Vol. 25, No. 1, pp. 101-107 (2025)
Journal of Agricultural Physics
ISSN 0973-032X
https://doi.org/10.56093/JAP.v25i1.10

Research Article

Optimizing Planting Geometries for Climate-Resilient Agriculture and Microclimatic Studies in Indian Mustard under Semi-arid Region

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ABSTRACT

Microclimate significantly influences crop growth by affecting canopy temperature, relative humidity (RH), and intercepted photosynthetically active radiation (IPAR). This study was conducted during the Rabi season 2023–24 at CCS HAU, Hisar (29°10′N, 75°46′E, 215.2 m elevation), and examined how phenological stages, diurnal variation, canopy levels, and planting geometry impact the microclimate of Indian mustard (*Brassica juncea*). RH was highest at the 50% flowering stage and declined with maturity, whereas canopy temperature increased. Diurnal patterns showed higher values of RH in the morning and maximum canopy temperatures in the afternoon. Planting geometry played a key role: East–West row orientation with closer spacing (30 × 10 cm) resulted in better PAR interception and favourable microclimatic conditions than North–South orientation with wider spacing (45 × 10 cm). The findings emphasize the importance of strategic planting geometry to improve photosynthesis under changing climatic conditions.

Key words: Canopy temperature, Indian mustard, Microclimate, Photosynthetically active radiation interception, Relative humidity

Microclimate refers to the localized climatic conditions near the ground or in the immediate vicinity of plants, typically extending up to approximately two meters in height (Maliwal, 2011). The microclimate of a plant encompasses various environmental factors, including temperature, humidity, and radiation, which influence its growth and development (Jones, 1985). Plant growth and development are primarily determined by genetic makeup and environmental conditions. Microclimate is particularly significant as it regulates key physiological processes such as photosynthesis, respiration, transpiration, and translocation. Microclimatic conditions can be modified by controlling wind speed, water balance, and heat load.

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Throughout the crop cycle, from planting to harvesting, various agronomic practices contribute to optimizing the microclimate. These practices include tillage, fertilizer and irrigation management, shading, the establishment of shelterbelts or windbreaks, diverse cropping systems, agroforestry, and the application of anti-transpirants (Kingra and Kaur, 2017; Reddy *et al.,* 2022; Kaur *et al*., 2023). Such interventions help mitigate temperature extremes, conserve soil moisture, and enhance radiation interception, ultimately creating a more favorable environment for crop growth and productivity.

Among the various factors influencing crop growth and development, within-season weather variability is considered a critical component of climatic variability. In arid and semi-arid regions, fluctuations in relative humidity within the canopy and variations in canopy temperature may significantly affect crop growth, in addition to weather factors such as rainfall, wind speed, wind direction and sunshine duration. The present study aims to evaluate microclimatic variations in different crop geometries in the semi-arid region of Haryana. Modifications in crop geometry influence the penetration of solar radiation, subsequently affecting within-canopy temperature and relative humidity (Khichar *et al*., 2004; Sharma *et al*., 2023 and Painkra *et al*., 2024). A deeper understanding of plant microclimate characteristics and their impact on physiological processes can be achieved by analyzing within-canopy microclimatic modifications (Schween *et al.,* 1997; Jaya *et al*., 2001).

Materials and Methods

A field experiment was conducted at the Research Farm of the Department of Agricultural Meteorology, Chaudhary Charan Singh Haryana Agricultural University, Hisar. The research site is situated at a latitude of 29°10′N and a longitude of 75°46′E, at an elevation of 215.2 meters above mean sea level. The region falls within a semi-arid, subtropical monsoonal zone, characterized by hot, dry summers with maximum temperatures often exceeding 45°C, and moderately cool winters. The soil at the experimental site was classified as sandy loam.

The experiment involved cultivars of Indian mustard (*Brassica juncea)* grown under two crop row orientations, D_1 (North-South) and D_2 (East-West), along with two distinct plant spacings: S_1 (30 × 10 cm) and S_2 (45 × 10 cm). The study was conducted during the rabi season of 2023–24 under irrigated conditions, in accordance with the recommendations of CCS HAU, Hisar. The experimental design followed a Factorial Randomized Block Design (FRBD) with three replications. Weather conditions during the crop growing season are represented in Figure 1.

To maintain an optimal soil moisture regime, in addition to pre-sowing irrigation, two supplementary irrigations were applied post-seeding: one at 50% flowering and another during siliqua formation. Manual weeding was carried out as needed in each plot.

