Research Article

Leaf area profile and light use efficiency study in maize as influenced by changes in the planting geometry and N-Rates

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Abstract

Dry matter (DM) partitioning is function of the solar radiation intercepted by the crop canopy and their plant's leaf area exposed within the canopy. Row orientation (RO) and Row-spacing (RS) within canopy influenced the leaf size and might be the light use efficiency. We, therefore, studied cob bearing leaf area and leaf-area-profile (LAP) of maize planted at different RO, RS and N-rates (0, 100, 150, and 200 kg ha⁻¹). ANOVA results revealed that RO north-south (NS) then east-west (EW) showed better cob bearing leaf area (cm²). Likewise, did by the RS 75x20 as compare to RS 50x30. Nitrogen 150 kg ha⁻¹ was superior with highest cob bearing leaf area then rest of the any other given N-rates. Comparing the LAP, RS 75x20 showed relatively greater leaf area from node 5 to 8. For the RO difference was higher for all nodes expanded further from nodal position 1st to 6th and gradually declined from node 6th onwards. Similarly, the N-rates also showed distinct differences at each rate in all nodes of a plant. Leaf area of the control plants was incomparable at any node with any level of the given N application rates. Interactive effect of treatments RO and RS with N-rates showed marked differences. Radiation use efficiency (RUE) was also found higher at NS than EW and in 75x20 than 50x30 spacing. The N-rate of 200 and 150 kg ha⁻¹ was almost similar in RUE but was found higher than 100 kg ha⁻¹ and the control plot. The study suggests that greater cob bearing leaf area of the treatments NS and 75x20 were due to greater spaces for the leaf elongation within the crop rows. However, overall response of treatment interaction supports 75x20EW geometry to yield better use efficiency of light for grain yield of maize.

Keywords: Row orientation, row spacing, cob's bearing leaf area, leaf area profile of plant, N-rates

Introduction

Radiation interception and its use efficiency by the crop canopy are useful information for assessment of the crop productivity [1, 2]. Biomass production has shown a linear relationship with amount of the intercepted radiations and hence provided a relatively more rational analysis of crop growth than previously did by classical growth functions [1, 3]. Photo-synthetically Active Radiation (PAR) use efficiency has been extensively used in the crop-modeling research [4]. Nonetheless, rate and the quantity of intercepted solar radiation by the crop canopy have shown a strong relationship with the crop leaf area index, its distribution within the canopy and the plant populations or plant densities per unit area [5]. Spreading of plant leaf area in the available spaces within rows and/or row's spacing in the canopy is a fundamental aspect of a plant growth and biomass accumulation rate, because that yields the amount of radiation intercepted and

in result the amount of assimilate produced (i.e. photosynthesis). Effort has been made to measure and characterize the leaf area distribution [6, 7] and leaf area profile [8, 9] by that one could easily approach for further yield improvement of the existing cultivars through manipulating leaf angle more upright or by tying them at an angle of 108 declinations from the stalk [10].

Previous studies has shown that plants grown at a density of about 59,304 ha⁻¹ has yielded 6.5% and 14.2% higher grains yield when all leaves or above the ear leaves were tied together, respectively [11, 12]. Computer advancement has made this work relatively easy though playing with available field data in the crop modeling program. Crop modeling could be an important tool for analyzing the influence of leaf angle and its interaction with leaf area for estimating grain yield and biomass production of crop species and different varieties of the same species. Maize yield is generally low in

Pakistan and particularly half of that in the province of the Khyber Pakhtunkhwa. Maize canopy has been modeled as multiple sets of horizontal layers [13] or three-dimensional zones [14] and the frequency distribution of foliage area by leaf angle has been approximated for each layer or zone using empirical frequency distributions or describing distribution of leaf area by angle using the angular distribution of surface area [15] for principles [16], calculations [13] and use in the crop canopy models [2]. Nevertheless, leaves on a maize plant are curved which complicates how the foliage angle can truly be expressed. Most of the available models have explained curvature for individual leaf but they are mostly plant-based growth models [17]. Plant response to leaf area profile in the crop canopy is poorly known when planting geometry changed by altering in plants distance or rows distances. Agronomic research, study of current regime, deals with modeling of crop canopy and turbid media applicable on homogenous stand [18] to more advanced to horizontally heterogeneous canopies of row-crop e.g. the maize, the wheat etc. and inter-crop [19, 20]. However, all the advanced and sophisticated models require detailed descriptions of geometrical structure of plants within the canopy. Despite time course of changes in the geometrical structure during growth is important to be made available for future improvement [21].

