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NITROGEN FERTILIZATION STRATEGIES FOR FORAGE OAT GENOTYPES: AGRONOMIC PERFORMANCE, ENERGY AND NITROGEN USE EFFICIENCY, ECONOMIC ASSESSMENT AND DETERMINATION OF ECONOMICAL N FERTILIZER RATE

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SUMMARY

The response of different fodder oat (*Avena sativa* L.) genotypes to varying nitrogen levels was studied in a field experiment at Pusa, Bihar. Ten genotypes (HFO-1009, HFO-1013, HFO-1003, JO-08-37, SKO-244, OL-1977, OL-1980, Kent, OS-6 and OS-403) were accommodated in the main plots of the split plot design and three nitrogen levels (80, 100, and 120 kg/ha) were used in sub-plots. Results revealed that OS-403 produced the maximum plant height (163.3 cm), green forage yield (516.5 q/ha) and production efficiency in term of green forage yield (5.07 q/ha/day) among the genotypes. However, the genotype OL-1980 produced the maximum dry matter yield and production efficiency in terms of dry matter yield and crude protein yield among the genotypes. The maximum gross (Rs. 103309/ha) and net returns (Rs. 72153/ha) and B:C ratio (3.32) was noted with OS-403 which was at par with OL-1980. The highest nitrogen level (120 kg N/ha) resulted in the highest green fodder (441.3 q/ha), dry matter (128.5 q/ha) and crude protein yield (11.8 q/ha) which significantly higher than rest of the N levels. N application enhanced the gross (Rs. 88267/ha) and net returns (Rs. 56850/ha) and B:C ratio (2.81) up to 120 kg/ha which was notably higher over other levels. The N fertilizer rate for maximum green forage yield and economical optimum N fertilizer rate for fodder oat was found to be 140.2 and 138.5 kg/ha, respectively.

Key words: Genotypes, fodder oat, nitrogen use efficiency, economical N fertilizer rate, energy use efficiency

Oat (*Avena sativa* L.) is one of the important feed resource of the world (Ma *et al.,* 2022). It is cultivated in 13.9 million hectares of land worldwide (Singh *et al.*, 2017). In India, oats is a key cereal fodder crop that is grown in the *Rabi* season (Paul *et al.*, 2022a; Paul *et al.*, 2022b). Oats has short growth duration and produce high quality nutrient-rich succulent fodder and has the potential for good growth after cutting (Paul *et al.*, 2022a). Nitrogen is essential for both qualitative and quantitative gains in fodder production (Nanda and Nilanjaya, 2022). When nitrogen is administered to oat, it responds quickly and produces higher forage yield under ideal environmental conditions (Sarkar *et al.*, 2022). Nitrogen is required for fodder production because it impacts cell elongation, cell division and intercellular expansion. It is also critical for the early development of crop. Singh *et al.* (2002) discovered that applying 80 kg N ha^{-1} resulted in the greatest plant height and tiller count. According to Godara *et al.* (2016), increasing the nitrogen rate from 40 kg/ha to 120 kg/ha had a substantial effect on all growth indicators. Green fodder yield (GFY) and dry matter yield (DMY) rose proportionally to nitrogen application from 40 kg/ha to 120 kg/ha. Because nitrogen is an amino acid component, a lack of it in grains, cereal husks, and fodder crops can cause serious illnesses in humans and animals (Midha *et al.*, 2015). Because of the expanding animal population, demand for fodder rises throughout the busiest periods of the year. Hence, determining the optimal nitrogen dose for a desirable oat yield is critical for addressing the fodder shortage during winter months. Taking all of the aforementioned facts into account, the current study was designed to analyze the effect of varying nitrogen levels on the growth and production of fodder oat genotypes.

