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# Effect of limited irrigation and planting systems on yield and water productivity of maize (*Zea mays*)

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ABSTRACT

A field experiment was conducted during the rainy (*kharif)* seasons of 2019 and 2020 at the research farm opf ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of limited irrigation application and planting systems on yield and water productivity of maize (*Zea mays* L.). The experiment was laid out in factorial randomized complete block design with 3 replications. The experiment consisted of two crop establishment methods as one factor, viz. Narrow bed planting and broad bad planting and 5 irrigation levels, viz. 25% DASM (Depletion of available soil moisture); 25% DASM at tasselling, silking, grain filling and 50% during rest of time; 50% DASM at all growth stages; 50% DASM + KCl spray at 40 DAS and at pre-tasselling; and 50% DASM+2% Urea spray at 40 DAS and at pre-tasselling. Experimental results revealed that the broad bed system of planting during 2019 and 2020 recoded significantly higher grain yields (4.37 and 4.57 t/ha) compared to the narrow bed system (4.23 and 4.38 t/ha), respectively. Regarding different irrigation levels, the highest water productivity (91.26 and 199.76 kg/ha-cm) was observed with irrigation at 50% DASM along with two sprays of urea at 40 DAS during both the years, respectively. It was concluded that broad bed along with irrigation at 50% DASM with two sprays of urea proved to be most effective approach to enhance water productivity and yield of maize crop.

**Keywords**: Crop establishment methods, Growth, Maize yield, Water productivity

Rice-wheat cropping system played a crucial role in ensuring food and livelihood security for a significant portion of the Indian population. However, this system's future sustainability is now in question due to several pressing issues. These challenges include natural resource degradation (Mishra *et al.* 2021, Kumar *et al.* 2021), a rapid decline in the water table (Singh *et al.* 2014) and deteriorating soil health (Parihar *et al.* 2016). To address some of these concerns, maize (*Zea mays* L.) emerges as a viable alternative to rice and a potential driver for diversifying the rice-wheat system. India ranks fourth in maize cultivation and seventh in production worldwide, representing approximately 4% of the global maize area and 2% of total production. The production of maize in India has increased significantly over the years, from 1.73 million MT in 1950–51 to 31.51 million MT by 2020–21, marking close to an 18-fold increase. This growth is attributed to 5.42 times increase in average productivity, from 547 to 2965 kg/ha, while the cultivated area increased by nearly three times. Maize is predominantly grown in two seasons in India: the rainy (*kharif*) and winter (*rabi*) seasons. But 83% of the maize area is dedicated to *kharif* cultivation. Consequently, the productivity of *kharif* maize (2706 kg/ha) is lower compared to *rabi* maize (4436 kg/ha), which is predominantly grown under assured irrigation (ICAR-IIMR 2021). For assuring the high grain yield, and enhance water productivity of maize which is susceptible to both drought as well as water logging, the irrigation should be applied at crop sensitive stage to conserve water and at the same time to attain higher water use efficiency and crop productivity.

Bed planting, where crops are grown on raised beds with furrows for irrigation, presents an opportunity for crop diversification and more efficient water use, both in rainfed and irrigated conditions. Rising population put more pressure on more production which can be done by, implementing high-yield and water-saving agricultural strategies. With the prevailing weather conditions leading to a decrease in the groundwater table and availability of irrigation water, the productivity of maize may decline, posing a challenge to providing sufficient food for the growing population. To ensure the sustainable yield of maize, it is essential to maintain sufficient moisture, particularly during critical stages of crop growth. Based on this scenario, present study aims to find potential solutions to improve the water use efficiency and productivity of maize, especially in regions facing water scarcity and fluctuating climatic conditions.

