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Improving Nitrogen Use Efficiency and Yields of Potato through Integrated Use of Nitrogen Fertilizer and Organic Manures under Irrigated Condition in Nepal

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Abstract

Optimization of nitrogen rate in combination with organic manure could improve nitrogen use efficiency and potato yield. This research was conducted in National Potato Research Program (NPRP), Lalitpur, Nepal for two consecutive years (2022-2023) to determine the optimum combination of N fertilizer across different rates of manures (farmyard manure (FYM) and poultry manure (PM)) to improve yield of potato (cv. Janakdev) under irrigated conditions. Treatments included two factors, where organic manures, both FYM and PM applied at three rates (10, 20 and 30 t/ha) and N applied at three rates (50, 100 and 150 kg/ha). Phosphorus and potassium fertilizers were applied from MOP and DAP as a basal during planting and N was applied from urea in two splits as top and side dressing. Results show that nitrogen and manure had significant interaction effects on tuber yields and nitrogen use efficiency. The highest yield (26.58 t/ha), agronomic efficiency (54.4 kg tuber/kg N) and apparent recovery efficiency of N (50.5%) was obtained from the treatment where FYM and N applied at 30t/ha and 100 Kg N/ha, respectively. Similarly, this treatment also improved soil organic matter. These results suggest that the highest rate of FYM (30t/ha) with 100 kg N/ha could help to achieve higher tuber yield and improve nutrient use efficiencies and soil organic matter.

Keywords: Farmyard manure, Nitrogen use efficiency, Nitrogen harvest index, Tuber yield, Nutrient interaction

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Introduction

Potato (*Solanum tuberosum*) is an emerging commercial crop in Nepal and plays a critical role in agriculture economy. It is cultivated across all geographical regions (Adhikari et.al., 2023). Its cultivation is reported in 77 districts of Nepal from the southern terai at an altitude of 100m above sea level to the northern mountains as high as 4000msl (AITC, 2024). According to Subedi (2021), the total potato cultivated area is 19.2% in high hills, 43.3% in mid-hills and 37.4% terai. In Nepal, its production, area of cultivation and productivity is 3,487,816 mt, 203,812 ha and 17.11mt/ha, respectively (MoALD, 2024). Potatoes are grown both for food and nutrition security ensuring income generation and combat poverty. Among several other food sources, the potato is cultivated widely, and it contributes substantially to combat poverty, hunger and malnutrition, particularly in developing countries (Devaux*et al.,* 2021). Potatoes are used as a subsidiary food as a part of vegetables in Terai region of Nepal whereas it is a staple food in Hill and Mountain regions (Krishi Suchana, 2020).

Potato is a nutrient exhaustive crop among the other crops cultivated in Nepal (Vista et al., 2022). Fertilizer applications help to increase the tuber size and weight and reduce the number of non-marketable tubers (Oliveria et al., 2020), thus, improve the crop productivity. In Nepal, most farmers use a high number of organic inputs such as farmyard manure (FYM) and compost as a source of plant nutrients, particularly across the mid hills subsistence upland farming system (Sharma et al., 2022). Besides FYM, poultry manure, goat manure, mustard cake are other important organic sources of nutrients to plants (Subedi et al., 2022). However, commercial farmers apply a substantial amount of fertilizers. It is reported that the use efficiency of the applied fertilizers is very low.The global average crop NUE average is estimated to be about 55%, meaning that about 45% of the applied N may be lost to the environment (Valenzuela, 2024). To increase the efficiency of applied nutrients, it is important to improve manure and fertilizer management practices including optimizing fertilizer rates. Improving nitrogen use efficiency depends on crop and soil management practices. Nitrogen use efficiency can be improved by proper adoption of 4Rs (right source, right rate, right time and right method) of nutrient stewardship approach and proper use of organic manures and amending problem soils (soil acidity).

Optimizing N rate increases crop vigor, increases leaf area index, produces a large tuber size as well as increases no of numbers. Cultivation of potato yielding about 25-30 t/ha tubers removes 120-140 kg N/ha (Dua, 2013). However, the application of nutrients beyond plant demand can increase losses and reduce nutrient use efficiency. Over application of fertilizers, especially inorganic fertilizers, could slow the growth of tubers, which have a watery texture and poor cooking quality (Sandhu & Sandhu, 2023). Moreover, intensified nitrogen fertilization decreased the content of dry matter and starch in potato tubers (Margus et al., 2022). Moreover, it increases the nitrogen content in dry matter and in non-starch dry substance of the potato tubers. Plants with high nitrogen have dense foliage that is sensitive to blight and delays the initiation and maturation of tubers. Excess N supply in latter in the season can delay maturity of the tubers and result in poor skin set, which harms the tuber quality and storage properties (Mikkelsen, 2006).

