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Potential land for plantation of *Jatropha curcas* as feedstocks for biodiesel in China

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As a renewable energy, biofuel has attracted great attention in China and the rest of world. Concerned with the national food security, China recently has shifted its biofuel development priority from grain-based to non-grain-based biofuels, including forest-based biodiesel, since 2007. *Jatropha curcas* is one of major biodiesel feedstocks. However, there is rising debate on availability of land for expanding *Jatropha curcas* areas. The overall goal of this paper is to evaluate potential land for *Jatropha curcas* used as feedstock for biodiesel in China. Based on remote sensing data on land use, data on meteorological, soil and land slope, and suitable environment for *Jatropha curcas* plantation, this study uses Agro Ecological Zone method and considers social-economic constraints to evaluate potential suitable land for *Jatropha curcas* plantation in China's major *Jatropha curcas* production region, Southwest China. The results show that while there are some potential lands to expand *Jatropha curcas* areas, amount of these lands will hardly meet the government's target for *Jatropha curcas*-based biodiesels development in the future. China may need to reconsider its long-term targets on the development of *Jatropha curcas*-based biodiesels.

biodiesel, *Jatropha curcas*, potential land, suitability evaluation, Southwest China

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Biofuels, as a renewable energy and driven by national energy security and environmental concerns, have been emerging and will grow rapidly in the future. Europe, America, and most of energy-short developed countries as well as many developing countries such as Brazil, India, Indonesia, and China have started large-scale biofuels programs and also set up their national long-term biofuel development targets. The global bioethanol and biodiesel reached 495×10^8 and 98×10^8 L, respectively, in 2007 [1, 2].

China is one of major biofuels producers in the world, though the nation has shifted its biofuel development priority from grain-based to non-grain-based biofuels since 2007. China is the third largest bioethanol producer next only to United States and Brazil. Bioethanol and biodiesel production reached 1.33×10^6 and 10^5 t, respectively, in 2007 [3]. However, due to global food price hiking in 2006–2007 and concerns on national food security, China has decided to develop its biofuels primarily based on non-grain feedstocks.

Forest-based biodiesel, especially *Jatropha curcas* (or *Jatropha* for short) based biodiesel that does not compete for cultivate land for food production, has attracted great attention by policy makers and biodiesel industry in China. In order to enhance forest-based biodiesel industry to improve national energy security, State Forestry Administra-

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tion (SFA) has released "National Planning on Energy-oriented Forest Development" and "Strategic Report on Forest-based Bioenergy Development"1). Among various species of tree, *Jatropha* is often considered as one of the most favorable biodiesel feedstock trees. India and some countries in Africa have developed their large-scale *Jatropha*-based biodiesel development program. Currently, China also focuses its biodiesel program on *Jatropha*.

Yunnan, Sichuan, and Guizhou in Southwest China are the major *Jatropha* production provinces. With active participations by the government and companies, *Jatropha*-based biodiesel industry has started to boom in this region. Each of these three provinces has set up its targets for *Jatropha*-based biodiesel program since 2006. According to their programs, there will be about 1.667×10^6 hm^2 of *Jatropha* plantation on barren hills and wastelands in next 10–15 years in this region, of which Yunnan, Sichuan, and Guizhou will plant 6.67×10^5, 6×10^5, and 4×10^5 hm^2, respectively. The record from SFA shows that *Jatropha* area reached 1.5×10^5 hm^2 in 2008, accounted for more than 95% of China total plantation *Jatropha* area. In addition, National Development and Reform Commission (NDRC) approved several *Jatropha*-based biodiesel commercialization and demonstration projects proposed by China National Petroleum Corporation, China Petrochemical Corporation, and China National Offshore Oil Corporation in June 2008, with an annual total production capacity of 200 thousand tons.

Although *Jatropha*-based biodiesel has showed a rapid growing trend in China, as a new industry, it will inevitably face many challenges and uncertainties. A successful development of forest-based biodiesel industry is strongly associated with its feedstock supply as well as biodiesel processing and refining, marketing, and utilization. Of those, feedstock supply is one of major uncertain factors that will shape the future trend of biodiesel industry. Currently, feedstocks account for about 70%–80% of the total biodiesel production cost [4].