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## MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif)* seasons of 2019 and 2020 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi. The soil of the experimental field was sandy loam and alkaline in nature (*p*H 7.5) with 0.39 dS/m EC, low in organic carbon (0.43%) and available nitrogen (234.8±22.5 kg/ha), and medium in available phosphorus (13.8±1.5 kg/ha) and potash (236.4±15.3 kg/ha). The experiment was laid out in a Factorial Randomized Complete Block Design and replicated trice. The Treatment consisted of two planting (crop establishment) systems as one factor i.e. $M_1$, Narrow bed; and $M_2$, Broad bed planting and 5 levels of irrigation at different stages as another factor i.e. $I_1$, 25% DASM (Depletion of available soil moisture); $I_2$, 25% DASM at tasselling, silking, grain filling and 50% during rest of time; $I_3$, 50% DASM at all growth stages; $I_4$, 50% DASM+K spray (KCl) at 40 DAS and at pre-tasselling; and $I_5$, 50% DASM+2% Urea spray at 40 DAS and at pre-tasselling. Maize cv. PMH 1 seeds were dibbled in single row on narrow bed spaced at 0.65 m (row to row) and in broad beds 2 rows were sown 0.60 m apart. Maize crop was fertilized with (150:26.2:33.2) Nitrogen: Phosphorous: Potassium (kg/ha).

Full dose of phosphorus and potassium along with 33% of nitrogen was applied as a basal at the time of sowing. The remaining nitrogen was applied in two equal splits i.e. at knee high and tasselling stage The measured amount of water was applied as irrigation in the furrows between beds on the basis of treatments in experiment. The recommended package of practices were followed for weed and insect-pest control etc.

Water productivity was calculated as:

$$\text{Water productivity (kg/ha-cm)} = \frac{\text{Grain yield}}{\text{Total water requirement}}$$

Total water requirement was calculated by including the effective rainfall (50%) plus quantity of water applied to the field for each treatment (Fig. 1).

## RESULTS AND DISCUSSION

*Moisture content at knee high and flowering stage*: During the year 2019, no significant difference in soil moisture content at the 0–15 cm depth was observed between broad beds and narrow bed systems. However, in 2020, a significant difference was noticed, with relatively higher moisture content in broad beds compared to the narrow (Table 1). At the 15–30 cm depth, soil moisture content showed significant variation in 2019 but not in 2020. Regarding the different irrigation regimes at the 0–15 cm depth, a significant difference in soil moisture content was observed. The treatment $I_1$ i.e. 25% DASM (depletion of available soil moisture) showed the highest moisture content (11.98 and 10.45% in both years, respectively) compared to the other treatments. Similar trends were observed at the 15–30 cm depth, with significant differences in soil moisture content among the different irrigation regimes.

The interaction effect between planting system and irrigation regimes studied were found to be non-significant in 2019 but significant in 2020 at 0–15 cm depth of soil. However, at deeper depth of 15–30 cm, the interaction effect was significant in both years. The variation in soil moisture content during 2019 was attributed to high initial rainfall, but uneven distribution of subsequent rainfall during the crop duration. In contrast, the rainfall distribution during 2020 was more consistent. The higher moisture content in the broad bed system can be attributed to the larger volume of soil available, allowing it to hold more quantity of water with less losses due to evaporation and surface percolation. These findings are in line with Pooniya *et al.* (2022). Overall, the study demonstrates that the choice of planting system and irrigation regime can significantly impact soil moisture content, especially during varying climatic conditions. The broad bed system, combined with appropriate irrigation practices, appears to be more