Solar radiation has been recognized a free available source of energy for crop photosynthesis providing both biochemical energy and carbon for plant growth [22]. Leaves within canopy are major light capturing source but the efficiency of light interception by crops' canopy depends on the species and environment [23] as well as planting geometry [24] and many other factors such as nutrient, weather and climate etc. However, the optimum leaf area exposed by the crop canopy with uniform vertical distribution is essential for maximum interception and growth rates [25]. Information is available but limited on planting geometry (i.e. row orientation and spacing) for maize to be adopted in the area for optimum production. We, therefore, study the effect of row orientation and spacing in maize treated with different N-rates focusing on the cob bearing leaf area in relation to leaf area profile and radiation use efficiency.

Materials and Methods

This study aimed to know the plant spacing, orientation and levels of nitrogen (N) application response on maize leaf area profile and light use efficiency by the crop canopy. Field experiment was conducted at Agronomy Research Farm, the University of Agriculture Peshawar, Pakistan in summer 2009. The site is about 1200 km north of Indian Ocean at an altitude of 350m above sea level. Peshawar valley surrounds by mountain from

all sides with two rivers flows in the center of the valley. Canal from rivers provide water for irrigation to the crops. Climate of Peshawar is predominated by hot relatively long summer and cold but short winter. Frost occurs between mid Nov. to early Feb. Experimental farm is situated at 34.01° N. Soil was low in organic matter (1.05%) and alkaline in nature with a pH of about 8.1. Nitrogen content of soil was generally also low and measured about 0.099% at the time of seedbed preparation. Erratic rainfall occurred mostly in spring in March and particularly in summer from June to August. Mean temperature of the crop growth season was 29.75±4°C during summer 2009, however the maximum mean temperature was 36.7±3°C and minimum was 22.8±4°C, with an average rainfall of about 16.5 mm and relative humidity 58.3%.

Sowing was done in summer on June 20, 2009. Treatments were arranged in split-plot, Randomize Complete Block (RCB) Design, each experimental unit was replicated three times. The row orientations (RO) and row spacing (RS) were allotted as the main-plot treatment and nitrogen rates (N) as the sub-plot treatment. The RO were North-South (NS) and East-West (EW) rows of the crop and RS were 75cm spaced between rows planted 20cm within rows (i.e. 75x20) and 50cm spaced between rows planted 30cm within rows (i.e. 50x30) to yield a uniform plant density in the experimental units. Each experimental unit was a square of 4.5m to accommodate 9 and 6 rows for the treatments 75x20 and 50x30 spacing geometry, respectively. Nitrogen was applied 0, 100, 150, and 200 kg ha⁻¹ applied in two splits, one at planting during seedbed preparation and other with second irrigation (V₇) about 35 days after sowing (DAS). In addition to the N-rate, Phosphorus and potassium were applied uniformly applied 100 (P₂O₅) and 50 (K) kg ha⁻¹, respectively during the seedbed preparation as carpet broadcast. The required population per unit area was adjusted by maintaining plant distance at emergence (14 DAS). The crop was harvested on October 14, 2009.

Data regarding leaf area index (LAI) was recorded non-destructively a week after the completion of silking in two central rows by using Plant Canopy Analyzer (LI-2000, LI-COR, USA). The machine was calibrated to take one reading above the canopy and three below the canopy to compute a single mean for an experimental unit. LAI data were stored in data logger and transferred to PC. Second LAI reading was repeated the same way close to crop reach physiological maturity. Leaf area per nodal position i.e. the leaf area profile (LAP) was focused on five uniformly selected tagged plants in an experimental unit after anthesis. Ten uniform plants in an experimental unit were tags at early growth stage (45 DAS). Five out of ten plants were harvested at anthesis and the rest close

to physiological maturity to measure cob bearing leaf area manually. All leaf blades were carefully cut at collar from sheath of a plant and passed through a leaf area machine (LI-3000A, LI-COR, USA). Data regarding leaf blade area, length, maximum and width were automatically stored for each leaf and plant. The leaf area profile was estimated from equation provided by Valentinuz and Tollenaar (2006) for maize crop. The measured and estimated values were in a strong correlation ($r^2 = 0.97$) with each other.

