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Research Article

Different planting methods and potassium levels affect the growth and yield of maize (Zea mays L.)

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Abstract
A field experiment was conducted at the School of Agriculture, Lovely Professional University research farm, Phagwara, Punjab, during the spring of 2023. The experiment used a Split Plot Design with three replications of 16 treatment combinations. The treatment combination comprises four different spacing in the main plot (flatbed:60 x 20 cm, ridge bed: 60 x 20 cm, flat bed: 45 x 20 cm and ridge bed: 45 x 20 cm) and four levels of potassium (0 kg K/ha, 20 kg K/ha, 40 kg K/ha and 60 kg K/ha). The soil of the experimental field was sandy loam in texture with normal pH and EC, and available nitrogen, phosphorus, and potassium were in the medium range (172.43, 27.4, 238.6 kg/ha). The treatment combination of Ridge Bed with a spacing of 45 x 20 cm and 40 kg K/ha gives the best results. It results in rapid tasselling, cob formation, maturity, and crop growth rate reaching its highest levels. Yield attributes such as cob length, cob girth, rows per cob, grains per row, grains per cob, grain and stover yields were also significantly higher in (ridge bed: 45 x 20 cm with 40 kg K/ha) over the other treatment combinations.

Keywords: Maize; planting methods; spacing; potassium levels; yield attributes

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1. Introduction

Maize (*Zea mays* L.) is a major cereal crop in Poaceae. Major maize-producing countries are the USA, China, India, South and Central Africa, Argentina, Brazil and Mexico. The highest grain-producing states in India are Utter Pradesh, Bihar, Rajasthan, Madhya Pradesh, Punjab, Karnataka, Himachal Pradesh and Andhra Pradesh. The area under cultivation for this crop is increasing year after year. According to APEDA, there was a recorded 35.67 Mt production of maize grains during the year 2023-24. Maize is the world's third most important cereal food crop after rice and wheat. Maize is grown worldwide in subtropical, tropical, and temperate regions. It is a staple crop in many countries. In India, 45 to 48% of maize produce (grain) is consumed by humans, and the rest is used for cattle and poultry feed by the starch and oil industries. It acts as a dual-purpose crop; maize serves both as a source of food for humans and as feed for livestock. Maize grain contains about 10% protein, 4% oil, 70% carbohydrates, 2.3% crude fibre, 10.4% albuminoids and 1.4% ash. Maize grain has significant quantities of vitamin A, nicotinic acid, riboflavin, and vitamin E and is low in calcium but high in phosphorus.

Production of maize crops depends on various biotic and abiotic factors and geometric practices. Plant population and spacing affect biomass production and grain yield (1). Amongst all, maize yield is closely related to plant population; changing the population density of plants is an agronomical practice that has continuously been studied. The recommended spacing of maize is 60 × 20 cm. Fodder maize sown at a closer row spacing of 40 cm has better growth in terms of foliage, height of plant and occurrence of internodes and stem girth (2). Considering the recommended spacing according to the cultivation objectives for fodder production or human consumption is also essential. The main purpose of increasing the plant density is to enhance yield in terms of grain, thus making the crop system more efficient and competitive per area unit. In maize crops, maintaining a spacing of 75 x 25 cm has significantly influenced the growth and yield of the crop (3). Maximum plant population per unit area increases yield because grain yield is directly proportional to the number of effective plants standing in the field at harvesting. The numbers of plants per unit area were influenced by the distance between rows to rows, the distance between plants to plant in a row, and the number of plants on a hill. Planting in an optimum plant spacing allows for ease of field operations, such as fertilizers application or weeding, minimizes competition among plants for light, water, and nutrients, and creates a favourable micro-climate to the canopy to reduce the risk for pests and diseases. Many farmers practised narrow spacing due to increased productivity and suppressed weed incidence compared to those of wider spacing. (4) Meeting the demands of the population requires a lot of crop productivity.