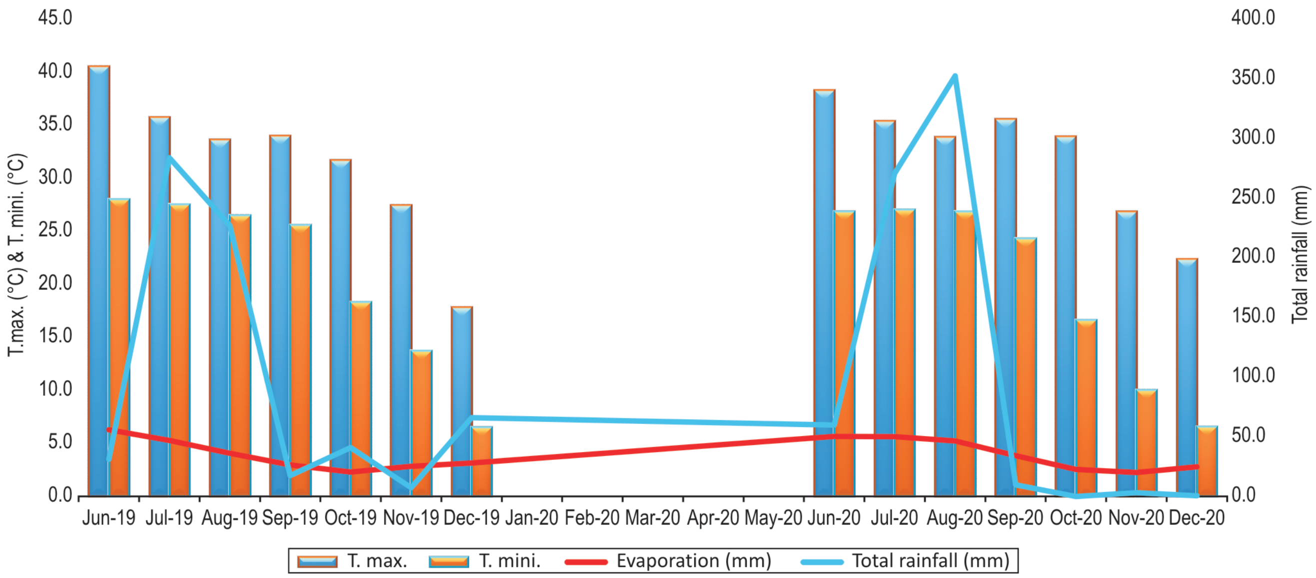


Fig. 1 Monthly meteorological data (June to December), 2019 and 2020 of ICAR-Indian Agricultural Research Institute, New Delhi.

Table 1 Effect of bed planting and limited irrigation on soil moisture content (%) at various depths during different growth stages of maize

| Treatment | Knee high (0–15 cm) | | At flowering (0–15 cm) | | Knee high (15–30 cm) | | At flowering (15–30 cm) | |
|---|---|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
| *Planting methods (M)* | | | | | | | | |
| $M_1$ | 10.65 | 8.05 | 9.64 | 8.04 | 8.04 | 6.85 | 6.56 | 6.35 |
| $M_2$ | 10.80 | 8.56 | 10.19 | 8.61 | 8.53 | 6.75 | 6.70 | 6.83 |
| SEm(±) | 0.18 | 0.13 | 0.27 | 0.17 | 0.14 | 0.07 | 0.11 | 0.16 |
| CD (P=0.05) | NS | 0.38 | NS | 0.50 | 0.41 | NS | NS | 0.47 |
| *Irrigation regimes (I)* | | | | | | | | |
| $I_1$ | 11.98 | 10.45 | 11.0 | 11.52 | 10.46 | 8.47 | 9.09 | 8.55 |
| $I_2$ | 11.00 | 10.44 | 10.25 | 11.00 | 10.41 | 8.75 | 8.50 | 8.59 |
| $I_3$ | 10.31 | 8.53 | 10.0 | 8.23 | 8.50 | 6.96 | 6.87 | 6.89 |
| $I_4$ | 10.09 | 7.22 | 9.45 | 5.87 | 7.17 | 5.89 | 5.05 | 5.12 |
| $I_5$ | 10.24 | 4.89 | 8.88 | 5.00 | 4.87 | 3.91 | 3.65 | 3.79 |
| SEm(±) | 0.28 | 0.20 | 0.43 | 0.26 | 0.22 | 0.11 | 0.17 | 0.25 |
| CD (P=0.05) | 0.83 | 0.60 | 1.28 | 0.79 | 0.64 | 0.34 | 0.51 | 0.74 |
| *Interaction M × I* | | | | | | | | |
| $M_1I_1$ | 11.84 | 9.62 | 10.54 | 11.25 | 9.70 | 8.08 | 9.66 | 8.33 |
| $M_1I_2$ | 10.95 | 10.20 | 9.88 | 10.93 | 10.21 | 8.64 | 7.92 | 8.11 |
| $M_1I_3$ | 10.23 | 9.15 | 9.84 | 7.49 | 9.12 | 7.60 | 6.89 | 6.86 |
| $M_1I_4$ | 10.04 | 6.73 | 9.34 | 5.30 | 6.67 | 6.03 | 4.70 | 4.77 |
| $M_1I_5$ | 10.18 | 4.53 | 8.57 | 5.21 | 4.50 | 3.89 | 3.62 | 3.68 |
| $M_2I_1$ | 12.12 | 11.28 | 11.45 | 11.79 | 11.22 | 8.86 | 8.52 | 8.77 |
| $M_2I_2$ | 11.05 | 10.67 | 10.62 | 11.06 | 10.60 | 8.86 | 9.07 | 9.07 |
| $M_2I_3$ | 10.39 | 7.92 | 10.15 | 8.97 | 7.88 | 6.33 | 6.85 | 6.92 |
| $M_2I_4$ | 10.15 | 7.70 | 9.56 | 6.43 | 7.68 | 5.76 | 5.39 | 5.47 |
| $M_2I_5$ | 10.30 | 5.24 | 9.19 | 4.78 | 5.25 | 3.94 | 3.67 | 3.89 |
| SEm(±) | 0.39 | 0.28 | 0.61 | 0.37 | 0.31 | 0.16 | 0.24 | 0.35 |
| CD (P=0.05) | NS | 0.84 | NS | NS | 0.91 | 0.48 | 0.72 | NS |

