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Sustainability of Sugarcane and Cassava-based Fuel-ethanol Production in China

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ABSTRACT

The possibility to relieve the energy crisis and reduce the greenhouse effect by using bio-fuels, such as fuel-ethanol, has attracted a great concern. Nevertheless, the cultivation of dedicated energy crops dose meet with some criticisms (conflict with food security and environmental degradation, for example). Sugarcane and cassava are regarded as the potential energy crops for fuel-ethanol production. This study evaluated the sustainable production by the usages of sugarcane and cassava as fuel-ethanol feedstock. Firstly, estimated the cost efficiency for sugarcane and cassava production by adopting the stochastic frontier cost function. Secondly, the sustainability of each crop production was evaluated. Empirical results reveal that either sugarcane or cassava production the scope to reduce cost by enhancing farmers' technical efficiency under the present technology is very limited. After considering sustainable production, cassava, which requires low agro-chemical, should be recommended as a prior energy crop in China with higher rates in ethanol conversion and dry matter.

Key words: Sugarcane, cassava, fuel-ethanol, stochastic frontier cost function, sustainable production

INTRODUCTION

The rapid increase in global energy consumption, together with the gradual depletion of fossil fuel reserves, has stimulated researches on new and renewable energy sources. The greenhouse effect resulted from increasing carbon dioxide emission has also driven searches for clean carbon-neutral fuels, such as biofuel. The major biofuel in use today is ethanol (NREL, 2012), which can be used for conventional automobiles if blended at less than 10%. Fuel-ethanol can be produced from such agricultural products as starch and sugar, or lingo- cellulosic biomass. Worldwide, a bulk of starch (maize and cassava) and sugar (sugarcane and sugar beet), including hydrolysis of starch and fermentation of sugar, is diverted to produce ethanol through an industrial processes (Yuan *et al.*, 2008). As shown in Table 1, the production of fuel-ethanol in the world increased by more than four times from less than 50 million liters per day in 2000 to 211 million liters per day in 2009. The rate of increase was accelerated from 14% per year in the former half of the decade to 23% per year in the latter half, reflecting massive efforts to shift to non-fossil energy that was prompted by the high-energy price regime set in the late 2000s.

Table 1: Production and consumption of fuel ethanol in the world and major producing countries, 2000-2009 ^(a)

Location	Production (million liters day ⁻¹)			Growth rate (% year ⁻¹)		Consumption (million liters/day)	
	2000	2005	2009	05/00	09/05	2009	Self-sufficiency rate (%)
World total	47.6	92.9	211.0	14	23	203.7	104
North America	17.4	41.2	116.4	19	30	118.1	99
Central and South America	29.4	45.3	75.8	9	14	64.4	118
Europe	0.3	2.2	9.9	48	45	12.3	80
Asia and Oceania	0.5	4.1	8.7	55	21	8.8	99
Main feed-stock							
United States	16.8	40.5	113.4	Maize		114.5	99
Brazil	29.2	43.9	71.5	Sugarcane		62.5	114
China	0.0	3.3	5.9	Maize/sugarcane		5.9	100
Canada	0.6	0.7	3.0	Maize/Wheat		3.6	82

International Energy Statistics (<http://www.eia.gov/countries/>)

