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Effects of Fertilizers on Biomass, Sugar Content and Ethanol Production of Sweet Sorghum

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/66814>

Abstract

Sweet sorghum (*Sorghum bicolor*) is a promising alternative crop for bioethanol production in developing countries. However, to extend the cultivative area of this crop, it needs to develop an appropriate growing protocol for farmers. This chapter describes the examination of different doses of fertilizers combined with manure and micronutrients, in various applied times, on biomass, sugar content and ethanol production of sweet sorghum. It was observed that the application of 90 N + 90 P₂O₅ + 60 K₂O provided maximum stem yield and optimum contents of sugar and ethanol yield, however nontreatment of any among P, P₂O₅ and K₂O caused significant reduction of biomass and ethanol production. Higher fertilization >90 N may provide greater productivity of this crop but it may cause lodging and economic deficit for farmers in developing countries. It was also found that the applied times of fertilization should be at 3–4 to 7–8 leaf stage. In contrast, when the fertilization was as close to the flowering stage caused remarkable reduction of stem yield and ethanol production. The supplementation of (NH₄)₂MO₇O₂·4H₂O at 5 kg/ha provided an increase of 10–12 tons/ha of stem yield and a remarkable enrichment of ethanol production. Findings of this study are useful for farmers and agricultural extensionists to promote biomass and ethanol productivity of this crop for bioethanol production. This research also highlights a greater possibility of exploiting sweet sorghum cultivation in infertile and hilly, abandoned areas for ethanol production.

Keywords: sweet sorghum, fertilizer, stem yield, biomass, ethanol yield, growing protocol, biofuel crops

1. Introduction

It has been estimated that there are 700 million light duty vehicles, automobiles, light trucks, SUVs and minivans on roadways around the world. These numbers may increase to 1.3 billion by 2030 and to over 2 billion vehicles by 2050, with most come from developing countries [1]. This growth will affect the stability of ecosystems and global climate as well as global oil reserves [2]. The use of biofuels can contribute to the mitigation of greenhouse gas emissions, provide a clean and sustainable energy source and may promote the agricultural income for rural poor in developing countries. Currently, biofuels are predominantly produced from biomass resources, because they are the renewable resource that could be sustainably developed, resulting in no net release of carbon dioxide and very low sulfur content and economic potential as fossil fuel prices can be increased in the future [2]. The principal sources of biofuels are liquid or gaseous fuels made from plant matter and residues, including agricultural crops, municipal wastes and agricultural and forestry by-products.

Bioethanol has a high octane number (108), broader flammability limits, higher flame speeds and higher heats of vaporization. It helps for a higher compression ratio and shorter burn time, which lead to efficiency advantage over gasoline in an IC engine [3]. Bioethanol can be directly used or it can be blended with gasoline in different ratio from 3 to 25%, depending on countries. The most common that has been widely used is E10 (10% bioethanol blended with 90% gasoline), however in Brazil, bioethanol 100% (E100) or bioethanol 25% (E25) are used [4].

Recently, the production of bioethanol has focused on crops, such as maize, sugarcane and soybean. It includes three major groups: sucrose-containing feedstocks (sugarcane, sugar beet, sweet sorghum and fruits), starchy materials (corn, milo, wheat, rice, potatoes, cassava, sweet potatoes and barley) and lignocellulosic biomass (wood, straw and grasses) [5]. Major countries produced bioethanol include Brazil (sugarcane 100%), the USA (corn 98%, sorghum 2%), China (corn 70%, wheat 30%), EU (wheat 48%, sugar beet 29%) and Canada (corn 70%, wheat 30%) [2]. Although the production of bioethanol can provide environmental and economic benefits, but food security in developing countries has been a key factor to the instability, whereas a large amount of bioethanol is produced from crops in developed countries, that has been the crucial social controversy for bioethanol production.

