Sustainable Energy Crop Production: A Case Study for Sugarcane and Cassava Production in Yunnan, China

Yu Zhang [a,*], jianhong Ni[b,] and Sizhu Zhang [c]

[a] *Department of Agricultural and Resource Economics, the University of Tokyo, Bunkyo-ku Tokyo, 113-8657, Japan*
[b] *Yunnan Agricultural Information Center, Kunming, China*
[c] *Institute of Agricultural Economy & Information of Yunnan Academy of Agricultural Sciences, Kunming, China*

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Abstract

The possibility of using biomass as a source of energy in reducing the greenhouse-effect imposed by carbon dioxide emission and relieving energy crisis is a matter of great interest, such as bioethanol production. Nevertheless, the cultivation of dedicated energy crops dose meet with some criticisms (conflict with food security and environmental degradation, for example). Nowadays sugarcane and cassava are regarded as the potential energy crops for bioethanol production. Endowed with natural resources and favorable weather condition, Yunnan province, China, is the major sugarcane and cassava production area in China. This paper presents production structures of these two crops in Yunnan and compares the sustainable production between the usages of sugarcane and cassava as bioethanol feedstock. Firstly, we estimated the technical efficiency for sugarcane and cassava production by adopting the production function and stochastic frontier production function. Field surveys from 61 sugarcane farmers and 50 cassava farmers were collected in June and September, 2008. Secondly, the sustainability of each crop production was evaluated. Since there is no generally accepted definition of sustainable production, a set of criteria was defined including 2 concerns (employment and food supply) from socio-economic area and 3 concerns (conversion rate to ethanol, water requirement, and fertilizer pollution) from environmental area. Empirical results demonstrated that the average production function was located below the frontier production function, 5% for sugarcane production and 7% for cassava production. These findings reflect the existence of technical inefficiency not only in the sugarcane production but also in the cassava production as well. But after considering sustainable production, cassava, which requires low agro-chemical, should be recommended as a prior energy crop in Yunnan with higher rates in ethanol conversion and dry matter.

Keywords: Energy crop, stochastic frontier production, Sustainable production, Yunnan province, Bioethanol,

Introduction

The possibility of using biomass as a source of energy in reducing greenhouse-effect imposed by carbon dioxide emissions and reliving energy crisis is a matter of great interests, such as bioethanol production. Bioethanol can be produced using agriculture products such as starch and sugar, or lignocellulosic biomass. According to the U.S energy information administration the world output of bioethanol was climb from 662 Thousand Barrels Per Day (2005) to 1636 thousand Barrels per day (2009). Nevertheless, the cultivation of dedicated energy crops does meet with some criticisms, such as, the confliction with food crop cultivation and the impact on environmental degradation [1]. For an overview of relevant issues see lawandowski and Faaij [2]. Therefore, Large-scale bioethanol production systems are ideally evaluated according to sustainability criteria that take into account the social, environmental and economical impacts [3].

The global situation has asked China for sustainable energy use and supply, since the nation has held the largest population in the world and the domestic production of oil will not be able to meet the future demand that will be magnified by economic development. Based on national strategies of oil security, Chinese government started "Denatured Fuel Ethanol" program and "Ethanol gasoline for motor vehicles" program in 2001, which is the background of bioethanol production possibility in China. For biofuel development, Chinese government introduced several incentives, for example, exempt 5% consumption tax of fuel ethanol. According to the Ministry of Finance (MOF) of (the) PRC, the specific subsidy of bioethanol sold was 1883RMB/t in 2005, and 1628RMB/t in 2006, and 1373RMB/t in 2007 and 2008 [4].China's fuel ethanol production capacity reached 1.94 Mt by 2008 [5]. Among the different types of energy crops, sugarcane and cassava are coincided as the attractive feedstock because high energy efficiency and low production cost. Yunnan province endowed with natural resources and favorable weather condition is the major sugarcane and cassava production area in China. In 2008, the sugarcane production was 19 million tons with planted area of 309,700 ha and the cassava production was 366,600 tons with planted area of 593,200 ha in Yunnan province [6]. However, the sugarcane and cassava production in Yunnan 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 input.

The goal of this study is to present production structures of sugarcane and cassava in Yunnan and compares the sustainable production between the usages of these two crops as bioethanol feedstock. Firstly, we estimated the technical efficiency for sugarcane and cassava production by adopting the average production function and stochastic frontier production function. Secondly, the sustainability of each crop production was evaluated. Since there is no generally accepted definition of sustainable production, a set of criteria was defined including 2 concerns (employment and competition with food production) from socio-economic area and 3 concerns (conversion rate to ethanol, water requirement, and fertilizer pollution) from environmental area. Table 1 shows the various criteria included in this study and how these are operationalised.

