Soil fertility dynamics and identify the most limiting nutrients affecting walnut productivity in Nepal

ABSTRACT

This study aimed to assess the soil nutrient status in walnut orchards of different ages in Jajarkot district, Nepal, to understand soil fertility dynamics and identify the most limiting nutrients affecting walnut productivity.The research employed a randomized complete block design (RCBD) with three treatments representing different age groups of walnut orchards (1-5 years, 6-10 years, and 11-15 years), each replicated seven times across various municipalities.The study was conducted in Jajarkot district, Karnali Province, Nepal, encompassing municipalities including Nalgad, Junichadey, and Barekot, from March to April 2023.Soil samples were collected from multiple depths (1, 2, and 3 feet) in each orchard and analyzed for pH, soil organic matter (SOM), total nitrogen, available phosphorus, and available potassium. Data analysis included descriptive statistics, one-way analysis of variance (ANOVA), and correlation analyses to explore relationships between soil parameters and orchard age. The study showed that significant variations were observed among different age groups of walnut orchards for soil pH, SOM, nitrogen, phosphorus, and potassium levels. Soil pH decreased with orchard age, while SOM, nitrogen, and phosphorus tended to increase with orchard age. Phosphorus was identified as the most limiting nutrient across all sampled soils, followed by nitrogen and potassium. Moreover, strong correlations were found between orchard age and soil N ($r = 0.894$, $p < 0.01$) and P ($r = 0.776$, $p < 0.01$), underscoring age-dependent nutrient dynamics.The study highlights the critical role of orchard age in shaping soil nutrient dynamics in walnut orchards. Older orchards exhibited higher levels of SOM, nitrogen, and phosphorus, indicating the accumulation of organic matter and nutrients over time. Phosphorus emerged as the primary limiting nutrient, essential for root growth, flowering, and fruiting in walnut trees. These findings underscore the importance of targeted fertilization strategies to optimize soil fertility and sustain long-term walnut productivity in the region.

Keywords: Walnut orchards, soil fertility, nutrient status, orchard age, Jajarkot, Nepal

1. INTRODUCTION

Walnut (Juglans. sp) belonging to the family Juglandaceae, which requires chilling temperature of 450-1500 hours, is the major nut fruit cultivated in Nepal at an altitude of about 1000-4000 meter above sea level [1]. Walnut (Juglans regia) is one of the top four nuts which is widely cultivated more than 60 countries in the world [2]. Nepal's total productive area under walnut was 2291 ha with 9162mt and 4 mt/ha production and productivity respectively [3]. In Jajarkot, walnut is grown in an area of about 157 Hectar, productive area 44 Hectar, production 177 metric tons and yield 4.05 mt/ha [4].

A major component of any orchard management strategy should be soil nutrient analysis. The nutritional status of trees can be impacted by other factors, like agricultural history and weather [5]. Accurate soil testing guides the strategic application of lime, phosphorus, and potassium for long-term soil health and crop success; furthermore, the main purpose of post-plant soil testing is to monitor soil pH since it has an impact on the nutrients that plants can access [6].

Organic matter is essential for fertileand productive soil which influences its physical, chemical, and biological properties by enhancing structure, tilth, aeration, infiltration, nutrient retention, and mitigating environmental impacts of pesticides and metals [7]. Soil organic matter buffers against changes in soil pH and contributes 20-90% of the mineral soil's adsorbing capacity [8]. Soils high in organic matter are ideal for walnut growth. For the purpose of growing walnuts, the soil should contain 2.0–3.5% organic matter [9]; thus, it is essential to apply suitable farmyard manure in order to increase the organic matter. Nevertheless, several natural elements influence soil organic matter (SOM), including temperature, soil moisture and water saturation, texture, terrain, acidity, vegetation, and biomass production [10].

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The land use and management system in the area under consideration affects the dynamics of soil organic matter [8]. Soil organic matter levels are lowered by erosion and continuous cropping; however, SOM can be increased via crop rotation, intercropping, applying animal and green manures, fallowing, and reduced tillage [11].

Nitrogen, an essential mineral nutrient for crop growth and yield, significantly impacts plant physiological characteristics, including chlorophyll concentration, metabolic enzyme activities, thereby influencing overall crop production [12] & [13]. Generally, trees should receive between 0.0045 kg to 0.0181 kgof nitrogen per year of age, with a maximum of 0.136 kilograms[14]. P is 1.3 times greater than in the open field, while the average N concentration in the soils beneath woody canopies is 1.9 times that of the open field [15]. Under N-deficient conditions, walnut seedlings exhibited significantly lower aboveground biomass, root biomass, chlorophyll a, chlorophyll b, carotenoid contents, net photosynthetic rate, stomatal conductance, and transpiration rate [16]. Plants uptake nitrogen as nitrate ($NO3^-$) and ammonium (NH4+), and it should be applied during the growing season at short intervals aligned with phenological periods because applying it after harvest, during winter, or early spring is wasteful and environmentally harmful [17].

Phosphorous fertilizer, which enhances root growth and boosts the quantity and quality of flowers and fruits, should not be used simultaneously with lime in low-pH soil; it should be applied one month after liming to ensure optimal walnut quality [18]. In addition, Due to their limited mobility within the soil, phosphorous fertilizers should be applied one month after liming, ideally once or twice a year in semi-tropical regions, during the dormant period of plants as base or top dressing applications [17]. Phosphorus levels in soils were significantly higher in orchards of various age groups compared to the control, likely due to the acidifying action of farm yard manure during decomposition, resulting more phosphorus available [19]. In Nepal, most of the phosphorus in the traditional fertility management is supplied via compost and livestock manure [20].

Potassium plays a vital role in improving crop productivity by facilitating sugar transport and starch formation. It also contributes to disease resistance, promotes strong kernel development, and improves winter hardiness, while preventing issues like hollow walnut formation [21]. Potassium doesn't form part of the plant's chemical structure but plays a crucial role in regulating development, improving yield and quality. Its availability varies widely due to complex interactions between roots and soil [22]. Potassium nutrients move quickly within plants, so they should be applied frequently during growth stages when plants need them most [17]. Walnut trees are sensitive to salt so it should not be fertilized with potassium fertilizer containing chlorine. The base dressing containing potassium sulphate is recommended as it increase fat, protein and aroma percent in the edible portion of walnut. [23]

Plant nutrients are influenced by the pH of the soil, which can also cause them to accumulate in the soil, become inaccessible, or have toxic effects that impede growth and development. Fruit trees typically thrive in soil with a pH range of 5.5 to 6.5, but fruit cultivation can also succeed in soils with a pH as high as 8.5 [24]. Walnuts, specifically, grow best in soil with a pH between 6.6 and 7.2 [9]. The growth of walnut trees can be affected by soil pH, with low pH potentially restricting root development. Therefore, applying liming materials in walnut orchards is recommended to maintain optimal nutrient availability [25].

