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SOIL SCIENCE | ORIGINAL ARTICLE

Evaluating Soil Nutrient Status of Mandarin Orchards across Varied Altitudes in Gorkha, Nepal

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ABSTRACT

Mandarin, a prominent crop in Nepal, exhibits remarkable adaptability to different altitudes, resulting in diverse soil and nutrient conditions in orchards. Understanding these variations is crucial for optimizing orchard management practices and ensuring sustainable fruit production. This research endeavor sought to assess the nutritional profile of the soil in mandarin positioned at diverse elevations in Gorkha district, Nepal. The orchards were classified into five elevation groups: 800 masl, 900 masl, 1000 masl, 1100 masl, and 1200 masl. Using randomized complete block design (RCBD), each altitude contained ten composite soil samples, and was then subjected to chemical analysis to assess their properties. The results showed that soil pH increased with altitude, with the highest pH (6.66±0.045) and soil organic matter (OM) (5.88±0.12%) at 1200 masl and the lowest pH (5.5±0.045) and OM (1.92±0.12%) at 800 masl. Soil acidity was observed 5.79±0.045 at 900 masl and 5.5±0.045 at 800 masl, while all other altitudes had neutral soils. Nitrogen content followed a similar trend, with the highest at 1200 masl (0.32±0.007%) and the lowest at 800 masl (0.10±0.007%). Phosphorus and potassium showed no significant variation with altitude. Available phosphorus was the highest at 1000 masl (72.93±2.02 kg ha-1) and the lowest at 800 masl (51.61±2.02 kg ha-1). Maximum available potassium (365.34±6.84 kg ha^{-1}) was observed at 1100 masl, while the minimum (337.63±6.84 kg ha^{-1}) was recorded at 800 masl. In 18% of the samples, nitrogen exhibited the lowest concentration, while phosphorus was limiting in 12% of the samples. Potassium was not found to be a limiting nutrient in any of the samples. Variations in soil pH, OM, and nutrient content call for altitude-specific nutrient management to optimize mandarin production. Further studies are required in diverse ecology to characterize nutrient requirements and enhance sustainable mandarin cultivation practices.

1. Introduction

Agriculture is a significant sector in Nepal, contributing to 21.32% country's gross domestic product (GDP) (O'Neill, 2023), and employing 65.6% of the population (MoF, 2019). Among the horticultural crops, fruit cultivation plays a vital role in Nepal's agricultural sector, contributing approximately 7.26% to the total agriculture GDP (MoALD, 2022). The eastern and western mid-hills of Nepal serve as fertile grounds for the widespread cultivation of citrus fruits, with a special emphasis on the mandarin variety, which offer favorable climatic conditions for their cultivation. Gorkha district, the fourth largest in term of area, is located in the mid-hills region and has a diverse geographical landscape that is suitable for growing a variety of fruits. Mandarin orchards cover a substantial area, i.e., 1125 ha in the Gorkha district, and their productivity (10.94 t ha^{-1}) is essential for the local economy (MoALD, 2022).

Gorkha district exhibits a wide range of altitudes, which can influence the nutrient status of the soil in mandarin orchards. Altitude differences have a significant impact on soil properties, including nutrient availability, soil erosion, and vegetation (Ghimire et al., 2023; Bargali et al., 2019). Elevating altitude brings about significant changes to the nutritional well-being of plants, resulting from the alteration of soil nutrient accessibility and the plants' capacity to acquire essential nutrients (Soethe et al., 2008). As one ascends along the gradient, the dynamic interplay between changing climatic conditions and the intricate cycles of plant and soil nutrients becomes increasingly apparent (Dar et al., 2012). Factors such as precipitation patterns, vegetation characteristics, and the underlying parent rock type contribute to notable disparities in nutrient cycling between higher and lower altitudes, reflecting the profound influence of evolving climatic conditions (Ghimire and Chhetri, 2023a).

