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Research Communication

Effect of fertilizer mechanism and harvest time on juice volume, sugar brix and bioethanol in three varieties of sweet sorghum (*Sorghum bicolor*)

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ABSTRACT

An experiment was conducted during the rainy season of 2014–2015 at Experimental Garden of Indonesian Research Cereals Institute, Gowa, Indonesia to evaluate the effect of fertilizer nutrient release mechanism and harvest time on volume and sugar content of juice and bioethanol yield of 3 varieties of sweet sorghum (*Sorghum bicolor* (L.) Moench). The experiment was performed in the field using split-split plots design, where the main plot received mechanism of fertilizer that consisted; fast release (P_1), slow release (P_2) and combination of both fast release and slow release (P_3), while the sub-plots received harvest time treatments, viz. Harvesting before physiological maturity (W_1), Harvesting at the exact physiological maturity (W_2) and Harvesting after physiological maturity (W_3), and in the sub-sub-plots 3 varieties viz. 'Numbu' (V_1), 'Super 1' (V_2) and 'Super 2' (V_3). The results showed that fertilization with P_3 gave the best average results of juice volume and others parameters compared to P_1. P_2 fertilization gave the best results of sugar content, while P_3 gave the best results of bioethanol produciton. W_1 gave the best results of volume of juice, while W_3 and W_2 gave the best results of sugar content. W_1 and W_3 recorded the best results on bioethanol. V_2 varieties recorded the highest volume of juice.

Key words **:** Bioethanol, Fertilizer mechanism, Harvest time, Juice, Sugar brix, Sweet sorghum,

Exploration of fossil energy which is a non-renewable energy is not line up to its formation process in nature that took millions of years. The world oil demand has reached to 96 million barrels/day or more than 35 billion barrels/year in 2016. Mineral oil stocks are decreasing day-by-day and supply going to be less than demand in future. So, the use of biomass as an alternative source of bioenergy is necessary now-a-days.

One of the commodity as an alternative source of bioenergy is sorghum. Grains from the sorghum can be processed for food, while the juice of stem can be extracted for bioenergy and forage or silage as feed. Composition of sorghum is similar to corn and it contains carbohydrates, protein, fat, vitamins and minerals. Sorghum has tolerance to drought and can be ratooned similar to sugarcane. Sweet sorghum being a C_4 plant is able to photosynthesize faster to produce more biomass than C_3 plants. Production of bioethanol from sweet sorghum depends on plant productivity (biomass) in the field and juice content. The biomass production and juice content of sorghum influenced by several factors, which include plant varieties, stage of harvest, health, soil conditions, climate, irrigation and fertilization.

Among the nutrients, primary nutrients, viz. NPK is very important factor for enhancing the productivity. Research of Ramesha *et al.* (2012), showed the higher production of juice to tune of 10,472 and 9,934 litres/ha during 2008 and 2009 as a result of application of 125 kg N/ha that enriched with vermi-compost, rock-phosphate, phosphorus solubilizing bacteria and mycorrhiza. Jat *et al.* (2014) showed that using full recomendation (100%) of NPK on soil test basis, gave the best result and increase harvest index by 22.9% over the control. Effect of fertilization on plant growth and development, in addition to dose factors, also influenced by the release mechanism of fertilizer nutrients into the soil. Some research results showed that the use of slow-release fertilizer on corn can improve uptaking of nutrients from the soil and enhances the production of seeds.

Stage of harvest of the sorghum, effect the production and quality of food and feed and juice obtained for ethanol production. Therefore, the harvesting of sorghum at right age optimize the results of food, seeds, bioenergy, and fodder, and this need further investigation to deter-

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mine the time of harvest with optimum yield components.

Productivity of bioethanol from sweet sorghum mainly supported by the productivity of crops (biomass) in the field, which further depend on the production potential of genotypes. Sweet sorghum hybrid 'NTJ 2' cultivated in India is capable of producing stem yield to the tune of 53 t/ha and juice 28,000 litres/ha, along with high fermentation efficiency. Sugar content of the juice from sweet sorghum stalks vary between with fermentation efficiency between (14–21%) 90–92% (Reddy and Dar, 2007).