In this study, soil nutrient status under different aged walnut orchids was observed and compared. The research will give an idea about the health of the soil and determines the most limiting nutrients from the walnut orchards to improve the soil fertility condition through the application of the fertilizers in the appropriate amounts as per the requirement of different aged Walnut trees. This will ensure the orchards' long-term productivity and high-quality output.

2. MATERIAL AND METHODS

2.1 Location

The research was conducted in Jajarkot district, located in Karnali Province, Nepal. The district covers an area of 2,230 square kilometers, extending from approximately 28°73'20'' north latitude to 82°20'40'' east longitude. It lies at an altitude ranging from 1148 to 2500 meters above sea level. The soil in the study areas, including Nalgad municipality (Baniya gau-11), Junichadey municipality (Mainpakha and Ookhaley), and Barekot rural municipality-1, is characterized as sandy loam with a pH ranging from 5.5 to 6.5.

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2.2 Soil sampling design

The sampling of walnut orchards was conducted based on a simple random sampling method. Samples was taken from different aged walnut orchards: 1-5th years, 6-10th years and 11-15th years. After the selection of the orchard, the soil samples were taken as per the standard sampling procedures. The sub- samples were collected from the depth of 1feet, 2 feet and 3 feet from each plot.

2.3 Soil Sample Preparation

Seven composite samples were collected from different orchards located at different municipalities. For each composite samples, 3 sub-samples were taken from the depth of 1feet, 2 feet and 3 feet and combined to get a composite sample of 0.5 kg. The collected soil samples were air dried, ground and passed through 1 mm sieve to get final soil sample.

2.4 Soil Analysis

Soil samples collected from each location and orchards were analyzed for soil pH, soil organic matter, total nitrogen, available phosphorus, and potassium content of the soil. Laboratory methods used for the analysis of different soil fertility parameters are given in table 3.

Table 1. Laboratory method of soil testing

Soil parameters	Analysis method
Soil pH	Digital pH meter [1]
Organic matter	Walkley-Black method [2]
Nitrogen	Determined from soil organic matter[3]
Phosphorus	Modified Olsen's method [4]
Potassium	Ammonium acetate extraction method [5] using flame photometer

2.5 Details of research

Table 2. Details of research

Design	randomized complete block design (RCBD)
Treatments	3
Replications	7
Total number of plots	21
Crop	Walnut
Season	Spring
Sampling time	March – April, 2023

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2.6 Data Collection

Data was collected from the analysis of composite soil samples. Soil samples was tested for pH, Soil Organic Matter content (SOM), Nitrogen (N), Phosphorus (P), and Potassium (K).

2.7. Laboratory analysis

Soil samples collected from each location were analyzed for soil pH, soil organic matter, total nitrogen, available phosphorus and available potassium content of the soil. Laboratory methods used for analysis of different soil fertility parameters are depicted in table 3.

Table 3. Laboratory soil test methods

Soil parameters	Analysis method
Soil pH	Digital pH meter [1]
Organic matter	Walkley – Black method [2]
Nitrogen	From Organic matter[3]
Phosphorus	Modified Olsen's Method [4]
Potassium	Ammonium acetate extraction method [5] using flame photometer

2.8 Data analysis technique

2.8.1 Characterization of soil nutrient parameter

The obtained data were entered in the MS Excel and analyzed using the R-Studio software. Each soil fertility parameter was categorized under standard ratings: low, medium, and high [6]. Data collected from laboratory evaluation were analyzed using both descriptive and statistical approaches. Three different aged group were taken as factor and one way analysis of variance was used to test the significance of factors. Simple descriptive statics like mean, standard deviation, pie chart, diagrams were used for the descriptive analysis of data. Also, the Duncan's multiple range test (DMRT) at 5% probability level was also carried out to test the significance among the factor means.

Table 4. Standard rating for soil parameters

Soil Physio-chemical parameters	Low	Medium	High
OM content (%)	<=2.5	2.51-5.0	>=5
Nitrogen (%)	<=0.10	0.11-0.20	>0.20
Phosphorus(kg/ha)	<=30	30.1-55	>55
Potassium(kg/ha)	<=110	110.1-280	>280

Source: [6]

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Table 5. Rating chart for soil reaction of studied soils

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

Source: [7]

4.8.2. Determination of most limiting nutrient

For the determination of most limiting nutrient the results from the laboratory were compared with the table from Soil Science Division, NARC

Table 6.Optimum soil test value for walnut

Soil Parameters	Optimum Range
Soil pH	5.5-7.5
Available Nitrogen (mg/kg)	86.7-122.4
Available Phosphorus (mg/kg)	5.9-17.8
Available potassium (mg/kg)	173.4-403.2

Source: [8]

3. RESULTS AND DISCUSSION

3.1. Soil chemical properties

Soil fertility parameters and organic matter content varied between different orchard ages of walnut. The NPK level, OM, and soil pH are shown in tables and described in subsequent sections. The values are rated according to the rating chart of Soil Testing Laboratory, Birendranagar, Surkhet.

3.1.1. Soil pH

Soil pH in walnut orchards showed significant variation with orchard age. The pH was highest at 6.95 for orchards aged 1-5 years, decreasing to 6.67 for those aged 6-10 years, and further to 6.38 for orchards aged 11-15 years. These differences were statistically significant, with an F-probability of 0.01. The least significant difference (LSD) at the 0.05 level was 0.31, indicating that pH differences greater than this are significant. The standard error of the mean (SEm) was 0.125, and the coefficient of variation (CV) was 4.02%, with a grand mean pH of 6.67, highlighting the substantial impact of orchard age on soil pH. According to the soil reaction rating chart by Khatri-Chhetri & Aryal [7], the majority of sampled soils were found to have a neutral pH. The observed decrease in soil pH with increasing orchard age aligns with findings by [9]&[10]. Phuong[11] also reported that pH gradually decreases with plant age, possibly due to nutrient imbalance as low pH leads to deficiency of major nutrients like Ca2+ and Mg2+ as well as Nitrogen and Phosphorus. Similarly, Gregory &Hinsinger[12] pointed that pH gradually decreases with plant age due to ion absorption through root systems releasing

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H+. Conversely, low organic matter content and leaching of exchangeable bases to lower horizons due to heavy rainfall cause a rise in pH during the initial years of orchard management [13]&[14].

