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Nagalaxmi Doddamani
Master' Student, Department of Agronomy, College of Agriculture, Rajendranagar, PJTAU, Telangana, India

M Madhu
Scientist (Agronomy), AICRP on Pigeonpea, RARS Warangal, Telangana, India

AV Ramanjaneyulu
Principal Scientist (Agronomy) & Head, AICRP on Agroforestry, Rajendranagar, PJTAU, Telangana, India

Ch. Ramulu
Scientist (Soil Science and Agricultural Chemistry), RARS, Warangal, Telangana, India

M Yakadri
Professor and Head, Department of Agronomy, College of Agriculture, Rajendranagar, PJTAU, Telangana, India

Corresponding Author:
Nagalaxmi Doddamani
Master' Student, Department of Agronomy, College of Agriculture, Rajendranagar, PJTAU, Telangana, India

Genotypic variation in pigeonpea response to sowing time and nutrient use efficiency in *rabi* season

Nagalaxmi Doddamani, M Madhu, AV Ramanjaneyulu, Ch. Ramulu and M Yakadri

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Abstract
An experiment was conducted during the 2023-24 *Rabi* season at the Siddapur Research Farm, Regional Agriculture Research Station, Warangal, Telangana, to evaluate the effects of sowing dates and pigeonpea genotypes on yield, nutrient uptake and nutrient use efficiency. The soil was mildly alkaline (pH 7.9) with low nitrogen (260.3 kg ha^{-1}), low phosphorus (29.1 kg ha^{-1}), moderate organic carbon (0.64%) and high potassium (316 kg ha^{-1}). Sixteen treatment combinations, arranged in a split-plot design with three replications, included four sowing dates (D_1-2nd fortnight of September, D_2-1st fortnight of October, D_3-2nd fortnight of October and D_4-1st fortnight of November) and four pigeonpea varieties (V_1-Telangana kandi-1 (WRGE-93), V_2-Telangana kandi-2 (WRGE-121), V_3-Warangal kandi-1 (WRGE-97) and V_4-WRGE-182). Crops sown in late September (D_1) achieved the highest seed (1392 kg ha^{-1}) and stalk (4151 kg ha^{-1}) yields, with peak nutrient uptake at flowering (60.8 kg ha^{-1} nitrogen, 2.41 kg ha^{-1} phosphorus, 105.6 kg ha^{-1} potassium) and harvest (82.2 kg ha^{-1} nitrogen, 3.67 kg ha^{-1} phosphorus, 120.3 kg ha^{-1} potassium). Nitrogen and phosphorus use efficiencies were highest in September (86 and 70, respectively) but declined through October and November. Among genotypes, WRGE-182 outperformed others, producing the highest seed (1181 kg ha^{-1}) and stalk (3801 kg ha^{-1}) yields, with superior nutrient uptake at flowering (58.5 kg ha^{-1} nitrogen, 2.41 kg ha^{-1} phosphorus, 114.0 kg ha^{-1} potassium) and harvest (73.4 kg ha^{-1} nitrogen, 2.57 kg ha^{-1} phosphorus, 111.7 kg ha^{-1} potassium).WRGE-182 also showed the highest nitrogen (73) and phosphorus (59) use efficiencies, followed closely by WRGE-121 (72, 58) and surpassing WRGE-93 (66, 53) and WRGE-97 (59, 48). In contrast, crops sown in early November (D_4) and genotype WRGE-97 recorded the lowest yields, nutrient uptake and nutrient use efficiency.