For diurnal temperature and humidity profiling, temperatures were recorded at three levels within the crop canopy (top - 200cm, middle – 100 cm, and bottom – 0 cm) at various growth stages, from emergence to physiological maturity. Measurements were taken at 0900 hrs, 1200 hrs, and 1500 hrs using an Assmann Psychrometer. Relative humidity (RH) was determined using a digital voltmeter.

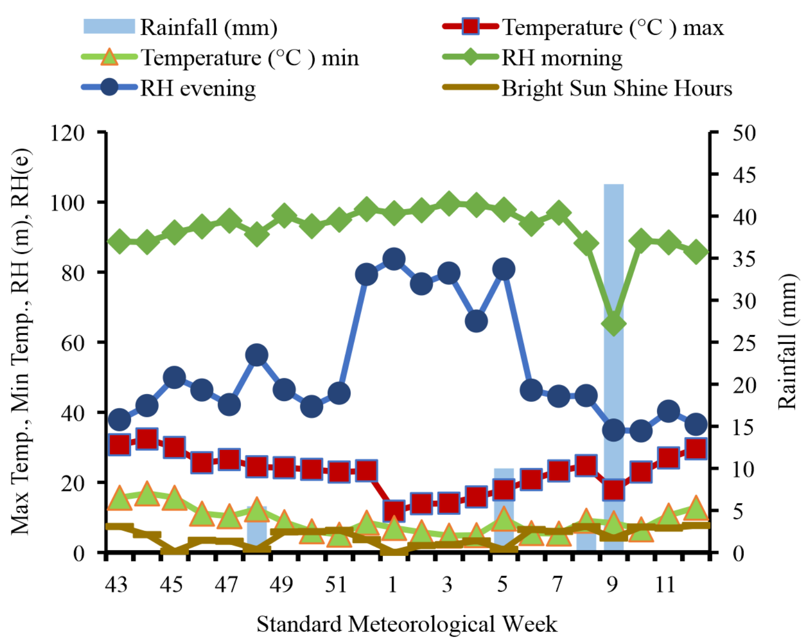


Fig. 1. Prevailing weather conditions during the crop period of Indian mustard

Intercepted Photosynthetically Active Radiation (PAR) was measured at 1100 hrs under clear sky conditions at different growth stages using a Line Quantum Sensor (LICOR 1500). The sensor's output was recorded with a digital multimeter. Measurements included incoming and outgoing PAR at the top of the canopy, as well as radiation penetration at the ground surface beneath the crop canopy. Observations were randomly collected from three locations within each plot. The percentage of PAR interception was calculated using the formula described by Flenet *et al*. (1996).

$$\text{PAR interception \%} = \frac{\text{PAR(incoming)} - \text{PAR(transmitted + reflected)}}{\text{PAR(incoming)}}$$

Results and Discussion

Micrometeorological effects in Indian mustard under two different planting geometries

Profile and diurnal relative humidity

Diurnal *and* vertical variation in relative humidity under two different crop row orientations i.e. D_1 (North-South) and D_2 (East-West); as well as two distinct plant spacings i.e. S_1 (30 × 10 cm) and S_2 (45 × 10 cm); are depicted in Figures 2 (a) to (d) for three canopy heights (top, middle, and bottom) across various phenological stages. RH dynamics within the crop canopy varied with phenological stages, diurnal patterns, and vertical stratification. Among the phenological stages, RH was highest at 50% flowering across all canopy levels, with the least diurnal variation. This was likely due to dense fog, reduced hours of bright sunshine, and maximum canopy development, which created a humid microclimate. As the crop progressed to physiological maturity, RH (%) declined rapidly due to plant senescence and greater canopy exposure to ambient conditions. Diurnally, RH profiles were characterized by a lapse in nature, being more pronounced at 0900 hrs due to lower temperatures and minimal transpiration losses, compared to 1500 hrs, when rising temperatures and increased evapotranspiration occurred. Vertically, the bottom canopy retained the highest RH (%) for all treatments, followed by the middle, while the top had the lowest RH (%), attributed to limited air circulation and shading effects in the lower canopy. These results agree with the findings of Painkra *et al.* (2024) and Khichar (2004).

Effect of crop row orientation

While the overall trend remained the same, statistically significant differences in RH across different canopy levels and times of the day suggested that crop row orientation influenced the microclimate by affecting wind flow patterns and solar radiation interception. The D_2 crop row orientation appeared to improve air circulation and solar radiation interception, resulting in lower RH (%) levels compared to the D_1 crop row orientation, where greater canopy shading likely contributed to higher RH (%).

