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CROP GROWTH PARAMETERS OF GRAIN SORGHUM VARIETIES (SORGHUM BICOLOR (L.) MOENCH) AT DIFFERENT CROP SPACING

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ABSTRACT
This research aimed at determining morphology, yield and photosynthesis partition of sorghum varieties at different crop spacing had been done at Agro Techno Park of University of Brawijaya (East Java, Indonesia). Observations on crop growth parameters were performed for 4 times (25, 50, 75, and 100 days after planting) which consisted of total leaf area, specific leaf area, leaf area index, crop growth rate and net assimilation rate. The crop spacing of 70 cm x 25 cm proved to provide better value for most parameters, except for crop growth rate and specific leaf area which used 70 cm x 15 cm crop spacing.

KEY WORDS
Sorghum, crop spacing, crop growth, morphology.

Sorghum is a potential commodity and has high economic value because it can be used as food, feed, and export commodities. The people of Rote Ndao Regency (RoNda), Timor Island and its surrounding islands (East Nusa Tenggara Province, NTT) name it as a "rote corn (*jagung rote*)", which is thought to be due to its visual resemblance to corn crops. In this region, sorghum has become an alternative functional food for generations, in addition to rice and corn. However, to the present, the productivity is still low, about 0.37-1.80 tons ha^{-1}, which makes sorghum has not taken farmers' interest as a commercial commodity. In fact, if it is cultivated with a touch of adequate technology, the results can reach 11 tons ha^{-1} of seeds, with an average of 7-9 tons ha^{-1} of seeds (House, 1985, Balitbangtan Kementan, 2013) or total dry material above ground level of 27.2 tons ha^{-1} (Garofalo et al., 2011).

The low production is presumed because sorghum is cultivated simply, it has irregular spacing, and only acts as a limiting crop/fencing crop (to protect the main rice commodities), as practiced by 'rote corn' farmers in RoNda District. Therefore, it is necessary to know the factors that affect the crops through the crop growth analysis approach that aims to determine what environmental factors affect growth and yield (Biscoe and Wellington, 1984). Numerous studies have shown that crop growth and development are influenced by genetic factors (varieties) and environmental factors such as temperature, flux and PAR duration (photosynthetically active radiation), availability of nutrients and water, and loss of photosynthetic tissues (Russelle et al., 1984; Shipley, 2006; Ahad, 1986 in Özalkan et al., 2010).

Crop growth analysis is an important approach for assessing the growth and productivity of crops (Wilson, 1981) or the basic technique used to measure growth components, as a first step in primary production analysis, and is the most practical method for assessing net photosynthetic production (Nogueira et al., 1994) or a quantitative method for describing and interpreting the overall crop system's well-being that grows under natural, semi-natural and controlled conditions (Hunt, 2003). This method can be approached on the individual crop or planting area by using the average of leaf area ratio (LAR), net assimilation rate (NAR), and other similar functions to describe crop growth (Russelle et al., 1984) or by using primary data such as weight, areas, volumes, and specific contents of crops or crop components to inactivate processes involving whole crops or harvested crops (Hunt, 2003) because growth processes (CGR and NAR) directly affect the economic results of crops (Srivastava and Singh, 1980).

The approach in crop growth analysis includes a number of parameters such as Crop Growth Rate (CGR), Unit Leaf Rate or ULR (also called as Net Assimilation Rate, NAR), Specific Leaf Area (SLA), and Leaf Weight Fraction (LWF) (Watson and Hayashice, 1965; Buttery, 1969; Poorter and Remkes, 1990; Karimi and Siddique, 1991; Hunt et al., 2002; Shipley, 2006; Poorter et al., 2009; Gul et al., 2013; Rahnama , 2006 in Ahmadi, Rad, and Delkhosh, 2014; Li et al., 2016):

$$CGR = NAR \times LAI = (RGR \times LAI) / (SLA \times LWF) = (RGR \times LAI) / (LAR)$$

$$RGR = ULR \text{ (atau } NAR) \times LAR$$

$$LAR = \frac{\frac{LA_1}{W_1}+\frac{LA_2}{W_2}}{2} \qquad LWR = \frac{\frac{LW_1}{W_1}+\frac{LW_2}{W_2}}{2} \qquad LWF = \frac{\frac{LA_1}{LW_1}+\frac{LA_2}{LW_2}}{2}$$

$$\underset{(RGR)}{\left(\frac{1}{W}\right)\left(\frac{dW}{dt}\right)} = \underset{(ULR)}{\left(\frac{1}{LA}\right)\left(\frac{dW}{dt}\right)} \; x \; \underset{(SLA)}{\left(\frac{LA}{LW}\right)} \; x \; \underset{(LWF)}{\left(\frac{LW}{W}\right)}$$

