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Impact of combined nutrient inputs on French bean and wheat yields in sustainable poplar based agroforestry systems

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Abstract
A field experiment was conducted in the year 2017-18 at the Agroforestry Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar. Nine treatment combinations involving different proportions of recommended NPK fertilizers, farmyard manure (FYM), vermi-compost (VC), and a microbial inoculant (Pantnagar Nodule Endophyte-PNE 21) were evaluated for French bean and wheat. Results indicated that treatments integrating organic and inorganic nutrient sources significantly improved plant growth parameters, yield attributes, and overall productivity compared to sole nutrient sources or control treatments.

In French bean, the highest grain yield (25.50 q ha^{-1}), pod number (37.66), and pod length (13.60 cm) were recorded under treatment T_7 (50% N through RDF + FYM + VC + inoculum), reflecting the benefits of balanced nutrient availability. In wheat, treatment T_8 (50% N through NPK + 25% N through FYM @ 6 t ha^{-1} + 25% N through VC @ 2 t ha^{-1}) achieved the highest grain yield (37.14 q ha^{-1}), straw yield (65.17 q ha^{-1}), and biological yield (102.31 q ha^{-1}), accompanied by a favorable harvest index (36.29%). These results were attributed to improved soil structure, moisture retention, microbial activity, and enhanced nutrient uptake due to organic amendments, in combination with the readily available nutrients from chemical fertilizers. Overall, the study concludes that integrated nutrient management practices optimize nutrient use efficiency, enhance crop performance, and contribute to sustainable intensification in Poplar-based agroforestry systems. The findings provide practical insights for improving the productivity and profitability of such systems while preserving soil health and ecosystem services.

Keywords: Organic, inorganic, agroforestry, wheat, Frenchbean

Introduction

Agroforestry systems, characterized by the deliberate integration of trees with crops and livestock, have emerged as a sustainable land-use practice that enhances biodiversity, improves soil health, and optimizes resource utilization (Jose, 2009) [10]. Among the various agroforestry models, the Poplar-based agroforestry system stands out for its adaptability and economic viability in diverse climatic zones (Tewari *et al*., 2014) [27]. Poplar (*Populus* spp.), with its deep root system and fast growth rate, not only provides valuable timber but also creates a microclimate conducive to intercropping (Singh & Lodhiyal, 2009) [23]. In this context, the cultivation of short-duration crops like French bean (*Phaseolus vulgaris* L.) and wheat (*Triticum aestivum* L.) within poplar alleys presents a promising strategy for maximizing land productivity while ensuring ecological sustainability. Nutrient management in agroforestry systems is a critical factor influencing crop yield and soil health. Traditional practices often rely solely on inorganic fertilizers to meet crop nutrient demands, potentially leading to soil degradation, reduced microbial activity, and environmental contamination (Lal, 2015) [14]. In contrast, organic amendments such as farmyard manure, compost, and green manure contribute to soil structure, enhance moisture retention, and stimulate beneficial microbial populations (Bhattacharyya *et al*., 2010) [2]. However, exclusive dependence on organic sources may not always meet the high nutrient requirements of intensively managed cropping systems (Drinkwater & Snapp, 2007) [6].
The integration of organic and inorganic nutrient sources termed 'conjoint nutrient management' has been identified as a sustainable approach to enhance nutrient availability, improve soil

fertility, and increase crop yield (Choudhary *et al*., 2018) [3-4]. This method leverages the immediate nutrient release from inorganic fertilizers alongside the long-term soil health benefits provided by organic amendments (Mandal *et al*., 2011) [16]. Conjoint application also mitigates nutrient losses through synchronized nutrient release, thereby promoting sustainable intensification in agroforestry systems (Singh *et al*., 2020) [22, 24]. Despite its potential, research on the effect of combined organic and inorganic nutrient inputs on the yield and yield attributes of French bean and wheat under Poplar-based agroforestry remains limited. Understanding these interactions is crucial for optimizing nutrient use efficiency, enhancing soil quality, and improving the economic viability of agroforestry systems. Keeping in view the above facts, it was thought pertinent to conduct the present study to evaluate the impact of conjoint nutrient management on the growth, yield, and soil health parameters of French bean and wheat intercropped with Poplar, thereby contributing to sustainable agroforestry intensification.

Material and Methods

The Experimental Site

The field experiment was carried out at the old site of the Agroforestry Research Centre, Patharchatta, under G.B. Pant University of Agriculture and Technology, located in Pantnagar, District Udham Singh Nagar, Uttarakhand. The experimental location is situated in the Tarai plains, approximately 30 km south of the Shivalik foothills of the Himalayas, at a latitude of 29°N, longitude of 79°29'E, and an elevation of 243.8 meters above mean sea level.