Effect of plant spacing

Narrower plant spacing (S_1) resulted in significantly higher RH (%) because the denser canopy reduced ventilation and limited evaporative cooling. In contrast, wider plant spacing (S_2) improved air circulation, resulting in lower RH (%) within the crop canopy.

Profile and diurnal temperature

Diurnal and vertical variation in temperature under two different crop row orientations i.e., D_1 (North-South) and D_2 (East-West); as well as two distinct plant spacings i.e., S_1 (30 × 10 cm) and S_2 (45 × 10 cm); are depicted in Figures 3 (a) to (d) for three canopy heights (top, middle, and bottom) across various phenological stages. The air temperature fluctuated between 8 and 26°C, irrespective of canopy levels, treatments, and times of day. Canopy temperature (°C) was lowest at 50% flowering across all canopy levels, with the least diurnal variation, likely due to dense fog, reduced sunshine hours, and dense canopy shading, which created a cooler microclimate. As the crop matured, senescence and a reduced leaf area index (LAI) increased exposure, leading to a gradual rise in temperature from pod initiation through physiological maturity. The diurnal canopy temperature profiles indicate that air temperature increased with crop height during the morning hours (0900 hrs) in all treatments throughout the crop cycle. Canopy temperature profiles at noon

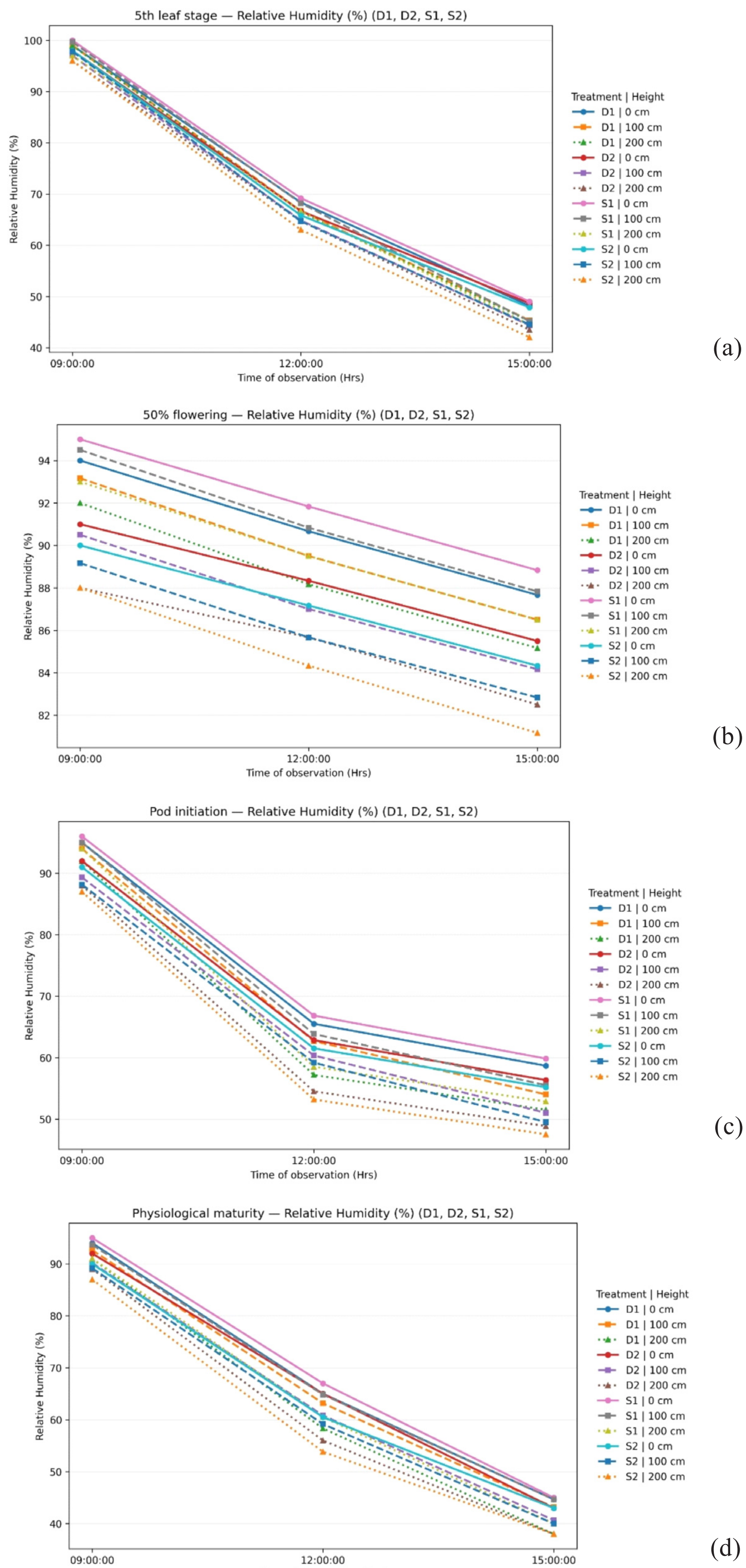
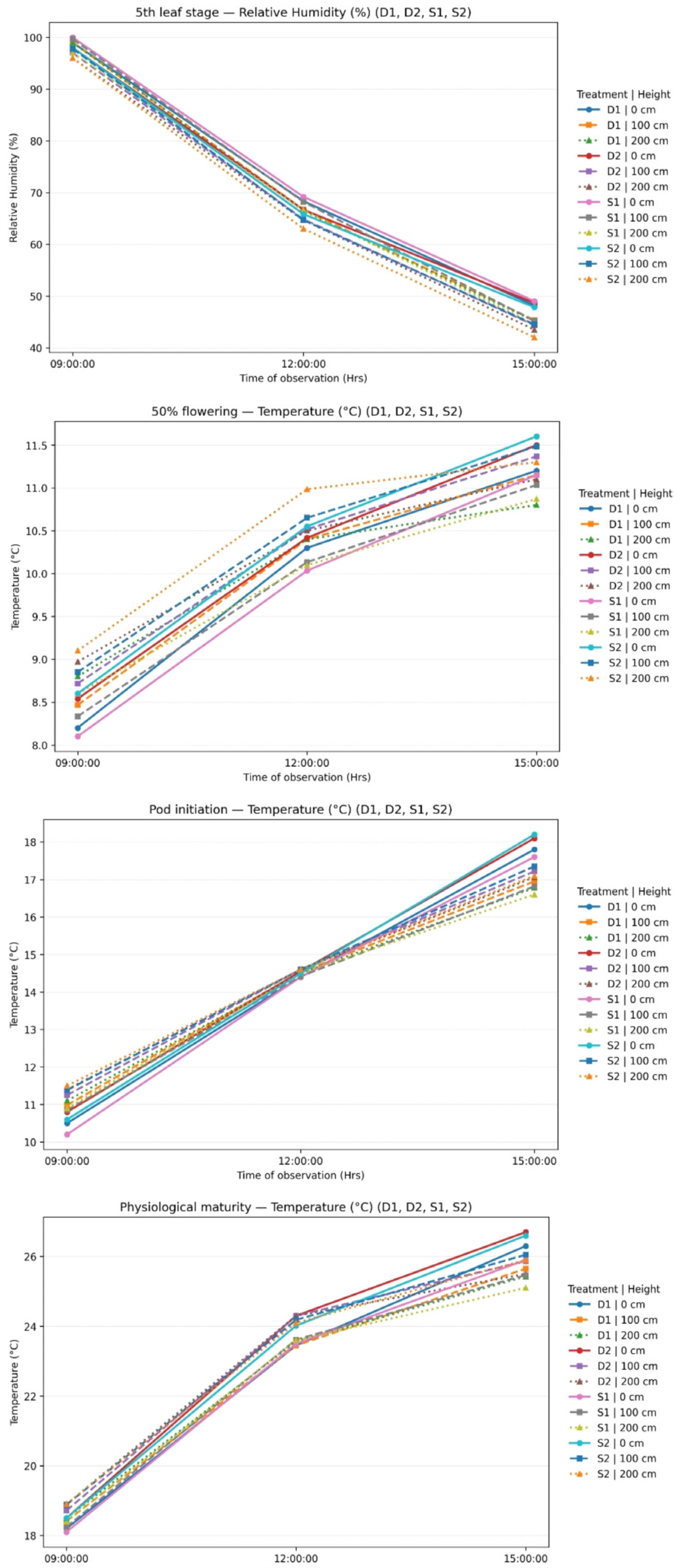


Fig. 2. Diurnal and vertical variation in RH at (a) 5th leaf stage (b) 50% flowering (c) pod initiation (d) physiological maturity at 0 cm, 100 cm and 200 cm from ground



(a)

(b)

(c)

(d)

Fig. 3. Diurnal and vertical variation in temperature at (a) 5[th] leaf stage (b) 50% flowering (c) pod initiation (d) physiological maturity at 0 cm, 100 cm and 200 cm from ground

(1200 hrs) were nearly isothermal in all treatments throughout the crop growth cycle. However, at evening hours (1500 hrs), the canopy temperature profiles exhibited a lapse pattern, meaning temperature decreased with crop height. This may be due to greater transmission of solar radiation to the ground surface, as the sun's rays were more perpendicular at noon. Additionally, the upper canopy remained cooler due to a higher rate of evapotranspiration at noon, attributed to the greater foliage density in the upper crop canopy. These results agree with the findings of Painkra *et al.* (2024) and Khichar (2004).