MATERIALS AND METHODS

During the *Rabi* season of 2022-23, the current trial was executed at the Cattle Farm, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar under AICRP on Forage Crops and Utilisation. Geographically, the test site is in the subtropical zone of the Indo-Gangetic Plains, next to the *Budhi Gandak* river. Ten genotypes (HFO-1009, HFO-1013, HFO-1003, JO-08-37, SKO-244, OL-1977, OL-1980, Kent, OS-6 and OS-403) were accommodated in the main plots of the split plot design and three nitrogen levels (80, 100 and 120 kg ha^{-1}) were allocated to sub-plots. The number of replications for this experiment was three. Seeds of the different genotypes were sown in line keeping row to row distance of 25 cm using a seed rate of 100 kg/ha on December 2, 2022. Prior to seeding, half of the nitrogen, phosphorous, and potassium were applied as a basal treatment. The rest amount of nitrogen was top dressed 21 days after sowing (DAS). Urea, DAP, and MOP were used as nitrogen, phosphorous, and potassium fertilizers, respectively. Other cultural operations were carried out in accordance with the standard set of procedures. When the fodder oat reached 50% flowering, it was harvested manually. Each net plot's crop stand was harvested and the green fodder yield was noted. 250g of green fodder from each plot was kept for determination of dry matter content to calculate the dry matter yield (DMY). The crude protein concentration was determined by multiplying the N content of fodder samples by 6.25. Crude protein yield (CPY) was calculated by multiplying CP% and DMY (Prajapati *et al.* 2023). The economic evaluation of forage oat production was done considering the cost of inputs from sowing to harvesting and prevailing market price of green fodder. Energy consumption was calculated based on use of different inputs as per their energy equivalents (Devasenapathy *et al.,* 2009). The calculation of energy output for the dry fodder produced involved multiplying the production amount by the corresponding energy equivalent. Similarly, the energy use indicators were also computed using the methodology provided by Mittal and Dhawan (1988) and Devasenapathy *et al.* (2009). Eco-efficiency was calculated by dividing the net returns with energy consumption as per Babu *et al.* (2020). The response of green forage yield to N fertilizer levels was fitted to quadratic equation ($Y= a + bX + cX^2$) in microsoft excel software with Y as green forage yield in q/ha, a as the intercept and b and c as regression co-efficients. Calculation of the economical N fertilizer rate was done as per Ali and Habib (2022) as follows:

$$\text{Economical N fertilizer rate (kg/ha)} = \frac{\text{Cost of N fertilizer per kg}}{\text{Price of green fodder per quintal}} \times \left(\frac{1}{2c}\right) - \left(\frac{b}{2c}\right)$$

Further, N fertilizer rate for maximum green forage yield was obtained as follows:

$$\text{N fertilizer rate for maximum yield (kg/ha)} = \frac{-b}{2c}$$

The nitrogen use efficiency indices like partial factor productivity of N fertilizer was calculated by dividing the DMY with quantity of fertilizer nitrogen applied (Singh *et al.* 2021). The nitrogen utilization efficiency (NutE) was calculated by dividing the DMY with nitrogen uptake (Nanda and Nilanjaya, 2022). The nitrogen fertilizer use efficiency was calculated by dividing the CPY with quantity of fertilizer nitrogen applied. Statistical analysis of data was done as per ANOVA for factorial experiment in randomized complete block design (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Growth, yield and productivity

Fodder oat genotypes caused significant variation in plant height, LSR, green forage yield, dry matter yield as well as their productivity (Table 1). The genotype OS-403 showed maximum plant height (163.3 cm), GFY (516.5 q/ha) and production efficiency of green forage (5.07 q/ha/day) which was markedly greater than all other genotypes except OL-1980 for GFY and its productivity. The lowest plant height, GFY and its productivity was recorded with SKO-244, Kent and HFO-1003, respectively. The genotype SKO-244 showed maximum LSR (0.31) which was at par with genotype OS-403, JO-08-37 and OL-1980. The lowest leaf: stem ratio was recorded with Kent and HFO-1003. The genotype OL-1980 recorded the maximum DMY (134.4 q/ha) which was which was markedly greater than all other genotypes except OS-403 (130.1 q/ha). The variation in dry matter yield in genotype was due to variatian in GFY and DM content (Table 1). The DM content varied from 25.2% in OS-403 to 33.7 in OS-6. Genotypes significantly affected the days to attend 50% flowering

TABLE 1
Effect of N levels on performance of promising genotypes of single cut oat