Keywords: Sowing dates, varieties, nutrient uptake, NPK use efficiency, seed yield and stalk yield

Introduction
Pigeonpea (*Cajanus cajan* L.), also known as redgram, arhar, or tur, is the most important grain legume of the *kharif* season, predominantly grown under rainfed conditions in India, including Telangana. India leads in pigeonpea production, producing 3.34 million tonnes over 4.04 million hectares, with an average yield of 826 kg ha^{-1}. Nationally, pigeonpea ranks second in pulse production, after chickpea. In Telangana, pigeonpea is grown on 1.78 lakh hectares, yielding 1.44 lakh tonnes with a productivity of 809 kg ha^{-1} (DES, Ministry of Agriculture & Farmers Welfare, GoI, 2023-24) [1]. Among many reasons attributed to lower productivity of pigeonpea in Telangana, optimum sowing date and high yielding varieties with multiple resistance is lacking.

Pigeonpea is naturally a perennial plant, but by adjusting the sowing date, it can be managed to resemble and function as an annual, completing its life cycle by the end of its reproductive phase. Since most pigeonpea varieties are photosensitive, the timing of sowing plays a crucial role in shaping both vegetative growth and reproductive development.

Sowing time is a critical, non-monetary factor that impacts vegetative and reproductive growth phases, the length of the growing season, degree days, and the incidence of pests and diseases, ultimately affecting seed quality and yield. Timely sowing enables deeper root development compared to late-sown crops, allowing access to moisture later in the season. It also boosts biomass production and extends the grain filling period, supporting high yield potential (Ramanjaneyulu *et al*., 2018) [2].

In pigeonpea, optimal sowing timing aligns the crop's vegetative and reproductive phases with seasonal climate patterns. Early sowing can lead to excessive dry matter buildup, while delayed sowing or planting beyond the ideal window results in reduced biomass and lower grain yields (Kumar *et al*., 2008) [3].

Nitrogen (N), phosphorus (P) and potassium (K), collectively known as NPK, are essential macronutrients crucial for plant growth, supporting key physiological and biochemical processes such as photosynthesis, protein synthesis, and energy transfer. The efficiency with which crops utilize these nutrients, termed NPK use efficiency (NPKUE), is a critical determinant of agricultural productivity and environmental sustainability. Enhancing NPKUE remains both a significant challenge and a promising opportunity in modern agriculture. By integrating advanced technologies, developing nutrient-efficient crop varieties, and adopting sustainable management practices, it is possible to boost productivity while minimizing environmental impacts.

In *rabi* pigeonpea, sowing date and variety selection play a vital role in optimizing NPKUE by synchronizing nutrient availability with crop demand. Sowing in September enables medium-duration varieties to establish robust root systems early, leveraging residual soil moisture and minimizing nutrient losses through leaching or volatilization. These varieties align critical stages, such as flowering and pod development, with favorable climatic conditions, ensuring effective nitrogen uptake and improved phosphorus and potassium utilization. By combining optimal sowing windows with appropriate varieties, farmers can enhance NPKUE, achieve higher yields and reduce environmental nutrient losses.

Materials and Methods

A field experiment was carried out at the Siddapur research farm of RARS, Warangal, during the *rabi* season of 2023-24. The experimental site is situated in the Central Telangana agro-climatic zone of Telangana. The soil at the site exhibited a high pH level (7.9), an electrical conductivity (EC) of 0.61 dsm^{-1}, low available nitrogen (260.3 kg ha^{-1}) and phosphorus (29.1 kg ha^{-1}), medium organic carbon content (0.64%) and high potassium levels (316 kg ha^{-1}).

The experiment included a total of sixteen treatments, arranged in a split-plot design with three replications. Treatments included were four dates of sowing in the main plot i.e., D_1-2nd fortnight of September, D_2-1st fortnight of October, D_3-2nd fortnight of October and D_4-1st fortnight of November and four treatments of varieties in sub plots i.e., V_1-Telangana kandi-1 (WRGE-93), V_2-Telangana kandi-2 (WRGE-121), V_3-Warangal kandi-1 (WRGE-97) and V_4-WRGE-182. The treatments were sown with a spacing of 90×10 cm. The recommended fertilizer dose of 16-20-00 kg NPK ha^{-1} was applied, using urea and single super phosphate. Adequate plant protection measures were implemented as needed. For data collection, five randomly selected plants from each plot were tagged to record various growth and yield parameters periodically and at harvest, using both destructive and non-destructive sampling methods. During the crop's growth period, a total of 24 mm of rainfall was received over 2 rainy days. The mean maximum temperature was 32.7°C, while the minimum temperature was 20.4°C. The average weekly bright sunshine hours ranged from 3.2 to 9.4 hours per day, with a mean of 6.9 hours per day. Statistical analysis of variance (ANOVA) was conducted for the split-plot design to analyze the recorded data.