Climate and weather conditions during experimental period

Pantnagar falls under subtropical and sub-humid climate zone with dry and hot summer; and cold winter. The *Tarai* region has a dry season from early October to mid-June, and a wet season from mid-June to early October. Temperature is lowest in December-January and highest in May-June. Relative humidity is lowest in April-May and highest in July-August. Total annual rainfall ranges from 1300-1500 mm of which about 85-90% is received from June to September. Few showers may also be received during the winter months. Frost generally occurs towards the end of December and may continue till the end of January. The daily average minimum temperature in coldest month varies from 1.0 to 9.0 °C and during summer, the maximum temperature varies from 30 to 43 °C.

Native Vegetation

The *Tarai* region has thick vegetation compared to adjoining *Bhabhar* region. This is mainly because of prevalence of moisture in *Tarai* belt. The *Tarai* forest is classified as low alluvial savannah (Puri, 1960) [20]. The common trees of the region are dhak (*Butea monosperma*), semal (*Salamalia maluberica*), khair (*Acacia catacheu*) and shesham (*Delbergia sissoo*) and consist of coarse perennial species of grasses such as common reed grass kernel (*Narenja porphyrocoma*), (*Phragmites karka*) and Johnson grass (*Sorghum helepense*) (Deshpande, 1971) [5].

Table 1: Detail of treatments in conjoint use of organic and inorganic nutrient sources in french bean and wheat crop.

Treatments	French bean (*Phaseolus vulgaris* L.)	Wheat (*Triticum aestivum* L.)
T_1	Control (Under poplar trees)	Control (Under poplar trees)
T_2	Recommended dose of NPK + inoculum	100% N through vermicompost (VC) @ 8 t ha^{-1}
T_3	100% N through vermicompost (VC) @ 8 t ha^{-1} + inoculum*	100% N through farm yard manure (FYM) @ 24 t ha^{-1}
T_4	100% N through farm yard manure (FYM) @ 24 t ha^{-1} + inoculum	100% N through NPK fertilizer
T_5	100% N through vermicompost (VC) @ 4t ha^{-1} + farm yard manure (FYM) @ 12 t ha^{-1} + inoculum	50% N through VC @ 4t + 50% N through FYM @12t ha^{-1}
T_6	Sole inoculum	50% N through NPK fertilizer + 50% N through VC @4t ha^{-1}
T_7	50% N through VC @ 2 t + FYM @ 6 t ha^{-1} + 50% N as RDF+ inoculum	50% N through NPK fertilizer + 50% N through FYM @12t ha^{-1}
T_8	25% N through VC 1t ha-^{1} + FYM @ 3 t + 75% N through RDF+ inoculum	50% N through NPK fertilizer + 25% N through FYM @ 6t + 25% N through VC @ 2t ha^{-1}
T_9	Open control (without poplar trees)	Open control (without poplar trees)

*Inoculum: Pantnagar Nodule Endophyte (PNE 21) @ 20 gm kg^{-1} seed
RDF for frenchbean-120:60:60 (NPK kg ha^{-1})
RDF for wheat crop-120:60:40 (NPK kg ha^{-1})

The following observations were taken under standard practices

Growth Attributes

Plant Height (cm)

The height of French bean and wheat plants was measured at physiological maturity from the ground level to the tip of the fully opened leaves on the main stem. Ten randomly tagged plants from each treatment plot were selected and measurements were taken using a calibrated meter scale.

Yield Components

Biological Yield (kg ha⁻¹)

To estimate the biological yield, the entire crop from the net plot area was harvested, bundled, and sun-dried for 4 to 5 days. The bundles were then weighed before threshing, and the weight was recorded as the biological yield, expressed in kilograms per hectare.

Grain Yield (kg ha⁻¹)

After biological yield estimation, the harvested produce was sun-dried, threshed, cleaned, and weighed to determine the grain yield. This value was then converted to kilograms per hectare for standardized reporting.

Straw Yield (kg ha⁻¹)

Straw yield was calculated by subtracting the grain yield from the total biological yield obtained from each net plot. The difference was expressed in kilograms per hectare.

Number of Pods per Plant (French Bean)

The number of pods was counted on ten randomly tagged French bean plants from each treatment plot, and the average number of pods per plant was calculated.

Number of Grains per Pod (French Bean)
Ten pods were randomly selected from the harvested lot, and the number of grains per pod was counted. The average was calculated for each treatment.

Pod Length (cm) (French Bean)
The length of ten randomly selected pods was measured after each harvest using a standard measuring scale. The average pod length for each treatment was calculated.

