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Dhruv S Desai
Senior Research Fellow, College of Veterinary Science and Animal husbandry, Kamdhenu University, Rajpur (Nava), Himmatnagar Gujarat, India

AK Saini
Assistant Research Scientist, Centre for Natural Resources Management, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India

Lalita H Saini
Assistant Research Scientist, Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India

Jil S Patel
Department of Agronomy, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India

Deepak D Chaudhary
Department of Agronomy, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India

Corresponding Author:
AK Saini
Assistant Research Scientist, Centre for Natural Resources Management, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India

Influence of split nitrogen application on nutrient uptake, quality and soil fertility in summer pearl millet

Dhruv S Desai, AK Saini, Lalita H Saini, Jil S Patel and Deepak D Chaudhary

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Abstract
A field experiment entitled "Influence of Split Nitrogen Application on Nutrient Uptake, Quality and Soil Fertility in Summer Pearl Millet (*Pennisetum glaucum* L.)" was conducted during summer 2024 at the Agronomy Instructional Farm, C. P. College of Agriculture, Sardarkrushhinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat. The study aimed to evaluate the effect of different nitrogen split schedules on grain quality, nutrient uptake, yield and post-harvest soil fertility status of summer pearl millet under North Gujarat conditions. The experiment was laid out in a Randomized Block Design with seven treatments replicated four times. Treatments consisted of different schedules of 100% and 75% recommended dose of nitrogen (RDN) applied in two, three and four splits at basal, tillering, earhead emergence and flowering stages. The results revealed that split application of nitrogen significantly influenced protein content, protein yield, grain and straw yield, nitrogen uptake and residual soil fertility status. Application of 100% RDN in four equal splits comprising 25% basal + 25% at tillering + 25% at earhead emergence + 25% at flowering (T_4) recorded significantly higher protein content (11.80%), protein yield (518 kg ha^{-1}), grain yield (4379 kg ha^{-1}), straw yield (7207 kg ha^{-1}), nitrogen uptake by grain (82.86 kg ha^{-1}) and straw (67.40 kg ha^{-1}), and available soil nitrogen after harvest (168.7 kg ha^{-1}) compared to most other treatments. The improvement in crop performance under T_4 was mainly attributed to continuous nitrogen availability, enhanced nitrogen use efficiency and better synchronization between nutrient supply and crop demand during critical growth stages. Treatments receiving 100% RDN in three splits also performed comparatively better than treatments receiving 75% RDN. Available phosphorus and potassium status in soil after harvest remained statistically unaffected by different nitrogen split schedules. Overall, the study indicated that application of 100% recommended nitrogen in four equal splits at basal, tillering, earhead emergence and flowering stages proved most effective for improving yield, quality, nutrient uptake and maintaining better soil fertility of summer pearl millet under North Gujarat conditions.

Keywords: Summer pearl millet, Split nitrogen application, Nitrogen uptake, Protein content, Soil fertility, Nitrogen use efficiency

Introduction
Pearl millet (*Pennisetum glaucum* L.) is an important cereal crop cultivated extensively in arid and semi-arid regions of India for food, feed and fodder purposes. The crop is well known for its adaptability to drought, high temperature and poor soil fertility conditions. Because of its hardy nature and efficient utilization of soil moisture, pearl millet has become an indispensable component of dryland and irrigated cropping systems in many parts of the country. Besides its agronomic importance, pearl millet grains possess high nutritional value with appreciable amounts of protein, carbohydrates, minerals and dietary fibre, making it an important crop for nutritional security. In recent years, cultivation of summer pearl millet has gained momentum in Gujarat due to the availability of irrigation facilities and adoption of intensive cropping systems. Summer cultivation offers several advantages such as higher solar radiation, better resource utilization, lower pest and disease incidence and stable productivity. Consequently, pearl millet has emerged as an economically viable crop in sequences like cotton–summer pearl millet, potato–summer pearl millet and tobacco–summer pearl millet.

However, sustaining higher productivity and maintaining soil fertility under intensive cultivation largely depend upon balanced and efficient nutrient management practices. Among the essential nutrients, nitrogen plays a pivotal role in crop growth, development and quality improvement. Nitrogen is an integral constituent of chlorophyll, amino acids, proteins, nucleic acids and several enzymes involved in metabolic activities of plants. Adequate nitrogen nutrition promotes vigorous vegetative growth, enhances photosynthetic activity and improves nutrient accumulation in plant tissues. Nitrogen also directly influences protein synthesis and thereby improves the nutritional quality of pearl millet grain and fodder. However, deficiency of nitrogen results in poor crop growth, reduced nutrient uptake and lower yield and quality.