Where t = time, W is the total dry weight per crop, LA is the total leaf area per crop, LW is the total dry weight of leaf per crop, LAI is the Leaf Area Index, and LWF is the Leaf Heavy Fraction, synonymous with LWR (Leaf Weight Ratio). CGR is the result of multiplication between NAR and LAI, whereas the result of SLA (ratio of leaf area per unit of leaf weight) and LWF (ratio of leaf weight per total of crop weight) is called as LAR (Leaf Area Ratio).

MATERIALS AND METHODS OF RESEARCH

The research was conducted from September to December 2015 at Agro Techno Park location of Faculty of Agriculture, University of Brawijaya (*FPUB*) in Jatikerto Village, Kromengan Subdistrict, Malang Regency, East Java Province, Indonesia and at a laboratory (Agro Techno Park, Crop Physiology, and Soil Chemistry of FPUB) located at 112.27-112.32^0 of East Longitude and 8.08-8.05^0 of South Latitude, 321 m above sea level. The climatic conditions of the site at the time of the study were carried out were as follows: the average temperature was 24.6-27.8^{0}C, the air humidity was 71-86%, the rainfall rate was 1948.6 mm per year (with 7 wet months and 126 rainy days) and solar radiation of 41-81% (Geophysics Station of Karangkates Malang, 2015).

The materials used in this study were sorghum seed, urea fertilizer with the dose of 200 kg ha^{-1}, SP-36 with the dose of 100 kg ha^{-1} (recommended dosage/ recommendation for sorghum) and KCl of 100 kg ha^{-1}, Furadan 3-G , pesticides, and fungicides. The superior varieties used were Numbu, Kawali, Super 1, and Super 2 obtained from Balitsereal, Maros, South Sulawesi Province, while the local variety of Rote was obtained from the sorghum farmer from RoNda District.

The tools used were luxmeter, PS 1200 type Nict Voor scale, 21037 FNR type Memmert oven, leaf area meter (LAM), freezer, tissue, tarpaulin, hoe, machete, sample ring, meter, scale, knive, crowbar , spade, plastic bucket, ruler, and stationeries. The data of temperature, air humidity, rainfall rate, radiation duration, and intensity of solar radiation (global) were obtained from Geophysics Station, BMKG Karangkates, Malang.

This study used two-factor Separate Plot Design (*RPT*) and three replications with Randomized Block Design (RAK) basic design. Factor I (main plot) was varieties of sorghum with 5 levels (v_1 = local varieties of Rote; v_2 = superior varieties of Numbu; v_3 = superior varieties of Kawali; v_4 = superior varieties of Super 1; and v_5 = superior varieties of Super 2). Factor II (sub plot) is a crop spacing with 3 levels (j_1 = 70 cm x 25 cm, j_2 = 70 cm x 20 cm, and j_3 = 70 cm x 15 cm). Observations were performed for 4 times (25, 50, 75, and 100 days after planting or *HST*) on the following parameters: Total Leaf Area, Specific Leaf Area, Leaf Area Index, Crop Growth Rate and Net Assimilation Rate.

Total Leaf Area (TLA). TLA measurements (usually called as Leaf Area Duration/LAD) (Fakorede and Mock, 1980; Kuchay and Zargar, 2016) used Leaf Area Meter (LAM), then the sample was put in oven for 72 hours at 80^0C until the weight became constant to obtain dry weight leaf.

Specific Leaf Area (SLA). SLA was a comparison between the leaf area and leaf weight containing leaf thickness information that could reflect the photosynthetic organelles unit (closely related to the rate of photosynthesis), where there was a positive relationship between leaf thickness with the number of stomata and chlorophyll content. On the contrary, there was a negative relationship between SLA and photosynthesis rate (Sitompul and Guritno, 1995; Sitompul, 2016).

SLA was calculated by using the formula below (Hunt et al., 2002; Shipley, 2006; Ahmadi et al., 2014; Rana and Rana, 2014; Sitompul, 2016; Li et al., 2016):

$$SLA = \left(\frac{LA}{LW}\right)$$

Where SLA = specific leaf area, LA = leaf area (cm^2), and LW = leaf dry weight (g).