Increasing nitrogen use efficiency and crop yields depends on soil fertility and application of organic manures. Organic manures contain both macro and micronutrients; thus, contributes significantly to increase crop yields, and soil fertility. In Nepal, organic manures are applied at 15-30t/ha depending upon availability. The government of Nepal has recommended fertilizers at 100kgN/ha, 100kg P_2O_5/ha, and 60kgK_2O/ha together with manures at 20t/ha. However, most farmers do not apply fertilizers at recommended rates, rather their fertilizer application is imbalanced, and they apply them haphazardly. Due to poor extension services, farmers are not aware of recommended fertilizers and application methods. Farmers do not know the fertility status of their own field. Considering the importance of integrated use of organic manures and inorganic fertilizers, the government must conduct programs that include promotion of organic manure and compost, green manuring, balanced use of chemical fertilizers, soil-testing services, farmers' field school regarding integrated plant-nutrient system, distribution of rhizobium inoculation packets, and other trainings and demonstrations (Pandey et al., 2018).

Organic manures contain balanced nutrients; it improves plant's nutrient uptake. Shafeeva et al. (2021) reported that application of poultry manure (PM) at 30 t/ha supplies 48 kg of nitrogen, 45 kg of phosphorus, and 24 kg of potassium to soils. Moreover, additional benefits could be achieved if supplemental N fertilizers applied together with organic manures, which not only increase tuber yield, but also improve soil fertility (Ayyildiz, 2021). According to Timilsina et al., (2024), applying nitrogen at the rate of 75 kg/ha, combined with 20 t/ha farmyard manure produced the highest tuber yield and farm profit in Kaski district, Nepal. Bhujel et al., (2021) affirmed that combining inorganic fertilizer and organic manure showed significant effect on yield components and potato yields. Sai and Paswan, (2024) suggested that potato farmers in Bajhang would benefit significantly from adopting KhumalSeto or Bajhang Local varieties with 150% of recommended fertilizer rates to achieve higher yields and profits. Lama et al (2016)., recommended the combination of 150 kg Nitrogen/ha and 60 kg potassium/ha to obtain the highest tuber yield of Kufri Jyoti (30.22 t/ha). Karkee and Bishwokarma (2023) in their study in Pyuthan stated that the application of organic manures led to an increase in soil properties such as organic carbon, nitrogen, phosphorus, and potassium. They also stated that application of recommended nitrogen as 50% via organic manures like poultry manures, FYM, and goat and 50% N via urea can enhance potato yield while also positively affecting soil properties.

In Nepal, Farmers often integrate their crop husbandry with the rearing of cattle, poultry, goats, and other domestic animals, and the waste from these are utilized in potato fields. The inclusion of these manures has maintained productivity by improving soil fertility status. However, research studies on the optimum rates of organic manure and N level, particularly to see whether organic manures interact with inorganic nitrogen are limited. Therefore, this study was conducted to determine the nitrogen use efficiency and tuber yield across different levels of organic manures and inorganic N with following specific objectives.

- Determine the N and organic manure interaction on N uptake and nitrogen use efficiency.
- Determine optimum rate of N and organic manures for increasing potato yield and farm profit.

Materials and Methods

Study Area

The study was conducted in the seed production block (Hattiban) of National Potato Research Program (NPRP), Khumaltar, Lalitpur for two consecutive years(2022 and 2023). It is in central Nepal (longitude of 27^0 38' 54.6" N and latitude of $85^0$19' 30.9" E) at 1350 meters above sea level with sub-tropical climate (NPRP, 2018). The soil texture of the study site is silty loam with pH of 6.35 and organic matter of 1.35%. The total nitrogen, available phosphorus and available potassium contents were 0.08%, 169.25 kg/ha and 176.18 kg/ha respectively. The available boron and available zinc were 2 ppm and 9.13 ppm, respectively (Table 1).

