

Evaluation of Potential Productivity of Woody Energy Crops on Marginal Land in China

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Abstract: Energy crops are a basic material in the bioenergy industry, and they can also mitigate carbon emissions and have environmental benefits when planted on marginal lands. The aim of this study was to evaluate the potential productivity of energy crops on marginal lands in China. A mechanistic model, combined with energy crop and land use characteristics, and meteorological and soil parameters, was used to simulate the potential productivity of energy crops. There were three main results. 1) The total marginal land in China was determined to be 104.78×10^6 ha. The 400-mm precipitation boundary line, which is the dividing line between the semi-humid and semi-arid zones in China, also divided the marginal land into shrub land and sparse forest land in the southeast and bare land, bare rock land, and saline alkali land in the northeast. 2) The total area of the marginal land suitable for planting energy crops was determined to be 55.82×10^6 ha, with *Xanthoceras sorbifolia* and *Cerasus humilis* mainly grown in the northern China, *Jatropha curcas* and *Cornus wilsoniana* mainly grown in the southwest and southeast, and *Pistacia chinensis* mainly grown in the central area, while also having a northeast-southwest zonal distribution. 3) Taking the highest yield in overlapping areas, the potential productivity of target energy crops was determined to be 32.63×10^6 t/yr. Without considering the overlapping areas, the potential productivity was 6.81×10^6 t/yr from *X. sorbifolia*, 8.86×10^6 t/yr from *C. humilis*, 7.18×10^6 t/yr from *J. curcas*, 9.55×10^6 t/yr from *P. chinensis*, and 7.78×10^6 t/yr from *C. wilsoniana*.

Keywords: energy crop; marginal land; potential productivity; mechanistic model; China

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1 Introduction

The widespread use of fossil fuels has led to global environmental and climatic problems, with oil shortages impeding socio-economic development at the same time; hence, the utilization of biomass energy has been promoted as a promising solution (Gelfand *et al.*, 2013). China is a major producer of biomass energy, with the country's investment in renewable energy and bioethanol production ranking first and second in the world in 2015, respectively (Renewable Energy Policy Network

for the 21st Century, 2016). There is no universal definition of an energy crop, but the *Renewable Energy Law of the People's Republic of China* defines energy crops as ‘herbs and woody plants that are specially grown to provide energy raw materials’, while other researchers have defined energy crops as ‘plants that produce bio-oil that is equivalent to or similar to fossil fuel’ or ‘annual or perennial plants that are dedicated to the production of biomass energy’ (Fu *et al.*, 2009; Liu *et al.*, 2009). Shao and Chu (2008) reported that China has 1554 species of oil producing plants, including 154 species with

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>40% oil content in their seeds, and 30 species of shrubs or woody plants with rich biofuel components. The utilization of bio-oil does not lead to additional carbon emissions, unlike the use of traditional fossil fuels, and the development of energy crops would not only reduce China's oil dependence, but would also lead to a better ecological environment (Liu *et al.*, 2016).

Although energy crops have many advantages, in China arable land is a crucial and strategic resource, and a certain amount must therefore be maintained. The use of marginal lands for energy crop plantations is therefore accepted, and this has become a hot topic in biomass energy research in China (Xue *et al.*, 2016). Marginal land is considered to be the transitional area between two or more heterogeneous land systems, where the ecological environment is poor and the ability to withstand interference is weak, and it can be used for growing certain plants with strong resistance to adverse environmental conditions (Tang *et al.*, 2010; Wu and Zhou, 2012; Gelfand *et al.*, 2013). In China, marginal land mainly includes natural grassland, sparse woodland, shrub land, and unused land (Dong *et al.*, 2014). If 10% of all marginal land was used to grow energy crops, China would produce 1.34×10^7 t of bio-oil per year (Zhuang *et al.*, 2011). Planting energy crops on marginal land can therefore be an economically effective way to meet energy needs, while increasing environmental sustainability (Xu *et al.*, 2013).