Table 1 The sustainability criteria included in this study

Area(s) of concern	Criterion
Ecological	
1 Conversion rate to ethanol	More bioethanol production from few 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 employment
5 Competition with food production	The production of energy crop is not allowed to endanger food supply

2. Methodology

2.1 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′). We selected them as case studies because both counties are in the climate zone of south sub-tropical monsoon which provides good growing conditions for sugarcane and cassava. Besides, both counties are located in the remote area of Yunnan province, the small and poor farming households abound and endowed with land, other natural resources and abundant labor. Therefore they have been identified as regions with a large potential for energy crop production. The distance from Kunming (the capital city of Yunnan Province), is 779 kilometers to longchuan and 329 kilometers to Honghe. Second, we selected three villages in Longhuang, the names which are Lameng (Village Ⅰ), Nongying (Village Ⅱ) and Feichuanha (Village Ⅲ) and one village, Shisa in Honghe. These villages are situated in major sugarcane or cassava producing areas in the region. Finally, sample farmers are selected randomly from each sample village. Survey questionnaire contains such questions as the characteristics of sugarcane/cassava farmers and the inputs/ outputs of sugarcane/ cassava production. The survey was conducted in June and September 2008. In total, 61 sugarcane farmers and 50 cassava farmers were interviewed. In addition, we 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 interview, we obtained information that gives rough cost estimate of sugar and ethanol production. The plant survey was conducted at the same time as farmers' survey.

2.2 Regression Models

2.2.1 Descriptive Analyses

Before the regression test, we examined general features of crops production and farmer's characteristics by simple tabulation of farmers' production shown as Table 2. In the analysis, production inputs are grouped into four major categories: (ⅰ) land area harvested (ⅱ) capital use (machine), (ⅲ) labor, and (ⅳ) fertilizer inputs.

2.2.2 Average production function (APF)

Production function for an average farmer is generally defined as:

$$Y = f(L, K, C, A) \quad (1)$$

If the technology exhibits a constant return to scale, it can be converted into per-hectare production function

$$Y/A = f(L/A, K/A, C/A)$$

where Y/A=output per area and X/A's=various inputs per area

2.2.3 Stochastic frontier production function (SFPF)

Estimating the technical efficiency (TE) of farmers is required to examine the potentiality of crop production in the area studied. The output-oriented TE is defined as the ratio of production of i-th farmer to the corresponding production of the frontier production. TE is calculated using SFPF, which has been independently proposed by Aigner, Lovell and Schmidt(1997) and Meeusen and van den Broeck (1977) [7] .

The model can be expressed in the following form:

$$Y_i = X_i + (V_i - U_i) \qquad ,i=1, \dots , \quad (2)$$

where

Y_i = the production (or the log-transformation thereof) of i-th farm;

X_i= the inputs (L, K, C, A; or the log-transformation thereof) of i-th farm;

β = column vector (k×1) of unknown parameters to be estimated;

V_i = random variables assumed to be iid. N (0, σ_v^2), and independ of U_i

U_i = non-negative random variables assumed to be iid. N (0, σ_u^2), accounting for technical inefficiency.

The parameter γ,

$$\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2) \quad (3)$$

defines the share in the total output variation ($\sigma^2 = \sigma_u^2 + \sigma_v^2$) of the variation ascribed to technical inefficiency. γ is lied in the range between 0 and 1. If $\gamma = 1$, all the errors ascribe to technically inefficiency.

Moreover, technical efficiency level of the i-th farm is given by

$$TE_i = \exp(-U_i) \quad (4)$$

2.3 Evaluation of sustainability

2.3.1 Ecological areas of concern

Conversion rate to ethanol

A direct comparison of bioethanol production yield from sugarcane and cassava was calculated. The conversion rates from crops to bioethanol were supplied by the interviewed sugar millers: convert 1 ton sugarcane into 0.05 ton bioethanol and convert 1 ton cassava into 0.17 ton bioethanol.

Water requirement

In the set of sustainable criteria requires that the production of bioethanol 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 or K_c). K_c is the ratio between the actual non-water limited water demands to the reference evapotranspiration (ET_0) [8]. 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 [8]. Secondly, the risk of groundwater depletion was analyzed by comparing the evapotranspiration of sugarcane and cassava with the effective rainfall. Due to lack of data on effective rainfall we use the total rainfall data to instead.

Data on the crop evapotranspiration coefficient (K_c) and evapotranspiration are derived from literature [9] [10] [11].