Table 1. Soil physicochemical properties of study site, Khumaltar, Lalitpur, Nepal

Parameters	Value	Analysis technique
Total Nitrogen (%)	0.08	Kjeldhal distillation unit (Bremner,1965)
Available phosphorous (kg/ha)	169.25	Modified Olsen bicarbonate method (Watanabe & Olsen, 1965)
Available potassium (kg/ha)	176.18	Ammonium acetate extraction method (Pratt, 1965)
Soil organic matter (%)	1.35	Wet digestion method (Walkley& Black, 1934)
Soil pH (w/w)	6.35	Digital pH meter

Experimental design and treatments

Experimental treatments included two factors—organic manures (farmyard manure and poultry manure) and inorganic nitrogen fertilizers. For organic manures there were six treatments from the combination of two sources and three rates (10, 20 and 30 mt/ha), while three treatments for nitrogen fertilizers (50, 100, and 150 kg/ha), altogether 18 treatments. These treatments were arranged in a randomized complete block design with three replications and experiment was conducted for two consecutive years (2022-2023).

Crop management

The tuber (variety: Janakdev) was planted at the spacing of 60 cm x 25 cm following a ridge planting method in each plot (7.2 m^2.). All the cultural practices were followed as per the recommendation by NPRP. Recommendation doses of fertilizers for potatoes were 100:100:60 kg N, P_2O_5, andK_2O/ha and FYM20t/ha. Phosphorus and potassium were applied through DAP and muriate of Potash at the time of planting and urea was applied in splits as top and side dressing. In the first year, it was planted on 1st February 2022 and harvested on 25 May 2022. In the second year, it was planted on 8 February 2023 and harvested on 1 June 2023. All the crop management practices including irrigation, pest and disease control measures were applied as and when necessary following NARC's recommendations.

For the nitrogen, 50% of the total amount (as per treatment) was applied as basal and remaining 50% as top dressing after 30 days of planting. The source of nitrogen was urea (46% N). Irrigation was applied every 15 days. The rest of the agronomic package of practices was adopted as per crop requirement. Earthing up and weeding was done after 30 days after planting and one more weeding was done after 50 days of planting. Plant protection measures were used as per standard recommendations in this region for potato crop to control diseases and insects at the right time. Organic manures were applied as basal fertilizers and the amount as per treatments. The nutrient contents of FYM and poultry manure is given in Table 2.

Table 2. Nutrient Content of Poultry and Farm yard Manure.

	PM		FYM	
N%	0.99	0.99kg Nin 100kg	0.722	(0.72kgN in 100kg FYM
P_2O_5%	0.786	0.786 kg P in 100kg	0.432	0.432 kg in 100kg
K_2O%	0.668	0.668 kg in 100 kg	0.72	0.72 kg in 100 kg
OM %	49.2		49.8	
pH %	8.367		7.56	

Harvesting and parameters recording

Data on germination, vigor, ground cover and uniformity were recorded at 30, 45 and 60 days after planting. Haulm pulling was done after 100 days of planting and harvesting after 120 days of planting. Before haulm pulling, number of stem per plant, plant height is taken into consideration. After harvest, tubers were categorized according to their weight and above 25-50 g tubers were taken as marketable tubers. Grading of tubers were followed by taking their weight according to the treatments. Tuber yield, numbers of tubers per ha and number of stems per plant were taken after harvesting the plants. Tuber yield was converted on a hectare basis.

Soil and Plant analysis

Composite soil samples were taken from each treatment to analyze nutrient status in soil after harvesting. The soil was analyzed for their total N, available phosphorus, available potassium, soil organic matter and soil pH.

For plant analysis, five sample plants were taken from each treatment, their haul and tubers weight were taken and samples were prepared for analysis of total N. Nitrogen use efficiency as agronomic efficiency, apparent nitrogen recovery, physiological efficiency and nitrogen harvest Index were calculated using following formula.

Nitrogen uptake by tuber and foliage: N uptake(kg/ha) = Dry Matter Yield (kg/ha)×N % content

Agronomic Efficiency (AE): To calculate Agronomic Efficiency of the treatments, potato tubers were harvested from both fertilized and control plots at the same maturity stage. Total tuber yield in kg/ha (or tons/ha. for all treatments were measured.

Agronomic Efficiency (AE, kg yield/kg N) = Yield increases (YN−Y0) due to N application (kg/ha.)