Grain Yield per Hectare (q ha⁻¹)
Grain yield per net plot was converted to quintals per hectare by multiplying the yield with a standard conversion factor (10,000/3.78).

Test Weight
1000-Grain Weight of Wheat (g)
A random sample of 1000 wheat grains was collected from the net plot yield, weighed using a digital balance, and expressed in grams.

100-Grain Weight of French Bean (g)
For French bean, 100 grains were randomly selected from each plot, weighed, and the average grain weight was recorded as the test weight.

Harvest Index
The harvest index (HI) was calculated to determine the efficiency of the crop in converting the total biological yield into economic yield. It was computed using the following formula:

$$HI = \frac{\text{Grain yield (q/ha)}}{\text{Biological yield (q/ha)}} x100$$

Statistical Analysis
All the observations on yield and analytical data recorded during the course of investigation were subjected to statistical analysis by using Randomized Block Design. The statistical analysis was carried out by the procedure defined by Snedcor and Cochran (1967) [26], the value of test at 5 percent level of significant were determined and the values of S.Em.±, CD were also calculated by using STPR software.

Results

Table 2: Effect of conjoint use of organic and inorganic sources of nutrient on french bean growth, yield, yield attributes and harvest index

Treatment	Plant height (cm)	No. of Pods/plant	No. of grains/pod	Pod length (cm)	100 grain weight (g)	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Harvest index
T_1	45.30	23.66	3.66	10.86	31.20	18.37	26.04	44.42	41.36
T_2	55.73	35.66	6.33	12.36	37.90	23.25	28.19	51.45	45.20
T_3	53.60	32.00	4.00	11.33	34.53	21.81	26.56	48.37	45.08
T_4	51.46	31.66	4.00	10.96	35.26	21.04	26.96	48.00	43.81
T_5	53.73	34.00	4.66	11.60	36.93	22.48	27.26	49.74	45.19
T_6	48.83	29.33	3.66	10.93	32.50	21.64	26.06	47.70	45.36
T_7	56.63	37.66	6.66	13.60	39.13	25.50	29.53	55.03	46.33
T_8	54.96	35.65	5.00	11.63	37.23	23.18	27.68	50.87	45.57
T_9	39.56	23.00	3.33	10.31	26.16	17.76	26.00	43.76	40.59
C.D. (p= 0.05)	0.74	3.66	1.24	0.13	NS	0.91	0.69	1.27	1.04

Plant Height (cm)
The highest plant height in case of French bean (56.63 cm) was observed under T_7 (50% N through Vermi-compost + FYM + 50% RDF + Inoculum), indicating that a balanced integration of organic (vermi-compost and FYM) and inorganic (RDF) nutrient sources significantly promotes vegetative growth. The control treatment under poplar (*T_1*) recorded a plant height of 45.30 cm, while the Open Control (T_9), which was cultivated outside the influence of poplar, had the lowest height (39.56 cm) (Table 2). This suggests that the microclimatic changes and root competition under poplar may limit height unless supplemented with adequate nutrients. Treatments involving combined organic and inorganic sources (T_2, T_5, T_7, and T_8) consistently outperformed single nutrient applications, highlighting the synergistic effect of nutrient integration.

The application of integrated organic and inorganic fertilizers significantly influenced the plant height of wheat under the poplar-based agroforestry system. Among the treatments, T_8 (100% NPK + FYM + VC) exhibited the maximum plant height of 96.77 cm, which was statistically at par with T4 (95.53 cm) but significantly taller than all other treatments. This enhanced growth can be attributed to the combined availability of quick-releasing nutrients from inorganic sources and the slow-releasing nutrients from organic amendments like FYM and VC, which improve soil health and nutrient retention (Kumar *et al.*, 2021; Singh *et al.*, 2022) [12, 25]. Organic matter improves soil structure, promotes root proliferation, and enhances nutrient and water absorption, contributing to increased plant height (Iqtidar *et al.*, 2006; Zeidan and Kramany, 2001) [9, 30]. Furthermore, the synergistic effect of organic and inorganic sources enhances nitrogen availability, crucial for cell division and elongation, resulting in taller plants (Sharma *et al.*, 2018) [21].

Number of Pods per Plant
Maximum pods per plant (37.66) were observed in T_7, followed by T_2 (35.66) and T_8 (35.65). The application of both organic (vermi-compost and FYM) and inorganic fertilizers, along with microbial inoculation, enhanced pod formation, likely due to improved soil fertility and nutrient availability. The open Control (T_9) had the lowest number of pods (23.00), showing that exposure to Poplar alleys alone is not a limiting factor; instead, nutrient supplementation is crucial.