Fertilizer use

There are environmental concerns that need to be taken into consideration when using fertilizer. Elements such as nitrogen and phosphorus 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 for as reasonable yield is achievable.

2.3.2 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 in turn could endanger the food security [12]. 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 or cassava production by using planted area data for each crop from 1995 to 2010.

Employment

The set of sustainable criteria requires that energy crop production contributes to the direct employment 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 and 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 [7]. 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.

3. Results

3.1 Estimation of Production Function

3.1.1 Descriptive Analysis of Sample Villages

A summary of the characteristics of crops farmers and farm production was given in Table 2.

Table 2 Summary statistics of the variables for crop production and farmer's characteristics a)

variables	Sugarcaen				Cassava			
	mean	St.Dev	Min	Max	mean	St.Dev	Min	Max
Land area (ha)	1.04	1.91	0.10	14.67	0.29	0.16	0.13	0.80
Inputs per hectare								
Yield (ton/ha)	95.8	18.2	63.2	138.0	29.3	5.2	12	45
Capital (000 yuan/ha)	0.7	0.6	0.0	1.8	N/a	N/a	N/a	N/a
Fertilizer (kg/ha)	867	176	525	1368	199	79	0	405
Labor (personday/ha)	258	47	174	342	356	69	144	525
Land tenancy: Owner (%)	78.6	30.6	0	100	62.7	36.7	0	100
: Fixed rent (%)	21.4	30.6	0	100	37.3	36.7	0	100
Other characteristics								
Age (yrs)	39	10	22	61	40	9	25	61
Education (yrs)	6	4	0	15	5	3	0	9
Farming exper. (yrs)	23	11	7	53	2	0	2	2
Traning program: Attend (%)	14.8	35.8	0	1	100	0	1	1
Sample size		61				50		

a) N/a notes for not applicable.

Data obtained from sugarcane farmers' survey showed that the average age of household heads was about 40 years old and they have attained the education of elementary school (Table 2). The land area dedicated to sugarcane production per farmer (1.04 ha) accounted for more than two-third of the total farming area (1.54 ha). While 79% of the land was owned by farmers, the predominant type of tenancy arrangement was leasehold, in which farmers paid a fixed rent to landowner. As for the summary of production variables, average sugarcane yield per hectare was calculated at 95.8 ton. Labor use, fertilizer use and capital input per hectare were 258 person-days, 867 kg and 700 Yuan respectively.

On the side of cassava production, data obtained from cassava farmers' survey showed that the average age of household heads was about 40 years old and they have attained 5 years of schooling (Table 2). The land area dedicated to cassava production per farmer was 0.29 ha. While 63% of the land was owned by farmers and 37% of the land was leased through paying a fixed rent to landowner. Average yield per hectare was calculated at 29 ton. Labor use and fertilizer use per hectare were 356 person-days and 199 kg respectively.

3.1.2 Average production function

The estimation results of average production function are presented in Table 3. An initial set of independent variables are conventional inputs and farmers' characteristic including: labor, capital and fertilizer, village Ⅰ dummy (Village Ⅰ = 1, otherwise = 0), village Ⅱ dummy (village Ⅱ = 1, otherwise = 0), tenant dummy (tenant land = 1, otherwise = 0). As to functional form, we choose the Cob-Douglas since its statistical performance is superior to others. We convert input variables into per hectare terms. Using per-hectare variables is favorable due to the easy interpretation and the statistical stability, avoiding multi-colinearity caused by land size.

The first column of the table 3 shows the estimation result of sugarcane sample using the initial variable set. Throughout the regression analysis, we use 50 observations instead of 61, since, for omitted samples, some variable are identified as outlier according to influential analysis using DIFITs and DFBETA. Though R2 was estimated at high value of 0.93, among independent variables of conventional inputs only labor and fertilizer were significant at conventional significant levels and for the dummy variables including in the production function, the location of respondents in village Ⅲ had a significant, negative coefficient, indicating that productivity for sugarcane production in Village Ⅲ was significantly lower. As for the cassava production, the estimation result of average production shows in the second column of table 3. The coefficients of the labor and fertilizer inputs were all statistically significant with an expected positive sign.

3.1.3 Stochastic frontier function

To examine the frontier technology of sugarcane production, we estimate stochastic frontier function. The functional form and the variables used are selected according to the estimated average function explained above. The result is shown as Table 4.