Table 7. Age-wise effect of walnut orchards on soil pH of Walnut zone, Jajarkot Nepal (2023)

Age of walnut orchards (years)	pH
1 to 5	6.95 a
6 to10	6.67 ab
11 to 15	6.38 b
LSD (0.05)	0.31
SEm (±)	0.125
F- probability	0.01**
CV, %	4.02
Grand Mean	6.67

*Note: The treatment mean followed by common letter (s) are not significantly different from each other based on Duncan Multiple Range Test at 5% level of significance, ** is significant at P<0.01*

3.1.2 Soil Organic Matter (SOM)

Table 8 illustrates the variation in soil organic matter (SOM) content across different age categories of walnut orchards. The highest SOM was observed in orchards aged 11-15 years (5.02%), followed by those aged 6-10 years (3.45%), and the lowest in orchards aged 1-5 years (2.44%). [15] reported similar findings, noting a rise in soil organic matter levels as trees mature, which is consistent with the patterns seen in this research. The standard error of mean (SEm) of ±0.21 provides precise estimates, underscoring the robustness of these findings with a highly significant F-probability of 0.001. The coefficient of variation (CV) of 26.81% suggests moderate variability in SOM measurements. The grand mean soil organic matter across all age groups was 3.67%. According to standard ratings for soil parameters by Shahu [6], the majority of sampled soils in this study fell within the medium soil organic matter content category.

Research conducted in China by Hou, Liu, and Zhao [16] also supported this trend, demonstrating increasing organic matter content with the age of apple orchards. Similarly, [17] observed that the amount of organic matter of soil per hectare increases with increasing apple tree age. The cumulation of soil organic matter in walnut orchards primarily results from the deposition and decomposition of dry leaves and husks on the orchard floor during each growing season. Lower organic matter in younger orchards may be attributed to higher nutrient uptake, dense canopy development, and less litter accumulation with faster nutrient turnover. On the contrary, mature orchards with lower tree density and reduced growth rates contribute to higher organic matter accumulation, facilitated by nutrient return and slower nutrient turnover rates [18].

Table 8. Age wise effect of walnut orchards on soil organic matter content of Walnut Zone, Jajarkot, Nepal (2023)

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Age of walnut orchards (years)	SOM (%)
1 to 5	2.44b
6 to10	3.45b
11 to 15	5.02a
LSD	1.14
SEm (±)	0.21
F- probability	0.001***
CV, %	26.81
Grand Mean	3.67

*Note: The treatment mean followed by common letter (s) are not significantly different from each other based on Duncan Multiple Range Test at 5% level of significance, *** is significant at P<0.001; SOM, Soil Organic Matter.*

3.1.3. Soil Nitrogen

According to typical rankings for soil characteristics put forward by Shahu [6], the majority of sampled soils have shown medium soil total nitrogen content. Maximum soil nitrogen content was observed in 10 to 15 years old orchards followed by 6 to 10 years old orchards and least nitrogen content was observed in 1 to 5 years old orchard. Similar results were reported by Slade & Wells [17]. Slade & Wells [17] also noted that the percentage of total nitrogen in the soil rose as apples became older. This is likely due to the annual addition of organic matter to orchards, which causes various organic N compounds to solubilize into more easily soluble forms. Additionally, Akhter, Padder and Maqb[19] observed that nitrogen is directly related with SOM content. Increasing soil nitrogen content with increasing age of apple orchards has been demonstrated in research conducted in China, likely attributed to nitrogen association with organic matter and adsorption of NH4-N by humus complexes in soils [16]. Moreover, the standard error of mean (SEm) of ±0.007 underscores the precision of these estimates. The coefficient of variation (CV) of 18.68% suggests moderate variability in nitrogen measurements. The grand mean nitrogen content across all age groups was 0.174%.

Table 9. Age wise effect of walnut orchards on soil nitrogen of Walnut Zone, Jajarkot, Nepal (2023).

Age of walnut orchards (years)	Nitrogen (%)
1 to 5	0.10 c
6 to10	0.16 b
11 to 15	0.25 a

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LSD	0.037
SEm (±)	0.007
F- probability	0.001***
CV, %	18.680
Grand Mean	0.174

*Note: The treatment mean followed by different letters are significantly different from each other based on Duncan Multiple Range Test at 5% level of significance, *** is significant at P<0.01*

3.1.4. Available Phosphorous

According to common rankings for soil characteristics put forward by Shahu [6], the majority of sampled soils have shown high available phosphorus content. Maximum available phosphorus was observed in six to ten years old orchard (160.14) followed by one to five years old orchard (151.85) and least soil available phosphorous was observed in eleven to fifteen years old orchard (142.71). The statistical analysis shows a significant difference among age groups, with an LSD of 9.45 indicating significant differences between means at the 5% level. The standard error of mean (SEm) of ±1.77shows how accurate these estimations are, and the coefficient of variation (CV) of 5.36% suggests low variability in phosphorus measurements. The grand mean phosphorus content across all age groups was 151.42 kg/ha.

It was discovered that the trend of the changing pH of the soil was nearly consistent with the increase in total accessible phosphorus in the soil that occurred first with age and then gradually decreased with age. Because it transforms into insoluble tricalcium phosphates, the availability of phosphorus reduces as soil pH rises [19]. Moreover, acidifying effects of FYM on native Phosphorus during their breakdown results change in amount of Phosphorus status in soils, making more P accessible[20]. Similar results were presented by Tsheringl[14]. The mineralization of organic manure competes with phosphorous for adsorption during their breakdown causes soil to repulse phosphates more. In addition, the combination of iron and aluminum oxide with organic matter reduce the ability to adsorb phosphates [21].

Table 10. Age-wise effect of walnut orchards on soil phosphorous of Walnut zone, Jajarkot, Nepal (2023).

Age of walnut orchards (years)	Phosphorous (kg/ha)
1 to 5	151.85 ab
6 to10	160.14 a
11 to 15	142.71 b
LSD (0.05)	9.45
SEm (±)	1.77

F- probability	0.01**
CV, %	5.36
Grand Mean	151.42

*Note: The treatment mean followed by different letter (s) are not significantly different from each other based on Duncan Multiple Range Test at 5% level of significance, **is significant at (p<0.01)*

3.1.5. Available Potassium

According to normal soil parameter ratings by Shahu[6], the majority of sampled soils is found to have high potassium content. Carson B,(1992) also reported Nepalese soil are rich in potassium content. High potassium content is due to the availability of potassium rich minerals in parent materials [14].