Current studies of energy crops have mainly focused on four aspects: 1) oil extraction and production technologies, 2) planting techniques, 3) potential productivity and spatial distribution characteristics, and 4) evaluation methods. Wang *et al.* (2015) used a Gaussian curve to match the optimum ecological niche of marginal land based on the demands of the ecological niche occupied by energy crops, and obtained the spatial distribution characteristics of land suitable for four potential liquid bioenergy crops in Guangdong Province, China. Hou *et al.* (2015) compared the traits of seven species of grasses used as energy crops through field experiments in an acid red soil, and provided a theoretical basis for the development and utilization of acidic red soil in the southern China. Lu *et al.* (2012) used *Pistacia chinensis* as the target species to quantitatively calculate the total amount of marginal land in China, and extrapolated the annual oil potential productivity of crops. Liu *et al.* (2013) measured the annual net energy output and total

greenhouse gas emission reduction of marginal land in the southwestern China using *Jatropha curcas* as the target plant. Xu (2013) determined the distribution characteristics of five energy crops in China, and estimated the size and distribution of energy-crop-based enterprises in terms of material supply.

The third-degree partition method, where the indicators are divided into 'not suitable, mildly suitable, and suitable', is a very ambiguous way to evaluate the potential productivity of energy crops (Zhuang *et al.*, 2011; Lu *et al.*, 2012). Studies evaluating both herbal and woody energy crops have identified an 'overlapping area', which makes the results obtained less accurate (Wang *et al.*, 2015; Xue *et al.*, 2016). In this study, we focused on woody energy crops, by fully considering the climate differences and regional land adaptability, with five different regionally representative woody plants selected for investigation. A mechanistic model was used to simulate the growth process of woody energy crops, with indicators such as temperature, precipitation, and soil characteristics weighted and divided into two to six hierarchies and then scored according to a literature review. These measurements ensured a meticulous and comprehensive evaluation of the potential productivity of woody energy crops in China.

2 Materials and Methods

2.1 Woody energy crops and marginal land

With a vast 9.6×10^6 km² land territory, including five climatic zones (tropical, subtropical, warm temperate, temperate, and cold temperate), there is an abundance of woody energy crop resources in China (Zhao *et al.*, 2006). As the growth and production traits of herbal and woody energy crops are very different, and the evaluation of both plant types will result in 'overlapping areas', this study mainly focused on woody energy crops. Based on existing studies and according to the regional climate characteristics in China, we selected *Cerasus humilis* (Liu and Hao, 2005; Chen *et al.*, 2007), *Cornus wilsoniana* (Li and Deng, 1996; Li *et al.*, 2005), *J. curcas* (Foidl *et al.*, 1996; Lin *et al.*, 2004; She *et al.*, 2005), *P. chinensis* (Pei and Chen, 2005); Qian and Zhuang, 2005; Peng, 2016), and *Xanthoceras sorbifolia* (Gao *et al.*, 2005; Yao *et al.*, 2013) as target energy crops. The major distribution areas, suitability and biological traits of these woody energy crops are shown in Table 1.

Table 1 Major distribution areas, suitability and biological traits of woody energy crops

Plant	Main area suitable for growth	Suitable elevation (m)	Suitable temperature (°C)	Suitable annual precipitation (mm)
<i>Xanthoceras sorbifolia</i>	Northeast China	400–1400	3–18	150–750
<i>Cerasus humilis</i>	Northwest China	300–1600	3–18	40–600
<i>Pistacia chinensis</i>	Central China	500–1500	10–18	380–2000
<i>Jatropha curcas</i>	Southwest China	700–1600	15–25	480–2380
<i>Cornus wilsoniana</i>	Southeast China	<1000	8–28	1500–2500
Plant	Growth characteristics	Yield characteristics		Reference
<i>Xanthoceras sorbifolia</i>	Favors light conditions, cold and drought tolerant. Prefers moist, fertile, and well-ventilated soil with a pH of 7.5–8.0	>50 kg/(plant·yr) or 15–35 kg/(plant·yr) for 10-year-old or 30 to 60-year-old trees. Every 100 g of seed can produce 48–52 g oil	Gao <i>et al.</i> , 2005; Yao <i>et al.</i> , 2013	
<i>Cerasus humilis</i>	Favors light conditions on sunny slopes. Drought resistant, but not adapted to waterlogging. A strong adaptability to various soils, but prefers limestone soils, with pH of 6.6–7.5	30000 strains/ha on average, with yield of 110 g/plant in the normal wild state	Li <i>et al.</i> , 2005; Chen <i>et al.</i> , 2007	
<i>Pistacia chinensis</i>	Temperate species, grows in secondary forest mostly on sunny and semi sunny slopes. Deep rooted and prefers soils with pH of 6.0–7.6	50–75 kg/(plant·yr). The average output of fruit is 100 to 150 kg/(ha·yr), with 42.5% of plants producing seeds when the diameter at breast height (DBH) is 30 cm. The oil yield is 20%–30%	Pei and Chen, 2005; Qian and Zhuang, 2005; Peng, 2016	
<i>Jatropha curcas</i>	Tropical plant that grows more vigorously under higher temperature. The preferred pH is 5.5–7.5	Average seed-yield is 3250 kg/(ha·yr) with 900 kg oil extracted from these seeds	Foidlet <i>et al.</i> , 1996; Lin <i>et al.</i> , 2004; She <i>et al.</i> , 2005	
<i>Cornus wilsoniana</i>	Prefers loose textured, well drained, fertile, and moist soils, where pH is 5.5–7.5	Average output of fruit is 5–10 kg/(plant·yr). At a plant density of 800 plants/ha, average annual fruit yield is 4500–9000 kg/(ha·yr) and oil yield is 630–1260 kg/(ha·yr)	Li and Deng, 1996; Dang <i>et al.</i> , 2000	