The sudden increase in demand for fuel-ethanol has opened up a new opportunity for energy crop and been welcomed by China's sugarcane and cassava producers who are predominantly smallholders. China takes the third place in the country ranking of fuel-ethanol production in 2009 (Table 1). In terms of large increases in energy consumption in the near future, however, the Chinese government established a national strategy for oil security and commenced two programs of "Denatured Fuel Ethanol" and "Ethanol Gasoline for Motor Vehicles" in 2001. The programs set a target of annual bio-ethanol production at 10 million tons and provided incentives, such as consumption tax exemption and guaranteed pricing, for bio-fuel development (Tian *et al.*, 2009). The main feedstock for fuel-ethanol production in China used to be maize. However, the increases in domestic demand for maize as food and feed and the draining of the carryover stock of inferior maize to be used for ethanol production, due to high ethanol demand, has been apt to preempt the use of maize for ethanol production. As a result, the Chinese government started to regulate maize-based ethanol production, which has left sugarcane and cassava as the most important sources of bio-ethanol production in future. But the cultivation of dedicated energy crops for ethanol production does meet with some criticisms, such as, the confliction with food crop cultivation and the impact on environmental degradation (Marta *et al.*, 2010; Lewandowski and Faaij, 2006). The sugarcane and cassava production in China are almost entirely dominated by small-scale, resource poor farmers. The problems of small-scale agriculture include the use of traditional technology of low productivity and unfriendly in environment and poor distribution of agricultural inputs. Therefore, Large-scale fuel-ethanol production systems are ideally evaluated according to sustainability criteria that take into account the social, environmental and economical impacts (Smeets and Faaij, 2010).

The goal of this study was to assess the sustainability of sugarcane and cassava-based fuel-ethanol production in China by examining the production structure of sugarcane and cassava farming and comparing sustainability of the usages of these two crops as fuel-ethanol feedstock.

MATERIALS AND METHODS

Data collection: Data in this study came from sugarcane production farmers in Longchuan County (N 24°08'-24°39', E 97°39'-98°17') and cassava production farmers in Honghe County (N 23°05'-23°27', E 101°49'-102°37').

Longchuan is 800 kilometers southwest of Kunming, the capital city of Yunnan Province. The county is in the climate zone of southern sub-tropical monsoon that provides good growing conditions for sugarcane (YBS, 2008). The study selected three villages in the county, Lameng (Village A), Nongying (Village B) and Feichuanha (Village C), situated in major sugarcane-producing areas in the region, for the survey. Most of the people in Villages A and B ethnically belong to the Han, while most of the people in Village C are an ethnic minority. Fifty-six sample farmers were selected randomly from the sample villages.

Honghe County is located in Honghe Hani and Yi Autonomous Prefecture, Yunnan province, China. The total area of Honghe is 2011 km², the mountain area accounted for 98% of the total area (YBS, 2008). It is a typical agricultural county in Yunnan mountain area. The average annual temperature is 15 degrees or so. The maximum temperature is around 33 degree and the minimal temperature is around 4 degree. The annual rainfall is 950 mm (YBS, 2008). The study selected one village, Shisa. In total 50 cassava farmers were interviewed.

In addition, the study interviewed two sugar millers, which have been equipped with ethanol-production facilities attached to sugar milling plants separate in the two regions. In the sugar mill interviews, the information that gives rough cost estimate of sugar and ethanol production was obtained. The interview survey was conducted from June to September 2008.

Productivity analytical framework: Agricultural production can be increased by following options; (1) by increasing production inputs under the present technology and the present level of technical efficiency, (2) by improving technical efficiency with the present level of inputs under the present technology, (3) by introducing new technology and (4) by mixing up some or all of these options. It is possible to increase production by Option (1). However, base on the developmental situation of China reveals that little room is left for China to increase crop production by this option. Under such a circumstance, it is important for the country to know how effective it is to pursue the possibility to increase it by means of Option (2). If farmers' technical efficiency were low, the potential would exist to increase the production by improving farmers' technical efficiency through, for example, multiplying policy efforts to strengthen the extension service for farmers, with a view to enhancing their technical efficiency in production. If there were no potential in this respect, the only option to increase the production would be by Option (3), i.e., to introduce new technology, such as new high-yielding varieties.

The study try to shed light on this issue of technical efficiency in sugarcane and cassava production by estimating stochastic frontier cost functions, using the following models. First define the cost function of *i*th farmer as follows:

$$C_i = f(L_i, K_i, C_i, Y_i, A_i, \beta) + v_i \quad (1)$$

where, *C* is total cost (yuan), *L* is wage rate (yuan), *K* is fixed capital rent (yuan), *C* is current input price (yuan), *Y* is output (tonnes) and *A* is planted area (ha). Moreover, β is a column vector of unknown parameters to be estimated and *v* is an error term distributed as $N(0, \sigma^2)$. In the estimation, the price of nitrogen applied is used as a proxy for current input price and dummy variables for villages, tenants and soil type are included to control farmers' characteristics.