Nutrient management is an essential factor in the cultivation of crops to achieve higher yields and maintain soil health. Maize has distinct requirements for nutrients at various stages of growth. Nitrogen, phosphorous and potassium are required in early growth stages for better root and shoot development. Potassium is provided to ensure plant health and tolerance to specific abiotic and biotic stresses. Increasing the application of potassium fertilizers can increase the grain yield of maize (5). Potassium fertilisation significantly increased the agronomic, physiological, growth and yield parameters of maize (6). Applying K increased the K concentration in the grain and straw of maize. Application of 150 kg/ha N and 30 kg/ha Zn resulted in higher values in the growth and yield of maize (7). Nutrients are provided to the plants in various forms and sources such as organic manures like compost, vermicompost, FYM, poultry manure, etc., which also enhances the soil structure as well as the soil microbial activity or as provided as inorganic compounds like rock phosphate, wood ash or conventional forms of fertilizers like urea, MOP, DAP, SSP, TSP, etc. Understanding the crop's requirements and the available nutrients in the soil is necessary before application to prevent excess and provide a balanced and precise level of fertilizers for optimum crop production, enhancing the yield of the maize crop. Providing adequate spacing and potassium fertilizers play an important role in the production of maize, and there is a significant positive correlation between growth and yield attributes (8).

2. Materials and Methods

The experiment was conducted during the spring of 2023 at Research Farm of Agronomy, School of Agriculture, Lovely Professional University, Phagwara Punjab, implementing 'Split Plot Design'. The soil at the location of the experiment has a high percentage of sand (70%) and was classified as sandy loamy soil. The experimental field was prepared with tractor-drawn cultivars, and plots were prepared according to the treatments. The field was irrigated regularly to meet the crop's moisture requirement. Fertilizers were applied per the recommendation rate, *i.e.*, N and P 120 kg/ha and 80 kg/ha were applied through urea and SSP. K was used according to the treatment details mentioned in Table 1, *i.e.*, 0 kg/ha, 20 kg/ha, 40 kg/ha and 60 kg/ha.

P1899 hybrid variety was sown by dibbling on ridges and flatbed according to treatments. The pre-emergence herbicide pendimethalin (0.75 l) was applied just after crop irrigation to reduce the emergence of unwanted weeds at early stages. Manual weeding was done at later stages of growth to keep the plot weed-free. The crop was harvested in June 2023 by cutting the plants at the ground level above the root zone using a sickle when the cobs were fully mature. After harvesting, the stalks were left in the field. Then, the harvested plant was kept under the sun for 6-7 days for drying, and all the yield-related observations were recorded.

For analysis and data collection, tagging was done on randomly selected plants from each plot. Yield and quality attributes were recorded at the time of harvesting. Crop parameters which were recorded were plant population at initial and final stage, plant height and dry weight at monthly intervals, days taken to germination, days taken to tasselling, days taken to cob formation and maturity, RGR (Relative Growth Rate), CGR (Crop Growth Rate), number of rows per cob, cob length, cob girth, number of grains per row, number of grains per cob, seed index, grain yield, straw yield, harvest index (%).

3. Results and Discussions

3.1 Growth and Developmental Studies

3.1.1 Plant population

The data about plant population indicated that the plant population of maize had been significantly influenced by different spacing and various potassium levels. The significantly highest plant population was recorded initially on the Ridge Bed at 45 x 20cm spacing (270.75). The lowest plant population was recorded at Flat Bed sown at 60 x 20cm (263.08). A higher plant population was recorded due to the close (45 x 20 cm) spacing between the row-row. (9) also reports similar results.

Among the different potassium levels, a significantly higher initial and final stages plant population was recorded with the application of 40 kg K/ha compared to the control plot during the study period. The utilization of potassium in maize may lead to an augmentation in cellular metabolism and enzyme activity, as well as the regulation of cellular osmosis. Moreover, it can enhance water absorption and promote the rate of photosynthesis, thereby contributing to the proliferation of plant population and overall plant development. Corresponding outcomes were reported in a study conducted (10).