Treatments	Plant height (cm)	LSR	DM (%)	GFY (q/ha)	DMY (q/ha)	Days to 50F	Production efficiency (q/ha/day)		CP (%)	CPY (q/ha)
							GFY	DMY		
Genotypes										
HFO-1013	133.8	0.24	28.6	423.7	121.6	96.7	4.38	1.26	9.15	11.1
OS-6	126.7	0.22	33.7	377.3	127.8	94.0	4.01	1.36	9.26	11.8
OL-1977	132.6	0.24	27.4	401.4	110.5	95.0	4.23	1.16	9.28	10.3
OS-403	163.3	0.28	25.2	516.5	130.1	101.8	5.07	1.28	8.83	11.5
SKO-244	101.1	0.31	26.7	443.0	118.4	104.5	4.24	1.13	9.10	10.8
OL-1980	146.3	0.26	27.6	486.4	134.4	97.7	4.99	1.38	8.97	12.1
HFO-1009	134.0	0.23	28.7	429.1	123.1	97.8	4.39	1.26	8.84	10.9
Kent	124.0	0.21	32.7	351.6	115.3	97.2	3.62	1.19	9.21	10.6
JO-08-37	102.8	0.26	25.6	360.0	92.4	101.3	3.55	0.91	9.35	8.6
HFO-1003	127.6	0.21	26.5	356.5	94.6	101.7	3.51	0.93	8.91	8.5
C. D. (P=0.05)	7.5	0.06	1.72	53.3	20.4	1.5	0.54	0.21	0.35	1.9
N levels (kg/ha)										
80	122.4	0.23	26.9	382.6	102.1	99.0	3.87	1.03	8.95	9.1
100	130.6	0.25	28.6	419.7	119.8	98.7	4.25	1.22	9.14	10.9
120	134.6	0.25	29.2	441.3	128.5	98.7	4.48	1.31	9.18	11.8
C. D. (P=0.05)	3.9	0.01	0.26	15.6	5.6	NS	0.16	0.06	0.15	0.6

stage (Table 1) and it varied from 94.0 days with OS-6 to 104.5 days with SKO-244 which also influenced production efficiency. Genotypic variability in term of plant height, leaf: stem ratio, DMY and GFY was also observed by Sarkar *et al.* (2022). Similar findings were also observed by Satpal *et al.* (2018) and Kumar *et al.* (2023). In, general, increasing N dose from 80 kg to 120 kg increased the values of plant height, LSR, GFY, DMY, production efficiency in terms of GFY and DMY (Table 1). Applying 120 kg N/ha exhibited the highest plant height, LSR, GFY, DMY, production efficiency in terms of GFY and DMY which was markedly greater than rest of the N doses except for LSR where 100 kg and 120 kg recorded similar LSR. Increasing N levels from 80 kg to 120 kg significantly increased the DM content and the applicaton of 120 kg N/ha recorded the markedly greater DM content among N levels. Similar results were reported by Sarkar *et al.* (2022) who marked increase in plant height, leaf:stem ratio, GFY, DMY when N application was increased from 40 kg/ha to 120 kg/ha. Our findings corroborated the work of Godara *et al.* (2016) and Kumar *et al.* (2023).

Fodder quality

Different fodder oat genotypes significantly influenced the CP content and CP yield (Table 2). The highest CP content (9.35%) was found with JO-08-37 which was at par with OL-1977 (9.28%), OS-6 (9.26%), Kent (9.21%), HFO-1013 (9.15%), SKO-244 (9.10%). The highest CPY was found with OL-1980 (12.1 q/ha) that was comparable with OS-6 (11.8 q/ha), OS-403 (11.5 q/ha), HFO-1013 (11.1 q/ha), HFO-1009 (10.9 q/ha), SKO-244 (10.8 q/ha), Kent (10.6 q/ha) and OL-1977 (10.3 q/ha). Genotypic

TABLE 2
Effect of N levels on performance of promising genotypes of single cut oat.