Nitrogen use efficiency in pearl millet is often low because of substantial losses through leaching, volatilization and denitrification, especially in sandy and sandy loam soils of North Gujarat. Application of excessive nitrogen at a single time may not only reduce nutrient use efficiency but may also lead to environmental problems and deterioration of soil health. Therefore, split application of nitrogen according to crop demand at different growth stages is considered an effective approach for improving nutrient availability, enhancing uptake efficiency and minimizing nutrient losses. Split nitrogen application helps synchronize nutrient supply with crop requirement and forms an important component of efficient nutrient management practices.

Several researchers have reported beneficial effects of split nitrogen application on nutrient content, nutrient uptake, protein content and quality parameters of pearl millet and other cereal crops. Proper scheduling of nitrogen not only improves crop productivity but also influences residual soil fertility status after harvest. Maintenance of soil nutrient balance is essential for sustaining crop productivity under intensive cropping systems. Nevertheless, information regarding the effect of different nitrogen split schedules on nutrient uptake, quality and soil fertility status of summer pearl millet under North Gujarat conditions is limited.

Considering these aspects, the present investigation entitled “Influence of Split Nitrogen Application on Quality, Nutrient Uptake and Soil Fertility of Summer Pearl millet (*Pennisetum glaucum* L.)” was undertaken to study the effect of different nitrogen split applications on quality parameters, nitrogen content and uptake, and post-harvest soil fertility status of summer pearl millet under North Gujarat conditions.

Materials and Methods

A field experiment entitled “Influence of Split Nitrogen Application on Quality, Nutrient Uptake and Soil Fertility of Summer Pearl millet (*Pennisetum glaucum* L.)” was conducted during the summer season of 2024 at the Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat. The experimental site is geographically located at 24°19′ North latitude and 72°19′ East longitude with an elevation of 154.52 m above mean sea level and falls under the North Gujarat Agro-climatic Zone. The region experiences a semi-arid and sub-tropical climate characterized by hot summers and mild winters. The weather conditions during the crop season remained favourable for satisfactory crop growth and no rainfall was received during the experimental period. Prior to initiation of the experiment, composite soil samples were collected from 0–15 cm depth and analyzed for physico-chemical properties. The experimental soil was loamy sand in texture, low in organic carbon (0.28%) and available nitrogen (164.71 kg ha^{-1}), medium in available phosphorus (31.79 kg P_2O_5 ha^{-1}) and high in available potassium (273.37 kg K_2O ha^{-1}). The soil was slightly alkaline in reaction with pH 7.51 and EC 0.12 dS m^{-1}.

The experiment was laid out in a Randomized Block Design (RBD) with seven treatments replicated four times. Pearl millet hybrid GHB 1129 was used as the test crop. The gross plot size was 6.0 m × 3.6 m and net plot size was 4.5 m × 2.7 m with row spacing of 45 cm. The crop was sown manually on 6 March 2024 using a seed rate of 3.75 kg ha^{-1}. The treatments consisted of different schedules of split nitrogen application viz., T_1: 100% recommended dose of nitrogen (RDN) applied as 50% basal + 50% at tillering, T_2: 100% RDN applied as 25% basal + 37.5% at tillering + 37.5% at earhead emergence, T_3: 100% RDN applied as 25% basal + 25% at tillering + 50% at earhead emergence, T_4: 100% RDN applied as 25% basal + 25% at tillering + 25% at earhead emergence + 25% at flowering, T_5: 75% RDN applied as 50% basal + 50% at tillering, T_6: 75% RDN applied as 25% basal + 25% at tillering + 50% at earhead emergence and T_7: 75% RDN applied as 25% basal + 25% at tillering + 25% at earhead emergence + 25% at flowering. Nitrogen was applied through urea as per treatment schedule, while phosphorus @ 60 kg P_2O_5 ha^{-1} was applied uniformly as basal through single super phosphate to all treatments. The experimental field was prepared by ploughing followed by harrowing and planking to obtain proper tilth. Irrigations were applied uniformly to all treatments according to crop requirement and soil moisture condition. Recommended agronomic practices including thinning, hand weeding and inter culturing were followed throughout the crop growth period. The crop was harvested at physiological maturity and produce from each net plot was separately threshed, cleaned and recorded. For quality analysis, representative grain samples collected from each treatment were analyzed for nitrogen content by Micro-Kjeldahl’s method as described by Jackson (1973). Protein content in grain was calculated by multiplying nitrogen content with a factor of 6.25. Protein yield was worked out by multiplying protein content with grain yield. Nitrogen uptake by grain and straw was calculated by multiplying nitrogen content (%) with corresponding grain and straw yield.