Frontier cost function can estimate the cost of technical efficiency of a farmer. The TE is defined as the ratio of total cost of *i*th farmer to the frontier total cost. The study set up a model for stochastic frontier cost function as follows:

$$Ci = f(Li, Ki, Ci, Yi, Ai) \cdot \exp(vi) \cdot TEi$$

$$\ln(Ci) = f(Li, Ki, Yi, Ai) + (vi + ui) \quad i = 1, \dots, N \quad (2)$$

where, ui is a non-negative random variable distributed as $N(0, \sigma^2)$, accounting for cost of technical inefficiency:

$$U_{it} = Z_{it}'\delta + W_{it} \quad (3)$$

where, Z_{it} is a row vector of farm specific inefficiency variables and w_{it} is the Truncated normal as $N(0, \sigma^2)$.

Note that the above model of frontier production gives the technical efficiency of individual farmers statistically, regardless of the allocative efficiency of farmers.

Evaluation of sustainability: The sustainability of each crop production was evaluated. The various criteria of sustainability in this study and operation were listed in the Table 2.

Ecological areas of concern

Conversion rate to ethanol: A direct comparison of fuel-ethanol production cost from sugarcane and cassava was calculated by using conversion rates. The conversion rates from crops to ethanol were supplied by the interviewed sugar millers, which are 0.05 for the sugarcane-based ethanol production and 0.17 for cassava-based ethanol production.

Water requirement: In the set of sustainable criteria requires that the production of fuel-ethanol crops is not allowed to result in a depletion of fresh water resource. Firstly, the relative demand for water of sugarcane and cassava was compared based on the crop and vegetation specific water demand factor, the crop evapotranspiration coefficient (K_c). K_c is the ratio between the actual non-water or limited water demands to the reference evapotranspiration (ET_0) (Smeets *et al.*, 2005). ET_0 is the evapotranspiration for a well-managed (disease free, well-fertilizer) hypothetical grass species grow in large field and for which water is abundantly available (Smeets *et al.*, 2005). Secondly, the risk of groundwater depletion was analyzed by comparing the evapotranspiration of sugarcane and cassava with the effective rainfall. Data on the crop evapotranspiration coefficient (K_c) and evapotranspiration are derived from literatures (FAO, 1998; Zhou, 2001; Nguyen *et al.*, 2007).

Table 2: The sustainability criteria included in this study

Area(s) of concern	Criterion
Ecological	
1: Conversion rate to ethanol	Lower fuel-ethanol production feedstock cost from energy crop input
2: Water requirement	Depletion of fresh water resources is not allowed
3: Fertilizer pollution	Energy crop production requires use fertilizer as few as possible as for as reasonable yield is achievable
Socio-economical	
4: Employment	Energy crop production contributes to the direct employment as much as possible
5: Competition with food production	The production of energy crop is not allowed to endanger food supply

Fertilizer use: In the agricultural production, there are several environmental concerns that need to be taken into consideration when using fertilizer. Elements such as nitrogen can get washed into our surface waters and cause algae blooms and excess plant growth. In the set of sustainability criteria requires that bioenergy crop production use fertilizer as few as possible as far as reasonable yield is achievable.

Socio-economical areas of concern

Competition with food production: The production of bioenergy crops requires land. The demand of land for energy crop production may compete with the land demand for food production, which could endanger the food security (Smeets *et al.*, 2008). In the set of sustainable criteria requires that bioenergy crop production is not allowed to endanger food supply. We analyzed correlate relation of planted area between rice and sugarcane, rice and cassava production, respectively. Total planted area data of rice and sugarcane in Longchuan and total planted area data of rice and cassava in Honghe from 1995 to 2010 were used.

