Effect of Integrated Nutrient Management (INM) on Soil Physico-Chemical Properties in Wheat (*Triticum aestivum*) Intercrop under Buel (*Grewia optiva* Drummond) based Agroforestry System and Open Condition

ABSTRACT

The raising human health hazards due to excessive use of chemical fertilizers and pesticises in Inida leads cancer patients. To overcome such problems there is need of Integrated Nutrient Management (INM) in our major crop wheat and further to improve soil fertility under agroforestry system. Therefore, the present investigation was carrid out to study the impact of INM on the physical and chemical properties of soil when wheat intercropped under buel (*Grewia optiva)* based agroforestry systems in the mid-hill region of Himachal Pradesh at Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP (India). INM practices were applied to evaluate their effectiveness in enhancing soil fertility, crop yield, and overall soil health. The experimental setup included various treatment combinations of organic and inorganic fertilizers *viz.*, T_1: RDF, T_2: FYM, T_3: Vermicompost, T_4: Goat manure, T_5: 50% RDF+50% FYM, T_6: 50% RDF+50% VC, T_7: 50% RDF+50% GM, and T_8: Control to determine their synergistic effects on the soil and cereal crop. These treatments were randomly assigned to plots under two planting conditions: S_1 (under Buel based agroforestry system) and S_2 (open conditions), with three replications each, following in a factorial randomized block design (RBD). The key physical parameters such as bulk density (g/cm^3), particle density (g/cm^3), porosity (%), and soil moisture (%) were measured alongwith chemical properties of soil including soil pH, EC (dS/m^1), organic carbon content (%), and nutrient availability of N, P and K in kg per hectare. The soil data of two consecutive years and pooled data were analysized in R Statistical Software. The results demonstrated that INM significantly improved both the physical and chemical soil properties in agroforestry systems as compared to control treatment *i.e.* open condtion. The use of 100 % FYM found to be best treatment during the course of study among various treatments of INM for soil porocity, soil moisture, soil pH, available N, P and K. The soil structure and nutrient availability were incersed in second year as compared to first year which will lead to improve the growth and yield of wheat crop. The study underscores the importance of adopting INM practices in agroforestry systems to achieve sustainable agriculture as well as chemical free agriculture in hilly regions of Himachal Pradesh which will be helpful for human health. Thus, the use 100 % FYM fertilizer is recommended for farmers in hilly area of Himachal Pradesh for sustainable agriculture and natural farming. The findings provide valuable insights for farmers and policymakers aiming to optimize crop production and maintain soil health in similar agro-ecological zones.

Keywords: Human Health, Plant Health, Soil Health, Agricultural Sustainability, Intercropping, Integrated Nutrient Management, FYM, Soil Fertility, Natural Farming

INTRODUCTION

The rising cancer patients and health hazards in India has been surpassed the global rates which leads to India as title of "cancer capital of the world". The major health issues resulting from the intake of nitrates from the excessive use of chemical fertilizers are methemoglobinemia and cancer (WHO, 2011). The major health hazards of pesticides and insecticides intake through food and water include cancers, tumours, skin diseases, cellular and DNA damage, suppression of immune system and other intergenerational effects (Margni et al., 2002). Besides, the continuous use of chemical fertilizers and pesticides has resulted in the depletion of soil health and soil fertility (Pahalvi et al., 2021). Form all of the above reasons, there is an urgent need of Integrated Nutrient Management (INM) and Agroforestry based agriculture systems in India which have been proven to overcome such problems. However, in the present scenario, it has been spotted that excessive use of inorganic manure is being practiced by farmers in order to raise the cultivation. Organic manures and inorganic fertilizers are essential in enhancing soil health by converting unavailable soil nutrients into accessible forms through improved mineralization and solubilization processes, their integration enables crops to efficiently absorb nutrients when required, unlike the sole dependence on chemical fertilizers (Wu and Ma, 2015). The incorporation of vermicompost and farmyard manure as organic sources holds great significance as it provides avenues to reduce dependency on costly chemical fertilizers. This decreased reliance on chemical fertilizers is pivotal in preventing long-term soil pollution risks. Nevertheless, Agroforestry has demonstrated its effectiveness in land management by enhancing soil quality and conserving water resources since the beginning of agriculture (Brown et al., 2018) and provide wood and others benefits to the farmers (Dhaka et al., 2020). Agroforestry is whispered to increase the soil organic carbon through litter fall, increase land productivity, check soil erosion, increase biodiversity, diversify the farm income etc. (Gupta et al., 2009). Moreover, it plays a vital role in preserving the environment and replenishing soil resources, crucial for sustaining future agricultural productivity.

Wheat is a major cereal crop cultivated throughout India. The botanical name of wheat is *Triticum aestivum* L. belongs to the grass family Poaceae. It is cultivated in an area of about 30.54 million hectares with a record production of 94.57 million tonnes of grain (Polisetty and Paidipati, 2019). It is mainly grown during the rabi season. It is primary food as a predominant ingredient in the human diet. Wheat is eaten in ddifferent forms such as chapati, bread, cakes, flakes, biscuits, macaroni, semolina, noodles and pasta. Bread wheat is grown on approximate 95% of the cropped area in India and is used to make mainly chappatis. Thus, wheat is a very important crop of Indian Agriculture (Reddy, 2024). Integrated nutrient management is a holistic approach for promoting crop productivity and sustainability of wheat based cropping system in India through optimizing the use of organic (vermicompost, FYM, compost, biostimulants etc.) and inorganic chemicals (macro- and micro-nutrients (Kaur et al. 2024). Furthermore, Rice and Wheat rotation is the most important agricultural cropping system of the Indo-Gangetic Plains (IGP) of India which is responsible for the food security of the region. The effect of different INM practices on soil organic carbon stocks and its fractions, the sequestration potential as well as the sustainability of the rice–wheat rotation system was studied by Nayak et al. (2012) in long term experiments conducted at different agroclimatic zones of IGP. Application of NPK fertilizers through inorganic fertilizers or combination of inorganic fertilizer and organics such as FYM or green manure or crop residue improved the soil organic carbon (SOC), particulate organic carbon (POC), microbial biomass carbon (MBC) concentration and their sequestration rate (Nayak et al. 2012).

Buel tree (*Grewia optiva*) belongs to the family Tiliaceae and holds a significance importance among various tree species cultivated in agroforestry across the Western Himalayas due to its fodder quality (Kar et al., 2019). It is a small tree species reaching up to 15 m in height. It is mainly distributed in sub-tropical climates of north-western Himalayas in an altitudibnal range of 150 to 2,500 m asl. This species is known as (MPFTs) multipurpose fodder tree species. It is generally grown on bunds, terrace risers and slope lands. Green leaves and tender twigs are mainly used in fodder. Fruits are also edible. The fibers obtained from bark of the plant are used for cordage and rope. Branches of the plant are used for making axe handles, oar shafts, cot frames, spears, bows, shoulder sticks etc. The green bark of the plant used by women for cleaning their hairs. This species accessed as LC (Least Concern) species in the IUCN Red List of Threatened Species (IUCN, 2022).