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Mandarins are known to be highly nutrient-responsive, and proper nutrient management is crucial for achieving optimal growth and yield (Srivastava et al., 2021; Hazarika et al., 2023). The nutrient requirements of mandarins can vary depending on soil fertility and type. Therefore, evaluating the nutrient status of the orchards becomes essential for understanding the overall health and longevity of the orchards. In agriculture, soil pH plays a crucial role as it governs the availability of plant nutrients by controlling their chemical forms and reactions (Oshunsanya, 2019). Soil, being a vital reservoir of nutrients, plays a central and indispensible role in the growth and development of crops. The three essential macronutrients for plant growth, namely nitrogen (N), phosphorus (P), and potassium (K), are manually supplemented into the soil (Ghimire et al., 2023; Ghimire and Gyawali, 2023). The dynamic nature of soil organic matter (SOM) wields a profound impact on soil fertility, exerting an influential force within its intricate ecosystem. It engenders transformative effects on the physical, biological, and chemical characteristics of the soil, leaving an indelible imprint on its intricate properties. Additionally, it mitigates the detrimental environmental effects of pesticides and metals, acts as a pH buffer, and accounts for a substantial portion (20-90%) of mineral soil's adsorptive capacity (Brady and Weil, 2008).

Beyond being a vital component of daily nutrition, mandarin fruits hold a dual role in the mid-hills of Nepal, acting as a dependable source of income generation. Despite the increasing demand for mandarins, the production does not meet the market requirements (MoALD, 2022). The yield potential of mandarin orchards in Nepal falls below international standards, showcasing a relatively lower productivity level. Various factors, including poor orchard management practices, inadequate nutrient supply, and the prevalence of diseases and insect pests, contribute to low-quality fruit production (Ghimire and Chhetri, 2023b; Poudel et al., 2022). The objective of this research is to evaluate the soil nutrient status, pH levels, and organic matter content within mandarin orchards situated across varying altitudes within the Gorkha district, and provide soil test-based fertilizer management recommendations. The findings contribute to stakeholders involved in mandarin cultivation about the impact of altitude on soil nutrient status, enabling them to develop effective strategies and policies to enhance productivity, improve mandarin quality, and maintain soil fertility.

2. Materials and Methods

2.1. Experimental site

The research endeavor was carried out within the Sahid Lakhan rural municipality (Finaudi, Dhadabari, Sauraha, Umlung, and Manakamana) of Gorkha district, Nepal, located at latitude 26°15'-28°22' N, longitude 84°15'-84°58' E, and encompassing an altitude range from 228 meters to 8163 meters above sea level (masl), shown in Fig. 1. The data collection phase for the study encompassed a timeframe spanning from April 2nd to June 25th, 2022.

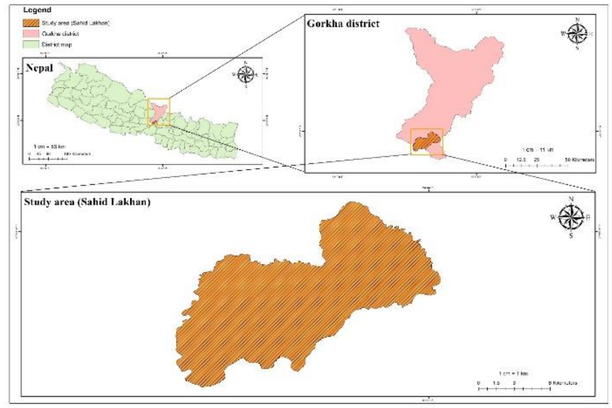

Figure 1. Map of experimental area

2.2. Experiment details, soil sampling design and sample preparation

The sampling of mandarin orchards was carried out using a standardized stratified simple random sampling method. The strata were defined based on the elevations of the orchards relative to sea level. Five distinct altitude categories, differing by 100 meter (m), were selected as experimental treatments. Mandarin orchards of the same age, facing north, and employing similar management practices were chosen from various elevations: specifically, 800 masl, 900 masl, 1000 masl, 1100 masl, and 1200 masl. These orchards were replicated 10 times using a randomized complete block design (RCBD).

Figure 2. Soil sample collection at a depth of 1 meter, and soil analysis at the soil testing laboratory, Pokhara, Kaski

Firstly, the altitudes of the mandarin orchards were determined using GPS data obtained from the citrus zone office in Gorkha. Following that, soil samples were meticulously gathered from a depth of 1 m, as depicted in Fig. 2. At each elevation, ten composite samples were obtained from different orchards. For each composite sample, four sub-samples were taken and combined to create a composite sample weighing 0.5 kg. Subsequently, the collected soil samples were subjected to the process of air-drying, ground, and sieved through a 1 mm mesh to obtain the final soil sample.