3.1.2 Plant height (cm)

Different spacing and levels of potassium treatments significantly influenced the plant height of maize at different growth stages. Table 2 indicated that significantly taller plants were recorded in Ridge Bed sowing at 45 x 20 cm at 90 DAS. The closer space of the plant also enhances the competition of height. (11) reported that the different plant spacing and densities generally influenced maize plant height. Among the different potassium levels, a significantly taller plant was recorded with the application of 40 kg K/ha at different stages of observation. However, it is also statistically on par with 60 kg K/ha at 90 DAS.

(10) has given similar results. These results could be the advantages of K fertilization's impact on providing optimal planting distance. The outcomes of (12) support similar results by employing potassium fertilizers in diverse maize planting schemes.

3.1.3 Plant dry weight (g per plant)

Significantly higher dry weight per plant was recorded in Ridge bed sowing at 60 x 20 cm at 90 DAS, similar to the results reported (13). Among the different potassium levels, 40 kg K/ha was the highest dry weight per plant recorded at 90 DAS, while the lowest dry weight of the maize plant was 0 kg K/ha.

Furthermore, sufficient potassium levels promote enhanced shoot growth and photosynthesis rates, ultimately improving the absorption of economically significant plant components; likewise, similar results have been observed by utilising potassium fertilizers in diverse maize planting configurations (13).

3.1.4 RGR (Relative Growth Rate) (g/g/days) & CGR (Crop Growth Rate) (g/m^2/days)

Optimal spacing and fertilization with potassium have significantly changed maize's relative and crop growth rates during the study period. Significantly higher RGR was recorded when on a Ridge bed at a spacing of 60 x 20 cm at 60-90 days compared to flatbed sowing at 60 x20 cm; it was found to support the outcomes observed by (15). Amongst the different potassium levels, the highest RGR was recorded at 60 kg K/ha; however, it was found statistically on par with the application of 40 kg K/ha at 60-90 DAS. Minimum RGR was recorded in the control plot. Similar results were also observed by (16) when maize was cultivated with integrated nutrient management practices evaluating the impact of different nutrient management strategies on maize growth and productivity.

Crop Growth Rate was recorded highest when sown on ridge beds 60 x 20 cm at 60-90 DAS compared to the Flat bed sowing at 60 x 20 cm spacing. A higher crop growth rate was recorded at 60 kg K/ha among the different potassium levels. However, the application of 60 kg K/ha was significantly on par with the application of 40 kg K/ha at 60-90 DAS. The minimum crop growth rate was recorded in the control plot. (14, 16) found similar results in maize cultivation with integrated nutrient management practices assessing different strategies' impact on growth and productivity.

3.2 Developmental studies

The data on parameters associated with developmental studies, *i.e*., germination, days taken to tasselling, days taken to cob formation, and maturity, presented in Table 3 indicate that the days taken to tasselling, cob formation, and maturity of maize have been influenced by spacing and various levels of potassium. There was no significant effect of spacing potassium on days taken to germination.

Optimal plant spacing minimizes interplant competition, enhancing both root and shoot development while maximizing resource utilization such as water and nutrients, thereby boosting growth rate and yield. Additionally, appropriate potassium levels promote increased shoot growth and photosynthesis rates, ultimately enhancing the assimilation of economically valuable plant parts. Likewise, (12) similar results were recorded when applying K fertilizers under different planting systems of maize.

3.3 Yield and Yield Contributing Attributes

3.3.1 Yield attributes

3.3.2 Cob dimensions

The yield and its associated characters were positively influenced by implementing different spacing and potassium levels, namely cob length and girth, during the study period. Longer and wider cobs were obtained when crops were sown on Ridges bed 45 x 20 cm spacing; however, this treatment was on par with those sown on Flatbed 60 x 20 cm. Cobs with shorter lengths and smaller girths were recorded in flat beds at 45 x 20 cm spacing during spring 2023.