Agroforestry practices in the mid-hills of Himachal Pradesh exhibit the unique cultivation method termed as Agri-silviculture. In modern agricultural practices, incorporating indigenous resources like FYM, vermicompost, goat manure, and poultry manure has become crucial. However, the use of inorganic fertilizers poses risks to soil structure, the environment and both plant and animal life. Long-term fertilizer experiments have discovered that continuous use of sub-optimal doses of chemical fertilizers to soil has led to the deterioration of soil health, environmental pollution and stagnation or decrease in crop productivity (Mahajan and Gupta 2009.). It is important that both the organic and inorganic fertilizers must be applied in an integrated manner so as to attain the benefits along with overcoming such limitations. Therefore, keeping all the points in mind, the present investigation was carrid out to study the impact of INM on the physical and chemical properties of soil in wheat intercrop under buel based agroforestry systems in the mid-hill region of Himachal Pradesh at Dr. Yashvant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP (India) during 2022 and 2023.

MATERIALS AND METHODS

Experimental site: The present field experiment was conducted at Experimnetal Farm in the Department of Silviculture and Agroforestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) in a 19-year-old existing agroforestry model of *Grewia optiva*. The farm is located at latitude of 30º 51' N and longitude of 76º 11' E with an elevation of 1200 m. This area falls under sub-tropical and sub-humid agro-climatic zone of Himachal Pradesh which receives annual rainfall of 1000-1400 mm. The soil of the farm belongs to Typic Eutrochrept subgroup as per the soil taxonomy of USDA.

Details of structural components and treatments: Rows of Buel tree oriented into East-West direction with spacing of 8m×3m since July, 2004. Wheat (*Triticum aestivum*), variety HD-3086 was grown under Grewia trees and in open condition in plots of size 4m×2m, adopting spacing of 22cm×10cm. The details of treatments applied in the present experiment is presented in Table 1.

Table 1: Details of INM treatments applied in the present experiment

Treatments		Details
T_1	:	RDF (Recommended Dose of Fertilizer)
T_2	:	FYM (Farm Yard Manure)
T_3	:	VC (Vermicompost)
T_4	:	GM (Goat Manure)
T_5	:	50% RDF + 50% FYM
T_6	:	50% RDF + 50% VC
T_7	:	50% RDF + 50% GM
T_8	:	Control

Collection and preparation of soil sample and Analysis: Random soil samples from each sampling unit at 0-30 cm soil depth were collected with the help of post hole soil auger before sowing and at the time of harvesting of Wheat for two consecutive years. The collected samples were placed in cloth bags, properly tagged and transported to laboratory. These samples were then air dried, crushed thoroughly and passed through 2 mm sieve and thereafter analyzed for physical soil parameters *viz.*, Bulk Density (g cm^{-3}), Particle Density (g cm^{-3}), Porosity (%), Soil Moisture (%) using standard methods and chemical soil parameters *viz.*, pH, EC (dS m^{-1}), OC (%) and available N, P, & K (kg ha^{-1}). Soil pH was measured with the help of digital pH meter by making 1:2 soil water suspensions following Jackson (1973) method. EC was estimated using the Electrical conductivity meter by making 1:2 soil water suspensions following Jackson (1973) method. Soil organic carbon (%) was determined with help of rapid titration method (Walkley and Black, 1934). Available nitrogen was estimated by following Subbiah and Asija (1956) method, available Phosphorus by Olsen *et al.* (1954) method and available potassium by Merwin and Peech (1951) method.

Initial soil properties of experiment site: The soil physical and chemical properties of the experimental field estimated before start of the field trial is given in the Table 2.

Table 2: Intitial soil physical and chemical properties of the experimental field before sowing

Sr. No.	Parameters	Under Buel (S_1)	Open Condition (S_2)
1	Bulk Density (g cm^{-3})	1.35	1.39
2	Particle Density (g cm^{-3})	2.65	2.77
3	Porosity (%)	50.77	50.13
4	Soil Moisture (%)	7.72	6.93
5	EC soil (dS m^{-1})	0.191	0.178
6	Soil pH	6.76	6.41
7	Organic Carbon (%)	1.18	1.05

8	Available Nitrogen (kg ha^{-1})	250.20	221.47
9	Available Phosphorus (kg ha^{-1})	34.29	32.12
10	Available Potassium (kg ha^{-1})	267.11	234.51

Where, S_1: Under *Grewia optiva* based agroforestry system and S_2: Open condition

Statistical analysis: The field experiment was designed in factorial Randomized Block Design (RBD) in three replications with eight treatment combinations. The entire data of present study were statistically analyzed by using analysis of variance (ANOVA) in R Statistical Software and treatment means were compared by using critical difference tests at 5 % of probability in accordance with the procedure described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Physical properties of soil in Wheat+Buel based agroforestry system after harvesting of Wheat

The analyzed result of physical soil parameters *viz.*, Bulk Density (g cm^{-3}), Particle Density (g cm^{-3}), Porosity (%) and Soil Moisture (%) has been presented and discussed in the following way:

Bulk Density: The data presented in Table 3 showed a significant effect of planting conditions and integrated nutrient management (INM) on the bulk density (g cm^{-3}) of soil after harvesting of wheat crop under buel based agroforestry systems. In 2022 and 2023, the higher bulk density was observed by S_2 (open condition) as compared to S_1 (under *Grewia optiva* based agroforestry systems). Among different doses of organic and inorganic fertilizers, the maximum bulk density (1.37 g cm^{-3}) was recorded by T_8 (control) and the minimum (1.25 g cm^{-3}) was recorded by T_2 (100% FYM) in 2022. The maximum bulk density at (1.36 g cm^{-3}) was observed by T_8 (control) which was significant at par with T_1 whereas, the minimum bulk density (1.24 cm^{-3}) was recorded by T_2 (100% FYM) in 2023. The combined effect of planting conditions and treatment (S×T) showed the non-significant effect on the bulk density. Similar trends were also found in pooled data analysis. The combined data showed that year wise and various interactions found to be non-significant effect on the bulk density of soil.

Table 3: Effect of planting conditions and integrated nutrient management (INM) on the Bulk Density (g cm^{-3}) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	1.29	1.36	**1.33**	1.30	1.33	**1.32**	1.30	1.35	**1.32**
T_2	1.21	1.28	**1.25**	1.23	1.25	**1.24**	1.22	1.27	**1.24**
T_3	1.24	1.31	**1.27**	1.25	1.28	**1.27**	1.25	1.29	**1.27**
T_4	1.25	1.32	**1.28**	1.26	1.29	**1.28**	1.26	1.30	**1.28**
T_5	1.22	1.29	**1.25**	1.23	1.26	**1.24**	1.22	1.27	**1.25**
T_6	1.25	1.32	**1.29**	1.27	1.31	**1.29**	1.26	1.32	**1.29**
T_7	1.28	1.35	**1.31**	1.29	1.32	**1.30**	1.28	1.33	**1.31**
T_8	1.33	1.40	**1.37**	1.35	1.37	**1.36**	1.34	1.38	**1.36**
Mean	**1.26**	**1.33**	**1.29**	**1.27**	**1.30**	**1.28**	**1.27**	**1.31**	
$CD_{0.05}$	**S**	**0.02**		**S**	**0.03**		**Y**	**NS**	
							S	**0.02**	
	T	**0.4**		**T**	**0.07**		**T**	**0.04**	
							Y×S	**NS**	
	S×T	**NS**		**S×T**	**NS**		**Y×T**	**NS**	
							S×T	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The two study years showed that the planting conditions and integrated nutrient management had a significant effect on the bulk density. Under open conditions, the bulk density of the soil registered greater values, while lower values were recorded under the shade of *Grewia optiva* trees, which can be attributed to the introduction of organic matter that results from the accumulation of leaf litter, twigs, and tree roots. The presence of a tree canopy facilitates the active addition of organic material to the soil, which plays a significant role in reducing bulk density and improving soil fertility and soil structure. The results of the present study are consistent with those of Lodh (2023), who observed that *Grewia* based agroforestry system had lower soil bulk density values than open conditions. Similarly, Dash (2020) verified a decrease in soil bulk density beneath Poplar, in contrast to the increased values reported in open condition. Ghosh et al. (2020) also documented similar findings, reported a lower soil bulk density beneath tree canopies than when crops were planted alone. The findings of the present study clearly showed that, in comparison to control conditions (no manure), the bulk density of the soil decreased under 100% FYM. The reduction in soil bulk density that has been seen in relation to organic manure can be attributed to the expansion of soil pores, improved soil aeration, and an increase in the amount of organic carbon present. Together, these elements support enhanced soil porosity and water-holding ability. As a result in this research study, adding organic matter (manure, compost and biochar) to the soil improves its structure and increases its porosity, which in turn lowers bulk density. Similar findings were also reported by Prasad et al. (2023); and Garima and Pant (2017), who found that higher bulk densities were recorded in open conditions without manure and lower bulk densities under integrated nutrient management and organic manure, respectively. In a similar vein, Bhatt et al. (2019) also reported that the addition of both inorganic and organic fertilizers resulted in a reduction in soil bulk density.