The radiation use efficiency (RUE) was derived as per procedure already published and explained [9] with changes of taking biomass at final harvest. Briefly, the light interception by crop canopy was measured periodically at two weeks interval using three light measuring sensors types (LI-190 and LI-191, LI-COR, USA). The LI-190 was used to record irradiance on top of the crop canopy and a pair of LI-191, the reflectance and transmittance by the crop canopy. All three sensors were calibrated before taking a reading. Minimum five minutes average readings were stored in a data logger (LI-1400, LI-COR, USA) for each experimental unit. All measurements were taken on a clear sunny day between 11-14 h of the day between emergence and physiological maturity. The fraction of intercepted light by the crop canopy for an experimental unit was calculated from five field measurements made during the crop growth and multiplied with corresponding cumulative PAR readings, which were obtained from the nearest weather station. PAR was estimated from solar radiation by multiplication with factor 0.47, as PAR fraction in the total light. Ratio of total biomass of two central rows and mean cumulative PAR absorbed by the crop canopy for period from emergence to physiological maturity was termed as RUE. Grain and biological dry matter yields were recorded at harvest in two central rows in an experimental unit.

All data were statistically analyzed using Gen-stat (Discovery Edition 3.0) computer software. Statistical analyses were made using appropriate analysis technique [26] for randomized complete block design, split plot arrangements. Treatments and their interaction were compared using LSD test ($P \leq 0.05$).

Results and Discussion

Mean leaf area of cob bearing node of maize for treatments (RO, RS and N) is shown in Fig. 1. Maize planted in row orientation NS exhibited significantly ($p < 0.05$) greater leaf area as compared to the row orientation EW. Likewise, RS 75x20 showed higher ($p < 0.05$) leaf area for cob bearing leaf as compared to RS 50x30 (Fig. 1a). Interaction of treatments (RO x RS) was also significantly different for cob bearing leaf area. The interactive effect of treatments 75x20-EW showed the highest ($p < 0.05$) leaf area followed by 50x30-NS and

50x30-EW. The lowest leaf area was observed in 75x20-NS (Fig. 1b). The highest cob bearing leaf area was observed at N 150 kg ha⁻¹, followed by the highest N (200 kg ha⁻¹) rate. The application of N 100 kg ha⁻¹ was almost at par in flag leaf area with N 100 kg ha⁻¹. Control plots with 0 N showed the lowest flag leaf area (Fig. 1c). We observed that relatively wider rows 0.75m allowed more dropping leaves than the narrow rows 0.50m and hence may have showed a higher leaf area. It is known from literature that leaf dimension and inclination changes with leaf azimuth distribution in the crop canopy due to plant-to-plant interactions, which modify both LAI and the light extension coefficient i.e. k [27, 28]. Researcher has considered role of leaf azimuth distribution of the plant in developing the crop canopy. A switch from a random to a distich orientation of the plant leaves (perpendicular to rows) was observed in higher density with almost a similar trend when maize grown at 0.76m vs. 0.5m row-width [29]. The seedling orientation (perpendicular vs. parallel to rows) has also revealed that maize leaves were preferentially across-row oriented [21]. The larger the row spacing at e.g. 75x20 might favors leaves to be extended longer over of the plant spaced at e.g. 50x30 spacing. Similarly, the RO NS over EW might have extended greater opportunities for well distribution of solar radiation in the crop canopy, which may have shown relatively higher area in NS orientation. As expected, optimum N availability promoted the plant vegetative growth and has reflected the greater leaf area [30]. Highest rate (200 kg ha⁻¹) of nitrogen might have exceeded the capacity of the plant to take it from the soil by exceeding N either as plant demand of the synthetic variety and/or limits its efficiency due to other limiting factors of the soil.

Leaf area profile i.e. leaf area vertical distribution at the nodal positions from bottom to top within the maize canopy was also influenced by treatments RO, RS and N rates including their possible interaction (Fig. 2). The figure showed that leaf area of maize was a bell-shaped for node 1 to 12 at either RS or RO. However, differences were smaller at leaf appears at nodal position 1 and 12 which gradually expands towards the middle nodes i.e. node 4 to 8 with relatively better differences at nodal position 7 and gradually plunged closure for any further top and bottom nodes (Fig. 2a). A similar response for leaf area per nodal position was observed for treatments RO but with relatively marked differences at each node starting from node 1 to 12. Compared to RS, differences in the RO for the leaf area per nodal positions were distinct with highest at node 5 to 7. The differences in leaf area per nodal positions expand to a stable rate on each higher node from node 1 to 6, remain static till node 7 and then declined at stable rates from node 8 onwards (Fig. 2b). Treatments interaction (RS x