Among the different levels of potassium, longer and thicker cobs (20.49cm and 4.9 cm) were obtained with the application of 40 kg K /ha as compared to the control, where shorter and narrower cobs were obtained (19.65cm and 4.59 cm). (15) Similar results were also reported using potassium fertilizers, which increased the maize yield attribute.

3.3.3 Grain yield attributes

Data about the number of rows per cob, number of grains per row, and seed index has been given in Table 5. Recorded data indicated that different spacing and potassium levels influenced the yield attributes at maturity. However, spacing and different potassium levels found no significant interactive effects. The observed increment in grain yield may be attributed to proper spacing between rows and applying specific amounts of potassium, reducing competition among plant species. It enhances the growth of roots and shoots by effectively utilizing resources like water and nutrients, thereby improving the overall growth rate and yield. Moreover, adequate potassium levels stimulate increased growth and photosynthesis, enhancing the absorption of important plant yield components.

Similarly, (15) obtained comparable findings by employing potassium fertilizers in various maize planting arrangements.

3.3.4 Yield

The yield was significantly enhanced, showing preferable characters on grain yield, stover yield and harvest index of maize as influenced by the different spacing and various potassium levels, as presented in Table 6. The yield on Ridge beds at 45 x 20 cm was 2.3%, 24.4%, and 25.5%, significantly higher than Ridge beds at 60 x 20 cm, Flatbeds 45 x 20 cm and Flatbeds 60 x 20 cm, respectively. The lowest grain yield was recorded in flatbed sowing at 60 x 20 cm. Close spacing in maize cultivation has been shown to affect grain yield in several ways positively. Research works of (17) indicate that moderately denser row spacing significantly increases grain yield by promoting early plant development, resulting in higher plant height, leaf area index, cob length, cob diameter, and other yield-attributing characteristics.

Among different potassium levels, significant grain values, stover yield, and harvest index were recorded in treatment with 40 kg K/ha over the control plot. The grain yield was 6.01% and 2.4% lower when 60 kg and 20 kg potassium were applied during the study period. Compared to 40 kg K/ha, 9.7% and 3.0% lower stover yield was obtained when 20 kg and 60 kg potassium were applied.

(18) recorded similar findings when providing different nutrient management strategies in maize cultivation under rainfed conditions. Likewise, Rahman *et al.* (2016) (19) highlight the importance of nutrient management and inter-row distances in influencing yield and related factors in maize cultivation, providing practical contributions to the farmers. However, it is essential to note that the benefits of close spacing may vary depending on factors like nutrient levels, highlighting the importance of optimizing these factors for maximizing maize yield and overall crop performance.

Research by (20) demonstrated that narrow row spacing at higher stand densities resulted in significantly higher ear ratio and dry matter content, potentially leading to increased stover yield. Lower losses in plant numbers were also observed, which could contribute to improved stover yield, although the effects were only consistently maintained during harvest time.

Table 1: Treatment Details

Main plot (Spacing)	
S_1 (Flat Bed)	60 x 20 cm
S_2 (Ridge Bed)	60 x 20 cm
S_3 (Flat Bed)	45 x 20 cm
S_4 (Ridge Bed)	45 x 20 cm
Subplot (Potassium levels)	
K_1	0 kg K/ha
K_2	20 kg K/ha
K_3	40 kg K/ha
K_4	60 kg K/ha

Table 2 Effect of different spacing techniques and levels of potassium on initial plant population, plant height (cm), plant dry weight (gm/plant), RGR and CGR of maize.