The nitrogen content was estimated by modified Micro Kjeldahl method by using Kel plus instrument, after digesting the powdered plant samples with diacid mixture using H_2SO_4 and H_2O_2. Nitrogen uptake was calculated by the formula.

$$\text{Phosphorous uptake (kg ha}^{-1}\text{)} = \frac{\text{Total dry weight (kg ha}^{-1}\text{) x Phosphorous content (\%)}}{100}$$

Phosphorus content was determined after digesting the crop (seed and haulm) samples with triacid mixture of 9:4:1 of HNO_3: H_2SO_4: $HClO_4$. The phosphorus concentration in the plant digest was determined by Vanado-Molybdo phosphoric yellow colour method. The intensity of the yellow colour was measured with spectrophotometer at 420 nm and the concentration was expressed in per cent. Phosphorus uptake was calculated by the formula.

$$\text{Potassium uptake (kg ha}^{-1}\text{)} = \frac{\text{Total dry weight (kg ha}^{-1}\text{) x Potassium content (\%)}}{100}$$

The potassium content in the triacid digested mixture was determined by using Flame photometer. Potassium uptake was calculated by the formula.

$$\text{Potassium uptake (kg ha}^{-1}\text{)} = \frac{\text{Total dry weight (kg ha}^{-1}\text{) x Potassium content (\%)}}{100}$$

The nitrogen use efficiency and phosphorus use efficiency were computed as follows-

$$\text{Nitrogen use efficiency} = \frac{\text{Seed yield (kg)}}{\text{Total nitrogen applied (kg)}}$$

$$\text{Phosphorus use efficiency} = \frac{\text{Seed yield (kg)}}{\text{Total phosphorus applied (kg)}}$$

Varietal description:

Telangana Kandi-1 (WRGE-93) and Telangana Kandi-2 (WRGE-121) are mid-early pigeonpea varieties (155-165 days) suitable for medium to black soils in rainfed areas across southern India. Both yield 1500-1800 kg ha^{-1} in *kharif* and late *kharif* seasons. WRGE-93 is moderately resistant to *Fusarium* wilt, with bold red seeds containing 19.86% protein. WRGE-121 is similarly disease-resistant and offers higher protein (23.09%), with iron (37.90 ppm) and zinc (25.04 ppm).

Warangal Kandi-1 (WRGE-97) is another mid-early variety (150-160 days) suited for black cotton soils, yielding 1500-1800 kg ha^{-1}. Released in 2019, it has spreading growth, brown-streaked pods, and large, brown seeds.

WRGE-182 is a mid-early variety (150-160 days) in its third year of minikit trials, showing promising yield potential and adaptability.

Results and Discussion

Effect of sowing time on yield and nutrient uptake

The seed yield ha^{-1} was significantly higher in the crop sown during 2nd fortnight of September (1392 kg ha^{-1}) than that of 1st fortnight of October (1228 kg ha^{-1}), 2nd fortnight of October (1035 kg ha^{-1}) and 1st fortnight of November (704 kg ha^{-1}). The higher seed yield witnessed in pigeonpea crop sown earlier might be a result of favorable environmental conditions, leading to greater leaf area and higher biomass accumulation, ultimately improving seed yield. These results are consistent with the findings of Rao *et al*. (2016) [4] and Doddamani *et al*. (2024) [5].