On feedstock production, the major uncertainties derive from potential lands suitable for *Jatropha* production and yield potential of *Jatropha* plantation. In particular, although the government has set up ambitious targets on *Jatropha*-based biodiesel program, some key issues are still unknown2). In the literature, no study has examined the amount of potential land (e.g., barren hills and wasteland) suitable *Jatropha* plantation. Although there are some experimental data on *Jatropha* yield [5], there is little sound data on yield of *Jatropha* plantation under different natural environments. Moreover, so far no improved variety could be commercially adopted by farmers in field. In addition, biodiesel lifecycle's environmental effects are also in need of great attention.

The overall goals of this paper are to evaluate potential land that is suitable for *Jatropha* plantation in its main production regions (Southwest China) and to provide scientific information for policy makers in government and private sector.

1 Data

Three datasets are used in this study. They are datasets on natural conditions (such as meteorological, elevation, and soil quality data), remote sensing land use, and social and economic constraints. With above datasets and necessary conditions for *Jatropha* growth, we can evaluate suitability of land for *Jatropha* plantation.

1.1 Natural conditions

(1) Meteorological data. The meteorological data used in this study is a set of meteorological observatories' observation data from 1950 to 2000 released by China Meteorological Administration. The data encompass annual mean temperature, annual extreme minimum temperature, annual extreme maximum temperature, above 0°C accumulated temperature, above 10°C accumulated temperature, annual mean precipitation, and humidity index. In the analysis, these data were converted into a grid dataset [6].

(2) Elevation data. The elevation data were derived from China 1:250000 digital elevation models, with a spatial resolution of 50 m. Average slope information was extracted on each 1 km × 1 km plot by GIS spatial analyzing function, and then was used as basic information for land suitability evaluation.

(3) Soil data. Soil data were from a multi-source. Firstly, the specific soil survey points were calibrated on local administrative division base map, based on carefully comparing the information on National Secondary Soil Survey data, Southwest China soil survey data, and 1:250000 topographic maps. Secondly, an Albert projection value for specific soil survey point was assigned onto the map and generated a soil survey base map. After that, soil attribute data were linked onto soil survey base map by Kring interpolation algorithm, and generated a spatial soil data encompassing soil type and physicochemical characters. Finally, these soil data were saved as ArcGIS Grid format, with soil type, soil depth, soil organic content, PH value, and soil texture information.

1) State Forestry Administration. "National Planning on Energy-oriented Forest Development" (2006) and "Strategic Report on Forest-based Bioenergy Development" (2008), Beijing.

2) Jongschaap R E E, Corre W J, Bindraban P S, et al. Claims and facts on *Jatropha Curcas* L.: Global *Jatropha curcas* evaluation, breeding and propagation programme. http://www.gnr-holding.com/fileadmin/user_upload/medien/Reports/ Jatropha/Claims-Facts.pdf.

1.2 Remote sensing land use data

Remote sensing land use data were from a 1:100000 land use dataset of Chinese Academy of Sciences (CAS) [7]. This dataset was interpreted from Landsat TM/ETM with a spatial resolution of 30 m ×30 m, and contained 6 first-order land use categories and 25 second-order land use categories. For our purpose, land categories were reclassified into arable land, close forest, bush forest, open forest, barren, grass land, water area, build-up land, and unused land3).

1.3 Social and economic data

Social and economic factors (e.g., land use policies and investment) have important impacts on potential land that could be used for *Jatropha* plantation. If only natural conditions were to be considered, all land categories except water area and build-up land could be used for *Jatropha* plantation. However, land use decision also needs to consider land use policies, crop's competition for limited land, and investment requirements, and other factors. Therefore, in this study, we took land use policy and regulations, local economic structure, and other social and economic factors as constraints in evaluating potential land that could be suitable for *Jatropha* plantation.

2 Methodology

2.1 Analytical framework and procedures

Several methods can be used to evaluate suitability of land for *Jatropha* plantation, of which Agro Ecological Zone (AEZ) developed by FAO (Food and Agriculture Organization) and IIASA (International Institute for Applied Systems Analysis) is the most popular method for land suitability evaluation [8–10].