As for sugarcane production, the coefficients of the labor and fertilizer input were statistically significant with an expected positive sign. As just a reference, in terms of factor shares for the entire samples, sugarcane production in the study area was characterized by the land share of 16%, the labor share of 41% and the fertilizer input share of 24%. Moreover, village Ⅲ dummy had a significant, negative coefficient. The parameter γ ($\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$) was estimated to be 0.83, which indicates that the technical inefficiency effects were a significant component of the total variability of sugarcane outputs. However, average and frontier production technologies cannot be statistically distinguished each other. This can be confirmed by the fact that the estimated coefficients of frontier function were almost the same as those of the average function. The mean technical efficiency (TE) was estimated to be 0.95. Theses result suggest that the high degree of homogeneity of sugarcane production technology among farmers.

For cassava production, the coefficients of fertilizer and labor input were about 0.71 and 0.15, respectively. The coefficient of tenancy dummy was negative with value about -0.01 at conventional significant level. Negative coefficient of tenancy indicates that owner operators tend to be more technically efficient than tenant operators. The γ-parameter associated with the variance of the technical inefficiency effects in the stochastic frontiers was estimated to be 0.9. Moreover, the mean technical efficiency (TE) was estimated to be 0.93. This means that there existed a 7% potential for increasing productivity at the existing level of production resources.

Table 3. Estimation results of average production functions[a)]

Variables		Sugarcane		Cassava	
		Coef.	p-value	Coef.	p-value
Inputs (log)					
Fertilizer	α	0.24	0.00	0.21	0.00
Capital [b)]	β	0.00	0.12	N/a	N/a
Labor	γ	0.75	0.00	0.56	0.00
Dummies					
Village II [c)]		0.01	0.72	N/a	N/a
Village III [c)]		-0.05	0.06	N/a	N/a
Tenant		-0.02	0.38	0.00	0.98
Constant		-1.22	0.00	- 1.07	0.02
Model fitting					
R-squared		0.93		0.81	
Mean VIF		2.02		1.64	
Sample size		50		45	

a) N/a notes for not applicable. Dependent variables are transformed into log values.

b) In case a value of capital is zero, it is replaced by 0.001 to apply log-transformation.

c) Vill. II, Vill. III are Nongying and Feichuanha, respectively.

Table 4. Estimation results of stochastic frontier production functions (normal distribution) [a)]

Variables	Sugarcane		Cassava	
	Coef.	p-value	Coef.	p-value
Inputs (log)				
Fertilizer	0.26	0.00	0.15	0.00
Capital [b)]	0.00	0.26	N/a	N/a
Labor	0.73	0.00	0.71	0.00
Dummies				
Village II [c)]	0.02	0.41	N/a	N/a
Village III [c)]	- 0.05	0.03	N/a	N/a
Tenant	- 0.01	0.51	- 0.01	0.00
Constant	- 1.20	0.00	- 1.50	0.00
$\ln(\sigma^2_v)$	- 6.99	0.00	- 38.82	0.92
$\ln(\sigma^2_u)$	- 5.38	0.00	- 4.45	0.00
$\gamma(=\sigma^2_u/(\sigma^2_v+\sigma^2_u))$	0.83	0.00	0.90	0.00
Pseudo LL	79.13		67.41	
AIC	- 140.26		- 122.82	
Mean TE	0.95		0.93	
Sample size	50		45	

a) N/a notes for not applicable. Dependent variables are transformed into log values.

b) In case a value of capital is zero, it is replaced by 0.001 to apply log-transformation.

c) Vill. II, Vill. III are Nongying and Feichuanha, respectively.

Table 6 Yearly average of evapotranspiration (ET) of sugarcane and cassava and the total rainfall of Yunnan Province

	mm y^{-1}
Evapotranspiration cassava	985.5
Evapotranspiration sugarcane	1119
Total rainfall in Yunnan [a)]	1165

a) Total rainfall of Yunnan Province in 2008

3.2 Evaluation of sustainability

3.2.1 Ecological areas of concern

Conversion rate to ethanol

According to the comparison results from table 5, the bioethanol yield was 4.8 ton/ha at average solution and 5 ton/ha at frontier solution by using sugarcane. However, take cassava as feedstock, bioethanol yield was 5 ton/ha at average solution and 5.4 ton/ha at frontier solution.

Water requirement

In the set of sustainability criteria requires that the production of bioenergy crops is not allowed to result in a depletion of fresh water resource

Table 6 shows that sugarcane plantation requires more water for optimal growth than cassava production. 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 [8]. In literature average evapotranspiration of sugarcane is 1119 mm y^{-1} [9] and evapotranspiration of cassava is 985 mm y^{-1} [10]. The total rainfall in Yunnan was 1165 mm y^{-1} in 2008 [6], which was sufficient to meet evapotranspiration of two crops in Yunnan. However, the surplus between the total rainfall and sugarcane evapotranspiration was not obviously. Considering the effective rainfall in reality, we concluded that there was a risk of grondwater depletion from sugarcane production.