Employment: The set of sustainable criteria requires that energy crop production contributes to the direct employment opportunities as much as possible. Direct employment effects are generated by the organizations directly involved in the production, transport and processing of the energy crop. However, in reality, the labor input is dependent on the price of labor compared to the price of machinery and other non-labor inputs, also on various other factors that determine the selection of a management system and harvesting method, such as the soil type, the climate and the accessibility of the plantation and availability of infrastructure (Smeets *et al.*, 2005). Thus, our results are only assumption in areas with very low wages, abundant labor or in remote, difficult to access areas, like the case study counties.

Statistical analysis: The impact of sustainability criteria on the cost and potential of usages of sugarcane and cassava as fuel-ethanol feedstock is analyzed in the study. Firstly, estimated the cost efficiency for sugarcane and cassava production by adopting the stochastic frontier cost function. Field surveys from 56 sugarcane farmers and 50 cassava farmers were collected. Secondly, the sustainability of each crop production was evaluated. Since there is no generally accepted definition of sustainability, a set of criteria was defined including 3 concerns (conversion rate to ethanol, water requirement and fertilizer pollution) from environmental area and 2 concerns (employment and competition with food production) from socio-economic area.

RESULT AND DISCUSSION

Structure of sugarcane and cassava production in China

Farm characteristics: The characteristics of sample sugarcane farmers and cassava farmers, also their farming are summarized in Table 3. For sample sugarcane farmers in China, the average age of household heads was about 40 years old, having the educational level of elementary school on average and the farming experience of 24 years. The land area dedicated to sugarcane production was 1.0 ha per farm. In terms of land area, about 80% of area planted to sugarcane was owned land and the rest 20% was tenanted land that was rented under leasehold arrangements from landowners in their villages, to enlarge their sugarcane cultivation. Average yield per hectare was 97 tons that is higher by about 20 tons than the national average shown in the previous table. The variation in yield per ha across farmers was not so large, suggesting that top yielders obtained the

Table 3: Summary statistics of the variables for crop production and farmer's characteristics

Variables	Sugarcane				Cassava			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Land area (ha)	1.05	2	0.10	14.67	0.29	0	0.13	0.80
Inputs per hectare								
Yield (ton ha ⁻¹)	96.7	19	63.2	138.0	24.4	5	10	38
Capital (000 yuan ha ⁻¹)	0.7	1	0.0	1.8	N/a	N/a	N/a	N/a
Fertilizer (kg ha ⁻¹)	875	175	525	1368	167	79	0	338
Labor (person-day ha ⁻¹)	262	47	174	342	297	69	120	438
Land tenancy: Owner (%)	79.2	-	0	100	62.7	37	0	100
Fixed rent (%)	20.8	-	0	100	37.3	37	0	100
Other characteristics								
Age (years)	40	10	22	61	40	9	25	61
Education (years)	6	4	0	15	5	3	0	9
Farming exper. (years)	24	11	7	53	2	0	2	2
Training program: Attend (%)	16	-	0	100	100	0	100	100
Sample size		56				50		

N/a: Note applicable

yield as high as around 130 tons ha⁻¹, while the yield of bottom yielders was around 60 tons ha⁻¹. Such a high level of yield was brought about by high intensity in fertilizer and labor use. Fertilizer intensity in terms of nitrogen was as high as 875 kg ha⁻¹ and labor intensity was as much as 262 man-days ha⁻¹. As is the case for yield, the variations of these inputs among farmers are not so large. In the case of fertilizer, the intensity of farmers who used less fertilizer, being situated around the lower bound of 95% confidence interval) was still 500 kg of nitrogen ha⁻¹ or even more. Sample cassava farmers in the China were on the similar age of sugarcane farmers, though they have the lower level of education. The land area planted to cassava was 0.29 ha/farm, smaller than the sugarcane sample. While 63% of the land was owned by farmers and 37% of the land was leased through paying a fixed rent to landowners. Average sugarcane yield per hectare was 24 tons, ranging 10 tons of low yielders to 38 tons of high yielders. Accordingly, fertilizer input of the cassava sample was much lower than those of sugarcane sample: 167 kg of nitrogen/ha, but labor intensities of the cassava sample were higher than sugarcane farmers: 297 man-days/ha. And there was no capital use in the cassava production.

