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EXPLORATION OF INTERCROPPING EFFECT ON THE VARIATIONS IN SOIL PROPERTIES IN KIWI ORCHARD

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SUMMARY

Intercropping is a well-known agricultural practice that capitalizes on the use of available land resources for higher output. The ensuing study aimed to identify the influence of intercropping on soil properties in the kiwi orchard after three years of intercropping. For the said study, two kiwi-based intercropping experiments took place. In the first experiment, the intercropping treatments were wheat intercropping (WI), oat intercropping (OI), pak choi intercropping (PCI), and no intercropping (NI) at Mianzhu County, China. In the second experiment, the treatments were corn intercropping (CI), pumpkin intercropping (PI), soybean intercropping (SI), and no intercropping (NI) at Cangxi County, China. The soil analysis comprised soil pH, organic matter, total nitrogen (N), total phosphorus (P), available N, and available P, with the samples collected from five depths (0–20, 20–40, 40–60, 60–80, and 80–100 cm). The results revealed PI (191.30%) and CI (86.03%) significantly improved the available N; PI (32.69%) significantly enhanced the available P; OI (31.30%) considerably boosted the total N; and all the intercropping treatments improved the total P, except SI, which reduced the total P (24.62%). Therefore, the intercropping in fruit orchards has the potential to improve soil fertility and keep soil healthy for future generations.

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Keywords: Soil profile, soil nutrients, soil health, intercropping, wheat, oat, pak choi, maize, soybean, pumpkin, young kiwi

Key findings: In the kiwi fruit orchard, the intercropping systems enhanced the available land resources. It was also helpful in improving soil nutrients and fertility.

INTRODUCTION

The global population estimates will reach 9.7 billion by 2050, with an increase of 2 billion people compared with the current population of 7.7 billion. This population enhancement will raise a serious concern for scientific societies to utilize limited resources efficiently by ensuring sustainable agriculture and feeding such a huge population (Galanakis, 2024). Presently, modern agriculture is already facing several challenges, such as soil degradation, climate change, water scarcity, biodiversity decline, and non-point pollution (Khatri *et al.,* 2024). A report also stated that about 19–23 hectares of land are lost every minute due to soil erosion and desertification. Moreover, urbanization is an alarming factor in reducing arable soil availability, with an estimate to reach 1.5 million km^2 by 2030 (Zabel *et al.,* 2014).

Intercropping is a well-adopted system employed worldwide, including in China, Mali, India, Indonesia, Niger, and Western Europe. It also has a wide adoption in the USA and Africa, as one-third of the cassava- and banana-growing areas are under intercropping with different crops (Wang *et al.,* 2015). Intercropping has numerous benefits, including sustainable agriculture, improved water, light, and nutrient use, increased yield, land use efficiency, controlled weeds and diseases, and enhanced soil conservation. In the 19th century, the practice of growing grass in orchards was high and found beneficial in the USA and Japan (Wang *et al.,* 2024). Planting grass in orchards properly can improve soil fertility (Tang *et al.,* 2022), fruit yield and quality (Ren *et al.,* 2023), and reduce pests and soil-borne disease severity, and, eventually, minimize the use of pesticides and inorganic fertilizers, which promotes environmental sustainability (Zhang *et al.,* 2025). Additionally, grass cultivation influences soil properties, such as soil moisture, pH, organic matter, porosity, permeability, temperature, and nutrient status (Wang *et al.,* 2023; Xu *et al.,* 2024), boosting soil biological and enzymatic activities (Xiang *et al.,* 2023) and improving nutrient cycling. Furthermore, enhanced soil fertility can also link with nutrient stoichiometry (Liu *et al.,* 2024).

Kiwi fruit (*Actinidia deliciosa*) is one of the most commercialized and nutritional fruits, as it contains vitamins and minerals with medicinal and therapeutic significance against diseases, i.e., diabetes, cancer, cardio, ortho, and eye diseases, kidney problems, and digestive disorders (Satpal *et al.,* 2021). China is the largest producer of the kiwi fruit, along with Italy, New Zealand, Chile, and Greece, contributing to ranking kiwi sixth in the marketable gross production (Rajan *et al.,* 2024). Kiwi fruit is a major fruiting crop for the local farming community; therefore, it is crucial to study its effects on land-use patterns, soil physiochemical properties, and soil-nutrient status (Lu *et al.,* 2016).

Soil fertility is the ability of soil to provide necessary nutrients to various crop plants for their growth and development and maintain the air and water quality with sustainable plant production (Wang *et al.,* 2014). Numerous studies investigated the relationship between agricultural practices, irrigation, fertilization, and other related factors; however, reports on information on the young kiwi fruit intercropping with different crops and its effects on soil profile are few, giving rise to the need for this study. We hypothesize that intercropping could improve the soil physiochemical properties and fertility at two localities with diverse weather conditions to identify a suitable intercrop for young kiwi plants. The presented research work will provide an understanding to adopt the most effective and economical practice for improving soil properties used for young kiwifruit plants. The conduct of this study had the following objectives: a) identify the variations in soil properties at different depths due to intercropping; b) compare the influence of intercropping on soil properties and nutrient status; c) formulate the interaction effects among the soil properties; and d) identify the suitable intercrop to improve soil health for young kiwi plants.