Particle Density (g cm^{-3}): In both years 2022 and 2023, open condition exhibited higher particle density as copmpared to under buel based agroforestry systems (Table 4). The combined data showed that year wise and various interactions found to be non-significant effect on the bulk density of soil. Among the organic and inorganic fertilizers doses, the maximum particle density (2.72, 2.69 and 2.70 g/cm^3) was observed by T_8 (control) whereas, the minimum particle density (2.53, 2.46 and 2.50 g/cm^3) occurred by T_2 (100% FYM) in both the years as well as pooled data analysis. Pooled data from both years revealed that among planting conditions, the maximum particle density of soil (2.62 g cm^{-3}) was recorded by S_2 (open condition), while the lowest (2.56 g cm^{-3}) occurred by S_1 (under *Grewia optiva* based agroforestry systems). Regarding various doses of integrated nutrient management (INM), the maximum (2.70 g cm^{-3}) particle density of soil was observed by T_8 (control), whereas the minimum (2.50 g cm^{-3}) was recorded by T_2 (100% FYM).

Table 4: Effect of planting conditions and integrated nutrient management (INM) on the Particle Density (g cm^{-3}) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	2.65	2.70	**2.68**	2.60	2.68	**2.64**	2.62	2.69	**2.66**
T_2	2.51	2.54	**2.53**	2.43	2.50	**2.46**	2.47	2.52	**2.50**
T_3	2.52	2.59	**2.56**	2.44	2.51	**2.47**	2.48	2.55	**2.51**
T_4	2.57	2.61	**2.59**	2.48	2.53	**2.51**	2.53	2.57	**2.55**
T_5	2.59	2.64	**2.62**	2.52	2.58	**2.55**	2.56	2.61	**2.58**
T_6	2.61	2.67	**2.64**	2.54	2.61	**2.57**	2.57	2.64	**2.60**
T_7	2.60	2.69	**2.65**	2.55	2.63	**2.59**	2.58	2.66	**2.62**
T_8	2.69	2.76	**2.72**	2.64	2.73	**2.69**	2.66	2.74	**2.70**
Mean	**2.59**	**2.65**	**2.62**	**2.52**	**2.60**	**2.56**	**2.56**	**2.62**	
$CD_{0.05}$	**S**	**0.01**		**S**	**0.01**		**Y**	**0.01**	
							S	**0.01**	
	T	**0.03**		**T**	**0.02**		**T**	**0.01**	
							Y×S	**NS**	
							Y×T	**NS**	
	S×T	**NS**		**S×T**	**NS**		**S×T**	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The difference in soil organic matter beneath a tree canopy enhances soil structure, probably because of the shade effect, which lowers evaporation losses. Since organic material inclusion lowers the density of the particles, as they are comparatively lighter than minerals. Furthermore, the presence of organic matter in trees increases microbial activity, which in turn creates solid soil aggregates with pore gaps that further reduce particle density. In addition, trees alter the hydrology of the soil by improving water absorption as well as retention through roots and leaf litter, which minimizes soil compaction. Dash (2020) found that Poplar trees had lower particle densities than sole turmeric farming. The present study result is also in line with the findings of Tandel et al. (2009), who also reported a decrease in particle density beneath trees when compared to sole cropping. In general, 100% FYM treatment showed the lowest particle density, comparable to the 100% vermicompost treatment. On the other hand, when manure was not included or when the RDF was applied alone, the highest particle density was observed. Because compost and animal manure are high in organic matter, they improve the soil structure, which explains the decreased particle density after organic manure treatments. By acting as a binding agent, organic matter helps to create pore spaces between soil particles and stable soil aggregates. Kaur et al. (2008), and Abiven et al. (2008) also reported similar phenomenon, which results in a drop in particle density under organic manure application.

Porosity (%): The planting condition, integrated fertilizer treatments and cultivation year recorded significant effects on soil porosity (%) after harvesting of wheat (Table 5). During the first year, second year and pooled data, soil porosity was reported higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition). Regarding the effect of fertilizer treatments, porosity was observed the highest by treatment T_2 (100% FYM), whereas the lowest porosity of soil was observed by treatment T_8 (control) in all the data sets. In the pooled data, year (Y), planting conditions (S), organic and inorganic fertilizer treatments (T) registered non-significant effect on soil porosity. However, the interactions between year and planting conditions (Y×S), the maximum (49.52%) porosity were found by Y_2S_2 and minimum (47.55%) by Y_2S_1.

Table 5: Effect of planting conditions and integrated nutrient management (INM) on Porosity (%) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	49.78	49.69	**49.74**	51.36	49.52	**50.44**	50.53	49.65	**50.09**
T_2	50.77	50.13	**50.45**	51.83	49.83	**50.83**	50.98	50.30	**50.64**
T_3	49.86	49.89	**49.88**	50.83	48.94	**49.89**	50.36	49.40	**49.88**
T_4	50.37	49.86	**50.11**	50.98	49.42	**50.20**	50.42	49.90	**50.16**
T_5	47.71	47.48	**47.59**	48.83	46.98	**47.91**	48.16	47.34	**47.75**
T_6	46.54	46.60	**46.57**	47.91	45.87	**46.89**	47.25	46.20	**46.73**
T_7	45.51	46.14	**45.82**	47.34	45.17	**46.25**	46.74	45.34	**46.04**
T_8	44.88	45.21	**45.05**	47.04	44.71	**45.88**	46.13	44.80	**45.46**
Mean	**48.18**	**48.12**	**48.15**	**49.52**	**47.55**	**48.54**	**48.82**	**47.87**	
$CD_{0.05}$	**S**	**0.84**		**S**	**NS**		**Y**	**NS**	
							S	**NS**	
	T	**NS**		**T**	**NS**		**T**	**NS**	
							Y×S	**1.42**	
	S×T	**NS**		**S×T**	**NS**		**Y×T**	**NS**	
							S×T	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The soil porosity data presented in Table 5 demonstrated significant effects under both integrated nutrient management and planting conditions. When it came to planting conditions, porosity was shown to be higher under a tree canopy and lowest in open conditions. The percentage of soil volume that remains unoccupied by solid materials is best described by the porosity of the soil. The increase in organic matter under trees may be the cause of the soil increased porosity because it increases the microbial population, which also improves the hydrophobicity of the minerals, which increases inter-mineral cohesion and porosity. Tree roots also improve soil porosity by retaining and allowing more water to permeate the soil. The present results are also consistent with studies carried out by Sharma et al. (2015) and Tripathi et al. (2017), who reported increased porosity under tree canopies relative to open conditions.