Treatment details are given under Materials and Methods.

effective in retaining soil moisture, which can be crucial for optimizing crop performance and water use efficiency.

*Moisture content at flowering stage*: During the flowering stage, soil moisture content at the 0–15 cm depth was found to be non-significant in 2019 but significant in 2020, with higher moisture content observed in the broad bed system. Similarly, different irrigation regimes also showed significant differences during both the years, with $I_1$ treatment recorded the highest moisture content (11.0 and 11.52% in 2019 and 2020, respectively) compared to rest of the treatments. However, the interaction effect between planting system and irrigation regime was non-significant. At 15–30 cm depth of soil, moisture content was non-significant between different planting systems during 2019 but significant during 2020, with higher moisture content in the broad bed (6.83%) compared to the narrow bed (6.35%) system of planting. In terms of irrigation regimes, significant differences were observed during both the years, with $I_1$ treatment showed the highest moisture content (9.09 and 8.55% in 2019 and 2020, respectively) compared to other treatments. The interaction effect was significant in 2019 but non-significant in 2020.

During the flowering stage, the overall variation in soil moisture in the field was not as extensive as observed during the knee-high stage of crop growth, primarily due to a fairly good distribution of rainfall. The variation in moisture was mainly attributed to the treatment effects. The higher moisture content in the broad bed system can be attributed to the increased availability of water in the root zone, facilitated by seepage of water in the broad bed. Similarly, in the different irrigation regimes, higher moisture content was a result of greater water application in the $I_1$ treatment compared to other irrigation methods. These findings are consistent with the previous studies conducted by Kaur *et al.* (2020, 2023), Huang C *et al.* (2022) and Pooniya *et al.* (2022), which have highlighted the influence of planting systems and irrigation regimes on soil moisture content during the flowering stage of the maize crop.

*Yield and water productivity*

*Grain yield (t/ha):* Diverse outcomes were noted in maize grain yield based on planting systems and irrigation levels. Broader bed planting recorded significantly higher grain yields (4.37 and 4.57 t/ha) as compared to narrower bed system (4.23 and 4.38 t/ha). Similarly, maintaining optimal moisture levels at treatment $I_1$ i.e. 25% DASM (Depletion of available soil moisture) led to notably higher grain yield (4.86 and 4.93 t/ha), while the treatment $I_5$ i.e. 50% DASM+2% Urea spray at 40 DAS and at pre-tasselling the lowest (3.91 and 4.02 t/ha). The interplay between distinct planting methods and irrigation regimens did not yield significant interaction effects. Nevertheless, the most robust grain yield (4.99 and 5.07 t/ha) was observed with treatment combination of broad beds with treatment $I_1$ i.e. 25% DASM (Depletion of available soil moisture) owing to the synergistic benefits of this specific pairing of planting system and irrigation treatment.