Soil analysis

Soil samples collected from each location and orchards were analyzed for soil pH, SOM, available N, P, and K content of the soil in the Directorate of Soil testing laboratory, Pokhara, Gandaki province. Laboratory methods used for the analysis of different soil fertility parameters are given in Table 1.

Table 1. Soil parameters and laboratory method adopted for soil testing

Parameters	Analysis method
Soil pH	Digital pH meter (Cottenie et al., 1982)
OM	Walkley-Black method (Houba et al., 1989)
N	Kjeldahl distillation method (Bremner and Hauck, 2015)
P	Modified Olsen's method (Watanabe and Olsen, 1965)
K	Ammonium acetate extraction method (Pratt, 2016), using flame photometer

2.3. Data type

2.3.1. Primary data

Primary data were gathered from orchard owners at the respective sites through a combination of key informant interviews, farm visits, and personal communication, as described by Ghimire and Chhetri (2023b) and Ghimire and Gyawali (2023). Also, primary data was collected from the laboratory analysis of the composite sample. The soil was analyzed for soil pH, OM, N, P, K, iron (Fe), and zinc (Zn).

2.4. Statistical analysis

The obtained data were entered in MS Excel 2010 (version 14.0.4734.1000), and analyzed using R-Studio (version R-3.6.3). Each soil fertility parameter was categorized under standard ratings as low, medium, and high based on standard ratings, as illustrated by Shah and Shriwastav (2015) (Table 2), and, soil reaction according to Khatri-Chhetri (1991) (Table 3). The laboratory-evaluated data were subjected to comprehensive analysis employing both descriptive and statistical methodologies. The five distinct elevations served as a factor, with one-way analysis of variance employed to determine the significance of these factors. Descriptive statistics, including mean, standard deviation, and diagrams, were employed to provide an insightful analysis of the data. Additionally, the Duncan's multiple range test (DMRT) was conducted at a 5% probability level to assess the significance among the means of the different factors.

Table 2. Soil parameters and standard ratings

Physio-chemical parameters	Low	Medium	High
OM content (%)	<=2.5	2.51-5.0	>=5
N (%)	<=0.10	0.11-0.20	>0.20
P (kg ha^{-1})	<=30	30.1-55	>55
K (kg ha^{-1})	<=110	110.1-280	>280

Table 3. Rating chart for soil reaction of studied soils

Soil pH value	Soil reaction rating
<6	Acidic
6.0-7.5	Neutral
>7.5	Alkaline

Table 4. Soil parameter and standard ratings

Soil fertility status	Low	Medium	High
OM content %	<2.5	2.5-5.0	>5
N%	<0.10	0.10-0.20	>0.20
P (kg ha^{-1})	<30	30-55	>55
K (kg ha^{-1})	<110	110-280	>280
Soil pH rating	Acidic	Acidic	Alkaline
Soil pH value	<6	6-7.5	>7.5

3. Results and Discussion

3.1. Soil chemical properties

3.1.1. Soil pH

The pH level at different altitude of mandarin orchard is shown in Fig. 3. The altitudinal variation resulted significant difference on the pH level (P<0.001) at mandarin orchards. It was found that soil acidity increased linearly with increase in altitude (Charan et al., 2013). The maximum pH was measured at 1200 masl (6.66) and the lowest pH was measured at 800 masl (5.5) elevation mandarin orchards. The pH of 1000 masl (6.04) was significantly similar to the pH value of 1100 masl (6.32). While the pH values of 1200 masl (6.66) and 800 masl (5.5) were statistically different from the value of 1000 masl.

