

Adaptation, Biomass and Ethanol Yields of Sweet Sorghum (*Sorghum bicolor* (L.) Moench) Varieties at Dryland Farming Areas of Jimbaran Bali, Indonesia

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The research was funded by the Directorate General for Higher Education of Republic of Indonesia and the Udayana University through its research and service institution (*LPPM*)

Abstract
Decreasing the availability of fossil energy sources in Indonesia, demand that an alternative and renewable source of energy is to be found. Sweet sorghum is a possible candidate for a cheap and renewable source of energy. An experiment was conducted to study the adaptation of sweet sorghum varieties and to find out the optimum rate of organic manure for high biomass and ethanol yields in dryland areas at Jimbaran, Badung, Bali. The experiment was a two factor experiment in a randomized complete block design with three replications. The first factor was four sorghum varieties, three varieties originated from Japan viz. Kotobun sorgo (FS501), Big sugar sorgo (FS902), Super sugar (KCS105) and Local Belu originated from East Lesser Sunda islands, Indonesia, and the second factor was four rates of organic manure of 0, 10, 20, 30 t ha^{-1}. The four varieties adapted well on dryland areas at Jimbaran, Badung, Bali, butFS902, KCS105 and Lokal Belu had better growth compared to FS501. The variety of KCS105 resulted in significantly ($P<0.05$) highest total biomass fresh and dry weight of 28.2 and 9.7 t ha^{-1} , respectively, stem sugar yield of 2.6 t ha^{-1}and stem ethanol yield of 6493.3 l ha^{-1}, which was 63.3% higher than that of Local Belu eventhough their ethanol content were similar. No significant effect was found in the rates of organic manures and the interaction between the two factors on biomass, sugar and ethanol yields. The optimum rate of manure for highest biomass, sugar and ethanol yields was not found in this experiment. It was concluded that the four sorghum varieties were well adapted and KC105 produced highest biomass and ethanol in dryland areas at Jimbaran, Badung, Bali.
Keywords: Adaptation, Biomass, Ethanol, Sweet sorghum (Sorghum bicolor (L.) Moench).

1. Introduction

A number of crops, such as sweet soghum, corn, wheat, sugarcane, sugar beet, sweet potatoes (Reddy *et al*., 2005; Drapcho *et al*., 2008) not only provide foods (Almodares *et al*., 2008c), feeds (Fazaeli *et al*., 2006), fibers (Murray *et al*., 2008) but also produce sugars which can be converted to alcohol that can be used as energy sources. Sorghum is classified as sweet grain cereals and forages (Almodares *et al.*, 2008a). Sweet sorghum as well as grain sorghum produces grains 3-7 t ha^{-1} (Almodares *et al*., 2006), however the sweetness of sorghum is not from its grains but from its stem which has a high sugar content (Almodares *et al*, 2008b). The sugar content in its stem is approximatly 54 - 69 t ha^{-1} (Almodares *et al*., 2008b), which vary with variety (Almodares *et al*., 1994). Depending on varieties, Brix value of sweet sorghum is in the range of 14,32 – 22,35% (Almodares *et al*., 1997).

The planting of sweet sorghum for bioethanol industries is encouraged by the government of Indonesia which requires large areas of land. Since sorghum can be grown in marginal land, there is no need to use arable land which is usually devoted for economic food crops (Hoeman, 2009). In Indonesia, there are around 143.9 millon hectares of land which are regarded as dryland. Of that amount, 31.5 million hectares are dryland which are slightly undulating (slope of < 8 %) and are suitable for sorghum planting (Trikoesoemaningtyas and Suwarto, 2006 unpublished results). These land is usually left fallow in the dry season, and putting these land for sweet sorgum growing will be of a great contribution to the sustainable bioethanol industries.

Southern areas of Badung regency in Bali Province of Indonesia are a dry, marginal land which is not suitable for arable food crops, especially in the dry season. Soil pH is high and the soil has a high rock content which is difficult to cultivate. Hence, the land is usually left fallow during the dry season. The soils in the areas are clay soils with a low content of organic matter and other nutrients (Mediastari, 2006). Mediastari (2006) and Eduardus (2007) reported 5 ton ha^{-1} corn yields in rainy season in the areas, which are much less than the potential yields of corn.