Reduced grain yield and related maize parameters in 2019 were attributed to excessive high-intensity rainfall during critical crop growth stages. In contrast, optimal microclimatic conditions favourably influenced the bed-sown crop, ensuring adequate moisture supply and subsequently higher grain yield. The loose composition of the soil in broader beds facilitated superior root and shoot growth, culminating in augmented plant vigour, expanded leaf area, increased crop biomass, effective translocation of photosynthates to grains and ultimately elevated grain yield (Table 2). These observations concur with the studies by Zhaoquan *et al.* (2018), Kaur *et al.* (2018, 2020), and Huang *et al.* (2022). Thus, the choice of planting system and irrigation regimen emerges as a pivotal determinant of maize grain yield. The broader bed planting approach coupled with meticulous irrigation management, particularly exemplified by 25% DASM resulted in improved grain yield due to enhanced soil conditions, improved crop growth, and optimized water availability. These findings underscore

Table 2 Effect of bed planting and limited irrigation on grain yield, biological yield and water productivity of maize

| Treatment | Grain yield (t/ha) | | Biological yield (t/ha) | | Water productivity (kg/ha-cm) | |
|---|---|---|---|---|---|---|
| | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
| *Planting methods (M)* | | | | | | |
| $M_1$ | 4.23 | 4.38 | 8.54 | 8.58 | 86.61 | 169.60 |
| $M_2$ | 4.37 | 4.57 | 8.96 | 9.07 | 89.36 | 176.93 |
| SEm(±) | 0.04 | 0.05 | 0.12 | 0.14 | 0.77 | 1.92 |
| CD (P=0.05) | 0.12 | 0.14 | 0.36 | 0.41 | 2.30 | 5.71 |
| *Irrigation regimes (I)* | | | | | | |
| $I_1$ | 4.86 | 4.93 | 9.28 | 9.40 | 91.89 | 163.68 |
| $I_2$ | 4.43 | 4.79 | 9.17 | 9.26 | 83.83 | 159.01 |
| $I_3$ | 4.27 | 4.42 | 8.74 | 8.81 | 89.11 | 176.22 |
| $I_4$ | 4.02 | 4.21 | 8.38 | 8.42 | 83.86 | 167.62 |
| $I_5$ | 3.91 | 4.02 | 8.20 | 8.26 | 91.26 | 199.79 |
| SEm(±) | 0.06 | 0.08 | 0.19 | 0.22 | 1.22 | 3.04 |
| CD (P=0.05) | 0.18 | 0.23 | 0.57 | 0.65 | 3.64 | 9.03 |
| *Interaction M × I* | | | | | | |
| $M_1I_1$ | 4.73 | 4.79 | 8.97 | 8.99 | 89.48 | 159.08 |
| $M_1I_2$ | 4.33 | 4.69 | 8.94 | 8.97 | 81.92 | 155.73 |
| $M_1I_3$ | 4.16 | 4.34 | 8.55 | 8.62 | 86.82 | 172.75 |
| $M_1I_4$ | 4.06 | 4.18 | 8.20 | 8.25 | 84.71 | 166.38 |
| $M_1I_5$ | 3.87 | 3.90 | 8.04 | 8.08 | 90.13 | 194.04 |
| $M_2I_1$ | 4.99 | 5.07 | 9.59 | 9.81 | 94.31 | 168.27 |
| $M_2I_2$ | 4.54 | 4.89 | 9.40 | 9.54 | 85.74 | 162.29 |
| $M_2I_3$ | 4.38 | 4.51 | 8.92 | 8.99 | 91.39 | 179.70 |
| $M_2I_4$ | 3.98 | 4.24 | 8.55 | 8.58 | 83.00 | 168.86 |
| $M_2I_5$ | 3.96 | 4.13 | 8.36 | 8.44 | 92.39 | 205.54 |
| SEm(±) | 0.09 | 0.11 | 0.27 | 0.31 | 1.73 | 4.30 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS |

Treatment details are given under Materials and Methods.

the critical role of selecting appropriate agricultural methodologies to maximize both grain yield and crop productivity of maize.