Sweet sorghum (*Sorghum bicolor*) is a C_4 crop and is considered as one of the most important food and fodder crops in arid and semiarid regions of the world [6]. This crop occupies approximately 45 million ha in Africa and India, accounts for >80% of the global cultivated area. Similar to grain sorghum, sweet sorghum has rapid growth and wide adaptability [7], good drought resistance [8], salinity tolerance [9] and high yield of biomass [10]. Sweet sorghum has played an important role in promoting the development of agricultural production, livestock husbandry [11], biofuel [12, 13], refining sugar and paper making [10]. Carbohydrates in sweet sorghum can be nonstructural as sugars and starch, or structural such as cellulose, hemicellulose and pectic substances [14]. The major sugars in sweet sorghum are

the monosaccharides, glucose and fructose; the disaccharides, sucrose and maltose; and the trisaccharide, raffinose. Depending on the kind of sugar in the stalk, there are saccharin and syrup types of sweet sorghum [14]. Sugars in sweet sorghum stalk are mostly sucrose and invert sugars are glucose, fructose, maltose and xylose [15]. It was reported that other sugars such as mannose, galactose and arabinose were not found in juice of the crop; therefore, the production of bioethanol from sweet sorghum is appropriate, as the carbohydrates present are easily converted to bioethanol. The bagasse and grain of the crop are also possible to produce bioethanol, but they are not economically efficacy [16].

Although sweet sorghum has been suggested as a potential crop for bioethanol production in developing countries [6, 17, 18], but it is still acknowledged as a new crop in many countries. To earn permission for cultivation in a large area for bioethanol production, the cultivation protocol for this crop should be critically examined. In our previous report, we have selected a cultivar 4a from 66 sweet sorghum cultivars through 3 years of cultivation in Vietnam and evaluated the effects of sowing times, densities and soils to biomass and bioethanol production [19]. In this chapter, we describe the application of different fertilizers, including the combinations, doses and time of fertilization and examined their effects on the productivity of biomass, sugar content and ethanol production of sweet sorghum.

2. Materials and methods

The cultivar 4a (India origin) was selected from a previous experiment as the most potential of high biomass and sugar content [19]. Seeds of this cultivars were tested and their germination rate was >95%.

The experiments were conducted in three different locations in northern Vietnam including Phu Tho, Hoa Binh and Bac Giang provinces, in continuous cropping seasons from 2010 to 2013. In Vietnam, all major ethanol factories are currently using cassava as a material for production, with exception of Phu Tho factory where both cassava and sugarcane can be produced for ethanol production. Therefore, Phu Tho province is the first priority to be chosen as a place of sweet sorghum production. Bac Giang and Hoa Binh are selected because their close distance to the ethanol factory in Phu Tho province (less than 100 km). In addition, the three provinces have a large area of hilly and abandoned areas which can be exploited for cultivation of sweet sorghum.

2.1. Applied doses

Different ratios of N, P₂O₅ and K₂O from 30, 60, 90 kg/ha with 2 tons/ha of manure were combined. The commercial fertilizers were purchased from Ha Bac nitrogenous fertilizer & chemicals company limited (Bac Giang city, Vietnam). The details of fertilizer ratios are presented in **Table 1**. Each treatment was conducted in thrice in a plot of 30 m² and repeated in three provinces Hoa Binh, Phu Tho and Bac Giang provinces, Vietnam. Effects of different-treated doses on stem yield, sugar content and ethanol production of the cultivar 4a were measured.

Doses	Fertilizer combinations
1	0 N + 60 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
2	30 N + 60 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
3	60 N + 60 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
4	90 N + 60 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
5	90 N + 0 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
6	90 N + 30 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
7	90 N + 90 P ₂ O ₅ + 60 K ₂ O + 2 tons/ha manure
8	90 N + 60 P ₂ O ₅ + 0 K ₂ O + 2 tons/ha manure
9	90 N + 60 P ₂ O ₅ + 30 K ₂ O + 2 tons/ha manure
10	90 N + 60 P ₂ O ₅ + 90 K ₂ O + 2 tons/ha manure

Table 1. Applied doses of fertilizers.

2.2. Chemical composition of soils in locations selected for the experiment

The criteria for selecting locations in each Hoa Binh, Phu Tho and Bac Giang provinces are where there are abandoned and difficult for cultivating food crops because of their low nutrient soils, to examine the possibility of exploiting the cultivation of sweet sorghum for ethanol production. There were nine villages were selected (total 27 villages) and soils in the selected area in each villages were taken and analyzed for pH, contents of percentages of N, P, K, OC (organic carbon), CEC (cation exchanged capacity) (cmol⁽⁺⁾/kg), Zn (mg/kg), Fe (mg/kg) and Al (mg/kg) (**Table 2**). The analysis of these criteria was conducted by conventional methods.