Treatments	**Initial Plant population**	**Plant height (cm) at 90 DAS**	**Dry weight (g/plant) at 90 DAS**	**RGR(g/g/days) at 60-90 DAS**	**CGR (g/m^2/days) at 60-90 DAS**
Main plot					
Flat Bed:60x20cm	263	175	56.2	3.98	0.04
Ridge Bed:60x20cm	266	185	61.1	3.98	0.08
Flat Bed:45x20cm	265	182	57.6	3.92	0.04
Ridge Bed:45x20cm	271	193	60.4	3.96	0.06
SE m (±)	0.92	0.67	0.76	0.01	0.00
C.D. (0.05)	3.18	2.34	2.63	0.04	0.01
Subplot					
0 kg K/ha	256	178	54.6	3.87	0.01
20 kg K/ha	265	184	56.7	3.91	0.05
40 kg K/ha	276	188	63.2	3.97	0.06
60 kg K/ha	269	185	60.3	4.01	0.07
SE m (±)	0.94	0.85	0.67	0.01	0.00
C.D. (0.05)	2.75	2.49	1.96	0.03	0.01
Interaction					
SE m (±)	**1.89**	**1.71**	**1.34**	**0.03**	**0.01**
C.D. (0.05)	**5.51**	**4.99**	**NS**	**NS**	**0.02**

Table 3. Effect of different spacing techniques and levels of potassium on the number of days taken for germination, tasseling, cob formation and maturity on maize.

Treatment	**Days taken to**			
	Germination	**Tasselling**	**Cob formation**	**cob maturity**
Main plot				
Flat Bed: 60x20cm	10.6	63.2	68.6	118
Ridge Bed: 60x20cm	10.5	63.3	68.7	115
Flat Bed: 45x20cm	10.8	63.3	68.6	117
Ridge Bed: 45x20cm	10.3	63.8	68.4	115
SE m (±)	0.07	0.09	0.06	0.52
C.D. (0.05)	0.24	0.32	0.23	1.80
Subplot				
0 kg K/ha	10.8	63.2	68.9	117
20 kg K/ha	10.6	62.9	68.7	116
40 kg K/ha	10.3	62.8	68.2	115
60 kg K/ha	10.5	63.5	68.5	116
SE m (±)	0.07	0.07	0.08	0.48
C.D. (0.05)	NS	0.22	0.23	1.40
Interaction				
SE m (±)	**0.14**	**0.15**	**0.16**	**0.96**
C.D. (0.05)	**NS**	**0.44**	**NS**	**NS**

Table 4 Effect of different spacing techniques and levels of potassium on cob length (cm), cob girth (cm) and final plant population of maize

Treatment	**Cob length(cm)**	**Cob girth(cm)**	**Final plant population**
Main plot			
Flat Bed: 60x20cm	19.8	4.42	253
Ridge Bed: 60x20cm	20.0	4.80	258
Flat Bed: 45x20cm	19.9	4.65	254
Ridge Bed: 45x20cm	20.5	5.07	263
SE m (±)	0.18	0.08	1.80
C.D. (0.05)	0.62	0.29	6.25
Subplot			
0 kg K/ha	19.7	4.59	250
20 kg K/ha	19.9	4.67	257
40 kg K/ha	20.5	4.9	266
60 kg K/ha	20.2	4.78	258
SE m (±)	0.12	0.05	1.21
C.D. (0.05)	0.37	0.15	3.54
Interaction			
SE m (±)	**0.25**	**0.11**	**2.43**
C.D. (0.05)	**0.74**	**NS**	**7.08**

Table 5. Effect of different spacing techniques and levels of potassium on number of rows per cob, number of grains per row, number of grains per cob and seed index of maize

Treatment	No. of rows per cob	No. of grains per row	No. of grains per cob	Seed index
Main plot				
Flat Bed:60x20cm	12.6	31.1	381	23.3
Ridge Bed:60x20cm	13.0	31.8	388	24.8
Flat Bed:45x20cm	12.8	31.6	383	24.1
Ridge Bed:45x20cm	13.0	31.9	393	27.3
SE m (±)	0.07	0.08	1.21	0.31
C.D. (0.05)	0.25	0.28	4.19	1.08
Subplot				
0 kg K/ha	12.5	30.8	367	23.2
20 kg K/ha	12.7	31.6	388	24.8
40 kg K/ha	13.2	32.1	396	25.2
60 kg K/ha	12.9	32.0	392	26.1
SE m (±)	0.09	0.15	1.73	0.22
C.D. (0.05)	0.27	0.45	5.06	0.64
Interaction				
SE m (±)	**0.19**	**0.32**	**3.47**	**0.61**
C.D. (0.05)	**NS**	**NS**	**NS**	**NS**

Table 6 Effect of different spacing techniques and levels of potassium on grain yield(q/ha), stover yield (q/ha) and harvest index (%) on maize.