*Biological yield (t/ha):* Marked disparities were evident in the biological yield of maize when subjected to distinct planting systems and varying irrigation approaches. Employing the broader bed planting system yielded notably superior biological yields (8.97 and 9.07 t/ha) in contrast to the narrower bed (8.54 and 8.58 t/ha) in the corresponding years. Similarly, among irrigation levels, particularly in treatment 25% DASM, correlated with higher biological yield (9.28 and 9.40 t/ha), while the treatment of 50% DASM+2% Urea spray at 40 DAS and at pre-tasselling led to the lowest biomass yield (8.20 and 8.26 t/ha) in 2019 and 2020 respectively. Interactions between planting methods and irrigation levels resulted non-significant effects. Nonetheless, the treatment broad beds with 25% DASM pairing demonstrated optimal outcomes, yielding the highest biological yield (9.59 and 9.81 t/ha) during 2019 and 2020 correspondingly, thereby underscoring the synergistic advantages derived from this specific amalgamation of planting system and irrigation treatment.

The highest biomass yield recorded with broad bed planting can be attributed to its creation of a conducive environment, coupled with an optimal moisture supply. The expansiveness inherent in broad beds facilitates enhanced root proliferation and shoot expansion, thereby fostering greater leaf area. This expanded leaf area subsequently contributes to an upsurge in biomass production (Table 2). These observations are in accordance with the conclusions drawn from investigations by Zhaoquan *et al.* (2018), Kaur *et al.* (2020) and Huang *et al.* (2022). The selection of a specific planting system and irrigation regimen distinctly influences the biological yield of maize. The utilization of the broad bed planting in conjunction with well-suited irrigation, particularly 25% DASM treatment recorded higaher biomass production due to the optimization of soil conditions, improved crop growth, and the facilitation of optimal water availability.

*Water productivity (kg/ha-cm):* Significant advancements in water productivity within maize cultivation were observed during two years of experimentation. Specifically, the utilization of a broad bed planting approach resulted in significantly elevated water productivity, measuring 89.36 kg/ha-cm and 176.93 kg/ha-cm, when compared to the narrow bed approach. Among the various irrigation regimens studied, the $I_1$ treatment yielded the highest water productivity at 91.89 kg/ha-cm in 2019, a statistically equivalent value to that of the $I_5$ treatment at 91.26 kg/ha-cm. However, in 2020, the $I_5$ treatment surpassed all other variants in terms of water productivity. It is noteworthy that no significant interaction effects were observed between the bed planting methodology and the distinct irrigation regimens. This substantial increase in water productivity can be attributed to the attainment of higher yields while concurrently employing reduced water quantities. Additionally, there was a pronounced enhancement in vegetative growth, dry matter production and overall yield. This judicious manipulation of both water and nutrient inputs collectively contributed to the amplification of water productivity within the maize cultivation domain.

These findings align with previous research conducted by Huang *et al.* (2022), Kaur *et al.* (2020 and 2023) and Pooniya *et al.* (2022), all of which underscore the positive impact of well-adapted planting systems and judicious irrigation practices on water productivity in maize cultivation. Optimizing water use efficiency and implementing effective nutrient management strategies are of paramount importance for sustainable agricultural practices, particularly in regions grappling with water scarcity and variable climatic conditions. The adoption of bed planting systems, coupled with limited irrigation during critical growth stages and the implementation of precision nutrient management, holds significant promise for enhancing water productivity and promoting overall sustainability in maize cultivation.

In conclusion, the experimental results indicated that the broad bed planting system consistently outperformed the narrow bed system in terms of grain yield, with significantly higher yields of 4.37 and 4.57 t/ha during 2019 and 2020, respectively, compared to 4.23 and 4.38 t/ha for the narrow bed system in the same respective years. Regarding the various irrigation levels, the highest water productivity, measured at 91.26 and 199.76 kg/ha-cm, was consistently achieved when employing irrigation at 50% DASM along with two urea sprays at 40 DAS during both the year (2019 and 2020, respectively). The findings from this study indicates that employing the broad bed planting system in conjunction with irrigation set at 50% DASM and two urea sprays at 40 DAS is the most effective approach for enhancing water productivity and overall yield in maize cultivation. This combination of planting method and irrigation management offers a promising strategy for optimizing maize crop production in the given agro-climatic conditions.

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