Number of Grains per Pod
The number of grains per pod was significantly higher in T_7 (6.66), reflecting the efficiency of balanced nutrition in supporting reproductive development. Treatments with solely organic inputs (T_3, T_4) had fewer grains (4.00 grains per pod), suggesting that organic sources alone may not meet peak reproductive demands. Control treatments (*T_1* and *T_9*) had the lowest grain counts, reaffirming that Poplar-based competition and lack of nutrient inputs limit reproductive efficiency.

Pod Length (cm) and test weight

The pod length (13.60 cm) and test weight (100 grain weight) (39.13 g) of French bean was found best in T_7, indicating that balanced nutrient application positively influences pod development. The lowest pod length (10.31 cm) and test weight (26.16 g) was reported in open control (T_9), further supporting the role of nutrient enhancement under poplar-induced stress and demonstrating the positive influence of combined organic and inorganic nutrition.

Test weight (1000 grain weight) of wheat grains, although statistically non-significant across treatments, was highest under T_8 (43.17 g) and lowest in the control plot (39.43 g). Li *et al*. (2020) [15] highlighted that appropriate nitrogen management improved post-anthesis N uptake and remobilization, thereby increasing grain weight and density in rice. The integrated application of nutrients enhances soil moisture retention and nutrient supply, contributing to denser and healthier grains (Singh *et al*., 2020) [22, 24].

Grain Yield (q ha⁻¹)

The highest grain yield of french bean (25.50 q ha^{-1}) was observed in T_7, significantly higher than the other treatments (Table 2). While in case of wheat maximum grain yield (37.14 q/ha) was recorded in T_8, followed by T_4 (37.10 q/ha), which were both superior to all other treatments (Table 3). The enhanced yield in T_8 treatment (50% N through NPK fertilizer + 25% N through FYM @ 6 t ha^{-1} + 25% N through vermicompost @ 2 t ha^{-1}) is attributed to the integrated application of inorganic fertilizers, which provide an immediate nutrient boost, and organic manures, which ensure a slow and sustained release of nutrients. This combination not only enhances nutrient use efficiency but also improves soil physical properties, microbial activity, and organic carbon content. Kumar *et al*. (2021) [12] demonstrated that combining organic and inorganic sources increased nitrogen use efficiency, contributing to better biomass accumulation and grain filling. Such synergistic effects of nutrient sources strengthen soil fertility over time and support sustainable crop productivity.

This finding is consistent with Yadhuvanshi (2003) [29], who reported that integrated nutrient management significantly boosts grain yield in wheat. This highlights the effectiveness of synergistic nutrient release from organic and inorganic sources, along with microbial inoculation. Solely organic treatments in French bean (T_3 and T_4) recorded moderate yields (21.81 q ha^{-1} and 21.04 q ha^{-1}), while control treatments showed the least productivity, indicating nutrient deficiency and competitive stress from poplar roots.

Straw Yield (q ha⁻¹)

Straw yield in french bean followed a trend similar to grain yield, with T_7 producing the maximum (29.53 q ha^{-1}). The lowest straw yield was observed in open control (T_9) (26.00 q ha^{-1}), reflecting the poor growth conditions in the absence of nutrient supplementation.

In wheat, treatment T_8 (50% N through NPK fertilizer + 25% N through FYM @ 6 t ha^{-1} + 25% N through vermicompost @ 2 t ha^{-1}) achieved the highest straw yield (65.17 q ha^{-1}), significantly higher than other treatments. The boost in straw yield can be attributed to enhanced vegetative growth driven by improved nutrient availability and soil health improvements due to organic matter inputs. Choudhary *et al*. (2018) [3-4] reported that integrated nutrient management in wheat increased tiller number, leaf area index, and straw yield by improving soil microbial activity and nutrient cycling. Yadav *et al*. (2020) [28] also found that combined application of FYM and vermicompost with chemical fertilizers enhanced soil moisture retention and root biomass, resulting in vigorous vegetative growth and higher straw production.

Biological Yield (q ha⁻¹)

The biological yield was highest under T_7 (55.03 q ha^{-1}), suggesting enhanced biomass accumulation due to optimal nutrient availability. Treatments with only organic inputs (T_3, T_4) were still effective but lagged behind the integrated treatments, indicating slower nutrient mineralization.