Treatment	Grain yield (q/ha)	Stover yield(q/ha)	Harvest index (%)
Main plot			
Flat Bed: 60x20cm	45.5	72.3	36.1
Ridge Bed: 60x20cm	59.9	85.7	41.0
Flat Bed: 45x20cm	46.4	81.3	38.0
Ridge Bed: 45x20cm	61.4	87.9	41.4
SE m (±)	0.50	2.17	0.53
C.D. (0.05)	1.72	7.51	1.84
Subplot			
0 kg K/ha	51.4	75.9	37.9
20 kg K/ha	53.4	79.0	39.3
40 kg K/ha	54.7	87.5	40.4
60 kg K/ha	53.6	84.9	38.9
SE m (±)	0.36	1.73	0.55
C.D. (0.05)	1.07	5.06	1.61
Interaction			
SE m (±)	**0.73**	**3.47**	**1.10**
C.D. (0.05)	**2.14**	**10.13**	**3.22**

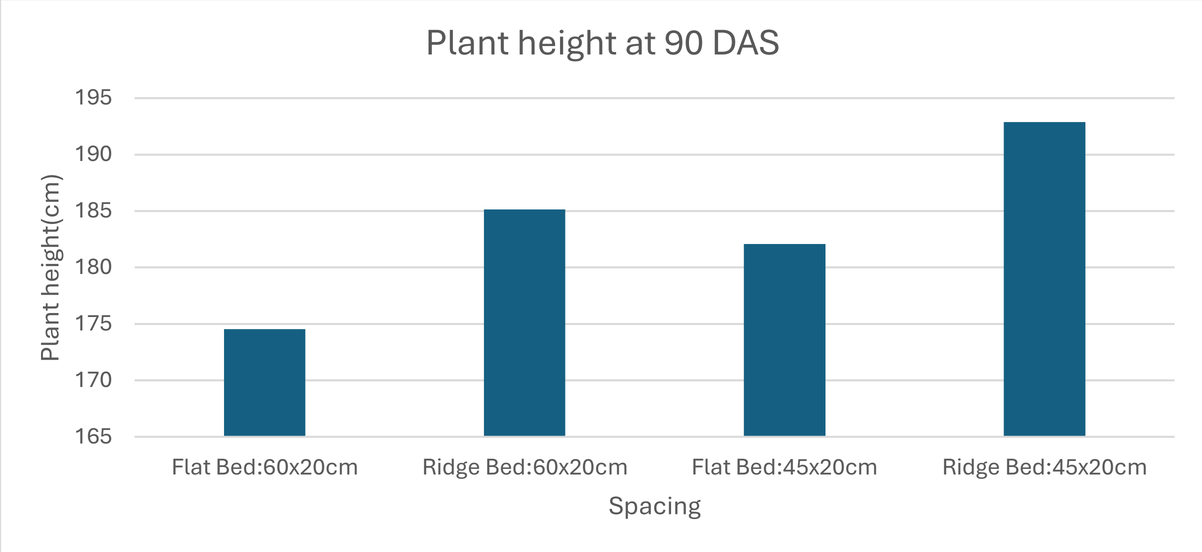

Fig. 1 Effect of different spacing techniques on maize plant height (cm) at 90DAS.