Soil Moisture (%): The perusal of the data presented in Table 6 revealed that planting conditions and organic and inorganic fertilizers had a significant effect on the moisture (%) of soil after harvest of wheat. The combined effect of treatment and planting conditions showed significant effect on the soil moisture with the maximum (15.22%) moisture content was recorded by S_1T_2 and the minimum (12.56%) by S_1T_2. However, the effect of various interactions between year and planting conditions (Y×S), year and treatments (Y×T), planting conditions and treatments (S×T) and year, planting condition and treatments (Y×S×T) was found to be non-significant for soil moisture after harvest of wheat in pooled data set. In both the years and pooled data, soil moisture found to be higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition). Among different doses of organic fertilizers, the highestsoil moisture (14.89, 15.03 and 14.96 %) was recorded by T_2 (100% FYM) which was significan whereas, the lowest soil moisture (12.36, 12.65 and 12.50 %) was oobserved by T_8 (control) in all the data set.

Table 6: Effect of planting conditions and integrated nutrient management (INM) on the Soil Moisture (%) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	12.97	12.35	**12.66**	13.27	12.84	**13.06**	13.12	12.60	**12.86**
T_2	15.19	14.59	**14.89**	15.22	14.84	**15.03**	15.21	14.72	**14.96**
T_3	15.14	14.54	**14.84**	15.17	14.77	**14.97**	15.16	14.66	**14.91**
T_4	14.70	14.19	**14.45**	14.94	14.41	**14.67**	14.82	14.30	**14.56**
T_5	14.40	13.41	**13.90**	14.38	13.85	**14.11**	14.39	13.63	**14.01**
T_6	13.82	13.28	**13.55**	13.88	13.42	**13.65**	13.85	13.35	**13.60**
T_7	13.61	13.00	**13.31**	13.79	13.28	**13.53**	13.70	13.14	**13.42**
T_8	12.46	12.26	**12.36**	12.73	12.56	**12.65**	12.60	12.41	**12.50**
Mean	**14.04**	**13.45**	**13.74**	**14.17**	**13.75**	**13.96**	**14.11**	**13.60**	
$CD_{0.05}$	**S**	**0.18**		**S**	**0.05**		**Y**	**0.09**	
							S	**0.09**	
	T	**0.36**		**T**	**0.10**		**T**	**0.18**	
							Y×S	**NS**	
	S×T	**NS**		**S×T**	**0.14**		**Y×T**	**NS**	
							S×T	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The two years data revealed that the planting conditions and INM had possessed a significant influence on the soil moisture content following crop harvest. In comparison to open conditions, *Grewia optiva* tree canopy showed the maximum soil moisture among planting conditions. The decrease in evapotranspiration via the tree canopy may also be a cause of this rise in moisture levels in tree-based systems. In addition, the organic matter that trees give to the soil through the decomposition of their leaves improves the moisture content and soil structure. Kumar et al. (2023) also noted that the moisture content beneath *Grewia optiva* trees was higher than when bhringraj was grown alone. Similar to this, Sarto et al. (2022) also verified that there is more moisture beneath the tree canopy than in the open. Similarly, the data related to the various integrated nutrient treatments showed that T_2 (100% FYM) had the maximum soil moisture content, while T_8 (control) had the lowest. This could be due to inclusion of organic manure, which has an elevated water retention capacity and can be composted or well-rotted animal dung. The breakdown of organic manures creates a layer of mulch that protects the soil surface. Further, it lowers soil exposure to direct sunlight and reduces the direct influence that wind has on soil surface, this mulch acts as a barrier to reduce evaporative losses. The current results align with research conducted by Kumar et al. (2023); Jagadeeshwari and Kumaraswamy (2000), all of which saw increased moisture content in their studies when used organic manures or integrated nutrition management, in comparison to control.

Chemical properties of soil in Wheat+Buel based agroforestry system after harvesting of Wheat

The physical soil parameters *viz.*, pH, EC (dS m^{-1}), OC (%) and available N, P, and K (kg ha^{-1}) has been presented and discussed in the following way:

Soil pH: The content of the data presented in Table 7 revealed that during both the years and pooled data, both planting conditions and INM showed significant effect on soil pH after harvesting of wheat. The soil pH was recorded higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition) in all the data sets. Among organic and inorganic fertilizers, the maximum soil pH (7.13, 6.85 and 7.09) was recorded by T_8 (control) whereas, the minimum soil pH (6.54, 6.49 and 6.51) was recorded by T_2 (100% FYM) in both the years as well as pooled data. The combined effect planting conditions and treatment (S×T) registered non-significant effect on the soil pH.

Table 7: Effect of planting conditions and integrated nutrient management (INM) on the soil pH after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	6.99	7.06	**7.03**	6.84	6.94	**6.89**	6.91	7.00	**6.96**
T_2	6.45	6.64	**6.54**	6.39	6.58	**6.49**	6.42	6.61	**6.51**
T_3	6.53	6.76	**6.64**	6.50	6.70	**6.60**	6.51	6.73	**6.62**
T_4	6.63	6.81	**6.72**	6.54	6.76	**6.65**	6.58	6.79	**6.69**
T_5	6.73	6.89	**6.81**	6.65	6.83	**6.74**	6.69	6.86	**6.77**
T_6	6.79	6.92	**6.85**	6.68	6.87	**6.78**	6.74	6.89	**6.82**
T_7	6.82	6.99	**6.91**	6.75	6.93	**6.84**	6.78	6.96	**6.87**
T_8	7.06	7.21	**7.13**	6.93	7.15	**7.04**	6.99	7.18	**7.09**
Mean	**6.75**	**6.91**	**6.83**	**6.66**	**6.85**	**6.75**	**6.70**	**6.88**	
$CD_{0.05}$	**S**	**0.05**		**S**	**0.03**		**Y**	**0.03**	
							S	**0.03**	
	T	**0.10**		**T**	**0.06**		**T**	**0.06**	
							Y×S	**NS**	
	S×T	**NS**		**S×T**	**NS**		**Y×T**	**NS**	
							S×T	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

In comparison to open conditions, there was decrease in soil pH under agroforestry conditions. There are several reasons for lower pH of the soil beneath tree canopies. This effect is exacerbated by the yearly deposition of leaf litter, which breaks down and emits carbon dioxide (CO_2) and organic acids that lower pH levels in the soil. The metabolic activities of tree roots also emit organic acids, which adds to the acidity of the soil under tree canopy results of the current study were also similar to the Dash (2020) who reported lowest values of soil pH under Poplar based agroforestry system as compare to sole cropping of turmeric. Conversely, distinct nutrient management strategies also have a significant effect on soil pH. The control had the highest pH, whereas the 100% FYM treatment showed lowest pH values, which were identical to the pH levels in 100% vermicompost treatment. The organic treatments have caused a decrease in soil pH, which can be ascribed to the acidifying effect of organic acids produced during the breakdown of organic supplements. The intricate relationships between organic additions, microbial activity, and soil pH variations are highlighted by this dual influence. These results are consistent with studies by Mehta (2023) who found that the control plot with no manure had the greatest pH and that the lowest pH was observed with 100% goat dung, which was comparable to the values of pH in the 100% FYM treatment. Additional evidence for these findings comes from study of Ghosh et al. (2020) who observed that the application of organic manures produced an ideal pH in comparison to control.