Locations	pH	N (%)	P (%)	K (%)	OC (%)	CEC (cmol ⁽⁺⁾ /kg)	Zn (mg/kg)	Fe (mg/kg)	Al (mg/kg)
Hoa Binh	6.4	0.234	0.059	1.392	0.286	8.06	265.48	58116.93	85879.64
Phu Tho	5.1	0.219	0.062	0.561	0.174	5.48	89.84	93138.45	75458.45
Bac Giang	5.6	0.027	0.224	0.135	0.962	5.46	64.01	66112.50	78512.50

Table 2. Chemical compositions of soils for sweet sorghum cultivation in different locations.

2.3. Applied time of fertilization

This experiment was conducted in a plot of 30 m² in thrice, in the three locations in Hoa Binh, Phu Tho and Bac Giang provinces in summer-autumn cropping season 2010 and repeated in 2011. The dose of fertilizers per ha included 90 N + 60 P₂O₅ + 60 K₂O + 2 tons manure. Applied times of fertilization are presented in **Table 3**.

2.4. Improvement of biomass and ethanol production by micronutrient fertilizers

This experiment was conducted to examine the role of micronutrient fertilizers by an additional application of (NH₄)₂MoO₇·O₂·4H₂O including 54% Mo (5kg/ha) on biomass and

ethanol production of the sweet sorghum 4a. The based fertilization (BF) was 90 N + 60 P₂O₅ + 60 K₂O + 2 tons/ha manure. Four trials were conducted: (i) BF, (ii) BF + (NH₄)₂MO₇O₂.4H₂O, (iii) BF + 60 kg/ha P₂O₅ and (iv) BF + 60 kg K₂O. This experiment was also conducted in the designated areas in the three provinces in the cropping season of summer-autumn 2010 and repeated in 2011.

Trials	Applied time
1	1st fertilization: plants at 3–4 leaf period: 1/2 total N + 1/2 total % K ₂ O 2nd fertilization: plants at 7–8 leaf period: 1/2 total N + 1/2 total % K ₂ O
2	1st fertilization: plants at 3–4 leaf period: 1/3 total N + 1/3 total % K ₂ O 2nd fertilization: plants at 7–8 leaf period: 1/3 total N + 1/3 total % K ₂ O, trimming seedlings at 20 cm space per plant 3rd fertilization: after the 2nd fertilization 20 d, provided the remained fertilizers
3	1st fertilization: plants at 3–4 leaf period: 1/3 total N 2nd fertilization: plants at 7–8 leaf period: 1/4 total N + 1/2 total K ₂ O 3rd fertilization: before flowering period: 1/2 total N + 1/2 total % K ₂ O

Table 3. Times of fertilization application.

2.5. Determination of biomass, sugar content (Brix %) and ethanol production

Sweet sorghum at flowering stages in different trials was harvested in random. The biomass weight, sugar content (Brix %) and ethanol production were determined by a method described in Ref. [19].

3. Statistical analysis

All trials of the study were conducted in a completely randomized design with three replications. Means and differences between the treatments were determined by using a two-way analysis of variance (ANOVA) with values of least significant difference (LSD) at $P \leq 5\%$ level from IRRISTAT program version 5.0.

4. Results

4.1. Effects of different applied doses of fertilizers on stem yield, sugar content and ethanol production of sweet sorghum

There were 10 different applied doses were used in the designated locations in Hoa Binh, Phu Tho and Bac Giang provinces. The effects of these different fertilization doses on stem yield, sugar content and ethanol production of the cultivar 4a are presented in **Table 4**.

It is observed that the stem yield of sweet sorghum varied between 44.7 and 77.3 tons/ha, depending on applied doses of fertilizers and locations (**Table 1**). The most effective dose was 90 N + 90 P₂O₅ + 60 K₂O, followed by 90 N + 60 P₂O₅ + 60 K₂O. It was found that