Research conducted at experimental garden of Indonesia Cereals Research Institute Gowa, Indonesia during the in rainy of season of 2014–2015. The study was conducted using the split-split plot design, with three factors. The main plot received nutrient release mechanism of fertilizer (P) comprises 3 levels, viz. NPK fast release or convensional (P_1), NPK slow release (P_2), a combination of conventional NPK + NPK slow release (P_3), each at a dose of 150–135–135 kg N-P-K/ha. Sub-plots received 3 stages of time of harvest, viz. harvesting before physiological maturity (W_1), harvesting at exact physiological maturity (W_2) and harvesting after physiological maturity (W_3). In the sub-sub-plots 3 varieties, viz. 'Numbu' (V_1), 'Super 1' (V_2) and 'Super 2' (V_3) were alloted. Experiment was replicated thrice with 81 plots. Planting was done at 75 cm × 25 cm spacing in plots of size 3 m × 4 m, thus each plot contained 64 populations. Fertilization is carried out twice for conventional NPK (P_1) at 10 and 35 days after planting, whereas for P_2 and P_3 application was done at 10 days after planting.

Parameters measured include the volume of juice, sugar levels (using a refractometer) and ethanol (using Gas Chromatography analysis). Ethanol is obtained through anaerobic fermentation at a temperature of 30°C for 72 hours using fermentors *Saccaromyches cerviceae* and as a nutritional using 1.5 g of NPK for juice samples with a volume of 300 ml. The average rainfall in the study site based on the observed data on station BBI Bonto-Bonto presented in Figure 1. The observed data calculated by analysis of variance. If there is a significant difference will be tested with the least significant difference at 5% level.

The highest juice volume average (12,833 litres/ha) was obtained from combination of conventional and slow release fertilizer (P_3), followed by the volume of juice obtained from slow release fertilizer (P_2) (12,437 litres/ha), and the lowest with the conventional fertilizer (P_1) (9,711 litres/ha). This variation in juice volume attributed to the fresh weight of the stem. Results of analysis of variance (data not shown) indicate that there were significant differences in stem fresh weight recorded with fertilizer mechanism (39.96 t/ha with P_2; 38.37 t/ha with P_3 and 31.35 t/ha with P_1). Fresh weight of stem with NPK slow

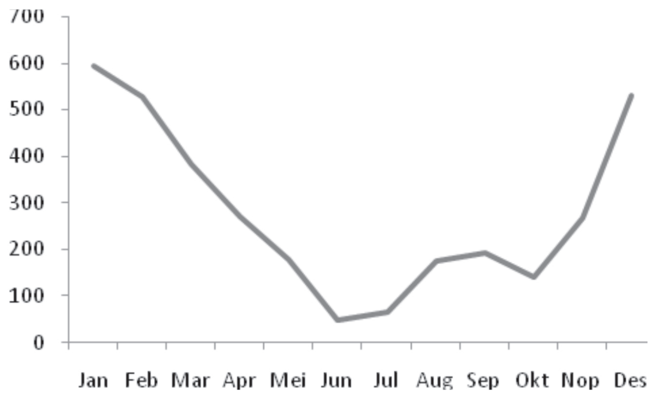

Fig. 1. Rainfall average monthly on station BBI Bonto Bonto from 2004 to 2014

release was 27.4% greater than conventional NPK (P_1).

The N-use efficiency depends on the magnitude of the factors triggering the loss ie evaporation, nitrification, leaching and runoff, especially in the rainy season . This can be reduced with the use of slow release NPK. Research of Duli *et, al.* (2005) showed that the deficiency of N in sorghum was observed 58 days after planting resulting significant reduction in leaf area, leaf chlorophyll content, photosynthetic value and low biomass yield.

Volume of juice tend to similar or not significantly different during the rainy season due to genotypes. This is primarily due to weather factors. Research conducted by Dalvi *et al.* (2013), reported similar juice volume of genotype 'SPH' and 'SPV' of sorghum in the rainy season of 2011.

Based on the time of harvest, harvesting before physiological maturity (W_1) recorded the highest (14,278 litres/ha) juice volume, which was significantly different from W_2 (11,309 litres/ha) and W_3 (9,393 litres/ha) (Table 1). Volume juice contribute to the fresh weight of the stem at the beginning of the harvest, while maturity level of the netting affect the fresh weight of the stem at the end of the harvest period.

The high volume of juice at an early harvest was because of the young plant tissue, which contains high levels of juice. Reduced volume in the second harvest, allegedly because the next stage is the differentiation formation and seed filling, while the third harvest, the reduction possible to occur due to the evaporation rate is faster when the capacity of cells to store liquids decreases.