Despite its tolerant to drought and saline-alkaline soils (Vasilakoglu *et al*., 2011), sweet sorghum has never been planted in the Southern areas of Badung, Bali. Having a C_4-pathway of CO_2 fixation sweet sorghum has a high water use efficiency, it is a robust plant and may be a better crop than corn for the areas in the dry season. However, no studies has ever been conducted to explore the possibility.

A field experiment was conducted to study the adaptation of sweet sorghum varieties and the effect of manure rates on the production of biomass and ethanol yields. It was expected that the experiment will contribute in providing the bioenergy resources and at the same time making use the unproductive dryland areas. The optimum rates of manures for biomass and ethanol production of those varieties were also studied.

2. Materials and Method

A field experiment was conducted from June until November 2012 at the dryland farming areas of Jimbaran, Bali (008° 44' 45"S-115°10' 09"E, 3 m above sea level). The soil has a very low soil organic carbon (0.84%) and N, P, K (Lab. Analysis, 2012), a high pH of 8, and with a high rock content. Means monthtly minimum-maximum temperatures and means temperatures for 2012 were 23.3-28.5 ^{o}C and 1.0-94.9 mm, respectively. The low fertility and unproductive land was left fallow since a few years ago.

A factorial experiment in a randomized complete block design with three replications was conducted with two treatment factors. The first factor was sweet sorghum varieties viz. (V): Kotobun Sorgo (FS 501), Big Sugar Sorgo (FS 902), super sugar (KCS105) (Homma *et al*., 2010) and local Belu NTT., while the second factor was manure rates (O) of : 0, 10, 20 and 30 t ha^{-1}. The soil was hand cultivated with spade during which the soil clods were broken. Plot size was (3.50 m x 1.00 m) with plant spacing of 70 cm x 20 cm. Manures used were Compost made from animal waste and crop residues. Minimal amount of water was applied when required to prevent water stress.

Harvests were carried out 45 days after heading in harvest areas of 1.26 m^2. The stem sugar content (Brix) was measured using a refractometer and averaged over nine plants. The ethanol content was determined in the laboratory by fermentation and distillation analysis and measured using gas chromatography (Analytical Lab., 2012). Soil organic carbon at the end of experiment was analyzed in the laboratory using Walkey and Black method (Soil Chem. Lab., 2012). Statistical analysis was conducted with CoHort Software computer program (1995), and separations of means were conducted with Least Significant Different analysis (Steel and Torrie, 1960) after data transformation where necessary.

3. Results and Discussion

3.1 Plant growth

The effects of variety were highly significant (P<.001) on all variable measured, while the effect of manure rates and interaction between the two factors were not significant (P=.05). All four varieties were adapted well at the dryland in Jimbaran, Badung as indicated by the growth variables (i.e. number of seedlings emerged at 6 days after planting (DAP), plant height at 90 dap, number of internodes at 90 DAP and stem diameter at 90 (DAP) (Table 1). These data indicated that sorghum is indeed adapted well in dry condition, tolerant to high temperature stress and wide range of soils. The varieties of FS902, KCS105 and Local Belu grew earlier and homogenously at 6 dap. The variety of Local Belu reached heading 4.3 days earlier resulted in earlier harvest compared to Japan originated varieties (FS501, FS902 dan KCS105) (Table 1). In the present experiment, all varieties reached heading around 62.2-64.3 DAP while harvest at 107.2 -109.2 DAP (45 days after heading).

Almodares *et al*. (2008c) reported that sweet sorghum for etahanol production should be harvested at the highest stalk sugar content that is close to post-anthesis which is ca. three months DAP. Non-structural carbohydrate contents in the stem increases after preboot and reach maximum close to post-anthesis (Almodares *et al*., 2008b). It is also indicated that the highest sugar content in the stem is affected by variety, soil fertility and other environmental conditions.