Effect of crop row orientation

Statistically significant differences in temperature between the D_1 and D_2 crop row orientations suggest that solar radiation interception and wind flow patterns influenced canopy temperatures. The D_2 crop row orientation likely experienced greater heat accumulation, possibly because the crop canopy was aligned with the sun's path.

Effect of plant spacing

Narrow plant spacing (S_1) generally exhibited significantly lower temperatures (°C) than wider plant spacing, possibly due to a higher plant population. In contrast, wider plant spacing (S_2) allowed more sunlight penetration, leading to higher canopy temperatures.

Intercepted Photosynthetically Active Radiation (%)

The variation in IPAR in Indian mustard under different crop row orientations and plant spacings is illustrated in Figures 4 and 5. Across all treatments, IPAR increased with crop growth, reaching its maximum at 95 DAS before declining due to reduced LAI and senescence (Jain *et al*., 2019). Figure 4 shows that the D_2 (East-West) crop row orientation consistently exhibited higher IPAR than the D_1 (North-South) crop row orientation, with the difference becoming more pronounced between 55 DAS and 95 DAS, reaching its highest value of 80.59% in the D_2 crop row orientation compared to 75.11% in the D_1 crop row orientation before declining. Figure 5 demonstrates that narrower plant spacing (S_1) resulted in significantly higher IPAR (86.07% at 95 DAS) compared to wider plant spacing (S_2) at 69.63%, likely due to higher plant population. The consistently higher IPAR observed in the D_2 crop row orientation and narrower plant spacing (S_1) highlights the importance of optimal planting geometry for maximizing PAR interception and improving photosynthetic efficiency in Indian mustard.

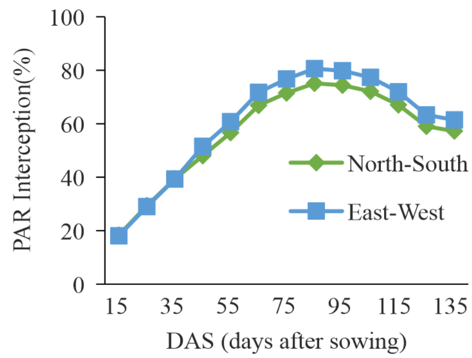


Fig. 4. IPAR under two different crop row orientations

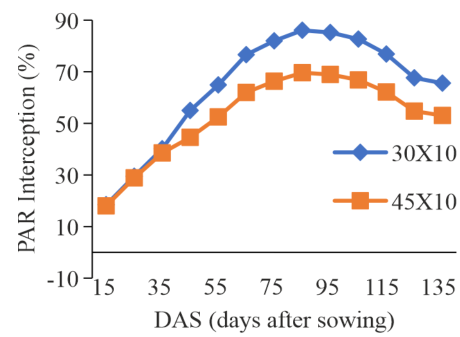


Fig. 5. IPAR under two different plant spacings

Conclusion

Based on the present experiment, optimization of crop row orientation and plant spacing was found to significantly influence PAR interception, canopy temperature, and relative humidity, thereby improving photosynthetic efficiency in Indian mustard. The study revealed that phenological stages, diurnal variations, canopy levels, and planting geometry collectively governed the crop microclimate. The 50% flowering stage had the highest RH and lowest temperatures due to dense canopy cover. In contrast, later stages experienced increased temperatures and reduced RH due to senescence and lower leaf area index. Temperature profiles varied throughout the day, with an inverse trend in morning, isothermal conditions at noon, and a lapse pattern in evening. Wider spacing resulted in a greater diurnal temperature range compared to narrower spacing. Relative humidity followed a lapse pattern across all treatments, with a less pronounced decrease in humidity with height in morning. The diurnal humidity range was higher in wider-spaced crops, highlighting the impact of planting geometry on microclimate regulation.

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Received: 3 April 2025; Accepted: 12 June 2025