EC soil (dS m^{-1}): The critical examinations of the data presented in the Table 8 revealed that both planting conditions and INM showed a significant effect on the EC of soil after harvesting of wheat. The soil EC was recorded higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition) in all the data sets. Among different doses of organic and inorganic fertilizers, the maximum soil EC (0.301, 0.267 and 0.284 dS m^{-1}) was recorded by T_2 (100% FYM) whereas, the minimum soil EC (0.105, 0.080 and 0.093 dS m^{-1}) was recorded in T_8 (control) in all the data sets. The combined effect of planting conditions and treatments was found the maximum soil EC by S_1T_2 and the minimum by S_1T_8 during both years as well as pooled data. Moreover, the interaction effect of year and planting conditions (Y×S) had also registered significant effect on soil EC with maximum (0.228 dS/m) soil EC was recorded in Y_1S_1 and minimum (0.107 dS/m) soil EC was recorded in Y_2S_2 in pooled data set.

Table 8: Effect of planting conditions and integrated nutrient management (INM) on the electrical Conductivity (dS m^{-1}) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	0.135	0.097	**0.116**	0.090	0.077	**0.084**	0.113	0.087	**0.100**
T_2	0.351	0.251	**0.301**	0.306	0.228	**0.267**	0.328	0.239	**0.284**
T_3	0.203	0.095	**0.149**	0.158	0.075	**0.117**	0.181	0.085	**0.133**
T_4	0.233	0.101	**0.167**	0.188	0.081	**0.135**	0.211	0.091	**0.151**
T_5	0.237	0.123	**0.180**	0.192	0.103	**0.148**	0.215	0.113	**0.164**
T_6	0.255	0.128	**0.192**	0.210	0.108	**0.159**	0.233	0.118	**0.175**
T_7	0.284	0.131	**0.208**	0.239	0.111	**0.175**	0.262	0.121	**0.191**
T_8	0.125	0.085	**0.105**	0.087	0.074	**0.080**	0.106	0.079	**0.093**
Mean	**0.228**	**0.126**	**0.177**	**0.184**	**0.107**	**0.145**	**0.206**	**0.117**	
$CD_{0.05}$	**S**	**0.003**		**S**	**0.003**		**Y**	**0.002**	
							S	**0.002**	
	T	**0.007**		**T**	**0.007**		**T**	**0.005**	
							Y×S	**0.003**	
							Y×T	**NS**	
	S×T	**0.010**		**S×T**	**0.010**		**S×T**	**0.007**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

Regarding planting conditions, *Grewia* optiva based agroforestry system produced the highest electrical conductivity whereas, open conditions displayed the lowest. When compared to a single crop, higher electrical conductivity in agroforestry system may be caused by the buildup and breakdown of leaf litter, which improves the soil basic salt concentration. The breakdown of organic matter releases ions, including salts, into the soil solution, which increases EC. Tree canopies can also intercept and concentrate rainfall, which results in higher concentrations of salts in the soil surrounding the tree base. These findings are supported by Kumar et al. (2023) who reported significantly higher electrical conductivity under *Grewia optiva* trees compared to open conditions. The findings of Kar et al. (2019) and Tripathi et al. (2017) who all showed higher EC content under trees compared to open condition, also corroborate with the present results. As a result, of the fertilizer treatments, T_2 (100 % FYM) showed the highest electrical conductivity, while T_8 (no manure) exhibited the lowest. The application of nutrient sources was found to boost electrical conductivity, with organic manure registering the highest values among the nutrient sources studied in this study. The presence of soluble ions like potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), and magnesium

(Mg^{2+}) in FYM may be the cause of high EC under FYM. Secondly, FYM decomposes in the soil into simpler forms throughout the decomposition process, releasing ions into the soil solution and raising the EC. As compared to alternative nutrient sources, the application of 100% FYM produced maximum electrical conductivity, which is consistent with the findings of several other researchers. Likewise, Lodh (2023) who found that the highest electrical conductivity is obtained when 100% vermicompost is used in conjunction with 100% FYM. The finding is supported by Kaushal et al. (2016) who found that applying organic manure raises the electrical conductivity (EC) of the soil.

Organic Carbon (%): The effect of planting conditions and INM showed a significant effect on organic carbon of soil after harvesting of wheat (Table 9). During both the years as well as pooled data, organic carbon was recorded higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition). Among different doses of organic and inorganic fertilizers, treatment T_2 (100% FYM) resulted the maximum organic carbon whereas, the minimum was recorded by T_8 (control) in all the data sets. The combined effect of planting conditions and treatment (S×T) showed significant effect on organic carbon of soil with the maximum (1.53 %) by S_1T_2 and the minimum (1.32 %) by S_2T_8 during second year as well as in pooled data anlysis.

Table 9: Effect of planting conditions and integrated nutrient management (INM) on the organic carbon (%) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	1.41	1.35	**1.38**	1.46	1.39	**1.43**	1.43	1.37	**1.40**
T_2	1.52	1.48	**1.50**	1.55	1.53	**1.54**	1.53	1.50	**1.52**
T_3	1.51	1.46	**1.49**	1.53	1.51	**1.52**	1.52	1.48	**1.50**
T_4	1.49	1.43	**1.46**	1.52	1.47	**1.50**	1.51	1.45	**1.48**
T_5	1.44	1.39	**1.41**	1.51	1.41	**1.46**	1.47	1.40	**1.44**
T_6	1.40	1.36	**1.38**	1.47	1.38	**1.43**	1.44	1.37	**1.40**
T_7	1.42	1.35	**1.38**	1.47	1.39	**1.43**	1.44	1.37	**1.41**
T_8	1.35	1.31	**1.33**	1.42	1.33	**1.38**	1.38	1.32	**1.35**
Mean	**1.44**	**1.39**	**1.42**	**1.49**	**1.43**	**1.46**	**1.47**	**1.41**	
$CD_{0.05}$	**S**		**0.01**	**S**		**0.01**	**Y**	**0.007**	
							S	**0.007**	
	T		**0.02**	**T**		**0.02**	**T**	**0.015**	
							Y×S	**NS**	
	S×T		**NS**	**S×T**		**0.02**	**Y×T**	**NS**	
							S×T	**0.02**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The planting conditions as well as nutrient management had a significant effect on the organic carbon content of soil. The results unequivocally showed that, in contrast to single cropping, the maximum organic carbon was found beneath of buel trees during planting conditions. The reduced oxidation of organic material in the vicinity of tree shade, the regular contribution of annual litter and the recycling of biomass and root exudates are all responsible for the improved level of organic carbon under the tree canopy. Furthermore, lignified cells can be found in the roots, bark and litter of trees, among other plant parts. Kar et al. (2019) showed that, in comparison to garden pea sole cropping, the *Grewia optiva* based agroforestry system had higher quantities of organic carbon. The results are also in conformity with the findings of Zahoor et al. (2021), and Garima and Pant (2017), who found that agroforestry systems had increased soil organic carbon content than open conditions. Talking of different fertilizer applications, an advantageous sequestration of soil organic carbon can be attributed to the collaborative relationships among soil organic carbon, boosted microbial life and the enzymes involved in carbon cycling, which resulted in a higher organic carbon content noticed during the organic manure application. In addition, adding organic manure promotes soil health and highlights other advantages too of using organic manure for effective carbon sequestration and long-term soil management. These results are consistent with the study conducted by Mehta (2023), which found that 100% goat manure had maximum soil organic carbon content (0.81%) than control plots (0.51%). Moreover, Garima and Pant (2017) found that 100% FYM had more soil organic carbon (15.18 g kg^{-1}) than the control (13.80 g kg^{-1}). Tripathi et al. (2017) observed greater organic carbon content under the organic manures as compared to inorganic and control.