In this study, we also used AEZ but imposed social and economic constraints to evaluate land suitability. The analytical framework and procedures are as follows: (1) Based on existing literatures and suggestions from experts in *Jatropha* field, we identify major natural conditions under three levels of suitability for *Jatropha* plantation. The major natural conditions include the requirements of *Jatropha* plantation on temperature, soil moisture, soil quality, and land slope. The three levels of suitability of land for *Jatropha* are suitable, moderate suitable, and unsuitable [8–10]. (2) In order to understand the relative importance of each factor affecting suitability of land for *Jatropha,* we started analysis by each of natural conditions (e.g., temperature, soil moisture, soil quality, and land slope). (3) After step (2), a multi-factor land suitability evaluation was conducted, which simultaneously considered temperature, soil moisture, soil quality, and slope factors. (4) Finally, we introduced the analysis by imposing social and economic constraints.

2.2 Natural conditions for *Jatropha* plantation

Several studies have examined the correlation between *Jatropha* production and natural conditions and provided regional distribution and suitability of *Jatropha* plant in each region [11–16]. Although these studies have not developed universally acceptable criteria to guide *Jatropha* plantation, there is a consensus that temperature, soil moisture, land slope, and soil quality are key factors that affect *Jatropha* growth and yield performance4).

(1) Temperature. *Jatropha* belongs to thermophyte plant, usually it growths better with higher temperature. Normally, *Jatropha* cannot survive in a location with extreme minimum temperature below 0°C. In addition, the yield of *Jatropha* seed will fall significantly when annual mean temperature falls below 15–17°C [11–16]. There are several indicators reflecting temperature condition, including annual mean temperature, higher than 0°C temperature, higher than 10°C accumulated temperature, and annual extreme maximum or minimum temperatures, etc. Based on existing literatures, annual mean temperature and extreme minimum temperature were used in this analysis. Details on temperature conditions and categories of land suitability for *Jatropha* plantation are summarized in Table 1.

(2) Soil moisture. Previous studies have shown that yield of *Jatropha* seed is positively correlated with soil moisture. Whereas too arid or too moisture both go against *Jatropha* growth, it is reported that *Jatropha* seed yield falls when annual mean precipitation is less than 700 mm or over 1300 mm in Southwest China though the exact numbers differ among regions [5, 12, 13]. Precipitation is one of major indicators that reflect soil moisture, the later also depends on many other factors (e.g., potential evapotranspiration). In order to appropriately measure soil moisture, we applied Thornthwaite humidity index, which considers both precipitation and evapotranspiration [17]. Details on Thornthwaite index numbers under three categories of land suitability for *Jatropha* plantation are summarized in Table 1.

(3) Land slope. Slope is an important indicator often used in land suitability analysis because it directly affects drainage, irrigation, and soil erosion. In agriculture land suitability evaluation, slope is usually categorized into five grades,

3) The definition on forest has been revised since Fifth National Forest Resource Inventory (see "National Forest Resource Inventory" 2005); however, we adopt the original definition on forest in this study. Therefore, area of various forests in this study would differ slightly from that published data by forestry sector in China.

4) In most studies, elevation was taken as a key index for evaluating land suitability for Jatropha. But elevation is strongly correlated with temperature, sunshine, rainfall, and other natural conditions. In order to avoid overlapping issue, we do not use elevation in this study.

where the land with a slope over 25° is regarded as unsuitable for crop as it easily causes water loss and soil erosion [18]. Based on regulation of slope land used for agriculture and conditions for *Jatropha* plantation, we define land with slope less or equal 15° as suitable land for *Jatropha* plantation, land with slopes of between 15° and 25° as moderate suitable, and the rest as not unsuitable land (Table 1).

(3) Soil quality. Soil quality is determined by various factors, including soil type, depth, organic content, PH value, and soil texture, etc. There is no common standard or measure for soil quality in land suitability analysis. Choices of quality indicator usually differ among studies and depend on types of plant studied.