Leaf Area Index (LAI). LAI was closely related to a number of physiological processes such as photosynthesis, transpiration and evapotranspiration (productivity (Gholz, 1982), and the rate of energy exchange between crops and the atmosphere (Gholz et al., 1991 ; Botkin, 1986 in Nel and Wessman, 1993), as it affected the capture of photons and assimilate partitions for the growth and formation of crop yields (Addai and Alimiyawo, 2015).

LAI was calculated by using the formula below (Nel and Wessman, 1993; Sitompul and Guritno, 1995; Addo-Quaye, Darkwa, and Ocloo, 2011; Ramazanzadeh and Asgharipour, 2011; Lukeba et al., 2013; Rana and Rana, 2014; Addai and Alimiyawo , 2015; Sitompul, 2016; Li et al., 2016):

$$LAI = \left(\frac{LA}{GA}\right)$$

Where LAI = Leaf Area Index, LA = leaf area (cm^2), and GA = land area covered by leaf or crop spacing (cm^2).

Crop Growth Rate (CGR). CGR was a growth index that described the increase of biomass per time unit per (initial) capital unit of the crop. CGR was calculated by the following equation (Watson, 1952; Fakorede and Mock, 1980; Karimi and Siddique, 1991; Sitompul and Guritno, 1995; Ramazanzadeh and Asgharipour, 2011; Addo-Quaye, Darkwa, and Ocloo, 2011; Rahnama, 2006 in Ahmadi et al., 2014; Alikhani, Etemadi, and Ajirlo, 2012; Gul et al., 2013; Rana and Rana; 2014; Sitompul, 2016; Li et al., 2016):

$$CGR = \left(\frac{dW}{dt}\right) = (W_2 - W_1)/GA(t_2 - t_1)$$

Where CGR = crop growth rate (g m^{-2} day^{-1}), W_1 = biomass dry weight at T_1 (g), W_2 = biomass dry weight at T_2 (g), GA or SA = ground area or soil area which was occupied by the sample crop, T_1 = crop age at observation of T_1 (day), and T_2 = crop age at observation of T_2 (day).

Net Assimilation Rate (NAR). NAR represented the dry weight addition per unit of leaf area (physiological index) per time unit (crop age), where the total dry weight (W) was not constant and had a linear relationship with the leaf area, calculated according to the following equation (Buttery, 1969; Beadle, 1987 Hunt et al., 2002; Shipley, 2006; Addo-Quaye et al., 2011; Ahmadi et al., 2014; Rana and Rana; 2014; Sitompul, 2016; Li et al., 2016; Kuchay and Zargar, 2016):

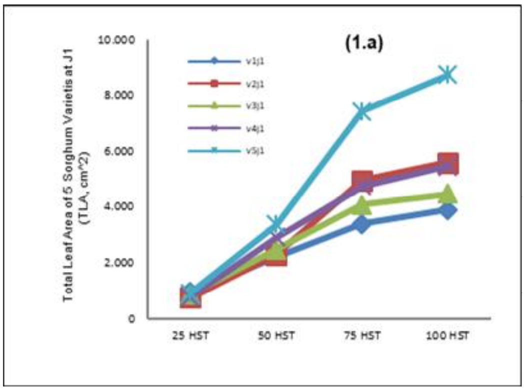
$$NAR = \frac{(W_2 - W_1)(lnLA_2 - lnLA_1)}{(LA_2 - LA_1)(T_2 - T_1)}$$

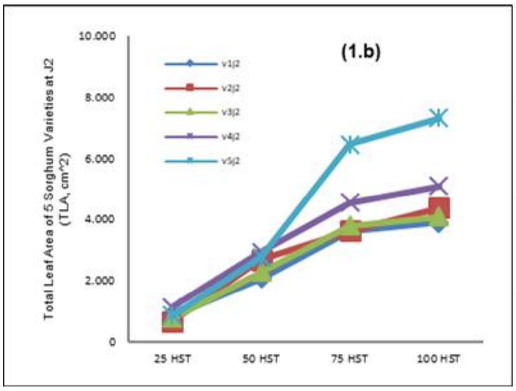
Where NAR = leaf unit price when total dry weight of crop had a linear relationship with leaf area, W_1 = biomass dry weight at T_1 (mg), W_2 = biomass dry weight at T_2 (mg), In = epixilon-based natural logarithm (e = 2.718), LA_1 = leaf area at T_1 (cm^2), LA_2 = leaf area at T_2 (cm^2), T_1 = crop age at observation of T_1 (day), and T_2 = crop age at observation of T_2 (day).

