors light penetration inside the canopy, promotes better fruit quality, controls pests and diseases, controls alternate bearing, and promotes rejuvenation of declined orchards (de Azevedo et al., 2013).

4.3.6. Application of bordeaux paste and bordeaux mixture

60.6% of the farmers in the study area apply Bordeaux paint on tree trunks and 50% practice foliar spray of Bordeaux mixture. Bordeaux components function as fungicides and bactericides controlling several diseases of citrus, including powdery mildew, sooty mold, citrus canker, etc (Raj, 1999).

4.3.7. Disease and insect management

The study revealed that 54.3% of farmers in the study area practice disease management through cultural and chemical methods and 61.7% of the farmers practice insect management using physical/cultural/chemical strategies. Effective disease and insect management reduces the decline of citrus orchards and enhances the productivity of trees (Ashraf et al., 2014).

4.4. Status of rejuvenation of declined orchard

Although the 88.24% of declined orchards in the study area had some rejuvenated trees (trees with restored vigor, vitality, and productivity), 11.76% of declined orchards did not show any rejuvenation. The average rejuvenation percentage of the declined trees was found to be 33.50%. Improved management practices might have contributed to the revitalization of the declining trees.

4.5. Rejuvenation of declining orchards through different management practices

4.5.1. Distribution of rejuvenated Mandarin trees according to FYM application

The mean rejuvenation percentage of declined trees in FYM applied less than 30 kg per plant per year was 23.79 ± 25.15 and in FYM applied more than 30 kg per plant per year was 38.15 ± 28.98, and the difference was significant at a 5% level of significance (Table 4). It indicates that FYM incorporated in adequate amounts promotes the rejuvenation of declining trees.

4.5.2. Distribution of rejuvenated Mandarin trees according to irrigation facility

The mean rejuvenation percentage of declined trees in the rainfed condition was 15.47 ± 18.99 and in irrigated condition was 37.76 ± 28.73, and the mean difference was significant at a 1% level of significance (Table 5). It shows irrigation has a positive influence on the revitalization of declining trees.

4.5.3. Distribution of rejuvenated Mandarin trees according to pruning practice

The mean rejuvenation percentage of declined trees in unpruned conditions was 17.32 ± 27.2 and in pruned conditions was 37.70 ± 27.42, and the mean difference was significant at a 1% level of significance (Table 6). It implies effective pruning stimulates the regeneration of declining trees.

4.5.4. Distribution of rejuvenated Mandarin trees according to use of bordeaux mixture

The mean rejuvenation percentage of declined trees in the non-use of Bordeaux mixture condition was 22.64 ± 22.74 and in the use of Bordeaux mixture condition was 51.04 ± 28.27, and the mean difference was significant at a 1% level of significance (Table 7). It reflects that the application of the Bordeaux mixture advocates the restoration of senile trees.

4.5.5. Distribution of rejuvenated Mandarin trees with insect management practices

The mean rejuvenation percentage of declined trees in insect unmanaged conditions was 25.44 ± 26.46 and in insect-managed conditions was 41.56 ± 28.40, and the mean difference was significant at a 1% level of significance (Table 8). It depicts that managing insect pests in the citrus orchard will promote the good health of trees and reinstate them from declining.

4.6. Productivity of Mandarin with different management practices

The productivity of the mandarin orchard is positively and significantly influenced by FYM application, chemical fertilizers, irrigation, etc (Raj, 1999).

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**Table 4. Distribution of rejuvenated mandarin trees according to FYM application.**

| Variable | FYM application (Mean ± Std. Dev) | Mean difference | t-value | p-value |
|----------|----------------------------------|----------------|--------|--------|
|          | Less than 30 kg/plant/year (n = 22) | More than 30 kg/plant/year (n = 46) |        |        |
| Rejuvenation (%) | 23.79 ± 25.15 | 38.15 ± 28.98 | -14.36 | -1.99** |

Source: Field Survey, 2021
Notes: ** indicates significant at 5% level.

**Table 5. Distribution of rejuvenated mandarin trees according to the irrigation facility.**

| Variable | Irrigation facility (Mean ± Std. Dev) | Mean difference | t-value | p-value |
|----------|-------------------------------------|----------------|--------|--------|
|          | Rainfed (n = 13) | Irrigated (n = 55) |        |        |
| Rejuvenation (%) | 15.47 ± 18.99 | 37.76 ± 28.73 | -22.29 | -2.66*** |

Source: Field Survey, 2021
Notes: *** indicates significant at 1% level.

---

**Table 6. Distribution of rejuvenated mandarin trees according to pruning practice.**

| Variable | Pruning practices (Mean ± Std. Dev) | Mean difference | t-value | p-value |
|----------|-----------------------------------|----------------|--------|--------|
|          | No (n = 14) | Yes (n = 54) |        |        |
| Rejuvenation (%) | 17.32 ± 27.27 | 37.70 ± 28.73 | -20.38 | -2.48*** |

Source: Field Survey, 2021
Notes: *** indicates significant at 1% level.
weeding, and Bordeaux application (Table 9). Productivity of mandarin was 59% higher in FYM applied more than 30 kg per tree per year compared to FYM employed less than 30 kg per tree per year, which was statistically significant at a 1% level of significance. Similarly, the productivity of mandarin was enhanced by 39%, 57%, and 14% in the use of chemical fertilizers, irrigation, and weeding conditions, respectively than the conditions where each of these management practices were not practiced, and the data were significant at a 5% level of significance. In the same way, the productivity was increased by 33% in the Bordeaux application situation than in their absence, which was significant at a 10% level of significance.