Marginal land was determined by conforming to the principle of ‘not using the grain intended for human consumption and not occupying the land intended for grain production’ (Wu *et al.*, 2010); hence, we selected shrub land, sparse forest land, bare land, bare rock land, and saline alkali land as marginal land. Shrub land contained dwarf woodland and shrub land where the canopy density was greater than 40% and the tree height was less than 2 m. Sparse woodland was woodland with 10%–30% canopy density, while bare land had <5% vegetation cover, and areas of bare rock had >5% coverage of rocks or gravels. The saline alkali land had scarce vegetation and salt accumulations on the soil surface, and was therefore only suitable for plants that have a strong tolerance to salt and alkali.

2.2 Data acquisition and technical route

Land use data were provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC). Land use was classi-

fied into six primary types and 25 secondary types. The primary types included cultivated land, forest land, grassland, water bodies, residential land, and unused land, and data production was based on Landsat thematic mapper (TM)/enhanced TM Plus (ETM+) remote sensing images through an artificial interpretation, with the production year being 2010. The digital elevation model (DEM) was from the Shuttle Radar Topography Mission (SRTM) of the Endeavor Space Shuttle, National Aeronautics and Space Administration (NASA). The soil data were derived from the Harmonized World Soil Database (HWSD), which included the effective soil layer content, soil reference depth, and soil pH value. The meteorological data was from the China Meteorological Data Network (CMDN), and included $0.5^\circ \times 0.5^\circ$ precipitation and temperature records. Specific data are given in Table 2.

All data were processed with the ArcGIS 10.2 software. The process was divided into four parts: data extraction, classified assignment, superposition analysis,