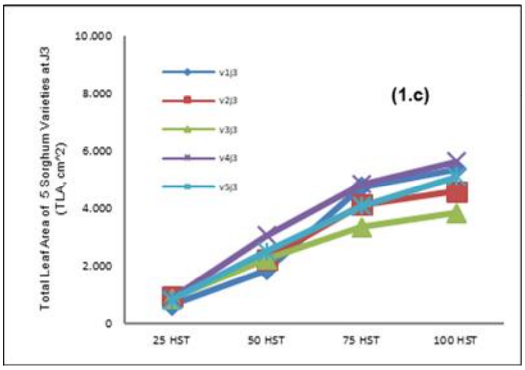
RESULTS AND DISCUSSION

Total Leaf Area. Varieties and crop spacing gave significant influence to TLA at 75 and 100 HST (Figure 1), with the highest TLA value at 75 HST was found in v_5j_1 and the lowest was found at v_1j_1, with the respective values of 6,460.3 and 3,386.4 cm^2. On the other hand, at 100 HST, the highest value was at v_5j_1 and the lowest was at v_3j_3 with successive values of 7,309.1 and 3,889.8 cm^2. While at 25 and 50 HST, the influence of interaction and the main factor was not significant. The closer the crop spacing, the TLA would decrease because the leaves shaded each other so that the lower leaves would lack of light. Therefore, the growth was not normal. TLA differences between varieties were determined by the interaction between varieties and environmental factors in which the crop grew and developed (Saberi and Siti Aishah, 2013). However, there was a tendency that varieties with longer lifespan would have larger TLA values and superior varieties would have larger TLA values than local varieties (Lukeba et al., 2013) because they had more number of leaves and had longer leaf size where there was a linear relationship between leaf number, leaf length and leaf area (Parmar and Chandra, 2002).

Specific Leaf Area. Varieties and crop spacing had significant effect on SLA at 75 and 100 HST (Fig. 2). On the other hand, the effect of interaction and the main factor was not significant at 25 and 50 HST. However, there was a tendency that the superior varieties had a larger SLA values. This was thought to be due to superior leaf varieties which had better leaf morphology (thighter and thicker) compared with local varieties (Poorter and Nagel, 2000). The crop spacing that gave a better SLA value was 70 cm x 15 cm, although it did not significantly different with other crop spacing. Lafarge and Hammer (2002) reported that there was no significant difference between the various treatments of crop density to SLA.

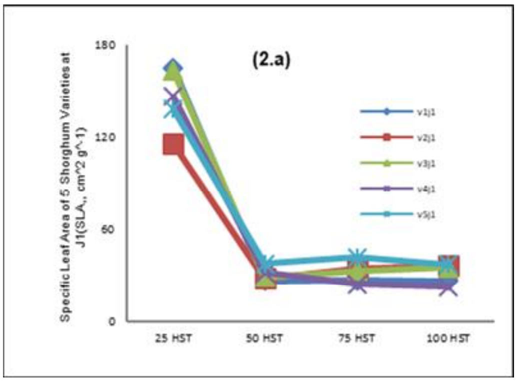


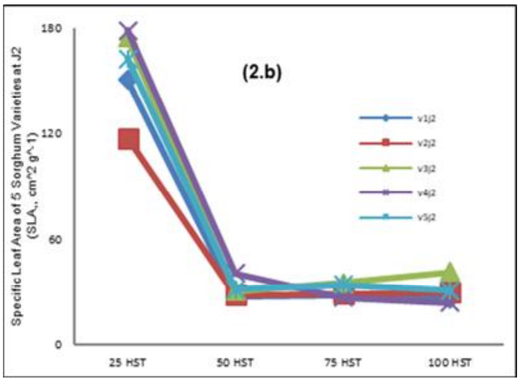


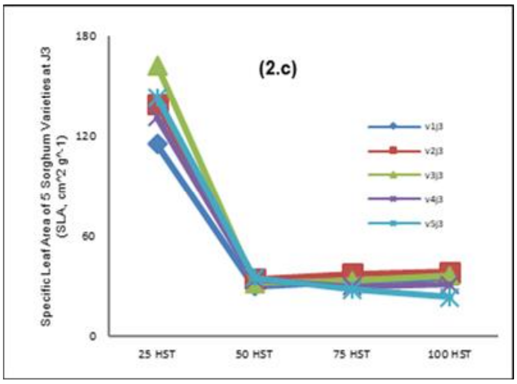


Informations:
1. *TLA = Total Leaf Area*
2. v = Sorghum varieties (v_1= local, Rote, v_2= superior, Numbu, v_3= superior, Kawali, v_4= superior, Super 1, v_5= superior Super 2)
3. j = crop spacing (j_1=70 cm x 25 cm, j_2=70 cm x 20 cm, j_3=70 cm x 15 cm)
4. Figures:
   (1.a) *TLA* of 5 Sorghum varieties at j_1 crop spacing
   (1.b) *TLA* of 5 Sorghum varieties at j_2 crop spacing
   (1.c) *TLA* of 5 Sorghum varieties at j_3 crop spacing