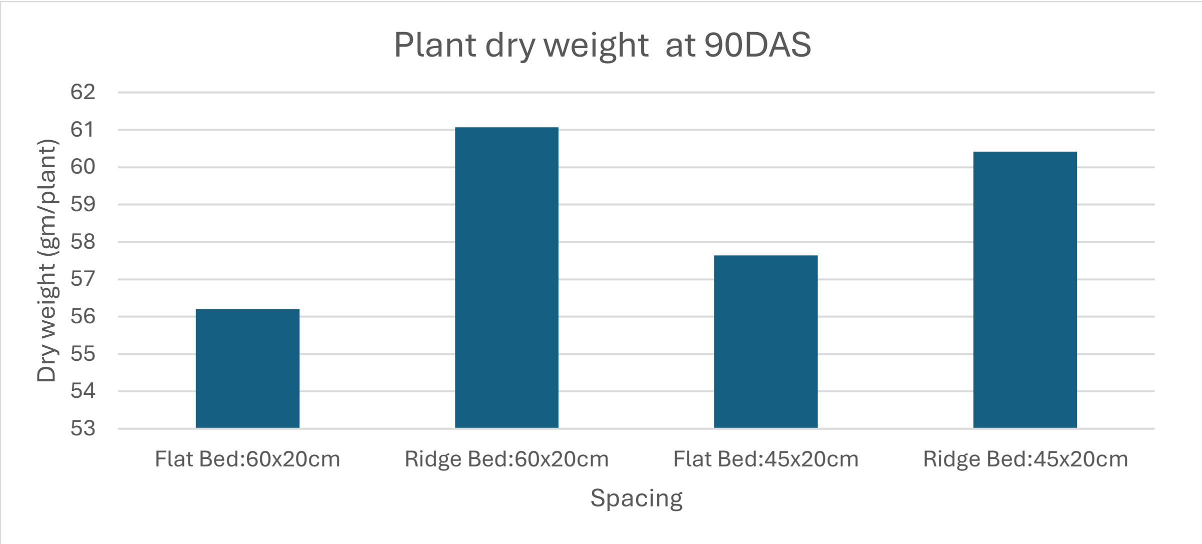

Fig. 2 Effect of different spacing techniques on maize plant dry weight (gm/plant) at 90DAS.

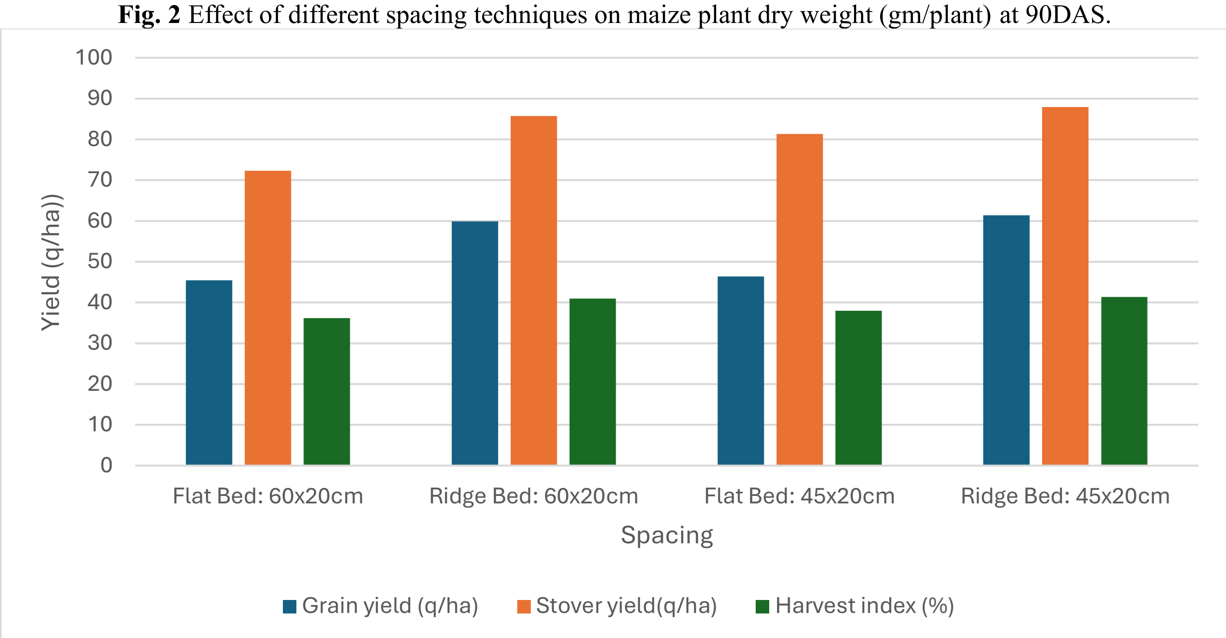

Fig. 3. Effect of different spacing techniques on grain and stover yield (q/ha) and harvest index (%) of maize.