The dominant soil composition in Nepal leans towards moderately acidic profiles, primarily influenced by parent materials such as sandstone, siltstone, quartzite, and shale (Ghimire and Bista, 2016; Panday et al., 2019; Pandey et al., 2018). A clear inverse relationship exists between soil pH and average temperature and precipitation levels (Ji et al., 2014). The relationship between altitude and climate unveils an intriguing pattern. As we descend to lower elevations, we encounter warmer temperatures and reduced precipitation when compared to higher altitudes. Consequently, this correlation influences the pH levels, causing higher altitudes to exhibit a greater acidic nature. The decline in pH levels at elevated altitudes can be attributed to the progressive buildup and gradual breakdown of organic matter, resulting in the release of acidic substances. Moreover, the heightened precipitation experienced at higher elevations may also contribute to this phenomenon. Similar result was found by Tasung and Ahmed (2017), and Bk et al. (2022) in which they found an increase in acidity stocks with increasing altitude. The gradual breakdown of leaf litter originating from trees fosters the liberation of organic acids, ultimately resulting in a decrease in soil pH levels (Gustafson, 1937). In regions of lower altitude, the prevalence of warmer temperatures accelerates the enzymatic degradation of labile soil organic matter when compared to higher altitudes characterized by cooler climates.

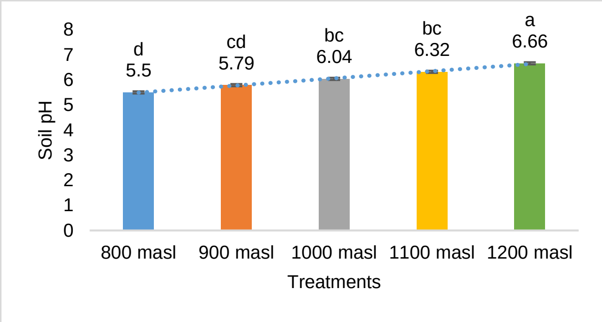

Figure 3. Variation of soil pH of mandarin orchards at different altitudes. Means with the same letter (s) indicate no significant difference at p=0.05, based on DMRT. Each reported value represents the mean of 10 replications, and vertical bars represent the standard error of the mean (SEM ±).

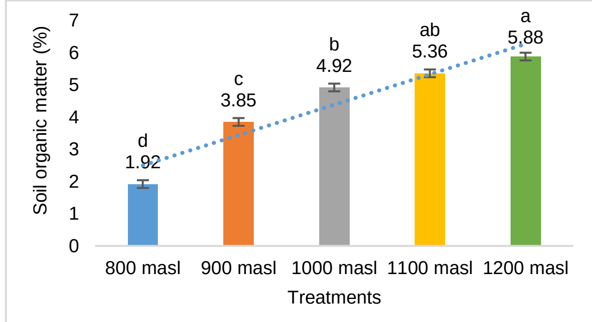

Figure 4. Variation of SOM content of mandarin orchards at different altitudes. Means with the same letter (s) indicate no significant difference at p=0.05, based on DMRT. Each reported value represents the mean of 10 replications, and vertical bars represent the standard error of the mean (SEM ±).

Moreover, the increased rainfall observed at higher elevations leads to the leaching of base-forming cations such as Ca_2+, Mg_2+, and K+, while simultaneously promoting the presence of ions such as Al_3+ and H+ (Brady and Weil, 2008). The relatively higher soil pH observed at higher elevations can be attributed to factors such as steeper slopes and reduced evaporation rates. Conversely, the lower pH levels observed at lower altitudes might be linked to the consistent application of chemical fertilizers in those areas. Particularly, N fertilizers are known to have an acidifying impact, where the continuous application of chemical fertilizers lead to a decrease in soil pH (Sharma et al., 2019). This decrease is a direct result of the application of ammonium fertilizers or urea, resulting in elevated levels of H+ ions within the soil (Sharma et al., 2019; Zhang et al., 2019). Overall, the research revealed that soil pH fluctuation highlights the dynamic interplay of climate and topography, emerging as the key influential factors, with a discernible drop in pH levels.

3.1.2. Soil organic matter

SOM content was more in higher altitude as compared to lower altitude mandarin orchard (Fig. 4). The altitudinal variation resulted significant difference on the SOM level (P<0.001) at mandarin orchards. SOM level increased linearly with increase in altitude. The highest amount of SOM was reported in 1200 masl (5.88%) whereas the lowest was found in 800 masl (1.92%) elevation mandarin orchards. The dearth of OM at lower altitudes can be ascribed to the prevalent practice of multiple cropping in those regions. This practice often involves the removal of crop residues during harvest, hindering the accumulation of organic matter and contributing to its scarcity in the soil. The variation in insolation, along with differences in altitude, soil temperature, and soil water content, could potentially contribute to this phenomenon (Bangroo et al., 2018).