Amount of N applied (kg N/ha)

Where, YN is yield (kg/ha) from N applied plot and Y0 is yield from control plot

Apparent Nitrogen Recovery (ANR): The matured harvested plant biomass (haulms + tubers) from both fertilized and control plots were weighed before and after drying to get dry matter yield**. N**itrogen concentration (%) in the plant tissue was analyzed and total N uptake in kg/ha for all plots and total N uptake was calculated.

ANR (kg N uptake/kg N applied) = (Nitrogen uptake in fertilized plot) −(Nitrogen uptake in unfertilized plot) ×100

Amount of N applied (kg/ha.)

Physiological Efficiency: Physiological Efficiency was calculated by considering dry matter yield from fertilized and control plot (kg/ha) and nitrogen uptake by total plant (tuber and haulm) using the formula

Dry matter yield of fertilized crop−Dry matter yield of unfertilized crop

Nutrient uptake by fertilized crop−Nutrient uptake by unfertilized crop

Nitrogen Harvest Index (NHI) in potatoes: Nitrogen Harvest Index (NHI) in potatoes were calculated by considering nitrogen content of both tuber and haulm by using the formula

Nitrogen Harvest Index (NHI)= (Nitrogen uptake by tubers) ×100

Total nitrogen uptake by aboveground biomass

The economic analysis

The economic analysis was conducted using a partial budget/ cost-benefit analysis to assess the profitability of the treatments. The costs considered included inputs such as seeds, manures, fertilizers, pesticides, labor, machinery, land rent and transportation while returns were calculated based on market prices of the potato. Data on input use and yields were collected from field trials conducted in Khumaltar during 2022 and 2023. Input prices and output values were sourced from local market surveys and validated with expert consultations. All monetary values were converted to Nepalese rupee, and sensitivity analysis was performed to account for variability in input prices and yield levels. The analysis used the following economic indicators: cost of production, Net Return (NR), net benefits and Benefit-Cost Ratio (BCR). Descriptive statistics and comparative analysis were carried out using Microsoft Excel.

Data Analysis: Data were gathered using MS-Excel and ANOVA was done to see the significance level and means were separated by Ducan's Multiple Range Test (DMRT) at 5% level of significance using GenStat 2018 version**.**

Results and Discussion:

The response variables were affected by the combinations of organic manure rates (poultry manure and FYM) with inorganic nitrogen rates (Table 3). There was a significant effect of the combination in tuber yield, agronomic efficiency, vigor, uniformity, and ground cover. The rest of the variables were not affected by the treatments.

Table 3: F probability value of different factors and their interaction

Source of variation	Tuber Yield (t/ha)	Agronomic Efficiency	Apparent Nitrogen Recovery (%)	Physiological Efficiency	Nitrogen Harvest Index	Germination %	Vigor	Uniformity	Ground Cover	Plant Height	Number of Stem	Tuber number/ha
Manure	*	*	*	ns	ns	*	*	*	*	ns	ns	*
Nitrogen	*	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Year	*	*	*	ns	ns	ns	ns	ns	ns	ns	ns	*
Manure* Nitrogen	*	*	ns	ns	ns	ns	*	*	*	ns	ns	ns
Manure* year	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Nitrogen * year	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Manure* Nitrogen * year	ns	ns	ns	0.008	ns	ns	ns	ns	ns	ns	ns	ns

Note: ns=non significant, * =significant, t/ha= ton/hectare

Effect on total tuber yield and tuber number

Both manures and nitrogen rates and their interaction had significant effects on the potato yield. In case of main effect of manure and nitrogen rates, the highest tuber yield (26.58 t/ha) was obtained from 30t/ha FYM and nitrogen at 100kg/ha, respectively followed by (21.04 t/ha) from FYM 30t/ha and 150 Kg N/ha than the lowest yield (11.88t/ha) obtained from Poultry Manure at 30 t/ha and 50kg/ha. The yield from the field without fertilizers was 9.35t/ha. In case of poultry manure, the highest yield (19.35t/ha) was obtained from PM at 20 t/ha with the N at 100kg/ha.