Figure 1 – The Effect of Varieties (v) and Crop Spacing (j) on Total Leaf Area (TLA, cm^2) of Sorghum at Age of 25, 50, 75, and 100 HST for Five Varieties at Three Crop Spacings



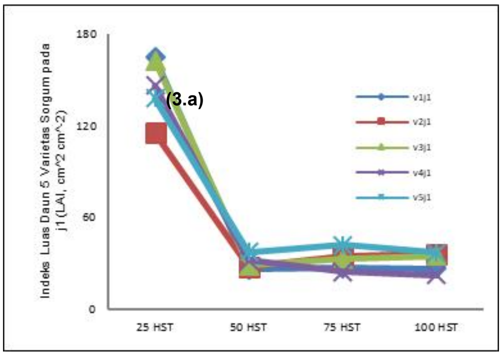


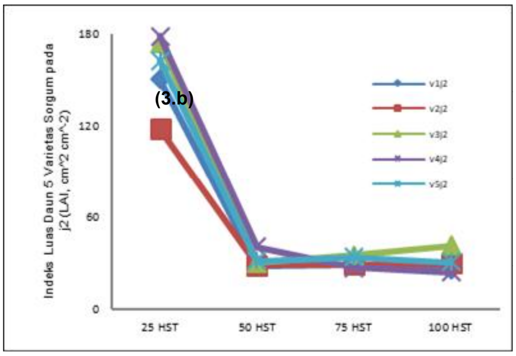


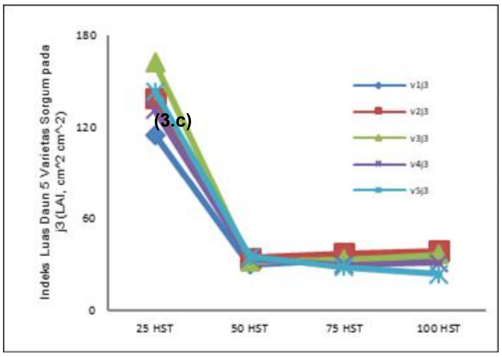
Informations:
1. *SLA = Spesific Leaf Area*
2. v = Sorghum varieties (v_1= local, Rote, v_2= superior, Numbu, v_3= superior, Kawali, v_4= superior, Super 1, v_5= superior, Super 2)
3. j = crop spacing (j_1=70 cm x 25 cm, j_2=70 cm x 20 cm, j_3=70 cm x 15 cm)
4. Figures:
   (2.a) *SLA* of 5 Sorghum varieties at j_1 crop spacing
   (2.b) *SLA* of 5 Sorghum varieties at j_2 crop spacing
   (2.c) *SLA* of 5 Sorghum varieties at j_3 crop spacing

Figure 2 – The Effect of Varieties (v) and Crop Spacing (j) on Specific Leaf Area (SLA, cm^2 g^{-1}) of Sorghum at Age of 25, 50, 75, and 100 HST for Five Varieties at Three Crop Spacings

At 75 HST, the highest SLA value was at v_5j_1 and the lowest was at v_4j_1, where the results were 41.8 and 26.7 cm^2 g^{-1}, respectively. While at 100 HST, the highest value was at v_2j_3 and the lowest was at v_1j_2, with successive values of 38.9 and 22.4 cm^2 g^{-1}.







