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Assessment of spacing and nutrient management effect on growth, yield attributes and yield of grain amaranth (*Amaranthus hypochondriacus* L.)

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Abstract

A field experiment was conducted during *rabi* 2020-21 and 2021-22 at the Research-cum-Instructional Farm, College of Agriculture, Raipur (Chhattisgarh), under clay loam soil conditions, to evaluate the effect of spacing and nutrient management on growth, yield attributes and yield of grain amaranth (*Amaranthus hypochondriacus* L.). The experiment was laid out in a split plot design with three replications, comprising three spacing levels (40 x 20, 50 x 20 and 60 x 20 cm) as main plots and eight sub-plot nutrient management treatments: control, 75% RDN, 100% RDN, 125% RDN, 75% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS, 75% RDN + foliar spray of cow urine (10%) + vermiwash (10%) twice at 40 and 60 DAS, 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS, and 100% RDN + foliar spray of cow urine (10%) + vermiwash (10%) twice at 40 and 60 DAS. Grain amaranth variety, Chhattisgarh Rajgira-1, was taken as test crop. Recommended dose of nutrient (RDN) applied to the crop was 60:40:20 kg N, P₂O₅ and K₂O ha⁻¹. Based on the mean values of two-year field data, results indicated that closer spacing (40 x 20 cm) significantly ($P \leq 0.05$) increased plant height, while wider spacing (60 x 20 cm) enhanced growth parameters such as number of leaves, leaf area, dry matter accumulation, and stem girth, along with yield attributes including inflorescence length, number of panicles, and panicle length due to reduced intra-specific competition. However, the highest grain (1068 kg ha⁻¹) and stover yield (2370 kg ha⁻¹) were obtained at 50 x 20 cm spacing, showing about 21% higher grain yield over wider spacing. Among nutrient management treatments, 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS significantly improved growth parameters (plant height, number of leaves, leaf area, dry matter accumulation and stem girth) and yield attributes (inflorescence length, number of panicles and panicle length), resulting in the highest grain yield (1288 kg ha⁻¹), which was approximately 185% higher than control, along with 142% higher stover yield. The interaction effect revealed that 50 x 20 cm spacing with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS was the most effective combination and can be recommended for enhancing productivity and supporting sustainable crop production under similar agro-climatic conditions.

Keywords: Grain amaranth (*Amaranthus hypochondriacus* L.), spacing, nutrient management, RDN, foliar spray, NPK (19:19:19), cow urine, vermiwash, growth parameters, yield attributes, grain yield, stover yield, sustainable agriculture

Introduction

Global food security is increasingly threatened by rapid population growth, climate change, and declining natural resources, with food production needing to rise by over 50% by 2050 (Garcia *et al.*, 2010) [7]. In countries like India, heavy dependence on major cereals such as rice, wheat, and maize, combined with shrinking freshwater resources, raises concerns about sustainability and nutritional security, as cereal-based diets often lack essential micronutrients. Crop diversification with resilient and nutrient-rich crops is therefore essential. Grain amaranth (*Amaranthus hypochondriacus* L.), a C4 plant, is a promising alternative due to its tolerance to drought, heat, and low-input conditions, and its dual use as both grain and leafy vegetable. It is highly nutritious, containing 14-15% protein with a balanced amino acid profile rich in lysine, along with iron, calcium, and antioxidants, and is also gluten-free (Rodas and Bressani, 2009 [20]).

Rastogi and Shukla, 2013)^[18]. Despite these advantages, productivity under Indian conditions remains low, largely due to inadequate agronomic practices. Among these practices, plant spacing and nutrient management critically influence growth, yield attributes and yield of grain amaranth. Growth parameters such as plant height, number of leaf plant⁻¹, leaf area and dry matter accumulation determine resource capture, while yield attributes including inflorescence length, number of panicles plant⁻¹, panicle length, 10 ml volume seed weight directly affect grain yield. Balanced fertilization with nitrogen, phosphorus, and potassium (NPK), along with integrated use of organic inputs such as cow urine and vermiwash, can enhance these growth and yield traits by improving nutrient availability, soil health, and plant physiological performance. Moreover, foliar application of water-soluble fertilizers like 19:19:19 NPK has shown promising results in improving growth, yield attributes and yield in other crops. However, limited information is available on the combined effect of plant spacing and nutrient management on the growth parameters, yield attributes and overall yield of grain amaranth under the agro-climatic conditions of Chhattisgarh. Therefore, the present study was undertaken to evaluate the effects of spacing and nutrient management on growth, yield attributes and yield of grain amaranth (*Amaranthus hypochondriacus* L.), with the aim of identifying practices that optimize productivity and sustainability.