MATERIALS AND METHODS

Experimental procedure

The study comprised two experiments. The first experiment transpired in Mianzhu County, and the second experiment took place in Cangxi County, China. Mianzhu County is in Deyang, Sichuan Province, China. It belongs to the subtropical humid climate, with a mild climate and abundant precipitation. The first experiment employed the following treatments, i.e., wheat intercropping (WI), oat intercropping (OI), pak choi intercropping (PCI), and no intercropping (NI) as the control. Cangxi County is in Guangyuan, Sichuan Province, China. It has a purple hilly area, but the slope is gentle, belonging to the subtropical humid monsoon climate zone. The second experiment engaged the following treatments, viz., corn intercropping (CI), pumpkin intercropping (PI), soybean intercropping (SI), and no intercropping (NI) as the control. At both locations, the intercropping proceeded for three years, and thereafter, the effects on soil characteristics attained examination. The assessment on fruit yield did not happen, as the kiwi orchard obtains its fruiting potential after five years.

Soil sampling and nutrient analysis

Soil samples sustained drying, crushing, and sieving through 1 mm and 0.25 mm for the soil characteristics' analysis—soil pH, organic matter, total and available N, and total and available P. Soil pH determination consisted of preparing a 1:2.5 soil-water (w/v) mixture using a pH meter to verify the value. Organic matter estimation used the volumetric method—the external-heating method (Walkley, 1947). Determining the total N utilized the Kjeldahl method (Kjeldahl, 1883), while the available N estimates applied the alkaline hydrolysis diffusion technique (Dodor *et al.,* 2022). For total P detection, the study used the alkaline fusion process (Dick and Tabatabai, 1977), and the available P analysis operated Olsen's P method, applying the procedure for sodium bicarbonate extraction (Olsen and Sommers, 1982).

Statistical analysis

All the recorded data underwent one-way analysis of variance (ANOVA), and the significant mean differences reached further assessment through Fisher's least significant difference (LSD) test using Statistix 10®. For data compilation, we used Microsoft Excel 2024®. The chord diagram preparation utilized R (version 4.4.2).

RESULTS

Soil physicochemical characteristics

Soil pH

The results obtained from Experiment 1 showed the soil pH was nearly neutral (Figure 1A-E). However, at the depth of 0–20 cm, it was nonsignificant, and at the depth of 20–40 cm, the oat intercropping (OI) and pak choi intercropping (PCI) significantly ($p \leq 0.05$) increased soil pH, and wheat intercropping (WI) was nonsignificant compared with no intercropping (NI). At the depth of 40–60 cm, the highest pH was evident with NI and WI, followed by PCI and OI, and at the depth of 60–80 cm, it was higher with PCI and OI than with NI. At the depth of 80–100 cm, the soil pH of OI was significantly ($p \leq 0.05$) lower than other treatments. In addition, the soil depth-wise comparison revealed the pH values range from 6.8 to 7.2, with an average of 6.98, with no specific trend with the depth observed among the different treatments.