The elevated soil acidity in the region could potentially play a role in the accumulation of high OM (Kidanemariam et al., 2012). Griffiths et al. (2009) reported that low temperatures and increased moisture are probably factors responsible for reduced decomposition rates and thus the accumulation of high SOM at higher elevations. The findings of this study corroborate the research outcomes of Charan et al. (2013), validating the ascending trend of SOM with increasing altitudes from 10,000 feet to beyond 12,000 feet. Moreover, the analysis highlights that the SOM content at 1,250 m (4.63%) exhibits a statistically indistinguishable resemblance to the SOM content observed at 1,350 m, further emphasizing the coherence in SOM distribution across these altitudinal ranges. The present study's results coincide with the observations made by Tasung and Ahmed (2017), indicating a rise in soil organic carbon stocks as altitude increases. Tillage enhances soil aeration and stimulates microbial activity, thereby expediting OM decomposition. Nevertheless, it is crucial to emphasize that excessive tillage can also exacerbate erosion risks. Hence, due to higher rate of tillage at lower elevation, the OM accumulation is significantly low. Extensive tillage and rigorous harvesting practices in low regions result in the deterioration of surface soil structure, intensifying the erosion process (Funderburg, 2016). To elucidate, the experiment suggests that higher altitude mandarin orchards exhibit increased SOM content, attributed to reduced decomposition rates and limited leaching of SOM in undisturbed soils at higher elevations, while multiple cropping, systems may experience soil erosion and leaching that diminish surface organic matter at lower altitude.

3.1.3. Available soil nitrogen

Higher altitude mandarin orange orchards showed significantly higher N content compared to lower altitude orchards, with a linear increase in N levels with increasing altitude, attributed to SOM and limited leaching in

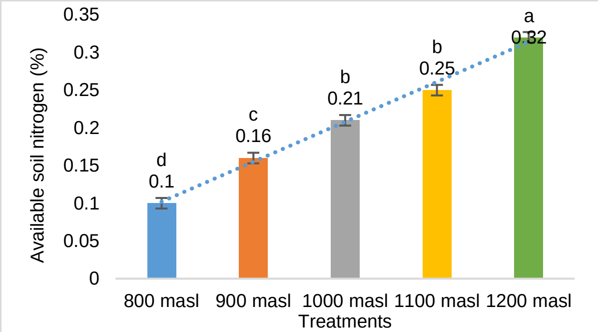

Figure 5. Variation of nitrogen content of mandarin orchard at different altitudes. Means with the same letter (s) indicate no significant difference at p=0.05, based on DMRT. Each reported value represents the mean of 10 replications, and vertical bars represent the standard error of the mean (SEM ±).

uncultivated land (Fig. 5). The total N content was the lowest in 900 masl (0.10%) and the highest in 1200 masl (0.32%). Statistically resonating N content was reported at 1000 masl and 1100 m, whereas N content at 1200 masl elevation is significantly different with 900 masl, 1000 masl, and 1100 masl.

The N content of the soil is closely correlated with the SOM content (Chen et al., 2019). A staggering 90% of the soil's precious N supply owes its existence to the nurturing embrace of organic sources (Matsumoto and Ae, 2004). The elevation of an area modifies the microclimate, creating diverse hydrothermal conditions. These conditions, in turn, indirectly impact microbial activity, thereby influencing the decomposition and transformation of SOM and N (Wang et al., 2018). The contrasting N levels observed low altitude areas can be ascribed to the limited OM content in the soil. Furthermore, the potential influence of tillage practices should be considered, as it has been linked to increased vulnerability to erosion (Funderburg, 2016). N content was reported to be sharply increasing with increasing elevation. Similar findings were put forward by Charan et al. (2013), who found that amount of N increases with increases in SOM because soil required N to decompose the organisms into OM. The availability of N to plants is substantially affected by the quantity and type of soil. Brady and Weil, (2008) noted that the dispersion of soil N closely mirrors that of OM owing to the presence of N, alongside other nutrients, in an organic amalgamation.

