Improvement of Light Interception by a Plant Canopy to Increase Maize Yield

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Abstract: The ability of a maize plant canopy to intercept sunlight during grain filling determines its yield. This research explored options to increase the ability of maize plants to intercept sunlight, especially at the end of vegetative growth. A field trial to study the effect of row planting orientations (north-south and east-west) and row patterns (single row and double row) was conducted under rainfed conditions in Lombok, Indonesia. In the single row treatment, the spacing was 70 cm between rows and 20 cm in the row (70 x 20 cm). A spacing of 35 x 20 cm was used for the double row treatment with 70 cm apart of the two double rows. Treatments were arranged in a Split-plot design with planting orientations as main plots and planting models as sub plots. Each treatment was replicated three times, and the size of each plot was 3.5 x 3.5 m. Results of the experiment showed that the canopy of the plants with north-south row orientation intercepted much more sunlight than that of the east-west orientation. At the end of the vegetative stage, the canopy of the plants planted in double rows intercepted 15% more sunlight than that in the single row. Maize grain yield in the double row was 25% higher than that grown in a single row.

1 INTRODUCTION

World maize production has been increasing in response to rising demand, particularly for animal feed. In addition to its use for animal feed, maize is also a staple food in much of South America and Africa, and its use extends to many other food products (Shiferaw *et al.*, 2011). The highest maize production is dominated by the USA, followed by China, Brazil, India and Argentina. In South-East Asia region, Indonesia is the country with the highest maize production, above The Philippines and Vietnam (World Atlas, 2016) and it ranks eighth in word production. As in China, most of maize produced in Indonesia is utilized as animal feed.

In tropical countries that grow significant amounts of maize, such as Brazil, Mexico, Indonesia and South Africa, the crop is mainly produced by small scale farmers in dryland areas. Smallholder farmers in these regions are exposed to high climatic variability and have low adaptive capacity to climate change impacts. The occurrence of climate change has brought about rainfall reduction in some regions accompanied by some extreme weather events that influence maize yield (Li *et al.*, 2011). Hence, rain water harvesting technology and its management have become important considerations in maize production in dryland areas. In addition to water availability, sunlight and photosynthetic capacity are important determinants of maize yield, and need to be optimized to improved yields in dryland areas.

Most smallholder farmers in Indonesia still use plant populations of traditional varieties of maize when they grow modern hybrid varieties. The modern varieties have been engineered to accommodate higher plant populations due to their narrow leaf angle (Pugano, 2007). With high plant populations and a narrow leaf angle, the modern maize hybrid can maximize light interception, especially during grain filling, which can increase maize grain yield (Andrade *et al.*, 2002). Therefore, it is necessary to develop high yielding maize production technology by maximizing sunlight interception, particularly in dryland regions that are being negatively impacted by climate change.

Light interception by the maize canopy can be increased by planting seed in narrow rows or increasing plant population to bring about complete canopy cover (Westgate *et al.*, 1997). For modern hybrid varieties, intraspecific competition among plants after canopy cover can increase plant yield (Toler *et al.*, 1999). This may be due to the leaf

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architecture of modern maize varieties tending to have a narrow angle (*upright*), permitting high photosynthesis activity (Stewart *et al.*, 2003). The result of a high photosynthesis activity on maize with upright leaves is a high grain yield. This paper reports the results three experiments aimed at finding an appropriate technique to increase sunlight interception and maize grain yield through exploring planting orientation and planting pattern in rainfed maize.

2 MATERIALS AND METHODS

A field experiment was conducted at Gumantar village, Kayangan sub-district, North Lombok (8.253654 S, 116.285695 E). The experimental site was dominated by soils with a high sand fraction and very low organic matter. Since the experiment was conducted during the dry season (May to August 2016), irrigation water was required. Water was supplied by a deep pump well located near the experimental units. This practice has been considered as very expensive by the local farmers and only dryland farmers that have sufficient money are able to grow maize during the dry season in that area. The experimental location was an open area with full sunlight to replicate normal field conditions of light interception, evaporation and transpiration.