In this study, based on existing literatures and views from experts in *Jatropha* field, we selected soil depth, organic content, and soil texture as soil quality indicators and used Fuzzy Membership Approach to evaluate suitability of land for *Jatropha* plantation. There are three major steps. First, we sort each of three soil quality indicators and categorize them into five grades. Then, for each of three soil quality factors, we indentified the best suitable range with Membership equaling 1.0 and transition zone with Membership values between 0.5 and 1.0, based on *Jatrapha's* requirement on soil quality indicators (Table 2). Second, based on the above three indicators' specific grades, best suitable range, and transition zone, we estimated the degree of Membership for each plot of lands using Membership Function (Semantic Import Model) [19, 20]. Finally, we aggregate the degree of Membership over three soil quality factors into one index with three categories of land (suitable, moderate suitable, and unsuitable for *Jatropha* plantation) for each plot of lands [19–22].

3 Results on land suitability for *Jatropha* plantation

Based on above data and methods, land suitability for *Jatropha* in Southwest China was evaluated. In this section, the results based on each of single-factor analysis, multi-factor analysis, and imposing social and economic constraint analysis are presented.

3.1 Results based on single-factor evaluation

The suitability analysis was conduced for each of four major factors (temperature, soil moisture, soil quality, and land slope). Figure 1 presents the spatial distribution of land suitability (suitable, moderate suitable, and unsuitable) for *Jatropha* plantation by each of four factors. Table 3 summarizes suitable and moderate suitable land areas by each of four factors and by province.

Table 3 and Figure 1 show several important results.

Table 1 Temperature, soil moisture, and land slope under three categories of land suitability for *Jatropha* plantation[a)]

	Suitable	Moderate suitable	Unsuitable
Annual mean temperature (℃)	⩾20	17–20	⩽17
Annual extreme minimum temperature (℃)	⩾2	0–2	⩽0
Thornthwaite humidity index	100–33.3	−33.3–−66.7	>100 or <−66.7
Average slope	⩽15°	15°–25°	⩾25°

a) Data resource: existing literatures and *Jatropha curcas* experts' views.

Table 2 Grade and ranges of soil attributes[a)]

Grade	5	4	3	2	1
Soil depth (cm)	⩾100	100–75	75–50	50–30	⩽30
Organic contents (%)	⩾5.0	3.5–5	2.5–3.5	1.5–2.5	⩽1.5
Soil texture (%)	⩾40	40–30	30–20	20–10	⩽10

a) Best suitable range of three indicators (degree of Membership equaling one) are greater than or equal to grade 4, transition zone of three indicators (degree of Membership 0.5–1.0) is 2 (e.g. grades 2–3).The percentage of loma volume ratio was used to denote soil texture index. Data source: existing literatures and *Jatropha curcas* experts' views.

Table 3 Land areas suitable and moderate suitable for *Jatropha* plantation based on single-factor analysis in Yunnan, Sichuan and Guizhou, Southwest China (Unit: ×1000 hm^2)

	Yunnan		Sichuan		Guizhou		Total	
	Suitable	Moderate suitable	Suitable	Moderate suitable	Suitable	Moderate suitable	Suitable	Moderate suitable
Temperature	917	7674	35	744	14	1102	966	9520
Soil moisture	36242	0	47922	10	17609	0	101773	10
Soil quality	21637	9713	20326	21995	3742	10644	45705	42352
Land slope	34704	3257	41229	6432	17442	165	93374	9853