Material and Methods

A field experiment was conducted at Research-cum-Instructional farm of College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur during *rabi* season of 2020-21 and 2021-22. The experiment was conducted using a split plot design with three replications. The main plot treatments consisted of three spacing levels: S₁ (40 x 20 cm), S₂ (50 x 20 cm), and S₃ (60 x 20 cm). The sub-plot treatments included eight nutrient management levels: N₀ (control), N₁ (75% RDN), N₂ (100% RDN), N₃ (125% RDN), N₄ (75% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS), N₅ (75% RDN + foliar spray of cow urine (10%) + vermiwash (10%) twice at 40 and 60 DAS), N₆ (100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS), and N₇ (100% RDN + foliar spray of cow urine (10%) + vermiwash (10%) twice at 40 and 60 DAS). The experimental site was clay loam in texture having pH 7.5, EC 0.26 dS m⁻¹, organic carbon 0.54% and soil available N, P and K, 208.75 (Low), 23.28 (Medium) and 240.67 kg ha⁻¹ (Medium), respectively. The grain amaranth variety 'Chhattisgarh Rajgira-1' was used as the test crop at a seed rate of 3.0 kg ha⁻¹ and sowing was carried out by dibbling seeds at pre-marked spots as per the specified spacing treatments. Recommended dose of nutrient 60:40:20 kg N, P₂O₅, and K₂O ha⁻¹ applied in the form of Urea, SSP (Single Super Phosphate) and MOP (Muriate of potash). The entire dose of phosphorus and potassium was applied at sowing as basal, while nitrogen was applied in two splits-one at basal and the remaining at 30 DAS. Calculation for the required amount of Urea, SSP and MOP was done as per the treatment details, for 75% RDN (45:30:15 kg N, P₂O₅, K₂O ha⁻¹), 100% RDN (60:40:20 kg N, P₂O₅, K₂O ha⁻¹) and 125% RDN (75:50:25 kg N, P₂O₅, K₂O ha⁻¹) and applied accordingly. Foliar spray of 19:19:19 NPK (2%), cow urine (10%), and vermiwash (10%) was executed at 40 and 60 DAS as per the treatment with the help of a knapsack sprayer during evening hours. Whereas the control plot received no application of fertilizer or foliar spray. Weed management was done manually by hand weeding at 25

and 45 DAS to maintain a weed-free environment. The experimental data were analysed using ANOVA for a split-plot design, and treatment differences were tested at 5% level of significance.

Results

Growth attributes

Plant height (cm)

Data presented in Table 1 revealed that plant height of grain amaranth increased progressively from 25 DAS to harvest. Spacing significantly affected plant height at 75 DAS and at harvest. Based on mean data, 40 x 20 cm spacing producing the tallest plants (81.0 and 121.2 cm at 75 DAS and at harvest, respectively), which remained at par with 50 x 20 cm (77.5 and 118.5 cm), while 60 x 20 cm resulted in the shortest plants (74.8 and 116.3 cm). Nutrient management significantly influenced plant height at all growth stages, with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS (N₆) consistently producing the tallest plants (15.8, 58.2, 96.4 and 130.1 cm at 25, 50, 75 DAS and at harvest, respectively based on mean data), statistically comparable to 125% RDN (14.8, 55.4, 91.4 and 125.7 cm) and, at harvest, also to 100% RDN + foliar spray of cow urine + vermiwash (N₇). The lowest plant height was observed under the control treatment (8.9, 23.8, 54.5 and 88.0 cm). The interaction between spacing and nutrient management was non-significant at all growth stages.

Number of leaves plant⁻¹

The number of leaves plant⁻¹ in grain amaranth increased with crop growth from 25 to 75 DAS as shown in Table 2. Spacing had a non-significant effect at 25 DAS but became significant at 50 and 75 DAS, where wider spacing (60 x 20 cm) recorded the highest number of leaves (mean 24.3 at 50 DAS and 39.0 at 75 DAS), remaining at par with 50 x 20 cm, while the lowest values were observed under 40 x 20 cm. Nutrient management significantly influenced leaf number at all growth stages, with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS producing the maximum number of leaves (mean values of 13.6, 30.4 and 47.4 leaves at 25, 50 and 75 DAS, respectively) throughout, though it was comparable to 125% RDN and 100% RDN + foliar spray of cow urine + vermiwash at 25 DAS. The control treatment consistently recorded the lowest leaf numbers. The interaction between spacing and nutrient management was non-significant at all stages.

Leaf area (cm²)

Leaf area of grain amaranth increased steadily from 25 to 75 DAS as evident from Table 3, attaining the highest values at 75 DAS. Spacing did not significantly influence leaf area at 25 DAS but showed a significant effect at 50 and 75 DAS, where the widest spacing (60 x 20 cm) recorded the maximum leaf area (967.2, 1045.4 and 1006.3 cm², in 2020-21, 2021-22 and on mean basis, respectively), followed by 50 x 20 cm, while the minimum was observed at 40 x 20 cm. Nutrient management had a significant effect at all growth stages, with 100% RDN + foliar application of 19:19:19 NPK twice at 40 and 60 DAS producing the highest leaf area (158.0 cm², 173.0 cm² and 165.5 cm²), remaining at par at certain stages with 125% RDN, 100% RDN + foliar spray of cow urine and vermiwash at 40 and 60 DAS, and 75% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS. The control treatment recorded the lowest leaf area. The interaction effect between spacing and nutrient management was non-significant throughout the growth stages.

Stem girth (mm)

Data presented in Table 4 reveal that stem girth of grain amaranth increased from 25 DAS to harvest. Effect of spacing on stem girth was non-significant at 25 and 50 DAS but became significant at 75 DAS and harvest, with 60 x 20 cm recording the highest girth (75 DAS: 11.0 mm; harvest: 18.6 mm) and 40 x 20 cm the lowest (10.3 mm; 17.6 mm), 50 x 20 cm being intermediate. Nutrient management significantly influenced girth at all stages, with 100% RDN + foliar 19:19:19 NPK (N_6) producing maximum girth (25 DAS: 3.2 mm; 50 DAS: 8.0 mm; 75 DAS: 12.1 mm; harvest: 21.8 mm), comparable with 125% RDN at later stages, while control consistently recorded the lowest (25 DAS: 2.8 mm; 50 DAS: 4.1 mm; 75 DAS: 8.2 mm; harvest: 11.2 mm). Interaction between spacing and nutrients was non-significant for stem girth.