Maximum available potassium was observed in six to ten years old orchard (652.85) followed by one to five years old orchard (543.85) and least soil available potassium was observed in eleven to fifteen years old orchard (433.85). Statistical analysis using an LSD of 162.60 at the 5% significance level reveals significant differences among age groups. The standard error of mean (SEm) of ±65.22 indicates the precision of these estimates, while the coefficient of variation (CV) of 25.68% suggests moderate variability in potassium measurements. The F-probability of 0.05 signifies statistical significance, albeit at a lower level. The grand mean potassium content across all age groups was 543.52 kg/ha. Akhter, Padder, and Maqb[19] also reported the similar result. The increase in the fruit load during fruit development increased uptake of potassium causing a notable decrease in potassium levels in the soil [22]&[23]

Table 11. Age-wise effect of walnut orchards on soil potassium of Walnut zone, Jajarkot, Nepal (2023).

Age of walnut orchards (years)	Potassium (kg/ha)
1 to 5	543.85ab
6 to10	652.85a
11 to 15	433.85b
LSD (0.05)	162.60
SEm (±)	65.22
F- probability	0.05*
CV, %	25.68
Grand Mean	543.52

Note: The treatment mean followed by different letter (s) are not significantly different from each other based on Duncan Multiple Range Test at 5% level of significance, is significant at P <0.05.*

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3.2. Simple correlation coefficient(r) among different soil nutrient parameters.

Significant correlations are observed between several variables at different levels of significance. Firstly, the age of the walnut plants shows strong positive correlations with soil nitrogen content ($r = 0.894$, $p < 0.01$) and phosphorus availability ($r = 0.305$, $p < 0.01$), indicating that older orchards tend to have higher levels of nitrogen and phosphorus in the soil. Conversely, there is a significant negative correlation between the age of plants and potassium availability ($r = -0.271$, $p < 0.05$), suggesting that potassium content decreases with orchard age. Soil organic matter (SOM) demonstrates a strong positive correlation with nitrogen content ($r = 0.726$, $p < 0.01$) and a significant negative correlation with pH ($r = -0.554$, $p < 0.01$), implying that higher SOM levels correspond to increased nitrogen content and lower soil pH. However, SOM shows a negative correlation with phosphorus availability ($r = -0.406$, $p < 0.05$), indicating that higher SOM may lead to reduced phosphorus availability in the soil. Overall, these correlations provide insights into how age-related factors and soil properties interrelate in walnut orchards, offering valuable implications for agricultural management and nutrient supplementation strategies.

Table 12. Correlation coefficient among different soil nutrient parameters in different aged walnut orchards in Jajarkot, Nepal.

Parameters	Nitrogen (%)	Phosphorous (kg/ha)	Potassium (kg/ha)	SOM (%)	pH
Age of Plant	0.894**	0.305**	-0.271*	-0.776	-0.658
SOM (%)	0.726**	-0.406*	0.41		-0.554**

Note: **. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.3 Relationship of age of plant with different soil parameters

3.3.1. Relationship between age of plant and total soil nitrogen

The correlation between age of plant and total soil nitrogen of orchard was significant ($r = 0.894^{**}$) positively. The coefficient of determination (R^2) value was 0.800 which means that the variation in soil nitrogen level contributes to 80.00% variation with age of plant while the rest effects was due to other factors as shown in figure 2. Similar results were noted by a study conducted in China [24]. As the plant age increases the percentage of nitrogen also increases due to the addition of organic matter in the soil every year [17].

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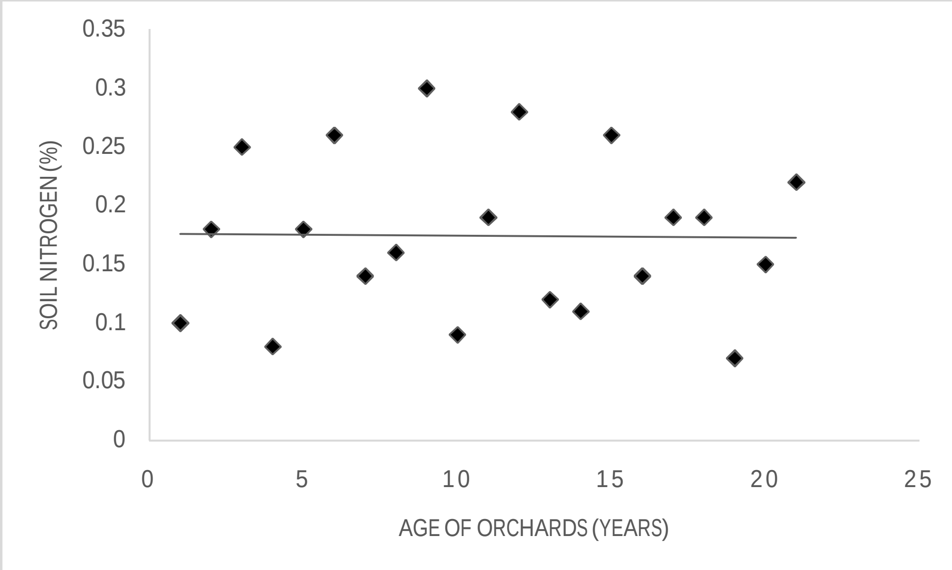

Figure 1. Relationship between soil nitrogen and age of plant of different aged walnut orchards in Jajarkot, Nepal (2023)

3.3.2. Relationship between age of plant and soil available phosphorous

The correlation between soil available phosphorous of orchard and age of plant was significant (r = 0.305**) positively. The coefficient of determination (R^2) was 0.09, indicating that the variation in soil phosphorous level contributes 9% variation with age of plant while the rest effects was due to other factors as shown in figure 3. Similar results were put forwarded by Zhao, et al. [24]. This is due to nutrient and energy release via decomposition of litter during the initial stage of flowering and fruiting of plant [25] and due to more hunger of plants during the initial stage of fruit production [23].