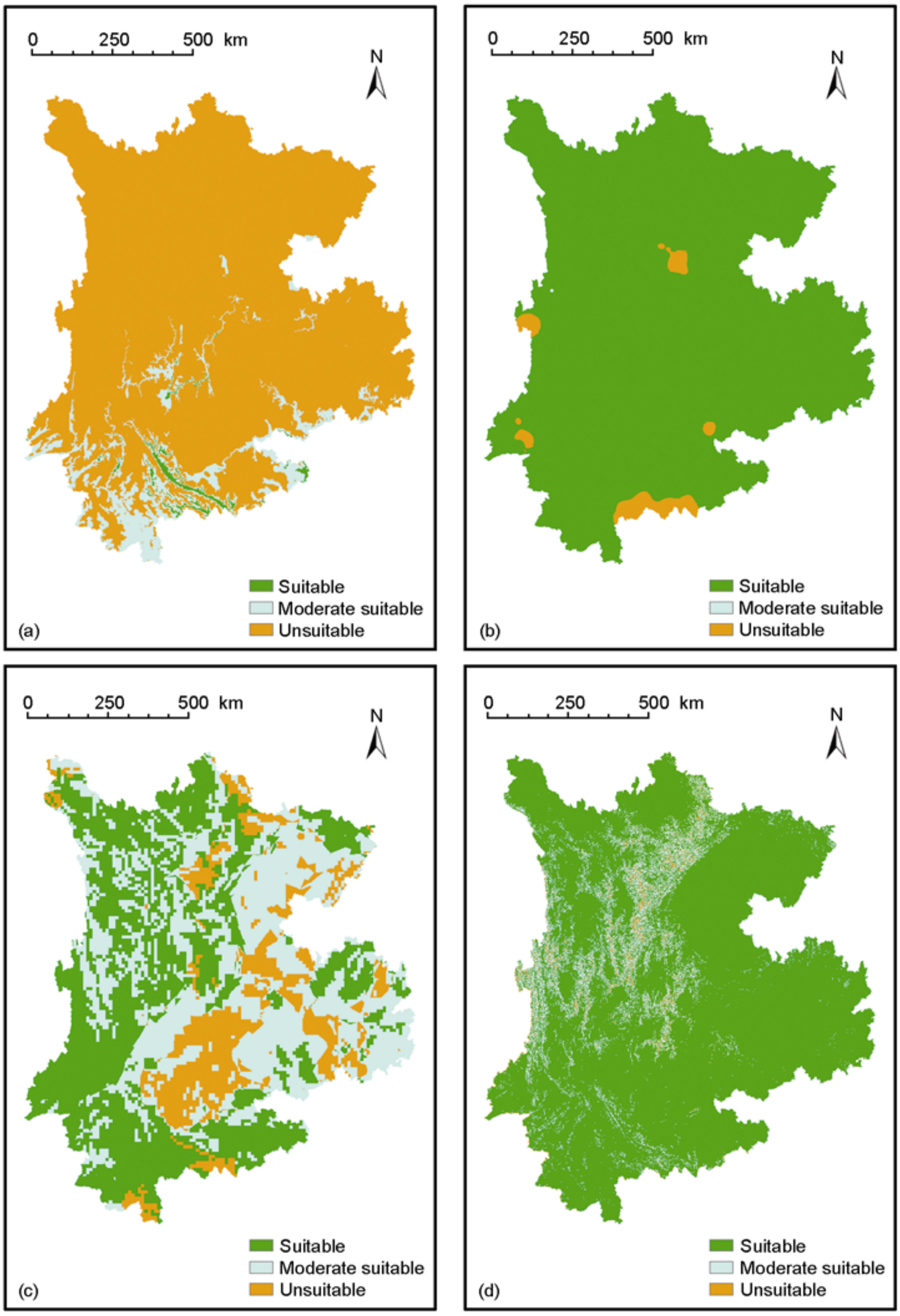

Figure 1 Spatial distribution of suitability of land for *Jatropha* plantation based on single-factor analysis.

First, temperature is the most important factor that limits *Jatropha* plantation (Figure 1(a)). The area of suitable land based on temperature condition is 9.66×10^5 hm^2, accounting for only 0.9% of three provinces' total area. Moderate suitable land area is much larger (9.52×10^6 hm^2, Table 3), but it still accounts for only 9.1% of total land area in this region.

Second, soil quality also has some impacts on *Jatropha* area expansion (Figure 1(c)). The areas of suitable and moderate suitable land based on soil quality are 4.5705×10^7 hm^2 and 4.2352×10^7 hm^2, respectively, and account for 43.8% and 40.6% of three provinces' total land area.