RO) showed significant response for area profile of maize. The plants sown at spacing 75x20-EW remained distanced from rest geometries for all leaves by yielding higher leaf area, followed by interactions of 50x30-NS and 50x30-EW. The lowest area per nodal position was observed in 75x20-NS. Interesting to note was that increased in leaf area from bottom to cob bearing leaf increased and then from node 6th onwards declined gradually till the tassel bearing node (Fig. 2c). N-rates showed a strong effect on all leaves of a maize plant. N 150 kg ha⁻¹ remains dominant on any other given N rate. The highest N 200 kg ha⁻¹ did not show higher leaf at any node but showed higher leaf area of almost all leaves in a plant than N 100 kg ha⁻¹. Control plots (no N) showed much lower leaf area profile at all nodes than any given N rates. The difference in leaf area was observed for all leaves of the plant within the canopy with relatively smaller at node 1 to 4, extended wider from node 4 to 7 and then gradually decreased from node 8 onwards (Fig. 2d). There are assumptions that azimuth angles of plant planes are evenly distributed but maize plants adjust azimuth angles to fill the inter-row space accordingly [5, 31]. From sowing to anthesis, total leaf number and rate of leaf appearance in maize has shown an increase when the incident to shortwave radiation increased from 10 to 20 MJ m⁻² d⁻¹ [32] but it is still not clear that is there any direct relationship exist between leaf number and rate of appearance to range LAP [33]. We noticed that row orientations or row spacing did not bother slope values of the regression of a bell shaped curve. The reason might be that leaf area in field was probably more uniformly distributed across the rows than the plants pacing within the row. However, the angle of leaf inclination needs to be investigated by changing the row spacing between maize plant and different varieties of the same species.

Interactive effects of treatment (RO and RS) with N-rates for LAP were significant and are shown in Fig. 3. The overall responses of LAP revealed that N150 kg ha⁻¹ was optimum for the soil and crop variety when compared with rest of the given N rates for all leaves starting from node 1 to 12 for the maize. However, differences do exist for geometry i.e. the NS and EW orientation or RS i.e.

the 50x30 and 75x20. The N effect on LAP was almost similar in fashion but varied for leaf development on different nodes of the plant subject to the availability of N rates i.e. N 150, N 200 kg ha⁻¹. Treatment N 100 kg ha⁻¹ responses on LAP was relatively greater on all leaves of the plant as compare to N (150 kg ha⁻¹) but more closer to the control treatment (Fig. 3a). The response of LAP at higher N 150 kg ha⁻¹ compared to lower N 100 kg ha⁻¹ was more pronounced at row orientation EW. The N-rate differences in LAP at N 100 kg ha⁻¹ compared to control were quite visible (Fig. 3b). Treatment RS 50x30 showed moderate differences in leaf area profile at various nodal positions at any given N rates, but with marked increases than control for all leaves of a plant with greater changes in leaf area at node 4 to 8 than rest of the plant nodes (Fig. 3c). The RS 75x20 showed different responses for LAP with given the N rates. The N 150 and 200 kg ha⁻¹ were almost identical in LAP and similarly observed the given N 100 kg ha⁻¹ and control treatment (Fig. 3d). Limitation of N to crop can be easily seen through leaf area growth at the plant nodal positions, leaf color and leaf mass, which might affected the canopy height, interception efficiency, photo-assimilate production, and subsequently the grain yield [34, 35]. At low N in soil, dry matter allocation to reproductive structures also decline, which adversely affects the kernel number and weight resulting lower production [36, 37, 38]. Despite these symptoms, substantial differences are noticed in maize varieties in their tolerance to low N under varying N rates [30, 39]. However, potential uptake capacity of a variety is essential to respond at a higher N application [40, 41].

Radiation use efficiency (RUE) of maize influenced by RO, RS and N rates are shown in Fig. 4. The RO of NS showed higher ($P<0.05$) RUE as compared with EW. Similarly the RS 75x20 showed higher ($p<0.05$) RUE than the 50x30 spacing (Fig. 4a). Interaction of treatments (RO x RS) showed higher RUE at 75x20-EW, followed by RO 50x30-NS. Treatments RO 50x30-EW and 50x30-NS showed lowest RUE with a non-significant ($p<0.05$) difference from each other.