The stalk yield was significantly influenced by different dates of sowing. Among the dates of sowing, the crop sown during 2nd fortnight of September recorded significantly higher stalk yield (4151 kg ha^{-1}) than that of 1st fortnight of October (3697 kg ha^{-1}), 2nd fortnight of October (3245 kg ha^{-1}) and 1st fortnight of November (2203 kg ha^{-1}). Sowing of pigeonpea during 2nd fortnight of September resulted maximum stalk yield due to optimum utilization of solar radiation, temperature, higher assimilates production and i ts conversion to starch resulting in higher stalk yield. These finding are similar to those reported by Egbe *et al.* (2013) [6] and Malik and Yadav (2014) [7].

At the flowering stage, crops sown in the second half of September had the highest nitrogen uptake (60.8 kg ha^{-1}), which was similar to those sown in the first half of October (56.0 kg ha^{-1}), while crops sown in early November had the lowest nitrogen uptake (40.1 kg ha^{-1}). By harvest, nitrogen uptake in both seed and stalk was measured separately: crops sown in late September showed the highest uptake, with 82.2 kg ha^{-1} in seeds and 64.4 kg ha^{-1} in stalks, and a similar nitrogen uptake in the stalks of crops sown in early October (62.6 kg ha^{-1}). In contrast, November-sown crops had the lowest uptake, with 47.1 kg ha^{-1} in seeds and 32.3 kg ha^{-1} in stalks. The increased soil moisture from late monsoon rains in September likely enhanced nitrogen solubilization and uptake (Jena *et al*., 2022) [8]. Nitrogen use efficiency was highest during the second fortnight of September (86), followed by the first fortnight of October (76), the second fortnight of October (64), and the first fortnight of November (44). For phosphorus, crops sown in late September had the highest uptake at flowering (2.41 kg ha^{-1}) and at harvest, with 3.67 kg ha^{-1} in seeds and 2.75 kg ha^{-1} in stalks, while November-sown crops had the lowest phosphorus uptake both at flowering (2.18 kg ha^{-1}) and at harvest (1.13 kg ha^{-1} in seeds and 1.41 kg ha^{-1} in stalks). Favorable climatic conditions such as moderate temperatures and adequate rainfall in early September likely promoted nutrient availability and root development, boosting phosphorus uptake (Singh and Ahlawat, 2007) [9]. Phosphorus use efficiency peaked during the second fortnight of September (70), with subsequent decreases observed in the first fortnight of October (61), the second fortnight of October (52), and the first fortnight of November (35). Potassium uptake followed a similar trend; crops sown in late September showed the highest uptake at flowering (105.6 kg ha^{-1}), comparable to early October sowing (105.4 kg ha^{-1}), with November-sown crops again having the lowest uptake (88.4 kg ha^{-1}). At harvest, crops sown in the second half of September had the highest potassium uptake (19.0 kg ha^{-1} in seeds and 120.3 kg ha^{-1} in stalks), with stalk potassium uptake similar for crops sown in early October (115.2 kg ha^{-1}). The lowest potassium uptake at harvest was observed in early November-sown crops (9.6 kg ha^{-1} in seeds and 59.2 kg ha^{-1} in stalks). The late September sowing period benefited from well-balanced nutrient levels and adequate moisture, enhancing the absorption of nitrogen, phosphorus and potassium by pigeonpea (Kumar *et al.*, 2023) [10].