Last but not the least, the impacts of soil moisture and land slope on *Jatropha* plantation are not significant (Figures 1(b) and (d)). For example, areas of suitable land based on soil moisture requirement alone reach 1.01773×10^8 hm^2, accounting for 98% of total area in this region (Table 3). Suitable (9.3374×10^7 hm^2) and moderate suitable (9.853×10^6 hm^2) land based on slope condition are also very large (Table 3), which account, respectively, for 90% and 9.5% of total area in the region.

3.2 Results based on multi-factor evaluation

Based on above single-factor evaluation results, a multi-factor evaluation is conducted. The major results are presented in Figure 2 and Table 4. In multi-factor analysis, we also exclude inland waters and build-up areas. From Figure 2 and Table 4, we summarize the following major results.

Overall, suitable land for *Jatropha* plantation is very limited, though moderate suitable land is relatively large (Figure 2). Based on the data presented in Table 4, total area of suitable land is only 3.7×10^5 hm^2, far less than total target of 1.667×10^6 hm^2 set by these three provinces. But potential for *Jatropha* expansion in moderate suitable land is high (7.437×10^6 hm^2).

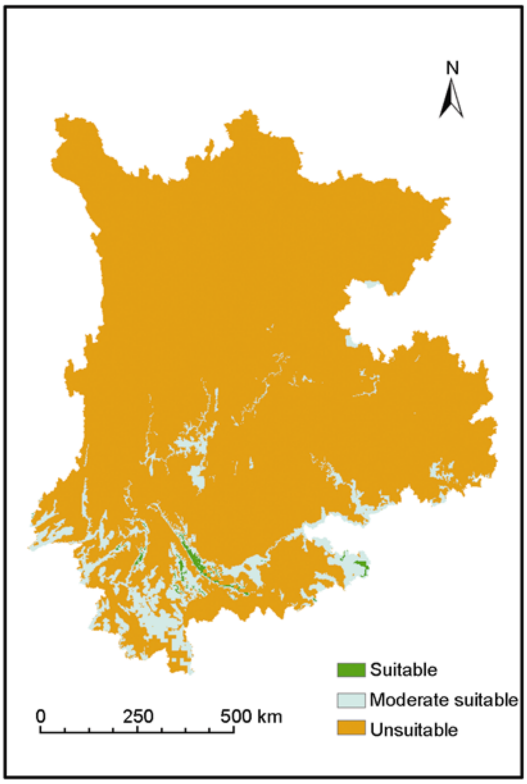

Figure 2 Spatial distribution of suitability of land for *Jatropha* plantation based on multi-factor analysis.

On provincial aspect, Yunnan has much larger potential land for *Jatropha* plantation than Sichuan and Guizhou. Table 4 shows that all suitable land is located in Yunnan. For moderate suitable land, Yunnan also accounts for about 82% of the total in three provinces. Area of moderate suitable land in Sichuan and Guizhou together is only 18% of total moderate suitable land in the three provinces.

From land use category point of view, bush land, barren/grass land and open forest land are the major suitable or moderate suitable land for *Jatropha* plantation (Table 4).

However, above multi-factor evaluation results are just based on natural conditions. Whether or not these lands could be used to plant *Jatropha* is still subject to social-economic constraints. Therefore, the results presented above should be considered as theoretically potential land that could be used for *Jatropha* plantation.

3.3 Results based on both natural conditions and social-economic constraints

In order to have our evaluation results more close to actual situations, it is imperative to consider social-economic factors that might further constrain *Jatropha* plantation.

Based on current national land use policies and a series of consultations with the officials from forestry and land authorities, experts in *Jatropha*, and local farmers, we made the following several adjustments to the results based on multi-factor evaluation presented above[5]: 1) We assumed that there will be 2% of suitable arable land that could be used for *Jatropha* plantation. According to the government's regulation, biofuel development should not compete for land with food production. This implies that the current arable land must be excluded from estimation of potential land for *Jatropha* plantation. However, farmers in Southwest China often plant *Jatropha* around crop fields as fences. Based on our field survey in Yunnan, we estimated that the potential area for *Jatropha* plantation in crop fields can reach about 2% of total suitable arable land in South-