Available Nitrogen (kg/ha): Result of the data presented in Table 10 reflected that the both planting conditions and INM showed significant effect on the available nitrogen (kg/ha) of soil after harvest of wheat crop in Rabi Season. In all he years, the maximum available nitrogen was recorded higher by S_1 as compared to S_2 (open condition). Among different doses of organic and inorganic fertilizers, the maximum available nitrogen (359.87, 371.55 and 365.71 kg/ha) was recorded by T_2 (100% FYM) whereas, the minimum (269.33, 280.86 and 275.10 kg/ha) was recorded by T_8 (control) in all the data sets. However, the interaction effect of year and systems (Y×S), year and treatments (Y×T), system and treatment (S×T) and year, system and treatment (Y×S×T) found to be non-significant effect on the available nitrogen content on the soil in pooled analysis.

Table 10: Effect of planting conditions and integrated nutrient management (INM) on the available nitrogen (kg/ha) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	305.25	280.37	**292.81**	320.40	289.93	**305.17**	312.83	285.15	**298.99**
T_2	370.86	348.88	**359.87**	382.01	361.08	**371.55**	376.44	354.98	**365.71**
T_3	360.86	343.35	**352.11**	371.15	353.71	**362.43**	366.01	348.53	**357.27**
T_4	356.28	340.38	**348.33**	367.43	349.70	**358.56**	361.86	345.04	**353.45**
T_5	347.92	334.88	**341.40**	358.81	345.63	**352.22**	353.37	340.25	**346.81**
T_6	339.38	327.57	**333.47**	350.27	337.14	**343.70**	344.83	332.35	**338.59**
T_7	335.28	318.82	**327.05**	347.02	329.03	**338.03**	341.15	323.93	**332.54**
T_8	278.03	260.64	**269.33**	289.77	271.96	**280.86**	283.90	266.30	**275.10**
Mean	**336.74**	**319.36**	**328.05**	**348.36**	**329.77**	**339.07**	**342.55**	**324.57**	
$CD_{0.05}$	**S**		**3.47**	**S**		**3.47**	**Y**	**2.36**	
							S	**2.36**	
	T		**6.95**	**T**		**6.95**	**T**	**4.73**	
							Y×S	**NS**	
	S×T		**NS**	**S×T**		**NS**	**Y×T**	**NS**	
							S×T	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The results revealed that planting conditions and fertilizer application had a significant effect on the soil nitrogen content in both years. The data showed that the agroforestry system comprised of *Grewia optiva* trees accumulates the highest content of available nitrogen than the open condition (sole cropping of field crops). Nitrogen directly influences metabolic processes that impact crop production and yield. Many processes, including quick decomposition of litter, reduction of nitrogen loss via the canopy, enhanced microclimate that reduces leaching and moderate rainfall intensity and regular nitrogen cycling, are responsible for the high nitrogen content underneath the tree crown. Additionally, the direct relationship between the amount of nitrogen in the soil and the organic carbon in the soil implies that higher levels of organic carbon in the soil lead to higher levels of nitrogen, highlighting the interrelated dynamics that affect the availability of nutrients in the soil. Kar et al. (2019) also found the higher nitogen (253.48 kg ha^{-1}) content under *Grewia optiva* based agroforestry systems as compared to sole cropping. Similarly, Bisht et al. (2017) reported the highest available nitrogen in agroforestry system as that of sole cropping systems. The available nitrogen concentration under organic manures (100 % FYM/Vermicompost/Goat manure) was higher than under other nutrient treatments. This could be because applying FYM supplies the earth with organic matter, starts a microbial-mediated breakdown process. This helps in humus formation, which acts as a reservoir for nutrients, especially nitrogen. Furthermore, the organic matter found in FYM is essential for reducing nitrogen loss through volatilization and leaching, improves the overall effectiveness of nitrogen uptake by plants. In contrast, nitrogen is released from inorganic fertilizers quickly, which causes losses from the system due to denitrification and conversion processes. Consequently, there is less nitrogen available in the soil. According to Kumar et al. (2023), organic manure exhibited the highest levels of soil accessible nitrogen compared to the control and chemical fertilizers used alone. The current findings are also consistent with the research conducted by Ghosh et al. (2020) who found that organic manures raised the nitrogen level than the control (no manure) plot.

Available Phosphorus (kg/ha): The data regarding the effect of planting conditions and integrated nutrient management (INM) on available phosphorus (kg/ha) of soil after harvest under *Grewia optiva* based agroforestry system had been recorded and presented in Table 11. The available phosphorus was recorded higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition). Among different doses of organic and inorganic fertilizers, the maximum the available phosphorus was recorded by T_2 (100% FYM) whereas, the minimum was recorded by T_8 (control) in all the years. In general, the maximum (44.94 kg/ha) available phosphorus was recorded in the year 2023 in comparison to the year 2022 (41.60 kg/ha). The combined effect of planting conditions and treatment (S×T) showed significant effect on the available phosphorus in soil with the maximum (49.66 kg/ha) by S_1T_2 and the minimum (30.30 kg/ha) by S_2T_8 in pooled data analysis.

Table 11: Effect of planting conditions and integrated nutrient management (INM) on the available phosphorus (kg/ha) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	**Mean**	S_1	S_2	**Mean**	S_1	S_2	**Mean**
T_1	35.39	31.18	**33.29**	38.82	34.46	**36.64**	37.10	32.82	**34.96**
T_2	48.29	41.91	**45.10**	51.02	45.36	**48.19**	49.66	43.64	**46.65**
T_3	47.08	38.86	**42.97**	50.50	42.14	**46.32**	48.79	40.50	**44.64**
T_4	46.13	38.95	**42.54**	49.35	42.23	**45.79**	47.74	40.59	**44.16**
T_5	44.12	37.01	**40.57**	47.55	40.29	**43.92**	45.83	38.65	**42.24**
T_6	40.31	32.52	**36.42**	43.74	37.01	**40.37**	42.03	34.76	**38.40**
T_7	38.43	31.86	**35.15**	42.31	35.14	**38.73**	40.37	33.50	**36.94**
T_8	33.03	27.87	**30.45**	36.24	32.72	**34.48**	34.64	30.30	**32.47**
Mean	**41.60**	**35.02**	**38.31**	**44.94**	**38.67**	**41.80**	**43.27**	**36.84**	
$CD_{0.05}$	**S**	**0.64**		**S**	**0.77**		**Y**	**0.50**	
							S	**0.50**	
	T	**1.28**		**T**	**1.55**		**T**	**1.00**	
							Y×S	**NS**	
							Y×T	**NS**	
	S×T	**NS**		**S×T**	**NS**		**S×T**	**1.41**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The result reflected the planting conditions and integrated nutrient management had a significant effect on the available phosphorus content in the soil. It has been noted that agroforestry systems based on *Grewia optiva* produced a higher content of accessible phosphorus than the open conditions. The combination of organic matter decomposition, mycorrhizal associations, effective nutrient cycling, decreased erosion and accumulation of organic matter in agroforestry systems jointly supports a rise in phosphorus levels in the soil, supporting plant growth and overall soil fertility. This may be the cause of the increase in phosphorus content under agroforestry. Furthermore, when organic compounds break down in the soil, organic acids are released. These acids reduce metal ions, chelate with phosphates to form complexes and compete with them for exchange sites, all of which contribute to the enhanced release of phosphorus. The results of this study are also aligned with previous research conducted by Kar et al. (2019) which showed the superiority of agroforestry systems for achieving the ideal phosphorus content. In the present investigation, with respect to different doses of organic and inorganic manures, T_2 (100% FYM) had the maximum content of significant effect on phosphorus while, T_8 (no manure) had the minimum available phosphorus. The results of this study demonstrated that the application of organic manure treatments mobilized the available soil phosphorus concentration on its peak. This may be increased due to increase in organic acids that occurs during the breakdown of organic manures, which promotes the proliferation of bacteria and fungi, hence augmenting the soil nutrient availability environment. These results are in harmony with the finding of Kumar et al. (2023), Garima et al. (2021) and Ghosh et al. (2020 who stated that the maximum amount of accessible soil phosphorus content was observed under organic manures as compared to the control (no manure).