5. Conclusions

The generality of the respondents in the study area were male, middle-aged, literate, belonging to Janajati ethnic group, and most households had agriculture as primary and remittance as a secondary source of income. More than two-thirds of the orchards (72.3%) were reported with citrus decline, of which trees above 20 years were most affected. Insect and disease incidence, climatic factors like hailstorm damage, nutrient deficiency, poor planting materials, and poor orchard management practices were associated with a citrus decline. Among them, insect infestation was significantly causing a citrus decline in the study area. Management practices like manuring, irrigation, pruning, Bordeaux application, and insect management had been adopted by the farmers, and these practices were significantly associated with the rejuvenation of the declining mandarin orchard. So, effective management practices help in combating the citrus decline problem. Productivity of the mandarin orchard was significantly enhanced by FYM application, chemical fertilizers, irrigation, weeding, and Bordeaux application.

Declarations

Author contribution statement

Anit Poudel: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Sabina Sapkota; Nabin Pandey; Dipesh Oli & Rajiv Regmi: Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

I would like to acknowledge Agriculture and Forestry University, Bharatpur, Nepal, and Prime Minister Agriculture Modernization Project, Government of Nepal for assisting this research. I would like to express my sincere gratitude to Prof. Durga Devkota, PhD, Dr. Sudhir Thapa, and Mr. Keshav Devkota for supervising the research. My special thanks go to all the informants, my beloved parents, and friends for their worthy support throughout the journey.
APPENDICES

Appendix 1: Logistic regression analysis of citrus decline with different factor causing citrus decline.

| Variable     | Odds Ratio | Std. Err. | z    | P>|z|   | [95% Conf. Interval] |
|--------------|------------|-----------|------|-------|----------------------|
| Insect_i     | 22.9948    | 26.47385  | 2.72 | 0.006 | 2.407928 - 219.5916  |
| Dsz_Incl     | 2.376361   | 2.271715  | 0.91 | 0.365 | 0.3649176 - 15.47699 |
| Hailstro     | 1.259732   | 0.7712537 | 0.87 | 0.006 | 0.3794389 - 4.18225 |
| Prim_Nun     | 5.123303   | 6.190485  | 1.35 | 0.076 | 0.4797815 - 54.70872 |
| Micro_De     | 2.036719   | 2.143991  | 0.68 | 0.006 | 0.2587266 - 16.03188 |
| Plntng_P     | 1.750862   | 2.402663  | 0.41 | 0.006 | 0.1189368 - 25.78302 |
| Pit_Size     | 2.313777   | 2.682196  | 0.72 | 0.006 | 0.2385528 - 22.44184 |
| Inercrop     | 1.40708    | 1.721679  | 0.28 | 0.006 | 0.1278769 - 15.48265 |
| Packagin     | 3.400079   | 5.911336  | 0.70 | 0.006 | 0.112616 - 102.6545  |
| _cons        | 0.0303197  | 0.0341399 | -3.10| 0.006 | 0.0033355 - 0.2756053 |

Appendix 2: Marginal effect after logistic analysis of citrus decline with different factor causing citrus decline.

Marginal effects after logistic
y = Pr(Decline) (predict)
= .88473356

| Variable     | dy/dx      | Std. Err. | z    | P>|z|   | [95% C.I. ]   | X |
|--------------|------------|-----------|------|-------|----------------|---|
| Insect_i*    | .5247358   | .26181    | 2.00 | 0.045 | .015597 - 1.03787 | .755319 |
| Dsz_Incl*    | .0950151   | .13574    | 0.62 | 0.422 | -.131823 - .321853 | .595745 |
| Hailstro     | .0235471   | .06193    | 0.38 | 0.704 | -.0970437 - 0.144931 | 1.8617 |
| Prim_Nun*    | .1733093   | .13371    | 1.32 | 0.186 | -.064831 - .432445 | .5 |
| Micro_De*    | .0774027   | .12246    | 0.63 | 0.527 | -.162617 - .317423 | .606383 |
| Plntng_P*    | .0553431   | .12676    | 0.44 | 0.662 | -.013304 - .307794 | .414944 |
| Pit_Size*    | .0769544   | .10442    | 0.77 | 0.466 | -.119874 - .273783 | .319169 |
| Inercrop*    | .0370752   | .14511    | 0.26 | 0.250 | -.102758 - .373734 | .734043 |
| Packagin*    | .0941997   | .09617    | 0.98 | 0.327 | -.094284 - .282684 | .180851 |