Table 4 Land areas suitable and moderate suitable for *Jatropha* plantation based on multi-factor analysis in Yunnan, Sichuan, and Guizhou, Southwest China (Unit: $\times1000$ hm^2)

	Yunnan		Sichuan		Guizhou		Total	
	Suitable	Moderate suitable	Suitable	Moderate suitable	Suitable	Moderate suitable	Suitable	Moderate suitable
Arable land	54	1100	0	146	0	170	54	1415
Closed forest	79	1080	0	42	0	121	79	1243
Bush land	97	1857	0	43	0	73	97	1973
Open forest land	46	737	0	85	0	242	46	1065
Barren/grass land	92	1319	0	76	0	337	92	1733
Unused land	0	7	0	1	0	1	0	9
Total	370	6101	0	393	0	944	370	7437

5) It is worth noting that this is a summary from various consultations with major players related to *Jatropha* plantation. We believe that these adjustments are reasonable though further adjustment could be made to reflect alternative situations.

west China. 2) Southwest China is one of major regions for "National Natural Forest Conservation Program" and "Grain for Green Program". The region's close forest and bush land play an important role in ecological service. Therefore, we excluded close forest and bush land from *Jatropha* plantation. 3) Although barren, grass, and open forestlands are suitable for *Jatropha* plantation, there has been an increasing demand for these lands by other sectors (e.g., livestock sector, cash forest). Therefore, we assumed that about 50% of barren, grass, and open forestlands that are suitable for *Jatropha* growth could be used for *Jatropha* plantation[6)].

Based on the above adjustments, we re-estimated the suitable and moderate suitable land areas in Southwest China. The results are presented in Table 5.

Table 5 shows that suitable land reduces sharply after adjustments based on social-economic factors. First, on total areas, suitable land declines from 3.7×10^5 hm^2 (Table 4, without adjustments) to 7×10^4 hm^2 (Table 5, with adjustments); Moderate suitable land also declines substantially from 7.437×10^6 hm^2 to 1.431×10^6 hm^2. Second, on spatial distribution, all suitable land and most of moderate suitable land are located in Yunnan Province. Even in Yunnan, total area of suitable and moderate suitable lands also fall sharply. Last but not least, on sources of land for *Jatropha* plantation, barren and grass lands are still the major sources and account for 65% of total suitable and moderate suitable lands. The next is open forestland, which accounts for 33%.

4 Conclusions and discussion

Southwest China is a major region for *Jatropha*-based biodiesel industry in China. The nation and the provinces in Southwest region have set up their ambitious development plans and production targets in this industry. Recently, a large scale plantation of *Jatropha* has been started. Establishment of *Jatropha*-based biodiesel refining factories is under preparation. However, as an emerging industry without careful evaluation, it will face many challenges and uncertainties in the future. Based on remote sensing land use data and data on meteorology, elevation, soil quality as well as social and economic constraint factors, this paper tries to evaluate the suitability of land for *Jatropha* plantation in Yunnan, Sichuan, and Guizhou Provinces using AEZ methods with imposing social and economic constraints. The major conclusions are as follows:

(1) On land potential for *Jatropha* plantation, the results show that reaching government's target of *Jatropha* expansion in Southwest China is challenging. According to the targets, three provinces will plant 1.677×10^6 hm^2 *Jatropha* in total in the coming 10–15 years, of which 6.67×10^5 hm^2 in Yunnan 6×10^5 hm^2 in Sichuan, and 4×10^5 hm^2 in Guizhou. However, the results from this study show that there are only 7×10^4 hm^2 suitable lands and 1.431×10^6 hm^2 moderate suitable lands for *Jatropha* plantation in these three provinces. This means that even all suitable and moderate suitable lands are used to plant *Jatropha*, it is still difficult to fully meet the expected targets. In order to achieve expected output of *Jatropha* production, it is essential for China to focus on its efforts in improving yield of *Jatropha* seed on per unit of land through plant breeding program and better plant field management technologies.