This experiment evaluated two row planting orientations (north-south and east-west) and two planting models (single row and double row). In the single row treatment, the spacing was 70 cm between rows and 20 cm in the row (70 x 20 cm). A spacing of 35 x 20 cm was used for the double row treatment with 70 cm apart of the two double rows. Treatments were arranged in a Split-plot design with planting orientations as main plots and planting models as sub plots. Each treatment was replicated three times, therefore there were 12 experimental units of 3.5 x 3.5 m plots.

At planting time, Phonska N-P-K (15-15-15) fertilizer was applied at a rate of 300 kg ha^{-1} along with Urea fertilizer at a rate of 100 kg ha^{-1}. Thirty-five days after planting (DAP) Phonska was reapplied at the same rate as at planting time. Then Urea was reapplied 56 DAP at a rate of 200 kg/ha. Before application of the second fertilization, hand weeding was done in all the experimental plots.

Watering was done with a gradient system, namely by supplying small water canals between experimental plots. In the early stages of growth, watering was performed once per week and as plants grew bigger, watering was undertaken twice per week up to cob maturity stage. The irrigation practice in this experiment provided an optimum water requirement for maize crops to grow on a dryland and that condition only can be achieved when the rainfall during the rainy season (December to March) is normal at about 700 mm. Pest and disease control was done only when necessary.

Plant variables observed were plant height, number of leaves, leaf area, and percentage of light interception at the end of the vegetative growth. Light interception was measured by using AccuPAR (PAR/LAI Ceptometer Model LP-80, Decagon Devices), during a bright day, full sunlight from 12.00 to 13.00, by measuring PAR (Photosynthetically Active Radiation) light at the above and below canopy in each treatment. Plant yield variables consisted of: cob length, cob diameter, cob weight, seed weight per cob, seed weight per plant, and seed weight per plot. Cob length, cob diameter, cob weight was determined immediately after harvest. Seed dry weight was measured after the seeds were dried with about 14% moisture content. Maximum and minimum temperatures were recorded daily.

3 RESULTS AND DISCUSSION

The results showed that plant height and leaf area index, which were measured at the highest rate of vegetative phase (42 days after planting = DAP) and at the end of vegetative phase (60 DAP), were not significantly influenced by plant row orientation. Plant row orientation had a significant effect only on percentage of light interception by the plant canopy (Table 1). Canopies of plants in north-south row orientation intercepted much more light than those in east-west row orientation. At 42 DAP, plants in north-south row orientation intercepted 11% more sunlight than those in east-west row orientation. The ability of the plant canopy to intercept sunlight increased as the age of plants increased as the difference in light interception between plants in north-south and east-west row orientation was 15% greater at 60 DAP than at 42 DAP.

Plant height was not significantly influenced by row pattern. Table 1 shows that row pattern significantly influenced leaf area index and percentage of light interception. Plants grown in double rows resulted in much higher leaf area index and light interception than those grown in single row. The higher leaf area index of plants grown in double rows compared with that in single rows was merely due to higher plant population per unit area.

Table 1: The effect of row orientation and planting pattern on plant height, leaf area, and percentage of sunlight interception by plant canopy at 42 and 60 DAP.

Observ ation time	Treatment	Variables		
		Plant height (cm)	Leaf area index	% light inter-ception
42 DAP	Orientation			
	North-South	149,7	1,94	47,30
	East-West	149,2	1,96	42,37
	$LSD_{0.05}$	-	-	0,42
	Rows			
	Single row	149,0	$1,70^{a*)}$	$42,98^{a}$
	Double rows	149,8	$2,20^{b}$	$46,68^{b}$
	$LSD_{0.05}$	-	0,0013	0,42
60 DAP	Orientation			
	North-South	225,5	3,24	$81,35^{a}$
	East-West	198,5	3,16	$70,95^{b}$
	$LSD_{0.05}$	-	-	0,62
	Rows			
	Single row	212,0	$2,68^{a}$	$73,08^{a}$
	Double rows	212,0	$3,71^{b}$	$79,21^{b}$
	$LSD_{0.05}$	-	0,0046	0,62

*) Numbers in the same column with the same treatment, followed by different letters are significantly different.