Fig. 1. Cob-bearing leaf area of maize influenced by the treatments (a) row-orientations and row-spacing, (b) interaction of treatments ROxRS and (c) nitrogen rates (kg ha⁻¹).

Fig. 2. Leaf area profile (LAP) of maize influenced by the treatments (a) row-orientations, (b) row-spacing, (c) interaction of treatments RO x RS and (d) nitrogen rates (kg ha⁻¹).

Fig. 3. Interactive effect of treatment N-rates and (a) RO NS, (b) RO EW, (c) RS 50x30 and (d) RS 75x20 on LAP in a maize plant.

Fig. 4. Radiation use efficiency (RUE) in maize influenced by treatment (a) RO and SP, (b) interaction of the treatments RO x RS, and (c) N-rates (kg ha⁻¹).

Fig. 5. Radiation use efficiency (RUE) in relation to mean leaf area plant⁻¹ of maize for (a) RO and RS, (b) interaction of treatments RO x RS, and (c) N-rates (kg ha⁻¹).

Among the given rates of N, treatment N 150 kg ha⁻¹ showed greater RUE, which were statistically at par ($p < 0.05$) with treatment N 200 kg ha⁻¹. However, the treatment N 100 kg ha⁻¹ showed lower RUE than N 200 kg ha⁻¹. Control showed the lowest RUE from any given N rate (Fig. 4c). RUE in relation to the mean leaf area of a plant is shown in Fig. 5. The higher RUE was observed in RO EW, which associates to the greater mean leaf area of plants (Fig. 5a). Likewise the higher RUE of RO 75x20 as compared to the RO 50x30 was due to greater mean leaf area of the plant (Fig 5b). Treatments (RO x RS) interaction was significant ($p < 0.05$) for the canopy RUE with highest reading for 75x20-EW, followed by 50x30-NS. Treatments geometry 50x30-EW showed the lowest RUE, which did not differ than planting geometry 75x20-NS. These differences in RUE were associated to the mean leaf area changes per plant of the crop (Fig. 5c). Similarly relationships of RUE with mean leaf area per plant were also varied by the given N rates. Treatment given N 150 kg ha⁻¹ showed a non-significant change in RUE when compared with N 200 kg ha⁻¹. This was due to higher mean leaf area expressed per plant by optimum N rates. RUE against the leaf area decreased at N 100 kg ha⁻¹ with lowest readings for the control plot (Fig. 5d). Light extinction coefficient of the crop canopy (k) is a function of the foliage architecture and also an indicator of PAR distribution within the crop canopy, which may differ significantly ($p < 0.05$) by changing planting geometry due to change in spreading rates of the available foliage in crop canopy [1]. Treatment RS compared to RO differed in fraction of PAR transmittance and might have resulted difference in RUE by resulting variations in fraction of total PAR interception. Average RUE of this study was observed relatively lower than reported values in literature [9, 24]. Possible reasons could be e.g. we observed the highest 83% interception rate at peak vegetative growth, which may be due to variations in heights of the plant within rows either by seeds-purity while maize is highly cross pollinated and is hard to produce pure seeds, variation in soil fertility or the crop canopy was unable to attain desired volume to produce foliage covering ground surface for a maximum light interception (approximately 90%) in the linear growth phase of growth. A reduction in light extinction coefficient has already reported (i.e., a more uniform light distribution across the canopy) as row spacing decreased from 1.0 m to 0.35 m [42, 43]. In literature it is also reported that this reduction is related to LAP [33]. The higher reading in N 200 kg ha⁻¹ for the relationship of plant mean leaf area with RUE can be associate to leaf luxury N levels for treatment (N 200 kg ha⁻¹) because N uptake in

leaves have been observed after full appearance [37, 43] due to carbon [44] and N supply/demand relationship of individual leaf [45].

Conclusion

The study suggests greater space in rows than within the plants of a row (75x20) has supported leaf expansion of a plant with maximum flag leaf area which in conflict was found missing in wider space within row for plants. Orientation, NS than EW showed greater leaf growth and similarly observed for 75x20 than 50x30 spacing. The LAP showed marked changes in plant leaves for orientation than spacing. Response of N on LAP expressed that appropriate geometry is equally important to express yield at higher N.

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