Estimation of cost function: The study estimated the stochastic frontier cost function. As the functional form of cost function, the Cob-Douglas (double-log) form was chosen since its statistical performance is superior to other forms. For the sugarcane samples, there are farmers who used no fixed capital inputs, which include the use of tractor and draft animal, doing land preparation manually. For these farmers with no capital input, 0.001 was inserted as capital inputs for applying log-transformation. The exclusion of the samples with no capital inputs does not alter the results of average production function. For both crop, the level of nitrogen applied by sample farmers was taken as the proxy for current inputs, since it gives the best result among many alternative trial runs we conducted.

Sugarcane: The results of estimation for sugarcane are shown in Table 4. The coefficients of the input prices were all statistically significant with an expected positive sign, namely, wage rent

Table 4: Estimation results of stochastic frontier cost functions (normal distribution)

Variables	Sugarcane	
	Coef.	p-value
Inputs (log)		
Wage rate	0.565	0.00
Nitrogen price ^(a)	0.452	0.00
Capital rent	0.013	0.00
Land area	0.005	0.02
Output	0.973	0.00
Dummies		
Clay	0.037	0.00
Tenant	- 0.032	0.00
Village B	- 0.012	0.32
Village C	0.002	0.43
Constant	0.897	
Inefficiency effects		
Age	0.000	0.30
Schooling	0.000	0.37
Extension	0.042	0.48
Sugarcane farming experience	- 0.001	0.05
Dummies		
Clay	- 0.031	0.02
Tenant	0.056	0.00
Village B ^(b)	0.042	0.48
Village C ^(b)	0.010	0.26
$\gamma (= \sigma_u^2/(\sigma_v^2 + \sigma_u^2))$	0.990	0.00
Log Likelihood	142.000	
Cost inefficiency index		
Mean	1.05	
Max.	1.17	
Min.	1.00	
Sample size	56.00	

^(a)In case a value of capital is zero, it is replaced by 0.001 to apply log-transformation, Village B, Village C are Nongying and Feichuanha, respectively

(0.57), nitrogen price (0.45) and capital rent (0.01). Moreover, the coefficients of output and land area were also significant with value of 0.01 and 0.97, respectively. According to the Cob-Douglas specification of the cost function, Shepard's Lemma states that the coefficients of the logarithm of input prices response to the cost-minimizing set of cost shares. Labor cost dominated the cost share which accounted for 57% of the total cost share. The cost share of fertilize was also high, accounted for 45%. The cost share of fixed capital was only 1%. Among the dummy variables including in the cost function, clay dummy had a significant, positive coefficient with value of 0.04. The coefficient of tenant dummy was negative and significant, despite the fact that the tenanted lands were all under leasehold contracts. This may be due to the fact that the land areas that the owner-cum-tenant farmers rented were generally of soil type less suited to sugarcane production.

Although, the existence of cost inefficiency (β) was highly significant, many of the farm specific variables that are included to explain the sources of inefficiency were insignificant, except for the sugarcane farming experience, clay dummy and tenant dummy. The coefficient of sugarcane