Table 4: Combined analysis of two-year effects of different combinations of manure and Nitrogen rates on tuber yield and tuber number (2022 and 2023)

	Tuber yield (t/ha)				Tuber number/ha			
	Nitrogen(kg/ha)				Nitrogen(kg/ha)			
Manure (mt/ha)	50	100	150	mean	50	100	150	mean
FYM10	12.73d	14.74d	15.63cd	14.36	243704	306250	316204	288719
FYM20	15.30d	13.51d	16.13cd	14.98	325231	313426	317824	318827
FYM 30	15.14d	26.58a	21.04b	20.92	314120	342593	317130	324614
PM10	12.14d	13.62d	15.26cd	13.67	272222	288426	339120	299923
PM20	13.26d	19.35bc	12.46d	15.02	308102	302778	288426	299769
PM30	11.88d	13.08d	13.12d	12.69	243056	267361	246759	252392
Yield in response to nitrogen rates	13.41	16.81	15.61	15.28	284406	303472	304244	297374
F Probability (manure)				*				*
F Probability (rate)				*				ns
F Probability (year)				*				*
F Probability (Manure*Rate)				*				ns
F Probability (Manure*year)				ns				ns
F Probability (Rate*year)				ns				ns
F Probability (Manure*Rate*Year)				ns				ns
CV%				21.2				16.3
SEM								19827
Lsd				3.709				55924

Note: FYM, farmyard manure; PM, poultry manure; number following by FYM and PM represent the amount of manures applied at t/ha

Effect on Agronomic Efficiency and Agronomic Nitrogen Recovery (%)

Agronomic efficiency (54.4 kg tuber/kg N) from the treatment FYM 30t/ha and 100 Kg N/ha was found significantly greater than (7.35) from PM 30t/ha and 50kg/ha Nitrogen. It means an additional 54.4 kilograms of potato yield was obtained by adding nitrogen from the treatment FYM 30t/ha and 100 Kg/ha nitrogen than that from PM 30t/ha and 50kg/ha Nitrogen in potato. Also, the agronomic efficiency was found greater in the second year with FYM 10 t/ha.

Table 5: Combined analysis of two-year effect of different combinations of manure and Nitrogen rates on Agronomic Efficiency and Apparent Nitrogen Recovery (%) (2022 and 2023).

Manures (t/ha)	Agronomic Efficiency			
	N Rates(kg/ha)			
	50kg/ha	100	150kg/ha	Mean
FYM 10	27.7bcd	31.3b	28.3bc	29.1 ab
FYM20	30.6b	17.1bcde	23.1bcde	23.6 bc
FYM30	21.7bcde	54.4a	31.89b	36 a
PM10	18.7bcde	21.5bcde	23.7bcde	21.3 bc
PM20	15.8bcde	33.6b	8.9cde	19.4 c
PM30	7.3e	9.4cde	8.4de	8.4 d
Mean	20.3 b	27.9 a	20.7 b	23
F Probability (nitrogen)				*
F Probability (Manure)				*
F Probability (Manure*nitrogen)				*
F Probability (Nitrogen*year)				ns
F Probability (Manure* year)				*
F Probability (Manure*nitrogen*year)				ns
CV%				48.8
SEM				4.58
Lsd	Lsd			12.93

Note: FYM, farmyard manure; PM, poultry manure; number following by FYM and PM represent the amount of manures applied at t/ha.

In case of Apparent Nitrogen Recovery, there was no significant effect of either interaction. However, we have recovered 50.5% of the nitrogen with FYM 30t/ha + 100kg/ha Nitrogen in potato than in the combination PM @30 t/ha + Nitrogen 50kg/ha. In case of manure and nitrogen rates also, the highest Apparent Nitrogen Recovery is 35.71% obtained from FYM 30t/ha and 100kg/ha Nitrogen, respectively.