(*) dy/dx is for discrete change of dummy variable from 0 to 1

Appendix 3: Distribution of rejuvenated mandarin trees according to FYM application.

```
ttest Rejuven, by(FYM_app)
```

Two-sample t test with equal variances

| Group        | Obs  | Mean  | Std. Err. | Std. Dev. | [95% Conf. Interval] |
|--------------|------|-------|-----------|-----------|----------------------|
| less tha     | 22   | 23.78545 | 5.361805 | 25.14909  | 12.63497 - 34.93594  |
| More tha     | 46   | 18.14783 | 4.272451 | 28.97717  | 29.54267 - 46.75290  |
| combined     | 68   | 33.50118 | 3.447122 | 28.4257   | 26.62069 - 40.38166  |

| diff         | -14.36237  | 7.210403  | -28.75807 - 0.38226 |

| diff = mean(less tha) - mean(More tha) | t  = -1.9919  |
| Ha: diff < 0 | Ha: diff = 0 | Ha: diff > 0 |
| Pr(|T| > |t|) = 0.056  | Pr(T < t) = 0.0253 |
| Pr(T > t) = 0.9747  |
Appendix 4: Distribution of rejuvenated mandarin trees according to the irrigation facility.

```
ttest rejuvenet, by(Irrigat

Two-sample t test with equal variances

| Group   | Obs | Mean  | Std. Err. | Std. Dev. | [95% Conf. Interval] |
|---------|-----|-------|-----------|-----------|---------------------|
| Rainfed | 13  | 15.46923 | 5.26733  | 18.99308  | 3.991826 – 26.94664 |
| Irrigate| 55  | 37.79327  | 3.874396 | 28.73327  | 29.39558 – 45.53096 |
| combined| 68  | 33.50118  | 3.447122 | 28.4257   | 26.62069 – 40.38166 |

diff = mean(Rainfed) – mean(Irrigate) t = -2.6556
Ho: diff = 0 degrees of freedom = 66

Ha: diff < 0 Ha: diff > 0
Pr(T < t) = 0.0050 Pr(|T| > |t|) = 0.0099 Pr(T > t) = 0.9950

Appendix 5: Distribution of rejuvenated mandarin trees according to pruning practice.

```
ttest rejuvenet, by(Pruning

Two-sample t test with equal variances

| Variable | Obs | Mean  | Std. Err. | Std. Dev. | [95% Conf. Interval] |
|----------|-----|-------|-----------|-----------|---------------------|
| No       | 14  | 17.31786 | 7.289    | 27.72294  | 1.57093 – 33.06478  |
| Yes      | 54  | 37.69685  | 3.731492 | 27.62076  | 30.21243 – 45.28128 |
| combined | 68  | 33.50118  | 3.447122 | 28.4257   | 26.62069 – 40.38166 |

diff = mean(No) – mean(Yes) t = -2.4007
Ho: diff = 0 degrees of freedom = 66

Ha: diff < 0 Ha: diff > 0
Pr(T < t) = 0.0079 Pr(|T| > |t|) = 0.0157 Pr(T > t) = 0.9922

Appendix 6: Distribution of rejuvenated mandarin trees according to Bordeaux application.

```
ttest rejuvenet, by(Bordeaux

Two-sample t test with equal variances

| Variable | Obs | Mean  | Std. Err. | Std. Dev. | [95% Conf. Interval] |
|----------|-----|-------|-----------|-----------|---------------------|
| No       | 62  | 22.64286 | 3.509243 | 22.74249  | 15.55558 – 29.72922 |
| Yes      | 26  | 51.04154  | 5.544241 | 28.27019  | 39.62296 – 62.46012 |
| combined | 68  | 33.50118  | 3.447122 | 28.4257   | 26.62069 – 40.38166 |

diff = mean(No) – mean(Yes) t = -4.5557
Ho: diff = 0 degrees of freedom = 66

Ha: diff < 0 Ha: diff > 0
Pr(T < t) = 0.0000 Pr(|T| > |t|) = 0.0000 Pr(T > t) = 1.0000

9
Appendix 7: Distribution of rejuvenated mandarin trees according to insect management.

```
test Rejuvenat, by( Insect_management )

Two-sample t test with equal variances

| Variable | Obs | Mean  | Std. Err | Std. Dev | [95% Conf. Interval] |
|----------|-----|-------|----------|----------|---------------------|
| No       | 34  | 25.43941 | 4.538386 | 26.46311 | 16.206 - 34.67283 |
| Yes      | 34  | 41.56294 | 4.689795 | 28.39554 | 31.65527 - 51.47061 |
| combined | 68  | 33.50118 | 3.447122 | 28.4257  | 26.62069 - 40.38166 |
| diff     |    | -16.12353 | 6.656715 | -29.41409 | -2.832969 |

diff = mean(No) - mean(Yes)  t = -2.4221  degrees of freedom = 66

H0: diff = 0  Ha: diff < 0  Ha: diff > 0
Pr(T < t) = 0.0591  Pr(|T| > |t|) = 0.0182  Pr(T > t) = 0.9909

Appendix 8: Linear regression analysis of productivity of mandarin orchard with different management practices.

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