Genotypic variation in yield and nutrient uptake

The variety WRGE-182 (1181 kg ha^{-1}) recorded significantly higher seed yield than WRGE-93 (1057 kg ha^{-1}) and WRGE-97 (955 kg ha^{-1}) varieties but on par with the seed yield of WRGE-121 (1166 kg ha^{-1}) pigeonpea variety. The greater seed yield in WRGE-182 and WRGE-121 may be attributed to their genetic potential and superior growth traits, such as a higher total number of branches $plant^{-1}$, number of pods $plant^{-1}$ and number of seeds pod^{-1}. These findings align with those reported by Math *et al*. (2023) [11]. Significantly higher stalk yield was reported by variety WRGE-182 (3801 kg ha^{-1}) than that of WRGE-93 (3025 kg ha^{-1}) and WRGE-97 (2725 kg ha^{-1}) varieties but on par with variety WRGE-121 (3744 kg ha^{-1}). The superiority of growth characters like plant height, branches, leaf area and dry matter accumulation may be the possible reason for the production of higher stalk yield in WRGE-182 and WRGE-121. These results align with those reported by Bansal *et al.* (2022) [12].

At the flowering stage, WRGE-182 recorded the highest nitrogen uptake (58.5 kg ha^{-1}), closely followed by WRGE-121 (56.0 kg ha^{-1}), while WRGE-97 had the lowest uptake (41.5 kg ha^{-1}). At harvest, WRGE-182 maintained the highest nitrogen uptake in both seed and stalk (73.4 and 60.5 kg ha^{-1}, respectively), comparable to WRGE-121 (71.1 and 59.0 kg ha^{-1}), with WRGE-97 again the lowest (60.3 and 40.4 kg ha^{-1}). The higher nitrogen uptake in WRGE-182 and WRGE-121 is likely due to their longer growth duration, allowing more time for nitrogen absorption during the lifecycle (Saxena *et al*., 2018) [13]. Nitrogen use efficiency was highest for WRGE-182 (73), comparable to WRGE-121 (72), and higher than WRGE-93 (66) and WRGE-97 (59). For phosphorus, WRGE-182 had the highest uptake at flowering (2.41 kg ha^{-1}), followed closely by WRGE-121 (2.37 kg ha^{-1}), while WRGE-97 had the lowest (2.11 kg ha^{-1}). By harvest, WRGE-182 continued to show the highest phosphorus uptake in both seed and stalk (2.57 and 2.45 kg ha^{-1}), comparable to WRGE-121 (2.46 and 2.35 kg ha^{-1}), with WRGE-97 recording the lowest uptake (1.79 and 1.56 kg ha^{-1}). The advantage in phosphorus uptake for WRGE-182 and WRGE-121 is attributed to their extensive root systems, enabling access to deeper, phosphorus-rich soil layers (Umesh *et al.*, 2013) [14]. Phosphorus use efficiency was highest for WRGE-182 (59), similar to WRGE-121 (58), and greater than WRGE-93 (53) and WRGE-97 (48). In terms of potassium, WRGE-182 had the highest uptake at flowering (114 kg ha^{-1}), with WRGE-97 the lowest (82.5 kg ha^{-1}). At harvest, WRGE-182 again exhibited the highest potassium uptake in both seed and stalk (16.4 and 111.7 kg ha^{-1}), with seed uptake comparable to WRGE-121 (16.3 kg ha^{-1}), while WRGE-97 showed the lowest in both seed and stalk (12.9 and 76.6 kg ha^{-1}). Plants with higher seed and stalk yields typically have a larger biomass, which demands more nitrogen, phosphorus, and potassium for optimal growth. The interaction between sowing dates and varieties had a significant impact on seed and stalk yields but did not significantly affect nitrogen, phosphorus and potassium uptake.