nonapplication of any N, K₂O and P₂O₅ caused severe marked reduction of stem yield, up to 20 tons/ha and the amount of N played a more significant role on the yield of this crop, than either K₂O or P₂O₅ application (**Table 1**). Accordingly, the ethanol yield was the highest in the doses of 90 N + 90 P₂O₅ + 60 K₂O and 90 N + 60 P₂O₅ + 60 K₂O. Nontreatment of N, K₂O and P₂O₅ also resulted in a critical decrease of ethanol yield and the lowest ethanol yield was the nontreatment of nitrogen fertilizer (2963.6 l/ha). Differently, the applied doses did not strongly influence on sugar contents of the cultivar 4a. The dose 90 N + 90 P₂O₅ + 60 K₂O also recorded the highest sugar quantity, but the treatment of 90 N + 60 P₂O₅ + 60 K₂O showed a significantly lower sugar content (12.0–13.3%). In addition, the dose 90 N + 60 P₂O₅ + 90 K₂O did not provide the highest stem yield (53.2–59.5 tons/ha), but it has a remarkable high sugar content and ethanol yield than other doses. Regarding to the location, in general, Bac Giang province has a significantly higher sugar content and ethanol yield than Hoa Binh and Phu Tho provinces (**Table 4**).

Doses	Evaluated categories								
	Stem yield (tons/ha)			Sugar content (Brix %)			Ethanol yield (l/ha)		
	Hoa Binh	Phu Tho	Bac Giang	Hoa Binh	Phu Tho	Bac Giang	Hoa Binh	Phu Tho	Bac Giang
90 N + 60 P ₂ O ₅ + 60 K ₂ O	64.6	66.0	66.9	12.0	12.0	13.3	4283.0	4375.8	4916.0
0 N + 60 P ₂ O ₅ + 60 K ₂ O	44.7	45.0	47.7	12.0	12.0	12.7	2963.6	2983.5	3347.0
30 N + 60 P ₂ O ₅ + 60 K ₂ O	53.2	53.2	55.6	13.0	13.0	13.0	3821.1	3842.6	3993.5
60 N + 60 P ₂ O ₅ + 60 K ₂ O	58.0	58.0	61.0	12.0	12.0	13.3	3845.4	3845.4	4482.4
90 N + 0 P ₂ O ₅ + 60 K ₂ O	46.0	46.0	54.3	12.0	12.0	10.3	3049.8	3049.8	3090.1
90 N + 30 P ₂ O ₅ + 60 K ₂ O	48.7	48.5	66.4	12.0	13.0	11.7	3228.8	3483.5	4292.3
90 N + 90 P ₂ O ₅ + 60 K ₂ O	68.6	69.0	77.3	14.0	14.0	13.7	5306.2	5337.2	5851.0
90 N + 60 P ₂ O ₅ + 0 K ₂ O	49.2	53.0	50.5	12.0	12.0	12.0	3262.0	3513.9	3315.0
90 N + 60 P ₂ O ₅ + 30 K ₂ O	52.6	52.0	54.4	13.3	13.3	10.0	3778.0	3734.9	3005.6
90 N + 60 P ₂ O ₅ + 90 K ₂ O	53.2	53.5	59.5	14.0	14.0	13.3	4408.9	4138.2	4372.2
LSD (5%)	8.76			0.15			1.1		
CV (%)	9.7			3.3			5.1		

Table 4. Effects of applied doses of fertilizers on sugar content, sugar yield and ethanol production of the sweet sorghum variety 4a.

4.2. Effects of applied times of fertilizers on stem yield, sugar content and ethanol production of sweet sorghum

There were three trials of fertilizer application in different times and fertilizer doses (Table 4), applied in the three locations in Hoa Binh, Phu Tho and Bac Giang provinces (Table 5). It indicated that times of fertilizer application at 3–4 to 7–8 leaf stages provided the highest stem yield and ethanol yield in every location and their values were markedly different as compared among the 1st, 2nd and 3rd applied times (Table 5). However, when the amount of fertilizers were divided into three times of application, of them, the third fertilization was either after 20 d of the second application (trial 2) and before flowering, the yields of stems and ethanol production were significantly reduced, as compared with other treatments (Table 5). The stem yield was markedly decreased >20 tons/ha, whereas the amount of ethanol production was significantly reduced > tons/ha. For location, Phu Tho province obtained higher yields of stems and ethanol production than Hoa Binh and Bac Giang provinces. For the sugar content (Brix %), different times of fertilizer application did not influence on the sugar content of sweet sorghum, as no significant difference among treatments were observed (Table 5).