Better adaptation of those sorghum varieties resulted in better growth of stems, leaves and panicles, and finally in high total biomass production in spite of the dry condition and limited addition of water. Among those four varieties, KCS105 produced the highest stem and leaf fresh weight and in turn the highest total biomass fresh weight of 28.2 t ha^{-1}(Table 2), although the panicle fresh weight was less than that of FS902. In Ibaraki Japan, variety FS902 produced the highest shoot biomass fresh and dry weights (6 t ha^{-1}) (Homma *et al*., 2010).

High number of KCS105 seeds eaten by birds (possibly due to the sweeter seeds) resulted in its lowest panicle weight. Sweet sorghum, similar to grain sorghum, may produce grain of 3-7 ton ha^{-1} (Almodares and Mostafafi, 2006), however in the present experiment grain harvesting was not done due to grains of several varieties were unavoidably eaten by birds.

3.2 Biomass and ethanol production

The highest stem and leaf FW of variety KCS105 resulted in the highest DW of stem and leaf and finally in the highest total biomass DW (Table 3). The highest total biomass FW and DW indicated highest photosynthetic activity which in turn resulted in the highest accumulation of sugar in the stem of variety KCS105. The highest accumulation of sugar was indicated by the highest sugar content and juice volume, that finally made the highest sugar production of 2.6 t ha^{-1} of this variety (Table 4). This result was slightly lower than the production of the same variety grown in Ibaraki, Japan (3.06 t ha^{-1}) reported by Homma et al. (2010). The lower sugar production reported in this present experiment might be due to lower plant population, which was 71.429 plants ha^{-1}. According to (Layaoen and Rosario, 2009) in dry conditions the population used should be 130.000 plants ha^{-1} resulted from the spacing of 75 cm x 10 cm. Hence to obtain higher sugar production, an experiment using higher population is recommended. Planting in the rainy season with population of 143000-150000 plants ha^{-1} will possibly be able to increase sugar production and ethanol as the relationship between stem FW and juice production was found to be linear (Y= -299.78+396.98 X; r=0.977**; R^2=0.955**) (Fig. 1).

Sugar content in stem juice of sweet sorghum varies with variety (Almodares *et al*., 1994). Almodares *et al*. (1997) also indicated that duration of sucrose accumulation in the stem varies with cultivar. Brix among sweet sorghum varieties were in the range of 14.32 – 22.35%. Stem of KCS105 variety showed the highest brix of 18.9% while that of FS 902 had the lowest of 14.8%. Interestingly, variety of local Belu showed brix of 17.4% and ethanol content of 93.7%, which was not significantly different from that of Japan originated varieties (Table 4). The highest values of sugar in the stem resulted in the highest ethanol production (2.4 ton ha^{-1}), since the ethanol content was also the highest (94.1%) in KCS105 (Table 4).

Generally, the juice of sweet sorghum can be converted to 85% ethanol or 54.4 l ethanol per 100 kg fresh stem (Rains *et al*., 1993). In the present experiment, the ethanol content produced was not much different from that reported by (Reddy *et al*., 2005), however, the production of stem ethanol was still considered low due to low the stem sugar production (Table 4). Lower plant population resulted in lower total biomass produced.

McBee and Miller (1990) reported that closer plant spacing significantly increased total carbohydrates at anthesis. Total drymatter and water soluble carbohydrates (WSC) also increased with increased population from 8 to 16 plants m^{-2} (Martin and Kelleher, 1984). The benefit of the closer row spacings was associated with higher interception of sunlight for photosyntheis prior to anthesis, that resulted in higher WSC at anthesis, thicker stem and higher stem production, which was closely correlated with post-anthesis WSC.

In the present experiment, wider plant spacing of 70 cm x 20 cm was used, therefore higher content of carbohydrates, sucrose and finally ethanol can be expected should the closer spacings was used. In addition, ethanol production varies with time at different locations, soil fertility (Almodares and Mostafafi, 2006; Almodares *et al*., 2008c), humidity at planting and harvesting (Almodares and Sepahi, 1997; Almodares and Mostafafi, 2006), therefore the experiment at different location, soil fertility levels, planting and harvesting time and closer plant spacings could result in appropriate conditions for maximum sugar and ethanol production.