Treatments	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio
Genotypes				
HFO-1013	31156	84741	53585	2.72
OS-6	31156	75457	44301	2.42
OL-1977	31156	80272	49116	2.57
OS-403	31156	103309	72153	3.32
SKO-244	31156	88593	57437	2.84
OL-1980	31156	97284	66128	3.12
HFO-1009	31156	85827	54671	2.75
Kent	31156	70321	39165	2.26
JO-08-37	31156	72000	40844	2.31
HFO-1003	31156	71309	40153	2.29
C. D. (P=0.05)	-	10661	10661	0.34
N levels (kg/ha)				
80	30895	76526	45631	2.48
100	31156	83941	52785	2.69
120	31417	88267	56850	2.81
C. D. (P=0.05)	-	3120	3120	0.10

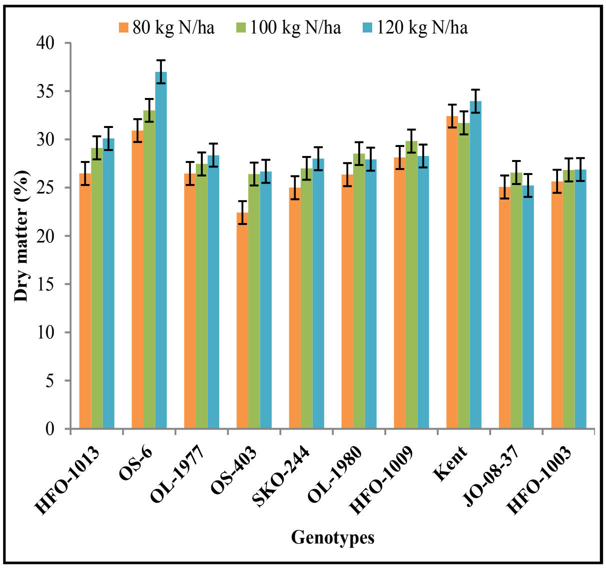

Fig. 1. Interaction effect of genotypes and N levels on dry matter content of fodder oat. Error bars indicate LSD values (p=0.05).

varition in CP content and yield has also been noted by Kumar *et al.* (2023). In, general, Increasing N dose from 80 kg to 120 kg increased the values of CP content and CP yield (Table 2). CP content (9.18 %) and CPY (11.8 q/ha) with 120 kg N/ha was markedly greater than other N levels except 100 kg N/ha for CP content which performed similar to application of 120 kg N/ha. Kumar *et al.* (2023) also increment in CP content and yield with increment in N fertilisation up to 120 kg/ha.

Production economics

Gross returns, net returns and B:C ratio were markedly affected by genotypes and nitrogen dose (Table 2). The maximum gross (Rs. 103309 ha^{-1}) and net returns (Rs. 72153 ha^{-1}) and B:C ratio (3.32) was noted with OS-403 which was at par with OL-1980. These findings corroborates with those of Kumar *et al.* (2023) who also found genotypic variation among fodder oat genotypes for production economics. Nitrogen application enhanced the gross (Rs. 88267 ha^{-1}) and net returns (Rs. 56850 ha^{-1}) and B:C ratio (2.81) up to 120 kg/ha which was markedly greater than other levels. Similar results were reported by Kumar *et al.* (2023).

Energy related parameters

Energy related parameters (energy output, net energy, energy use efficiency and EP) were markedly influenced by genotypes (Table 3). The highest energy output, net energy, energy use efficiency and EP was recorded with OL-1980 (168034 MJ/ha, 156246 MJ/ha, 14.2 and 1.14 kg MJ^{-1}) which was at par with genotypes HFO-1013, OS-6, OL-1977, OS-403, SKO-244, HFO-1009, Kent. However, OS-403 noted the highest eco-efficiency (Rs. 6.16/MJ) which was comparable to OL-1980. Energy output and net energy were markedly influenced by N levels (Table 3). The maximum energy output and net energy was recorded

TABLE 3

Energy related parameters and eco-efficiency as affected by nitrogen application to promising genotypes of single cut oat.