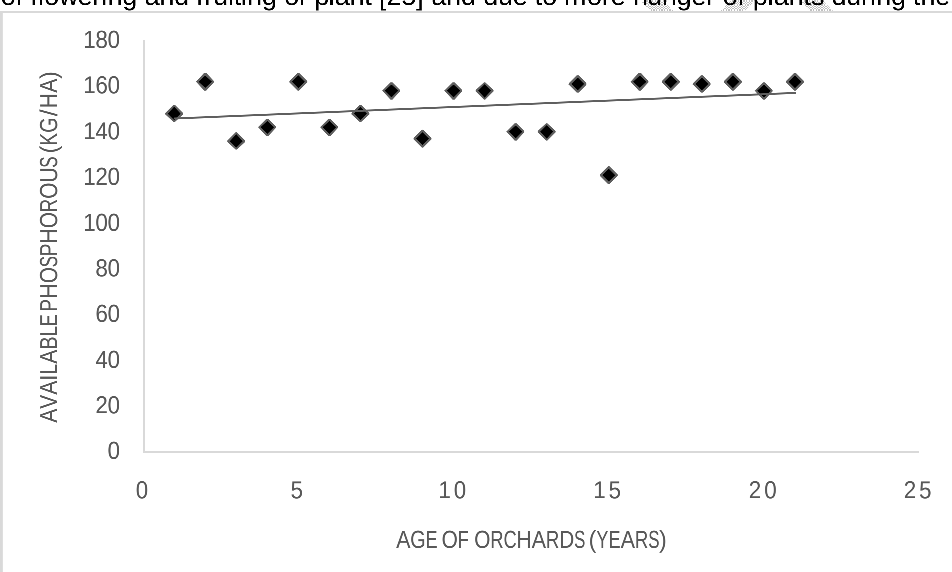

Figure 2. Relationship between soil phosphorous and age of plant of different aged walnut orchards in Jajarkot, Nepal (2023)

3.3.3. Relationship between age of plant and soil available potassium

The age of plant and soil available potassium of orchard was negatively correlated (r = -0.271**). The coefficient of determination (R^2) was 0.073, stating that the variation in soil potassium level contributes 7.3% variation with age of plant. However, the rest effects were because of other factors as shown in figure 4. There was significant difference in between soil available potassium and age of plant in which plant age of 6-10 years had higher level of available

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phosphorous than 1-5 and11-15 years plant. Similar observation was presented by Zhao, et al. [24]. This is due to more absorption of potassium by plants roots during flowering and fruit development stage [22].

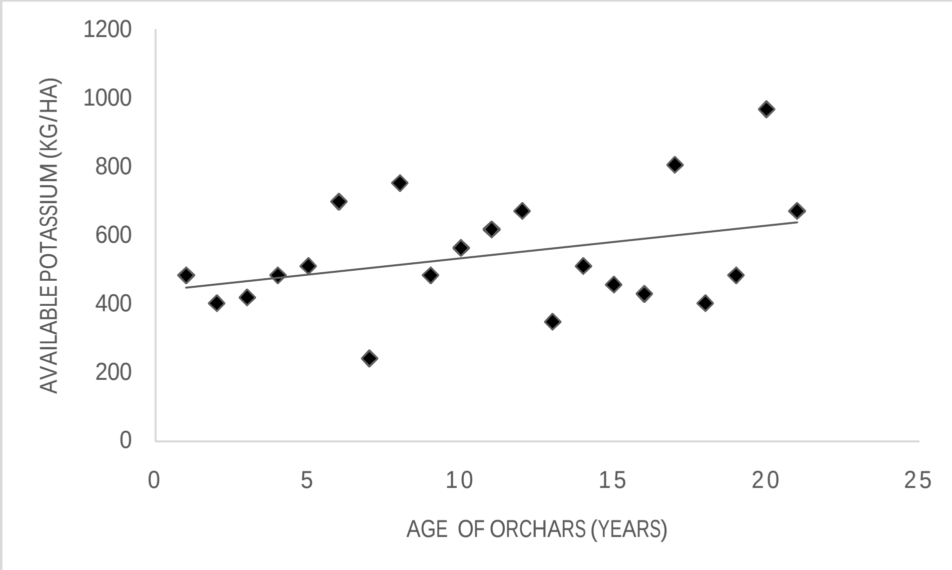

Figure 3. Relationship between soil potassium and age of plant of different aged walnut orchards in Jajarkot, Nepal (2023)

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3.3.4. Relationship between age of plant and soil pH

The correlation between age of plant and soil pH of orchard was negative (r = -0.658). The coefficient of determination (R^2) value was 0.4329 which means that the variation in soil pH level contributes to 43.29% variation with age of plant. On the other hand, the rest effects were due to other factors as shown in figure 5. Similar results were put forwarded by Zhao, et al [24]. However, soil pH gradually decreases with increasing age of plant this is due to the, nutrient imbalance, low organic matter content and leaching of exchangeable bases to lower horizons due to heavy rainfall. Non-significant difference was seen in between soil pH and age of plants: 1-5years, 6-10years, and 11-15 years.

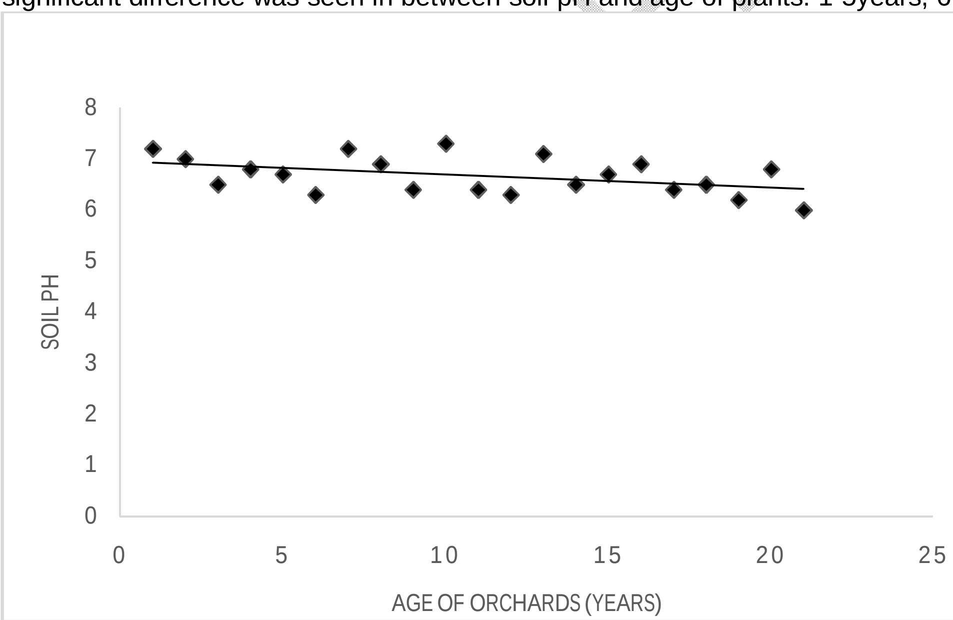

Figure 4. Relationship between soil pH and age of plant of different aged walnut orchards in Jajarkot, Nepal (2023)