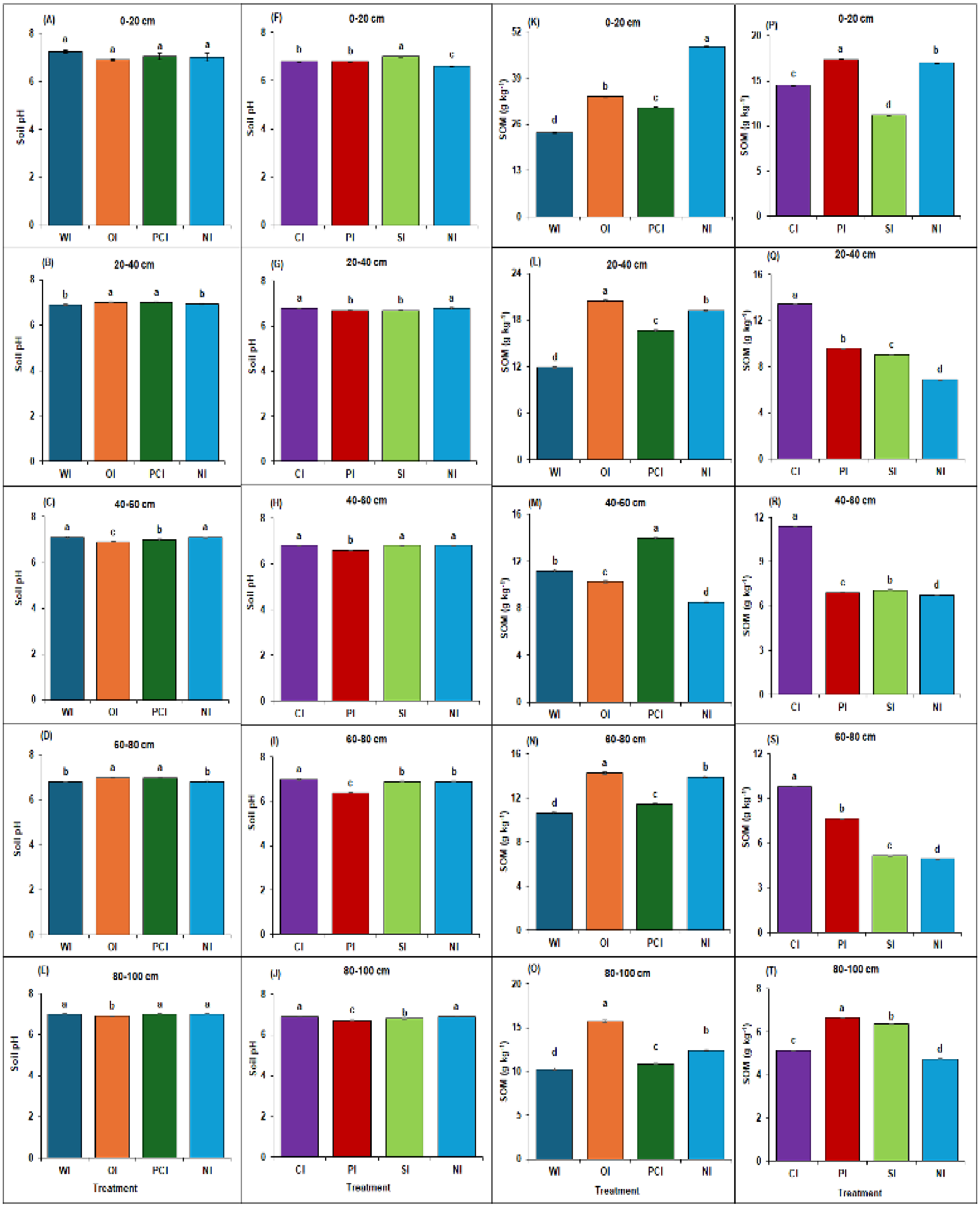

Figure 1. Soil pH at Mianzhu County (A-E) and Cangxi County (F-J); the soil organic matter (SOM) at Mianzhu County (K-O) and Cangxi County (P-T).

Experiment 2 indicated the soil pH has been nearly neutral (Figure 1F-J). However, at the depth of 0–20 cm, the soil pH for soybean intercropping (SI) was considerably higher, whereas NI showed the lowest soil pH value. At the depth of 20–40 cm, pH was significantly high in corn intercropping (CI) and NI, and it declined significantly ($p \leq 0.05$) with pumpkin intercropping (PI) in three-bottom depths.

Organic matter

The outcomes gathered in Experiment 1 revealed soil organic matter varies with intercropping and soil depth (Figure 1K-O). The results showed the highest organic matter at the depth of 0–20 cm is in NI (47.79 g kg^{-1}), followed by OI (33.73 g kg^{-1}), PCI (30.69 g kg^{-1}), and WI (23.64 g kg^{-1}). However, at 20–40 cm depth, the soil organic matter was optimum with OI (20.49 g kg^{-1}), followed by NI (19.24 g kg^{-1}), PCI (16.66 g kg^{-1}), and WI (11.88 g kg^{-1}). At 40–60 cm depth, organic matter was higher with PCI (13.98 g kg^{-1}), followed by WI (11.2 g kg^{-1}) and OI (10.26 g kg^{-1}). Meanwhile, NI gave the lowest organic matter (8.53 g kg^{-1}). The 60–80 and 80–100 cm depths displayed a similar trend as observed in the 20–40 cm depth, where NI provided the lowest soil organic matter content.

In Experiment 2, the soil organic matter was significantly ($p \leq 0.05$) higher in PI (17.4 g kg^{-1}), followed by NI (17 g kg^{-1}), CI (14.5 g kg^{-1}), and SI (11.2 g kg^{-1}) at the 0–20 cm depth (Figure 1P-T). At the 20–40 cm depth, CI showed the highest organic matter (13.4 g kg^{-1}), followed by PI (9.58 g kg^{-1}), SI (9.06 g kg^{-1}), and NI (6.89 g kg^{-1}). Exploring the depth of 40–60 cm, CI showed the supreme organic matter (11.4 g kg^{-1}), followed by SI (7.08 g kg^{-1}), PI (6.93 g kg^{-1}), and NI (6.73 g kg^{-1}). However, at the depth of 60–80 cm, the organic matter was at its maximum with CI (9.81 g kg^{-1}), followed by PI (7.64 g kg^{-1}), SI (5.15 g kg^{-1}), and NI (4.93 g kg^{-1}). At the depth of 80–100 cm, the organic matter was the highest with PI (6.66 g kg^{-1}), followed by SI (6.36 g kg^{-1}), CI (5.14 g kg^{-1}), and NI (4.74 g kg^{-1}). The depth-wise comparison revealed the organic matter content was higher in the topsoil and gradually decreased with depth.

Soil nutrient status

Total nitrogen and phosphorus

In Experiment 1, results indicated soil nutrient status also varies with the soil depth, as well as intercropping patterns. Soil total nitrogen (TN) was the highest with OI (1.51 g kg^{-1}), followed by NI (1.15 g kg^{-1}), PCI (0.72 g kg^{-1}), and WI (0.56 g kg^{-1}) at the 0–20 cm depth (Figure 2A). Moving toward the depth of 20–40 cm, the optimum TN was evident with OI (1.51 g kg^{-1}), followed by PCI (0.43 g kg^{-1}), NI (0.39 g kg^{-1}), and WI (0.29 g kg^{-1}) (Figure 2B). At the depth of 40–60 cm, OI has the highest TN (0.77 g kg^{-1}), followed by NI (0.73 g kg^{-1}), WI (0.26 g kg^{-1}), and PCI (0.17 g kg^{-1}) (Figure 2C). With the 60–80 cm depth, NI has the highest TN (0.69 g kg^{-1}), followed by WI (0.64 g kg^{-1}) and OI (0.42 g kg^{-1}) (Figure 2D). At the highest depth (80–100 cm), the NI was higher in TN (0.70 g kg^{-1}), followed by OI (0.63 g kg^{-1}), PCI (0.60 g kg^{-1}), and WI (0.21 g kg^{-1}) (Figure 2E). With WI, the total N was higher in the topsoil and decreased with the 20–40 cm depth. However, it was highest at the depth of 60–80 cm. The OI and PCI showed a declining trend in organic matter.