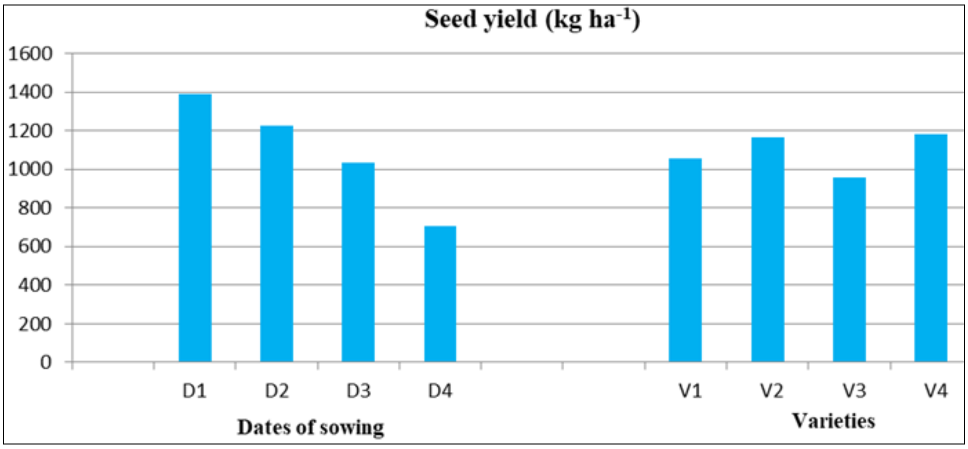

Fig 1: Seed yield (kg ha^{-1}) of pigeonpea as influenced by different dates of sowing and varieties

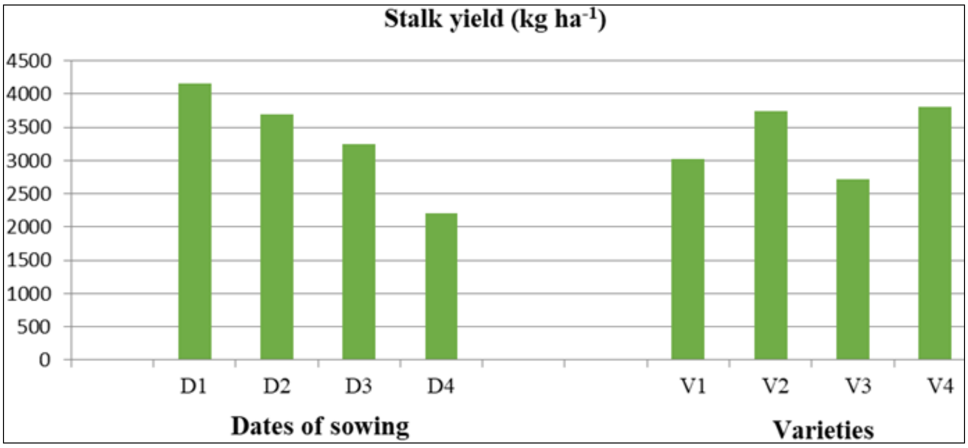

Fig 2: Stalk yield (kg ha^{-1}) of pigeonpea as influenced by different dates of sowing and varieties

Table 1: Nitrogen uptake (kg ha^{-1}) by pigeonpea as influenced by different dates of sowing and varieties

Treatments	N uptake (kg ha^{-1})				Nitrogen use efficiency (kg kg^{-1})
	Flowering	Harvesting		Total N uptake at harvest	
		Seed	Stalk		
Main factor: Dates of Sowing					
D1: 2nd fortnight of September	60.8	82.2	64.4	146.6	86
D2: 1st fortnight of October	56.0	77.0	62.6	139.6	76
D3: 2nd fortnight of October	47.2	64.8	48.6	113.4	64
D4: 1st fortnight of November	40.1	47.1	32.3	79.4	44
SEm ±	1.9	0.8	3.7	3.8	0.7
CD (p=0.05)	6.6	2.7	12.7	13.1	2.4
Sub factor: Varieties					
V1: WRGE- 93 (Telangana kandi-1)	48.2	66.2	48.0	114.2	66
V2: WRGE-121 (Telangana kandi-2)	56.0	71.1	59.0	130.1	72
V3: WRGE-97 (Warangal kandi-1)	41.5	60.3	40.4	100.7	59
V4: WRGE-182	58.5	73.4	60.5	133.9	73
SEm ±	2.1	0.8	2.4	2.6	0.5
CD (p=0.05)	6.0	2.4	7.1	7.6	1.4
Dates of sowing at same or different level of varieties					
SEm ±	4.0	1.6	5.6	5.9	1.1
CD (p=0.05)	NS	NS	NS	NS	NS
Varieties at same level of dates of sowing					
SEm ±	4.1	1.7	4.9	5.2	0.9
CD (p=0.05)	NS	NS	NS	NS	NS