Dry matter accumulation (g plant⁻¹)

Dry matter accumulation in grain amaranth increased progressively from 25 DAS to harvest as reflected in Table 5. Spacing had no significant effect at 25 DAS, but at 50 DAS, 60 x 20 cm recorded the highest dry matter (11.5 g plant⁻¹) followed by 50 x 20 cm (11.0 g plant⁻¹) and lowest at 40 x 20 cm. At 75 DAS and harvest, 60 x 20 cm (75 DAS: 25.4 g; harvest: 34.9 g) and 50 x 20 cm (24.9 g; 34.8 g) produced significantly higher dry matter than 40 x 20 cm (23.2 g; 26.4 g). Nutrient management significantly influenced dry matter at all stages, with 100% RDN + foliar 19:19:19 NPK twice at 40 and 60 DAS (N_6) producing maximum values (25 DAS: 3.2 g; 50 DAS: 14.6 g; 75 DAS: 28.2 g; harvest: 39.9 g), at par with 125% RDN at later stages, while the control consistently recorded the lowest (25 DAS: 1.5 g; 50 DAS: 6.8 g; 75 DAS: 13.2 g; harvest: 20.0 g). Interaction between spacing and nutrient management was non-significant.

Yield attributes**Inflorescence length (cm)**

The inflorescence length of grain amaranth was significantly influenced by both spacing and nutrient management, with a significant interaction effect (Table 6). Among spacings, the widest spacing (60 x 20 cm) produced the longest inflorescences (54.9, 57.7, 56.3 cm in 2020-21, 2021-22, and mean), followed by 50 x 20 cm (52.5, 55.5, 54.0 cm), while the shortest was recorded under 40 x 20 cm (49.0, 51.8, 50.4 cm). With respect to nutrient management treatment, the longest inflorescence was recorded with 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS, which was significantly higher (57.9, 61.1 and 59.5 cm) over all other treatments except, 125% RDN (55.5, 57.9 and 56.7 cm), which was at par to it. The lowest inflorescence length was recorded under control treatment (44.7, 47.2 and 46.0 cm). The interaction between spacing and nutrient management had a significant effect on inflorescence length, with the maximum inflorescence length recorded under wider spacing (60 x 20 cm) when combined with nutrient management treatment of 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS.

Number of panicles plant⁻¹

The number of panicles plant⁻¹ in grain amaranth was significantly influenced by both spacing and nutrient management is clearly depicted in Table 6. Among spacings, the widest spacing (60 x 20 cm) produced the highest number of panicles (30.7, 35.8, 33.3 in 2020-21, 2021-22, and mean), followed by 50 x 20 cm (28.6, 34.6, 31.6), while the lowest was observed under 40 x 20 cm (26.6, 32.5, 29.5). Wider spacing likely promoted panicle emergence by providing more space per

plant. Nutrient management significantly enhanced panicle number across all treatments, with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS producing the maximum number of panicles (37.6, 44.9, 41.2), followed by 125% RDN (34.2, 39.4, 36.8), whereas the control consistently had the lowest number of panicles (16.2, 24.4, 20.3). However, interaction of spacing and nutrient management for number of panicles of grain amaranth was found non-significant during both the years and on mean data.

Panicle length (cm)

It is clear from Table 6 that panicle length of grain amaranth was significantly influenced by both spacing and nutrient management. The widest spacing (60 x 20 cm) produced the longest panicles (28.9, 31.8, 33.4 cm in 2020-21, 2021-22 and mean), which was at par with 50 x 20 cm spacing (27.5, 29.8, 28.7 cm), while the shortest panicles were recorded under 40 x 20 cm (23.7, 26.9, 25.3 cm). Nutrient management also significantly affected panicle length, with 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS producing the maximum length (33.6, 38.0, 35.8 cm), followed by 125% RDN (29.6, 33.7, 31.7 cm), and the control showing the lowest values (17.3, 20.1, 18.7 cm). The interaction between spacing and nutrient management was non-significant, indicating that the effects of spacing and nutrients on panicle length were independent.

10 ml volume seed weight (g)

The data presented in Table 6 clearly demonstrate that the 10 ml volume seed weight of grain amaranth was not significantly affected by spacing, nutrient management, or their interaction, with values ranging from 7.5 to 8.1 g. Numerically, the highest seed weight was observed at 60 x 20 cm spacing (7.7, 8.0, 7.9 g) and under 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS (7.9, 8.1, 8.0 g), while the lowest was recorded at 40 x 20 cm spacing (7.7, 7.8, 7.8 g) and in control treatment (7.5, 7.6, 7.6 g).

Yield**Grain yield (kg ha⁻¹)**

The data presented in Table 7 revealed that grain yield of grain amaranth was significantly influenced by plant spacing and nutrient management in both years, with yields higher in 2021-22 than 2020-1. Among spacings, 50 x 20 cm produced the highest mean grain yield (1068 kg ha⁻¹), followed by 40 x 20 cm (995 kg ha⁻¹), while 60 x 20 cm recorded the lowest (880 kg ha⁻¹). Nutrient management showed that 100% RDN combined with foliar spray of 19:19:19 twice at 40 and 60 DAS produced the highest mean yield (1288 kg ha⁻¹), followed by 125% RDN (1200 kg ha⁻¹) and 100% RDN + foliar spray of cow urine and vermiwash at 40 and 60 DAS (1165 kg ha⁻¹), with control giving the lowest yield (452 kg ha⁻¹). Significant interaction effects indicated that the combination of 50 x 20 cm spacing with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS (N_6) was most effective for maximizing grain yield across both years.