Among the varieties, the highest volume of juice obtained by 'Super 1' (V_2), which was significantly different from 'Numbu' (V_1) and 'Super 2' (V_3). V_2 recorded 15,238 litres juice/ha, V_1 reached to 13,236 litres/ha, while V_3 reached to 6,507 litres/ha. Variety is a population of plants within a species that show different characteristics. Each

Table 1. Effect of treatment on juice volume (litres/ha) of sorghum

Fertilizer mechanism	Harvest time	Varieties V_1	V_2	V_3	$P_{1,2,3}$ Average	$W_{1,2,3}$ Average	$V_{1,2,3}$ Average
P_1	W_1	13219	14599	5497	P_1	W_1	V_1
	W_2	11875	12053	5970			
	W_3	8463	11804	3916			
	average	11185	12819	5128	9,711	14,278	13,236
P_2	W_1	15840	19048	10448	P_2	W_2	V_2
	W_2	13208	17473	4694			
	W_3	11540	12841	6845			
	average	13529	16454	7329	12,437	11,309	15,238
P_3	W_1	17025	20695	12134	P_3	W_3	V_3
	W_2	15072	16198	5240			
	W_3	12882	12430	3816			
	average	14993	16441	7063	12,833	9,393	6,507
CD (P=0.05)					2,660	2,672	1,596

variety has its own potential and adaptability. The results showed that the 'Super 1' varieties produce larger volumes of juice, significantly different with 'Numbu', and both of them significant different with 'Super 2'. These variations can be expected due to genetic traits variation of each variety.

The highest brix percent was recorded with P_2 (13.39%), which was significantly different from the P_3 (12.52%) and P_1 (12.38%). These results indicated that P_2 is more effective than P_3, and both were more effective than P_1. Thus, it can be concluded that with the same dose, the release of nutrients in a slow release fertilizer is more effective than the combination of fertilizer and significantly different from conventional fertilizers for the higher brix. As a comparison, another study with a dose level of fertilization by Uchino *et al*. (2013) found no significant difference between the sugar brix of various doses of N using conventional urea fertilizer. The use of slow release fertilizer is thus recommended to improve the effectiveness of the fertilizers.

Based on time of harvest treatment, the highest brix percent was received with W_3 (14.25%), which was significantly different from W_2 (13.26%) and very significantly different from W_1 (10.78%). Inversely proportional to the volume of juice, sugar content increases in line of sorghum age especially since the process of filling and ripening grain sorghum is took place. The results of the study conducted by Subramanian *et al.* (2009) on sweet sorghum 'M81E' showed an increasing trend in brix (5.4%) since the emergence of the flag leaf to grain sorghum began to harden, a slight decrease in time to mature physiologically and rise again after physiologically maturity (6.9%).

Results showed that each variety respond differently to time of harvest. Data in Table 1 shows that the brix percent of V_1 gives the best average in the third harvest W_3 (15.7%) and second W_2 (14.3%). Overall each variety were harvested at W_3 and W_2 produces sugar levels significantly different from W_2. From these results it can be seen that the best volume of juice was produced by V_2, but the best sugar content was given by V_1.

Effect of fertilization P_2 and P_3 gave different results in the majority of the growth parameters than P_1. Similarly, the effect of the volume of the juice and sugar. The volume

Table 2. Effect of fertilizer mechanism, time of harvest and varieties on the content of sugar (Average)

Fertilizer mechanism		Harvest varieties time	V_1	V_2	V_3
P_1	12.38^b	W_1	11.90^{az}	11.57^{ay}	8.87^{by}
P_2	13.39^a	W_2	14.29^{ay}	13.06^{bx}	12.43^{bx}
P_3	12.52^b	W_3	15.77^{ax}	13.90^{bx}	13.09^{bx}
CD (P=0.05)	0.49	CD (P=0.05)		0.9	