farming experience was positive and significant (-0.001). In this analysis, the age coefficient is positive while experience is negative. This finding is in parallel with Padilla-Fernandez and Nuthall (2001), they found experience to be a better predictor of technical efficiency than age for sugarcane production in Philippine. They argued that sugarcane production giving younger farmer an advantage. Sugarcane farming experience was found to be a good predictor of efficiency, better than education and exposure to extension services. Corresponding, tenant dummy had a positive significant coefficient (0.06), which means tenant operators tend to be less technically efficient than owner operators. This confirmed the finding of Aquino *et al.* (1999). The clay dummy had a negative significant coefficient (-0.03), indicated that land productivity for sugarcane production in clay soil was significantly higher and therefore results in a much lower cost than that in dry land. The result corroborate closely with Ali and Chaudhry (1990), it differs from Padilla-Fernandez and Nuthall (2001). Padilla-Fernandez and Nuthall (2001) concluded that the sign of clay is positive for technical inefficiency which is unexpected. They thought this is perhaps due to the drought in Crop year 1997-98 interfered. It is remarkable that the mean cost inefficiency was as low as 1.05, indicating that, given the presently available technology, sugarcane farmers in Yunnan were on average less efficient than the most efficient farmer only by 5%. As observed earlier, however, the input intensity of sample farmers in China was already very high for these production inputs. In particular, nitrogen intensity is already so high that additional fertilizer application would not be desirable from the environmental point of view. Besides, prospective increases in wage rates as the Chinese economy develops would make it not feasible to increase labor intensity beyond the present level. Considering strong population pressure in rural areas where sugarcane can be grown, the prospect is also not so positive, even if any, to increase land area planted to sugarcane. Furthermore, the estimated frontier cost function implies that the potential of increasing production by means of Option (2), exists, but it is very limited. These observations lead to a conclusion that a substantial increase in sugarcane production necessitates Option (3), i.e., the developments of new technology that enhances sugarcane yield per unit of land area.

Cassava: For the cassava production, the results of estimation are summarized in Table 5. Among the conventional inputs, the coefficients of nitrogen price and labor price were statistically significant with value of 0.81 and 0.01 respectively. The coefficient of output was over 1. And the coefficient of tenancy dummy was significant positive.

As for the factors explaining inefficient, the coefficient of age was positive and significant (0.001), indicated that the older farmers the less technically efficient they are. This finding is in parallel with Seyoum *et al.* (1998) analyses maize production in Ethiopia and however it differs from Tan *et al.* (2010). Tan *et al.* (2010) concluded that age was found to have statistically significant positive effects on TE of rice production in China. It is worthy to mention that tenancy Casanova dummy had a negative, significant coefficient (-0.06), indicting owner operators tended to be less technical efficient than tenant operators. This fact is contradictory with the sugarcane estimation result. Since among the sample cassava farmers, most of tenant operators operate larger farms than owners. Except the leased land the tenant operators also had owned land. The result was related to the coefficient of farm size was negative, which means less inefficiency due to the larger farm size. This is in contrast to rice farming as analyzed by Herdt and Mandac (1981). However, the finding confirmed the conclusion reached by Aquino *et al.* (1999) that farm size significantly determines levels of technical efficiency in Corn Farms. Moreover, the mean cost

Table 5: Estimation results of stochastic frontier production functions (normal distribution)

Variables	Cassava	
	Coef.	p-value
Inputs (log)		
Wage rate	0.818	0.00
Nitrogen price	0.014	0.00
Land area	0.010	0.02
Output	1.017	0.00
Dummies		
Tenant	0.019	0.00
Constant	0.137	0.01
Inefficiency effects		
Age	0.001	0.06
Schooling	0.001	0.31
Land area	- 0.032	0.00
Dummies		
Tenant	- 0.059	0.00
$ \gamma(\sigma_u^2/(\sigma_v^2 + \sigma_u^2)) $	0.990	0.00
Log Likelihood	128.000	
Cost inefficiency index		
Mean	1.04	
Max.	1.15	
Min.	1.01	
Sample size	50.00	

efficiency was estimated to be 1.04. Cassava production could be increased by means of Option 1 the result shows the larger area the higher technical efficient. Besides, cassava could be planted on the dry land. The remote area of China is abundant of mountains which are suitable for cassava planting. If both were pursued and attained together, it would contribute not only to increasing cassava production but also to reducing rural poverty in remote areas.