Stover yield (kg ha⁻¹)

As shown in Table 7 stover yield of grain amaranth was significantly influenced by spacing and nutrient management in both years, with 50 x 20 cm spacing producing the highest mean stover yield (2370 kg ha⁻¹), followed by 40 x 20 cm (2199 kg ha⁻¹), while 60 x 20 cm gave the lowest (2027 kg ha⁻¹). Among nutrient treatments, 100% RDN + foliar spray of

19:19:19 NPK twice at 40 and 60 DAS resulted in the highest mean stover yield (2746 kg ha^{-1}), statistically at par with 125% RDN (2588 kg ha^{-1}) and 100% RDN + foliar spray of cow urine and vermiwash at 40 and 60 DAS (2575 kg ha^{-1}), while control produced the lowest (1137 kg ha^{-1}). Interaction effects between spacing and nutrient management were non-significant, indicating that the individual effects of spacing and nutrient management predominantly influenced stover production.

Harvest index (%)

Table 7 shows that harvest index of grain amaranth was not significantly influenced by spacing, with mean values ranging narrowly from 30.2% (60 x 20 cm) to 30.9% (40 x 20 and 50 x 20 cm). In contrast, nutrient management significantly affected harvest index, with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS producing the highest mean harvest index (32.0%), significantly higher than control (28.5%), while other treatments recorded intermediate values. Interaction effects between spacing and nutrient management were non-significant, indicating that nutrient management primarily governed harvest index rather than plant density.

Discussion

Growth attributes

Spacing and nutrient management significantly influenced the growth attributes of grain amaranth. Plant height was higher under closer spacing (40 x 20 cm), at par with 50 x 20 cm, while the widest spacing (60 x 20 cm) recorded the shortest plants, possibly due to increased competition for light under closer spacing leading to greater elongation, which is in line with the findings of Bongase *et al.* (2019) [12]. Nutrient management enhanced height at all stages, with 100% RDN + foliar 19:19:19 NPK twice at 40 and 60 DAS (N_6) producing the tallest plants, at par with 125% RDN and 100% RDN + foliar spray of cow urine and vermiwash at 40 and 60 DAS, while control was lowest. Increased height under higher nutrient supply may be attributed to adequate nitrogen for cell elongation, phosphorus for energy transfer, and potassium for structural support, with foliar feeding maintaining nutrient availability at critical stages. Similar results were also reported by Premsekhar and Rajashree (2010) [17] with the foliar spray of 19:19:19 NPK along with 100% recommended dose of nutrients. Number of leaves was significantly influenced by spacing from 50 DAS onwards. The widest spacing (60 x 20 cm) produced the most leaves, which was at par with 50 x 20 cm, whereas the least number of leaves recorded under 40 x 20 cm, reflecting better resource availability under wider spacing. This finding is in conformity with the earlier findings reported by Patel *et al.* (2011) [15], Bongase *et al.* (2019) [12]. Nutrient management showed significant differences at all stages for number of leaves. 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS produced the most leaves, closely followed by 125% RDN, while control had the fewest. Foliar feeding at active growth stages may have sustained leaf initiation and retention. The result is in agreement with findings of Shikandar (2021) [21]. Leaf area was significantly higher at wider spacing (60 x 20 cm), at par with 50 x 20 cm, than at closer spacing. Wider spacing reduced competition, allowing greater leaf expansion and improved light interception. Higher leaf area with wider spacing as compared to narrow spacing were also reported by Mouneke and Ndukwe (2008) [12]. Among nutrient treatments, 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS recorded the highest leaf area, closely followed by 125% RDN and 100% RDN + foliar spray of cow urine and vermiwash at 40 and 60

DAS. This response may be linked to nitrogen-driven chlorophyll formation, phosphorus-assisted cell division, and potassium-mediated turgor regulation, with foliar sprays enhancing photosynthetic potential and delaying senescence. This result is in conformity with the findings of Omolayo and Ayodele (2009) [13], where nutrient application at basal and later stages of the crop gave higher leaf area. Stem girth was significantly higher at 75 DAS and at harvest under 60 x 20 cm spacing, at par with 50 x 20 cm, compared to 40 x 20 cm. Wider spacing likely enhanced radial growth through better light penetration and nutrient access. The result is in conformity with the finding of Verma *et al.* (2022) [23] where widest spacing recorded the highest stem girth. Nutrient management effects were significant at all stages; 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS produced the thickest stems, followed by 125% RDN and 100% RDN + CU+VW foliar spray at 40 and 60 DAS. Stronger stems under higher nutrient input could have result from nitrogen-induced cambial activity, phosphorus-driven tissue differentiation, and potassium-enhanced cell wall strength. Similar results were also reported by Modhvadia *et al.*, (2007) [11] with the increasing nutrient application to the crop. Dry matter accumulation increased significantly with wider spacing from 50 DAS onwards, this might be due to larger canopy size, better light capture, and higher photosynthetic efficiency. The result supports the finding of Igbokwe and Hollins (2000) [8], Malligawad and Patil (2001) [10], who have also reported that wider spacing significantly enhance the dry matter accumulation in the plant. Nutrient management showed a consistent trend, with 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS producing maximum biomass, followed by 125% RDN and 100% RDN + foliar spray of CU + VW at 40 and 60 DAS. These treatments promoted vigorous vegetative growth, sustained metabolic activity, and delayed senescence, while control had the lowest biomass due to nutrient limitations. Similar results of nutrients increasing the dry matter accumulation with the increased nutrient application was also reported by Majumder (2007) [9].