After harvest of the wheat crop, total biomass production was highest in treatment T_8 (50% N through NPK fertilizer + 25% N through FYM @ 6 t ha^{-1} + 25% N through VC @ 2 t ha^{-1}), recording 102.31 q ha^{-1}. This improvement is attributed to the combined effect of organic and inorganic nutrients, which enhance both grain and straw production. Organic amendments improve soil porosity, water-holding capacity, and microbial activity, while inorganic fertilizers supply readily available macro-nutrients essential for vigorous vegetative and reproductive growth. Kumar *et al*. (2021) [12] found that integrated nutrient management significantly enhanced wheat biomass by improving nutrient synchronization, soil enzymatic activity, and microbial biomass carbon. Mandal *et al*. (2019) [17] observed that organic manures improved soil aggregation and root proliferation, which enhanced nutrient uptake and water absorption, contributing to higher total dry matter production. Likewise, Patel *et al*. (2022) reported that combining FYM and vermicompost with NPK increased chlorophyll content, root volume, and leaf area index, leading to better photosynthetic efficiency and overall biomass accumulation.

Harvest Index (%)

The harvest index (HI), representing the efficiency of biomass conversion into grain yield, was maximized in T_7 (46.33%), which had the most balanced input of nutrients. Lower HI values in T_1 (41.36%) and T_9 (40.59%) imply poor biomass partitioning towards economic yield, mainly due to nutrient constraints.

The harvest index (HI), reflecting the efficiency of the plant in converting biomass into economic yield, was highest in T_8 (36.29). This indicates optimal partitioning of assimilates towards grain production under integrated nutrient management. The balanced nutrition from organic and inorganic sources enhances photosynthetic efficiency, reduces stress, and ensures better translocation of nutrients towards grain filling (Kumar *et al*., 2017; Singh *et al*., 2020) [13, 21]. The improvement in highlights the role of nutrient synchronization in enhancing the reproductive efficiency of wheat.

Table 3: Effect of conjoint use of organic and inorganic sources of nutrient on wheat growth, yield, yield attributes and harvest index

Treatment	Plant height (cm)	Spike length (cm)	No. of grains/ear	Test weight (g)	Grain yield (q/ha)	Straw yield (q/ha)	Biological yield (q/ha)	Harvest index
T_1	82.50	9.32	46.00	41.03	30.98	57.46	88.45	35.02
T_2	86.37	9.75	47.67	41.76	36.00	63.53	99.53	36.16
T_3	84.10	9.55	47.33	41.46	32.00	58.00	90.00	35.55
T_4	95.53	10.32	49.67	42.57	37.10	65.15	102.26	36.28
T_5	87.33	9.95	47.67	41.93	36.05	64.98	101.03	35.68
T_6	88.30	10.22	48.67	42.43	37.04	65.13	102.17	36.25
T_7	87.33	10.05	48.33	42.17	36.68	65.05	101.73	36.05
T_8	96.77	10.34	50.00	43.17	37.14	65.17	102.31	36.29
T_9	81.07	9.24	45.33	39.43	30.97	57.66	88.63	34.94
SEm±	1.46	0.09	0.87	0.67	0.33	0.73	0.90	0.28
C.D. (p= 0.05)	4.44	0.28	2.65	NS	1.01	2.23	2.72	0.85

Spike Length

The length of wheat spikes showed significant variation across different nutrient management practices. Treatment T_8 recorded the longest spike length (10.34 cm), followed by T_6 (10.22 cm) and T_4 (10.32 cm). The extended spike length under T_8 is likely due to better nutrient uptake and balanced nutrient availability throughout the crop growth period, which supports more robust vegetative growth and spike development (Kumar *et al*., 2019; Afzal *et al*., 2005) [11, 1]. Organic amendments are known to enhance soil microbial activity, improving phosphorus availability, which is critical for spike development (Gupta *et al*., 2020) [7]. These findings are consistent with earlier studies demonstrating that integrated nutrient management boosts spike length and grain setting (Mandal *et al*., 2018) [18].

Number of Grains per Ear

The conjoint application of organic and inorganic nutrients significantly influenced the number of grains per ear. Treatment T_8 showed the highest number of grains per ear (50.00), which was superior to all other treatments. The enhanced number of grains per ear under T_8 can be attributed to better spike length, improved pollination, and grain filling due to a continuous and balanced supply of nutrients (Hossain *et al*., 2002; Metho *et al*., 1997) [8, 19].

Conclusion

The integrated application of organic and inorganic fertilizers (T_8: 100% NPK + FYM + VC) demonstrated superior performance in terms of growth, yield attributes, and overall productivity of wheat under a poplar-based agroforestry system. The results suggest that integrated nutrient management enhances soil health, optimizes nutrient availability, and improves plant growth, which collectively contributes to higher yields. These findings are consistent with sustainable intensification strategies aimed at maximizing crop output while maintaining soil health in agroforestry systems**.**

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