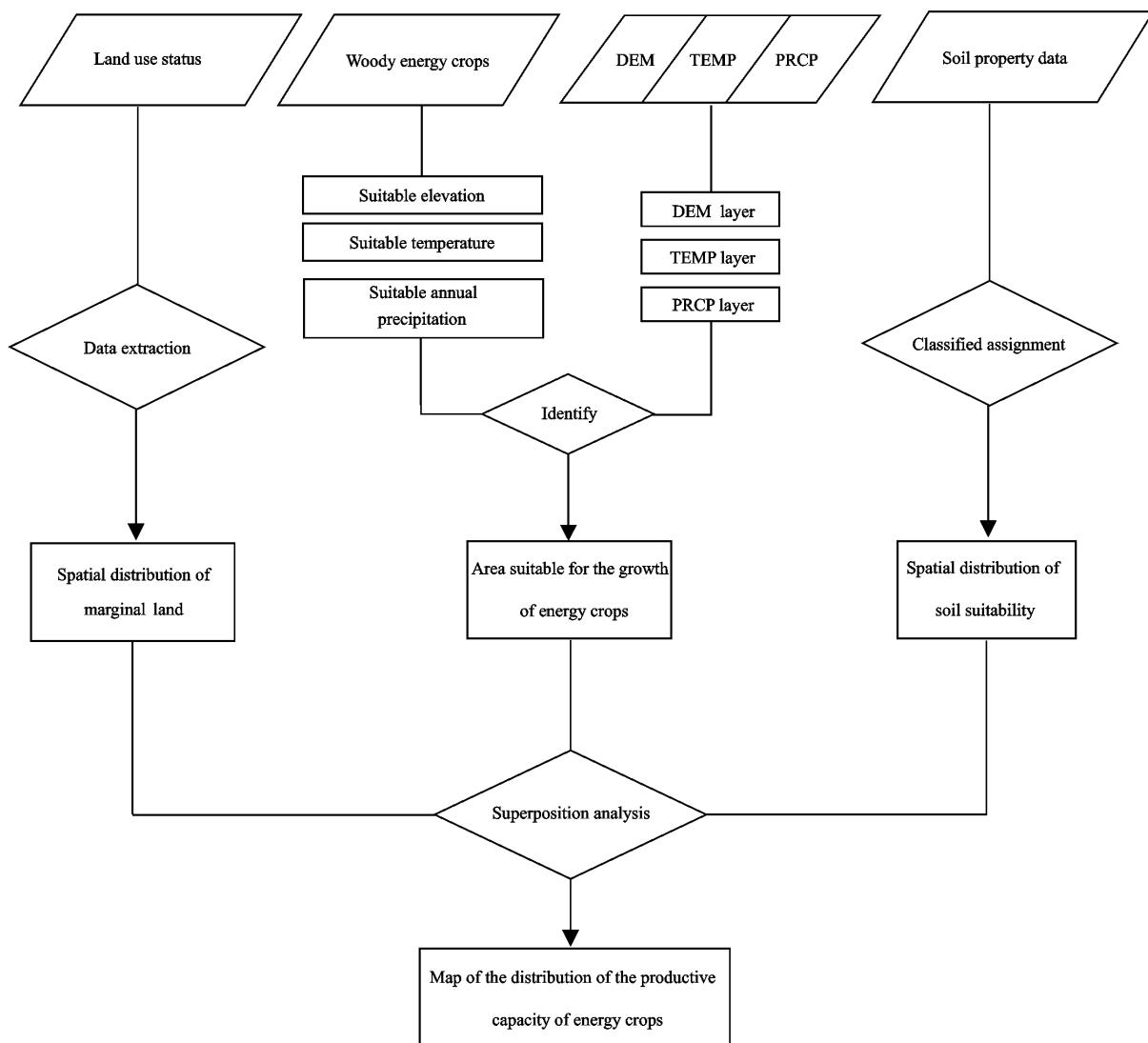
Table 2 Land use, soil, and meteorology data in this study

Data	Resolution (Scale)	Source	Year	Data description
Land use status	1 : 100000	RESDC	2010	Six primary types and 25 secondary types
DEM	90 m	NASA	2003	Extraction of elevation and slope information
Soil	1 km	HWS	2009	Soil texture, degree of erosion, reference depth, and pH
Meteorology	0.5° × 0.5°	CMDN	2010–2015	Temperature and precipitation

and visual expression. Spatial distribution of marginal land, area suitable for the growth of energy crops, and spatial distribution of soil suitability was generated through three independent processes, respectively. Then a map of the distribution of the productive capacity of energy crops was obtained by superimposing these three maps. The technical workflow is shown in Fig. 1.

2.3 Mechanistic model

The conventional methods for the evaluation of potential productivity are the analytic hierarchy process (Gao and Liu, 2000), agro-ecological zoning method (Chen *et al.*, 2014), multi-factor comprehensive evaluation (Lu *et al.*, 2012; Liu *et al.*, 2013), and mechanistic models (Dang *et al.*, 2000). Of these methods, the mechanistic

**Fig. 1** Workflow of the evaluation of the potential productivity of woody energy crops

model is widely used for evaluating plant potential productivity, based on comprehensive analyses of light, temperature, water, soil, and other natural ecological factors (e.g., energy conversion and yield); the formulation is then gradually decreased to estimate the potential productivity. Indicators in the mechanistic model are quantified so that the evaluation process can be mathematically conducted.

Climate is a basic condition for plant growth. Temperature and precipitation are the most important factors that reflect climate differences and are quantitative features. Considering the analysis described above, the potential productivity of woody energy crops was calculated as follows (Dang *et al.*, 2000):

$$Y_L = P_i \times f(T) \times f(W) \times f(S) \quad (1)$$

where Y_L is the potential productivity of the woody energy crop; P_i is the potential productivity capacity of photosynthesis of the i th woody energy crop, for which we used the highest yield kg/(ha·yr) of the i th woody energy crop as the substitute value; $f(T)$ is the effective coefficient of temperature; $f(W)$ is the effective coefficient of water; and $f(S)$ is the effective coefficient of soil.

The effective coefficient of temperature was calculated as follows:

$$f(T) = \begin{cases} 1, & N \geq 4 \\ 0, & N < 4 \end{cases} \quad (2)$$

where N is the number of monthly average temperatures that are within the temperature range suitable for growth.