3.1.4. Available phosphorus

Altitude did not have a significant impact on available P content in mandarin orchards (Table 5), as indicated by the non-significant altitudinal variation (P<0.001), with maximum P content at 1000 masl (72.93 kg ha^{-1}) and minimum at 800 masl (51.61 kg ha-1). The assessment of soil parameters and standard ratings indicates that the soil possesses a moderate to high level of P content (Shah and Shriwastav, 2015).

Table 5. Altitudinal effect on nitrogen of mandarin orchard, Gorkha

Treatments	Available phosphorus (kg ha^{-1})
800 masl	51.61^{b}
900 masl	56.66^{ab}
1000 masl	72.93^{bc}
1100 masl	66.30^{ab}
1200 masl	63.10^{ab}
Sem (±)	2.02
F-test	NS
LSD (0.05)	NS
CV%	29.29
Grand mean	62.12

Letters in a column denoting the same symbol (s) indicate non-significant at p=0.05, as determined by the DMRT. SEm represents the Standard Error of Mean, CV stands for Coefficient of Variation, and NS indicates non-significance.

The availability of P in soil is greatly influenced by the pH level of the soil (Lindsay, 1979). Therefore, the observed scarcity of K at lower altitude (800-900 masl), K can be ascribed to their relatively lower pH levels. The acidic condition of the soils might have caused the transition of phosphate into less soluble compounds with Fe and Al. At higher altitudes, available P is very low because of the strongly acidic soils (Cui et al., 2021). The presence of K in the soil is greatly influenced by the underlying bedrock, which serves as the parent material. Through the intricate workings of nature, deep-rooted perennial plants diligently absorb K from the subsoil depths, redistributing it to the soil's surface by means of translocation into their leaves. The cycle continues as the leaves eventually descend to the ground, decompose, and nourish the soil. However, at an elevation below 1000 masl, the available P content seems to be at a low, possibly attributed to increased leaching losses and heightened P extraction from the soil due to agricultural activities and tillage (Brady and Weil, 2008).

3.1.5. Available potassium

The altitudinal variation observed in mandarin orchards did not yield a significant difference in the K content (P<0.001), as illustrated in Table 6. The highest available K was found in 1100 masl (365.34 kg ha^{-1}) followed by 1000 masl (351.68 kg ha^{-1}), 1200 masl (347.88 kg ha^{-1}), 900 masl (338.42 kg ha^{-1}) and 800 masl (337.63 kg ha^{-1}). The lowest available K was found in 800 masl (337.63 kg ha^{-1}).

The soil K was high in all soil samples according to the soil parameters and standard ratings (Shah and Shriwastav, 2015). Carson (1992) also reported that Nepalese soils are rich in amount of K. Similar results were documented in the study conducted by Baral et al. (2021), where no notable variation was observed in the available K content of the soil across different altitudes. The K content in soil is influenced by various factors, including the composition of the parent materials, the degree of weathering, the amount of K fertilizer applied, and the losses incurred due to crop removal, erosion, and leaching.

Table 6. Altitudinal effect on available potassium of mandarin orchard, Gorkha

Treatments	Available potassium (kg ha^{-1})
800 masl	337.63[a]
900 masl	338.42[a]
1000 masl	351.68[a]
1100 masl	365.34[a]
1200 masl	347.88[ab]
SEm (±)	6.84
F-test	NS
LSD (0.05)	NS
CV%	13.91
Grand mean	348.20

Letters in a column denoting the same symbol (s) indicate non-significant differences at p=0.05, as determined by the DMRT. SEm represents the Standard Error of Mean, CV stands for Coefficient of Variation, and NS indicates non-significance.

K originating from the deep subsoil horizons is efficiently absorbed by deep-rooted perennial plants and subsequently recycled to the soil surface through a process of translocation into leaves. This valuable nutrient is then returned to the soil through leaf fall and subsequent decomposition, contributing to the overall nutrient cycle and maintaining soil fertility (Lehmann and Schroth, 2002). The diminished level of P at altitudes exceeding 1100 masl could potentially be ascribed to the soil's limited capacity to retain nutrients, more K leaching and harvest, as the region face higher precipitation due to higher altitude (Brady and Weil, 2008; Tshering et al., 2020).