Treatments	Energy input (MJ/ha)	Energy output (MJ/ha)	Net energy (MJ/ha)	Energy use efficiency	Energy productivity (kg/MJ)	Eco-efficiency efficiency (Rs./MJ)
Genotypes						
HFO-1013	11789	151963	140174	12.9	1.03	4.54
OS-6	11789	159785	147996	13.5	1.08	3.77
OL-1977	11789	138083	126294	11.7	0.93	4.14
OS-403	11789	162684	150895	13.8	1.10	6.16
SKO-244	11789	147957	136168	12.5	1.00	4.88
OL-1980	11789	168034	156246	14.2	1.14	5.59
HFO-1009	11789	153925	142136	13.1	1.05	4.66
Kent	11789	144118	132330	12.2	0.98	3.30
JO-08-37	11789	115544	103755	9.8	0.79	3.46
HFO-1003	11789	118191	106402	10.0	0.80	3.37
C. D. (P=0.05)	-	25482	25482	2.2	0.17	0.90
N levels (kg/ha)						
80	10577	127646	117069	12.1	0.97	4.31
100	11789	149806	138018	12.7	1.02	4.48
120	13001	160633	147632	12.4	0.99	4.37
C. D. (P=0.05)	-	6974	6974	NS	NS	NS

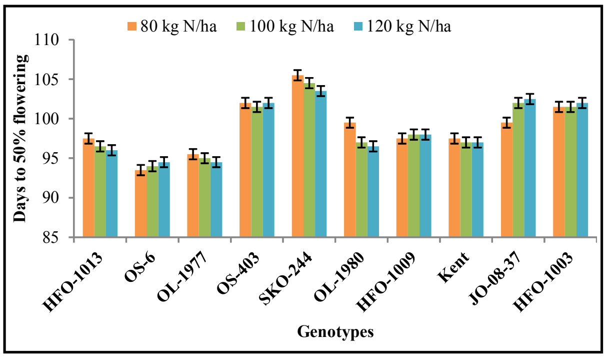

Fig. 2. Interaction effect of genotypes and N levels on days to 50% flowering of fodder oat. Error bars indicate LSD values (p=0.05).

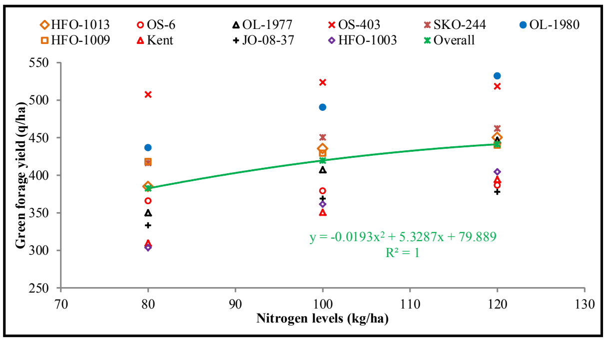

Fig. 3. Response of different fodder oat genotypes to varied N levels.

with application of 120 kg N/ha which was significantly higher than the lower levels. The percent increase in energy output and net energy with 120 kg N/ha was 28.8 and 26.1% than that of 80 kg N/ha which was primarily due to increased DMY with 120 kg N/ha.

Determination of economical N fertilizer rate

Optimal N fertilizer application is the need for maximizing the framers profit while minimizing the environmental hazards associated with excess N fertilization. Economical N fertilizer rate is the point where change in input cost equals change in value of the produce (Kyveryga *et al.,* 2007). The N fertilizer rate for maximum green forage yield (Nmax) and economical optimum N fertilizer rate (Neco) for fodder oat was found to be 140.21 and 138.52 kg/ha, respectively in the present investigation keeping the cost of N fertilizer per kg as Rs. 12.87 and price of green fodder per quintal as 200 using the response equation GFY = $-0.019x^2 + 5.328x + 79.88$ (Fig. 3).