Informations:
1. *LAI = Leaf Area Index*
2. v = Sorghum Varieties (v_1= local, Rote, v_2= superior, Numbu, v_3= superior, Kawali, v_4= superior,I Super 1, v_5= superior, Super 2)
3. j = crop spacing (j_1=70 cm x 25 cm, j_2=70 cm x 20 cm, j_3=70 cm x 15 cm)
4. Figures:
   (3.a) *LAI* of 5 sorghum varieties at j_1 crop spacing
   (3.b) *LAI* of 5 sorghum varieties at j_1 crop spacing
   (3.c) *LAI* of 5 sorghum varieties at j_1 crop spacing

Figure 3 – The Effect of Varieties (v) and Crop Spacing (j) on Leaf Area Index (LAI) of Sorghum at Age of 25, 50, 75, and 100 HST for Five Varieties at Three Crop Spacings

SLA appeared high at the beginning, and then it began to decrease sharply in the active vegetative phase and decreased slowly in generative and mature physiological phases because SLA was determined by the interaction between light and nutrient content of the crop (Meziane and Shipley, 1999). SLA was positively correlated with light and nutrient content, therefore, in older and denser crops; they had lower ability to catch light due to lower nitrogen content (Lee, Goudriaan and Challa, 2003; Tei, Scaife and Aikman, 1996; Kuchay and Zargar, 2016). However, there was an inverse relationship between radiation quanta and biomass production where SLA would decrease when the total dry weight of the crop was higher as the age of the crop increased. It suggested that light quanta was more instrumental in driving properties activity in crops (crop metabolism and genetic) compared to the crop biomass production (Sitompul, 2016).

Leaf Area Index. Varieties and crop spacing had a significant effect on LAI at 75 and 100 HST (Figure 3), whereas at 25 and 50 HST, only crop spacing had a significant effect. However, there was a tendency that only superior varieties with longer lifespan would have larger LAI values. It was in line with the opinion of Bueno and Atkins (1982) that LAI would increase in line with the age of the crop. The crop spacing that gave a better LAI value was 70 cm x 15 cm. At 75 HST, the highest LAI value was at v_5j_2 and the lowest was at v_1j_1, where the results were 4.61 and 1.9, respectively. While at 100 HST, the highest value was at v_5j_2 and the lowest value was at v_1j_1, where the results were 5.22 and 22.3.

In general, there was a similar tendency between TLA and LAI parameters. At both ages, there was a similar tendency in which the highest LAI values were at j_1 (70 cm x 25 cm) and j_2 crop spacing (70 cm x 20 cm) for Super 2 varieties, while Super 1 was at j_3 crop spacing (70 cm x 15 cm). The high value of LAI on Super 2 varieties was in line with relatively high crop morphology with longer and wider leaf size when compared to the other two superior varieties (Numbu and Kawali). The size of Rote's (local varieties) leaf actually had a length that was almost the same as the Super 2 varieties, but it was narrower, which resulted in lower LAI value.

At the age of 25 and 50 HST, only crop spacing affected the LAI, where the highest LAI value was at the crop spacing of 70 cm x 15 cm because the crops tended to be dense, causing intercurrent covering.