Yield attributes

Inflorescence length was significantly influenced by spacing and nutrient management. The widest spacing (60 x 20 cm) produced the longest inflorescences, followed by 50 x 20 cm, whereas the shortest under 40 x 20 cm, likely due to reduced competition and better light penetration promoting reproductive growth. The longer inflorescence length with wider spacing was also observed by Chaudhary *et al.* (2009) [4]. Among nutrients, 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS (N_6) and 125% RDN produced the longest inflorescences, far exceeding the control. Similar results were also reported by Reddy *et al.* (2018) [19]. Interaction effects were significant, with the best result recorded when wider spacing (60 x 20 cm) combined with higher nutrient levels (100% RDN + foliar spray of 19:19:19 twice at 40 and 60 DAS), indicating that optimum resource availability supports both vegetative and reproductive organ development. The number of panicles increased significantly with wider spacing, with 60 x 20 cm producing the most, followed by 50 x 20 cm. This might be due to greater space per plant enabling more panicle initiation sites. Nutrient management effects were also significant, with 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS giving the highest counts, followed by 125% RDN, while control plants produced the fewest. This shows that optimum nutrient supply at critical stages may promote panicle differentiation and retention. The consistent nutrient supply from early growth stages not only

improves photosynthetic efficiency but also enhances the availability of essential metabolites and assimilates required for the development of reproductive structures, ultimately resulting in higher number of panicles. Similar results were also reported by Chaudhary and Gautum (2007) ^[5]. Panicle length followed the same trend as the number of panicles, with 60 x 20 cm spacing giving the longest panicles, followed by 50 x 20 cm. The highest nutrient response was under 100% RDN + foliar 19:19:19 NPK twice at 40 and 60 DAS, closely followed by 125% RDN. Greater panicle size under these treatments is attributed to enhanced assimilate supply to the reproductive sink, supported by adequate nutrition and reduced competition. Similar results were also reported by Pratap and Datta (2010) ^[16] and Reddy *et al.* (2018) ^[19], who observed improved results with the foliar application of nutrients. 10 ml seed volume weight was not significantly affected by spacing or nutrient management, though numerically higher values were observed under 100% RDN + foliar spray of 19:19:19 NPK and 125% RDN compared to the control. This indicates that while seed filling is relatively stable across plant spacings, balanced nutrition may slightly enhance grain plumpness and density.

Yield

Grain yield was significantly influenced by both factors, with 50 x 20 cm spacing producing the highest yield, at par with 40 x 20 cm, and significantly higher than 60 x 20 cm. Optimum plant density likely ensured better canopy structure and resource use efficiency compared to both closer and wider spacings. Supporting the findings, Vaghela *et al.* (2018) ^[22], Patel *et al.* (2011) ^[15], Patel (2003) ^[14] and Malligawad and Patil (2001) ^[10] have also reported higher yields with optimum plant population with moderate spacing. Nutrient management, 100% RDN +

foliar spray of 19:19:19 NPK recorded the highest yield, followed by 125% RDN and 100% RDN + foliar spray of cow urine + vermiwash, while the control yielded the lowest. Interaction effects were significant, with the best yields achieved through optimal spacing (50 x 20 cm) combined with high nutrient inputs (100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS), reflecting synergy between plant density and nutrition in determining productivity. Chakraborty *et al.* (2016) ^[3], Das and Ghosh (1999) ^[6] and Arya and Singh (2001) ^[1] also reported higher yields with foliar spray of 19:19:19 NPK. Stover yield was highest under 50 x 20 cm spacing, followed by 40 x 20 cm and with 60 x 20 cm spacing the lowest, suggesting that intermediate density maximized biomass production without excessive competition. Similarly, Vaghela *et al.* (2018) ^[22], Patel *et al.* (2011) ^[15], Patel (2003) ^[14] and Malligawad & Patil (2001) ^[10] also reported higher stover yields with optimum plant population in moderate spacing. Among nutrient treatments, 100% RDN + foliar spray of 19:19:19 NPK was superior, followed by 125% RDN, indicating that sustained nutrient supply enhances vegetative growth and total biomass accumulation. Chakraborty *et al.* (2016) ^[3], Das & Ghosh (1999) and Arya & Singh (2001) ^[1] also reported similar results. Harvest index was unaffected by spacing but was significantly improved by nutrient management. The highest HI was obtained under 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS, being at par with 125% RDN and 100% RDN + foliar spray of cow urine + vermiwash, while the control recorded the lowest HI. This shows that balanced nutrition not only increases biomass but also improves the proportion of assimilates allocated to grain production, enhancing overall efficiency.