Experiment 2 signified that TN was the highest with CI (0.71 g kg^{-1}), followed by PI (0.54 g kg^{-1}) and NI (0.51 g kg^{-1}) at 0–20 cm depth (Figure 2F). The CI gave the maximum TN at the depths of 20–40 cm (0.68 g kg^{-1}), 60–80 cm (0.62 g kg^{-1}), and 80–100 cm (0.33 g kg^{-1}) (Figure 2G). Meanwhile, the NI (0.52 g kg^{-1}) was significantly ($p \leq 0.05$) highest at the depth of 40–60 cm, followed by SI (0.36 g kg^{-1}), PI (0.32 g kg^{-1}), and CI (0.19 g kg^{-1}) (Figure 2H). Additionally, the depth-wise comparison revealed that with CI, the total N decreased up to 60 cm depth, and later, it increased in the soil (Figure 2I-J).

Soil total phosphorus (TP) was significantly higher in NI (1.87 g kg^{-1}), followed by OI (1.06 g kg^{-1}), PCI (1.01 g kg^{-1}), and WI (0.86 g kg^{-1}) at the depth of 0–20 cm (Figure 2K). However, at the depth of 20–40 cm, TP

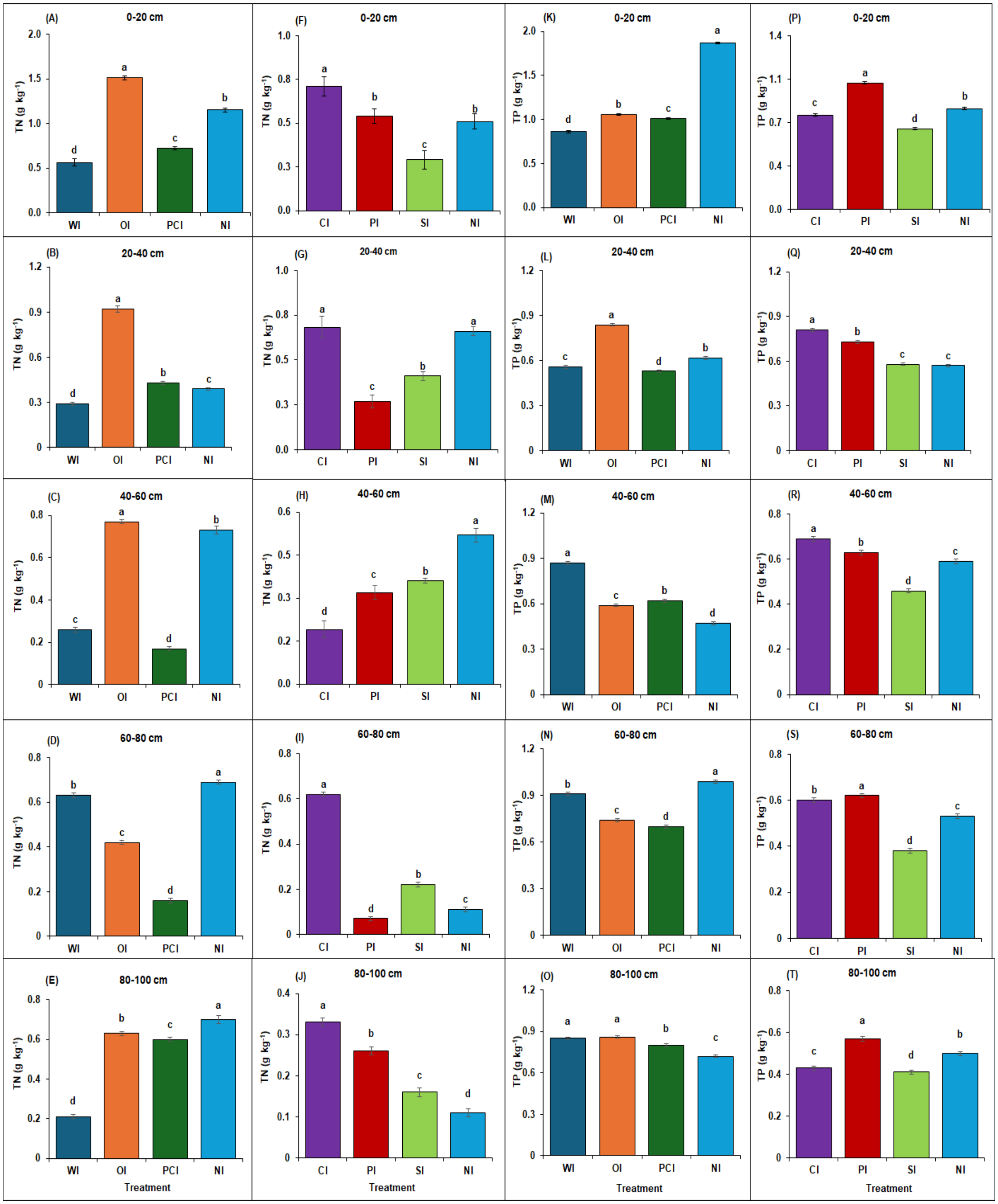

Figure 2. Soil total nitrogen (TN) at Mianzhu County (A-E) and Cangxi County (F-J); total phosphorus (TP) at Mianzhu County (K-O) and Cangxi County (P-T).

was the highest in OI (0.84 g kg^{-1}), followed by NI (0.62 g kg^{-1}), wheat (0.56 g kg^{-1}), and pak choi (0.53 g kg^{-1}) (Figure 2L). At the depth of 40–60 cm, WI gave the topmost TP (0.87 g kg^{-1}), followed by pak choi (0.62 g kg^{-1}), oat (0.59 g kg^{-1}), and NI (0.47 g kg^{-1}) (Figure 2M). For the 60–80 cm depth, NI showed the ultimate TP (0.99 g kg^{-1}), followed by WI (0.91 g kg^{-1}), OI (0.74 g kg^{-1}), and PCI (0.7 g kg^{-1}) (Figure 2N). At the maximum depth, the TP was notably superior with oat (0.86 g kg^{-1}) and wheat (0.86 g kg^{-1}) intercroppings, followed by pak choi intercropping (0.8 g kg^{-1}) and no intercropping (0.72 g kg^{-1}) (Figure 2O).