3.3.5. Relationship between age of plant and soil organic matter

The correlation between age of plant and soil organic matter of orchards was negative (r = -.776). The coefficient of determination (R^2) value was 0.6021, denoting that the variation in soil organic matter level contributes 60.21%

variation with age of plant; nevertheless, the remaining effects were due to other factors as shown in figure 6. Similar result was noted by Zhao, et [24]. However, soil organic matter increases with increasing age of orchard is owing to the decomposition of dry leaves and husk that fall during each growing season on the orchard floor, resulting more mineralization and microbial growth [17].

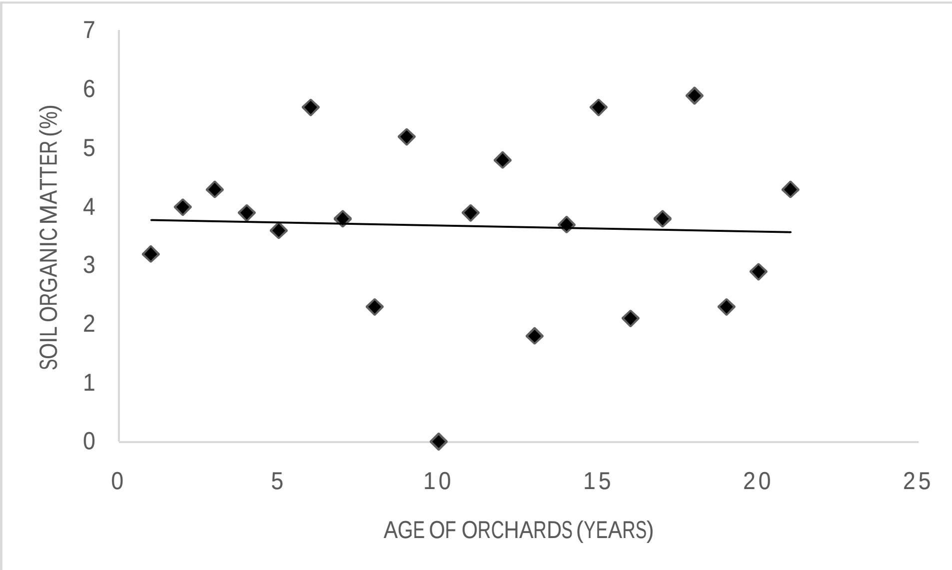

Figure 5. Relationship between soil organic matter and age of plant of different aged walnut orchards in Jajarkot, Nepal (2023)

3.4. Relationship between soil organic matter with different soil parameters

3.4.1. Relationship between SOM content and soil pH

The soil organic matter and soil pH was negatively correlated (r = -0.554). The coefficient of determination (R^2) was 0.3069, indicating that the variation in soil organic matter level contributes 30.69% variation in soil pH level; nonetheless, the remaining effect was on account of other factors (Figure 7). Soil organic matter had significant negative effect on soil pH. Similar findings were noted by one of the studies in China Zhou, et al.,[26]&[27] . As soil organic matter increases, pH goes on decreasing which might be due to binding of H^+ ion during the microbial decomposition and hydrolysis of organic matter [28]& due to more hunger of plants during the initial stage of fruit production due to more hunger of plants during the initial stage of fruit production [29].

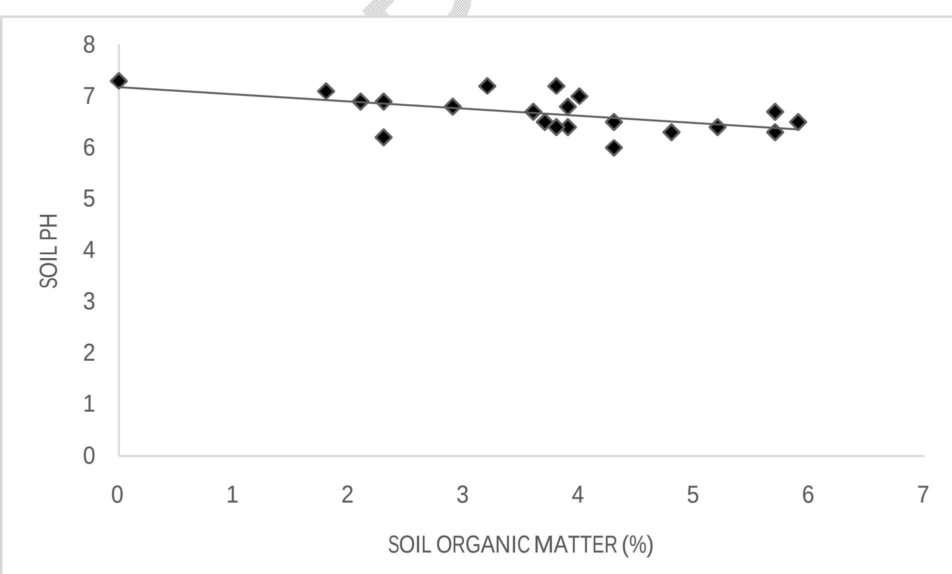

Figure 6. Relationship between soil organic matter content and soil pH in different aged walnut orchards in Jajarkot, Nepal (2023)

3.4.2. Relationship between SOM content and soil nitrogen

The positive correlation was observed between SOM and total nitrogen content (r=0.726). Luyssaert, et al. [30] also shows the comparable results. Soil organic matter and total nitrogen content are interlinked and influenced by factors such as soil microbial activity, pH, and C/N ratio [31] . Land use system also plays key role on distribution of soil organic matter which in turn affects total nitrogen[32]. The value of coefficient of determination (R^2) value was 0.5270, indicating that the variation in soil organic matter level contributes 52.70% variation in soil nitrogen level while the rest effects was due to other factors (Figure 8). Soil organic matter had significant effect on soil nitrogen.