Locations	Trials	Stem yield (tons/ha)	Sugar content (Brix %)	Ethanol yield (l/ha)
Hoa Binh	1	68.6	14.0	5306.2
	2	62.7	14.0	4849.9
	3	47.5	14.0	3674.1
Phu Tho	1	72.5	14.0	5607.9
	2	65.5	14.0	5066.4
	3	49.5	14.0	3828.8
Bac Giang	1	69.5	14.0	5375.8
	2	61.5	14.0	4757.0
	3	46.6	13.0	3347.0
LSD (5%)		0.4	1.4	60.0
CV (%)		0.7	5.8	0.7

Note: Trials 1–3 are different applied times as indicated in Table 3.

Table 5. Effects of different times of fertilizer application on stem yield, sugar content and ethanol production of sweet sorghum.

4.3. Effects of micronutrient fertilizers on stem yield, sugar content and ethanol production of sweet sorghum

In this experiment, the control was the based fertilization (BF) that included 90 N + 60 P₂O₅ + 60 K₂O + 2 tons/ha manure. Other treatments consisted of BF + (NH₄)₂MO₇O₂.4H₂O (Mo), BF + 60 K₂O and BF + 60 P₂O₅. The effects of these treatments on stem yield, sugar content and ethanol productivity are presented in Table 6.

Treatments	Stem yield (tons/ha)			Sugar content (Brix %)			Ethanol yield (l/ha)		
	Hoa Binh	Phu Tho	Bac Giang	Hoa Binh	Phu Tho	Bac Giang	Hoa Binh	Phu Tho	Bac Giang
Based fertilization (BF)	64.4	66.0	62.4	14.8	15.0	14.8	5266.0	5469.8	5012.5
BF + Mo	74.3	79.0	75.9	14.9	15.0	14.9	6116.6	6547.1	6248.3
BF + P ₂ O ₅	70.4	75.4	71.5	15.5	15.0	15.5	6028.9	6248.8	6123.1
BF + K ₂ O	68.5	69.5	70.5	15.5	15.0	14.9	5866.2	5759.8	5073.7
LSD (5%)	0.9			0.8			138.7		
CV (%)	0.7			3.1			11.3		

Table 6. Effects of micronutrient fertilizers on stem yield, sugar content and ethanol production of sweet sorghum.

It was found that by the application of based fertilization, the stem yield of sweet sorghum was 62.4–66.0 tons/ha. However, the supplemented application of Mo significantly increased the stem yield 10–12 tons/ha and it was higher than either the supplementation of P₂O₅ or K₂O (Table 6). For the sugar content, there was no remarkable difference among treatments (14.8–15.5 Brix %). Following the promoted amount of stem yield, the ethanol productivity was the maximum with Mo application, followed by P₂O₅ and K₂O supplementation. They were all significantly higher than the application of unique-based fertilizers (Table 6).

5. Discussion

Although sweet sorghum is well adaptable to many soils and climates and has a strong resistance to pests and diseases, an effective fertilization protocol is crucial to farmers and agricultural extensionists to promote the biomass and ethanol productivity of this crop. Trials of this study were replicated in the three locations in three different provinces, where are the most suitable for ethanol production in the North of Vietnam [19]. Among different doses of fertilizers, this study found that the application of 90 N + 90 P₂O₅ + 60 K₂O was the best for maximum biomass and ethanol productivity of the crop. Their values were significantly higher than those of other treatments (Table 4). Nontreatment of N, P₂O₅ and K₂O was examined and the lack of fertilization of any among these nutrients caused severe markedly reduction of stem yield, sugar content and ethanol production; however, N was the most important for biomass and ethanol productivity (Table 4).

It has been described that sweet sorghum can become a profitable crop for farmers in developing countries, however its agronomic practices should be optimized to improve the productivity. Among them, nitrogen is the most important nutrient element as this crop responds well to N fertilization [20]. Turgut et al. [21] investigated the optimum N input for maximizing sweet sorghum yield in a clay loam soil. Reddy et al. [22] also studied the effects of N input on sweet sorghum growth. Uchino et al. [20] reported that the amount of N from 90 to 120 kg/ha was the optimum for ethanol productivity, but the

amount of N >150 kg/ha may cause lodging. In this study, the application of N >90 kg/ha was not studied as it may cause economic troublesome for farmers in developing countries such as Vietnam.