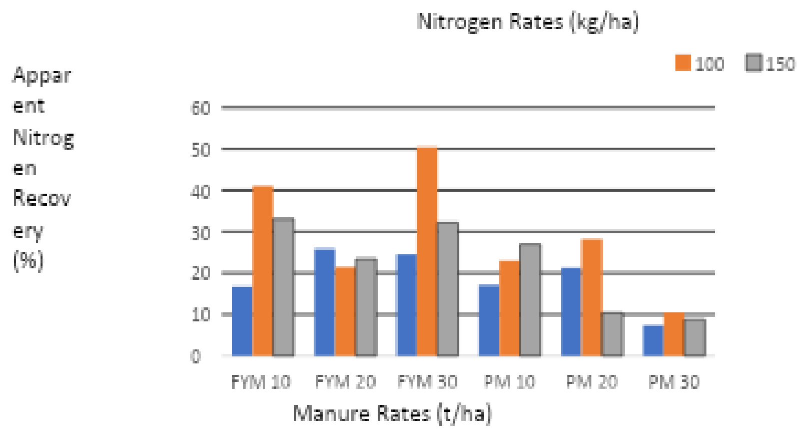
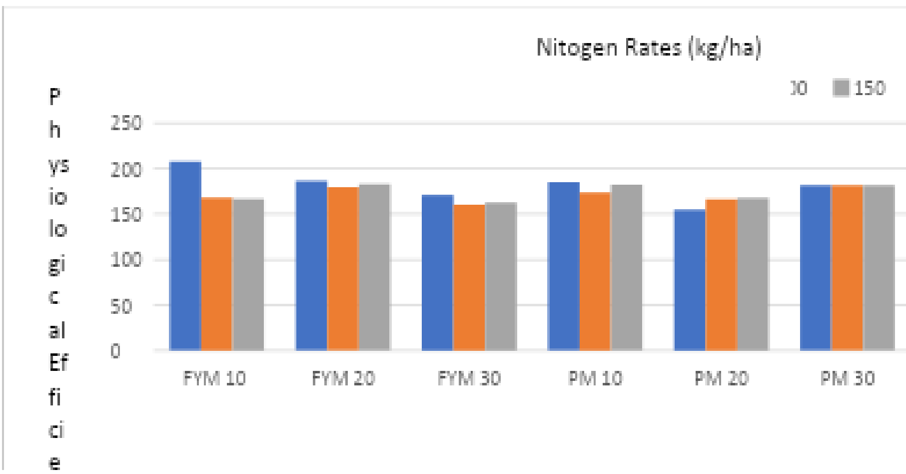


Fig. 1. Effect of combinations of manure and Nitrogen rates on Apparent Nitrogen Recovery (2022 and 2023).

Effect on Physiological Efficiency and Nitrogen Harvest Index

Physiological Efficiency was found higher (207.8) with the treatment FYM 10t/ha. and 50 Kg N/ha. followed by FYM 20t/ha. and 50 Kg N/ha. So, for every kilogram of nitrogen the plant absorbs from FYM 10t/ha and 50 Kg N/ha, it produces about 207.8 kilograms of biomass. The lowest PE was obtained from PM 20t/ha and 50 Kg N/ha.



Manure Rates (t/ha)

Fig. 2. Effect of combinations of manure and Nitrogen rates on Physiological Efficiency.

The highest Nitrogen Harvest Index 75.6 was obtained from FYM 30t/ha + 100 Kg N/ha which was at par with 75.5 from PM 10t/ha and 50 Kg N/ha. It means 75% of the total nitrogen in the plant is found in the tubers which seems very Efficient. The manure and nitrogen rates and their interaction do not have any significant effect on Nitrogen Harvest Index

Effect of different combinations of manure and Nitrogen rates on Vigor, Uniformity and Ground Cover:

The potato plants seem significantly vigorous, uniform with strong ground cover with the FYM application in either rate than the poultry manure.

Table 6. Combined analysis of two-year effects of different combinations of manure and Nitrogen rates on Vigor, Uniformity and Ground Cover (year 2022 and 2023

Manures (mt/ha)	Vigor (2022 and 2023),				uniformity (2022 and 2023),				Ground Cover (2022 and 2023),			
	Nitrogen (kg/ha)				Nitrogen (kg/ha)				Nitrogen (kg/ha)			
	50	100	150	mean	50	100	150	mean	50	100	150	Mean
FYM10	3.667ab	4a	4a	3.88	4.5a	4a	4.33ab	4.278	76.67ab	81.67a	78.33ab	78.89
FYM 20	4a	4a	3.667ab	3.88	4.167abc	4.167 abc	4.33ab	4.22	85.83a	78.33ab	80a	81.39
FYM30	3.667ab	3.91a	3.08c	3.55	4bc	3.9bc	3.5de	3.806	76.67ab	85a	70bc	77.22
PM10	3.33bc	3.33bc	3.33bc	3.33	3.83cd	4bc	3.83cd	3.889	63.33 cde	60.83def	66.67	63.61
PM20	3c	3c	3c	3	3.33ef	3.33ef	3f	3.22	58.33 defg	50gh	55efgh	54.44
PM30	3.33bc	3.33bc	3c	3	3.33ef	3.167ef	4bc	3.5	51.67fgh	48.33h	55efgh	51.67
mean	3.5	3.59	3.51	3.537	3.861	3.764	3.833	3.819	68.75	67.36	67.50	67.87
F Probability (Nitrogen)				*				*				*
F Probability (Manure)				*				*				*
F Probability (Manure*nitrogen)				*				*				ns
CV%				10				8.6				10.7
SEM												
LSD				0.41				0.37				8.33