In Experiment 2, the PI has the highest TP (1.02 g kg^{-1}), followed by NI (0.81 g kg^{-1}), CI (0.76 g kg^{-1}), and SI (0.65 g kg^{-1}) at the depth of 0–20 cm (Figure 2P). At the depth of 20–40 cm, the supreme TP appeared with CI (0.81 g kg^{-1}), followed by PI (0.73 g kg^{-1}) (Figure 2Q). A similar trend was apparent at the depth of 40–60 cm for CI (0.69 g kg^{-1}), followed by PI (0.63 g kg^{-1}) (Figure 2R). For the 60–80 cm depth, PI was the highest in TP (0.62 g kg^{-1}), followed by CI (0.6 g kg^{-1}) (Figure 2S). At the 80–100 cm depth, CI was significantly ($p \leq 0.05$) lowest in TP (0.43 g kg^{-1}) (Figure 2T).

Available nitrogen and phosphorus

For soil available N, the variation was evident with the different intercropping patterns (Figure 3A-J). In Experiment 1, at the 0–20 cm depth, available N was the highest in NI (105.60 mg kg^{-1}), followed by OI (96.41 mg kg^{-1}), WI (91.98 mg kg^{-1}), and PCI (81.76 mg kg^{-1}) (Figure 3A). At the depth of 20–40 cm, WI displayed the maximum available N concentration in soil (102.17 mg kg^{-1}), followed by PCI (55.53 mg kg^{-1}), NI (29.64 mg kg^{-1}), and OI (26.56 mg kg^{-1}) (Figure 3B). For the 40–60 cm depth, PCI has the highest available N concentration (49.43 mg kg^{-1}), with oat following (41.89 mg kg^{-1}), then wheat (31.33 mg kg^{-1}) and NI (19.42 mg kg^{-1}) (Figure 3C). At the depth of 60–80 cm, PCI has the topmost available N (59.62 mg kg^{-1}), followed by WI (23.14 mg kg^{-1}), NI (17.71 mg kg^{-1}), and OI (16.01 mg kg^{-1}) (Figure 3D). WI has the highest concentration (38.15 mg kg^{-1}), followed by NI (24.45 mg kg^{-1}) at the depth of 80–100 cm. However, the PCI and OI revealed at par values for the available N concentration (Figure 3E).

In Experiment 2, the soil available N was the highest with PI at the depth of 0–20 cm (79.46 mg kg^{-1}) (Figure 3F) and 20–40 cm (78.65 mg kg^{-1}) (Figure 3G), followed by CI at the depth of 0–20 cm (50.74 mg kg^{-1}) (Figure 3F) and 20–40 cm (59.66 mg kg^{-1}) (Figure 3G). At the depth of 40–60 cm, CI was the peak in available N (37.11 mg kg^{-1}), followed by SI (16.67 mg kg^{-1}) (Figure 3H). For the 60–80 cm depth, NI was the lead in available N (61.33 mg kg^{-1}) and CI (36.12 mg kg^{-1}) (Figure 3I). At the 80–100 cm depth, SI (68.78 mg kg^{-1}) was the highest, followed by PI (20.80 mg kg^{-1}) (Figure 3J).

The intercropping patterns significantly ($p \leq 0.05$) influenced the soil available P with the depth series (Figure 3K-T). In Experiment 1, at 0–20 cm depth, NI has the highest available P concentration in soil (88.98 mg kg^{-1}), followed by intercropping with wheat (73.19 mg kg^{-1}), pak choi (59.69 mg kg^{-1}), and oat (56.94 mg kg^{-1}) (Figure 3K). At the depth of 20–40 cm, NI (72.58 mg kg^{-1}) has the highest Olsen P concentration, followed by intercropping with oat (46.44 mg kg^{-1}), wheat (24.88 mg kg^{-1}), and pak choi (21.07 mg kg^{-1}) (Figure 3L). With the 40–60 cm depth, WI was significantly ($p \leq 0.05$) higher in available P concentration (Figure 3M). At the depth of 60–80 cm, PCI (35.50 mg kg^{-1}) was significantly ($p \leq 0.05$) higher in available P concentration (Figure 3N). For the highest depth (80–100 cm), WI and NI were at par in available P concentration (Figure 3O).

In Experiment 2, soil available P was the highest with PI (92.40 mg kg^{-1}), followed by NI (69.63 mg kg^{-1}) and CI (65.31 mg kg^{-1}) at the 0–20 cm depth (Figure 3P). For the 20–40 cm depth, CI led in available P (85.10 mg kg^{-1}), followed by PI (49.77 mg kg^{-1}), SI (46.55 mg kg^{-1}), and FL (32.66 mg kg^{-1}) (Figure 3Q). Likewise, CI was the highest in available P (70.03 mg kg^{-1}), followed by PI (39.46 mg kg^{-1}), SI (30.07 mg kg^{-1}), and FL (19.91 mg kg^{-1}) at the depth of 40–60 cm