3.2. Optimum nutrients requirement and nutrient status in mandarin orchards

Standard soil rating helps to characterize the soil and by comparing soil nutrient status with standard ratings given by Soil Division, NARC. Through rigorous estimation, the study identified the most constraining soil nutrient for mandarin production, unveiling N (18%), as the paramount limiting factor, followed by P (12%) in overall sampled soils (Fig. 6). K was in abundant quantity, i.e., 100%. N and P is a very important nutrient for a plant's growth and development (Chen et al., 2020; Rehman et al., 2020; Yang et al., 2021). Producers are suggested to apply the optimum amount of nitrogenous and phosphorous fertilizers in order to meet requirements for the growth and development of mandarin. Also, it is suggested that N should be applied in split doses instead of bulk so as to control leaching and increase its availability to plants.

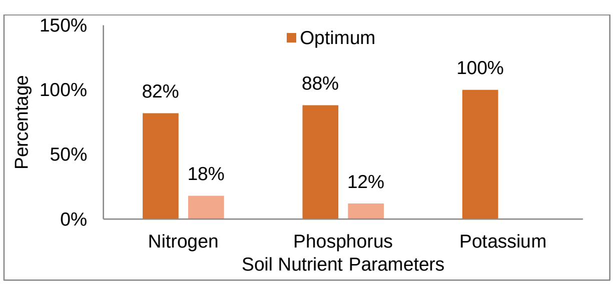

Figure 6. Bar diagram showing soil nutrients status of Sahid Lakhan, Gorkha

3.3. Correlation among various parameters

The soil pH takes center stage, guiding the interactions among the various elements (S. Ghimire et al., 2023). It holds a strong positive correlation of 0.94 with the SOM%, indicating their inseparable connection, which resonates to the findings of Neina (2019). The Soil N percentage joins this alliance, displaying a remarkable correlation of 1 with soil pH and 0.94 with SOM, highlighting its alignment with pH and SOM changes. Soil P content emerges as a character with moderate positive correlations of 0.59 with soil pH and 0.77 with SOM, responding to the influence of both variables. Similarly, Soil K plays its part, with a moderate positive correlation of 0.62 with soil pH and 0.70 with SOM. As the story unfolds, we witness the orchestration of the soil pH, harmonizing the behavior of other elements, as shown in Fig. 7.

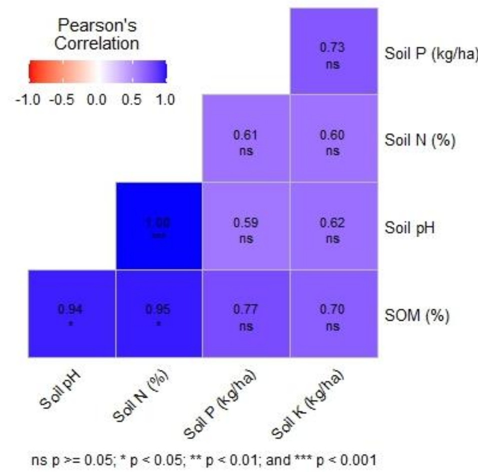

Figure 7. Correlation among various parameters

4. Conclusion

The study revealed notable variations in soil pH, SOM, N, P, and K with respect to altitude. At higher altitudes (1200 masl), the soil exhibited the highest levels of nutrients, including N, SOM, and pH, while the lowest levels were observed at 800 masl. However, no significant impact of altitude on P and K levels was observed. Interestingly, there was a positive correlation between increasing altitude and soil acidity, SOM, and N concentrations. In the realm of mandarin production, N emerged as the foremost limiting nutrient in the area, closely followed by P. An altitude range between 800-1200 masl, adorned with abundant nutrients and flourishing SOM, emerges as an enchanting realm for mandarin cultivation. Further exploration of soil properties in larger ecological regions along with micronutrients is needed, and also implementing N management strategies and regular monitoring of soil nutrient levels and pH for sustainable mandarin cultivation.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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