Note: There was interaction between harvest time and varieties

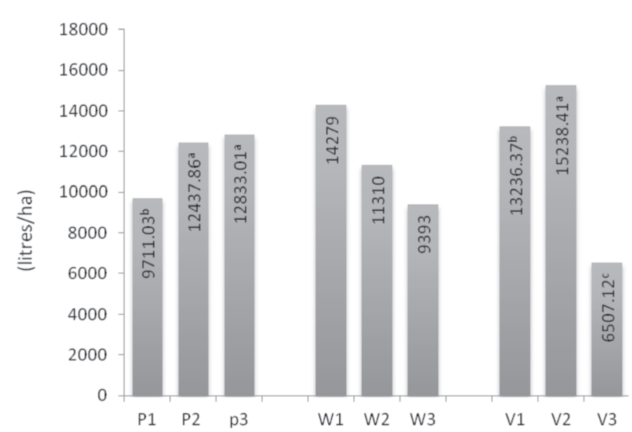

Fig. 2. Juice Volume on various fertilizer mechanism, harvest time and varieties

Table 3. Effect of treatment on the bioethanol (litres/ha) production of sorghum

Fertilizer mechanism	Harvest time	Varieties V_1	V_2	V_3	P1,2,3 Average	W1,2,3 Average	V1,2,3 Average
P_1	W_1	739.90	817.46	307.67	P_1	W_1	V_1
	W_2	665.39	675.21	334.58			
	W_3	595.02	829.70	275.41			
	average	666.77	774.12	305.89	582.26	799.13	793.15
P_2	W_1	886.21	1,066.01	584.94	P_2	W_2	V_2
	W_2	738.48	978.97	262.77			
	W_3	809.26	903.18	481.25			
	average	811.32	982.72	442.99	745.68	633.51	912.26
P_3	W_1	953.14	1,158.04	678.82	P_3	W_3	V_3
	W_2	845.07	907.65	293.43			
	W_3	905.84	874.13	268.35			
	average	901.35	979.94	413.53	764.94	660.24	387.47
CD (P=0.05)					137.29	162.19	95.97

of bioethanol produced at P_2 and P_3 is determined by the parameters of the volume of juice and sugar brix. The average yield of bioethanol (Table 3) showed that P_3 provided the best results of 764.94 litres/ha, which were statistically at far with P_2 fertilization (745.68 litres/ha) and both significantly different from P_1 (582.26 litres/ha). The use of slow release fertilizer either alone or in combination with conventional fertilizers recommended to plant growth and development so as to provide optimum bioethanol.

The conversion efficiency of sweet sorghum for bioethanol is determined by the volume of juice and sucrose which can be measured by the sugar content. Research of Kumar (2008) showed that increasing the dose of N ranging from 30 kg/ha, 60 kg/ha, 90 kg/ha and 120 kg/ha gave the effect of an increase in the volume of juice. The use of slow release NPK allegedly gave the influence of increasing nutrient availability, especially N in the soil thus increase the yield of bioethanol.

Based on the time of harvest, volume of juice from W_1 to W_2 and then W_3 decreases, while the sugar levels increases. The measurement results show that the bioethanol recorded with W_1 and W_3 was more and significantly different from W_2. W_1 with low sugar content but produces a high volume of juice, finally produce high volumes of bioethanol (799.13 litres/ha), while W_3 with low volume of juice but high sugar content produced more bioethanol. Tsuchihashi (2015) conducted research over 3 years and reported that with the advancement of age from 111 days, the volume of juice tends to decrease.

Among the variety, 'Super 1' (V_2) gave higher bioethanol yield 912.26 litres/ha, mainly due to the high volume of juice, significantly different from 'numbu' (V_1) of 793.15 litres/ha. Based on GC analyses, result of this research showed that the best varieties was V_2 'Super 1' in bioethanol production.

Based on the above analysis it can be concluded that combined application of conventional and slow release fertilizers and harvesting at pre-physiological maturity stage of variety 'Super 1' is the best practice for harvesting higher ethanol from sweet sorghum.

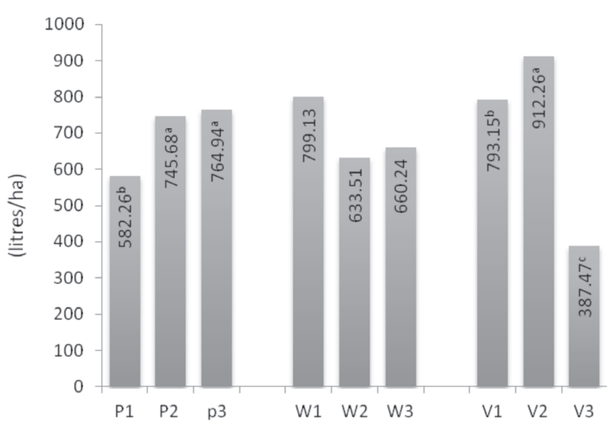

Fig. 3. The average yield of bioethanol each treatment; fertilizer mechanism, time of harvest and varieties.

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