Post-harvest soil samples were collected from each plot at 0–15 cm depth and analyzed for available nitrogen, phosphorus and potassium using standard analytical procedures. Available nitrogen was estimated by alkaline permanganate method, available phosphorus by Olsen’s method and available potassium by flame photometric method. The experimental data obtained for quality parameters, nutrient content, nutrient uptake and soil fertility status were statistically analyzed using analysis of variance technique appropriate to Randomized Block Design as suggested by Panse and Sukhatme (1967). The significance of treatment differences was tested by ‘F’ test and critical difference (CD) at 5% level of significance was used for comparison of treatment means.

Table 1: Effect of split application of nitrogen on protein content in grain and protein yield of summer pearl millet

Treatments	Protein content (%)	Protein yield (kg/ha)
Splits of nitrogen		
T_1 : 100% RDN (50% basal + 50% at tillering)	10.11	349
T2 : 100% RDN (25% basal + 37.5% at tillering + 37.5% earhead emergence)	10.25	367
T3 : 100% RDN (25% basal + 25% at tillering + 50% earhead emergence)	11.23	440
T4 : 100% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	11.80	518
T5 : 75% RDN (50% basal + 50% at tillering)	9.19	295
T6 : 75% RDN (25% basal + 25% at tillering + 50% earhead emergence)	10.05	334
T7 : 75% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	11.44	458
S.Em. ±	0.32	29
C.D. (P = 0.05)	0.96	85
C.V.%	6.11	12.4

Table 2: Effect of split application of nitrogen on grain and straw yield of summer pearl millet

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)
Splits of nitrogen		
T_1 : 100% RDN (50% basal + 50% at tillering)	3455	5828
T2 : 100% RDN (25% basal + 37.5% at tillering + 37.5% earhead emergence)	3546	6173
T3 : 100% RDN (25% basal + 25% at tillering + 50% earhead emergence)	3908	6440
T4 : 100% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	4379	7207
T5 : 75% RDN (50% basal + 50% at tillering)	3206	5401
T6 : 75% RDN (25% basal + 25% at tillering + 50% earhead emergence)	3327	5535
T7 : 75% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	4018	6822
S.Em.±	229	320
C.D. (P = 0.05)	681	950
C.V.%	12.4	10.3

Table 3: Effect of split application of nitrogen on N content in grain and straw of summer pearl millet

Treatments	N content (%)	
	Grain	Straw
Splits of nitrogen		
T_1 : 100% RDN (50% basal + 50% at tillering)	1.62	0.83
T2 : 100% RDN (25% basal + 37.5% at tillering + 37.5% earhead emergence)	1.64	0.84
T3 : 100% RDN (25% basal + 25% at tillering + 50% earhead emergence)	1.80	0.91
T4 : 100% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	1.89	0.93
T5 : 75% RDN (50% basal + 50% at tillering)	1.47	0.76
T6 : 75% RDN (25% basal + 25% at tillering + 50% earhead emergence)	1.61	0.84
T7 : 75% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	1.83	0.92
S.Em.±	0.05	0.03
C.D. (P = 0.05)	0.15	0.08
C.V.%	6.11	5.75

Table 4: Effect split application of nitrogen on available nutrients in soil after harvest of summer pearl millet

Treatments	Available nutrients in soil after harvest (kg/ha)		
	N	P2O5	K2O
Splits of nitrogen			
T_1 : 100% RDN (50% basal + 50% at tillering)	141.2	33.1	261.3
T2 : 100% RDN (25% basal + 37.5% at tillering + 37.5% earhead emergence)	142.9	33.8	259.3
T3 : 100% RDN (25% basal + 25% at tillering + 50% earhead emergence)	164.7	32.5	263.4
T4 : 100% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	168.7	37.9	280.7
T5 : 75% RDN (50% basal + 50% at tillering)	137.1	32.1	256.7
T6 : 75% RDN (25% basal + 25% at tillering + 50% earhead emergence)	142.9	33.6	260.9
T7 : 75% RDN (25% basal + 25% at tillering + 25% earhead emergence + 25% flowering)	166.9	36.6	272.2
S.Em.±	5.2	1.3	10.0
C.D. (P = 0.05)	15.4	NS	NS
C.V.%	6.8	7.6	7.5

Results and Discussion

Different schedules of split nitrogen application significantly influenced quality parameters, nutrient uptake and post-harvest soil fertility status of summer pearl millet. The results indicated that application of 100% recommended dose of nitrogen (RDN) in four equal splits comprising 25% basal + 25% at tillering + 25% at earhead emergence + 25% at flowering (T_4) proved superior over other treatments with respect to quality improvement and nutrient dynamics.