(2) On provincial aspect, Yunnan has high potential to expand its *Jatropha* plantation, while this potential is very limited in Sichuan and Guizhou. In Yunnan, there are 7×10^4 hm^2 that are suitable for *Jatropha* plantation, and there are additional 1.054×10^6 hm^2 that are moderate suitable land. Although Yunnan could achieve its target of 6.67×10^5 hm^2, most of *Jatropha* has to be planted in moderate suitable land. To bring this land into plantation, there will be significant implications for investments on land and rural infrastructure. Moreover, *Jatropha's* yield is not expected to be high in the moderate suitable land. As to Sichuan and Guizhou, there is no way that the local government could achieve their targets, even if all their suitable lands are to be used to plant *Jatropha*.

(3) On sources of suitable land, barren and grass lands are major lands that could be transferred to *Jatropha* plantation. However, shifting large scale of grass land to *Jatropha* plantation will have substantial negative effects on the local livestock sector. This study shows that barren and grass lands, which could be used for *Jatropha* plantation and are currently often used by farmers for livestock production, account for about 65% of total suitable and moderate suit-

Table 5 Land areas suitable and moderate suitable for *Jatropha* plantation based on multi-factor analysis with imposing social-economic constraints in Yunnan, Sichuan and Guizhou, Southwest China (Unit: ×1000 hm^2)

	Yunnan		Sichuan		Guizhou		Total	
	Suitable	Moderate suitable	Suitable	Moderate suitable	Suitable	Moderate suitable	Suitable	Moderate suitable
Arable land	1	22	0	3	0	3	1	28
Open forest land	23	369	0	43	0	121	23	532
Barren/grass land	46	660	0	38	0	169	46	866
Unused land	0	4	0	0	0	0	0	4
Total	70	1054	0	84	0	293	70	1431

6) In general, competition for land is determined by the profitability of land in different uses. As profitability of land uses by sector changes over time and is hard to predict, here we selected 50%, which is just one of several potential scenarios that could occur in the future.

able lands for *Jatropha* plantation. Indeed, livestock sector plays a very important role in local agriculture in Southwest China. Statistics show that, in these three provinces, output value of livestock sector accounts for 42.6% of total agricultural outputs in 2007. In Sichuan, the share reaches 50.6% in the same year [23].

The results from this study have several policy implications:

(1) While China has made right decision to develop *Jatropha*-based biodiesel, China needs a smooth path of biodiesel development. Although there is no doubt that, in long term, *Jatropha*-based biodiesel industry will become one of prosperity industries as it will not much compete with grain for land use and is consistent with China's overall development strategy of national biofuel program, potential lands for *Jatroph* plantation are limited in Southwest China. Moreover, *Jatropha*-based biodiesel industry is still in its initial stage. Currently, there are not much improved varieties and good field management technologies for commercial plantation of *Jatropha*. If China is in a rush to promote *Jatropha*-based biodiesel, China will face great challenges in health development of this industry. In the coming years, more efforts may be needed to enhance its *Jatropha* varieties breeding program and improvement of high-yield cultivation technique.

(2) China should reconsider its regional focus of *Jatropha*-based biodiesel program. Currently, Yunnan, Sichuan, and Guizhou in Southwest have been listed as major provinces for *Jatropha*-based biodiesel program; however, potential lands in Sichuan and Guizhou are very limited. According to our analysis, Yunnan is only one province in the region that has high potential to develop large scale of *Jatropha* plantation. Caution should be taken in initiation of *Jatropha*-based biodiesel in Sichuan and Guizhou provinces.

(3) More efforts should also be made to assess environmental and economic impacts of *Jatropha*-based biodiesel program. Barren and grass land is the major land categories that could be used to plant *Jatropha*, accounting for two third of total suitable and moderate suitable land. If all these lands will be used to plant *Jatropha* in the future, they will inevitably have impacts on local livestock production and ecological system. Therefore, it is essential to conduct comprehensive impact assessments before pushing forward *Jatropha*-based biodiesel industry in large scale.

To sum up, this study is just one of initial efforts to understand suitability of land for *Jatropha* plantation. As more data and information become available on the necessary conditions for *Jatropha* plantation in the future, further studies on the issues mentioned in this paper should be conducted.

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