Available Potassium (kg/ha): The perusal of the data regarding the effect of planting conditions and integrated nutrient management (INM) on the available potassium (kg/ha) of soil after the harvest of wheat under the *Grewia optiva* based agroforestry system showed a significant effect and presented in Table 12. During both the years, the available potassium was recorded higher by S_1 (under *Grewia optiva* based agroforestry systems) as compared to S_2 (open condition). Moreover, among different doses of organic and inorganic fertilizers, the maximum available potassium was recorded by T_2 (100% FYM) whereas, the minimum was recorded by T_8 (control) in all the data sets. In general, the maximum (289.94 kg/ha) available potassium was recorded in the year 2023 in comparison to the year 2022 (281.06 kg/ha). The combined effect of year and planting conditions (Y×S) showed significant effect on the available phosphorus in soil which the maximum (297.18 kg/ha) by Y_2S_1 while, the minimum (275.84 kg/ha) by Y_1S_2 in pooled data analysis.

Table 12: Effect of planting conditions and integrated nutrient management (INM) on the available Potassium (kg/ha) of soil after harvesting of wheat under buel based agroforestry system

Systems (S) / Treatments (T)	1st Year (2022)			2nd Year (2023)			Pooled		
	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
T_1	272.39	262.55	**267.47**	283.54	268.57	**276.06**	277.97	265.56	**271.76**
T_2	303.79	290.55	**297.17**	315.28	299.21	**307.24**	309.53	294.88	**302.21**
T_3	298.74	287.27	**293.01**	309.34	294.09	**301.72**	304.04	290.68	**297.36**
T_4	294.75	284.42	**289.58**	305.90	290.20	**298.05**	300.32	287.31	**293.81**
T_5	289.04	280.61	**284.83**	299.93	287.82	**293.88**	294.49	284.22	**289.35**
T_6	283.06	273.36	**278.21**	293.45	279.39	**286.42**	288.26	276.37	**282.31**
T_7	281.43	271.51	**276.47**	293.17	278.18	**285.68**	287.30	274.85	**281.07**
T_8	267.00	256.44	**261.72**	276.80	264.22	**270.51**	271.90	260.33	**266.12**
Mean	**286.28**	**275.84**	**281.06**	**297.18**	**282.71**	**289.94**	**291.73**	**279.27**	
$CD_{0.05}$	**S**	**2.29**		**S**	**2.44**		**Y**	**1.62**	
							S	**1.62**	
	T	**4.59**		**T**	**4.89**		**T**	**3.24**	
							Y×S	**2.29**	
							Y×T	**NS**	
	S×T	**NS**		**S×T**	**NS**		**S×T**	**NS**	
							Y×S×T	**NS**	

Note: S_1: under *Grewia optiva* based agroforestry system and S_2: Open conditions

The data of two consecutive years revealed that the soil potassium was significantly influenced by the planting condition and fertilizer sources. The increased potassium concentration beneath tree canopy can be attributed to the high mineralization, addition of leaf litter, which raises the potassium levels in the soil under the tree cover (Garima et al. 2021). Potassium influences the efficiency of photosynthesis, modifies the activity of enzymes, and maintains the skeletal strength of plant membranes. Moreover, potassium optimization is essential for improving osmotic potential of plants and guarantees general resistance and flexibility to changes in the environment (Erel et al. 2015). Thakur (2023) also reported higher potassium content under agroforestry than the sole cropping system. However, among different manures and fertilizers, the available soil potassium was exhibited maximum under pure organic treatments *i.e.*, 100 % FYM which was at par with vermicompost and goat manure, while the minimum was recorded in control. The increased potassium content in soils treated with organic manures, especially FYM, can be attributed to several factors. The application of organic manures leads to an increased release of potassium through the gradual decomposition of organic matter. This process is further augmented by the formation of humus, improved microbial activity and the enhanced cation exchange capacity of the soil, collectively contributing to the sharp availability of potassium in the soil. Similar study was also conducted by Ghosh et al., (2020) also reported that integration of organic and inorganic manures increases the potassium content of the soil as compared to RDF alone. The findings of the present study are also consistent with Kumar et al. (2023) and Dash (2020) who all substantiated that potassium content tended to be high in the organic manures compared to control.

CONCLUSION

From the present study, it is concluded that the physical as well as chemical properties of soil were improved under buel based agroforestry systems as compared to open conditions when wheat crop intercropped in agroforestry system. The combined data from both years showed that agroforestry systems effectively enhanced soil conditions by reducing bulk density, particle density and pH along with increasing porosity, soil moisture, electrical conductivity, organic carbon, available nitrogen, available phosphorus and available potassium. Under integrated nutrient management, the use of organic and inorganic manures possesses a significant effect on all the physical and chemical properties of the soil. In fertilizer treatments, the application of 100 % FYM led to significant improvement in soil physico-chemical properties with decreased bulk density, particle density and pH, together with increased porosity, soil moisture EC, organic carbon, available nitrogen, available phosphorus and available potassium. Moreover, all the soil parameters were improved in the second year as compared to first year. Thus, the application of 100 % FYM fertilizer is recommended for farmers in hilly area of Himachal Pradesh for sustainable agriculture and natural farming. This finding will also provide a valuable insight to policymakers as aiming to optimize crop production and maintain soil health in similar agro-ecological zones to reduce hazards for plant health and ultimately human health.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMFLICT OF INTEREST

There is no comflict of interest among authers.

REFERENCES

Abiven S, Menasseri S and Chenu C. 2008. The effects of organic inputs over time on soil aggregate stability – a literature analysis. *Soil Biology and Biochemistry*. 41:1-12.

Bhatt MK, Labanya R, Joshi HC and Nand M. 2019. Effect of long-term inorganic and organic manure on physical and biological properties of soil in Uttarakhand-A review. *ENVIS Bulletin Himalayan Ecology*. 27:49-54.

Bisht N, Sah VK, Satyawali and Tiwari S. 2017. Comparison of wheat yield and soil properties under open and poplar-based agroforestry system. *Journal of Applied and Natural Science* 9:1540-1543.

Brown, S.E., Miller, D.C., Ordonez, P.J. and Baylis, K., 2018. Evidence for the impacts of agroforestry on agricultural productivity, ecosystem services, and human well-being in high-income countries: a systematic map protocol. *Environmental evidence*, *7*, pp.1-16.