Manure rates did not yet significantly affected all variables measured (Table 4). Organic matter required period of decomposition and mineralization of nutrients to become available for plants. Possibly due to that reason the effects of manures even at the rates of 30 t ha^{-1} did not affect the growth and sugar yields of the four sweet sorghum varieties. Therefore the optimum rates of manures to produce the highest sugar and ethanol production was not found in the present experiment. A follow up research of residual effects of the manures on sugar and ethanol production of sweet sorghum was urgently needed.

4. Conclusion

Variety had significant effects on all variables measured, however no significant effects of both rates of manures and interaction between the two factors were found. Varieties FS501. FS902. KCS105 and Local Belu adapted well at dryland farming area of Jimbaran, Badung although planted in a dry season. Varieties FS902. KCS105 and Local Belu grew better than FS501. Variety KCS105 gave the highest production of fresh biomass (28.2 t ha^{-1}) dry biomass (9.7 t ha^{-1}), stem sugar (2.6 t ha^{-1}) and ethanol (2.4 t ha^{-1}). Variety Local Belu produced similar ethanol content from the three Japan originated varieties. The effects of manures rates on production of biomass, stem sugar and ethanol content of the four sweet sorghum varieties, were not significant. The optimum rate of the manures was not found.

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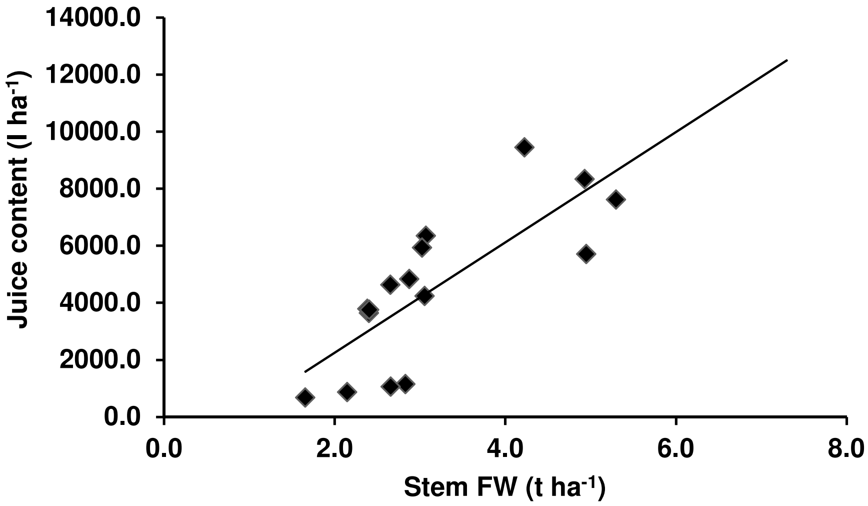

Figure 1. The relationship between stem FW and juice production. Y= -299.78+396.98 x; r=0.977**; R^2=0.955**

Table 1. The single effect of variety and rates of manures on the number of seedling emergence at 6 DAP, plant heights, number of internodes, at 90 DAP, heading and harvest

Treatments	Number of seedlings emergence at 6 DAP	Plant heights at 90 DAP	Number of internodes at 90 DAP	Stem diameter at 90 DAP	Heading	Harvest
	(seedlings)	(cm)	(internodes)	(mm)	(DAP)**	(DAP)
Variety						
FS501	18.3 b*	143.3 c	9.1 b	11.1 b	63,2 a	108.2 a
FS902	20.2 ab	188.1 ab	9.9 ab	12.3 ab	64.3 a	109.3 a
KCS105	21.5 a	179. 2 b	10.1 a	13.4 a	62.2 a	107.2 a
Local Belu	22.1 a	207. 5 a	10.0 a	9.1 c	57.9 b	102.9 b
5% LSD	2.405	24.283	0.738	1.89	3.26	3.26
Rates of manures (t ha^{-1})						
0 (Po)	20.3 a	182.1 a	9.6 a	12.1 a	63.2 a	108.2 a
10 (P1)	19.6 a	166.7 a	9.8 a	11.3 a	61.6 a	106.6 a
20 (P2)	20.6 a	184.5 a	9.8 a	11.9 a	62.1 a	107.1 a
30 (P3)	21.6 a	180.0 a	9.9 a	10.6 a	60.9 a	105.9 a
5% LSD	-	-	-	-	-	-