Farmers' technical efficiency in developing countries: In order to provide references for the technical efficiency to be estimated in this study, the farmers' mean TE's for various crop productions, obtained from past studies, are summarized in Table 6. There are only two studies at hand that estimated the TE of sugarcane production. One of them is for Central Negros, one of major traditional sugarcane producing areas in the Philippines (Padilla-Fernandez and Nuthall, 2001). The other one is for Pakistan Punjab, which is a farm-based TE estimate for farmers who grow various crops including sugarcane (Ali and Chaudhry, 1990). Although, the number of cases is too small to make a meaningful comparison among crops, the technical efficiency either in sugarcane production or in cassava production seems to be in the ordinary range of the TE of other crops, neither too high nor too low.

Evaluation of sustainability

Ecological areas of concern

Conversion rate to ethanol: According to the comparison results of feedstock cost of ethanol production from Table 7, feedstock cost of sugarcane-based ethanol production was 4080 yuan ton^{-1} , however, the cassava-based ethanol production was 2598 yuan ton^{-1} . The feedstock cost of

Table 6: Past estimate of farmers' technical efficiency in developing countries

Crops	Country/region	Mean TE	Method ^(a)	Source
Sugarcane	Philippines/Negros	76	DEA	Padilla-Fernandez and Nuthall (2001)
	Pakistan/Punjab	87	DEA	Ali and Chaudhry (1990)
Rice	China (Hybrid variety)	74-85	SFA	Xu and Jeffrey (1998)
	China (Ordinary variety)	87-94	SFA	Xu and Jeffrey (1998)
	Philippines (Irrigated)	76-79	SFA	Mariano <i>et al.</i> (2010)
	Philippines (Rainfed)	70-84	SFA	Mariano <i>et al.</i> (2010)
	China/Southeastern	80-91	SFA	Tan <i>et al.</i> (2010)
	India/Tamil Nadu	83	SFA	Tadesse and Krishnamoorthy (1997)
	Pakistan/Punjab	80	DEA	Ali and Chaudhry (1990)
Maize	Kenya	58-68	SFA	Kipkoech <i>et al.</i> (2008)
	Ethiopia (w/o. extension)	79	SFA	Seyoum <i>et al.</i> (1998)
	Ethiopia (w/. Extension)	99	SFA	Seyoum <i>et al.</i> (1998)
	Nicaragua	70	SFA	Awudu and Eberlin (2001)
	Nicaragua	74	SFA	Awudu and Eberlin (2001)
Beans	Turkey	82	SFA	Bozoglu and Ceyhan (2007)
Rubber	Vietnam	59	SFA	Vo Hung Son <i>et al.</i> (1993)
Cotton	Pakistan / Punjab	83	DEA	Ali and Chaudhry (1990)
Mixed crops	India / semi-arid	84	SFA	Battese and Tessema (1993)

^(a) DEA stands for data envelopment analysis and SFA stands for stochastic frontier analysis

Table 7: Comparison of fuel-ethanol feedstock cost from sugarcane and cassava

Crops	Conversion rate to ethanol	Crop production cost (yuan ton ⁻¹)	Fuel-ethanol feedstock cost (yuan ton ⁻¹)
Sugarcane	0.05	448	4080
cassava	0.17	204	2598

cassava-based ethanol was much less than sugarcane-based ethanol production. This confirmed by the finding of Jansson *et al.* (2009), they conclude that the annual yield of fuel-ethanol was found to be higher for cassava than for any other crops, including sugarcane.

Water requirement: In the set of sustainability criteria requires that the production of bioenergy crops was not allowed to result in a depletion of fresh water resource.