Table 1: Plant height of grain amaranth as influenced by various spacing and nutrient management treatments at different time interval during 2020-21 and 2021-22

Treatments	Plant height (cm)											
	25 DAS			50 DAS			75 DAS			At harvest		
Spacing	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
S ₁ : 40 x 20 cm	13.3	13.7	13.5	44.8	49.8	47.3	79.0	83.0	81.0	119.9	122.4	121.2
S ₂ : 50 x 20 cm	12.9	13.4	13.2	42.8	47.7	45.2	75.5	79.5	77.5	117.7	119.4	118.5
S ₃ : 60 x 20 cm	12.7	13.1	12.9	42.1	46.9	44.5	73.0	76.6	74.8	115.3	117.3	116.3
SEm±	0.2	0.2	0.2	0.6	0.7	0.7	1.0	0.9	0.9	1.4	1.3	1.4
CD (P=0.05)	NS	NS	NS	NS	NS	NS	3.8	3.4	3.61	3.7	3.7	3.7
Nutrient management												
N ₀ : Control	8.7	9.2	8.9	22.5	25.1	23.8	52.7	56.2	54.5	84.8	91.2	88.0
N ₁ : 75% RDN	11.8	12.1	11.9	34.8	38.7	36.7	68.3	71.7	70.0	115.6	116.8	116.2
N ₂ : 100% RDN	13.1	13.4	13.3	43.8	48.8	46.3	72.0	75.6	73.8	121.3	122.5	121.9
N ₃ : 125% RDN	14.5	15.1	14.8	52.4	58.4	55.4	89.2	93.6	91.4	125.1	126.3	125.7
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	13.5	13.9	13.7	46.4	51.6	49.0	77.6	81.4	79.5	121.9	123.2	122.6
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	12.5	12.8	12.7	40.7	45.3	43.0	69.9	73.3	71.6	119.6	121.1	120.4
N ₆ : 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	15.6	16.1	15.8	54.9	61.5	58.2	94.1	98.7	96.4	129.0	131.1	130.1
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	14.1	14.6	14.4	50.1	55.8	52.9	82.8	86.9	84.9	123.7	125.3	124.5
SEm±	0.2	0.3	0.3	0.9	1.0	0.9	2.0	2.1	2.0	2.6	2.6	2.6
CD (P=0.05)	0.7	0.9	0.8	2.6	2.8	2.7	5.6	5.9	5.7	7.4	7.4	7.4
Interaction (SxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2: Number of leaves plant⁻¹ of grain amaranth as influenced by various spacing and nutrient management treatments at different time interval during 2020-21 and 2021-22

Treatments	Number of leaves plant ⁻¹								
	25 DAS			50 DAS			75 DAS		
Spacing	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
S ₁ : 40 x 20 cm	11.0	12.1	11.5	21.8	23.8	22.8	33.6	39.6	36.6
S ₂ : 50 x 20 cm	11.4	12.5	11.9	22.6	24.7	23.7	34.8	40.5	37.6
S ₃ : 60 x 20 cm	11.5	12.6	12.0	23.2	25.4	24.3	35.7	42.3	39.0
SEm±	0.1	0.1	0.1	0.3	0.3	0.3	0.4	0.5	0.5
CD(P=0.05)	NS	NS	NS	1.0	1.1	1.0	1.5	2.0	1.8
Nutrient Management									
N ₀ : Control	8.4	9.2	8.8	17.3	18.9	18.1	26.6	28.4	27.5
N ₁ : 75% RDN	9.1	9.9	9.5	20.3	22.1	21.2	31.2	36.7	33.9
N ₂ : 100% RDN	11.8	12.9	12.3	20.6	22.5	21.6	31.8	39.4	35.6
N ₃ :125% RDN	12.6	13.8	13.2	24.8	27.0	25.9	38.1	46.2	42.2
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	12.5	13.7	13.1	23.3	25.4	24.4	35.8	43.9	39.8
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	10.6	11.6	11.1	21.5	23.4	22.5	33.0	37.7	35.4
N ₆ : 100% RDN + foliar spray of 9:19:19 NPK at 40 and 60 DAS	13.0	14.2	13.6	29.0	31.7	30.4	44.6	50.1	47.4
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	12.4	13.6	13.0	23.7	25.9	24.8	36.5	44.0	40.2
SEm±	0.3	0.3	0.3	0.7	0.8	0.8	1.1	0.9	1.0
CD(P=0.05)	0.8	0.8	0.8	2.0	2.2	2.1	3.1	2.4	2.8
Interaction (SxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Leaf area plant⁻¹ of grain amaranth as influenced by various spacing and nutrient management treatments at different time interval during 2020-21 and 2021-22

Treatments	Leaf area plant ⁻¹ (cm ²)								
	25 DAS			50 DAS			75 DAS		
Spacing	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
S ₁ : 40 x 20 cm	134.2	146.9	140.5	907.7	981.4	944.6	2071.5	2236.1	2153.8
S ₂ : 50 x 20 cm	138.4	151.5	145.0	941.5	1017.8	979.6	2125.7	2284.3	2205.0
S ₃ : 60 x 20 cm	139.3	152.5	145.9	967.2	1045.4	1006.3	2236.6	2401.2	2318.9
SEm±	1.4	1.5	1.4	10.8	11.4	11.1	25.4	25.9	25.6
CD(P=0.05)	NS	NS	NS	42.5	44.9	43.7	99.7	101.5	100.6
Nutrient Management									
N ₀ : Control	102.5	112.2	107.4	719.6	778.0	748.8	1194.9	1322.4	1258.6
N ₁ : 75% RDN	110.3	120.7	115.5	842.6	911.1	876.9	1968.8	2105.5	2037.1
N ₂ : 100% RDN	142.7	156.3	149.5	859.4	929.0	894.2	2110.7	2255.1	2182.9
N ₃ :125% RDN	153.3	167.9	160.6	1030.3	1114.0	1072.2	2475.3	2644.0	2559.6
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	152.0	166.4	159.2	969.6	1048.1	1008.8	2348.4	2507.9	2428.1
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	128.3	140.5	134.4	893.8	966.2	930.0	2015.7	2150.8	2083.2
N ₆ : 100% RDN + foliar spray of 9:19:19 NPK at 40 and 60 DAS	158.0	173.0	165.5	1208.3	1305.8	1257.0	2685.6	2919.3	2802.4
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	151.2	165.5	158.4	986.9	1066.7	1026.8	2357.5	2552.5	2455.0
SEm±	3.2	3.5	3.4	29.9	32.2	31.1	46.9	49.0	48.0
CD(P=0.05)	9.2	10.1	9.6	85.3	91.9	88.6	133.8	139.9	136.9
Interaction (SxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Stem girth of grain amaranth as influenced by various spacing and nutrient management treatments at different time interval during 2020-21 and 2021-22