Pollution from fertilizer

In the set of sustainability criteria requires that use fertilizer as few as possible as for as reasonable yield is achievable. According to the table 7, consumption 1 ton bioethanol, the relative fertilizer use was 181kg for sugarcane production and 40kg for cassava production. The results show that to achieve the same amount of bioethanol fertilizer use for cassava production was less than sugarcane.

Table 5 Comparison of bioethanol production from suagrcane and cassava

Crops	Yield ton/ha	Converstion rate to ethonal	Bioethonal yield ton/ha
Sugarcane			
Average production	95.8	0.05	4.8
Frontier production	100.8	0.05	5.0
Cassava			
Average production	29.3	0.17	5.0
Frontier production	31.7	0.17	5.4

Table 7 Comsunption per ton ethanol, average direct labor and fertilizer inputs in sugarcane and cassava ethanol system

Item	Fertilizer kg/ton	Lourbour used for farming Persondays/ton
Sugarcane farming	181	54
Cassava farming	40	72

3.2.2 Socio-economical area of concern

Competition with food production

The statistical correlation between the rice planted area and sugarcane planted area or cassava planted area was measured by using the data from 1995 to 2010 of survey counties.

The resulting correlation coefficient between rice and sugarcane planted area was about -0.73 at significant level. This indicates a significant negative correlation; more planted area for sugarcane tends to be less planted area for rice. And the planted area correlation between rice and cassava shows insignificant, which means there was no correlation between them.

Employment

The set of sustainable criteria requires that energy crop production contributes to the direct employment.

According to the results from table 7, consumption per ton bioethanol, the average labor requirement was calculated to be 54 person-days for sugarcane farming and 72 person-days for cassava farming. The labor input was higher in cassava production compared to sugarcane production.

4. Discussion and 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 technical efficiency and sustainability of production between sugarcane and cassava which could be used as bioethanol feedstock.

Firstly, from the aspect of production technical efficiency, the analysis of crops production shows that both crops production performance were determined by the two conventional factors of labor and fertilizer inputs. As for sugarcane production, the explanation power of the average production regression is so high and the frontier production function is not statistically different from the average one. These findings imply that the productivity of sugarcane production is hardly to be increased by improving farmers' technical disparity through agricultural extension activities. Therefore, should the sugarcane production to be increased, farmer would have to increase fertilizer inputs or to expand planted area. Since farmers' activities are not generally sustainable, local government should pay more attention on the environmental problems, e.g. deforestation, soil erosion and so on.

As for cassava production, the mean efficiency was 0.93 implying that, on average, the cassava production could increase its output by 7 percent from a given mix of inputs through the adoption of the best practices of the efficient farms. Except look into increasing agricultural land for cassava development, the cassava farmers have choices to focus on increasing its current productivity through improved the farming techniques. Moreover, tenancy dummy coefficient was negative at significant level in cassava production. Thus, local governments have an important role to play in ensuring safeguards on land rights, especially the informal rights of the rural poor.

Secondly, from the aspect of sustainable production, 5 areas of concern were formulated to evaluate the sustainability of each crop production. The results indicate that competition with food production and water requirement are potential bottlenecks for a sustainable sugarcane-based ethanol production. The bioethanol yield was calculated to be 4.8 ton/ha-5ton/ha for sugarcane-based production and 5ton/ha-5.4ton/ha for cassava-based production dependent on different farmer's technical efficiencies. It was obviously, cassava compared favorably to sugarcane. Indeed, the yield of bioethanol was found to be higher for cassava than sugarcane. Furthermore, compare factor inputs change from average production to frontier production for each crop. The social-economic criteria related to employment decrease of 2% in sugarcane production and increase of 15% in cassava production and the environmental criteria related to fertilizer use increase of 2% in sugarcane production and decrease of 6% in cassava production. These results show that no matter under the average production technology or frontier production technology, cassava production requires less fertilizer and provides more employment opportunities. For the employment in our study was limited to direct impact within the boundaries of the farm and its employees only. Widening of the scope could lead to different outcomes.

The analysis in the paper is based on a subjective assessment of different areas of concern and also on incomplete information. Moreover, the methodology 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.

All in all, considering the rapidly increase demand of biofuel feedstock, Yunnan governments should strengthen the agricultural infrastructural construction; strengthen the reconstruction of low-yielding fields. Compare the technical efficiency and sustainable production between the usages of sugarcane and cassava as bioethanol feedstock in Yunnan, We suggest that cassava which requires low agro-fertilizer use, should be recommended as a prior energy crop in Yunnan with higher rates in ethanol conversion and dry matter.

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