Dash, U., 2020. Phenotypic and functional traits of *Curcuma longa* in response to nutrient sources and *Populus deltoides* tree spacings. *M.Sc. Thesis.* Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP. 144p.

Dhaka, R.K., Gunaga, R.P., Sinha, S.K., Thakur, N.S. and Dobriyal, M.J., 2020. Influence of tree height and diameter on wood basic density, cellulose and fibre characteristics in Melia dubia Cav. families. *Journal of the Indian Academy of Wood Science*, *17*, pp.138-144.

Erel R Yermiyahu U Ben-Gal A Dag A Shapira O and Schwartz A. 2015. Modification of non-stomatal limitation and photoprotection due to K and Na nutrition of olive trees. *Journal of Plant Physiology.* 177:1-10.

Garima and Pant KS 2017. Effect of integrated nutrient management and tree spacing on production potential of maize (*Zea mays*) under poplar-based agroforestry system. *International Journal of Current Microbiology and Applied Sciences.* 6:2692-2697.

Garima Bhardwaj DR Thakur CL Kaushal R Sharma P Kumar D and Kumari Y 2021. Bamboo-based agroforestry system effects on soil fertility: Ginger performance in the bamboo subcanopy in the Himalayas (India). *Agronomy Journal*. 113(3):2832-2845.

Ghosh, S., Paul, J., Kholiya, D., Pareek, N. and Dwivedi, G.K., 2020. Effect of integrated nutrient management on some physical properties of soil under poplar based agroforestry system in Himalayan foothills, India. *The Pharma Innovation Journal*. 9:22-25.

Gomez, K.A. and Gomez, A.A., 1984. *Statistical procedures for agricultural research*. John Wiley & Sons.

Gupta, N., Kukal, S.S., Bawa, S.S. and Dhaliwal, G.S., 2009. Soil organic carbon and aggregation under poplar based agroforestry system in relation to tree age and soil type. In *Advances in Agroforestry* (pp. 27-35). Springer, Dordrecht.

IUCN. 2022. SSC Global Tree Specialist Group, Botanic Gardens Conservation International (BGCI), Lakhey, P. & Pathak, J. Grewia optiva. The IUCN Red List of Threatened Species 2022: e.T150220524A152201442. https://dx.doi.org/10.2305/IUCN.UK.20221.RLTS.T150220524A152201442.en

Jackson, M.L., 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Jagadeeshwari PV and Kumaraswamy K 2000. Long term effect of manure, fertilizer schedule on the yield and nutrient uptake by rice crop in a permanent manurial experiment. *Journal of the Indian Society of Soil Science.* 48: 833-836.

Kar, S., Pant, K.S., Chandel, A. and Roshanzada, S.R., 2019. Trend of soil parameters under different spacings of Grewia based agroforestry system in the mid hill zones of Himachal Pradesh. *International Journal of Chemical Studies*, *7*(1), pp.1904-1907.

Kaur G, Singh I, Behl RK, Dhankar A. 2024. Effect of Different Integrated Nutrient Management Approaches on Growth, Yield Attributes and Yield of Wheat (*Triticum aestivum* L.) Crop: A Review. *Asian Journal of Soil Science and Plant Nutrition*. 10(1):457-468.

Kaur T, Brar BS and Dhillon NS. 2008. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system. *Nutrient Cycling Agroecosystems.* 81:59-69.

Kaushal R, Verma A, Mehta H and Mandal D. 2016. Soil quality under *Grewia optiva* based agroforestry systems in Western sub Himalaya. *Range Management and agroforestry* 37:50-55.

Kumar J, Thakur CL, Bhardwaj DR, Kumar S and Dutt B. 2023. Effects of integrated nutrient management on performance of bhringraj (*Eclipta prostrata* L.) and soil fertility under the *Grewia optiva* Drummond. canopy in a mid-hill agroecosystem of north western Himalayas. *Agroforestry Systems.* 97:711-726.

Lodh, U., 2023. Effect of tree spacing and integrated nutrient management on growth and yield of cereals and pulses under *Grewia optiva* based agroforestry system. *Ph.D. Thesis.* Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan. 195p.

Mahajan A, Gupta RD, editors. 2009. Integrated nutrient management (INM) in a sustainable rice—wheat cropping system. Dordrecht: Springer Netherlands.

Margni, M.D.P.O., Rossier, D., Crettaz, P. and Jolliet, O., 2002. Life cycle impact assessment of pesticides on human health and ecosystems. *Agriculture, ecosystems & environment*, *93*(1-3), pp.379-392.

Mehta M. 2023. Effect of organic manures on growth, yield and oil quality parameters of lemon grass under wild pomegranate based agroforestry system. *Ph.D. Thesis*. Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP. 138p.

Merwin, H.D. and Peech, M., 1951. Exchangeability of soils potassium in the silt and clay fractions as influenced by the nature of the complimentary exchangeable cations. *Soil Science Society of American Proceedings* 15:125-128.

Nayak AK, Gangwar B, Shukla AK, Mazumdar SP, Kumar A, Raja R, Kumar A, Kumar V, Rai PK, Mohan U. 2012. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. *Field Crops Research*. 127:129-39.

Olsen, S.R., Cole CV, Watanable, F.S. and Dean, L.A.,1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate (No. 939). *USDA Circular,* 939:1-19.

Pahalvi, H.N., Rafiya, L., Rashid, S., Nisar, B. and Kamili, A.N., 2021. Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs*, pp.1-20.

Polisetty, K. and Paidipati, K.K., 2019. Statistical assessment of trend analysis on production of wheat crop over India. *Sarhad Journal of Agriculture*, *36*(1), pp.178-184.

Prasad R, Arunachalam A, Shukla A, Gupta A, Saroj NK and Tripathi VD. 2023. Field management practices in agroforestry systems influence organic carbon and biological properties of soil. *Agroforestry System.* 97:1375–1390.

Reddy SR. 2024. Principles of Agronomy 7th Edition. Kalyani Publishers, New Delhi.

Sarto MV, Borges M, Bassegio WLB, Nunes D, Rice MR and Rosolem CA. 2022. Deep soil water content and forage production in a Tropical Agroforestry System. *Agriculture*. 12(3):343-359.

Sharma S, Singh B and Sikka R. 2015. Changes in some physico-chemical characteristics of soils under poplar-based agroforestry system. *Agricultural Research Journal.* 52:19-22.

Subbiah, B.V. and Asija, G.L., 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* 25: 259-260.

Tandel MB, Kukadia MU, Kolambe BN and Jadeja DB. 2009. Influence of tree cover on physical, properties of soil. *Indian Forester*. 3:420-424.

Thakur P. 2023. Performance of *Abelmoschus esculentus* L. *Moench* (okra) and *Triticum aestivum L.* (wheat) under agrihorticulture land use system. *Ph.D. Thesis*. Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, HP. 125p.

Tripathi P, Kashyap SD, Shah S and Pala NA. 2017. Effect of organic manure on soil physicochemical properties under fruit-based agroforestry system. *Indian Forester.* 143:48-55.

Walkley, A. and Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, *37*(1), pp.29-38.

WHO. 2011. Nitrate and nitrite in drinking water. New Delhi, World Health Organisation.

Wu, W. and Ma, B., 2015. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Science of the Total Environment*, *512*, pp.415-427.
Zahoor S, Dutt V, Mughal AH, Pala NA, Qaisar KN and Khan PA. 2021. Apple-based agroforestry systems for biomass production and carbon sequestration: implication for food security and climate change contemplates in temperate region of Northern Himalaya, India. *Agroforestry Systems*. 95:367-382.