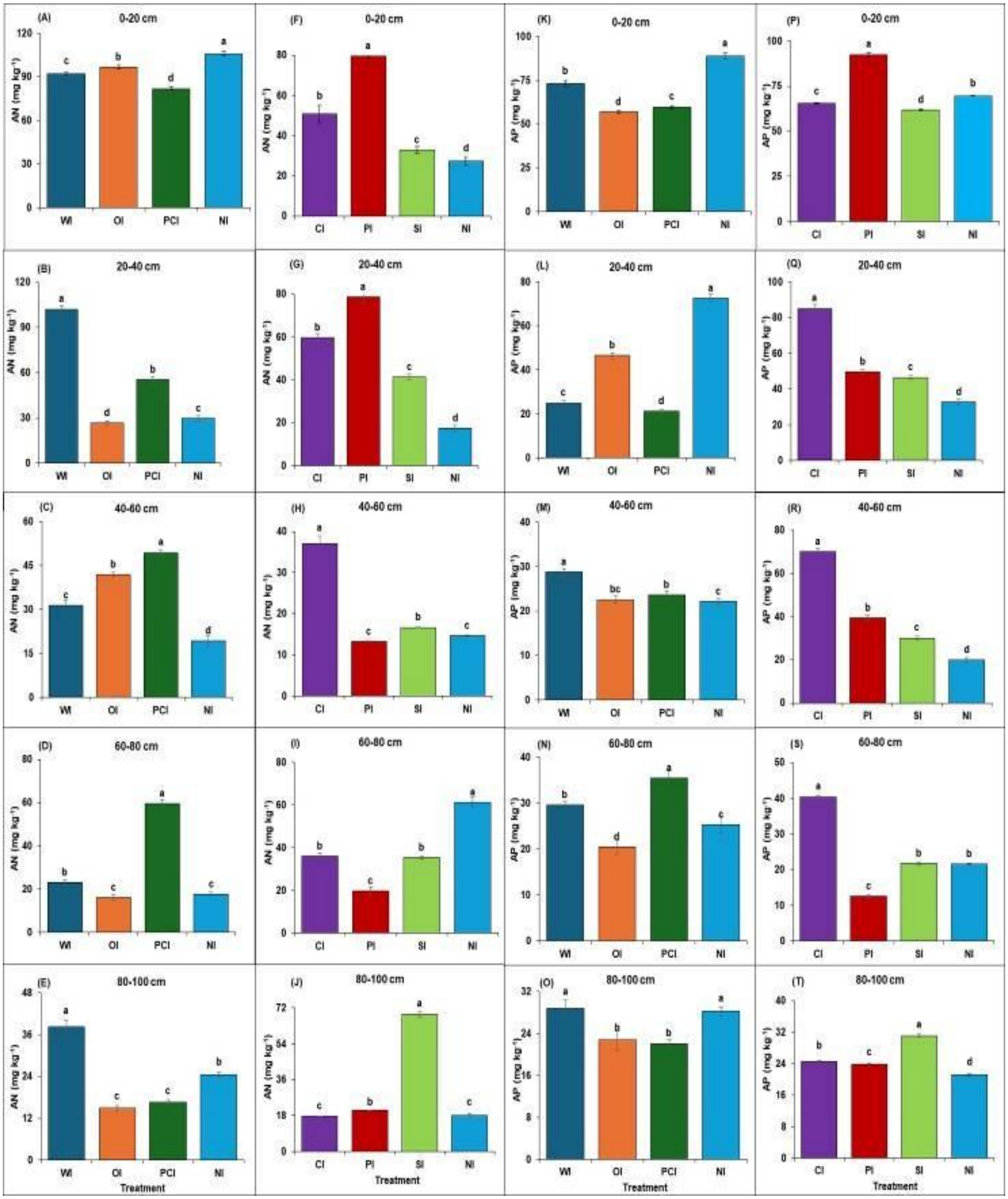

Figure 3. Soil available nitrogen (AN) at Mianzhu County (A-E) and Cangxi County (F-J); the available phosphorus (AP) at Mianzhu County (K-O) and Cangxi County (P-T).

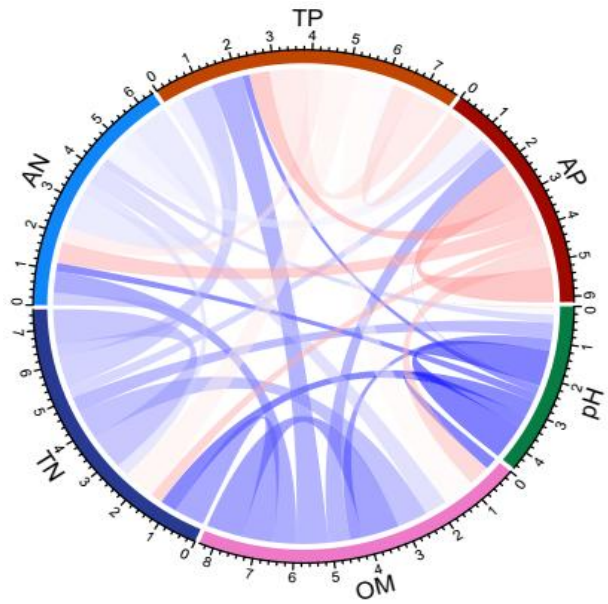

Figure 4. Pearson Correlation among the soil properties and nutrients.

(Figure 3R). The CI was also optimum in available P (40.44 mg kg^{-1}) at the 60–80 cm depth (Figure 3S). For the highest depth (80–100 cm), SI was supreme (31.03 mg kg^{-1}), followed by CI (24.40 mg kg^{-1}), PI (23.77 mg kg^{-1}), and NI (21.07 mg kg^{-1}) (Figure 3T).