Table 2: The effect of row orientation and row pattern on maize yield variables at harvest.

Treatments	Variabel			
	Fresh cob weight (g)	Fresh cob weight /plot (kg)	Cob length (cm)	Cob diamet er (mm)
Orientation				
North-South	254,50	12,13	17,27	46,87
East-West	281,97	12,23	18,17	44,67
$LSD_{0.05}$	-		-	-
Rows				
Single row	265,33	$10,42^{a}$	17,93	45,77
Double rows	271,13	$13,95^{b}$	17,50	45,77
$LSD_{0.05}$	-	0,029	-	-

*) Numbers in the same column with the same treatment, followed by different letters are significantly different.

The canopy of plants grown in north-south row orientation intercepted more light than those grown in east-west orientation. This was in accordance with the results of Jaya *et al.* (2001) who reported that light interception coefficient of plants grown in north-south row orientation was higher than that of plants grown in east-west row orientation. Consequently, to maximize sunlight interception, maize planting orientation will be better in north-south direction. In this experiment, however, light interception at the end of the vegetative phase reached just 79%. This value is still far below that suggested by Jeschke (2014) who asserted that 95% light interception was achievable from the end of the vegetative phase until grains filling. The lower light interception found in this study was not due to low plant population but rather by low leaf area index resulting from less than maximum plant growth.

Plant yield variables at harvest, such as fresh cob weight, fresh cob weight per plot, cob length, and cob diameter were not significantly influenced by row orientation (Table 2). Meanwhile, plants grown in a double row pattern resulted in cob weight per plot significantly higher than those grown in a single row pattern due to the difference in plant populations.

Dry yield variables such as seed weight per cob, percentage of seed per cob, seed weight per plot, and weight of 1000 seeds were not significantly influenced by planting orientation. Maize yield (seed weight per plot) was only significantly influenced by row pattern. Plants grown in double row pattern resulted in yield about 25% higher than those in single row did (Table 3).

Results presented in Table 3 show that the increase in plant population by using double rows was not sufficient to proportionately increase plant yield. The yield increase was 25% compared with a plant population increase of 28% from planting in double rows. Less than optimum plant growth is suggested as the main cause of the proportionately lower yield increase, as the plant canopy was only able to intercept 79% of the light at the end of the vegetative phase. As mentioned previously that percentage of light interception at this phase should achieve 95% (Jeschke, 2014). High sunlight interception at the grains filling phase can increase plant photosynthetic capacity in such a way that plant yield increase (Andrade *et al.*, 2002). The other possibility is that the plant population used was not optimum enough for NK22, a variety with a narrow leaf angle.

Table 3: The effect of row orientation and row pattern on dry maize yield variables

Treatment	Variable			
	Seed weight/c ob (g)	% seed/ cob	Seed weight/p lot (kg)	Weight of 1000 seeds (g)
Orientation				
North-South	154,77	78,06	7,97	393,83
East-West	162,67	77,55	7,65	388,67
$LSD_{0.05}$	-	-	-	-
Rows				
Single row	167,93	77,30	$6,93^{a*)}$	399,67
Double rows	149,50	78,31	$8,68^{b}$	382,83
$LSD_{0.05}$	-	-	0,024	-

*) Numbers in the same column with the same treatment, followed by different letters are significantly different.

4 CONCLUSIONS

It can be concluded that improvement of sunlight interception can be achieved by using a north-south plant row orientation and increasing plant populations up to 98.000 plants/ha through using double row planting. In this study, the increase in plant population from 71.000 (single row) to 98.000 plants/ha (double row) could increase maize yield by 25%. This has the potential to significantly improve productivity of smallholder farmers growing maize in tropical, dryland farming systems.

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