Table 8 showed that compare with cassava, sugarcane plantation requires more water for optimal growth. Consequently, the K_c factor found in literature varies roughly between 0.3 to 0.8 for cassava and 0.4 to 0.125 for sugarcane plantation (FAO, 1998). Moreover, in literature average evapotranspiration of sugarcane is 1119 mm y⁻¹ (Zhou, 2001) and evapotranspiration of cassava is 985 mm y⁻¹ (Nguyen *et al.*, 2007). The total rainfall in Yunnan was 1165 mm y⁻¹ in 2008 (YBS, 2008), which was sufficient to meet evapotranspiration of two crops in Yunnan. However, the sugarcane evapotranspiration was closed to the total rainfall, so that irrigation is needed for sugarcane production in the less rainfall years. Considering the effective rainfall in reality, we concluded that there was a risk of groundwater depletion from sugarcane production.

Pollution from fertilizer: In the set of sustainability criteria required that use fertilizer as few as possible as far as reasonable yield is achievable. According to the Table 9, consumption 1 ton fuel-ethanol, the relative nitrogen use was 181 kg for sugarcane production and 40 kg for cassava production. To achieve the same amount of fuel-ethanol nitrogen use for cassava production was less than sugarcane production.

Table 8: Yearly average of evapotranspiration (ET) of sugarcane and cassava and the total rainfall of Yunnan Province

Parameter	Value (mm year ⁻¹)
Evapotranspiration cassava	985.5
Evapotranspiration sugarcane	1119
Total rainfall in Yunnan	1165

*Yunnan statistical yearbooks (YBS, 2008)

Table 9: Consumption per ton ethanol, average direct labor and fertilizer inputs in sugarcane and cassava ethanol system

Item	Fertilizer (kg ton ⁻¹)	Labor used for farming (Person days ⁻¹)
Sugarcane farming	181	54
Cassava farming	40	72

Socio-economical area of concern

Competition with food production: The statistical correlation between the rice planted area and sugarcane planted area, rice planted area and cassava planted area were measured by using the planted area data from 1995 to 2010 of survey counties.

The resulting correlation coefficient between rice and sugarcane planted area was -0.73 at significant level, which indicates more planted area for sugarcane tends to be less planted area for rice. However, the planted area correlation between rice and cassava shows insignificant, which means there was no correlation between them. This finding confirm the conclusion reached by Kostka *et al.* (2009) that sugarcane used as a feedstock to meet the rising energy demand will come at the expense of converting fertile land for non-food purpose.

Employment: The set of sustainable criteria required that energy crop production contributes to the direct employment.

According to the results from Table 9, consumption per ton fuel-ethanol, the average labor requirement was 54 person-days for sugarcane farming and 72 person-days for cassava farming. The labor input was higher in cassava production than sugarcane production.

CONCLUSION

A prerequisite for the large-scale production of dedicate bioenergy crops and trade of modern bioenergy is not only with respect to increase agricultural productivity but also with respect to use a sustainable production way. In the study compared the cost of technical efficiency and sustainability of production between sugarcane and cassava which could be used as fuel-ethanol feedstock. Firstly, we estimated the technical efficiency for sugarcane and cassava production by adopting the stochastic frontier cost function. And then, the sustainability of each crop production was evaluated. The estimation of frontier cost function revealed that the prospect to increase either sugarcane or cassava production by enhancing farmers' technical efficiency under the present technology is very limited; the need to develop new technology becomes critical for increasing production. Competition with food production and water requirement are potential bottlenecks for a sustainable sugarcane-based ethanol production. Cassava-based ethanol production requires lower agro-fertilizer use and higher rates in ethanol conversion.

In addition, the analysis in the study is based on a subjective assessment of different areas of concern and also on incomplete information. The methodology to evaluate the production sustainable that we have developed is still in need of further refinement, such as more accurate

methodologies, indicators and criteria to estimate the indirect and induced impacts of ethanol production, which are particular relative to the effect on employment, pollution from fertilizer and food security.

Considering the rapidly increase demand of fuel-ethanol feedstock, China governments should strengthen the reconstruction of low-yielding fields. Compare the technical efficiency and sustainable production between the usages of sugarcane and cassava as fuel-ethanol feedstock, we suggest that cassava which requires low agro-fertilizer use, should be recommended as a prior energy crop in China with higher rates in ethanol conversion and dry matter.

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