Protein content and protein yield were markedly affected by various nitrogen split schedules. Treatment T_4 recorded significantly higher protein content (11.80%) and protein yield (518 kg ha^{-1}) compared to most of the other treatments. The increase in protein content under T_4 might be attributed to continuous nitrogen availability throughout the crop growth period, which enhanced nitrogen assimilation and protein synthesis in grains. Nitrogen is an important constituent of amino acids and proteins; therefore, adequate nitrogen supply during critical growth stages promoted greater accumulation of protein in pearl millet grains. Higher protein yield under T_4 was mainly due to combined effect of increased grain yield and higher protein content. Treatments receiving 100% RDN in three splits, particularly T_2 and T_3, also recorded comparatively higher protein content and protein yield over treatments receiving 75% RDN. Lower values observed under reduced nitrogen levels might be due to insufficient nitrogen availability for protein synthesis and reduced photosynthetic activity. Similar beneficial effects of split nitrogen application on grain protein content and quality parameters have also been reported by Kumar *et al*., Yadav *et al*., Patel and Patel and Meena *et al*. in pearl millet and other cereal crops.

Grain and Straw Yield

Grain and straw yields of summer pearl millet were markedly influenced by different schedules of nitrogen application. Among the various treatments, application of 100% recommended dose of nitrogen (RDN) in four equal splits (T_4) produced the maximum grain yield (4379 kg ha^{-1}) and straw yield (7207 kg ha^{-1}), and proved significantly superior to most of the other treatments. The higher yields recorded under T_4 could be attributed to the sustained availability of nitrogen throughout the crop growth period, which favourably influenced vegetative growth and yield-contributing characters. Adequate and timely nitrogen supply enhanced chlorophyll formation, photosynthetic activity and dry matter production, resulting in better translocation of assimilates towards economic yield. Moreover, split application minimized nitrogen losses through leaching and volatilization, thereby improving nitrogen use efficiency under the loamy sand soils of North Gujarat. Treatments receiving 100% RDN in three splits (T_2 and T_3) also resulted in comparatively higher grain and straw yields and were statistically comparable with T_4 in certain cases. In contrast, treatments supplied with only 75% RDN exhibited significantly lower yields due to insufficient nitrogen availability during critical growth stages, which adversely affected crop growth and biomass accumulation. The minimum grain and straw yields were recorded under T_5 treatment (75% RDN applied in two splits), highlighting the necessity of both adequate nitrogen dose and proper scheduling for achieving higher productivity in summer pearl millet.

Nitrogen content and uptake by grain and straw were also significantly influenced by split application of nitrogen. The treatment T_4 recorded significantly higher nitrogen uptake by grain (82.86 kg ha^{-1}) and straw (67.40 kg ha^{-1}). Enhanced nitrogen uptake under T_4 might be due to improved root growth, higher dry matter production and continuous nutrient availability throughout crop growth stages. Split application synchronized nutrient supply with crop demand and minimized nitrogen losses through leaching and volatilization under loamy sand soils of North Gujarat, thereby improving nitrogen use efficiency.

Higher nutrient uptake observed under T_4 may also be attributed to improved translocation of assimilates and nutrients from vegetative parts towards reproductive structures during grain development. Treatments T_2 and T_3 also recorded comparatively higher nitrogen uptake and remained statistically comparable with T_4 in some observations. On the other hand, treatments receiving 75% RDN recorded lower nitrogen uptake due to poor crop growth, reduced biomass accumulation and limited nutrient availability. Similar findings regarding enhancement of nutrient uptake through split nitrogen application were also reported by Patel *et al*., Singh and Bana, Chaudhary *et al*. and Verma *et al*. in cereal crops.

Post-harvest soil fertility status was also influenced by different nitrogen split schedules. The treatment T_4 maintained comparatively higher available nitrogen status in soil after harvest (168.7 kg ha^{-1}). The higher residual soil nitrogen under T_4 might be due to gradual and efficient utilization of nitrogen through split application, which reduced nutrient losses and improved nitrogen balance in soil. Split application ensured continuous nutrient availability and better synchronization between nutrient release and crop requirement, thereby improving nitrogen use efficiency and maintaining soil fertility.

Available phosphorus and potassium status after harvest did not differ significantly among treatments because phosphorus and potassium were applied uniformly to all treatments and these nutrients are relatively less mobile in soil. Similar results regarding improvement in residual soil fertility through split nitrogen application were also reported by Choudhary *et al*., Meena *et al*., Sharma *et al*. and Rathore *et al*. Overall, the results clearly indicated that application of 100% recommended dose of nitrogen in four equal splits at basal, tillering, earhead emergence and flowering stages proved most effective in improving quality parameters, enhancing nitrogen uptake and maintaining better soil fertility status of summer pearl millet under North Gujarat conditions. The beneficial effects of split nitrogen application were mainly associated with continuous nutrient availability, improved nitrogen use efficiency and better synchronization between nutrient supply and crop demand throughout the crop growth period. These findings are in close conformity with the observations of Aulakh and Malhi, Patel *et al*., Kumar *et al*., Yadav and Yadav and Singh *et al*. who also reported positive effects of split nitrogen application on crop quality, nutrient uptake and soil fertility.

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