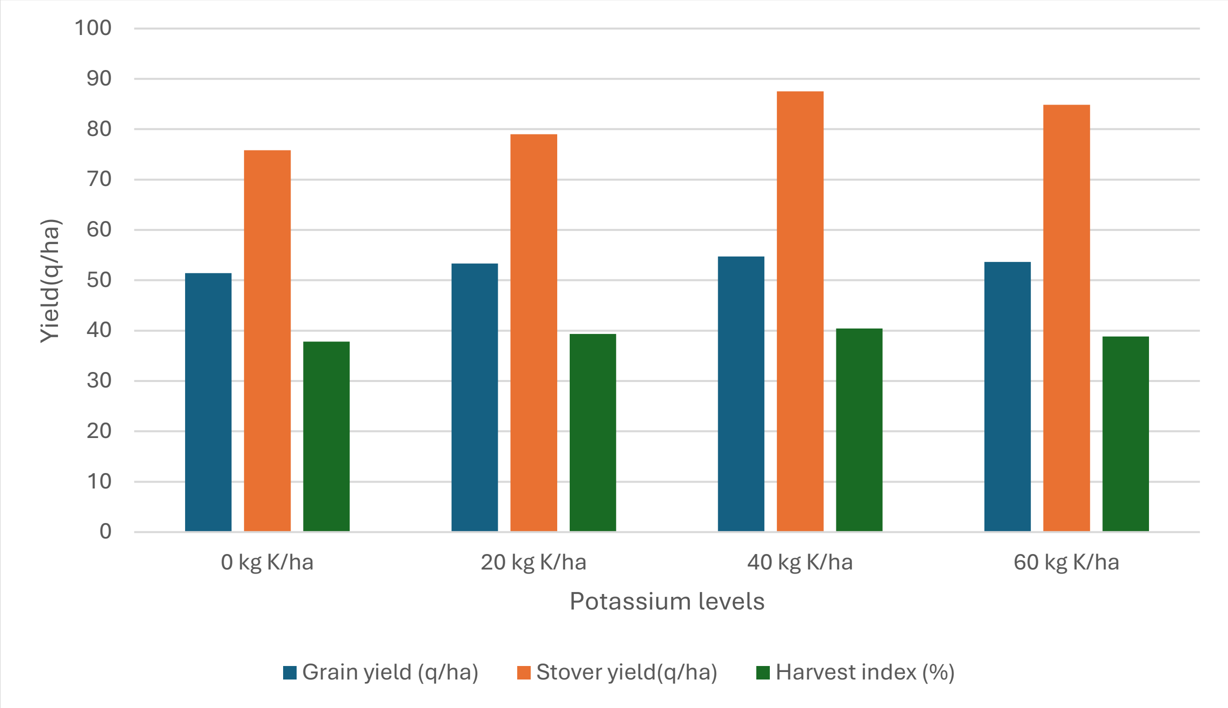

Fig. 4. Effect of different potassium levels on grain and stover yield (q/ha) and harvest index (%) of maize.

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4. Conclusions

Our results show that row spacing of Ridge bed 45 x 20 cm and potassium application of 40 kg/ha significantly influenced plant population, plant height, days taken to tasselling, cob formation, grain yield, stover yield and harvest index of maize crop. However, the Ridge bed, which was 45 x 20 cm and 60 kg K/ha, significantly affected the number of rows per cob, the number of grains per row, and the seed index of maize.

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Compliance with ethical standards

Conflict of Interest: The authors declare that there is no conflict of interest.

Ethical issues: None.

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