*Means followed by the same letter in the same column are not significantly different at 5% LSD. **DAP = days after planting

Table 2. The single effect of variety and rates of manures on stem, leaf, panicles and total biomass fresh weight (FW)

Treatments	Stem FW	Leaf FW	Panicle FW	Total Biomass FW
	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})
Variety				
FS501	10.9 b*	6.5 b	0.81 c	18.1 b
FS902	13.0 b	5.9 b	3.67 a	22.0 b
KCS105	18.2 a	8.9 a	1.32 bc	28.2 a
Lokal Belu	6.3 c	3.2 c	1.98 b	11.5 c
5% LSD	4.34	1.72	0.69	6.05
Rates of manures (t ha^{-1})				
0	10.4 a	5.4 a	1.20 b	16.9 a
10	11.4 a	6.4 a	2.00 a	19.6 a
20	15.1 a	6.7 a	2.27 a	23.8 a
30	11.6 a	6.1 a	2.32 a	19.6 a
5% LSD	-	-	-	-

*Means followed by the same letter in the same column are not significantly different at 5% LSD.

Table 3. The single effects of variety and rates of manures on baggase, leaf, panicles and total biomass dry weight and juice production

Treatments	Baggase DW	Leaf DW	Panicle DW	Total biomass DW	Juice production
	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(l ha^{-1})
Variety					
FS501	2.6 bc	2.7 b	0.64 c	6.0 b	4622.4 b
FS902	3.3 b	2.9 b	3.07 a	9.3 a	4628.3 b
KCS105	4.4 a	4.3 a	1.07 c	9.7 a	7832.7 a
Local Belu	2.3 c	2.0 c	2.08 b	6.0 b	934.5 c
5% LSD	0.918	0.59	0.87	1.98	1772.04
Rates of manures (t ha^{-1})					
0	2.8 a	2.7 a	1.13 a	6.7 a	4122.4 a
10	2.8 a	2.9 a	1.79 a	7.6 a	4345.3 a
20	3.9 a	3.1 a	2.08 a	9.0 a	4561.5 a
30	3.1 a	3.2 a	1.87 a	8.1 a	4988.8 a
5% LSD	-	-	-	-	-

Notes: Means followed by the same letter in the same column are not significantly different at 5% LSD. *DW=oven dry weight

Table 4. The single effect of variety and rates of manures on sugar and ethanol content, sugar and ethanol yields and soil organic carbon before and after the experiment

Treatments	Sugar content (brix)	Sugar production	Ethanol content	Ethanol production	Soil organic carbon	
					Before experiment	After experiment
	(%)	(t ha^{-1})	(%)	(l ha^{-1})	(%)	
Variety						
FS501	17.9 b*	1.5 b	92.6 b	4381.9 a	0.840 a	0.802 a
FS902	14.8 c	1.4 b	92.9 b	4741.8 a	0.840 a	0.694 a
KCS105	18.9 a	2.6 a	94.1 a	6493.3 a	0.840 a	0.805 a
Local Belu	17.4 b	0.7 c	93.7 ab	1060.1 b	0.840 a	0.732 a
5% LSD	1.06	0.67	1.02	229.70	-	-
Rates of manures (t ha^{-1})						
0	17.6 a	1.4 a	93.3 a	4382.2 a	0.840 a	0.755 a
10	17.8 a	1.5 a	93.7 a	4581.9 a	0.840 a	0.811 a
20	16.7 a	1.9 a	92.9 a	3079.5 a	0.840 a	0.804 a
30	16.9 a	1.5 a	93.2 a	4633.5 a	0.840 a	0.664 a
5% LSD	-	-	-	-	-	-

*Means followed by the same letter in the same column are not significantly different at 5% LSD.