Nitrogen uptake and use efficiency

Nitrogen uptake and its use efficiency indices (NUtE, PFPN and NFUE) were markedly influenced by genotypes (Figure 4). The highest nitrogen uptake was recorded with OL-1980 (193.2 kg ha^{-1}) which was markedly greater over rest of the genotypes whereas the genotype HFO-1003 recorded the lowest N uptake (135.9 kg/ha). Regarding NUtE, the genotype OS-403 and HFO-1009 recorded the highest value (70.9 kg DM/kg N uptake) which was comparable with the genotypes HFO-1003, SKO-244, HFO-1013 and OL-1980. The highest PFPN (131.9 kg DM/kg N applied) was noted with OL-1980 which was at par with OS-403, HFO-1009, Kent, SKO-244, OS-6 and HFO-1013. The highest NFUE (131.9 kg CPY/kg N applied) was noted with OL-1980 which was at par with OS-403, HFO-1009, Kent, SKO-244, OS-6, OL-1977 and HFO-1013. With increasing the N levels, the total N uptake increased significantly up to 120 kg N/ha. The highest NUtE (69.9 kg DM/kg N uptake) was noted with application of least amount of N (80 kg N ha^{-1}). Variation among genotypes with respect to nitrogen use efficiency indices like agronomic efficiency and utilization efficiency of forage pearl millet has been reported by Nanda and Nilanjaya (2022). PFPN and NFUE evidenced a decline with enhancement of N levels from 80 to 120 kg N/ha. The highest NutE of 69.9 kg DM/kg N uptake was found when 80 kg N/ha was applied which reduced to 68.3 kg DM/kg N uptake when 120 kg N/ha was applied. Similarly, the value of PFPN and NFUE declined from 127.6 kg DM/kg N applied and 11.4 kg CPY/kg N applied in 80 kg N/ha treated plots to 107.1 DM/kg N applied and 9.8 kg CPY/kg N applied in 120 kg N/ha treated plots, respectively. These findings are in line with those of Nanda and Nilanjaya (2022) in forage pearl millet where increase in N application

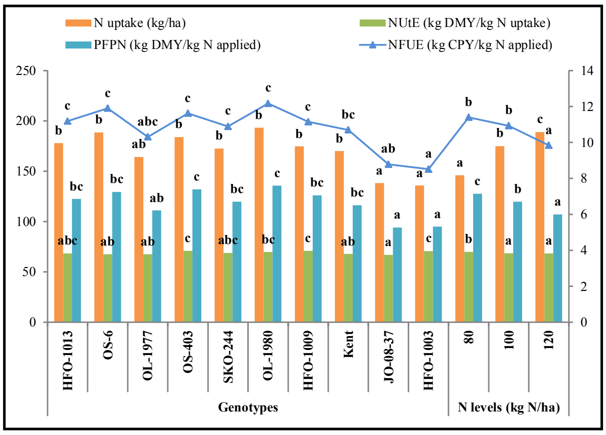

Fig. 4. Nitrogen uptake and its use efficiency by fodder oat as affected by genotypes and nitrogen application. Bars with at least a common letters are not significantly different from each other as per LSD test.

reduced agronomic efficiency and NUtE. Declining PFPN with enhancement in N dose in our study was because of smaller rate of increase in dry matter yield per incremental dose of N. Similar to our finding, Ma *et al.* (2022) also observed significantly higher nitrogen uptake with 120 kg N than 60 kg N/ha but with significantly lower NUE.

Relationship among different parameters

The pearson correlation co-efficient between different parameters presented in Fig. 5 showed that GFY was positively and significantly correlated with nitrogen uptake (r = 0.704), plant height (r = 0.669) and leaf: stem ratio (r = 0.643). Similarly, DMY was positively and significantly correlated with nitrogen uptake (r = 0.990) and green forage yield (r = 0.760), plant height (r = 0.596), dry matter content (r = 0.455). NFUE was positively and significantly correlated with PFPN (r = 0.990) and dry matter yield (r = 0.424). Similarly, NUtE was negatively and significantly correlated with CPC (-0.993) but was positively and significantly correlated with PFPN (r = 0.435). PFPN was positively and significantly correlated with DMY (0.381) and GFY (0.378) but was negatively and significantly correlated with CPC (r = 0.482).

CONCLUSION

On the basis of the results, it could be concluded that among genotypes, OS-403 was considerably superior for green fodder and dry matter yield compared to other genotypes, with the exception of OL-1980 for dry matter yield. The maximum green fodder, dry matter and crude protein yield were