Note: FYM, farmyard manure; PM, poultry manure; number following by FYM and PM represent the amount of manures applied at mt/ha

Effect on Germination, plant height and number of stems.

The Effect of different combinations of manure and nitrogen rates on germination, plant height and number of stems was found insignificant. However, the highest germination (97.06%) was from FYM 30t/ha and 100 Kg N/ha. The significantly highest germination (94.3%) was found from FYM 30t/ha but the response to nitrogen rates was non-significant and was from 150kg N/ha. It was also observed that there was no significant change on the number of stem and plant height of potato plants in response to the manure and nitrogen rates and their interaction.

Economic Analysis: The partial budget analysis provides the exhaustive sketch of total cost of production, total possible income, net benefits and benefit cost ratios as per different treatment combinations. The cost of production is increased in the combinations with higher manure and nitrogen rates. The net benefit (715135.5 NPR) was from FYM 30t/ha and 100 Kg N/ha with cost of production 348065 NPR and consequently the highest benefit-cost ratio of 2.05. This ratio means that for every 1 unit of cost (NPR), the treatment combination is expected to generate 2.05 units of benefit**.** Following this treatment, the next highest net benefits of NPR 491220.25 and B:C ratios of 1.40 were observed at the FYM 30t/ha and 150 Kg N/ha.

Table 7: Economic analysis of potato production with different treatments estimated for a hectare of land.

S.N.	Manure(t/ha)	N Rate(kg/ha)	Yield(t/ha)	total cost of production (NPR/ha)	total income (NPR/ha)	BC ratio
1	PM10	50	12.14	373249.3	485600	0.30
2	PM10	100	13.62	375564.5	544800	0.45
3	PM10	150	15.26	377879.8	610400	0.62
4	PM20	50	13.26	460749.3	530400	0.15
5	PM20	100	19.35	463064.5	774000	0.67
6	PM20	150	12.46	465379.8	498400	0.07
7	PM30	50	11.88	548249.3	475200	-0.13
8	PM30	100	13.08	550564.5	523200	-0.05
9	PM30	150	13.12	552879.8	524800	-0.05
10	FYM10	50	12.73	305749.3	509200	0.67
11	FYM10	100	14.74	308064.5	589600	0.91
12	FYM10	150	15.63	310379.8	625200	1.01
13	FYM20	50	15.3	325749.3	612000	0.88
14	FYM20	100	13.51	328064.5	540400	0.65
15	FYM20	150	16.13	330379.8	645200	0.95
16	FYM30	50	15.14	345749.3	605600	0.75
17	FYM30	100	26.58	348064.5	1063200	2.05
18	FYM30	150	21.04	350379.8	841600	1.40

Note: FYM, farmyard manure; PM, poultry manure; number following by FYM and PM represent the amount of manures applied at mt/ha

Soil nutrient status after the harvesting of the potato tubers.

The effect of manure rates was significant in soil organic matter only where the highest soil organic matter of (3.99%) was obtained from FYM 30 and lowest from PM10. The Nitrogen rate was insignificant to all the soil properties. In manure rates and nitrogen rates interaction, the soil organic matter (4.20%) from FYM 30t/ha and 100 Kg N/ha which was at par with (4.19%) from FYM 30t/ha and 150 Kg N/ha are significantly higher than those from all other combinations.