Treatments	Stem girth (mm)											
	25 DAS			50 DAS			75 DAS			At harvest		
Spacing	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
S ₁ : 40 x 20 cm	2.9	3.0	2.9	6.4	6.7	6.5	10.1	10.4	10.3	17.3	17.8	17.6
S ₂ : 50 x 20 cm	3.0	3.0	3.0	6.5	6.9	6.7	10.5	10.8	10.7	17.8	18.3	18.0
S ₃ : 60 x 20 cm	3.0	3.1	3.0	6.7	7.1	6.9	10.9	11.2	11.0	18.4	18.9	18.6
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
CD(P=0.05)	NS	NS	NS	NS	NS	NS	0.4	0.5	0.5	0.7	0.8	0.8
Nutrient management												
N ₀ : Control	2.8	2.8	2.8	4.0	4.2	4.1	8.1	8.4	8.2	11.0	11.5	11.2
N ₁ : 75% RDN	2.8	2.8	2.8	6.1	6.4	6.2	9.9	10.2	10.1	16.1	16.5	16.3
N ₂ : 100% RDN	3.0	3.0	3.0	6.5	6.8	6.7	10.3	10.6	10.5	17.9	18.4	18.2
N ₃ :125% RDN	3.1	3.2	3.1	7.6	8.0	7.8	11.4	11.8	11.6	20.3	20.8	20.6
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	3.0	3.1	3.1	6.9	7.2	7.1	10.8	11.1	10.9	19.2	19.8	19.5

60 DAS												
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	2.8	2.9	2.9	6.4	6.7	6.5	10.2	10.5	10.3	17.1	17.6	17.3
N ₆ : 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	3.2	3.3	3.2	7.8	8.1	8.0	11.9	12.2	12.1	21.5	22.1	21.8
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	3.0	3.0	3.0	7.2	7.5	7.4	11.3	11.6	11.4	19.5	20.0	19.8
SEm±	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.4
CD(P=0.05)	0.3	0.3	0.3	0.5	0.5	0.5	0.6	0.6	0.6	1.0	1.0	1.0
Interaction (SxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5: Dry matter accumulation of grain amaranth as influenced by various spacing and nutrient management treatments at different time interval during 2020-21 and 2021-22

Treatments	Dry matter accumulation (g plant ⁻¹)											
	25 DAS			50 DAS			75 DAS			At harvest		
Spacing	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
S ₁ : 40 x 20 cm	2.5	2.6	2.5	10.3	11.0	10.7	22.6	23.8	23.2	25.4	27.3	26.4
S ₂ : 50 x 20 cm	2.5	2.7	2.6	10.7	11.4	11.0	23.8	26.1	24.9	33.7	35.9	34.8
S ₃ : 60 x 20 cm	2.6	2.8	2.7	11.1	11.9	11.5	24.2	26.5	25.4	33.1	36.7	34.9
SEm±	0.03	0.03	0.03	0.11	0.11	0.11	0.24	0.27	0.26	0.31	0.44	0.38
CD(P=0.05)	NS	NS	NS	0.42	0.42	0.42	0.96	1.07	1.01	1.22	1.74	1.48
Nutrient management												
N ₀ : Control	1.2	1.8	1.5	6.3	7.4	6.8	15.3	17.0	16.2	19.5	20.6	20.0
N ₁ : 75% RDN	2.1	2.2	2.1	8.0	8.5	8.3	17.7	19.0	18.3	24.0	26.8	25.4
N ₂ : 100% RDN	2.6	2.7	2.6	10.3	10.9	10.6	24.1	25.8	25.0	31.8	34.6	33.2
N ₃ : 125% RDN	3.0	3.2	3.1	13.3	14.1	13.7	28.7	30.6	29.6	36.8	38.4	37.6
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	2.8	2.9	2.9	12.0	12.8	12.4	24.3	26.3	25.3	32.5	35.8	34.2
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	2.4	2.5	2.4	9.2	9.7	9.5	21.7	23.6	22.7	28.0	30.7	29.4
N ₆ : 100% RDN + foliar spray of 9:19:19 NPK at 40 and 60 DAS	3.1	3.3	3.2	14.2	15.0	14.6	28.8	31.8	30.3	38.6	41.1	39.9
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	3.0	3.1	3.0	12.4	13.1	12.8	27.4	29.6	28.5	34.8	38.3	36.6
SEm±	0.04	0.04	0.04	0.18	0.18	0.18	0.52	0.55	0.54	0.68	0.91	0.80
CD(P=0.05)	0.12	0.13	0.13	0.50	0.53	0.52	1.48	1.58	1.53	1.93	2.60	2.27
Interaction (SxN)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 6: Inflorescence length (cm), number of panicles plant⁻¹, panicle length (cm) and 10 ml volume seed weight (g) of grain amaranth as influenced by various spacing and nutrient management treatments during 2020-21 and 2021-22