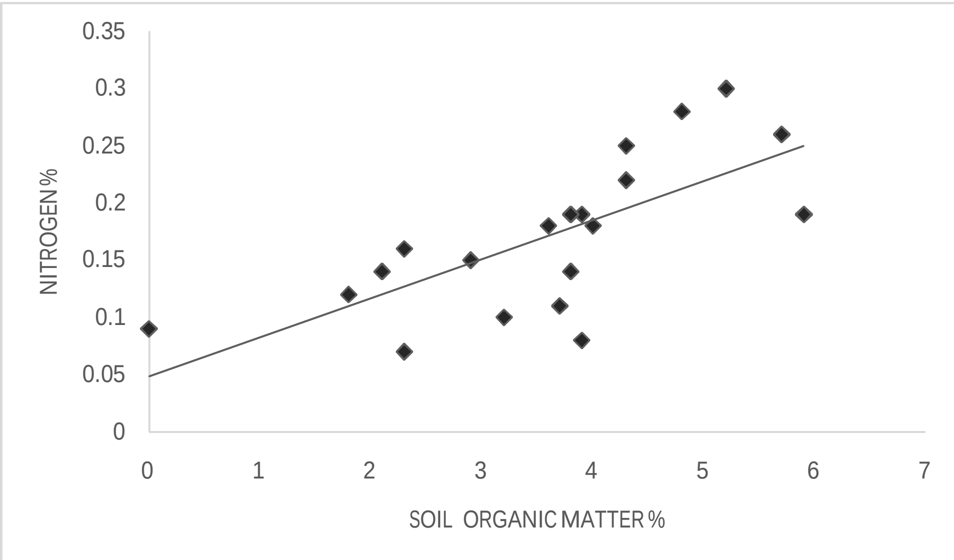

Figure 7. Relationship between soil organic matter content and soil nitrogen in different aged walnut orchards in Jajarkot, Nepal (2023)

3.4.3. Relationship between SOM content and available phosphorus

The correlation between soil organic matter and available phosphorus content was significantly negative (r = -0.406) which similar to the findings of Mabagala&Mngong[33]& Rao [34]. The value of the coefficient of determination (R^2) was 0.164, indicating that 16.40% of the variation in available phosphorus level is attributed to the variation in soil organic matter level, while the remaining effects being caused by other factors (Figure 9). As the level of phosphorous in soil increases, the quantity of organic matter within the soil decreases, as a higher concentration of phosphorous attaches to the soil, suggesting that organic matter inhibits phosphorous from attaching to the soil [35]. In highly phosphorus fertilized intensive agriculture, there might be low soil organic matter; however, available phosphorus can be in high amount[34].

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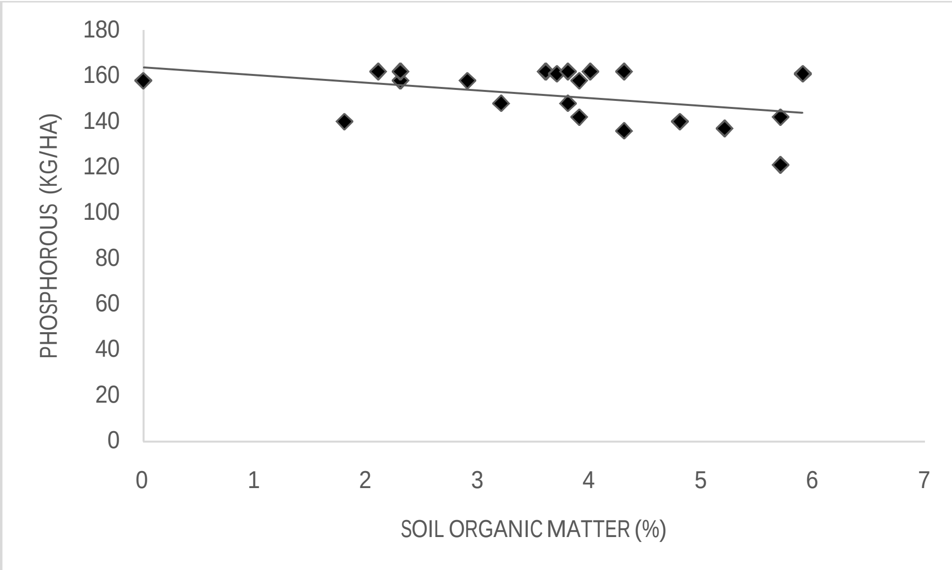

Figure 8. Relationship between soil organic matter content and soil phosphorous in different aged walnut orchards in Jajarkot, Nepal (2023

3.4.4. Relationship between SOM content and available potassium

There is no significant correlation (r = 0.41) between soil organic matter and available potassium content in various aged walnut orchards). The coefficient of determination (R^2) value of 0.1681 indicates that 16.81% of the variability in available potassium level is caused the variation in soil organic matter level (Figure 10). The increasing availability of potassium leads to increase in SOM content signifies their positive correlation. Cation exchange capacity increases and potassium being of lower positive charge is easily up taken by plants in light of the increase in organic matter present in the soil[36].

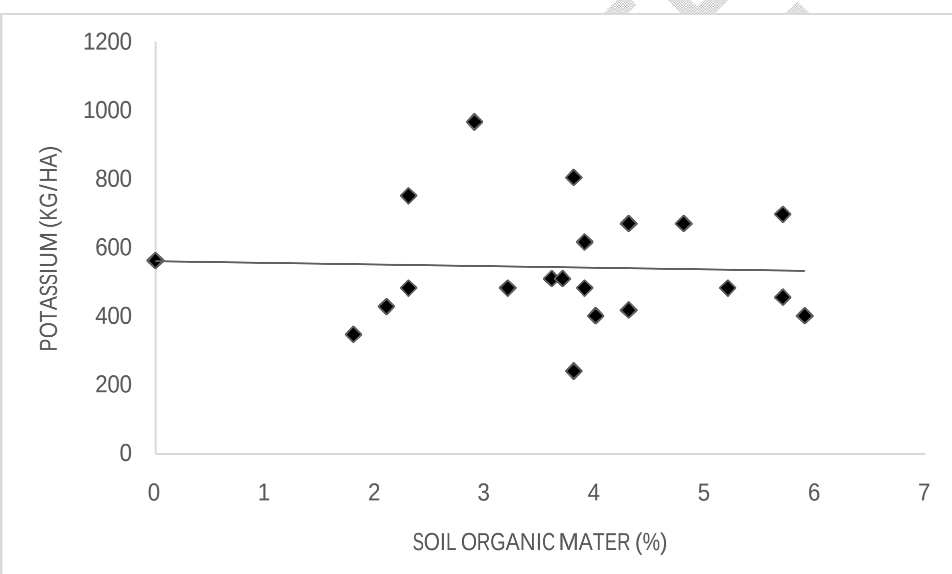

Figure 9. Relationship between soil organic matter content and soil available potassium in different aged walnut orchards in Jajarkot, Nepal (2023)

3.5. Optimum nutrients requirement and nutrient status in walnut orchards

3.5.1. Overall soil fertility status according to optimum nutrient requirement of walnut orchards

Standard soil rating only helps to characterize the soil but it may not be in accordance with the exact walnut nutrient requirement. So, comparing soil nutrient status in accordance with optimum range as walnut requirements will help to identify which nutrient factor is the most limiting factor in the production of quality walnut.