Table 2: Phosphorous uptake (kg ha^{-1}) by pigeonpea as influenced by different dates of sowing and varieties

Treatments	P uptake (kg ha^{-1})				Phosphorous use efficiency (kg kg^{-1})
	Flowering	Harvesting		Total P uptake at harvest	
		Seed	Stalk		
Main factor: Dates of Sowing					
D1: 2nd fortnight of September	2.41	3.67	2.75	6.42	70
D2: 1st fortnight of October	2.34	2.40	2.11	4.51	61
D3: 2nd fortnight of October	2.27	1.72	2.07	3.79	52
D4: 1st fortnight of November	2.18	1.13	1.41	2.54	35
SEm ±	0.02	0.09	0.06	0.07	0.6
CD (p=0.05)	0.06	0.31	0.21	0.24	1.9
Sub factor: Varieties					
V1: WRGE- 93 (Telangana kandi-1)	2.31	2.10	1.98	4.08	53
V2: WRGE-121 (Telangana kandi-2)	2.37	2.46	2.35	4.81	58
V3: WRGE-97 (Warangal kandi-1)	2.11	1.79	1.56	3.35	48
V4: WRGE-182	2.41	2.57	2.45	5.02	59
SEm ±	0.02	0.10	0.06	0.10	0.4
CD (p=0.05)	0.05	0.28	0.16	0.30	1.1
Dates of sowing at same or different level of varieties					
SEm ±	0.03	0.19	0.12	0.19	0.9
CD (p=0.05)	NS	NS	NS	NS	NS
Varieties at same level of dates of sowing					
SEm ±	0.03	0.19	0.11	0.21	0.7
CD (p=0.05)	NS	NS	NS	NS	NS

Table 3: Potassium uptake (kg ha^{-1}) by pigeonpea as influenced by different dates of sowing and varieties

Treatments	K uptake (kg ha^{-1})			
	Flowering	Harvesting		Total K uptake at harvest
		Seed	Stalk	
Main factor: Dates of Sowing				
D1: 2nd fortnight of September	105.6	19.0	120.3	139.3
D2: 1st fortnight of October	105.4	17.0	115.2	132.2
D3: 2nd fortnight of October	93.1	14.9	80.9	95.8
D4: 1st fortnight of November	88.4	9.6	59.2	68.8
SEm ±	1.3	0.4	5.2	5.1
CD (p=0.05)	4.6	1.5	17.8	17.8
Sub factor: Varieties				
V1: WRGE- 93 (Telangana kandi-1)	100.8	14.9	97.1	112.0
V2: WRGE-121 (Telangana kandi-2)	95.3	16.3	90.3	106.6
V3: WRGE-97 (Warangal kandi-1)	82.5	12.9	76.6	89.5
V4: WRGE-182	114.0	16.4	111.7	128.1
SEm ±	1.7	0.4	3.3	3.4
CD (p=0.05)	4.8	1.2	9.7	9.8
Dates of sowing at same or different level of varieties				
SEm ±	3.2	0.8	7.7	7.8
CD (p=0.05)	NS	NS	NS	NS
Varieties at same level of dates of sowing				
SEm ±	3.3	0.8	6.7	6.7
CD (p=0.05)	NS	NS	NS	NS

Conclusion

Crops sown during the second half of September achieved the highest yield and NPK use efficiency, with maximum nitrogen, phosphorus, and potassium uptake recorded at both flowering and harvest stages. Conversely, crops sown in early November showed the lowest NPK use efficiency. Among the varieties, WRGE-182 achieved the greatest yield, NPK use efficiency and nutrient uptake, closely followed by WRGE-121.

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