This research also verified the application of K_2O and P_2O_5 in combination with nitrogen and manure (**Table 4**) to reduce the dependency on nitrogen application. The use of manure, K_2O and P_2O_5 with reduced quantity of nitrogen fertilizers are efficacy for soil health and maintain the biomass and ethanol productivity of sweet sorghum. The time of application was also examined to optimize the time of application and doses of fertilizers. The best time for fertilization was found to be on 3–4 to 7–8 leaf stage (**Table 5**). Findings of this study indicate that fertilization should not be conducted after 7–8 leaf stage, as the application of fertilizers at 20 d after the second application (7–8 leaf stage) to flowering stage caused significant reduction of stem yield and ethanol production, although the sugar content (Brix %) was not influenced (**Table 5**). This also helps to save the labor costs as the too much fertilization may attribute to heavy fieldwork and economic deficit in sweet sorghum cultivation.

In this study, for micronutrient fertilization, 5 kg/ha of $(NH_4)_2MO_7O_2 \cdot 4H_2O$ (Mo) was used as supplement to the base fertilizer application of 90 N + 60 P_2O_5 + 60 K_2O + 2 tons/ha manure. The supplements of 60 kg/ha of P_2O_5 and K_2O were also conducted to compare with that of the Mo supplement. Interestingly, the use of Mo was the most effective in enhancing the biomass and ethanol production and it was higher than that of either P_2O_5 or K_2O supplements (**Table 6**). The use of Mo was found to be more effective than the adding of P_2O_5 and K_2O . In addition, the application of Mo at 5 kg/ha provided less heavy fieldwork than the supplementation of 60 kg of either P_2O_5 or K_2O . The application of micronutrients such as $ZnSO_4$ and sodium borate was effective on the stalk yield of the sweet sorghum ICSV 93046 variety, which is widely cultivated in India and Philippines [23]. The supplements of micronutrients of Zn and Fe significantly promote the stalk yield of sweet sorghum [24]. It is therefore proposed that the application of micronutrient fertilizers is effective to improve the productivity and profitability of sweet sorghum than the supplement of unique either P_2O_5 or K_2O .

The influences of fertilization including times of application and applied doses on energy crops have been extensively studied. It has been reported that the application of N fertilizer significantly improves the production of bioenergy crops, such as switchgrass (*Panicum virgatum* L.) and corn (*Zea mays* L.) [25]. Individual applications of N, P, or K fertilizers markedly improved cassava (*Manihot esculenta* Crantz) yield. The best yield performance in this research to increase the yield of cassava (62.8 t/ha) was the use of 400, 200 and 400 kg/ha of N, P, K fertilizers, respectively, although the use of P fertilizer incorporation with high levels of N and K fertilizers was not effective to improve cassava yields [26]. In addition, Olugbemi and Ababyomi [27] examined different treatment of nitrogen fertilizer on the growth and ethanol yield of four sweet sorghum varieties and found that the application of 120 kg N/ha was the best for ethanol production. There are also several research studies on optimizing the nitrogen requirements of sweet sorghum for various environments and soil types [20–21]. The applied doses on sugarcane were important on the yield and ethanol production in Brazil [28]. Appropriate doses of fertilizers are useful to increase the yield and

ethanol production of biofuel crops, but the overuse of fertilizers may cause critical environmental pollution [29]; therefore, the examination of applied doses and times of application as conducted in this research is indispensable for the cultivation of biofuel crops.

6. Conclusions

Sweet sorghum is a promising alternative crop for bioethanol production in developing countries to reduce the social criticisms on the use of food crops for biofuel production. Findings of this study, together with a previous work, examined the sowing times, densities and soil chemicals [19] to determine the cultivar 4a which was continuously examined in this research for different doses of fertilizers and times of application. Achievements of the two research studies are useful to establish a protocol of sweet sorghum cultivation for farmers and agricultural extensionists in developing countries, as the fertilization of different doses and times was examined in different locations with low nutrient contents that were difficult to cultivate other crops. This study also highlighted the higher possibility of using sweet sorghum in infertile soil in hilly areas than other bioenergy crops. The combination of manure and micro-nutrients with a reduced amount of inorganic fertilizers is crucial to establish a sustainable agriculture in sweet sorghum production.

Acknowledgements

The author express sincere thanks to Ministry of Trade, Vietnam, for funding to this research. Thanks are also due to Phung Thi Tuyen, La Hoang Anh, Truong Ngoc Minh and Do Tan Khang for their assistance to the manuscript's preparation.

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