Correlation

The correlation among different soil properties appears in Figure 4, which indicates the dedication of each segment to the specific soil characteristic, and the chords represent the association among them. The blue and red colors signify the positive and negative associations, respectively. Moreover, the thickness explains the strength of the correlation. A positive association was noticeable between organic matter and other treatments. Total N and total P also expressed a positive association with each other. A moderate positive association emerged between total P and available P. Furthermore, the negative association of pH was indicative of total P and available N and P (Figure 4).

DISCUSSION

The soil pH was nonsignificant at the surface soil; however, it showed variations with intercropping patterns as well as soil depth. On average, the intercropping increased the soil pH compared with NI. The soil organic matter was the highest in the surface soil with NI, and it might be due to the deposition of kiwi plant leaves (Figure 1). Meanwhile, the intercropping enhanced the decomposition of soil organic matter in soil, and it could be because of the higher litter inputs and improved N retention (Cong *et al.,* 2015). Additionally, root exudates have a considerable relationship with soil microbes. Root exudates influenced the microbial population and biodiversity that may also influence the decomposition of organic matter in the soil (Yahya *et al.,* 2021).

Furthermore, wheat generally has a deep root system, oat roots reach 60 cm, and pak choi has a shallow root system reaching 20–40 cm depth, causing improved microbial activity and decomposition of organic matter in these regions due to root exudates. Pumpkin is a high nutrient-demanding crop and has a shallow, fibrous root system, resulting in reduced organic matter in the soil profile. A past study reported corn retains 17% of root-derived C as soil organic matter (SOM) because corn adds more C inputs to soil than wheat. However, C conversion to organic matter was comparatively less than wheat (Bolinder *et al.,* 1999). Meanwhile, soybeans are a legume-based crop that requires low inorganic N and may contribute to soil organic matter mining (Luo *et al.,* 2024).

In the soil profile, the total nutrients obtained significant influences from intercropping (Figure 2). It might be due to the soil enzymes' activity, interspecific root interactions in intercropping systems, nutrient cycling, and soil-organic residue decomposition (Nasar *et al.,* 2022). Intercropping influenced the concentration of available nutrients in soil (Figure 3). It could have an association with root exudates, rhizosphere acidification, symbiotic nitrogen fixation by legumes (soybean), microbial activity, and the adequate application of fertilizers (Nasar *et al.,* 2022). For NI, the available N was the highest at surface soil, which could refer to the application of fertilizers to kiwi plants.

The WI- and OI-increased nutrient availability provided nutrients for plant growth. The PI is shallow-rooted and takes up nutrients in above-soil depths. Pumpkin is a high-nutrient-demanding crop, and it depletes nutrients with root penetration (Chen *et al.,* 2019). Similarly, soybean is a leguminous crop that contributes to N fixation and enhances the N availability in soil (Luo *et al.,* 2024). In addition, reports on legumes have stated them to mitigate the P deficiency by altering the soil pH (Latati *et al.,* 2014). The CI also reduced the available P concentration with soil depth due to its highest nutrient demand. It also increased P availability compared with other intercropping systems, possibly through microbial association such as arbuscular mycorrhizal fungi (Cozzolino *et al.,* 2013).

The correlation matrix revealed that organic matter has a positive association with the nutrient status of the soil (Figure 4), and it could be due to nutrient sources such as the litter and root residues. The available P has a weak association with other variables, and it could refer to linkages with microbial activity, enzyme activities, and root exudates. Soil pH also indicated a positive link with total and available N, which could point to cropping patterns, as leguminous crops enhance the soil acidity by absorbing more cations than anions from the soil.

CONCLUSIONS

The study concludes intercropping proved to be an effective technique to utilize the spaces in kiwi orchards. Moreover, it helps improve the soil productivity and its nutrient status. Intercropping better utilizes resources such as fertilizers, water, and soil efficiently. Although the study has some limitations, including the lack of fruit yield measurement and the economic analysis, because the kiwifruit starts fruit production after five years. Therefore, the authors recommended considering the lacking aspects in future research, including the long-term effects of intercropping, crop rotation, and crop duration that may also influence soil properties and the kiwi fruit yield. The practical implementation of this study will help farmers improve soil health and land use, minimize water losses, and reduce fertilizer use efficiency, which could enhance farm productivity and income.

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REFERENCES

Bolinder MA, Angers DA, Giroux M, Laverdière MR (1999). Estimating C inputs retained as soil organic matter from corn (*Zea mays* L.). *Plant Soil* 215(1): 85–91.

Chen Y, Zhou X, Lin Y, Ma L (2019). Pumpkin yield affected by soil nutrients and the interactions of nitrogen, phosphorus, and potassium fertilizers. *HortScience* 54(10): 1831–1835.

Cong WF, Hoffland E, Li L, Janssen BH, Van-der-Werf W (2015). Intercropping affects the rate of decomposition of soil organic matter and root litter. *Plant Soil* 391(1–2): 399–411.

Cozzolino V, Di Meo V, Piccolo A (2013). Impact of arbuscular mycorrhizal fungi applications on maize production and soil phosphorus availability. *J. Geochem. Explor.* 129: 40–44.

Dick WA, Tabatabai MA (1977). An alkaline oxidation method for determination of total phosphorus in soils. *Soil Sci. Soc. Am. J.* 41(3): 511–514.

Dodor DE, Kamara MS, Asamoah-Bediako A, Adiku SG, MacCarthy DS, Kumahor SK, Neina D (2022). Evaluation of alkaline hydrolyzable organic nitrogen as an index of nitrogen mineralization potential of some coastal savannah soils of Ghana. *Nitrogen (Switzerland)* 3(4): 652–662.