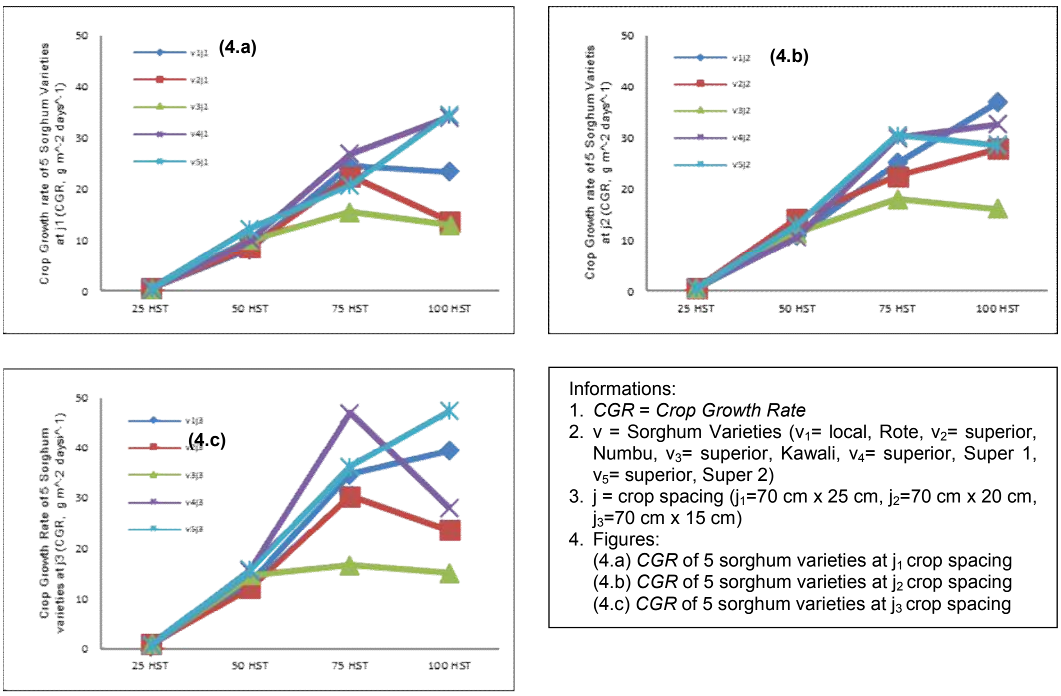


Figure 4. The Effect of Varieties (v) and Crop Spacing (j) on Crop Growth Rate (CGR, g m^{-2} day^{-1}) of Sorghum at Age 25, 50, 75, and 100 HST for Five Varieties at Three Crop Spacings

Thus, the closer a crop was, the LAI value tended to increase until it reached the optimum value at the time of maximum extinction coefficient (k) (Tei et al., 1996; Alikhani et al., 2012) because LAI was strongly influenced by the canopy structure which consisted of position, size and shape of the vegetative element (Ross, 1981) and the sun angle (Nel and Wessman, 1993). In addition, the PAR diffusion substraction was able to increase the value of LAI (Nel and Wessman, 1993).

Crop Growth Rate. Varieties had significant effect on CGR at age of 75 and 100 HST, while crop spacing had significant effect on CGR at age of 50 and 75 HST (Figure 4). The crop spacing that gave a better NAR value was 70 cm x 25 cm. At 75 HST, the highest CGR value was at v_4j_3 and the lowest was at v_3j_1, where the results were 47.009 and 15.472 mg cm^{-2} day^{-1}, respectively. At 100 HST, the highest CGR value was at v_1j_3 and the lowest was at v_3j_1 with successive values of 39.555 and 12.980 mg cm^{-2} day^{-1}. At the age of 25 HST, all treatments were not significant. However, there was an interesting tendency that the closer the crop spacing, then the more the CGR value increased. In addition, long-lived superior varieties were found to have higher CGR compared with shorter-lived superior varieties and local varieties (Rote).

This was in line with what Ramazanzadeh and Asgharipour (2011) reported that CGR tended to be low on initial growth due to imperfect land cover resulting in low light interception due to a lot of passing light. However, as the leaf area increased and the less light passed through the lower canopy layer, the CGR value increased rapidly and reached optimum at flowering/efflorescence stage. The same opinion was expressed by Addo-Quaye and Ocloo (2011), who stated that CGR had a linear relationship with LAI, where the higher perceived light would reslut in higher LAI and CGR value, and vice versa.