Discussion

Most of the yield attributes are significantly influenced by higher amounts of FYM. Based on the report of research works done in different parts of the world at different periods, Gelaye (2023) and Murat, (2024) recommended an average of 31t/ha of organic manure and 187.5/ha of nitrogen fertilizer as the ideal combinations for the optimum yield. Kumar et al., (2020) also recommended low inorganic nitrogen and higher amount organic manure. Lerna and Distefano (2024) suggested that farmyard manure (FYM) increased potato tuber yield by 35–82%, depending on fertilizer combinations while mineral fertilizer efficacy on the background without FYM was up to 28% higher based on the long-term experimental data. The nutrient content of FYM and poultry manure depends on method and composition of composting materials. Incorporating farmyard manure into the soil boosted both total and available nitrogen, phosphorus, and potassium levels in the soil.

The result from this two-year experiment recommended the application of 30 t/ha FYM and 100 kg/ha would give higher yield, Agronomic efficiency, Apparent Nitrogen recovery and Nitrogen harvest Index. Asghari et al., (2015) mentioned that the maximum average tuber weight and yield were obtained from 40 t of FYM and 200 kg of nitrogen fertilizer. Also, Bashir and Qureshi (2014) reported the highest tuber yield with the application of 180 kg N/ha and FYM 24t/ha. Prativa & Bhattarai, (2011) insisted the effect of integrated nutrient management on the vegetative growth, yield, quality and yield of potatoes with maximum yield of (27.9 tons/ha) from the integrated use of 75% recommended dose of NPK + 50 tons/ha farmyard manure +10 kg/ha phosphorus solubilizing bacteria (PSB). Combined use of organic and inorganic sources of nutrient could be attributed to better synchrony of nutrient availability to the crop, which was reflected in higher tuber yield and biomass production and also the higher nutrient use efficiency. US/IFAS (2024) recommends 220 kgN/ha to produce 33 t/ha of potato to provide crop N requirements.

The greater yield from higher FYM may be due to abundant availability of macro and micro-nutrients and more organic matter. This is supported by Rai et.al., (2024) in their research in potato in Bajhang. Chaudhary and Narwal (2005) also mentioned that at every successive dose of FYM, the total Zn, Fe, Cu and Mn content of the soil increased significantly in all depths. Dhaliwal et al., (2019) lined up with them and explained the higher micronutrient uptake found with combined organic and inorganic fertilizers. It is better at improving soil structure, microbial activity, and water holding capacity. In contrast, poultry manure is nutrient-dense, may have higher levels of salts and ammonia, has less organic matter and also can be more acidic and may burn plants if not properly composted before use. FYM is gentle and releases nutrients slowly offering long-term soil benefits and making it safer for direct application whereas poultry manure decomposes quickly and provides nutrients rapidly. So, for long-term soil health**,** FYM is generally the better option.

The soil organic matter (4.20%) from FYM 30t/ha and 100 Kg N/ha and (4.19%) from FYM 30t/ha and 150 Kg N/ha are significantly higher than that from all other combinations. Rasool et al., (2008) also lined up with the fact of increasing SOM with increasing FYM amount. This higher SOM consequently may have increased the tuber yield as SOM serves as a reservoir of essential nutrients, including nitrogen, phosphorus, sulfur and some micronutrients, released upon decomposition (Lindasy, 1979). Higher SOM also improves water holding and cation exchange capacity of soil and consequently provide nutrition to the plants. The organic sources can reduce the mining of soil nutrient and improve soil organic matter, humus and overall soil productivity

Conclusion

It was found that 30 t/ha of FYM with 100kg Nitrogen/ha of fertilizer in potato growing provide the highest tuber yield under irrigated conditions. The highest tuber yield from poultry manure was obtained amounting to 20 t/ha with Nitrogen 100kg/ha. The highest Agronomic Efficiency and Apparent Nitrogen Recovery was also obtained by the treatment FYM 30t/ha and 100 kgN/ha. Similarly, the highest Nitrogen Harvest Index was obtained from both FYM 30t/ha + 100kgN/ha and PM 10t/ha + 50 kg N/ha. The potato plants seem significantly vigorous, uniform with strong ground cover with the FYM application in either rate than the poultry manure. The findings from the above research strongly recommends the application of 30t/ha of FYM with100kg nitrogen/ha to get higher tuber yield and improve nutrient use efficiencies. Also, the combination of FYM 30t/ha and 100 Kg N/ha will be profitable because the benefits outweigh the costs significantly and the combination is economically viable. The results clearly indicated that there was balanced/ sufficient nutrient application from 30 t/ha of FYM with 100kg Nitrogen/ha aided in crop nutrient removal.

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