Galanakis CM (2024). The Future of Food. *Foods* 13(4): 506.

Khatri P, Kumar P, Shakya KS, Kirlas MC, Tiwari KK (2024). Understanding the intertwined nature of rising multiple risks in modern agriculture and food system. *Environ. Dev. Sustain.* 26(9): 24107–24150.

Kjeldahl J (1883). Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern. *Zeitschrift für Anal. Chemie* 22(1): 366–382.

Latati M, Blavet D, Alkama N, Laoufi H, Drevon JJ, Gerard F, Pansu M, Ounane SM (2014). The intercropping cowpea-maize improves soil phosphorus availability and maize yields in an alkaline soil. *Plant Soil* 385(1–2): 181–191.

Liu R, Yang L, Zhang J, Zhou G, Chang D, Chai Q, Cao W (2024). Maize and legume intercropping enhanced crop growth and soil carbon and nutrient cycling through regulating soil enzyme activities. *Eur. J. Agron.* 159: 127237.

Lu Y, Chen Z, Kang T, Zhang X, Bellarby J, Zhou J (2016). Land-use changes from arable crop to kiwi-orchard increased nutrient surpluses and accumulation in soils. *Agric. Ecosyst. Environ.* 223: 270–277.

Luo B, Zhou J, Yao W, Wang Y, Guillaume T, Yuan M, Han D, Bilyera N, Wang L, Zhao L, Yang Y (2024). Maize and soybean rotation benefits soil quality and organic carbon stock. *J. Environ. Manag.* 372: 123352.

Nasar J, Shao Z, Gao Q, Zhou X, Fahad S, Liu S, Li C, Banda SK J, Kgorutla LE, Dawar KM (2022). Maize-alfalfa intercropping induced changes in plant and soil nutrient status under nitrogen application. *Arch. Agron. Soil Sci.* 68(2): 151–165.

Olsen SR, Sommers LE (1982). Phosphorus. Methods of soil analysis, Argon No 9, Part 2: Chemical and Microbiological Properties, 2nd Ed., Am. Soc. Agron., Madison, WI, USA. pp. 403–430.

Rajan P, Natraj P, Kim M, Lee M, Jang YJ, Lee YJ, Kim SC (2024). Climate change impacts and response strategies for kiwi fruit production: A comprehensive review. *Plants* 13(17): 2354.

Ren J, Li F, Yin C (2023). Orchard grass safeguards sustainable development of fruit industry in China. *J. Clean. Prod.* 382.

Satpal D, Kaur J, Bhadariya V, Sharma K (2021). *Actinidia deliciosa* (Kiwi fruit): A comprehensive review on the nutritional composition, health benefits, traditional utilization, and commercialization. *J. Food Process. Preserv.* 45(6): e15588.

Tang W, Yang H, Wang W, Wang C, Pang Y, Chen D, Hu X (2022). Effects of living grass mulch on soil properties and assessment of soil quality in Chinese apple orchards: A meta-analysis. *Agronomy* 12(8): 1974.

Walkley A (1947). A critical examination of a rapid method for determining organic carbon in soils — effect of variations in digestion conditions and of inorganic soil constituents. *Soil Sci.* 63(4): 251–264.

Wang J, Qin X, Tan Y, Du Y, Tudi Y, Yang Y, Ping X (2024). Impact of grass cover on the soil physicochemical properties in China's orchards: A meta-analysis. *Agrofor. Syst*. 98(6):1745-58.

Wang Z, Liu R, Fu L, Tao S, Bao J (2023). Effects of orchard grass on soil fertility and nutritional status of fruit trees in korla fragrant pear orchard. *Horticulturae* 9(8): 903.

Wang ZG, Bao XG, Li XF, Jin X, Zhao JH, Sun JH, Christie P, Li L (2015). Intercropping maintains soil fertility in terms of chemical properties and enzyme activities on a timescale of one decade. *Plant Soil* 391(1–2): 265–282.

Wang ZG, Jin X, Bao XG, Li XF, Zhao JH, Sun JH, Christie P, Li L (2014). Intercropping enhances productivity and maintains the most soil fertility properties relative to sole cropping. *PLoS One* 9(12): e113984.

Xiang Y, Chang SX, Shen Y, Chen G, Liu Y, Yao B, Xue J, Li Y (2023). Grass cover increases soil microbial abundance and diversity and extracellular enzyme activities in orchards: A synthesis across China. *Appl. Soil Ecol.* 182: 104720.

Xu S, Zhang W, Goodwin PH, Wang Y, Zheng SJ, Li X (2024). Effect of cover crop on soil fertility and bacterial diversity in a banana plantation in Southwestern China. *Soil Tillage Res.* 240: 106092.

Yahya M, Islam EU, Rasul M, Farooq I, Mahreen N, Tawab A, Irfan M, Rajput L, Amin I, Yasmin S (2021). Differential root exudation and architecture for improved growth of wheat mediated by phosphate solubilizing bacteria. *Front. Microbiol.* 12: 744094.

Zabel F, Putzenlechner B, Mauser W (2014). Global agricultural land resources - A high resolution suitability evaluation and its perspectives until 2100 under climate change conditions. *PLoS One* 9(9): e107522.

Zhang H, Bai M, Gou Y, Chang T, Wei J, Quan Y, Gan X, Lin Y, Lu S, Shi X, Zhang X (2025). Effects of short-term intercropping of forage crops on soil microbial communities in *Ziziphus jujuba cv*. *Lingwuchangzao* orchards in Northwest China. *Agronomy* 15(2): 319.