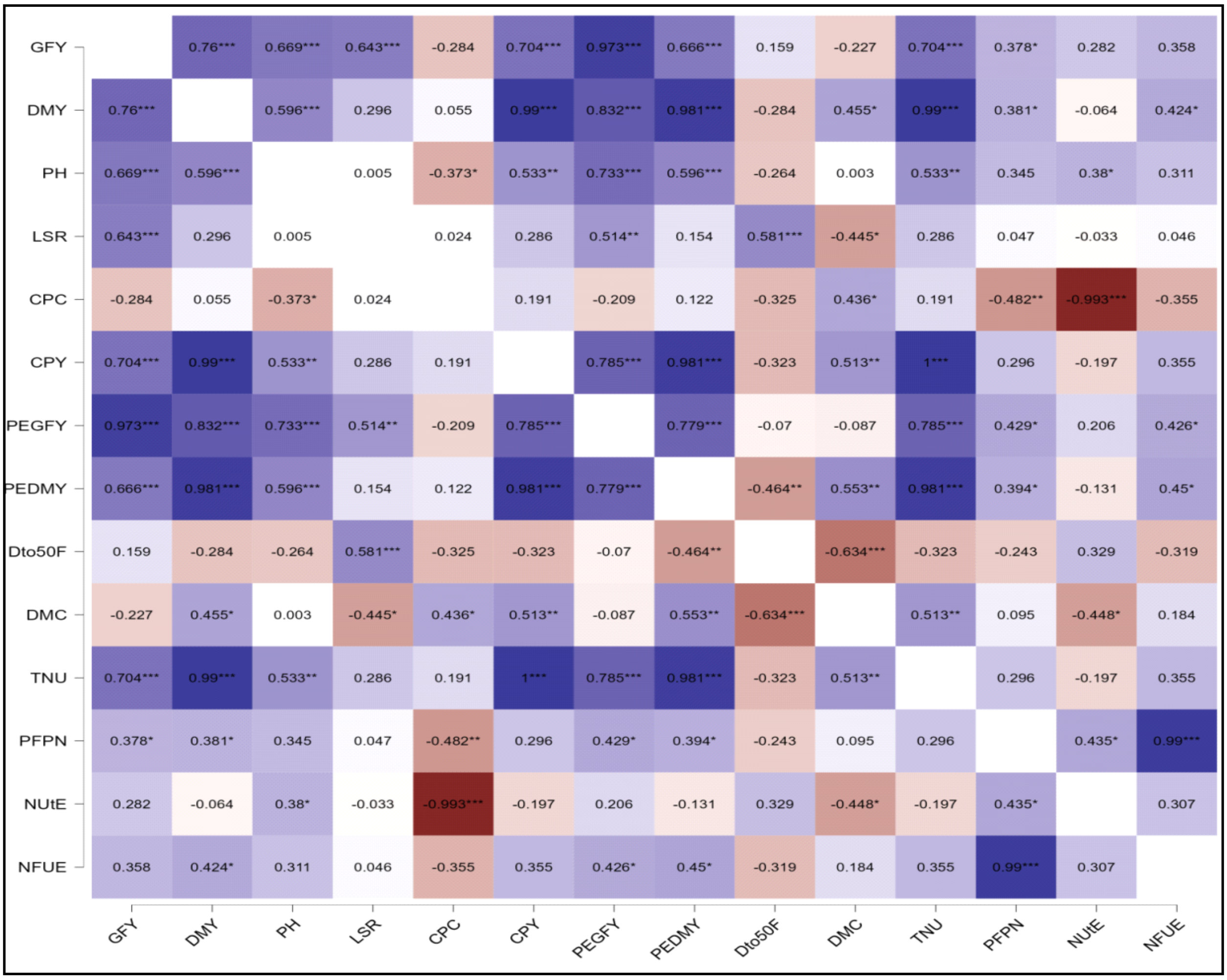

Fig. 5. Correlation among different parameters. GFY-green forage yield; DMY-dry matter yield; PH- plant height, LSR- leaf:stem ratio; CPC- crude protein content; CPY- crude protein yield; PEGFY- production efficiency in terms of GFY; PEDMY- production efficiency in terms of DMY; DMC- Dry matter content; TNU- nitrogen uptake; PFPN- partial factor productivity of N fertilizer; NUtE- Nitrogen utilization efficiency; NFUE- Nitrogen fertilizer use efficiency.

obtained with an application of 120 kg N/ha, which was much higher than the rest N levels. The N fertilizer rate for maximum green forage yield and economical optimum N fertilizer rate for fodder oat was found to be 140.2 and 138.5 kg/ha, respectively. So, it can be concluded that genotype OS-403 with 120 kg N/ha treatment produced higher quality and yield of fodder oat with higher with profit in North Bihar conditions.

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