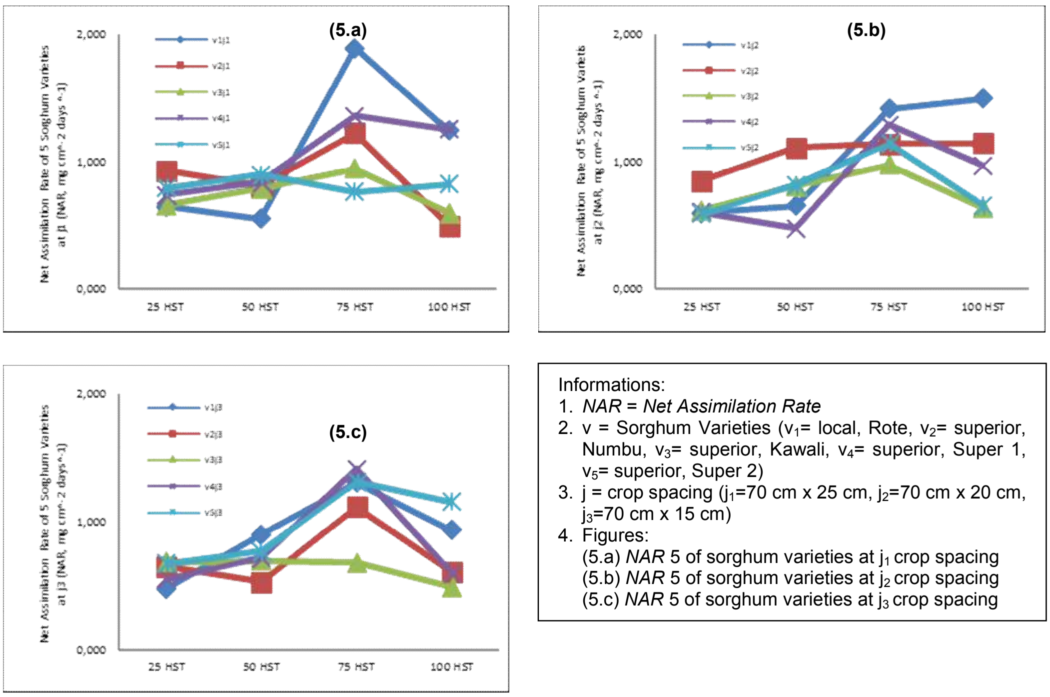


Figure 5 – The Effect of Varieties (v) and Crop Spacing (j) on Net Assimilation Rate (NAR, mg cm^{-2} day^{-1}) of Sorghum at Age of 25, 50, 75, and 100 HST for Five Varieties at Three Crop Spacings

Net Assimilation Rate. Varieties and spacing gave a significant effect on NAR only at 50 HST (Figure 5), while at the other three observations had no significant effect, but there was a tendency, where NAR value was low at the beginning, then it peaked at 75 HST and then decreased at 100 HST. The crop spacing that gave a better NAR value was 70 cm x 25 cm. At 50 HST, the highest NAR value was at v_1j_3 and the lowest was at v_4j_2 with successive values of 0.903 and 0.479 mg cm^{-2} day^{-1}. Increased NAR values between 50 and 75 HST indicated that crops were at a high rate of photosynthesis (Parmar and Chandra, 2002).

While the tendency of decreasing NAR values at 100 HST showed that crops had shifted from vegetative to generative phases (had entered physiological maturity) (Addo-Quaye and Ocloo, 2011) and most of them had aged so that the rate of photosynthesis as well as the nitrogen concentrations contained in low leaves experienced a decrease (Li et al., 2016). In addition, NAR was inconsistent with time (Enyi, 1977, Gardner, Pearce, and Mitchell, 1991) and was influenced by LAI. Therefore, NAR would decrease as the crop spacing got closer and leaves began shading each other (when LAI reached optimum), contradicted with NAR and LAI (Buttery, 1969; Machado et al., 2002; Kuchay and Zargar, 2016).

CONCLUSION

A research aimed at determining morphology, yield, and photosynthesis partition of sorghum varieties at different crop spacing had been done at Agro Techno Park of University of Brawijaya, Jatikerto Village, Kromengan Subdistrict, Malang Regency, East Java, Indonesia. The study used a two-factor separate plot design, where the main plot was varieties and the sub plot was crop spacing. Observations on growth parameters were performed for 4 times (25, 50, 75, and 100 HST) which consisted of Total Leaf Area (TLA), Specific Leaf Area (SLA), Leaf Area Index (LAI), Crop Growth Rate (CGR), and Net Assimilation Rate (NAR). The results showed that at 75 HST, the highest TLA value was at v_5j_1 and the lowest was at v_1j_1, where the results were 6,460.3 and 3,386.4 cm2. While at 100 HST, the highest TLA was at v_5j_1 and the lowest was at v_3j_3, with successive values of 7,309.1 and 3,889.8 cm^2. For SLA parameter, there was a tendency that superior varieties had greater value. At 75 HST, the highest SLA value was at v_5j_1 and the lowest was at v_4j_1, with the results of 41.8 and 26.7 cm^2 g^{-1}. While at 100 HST, the highest SLA was at v_2j_3 and the lowest was at v_1j_2, with successive values of 38.9 and 22.4 cm^2 g^{-1}. LAI at 75 HST indicated that the highest value was at v_5j_2 and the lowest was at v_1j_1, with the results of 4.61 and 1.94. While at 100 HST, the highest LAI was at v_5j_2 and the lowest was at v_1j_1 with successive values of 5.22 and 22.3. At 75 HST, the highest CGR value was at v_4j_3 and the lowest was at v_3j_1, with the results of 47.009 and 15.472 mg cm^{-2} day^{-1}, respectively. At 100 HST, The highest CGR was at v_1j_3 and the lowest was at v_3j_1 with successive values of 39.555 and 12.980 mg cm^{-2} day^{-1}. Superior varieties had a higher value than local varieties for CGR parameter. NAR tended to be low at the beginning and then it peaked at 75 HST and decreased at 100 HST. At 50 HST, the highest NAR value was at v_1j_3 and the lowest was at v_4j_2, with the results of 0.903 and 0.479 mg cm^{-2} day^{-1}, respectively. The crop spacing of 70 cm x 25 cm proved to provide better value for most parameters, except for CGR and SLA, which the crop spacing was 70 cm x 15 cm.

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