It was shown that the most limiting nutrient for walnut production is phosphorous (100%) in overall sampled soils. Phosphorous strengthens root growth, increases the number of flowers and fruits and also increases the quality of walnut; therefore, it is recommended to apply the optimum amount of phosphatic fertilizers to meet the requirements of walnut plants in order to maintain healthy and vigorous plants.

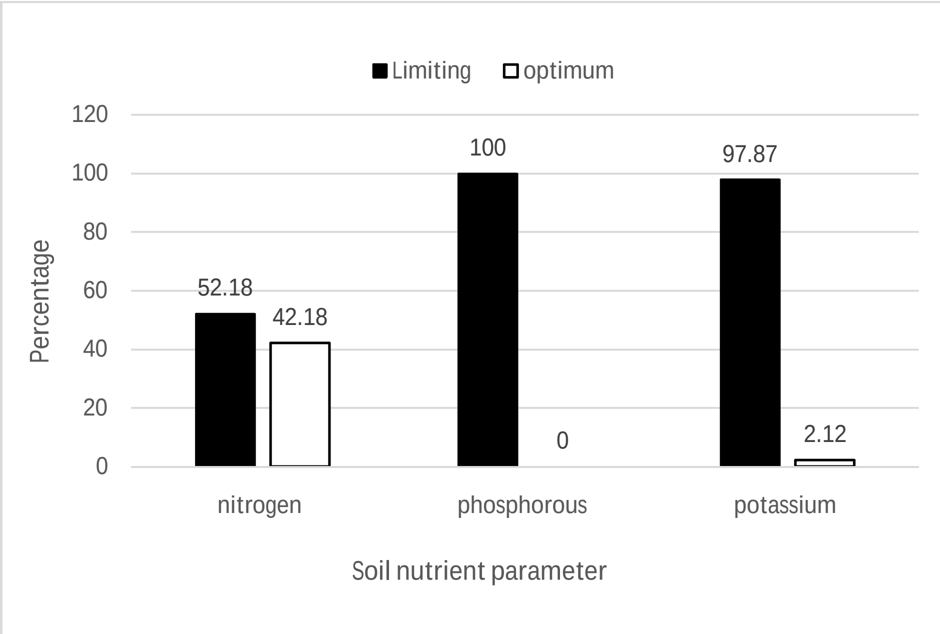

Figure 10. Bar diagram showing soil nutrients status of walnut orchards of Jajarkot, Nepal

3.5.2. Available soil nitrogen status

As per the optimum available soil nitrogen requirement of walnut, it was revealed that 52.18% of total sampled soils were in limiting range of available nitrogen whereas 42.18% of total samples soils were in optimum range.

Table 13. Status of available soil nitrogen status as per the walnut requirement in Jajarkot, Nepal (2023).

Variable	Rating	Percentage
Available Soil Nitrogen	Limiting	52.18%
	Optimum	42.18%

3.5.3. Available soil phosphorus status

As per the optimum available soil phosphorous requirement of walnut, it was shown that 100% of total sampled soils were in limiting range. It was observed that phosphorous is the most limiting nutrients as compared to other nutrients for walnut orchards as per optimum requirements range.

Phosphorous deficiency limits the number of flowers and fruits and decreases walnut quality; thus, producers should apply the optimum amount of phosphatic fertilizers, ensuring their use one month after lime application, to meet growth and development requirements [37].Due to their limited soil mobility, phosphorous fertilizers should be applied once or twice a year during the dormant period of plants in semi-tropical regions, utilizing base or top dressing methods[38].

Table 14. Status of available soil phosphorus status as per the walnut requirement in Jajarkot, Nepal (2023).

Variable	Rating	Percentage
Available Soil Phosphorus	Limiting	100%
	Optimum	0%

3.5.4. Available soil potassium status

As per the optimum available soil potassium requirement of walnut, it was revealed that 97.87% of total sampled soils were in limiting range of available potassium whereas 2.12% of total samples soils were in optimum range.

Table 15. Status of available soil potassium status as per the walnut requirement in Jajarkot, Nepal (2023).

Variable	Rating	Percentage
Available Soil Potassium	Limiting	97.87%
	Optimum	2.12 %

4. CONCLUSION

Based on the findings of this study, it is evident that soil nutrient dynamics in walnut orchards vary significantly with orchard age. The research extensively examined soil pH, organic matter content, and nutrient levels such as nitrogen, phosphorus, and potassium across different age categories of walnut orchards. Key observations include a consistent decrease in soil pH with increasing orchard age, coupled with a notable rise in soil organic matter content. Furthermore, there was a substantial increase in soil nitrogen and phosphorus levels as orchards aged, contrasting with a decline in available potassium. These findings underscore the necessity for tailored nutrient management strategies to maintain soil fertility and enhance walnut orchard productivity over the long term.

These findings have great implications for agricultural practices, suggesting that older walnut orchards may require distinct fertilizer formulations and application rates compared to younger ones. Specifically, the study identifies phosphorus as a critical nutrient limiting root development, flowering, and walnut quality. By offering specific insights into nutrient dynamics in walnut orchards, this research guides effective soil management strategies aimed at optimizing walnut production sustainably. A significant contribution of this study lies in its detailed analysis of age-related changes in soil properties (soil pH, Soil organic matter and nutrient availability, providing a nuanced understanding of soil fertility dynamics in walnut orchards. Nonetheless, limitations include the study's geographic specificity and the need for future research to explore seasonal variations and other factors influencing soil nutrient dynamics comprehensively. Further investigations could also explore the impact of diverse soil management practices on nutrient retention and availability to refine agricultural strategies further.

Disclaimer (Artificial intelligence)

The author(s) confirm that no generative AI technologies, including Large Language Models (such as ChatGPT or COPILOT) or text-to-image generators, were utilized in the writing or editing of this manuscript.

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