Treatments	Inflorescence length (cm)			Number of panicles plant ⁻¹			Panicle length (cm)			10 ml volume seed weight (g)		
	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
S ₁ : 40 x 20 cm	49.0	51.8	50.4	26.6	32.5	29.5	23.7	26.9	25.3	7.7	7.8	7.8
S ₂ : 50 x 20 cm	52.5	55.5	54.0	28.6	34.6	31.6	27.5	29.8	28.7	7.5	7.9	7.7
S ₃ : 60 x 20 cm	54.9	57.7	56.3	30.7	35.8	33.3	28.9	31.8	33.4	7.7	8.0	7.9
SEm±	0.7	0.8	0.8	0.3	0.4	0.4	0.7	0.5	0.6	0.1	0.1	0.1
CD (P=0.05)	2.6	2.9	2.9	1.3	1.5	1.4	2.8	2.0	2.4	NS	NS	NS
Nutrient Management												
N ₀ : Control	44.7	47.2	46.0	16.2	24.4	20.3	17.3	20.1	18.7	7.5	7.6	7.51
N ₁ : 75% RDN	49.7	52.5	51.1	24.9	30.5	27.7	24.1	24.7	24.4	7.7	7.9	7.77
N ₂ : 100% RDN	52.8	55.8	54.3	27.9	34.3	31.1	26.7	29.1	27.9	7.6	8.0	7.81
N ₃ : 125% RDN	55.5	57.9	56.7	34.2	39.4	36.8	29.6	33.7	31.7	7.7	8.1	7.88
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	51.5	54.4	53.0	30.3	36.3	33.3	28.6	30.5	29.6	7.6	7.9	7.75
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	50.7	53.6	52.1	26.5	34.3	30.4	24.3	25.6	25	7.5	7.9	7.71
N ₆ : 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	57.9	61.1	59.5	37.6	44.9	41.2	33.6	38	35.8	7.9	8.1	8.01
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	54.4	57.5	56.0	31.3	36.9	34.1	29.4	33.3	31.4	7.6	7.9	7.75
SEm±	1.1	1.1	1.1	0.9	0.9	0.9	0.8	0.6	0.7	0.1	0.1	0.1
CD(P=0.05)	2.9	3.0	3.0	2.7	2.4	2.6	2.3	1.8	2.1	NS	NS	NS
Interaction (S xN)	S	S	S	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 7: Grain yield (kg ha⁻¹), stover yield (kg ha⁻¹) and harvest index (%) of grain amaranth as influenced by various spacing and nutrient management treatments during 2020-21 and 2021-22

Treatment	Grain yield (kg ha ⁻¹)			Stover yield (kg ha ⁻¹)			Harvest index (%)		
	2020-21	2021-22	Mean	2020-21	2021-22	Mean	2020-21	2021-22	Mean
Spacing									
S ₁ : 40 x 20 cm	982	1007	995	2093	2305	2199	31.7	30.2	30.9
S ₂ : 50 x 20 cm	1051	1084	1068	2285	2455	2370	31.3	30.4	30.9
S ₃ : 60 x 20 cm	867	892	880	1923	2130	2027	31.0	29.4	30.2
SEm±	20	12	16	21	35	28	0.4	0.24	0.3
CD(P=0.05)	57	46	52	85	142	111	NS	NS	NS
Nutrient Management									
N ₀ : Control	449	454	452	1108	1166	1137	28.9	28.1	28.5
N ₁ : 75% RDN	756	782	769	1646	1905	1776	31.5	29.2	30.3
N ₂ : 100% RDN	1006	1046	1026	2194	2429	2312	31.5	30.1	30.8
N ₃ : 125% RDN	1181	1219	1200	2518	2657	2588	31.9	31.4	31.7
N ₄ : 75% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	1032	1064	1048	2261	2554	2408	31.4	29.4	30.4
N ₅ : 75% RDN + foliar spray of CU+VW at 40 and 60 DAS	883	911	897	1929	2167	2048	31.5	29.6	30.5
N ₆ : 100% RDN + foliar spray of 19:19:19 NPK at 40 and 60 DAS	1280	1296	1288	2666	2826	2746	32.5	31.5	32.0
N ₇ : 100% RDN + foliar spray of CU+VW at 40 and 60 DAS	1147	1183	1165	2479	2670	2575	31.7	30.7	31.2
SEm±	20	21	21	51	72	62	0.6	0.4	0.5
CD(P=0.05)	57	60	59	147	206	176	1.6	1.1	1.4
Interaction (SxN)	S	S	S	NS	NS	NS	NS	NS	NS

Conclusion

Grain amaranth growth, yield attributes, and yield were significantly influenced by spacing and nutrient management treatments. Wider spacing (60 x 20 cm) improved growth parameters and yield attributes, whereas the highest grain yield was recorded under 50 x 20 cm due to optimum plant population. Among nutrient treatments, 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS consistently produced superior performance, closely followed by 125% RDN. The interaction between spacing and nutrient management was significant for grain yield and inflorescence length. Based on the results, cultivation of grain amaranth with 50 x 20 cm spacing combined with 100% RDN + foliar spray of 19:19:19 NPK twice at 40 and 60 DAS is recommended for achieving higher productivity.

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