The effective coefficient of water was calculated as

follows:

$$f(W) = \begin{cases} J/E_0, & 0 < J/E_0 \leq 1 \\ 1, & 1 < J/E_0 \leq 3 \\ 0.5, & 3 < J/E_0 \leq 5 \\ 0, & 5 < J/E_0 \end{cases} \quad (3)$$

where J is the annual precipitation (mm) and E_0 is the minimum value (mm) of the annual precipitation required for growth.

The effective coefficient of soil was calculated as follows:

$$f(S_i) = \sum_{j=1}^6 (M_{ij} \cdot W_j) \quad (4)$$

where M_{ij} is the score of the j th index of the i th woody energy plant, and W_j is the weight of the j th item.

The soil properties are the main factors that must be considered in the study of land resources. The physical and chemical properties of the soil determine the potential productivity of the land. Soil texture and reference depth are important parameters that determine plant growth, while soil organic matter, soil erosion, and pH are important parameters that determine plant yield. Slope is the decisive factor among the terrain conditions, and determines the redistribution of water and nutrients and the cost of transportation. According to previous studies (Dang *et al.*, 2000; Zheng *et al.*, 2003; Yu *et al.*, 2006), we used soil texture, organic matter, slope of the terrain, and the degree of erosion as indicators of the effective coefficient of soil (Table 3).

Table 3 Criterion and weighting of effective coefficient of soil

Indicator	Weight	Item	Score					
			L	LS, SL	LC, CL	SLC, SCL	SC, C	S
Soil texture	0.163	Type						
		Score	1.0	0.9	0.7	0.6	0.5	0.4
Organic content (%)	0.307	Content	≤1.5	1.5–2.5	2.5–3.5	>3.5		
		Score	0.4	0.6	0.8	1.0		
Slope (°)	0.175	Degree	≤7	7–15	15–25	>25		
		Score	1.0	0.9	0.7	0		
Degree of erosion (%)	0.165	Percent	≤15	15–20	20–30	>30		
		Score	1.0	0.8	0.6	0		
Reference depth (cm)	0.090	Range	≤30	30–60	60–100			
		Score	0.5	0.7	1.0			
pH	0.100	Range	pH ∈ (A–B)		pH ∈ (A–B)			
		Score	0		1			

Notes: This table was modified according to Zheng *et al.* (2003) and soil texture was classified according to the American Soil Texture Classification System. S is sandy, L is loamy, and C is clay. A and B in pH column indicate maximum and minimum values of pH range suitable for growth

3 Results and Discussion

3.1 Distribution of marginal land in China

Fig. 2 shows the distribution of marginal land in China in 2010, the area and spatial distribution of different types of marginal land were generated using ArcGIS 10.2, through which statistical analyses of the area of each type of marginal land were obtained.

In terms of its spatial characteristics, the distribution of the different types of marginal land types varied significantly across China (Fig. 2). Generally, the 400-mm precipitation boundary line, which is the dividing line between the semi-humid and semi-arid zones of China, divided the marginal land into two regions, with shrub land and sparse forest land on the southeastern side and bare land, bare rock land, and saline alkali land on the northeastern side. Shrub land and sparse forest land were found to be mixed with each other, and were mainly located in provinces that intersected with the Heihe-Tengchong Line and the southern region of the Yangtze River, which includes the densely populated provinces of Yunnan, Guizhou, Guangxi, and Sichuan, as well as Shanxi, Shaanxi, Hubei, Liaoning, Heilongji-

ang, and Jilin provinces. Saline alkali land and bare rock land were aggregated in north Xinjiang, central-north Qinghai, most of Gansu, and central-west Inner Mongolia. Small areas of saline alkali land were found in the area where Heilongjiang, Inner Mongolia, and Jilin met. There were fewer areas of bare land, and they mainly surrounded the saline alkali land and areas of bare rock in Northwest China.

In terms of quantity, China has rich marginal land resources, which total 104.78×10^6 ha in 2010. The area of shrub land accounted for about one-third of this area, sparse woodland and areas of bare rock accounted for about one-fourth, saline alkali land for about one-tenth, and bare land for 2.52% (Table 4).

3.2 Distribution of target woody energy crops

Based on the temperature, elevation, and precipitation suitable for the growth of the woody energy crops investigated in this study (Table 1), we generated a distribution map of woody energy crops in China in 2010 with ArcGIS 10.2 (Fig. 3) and determined the area suitable for the growth of each species (Table 5).

From a spatial perspective, the woody plants had a

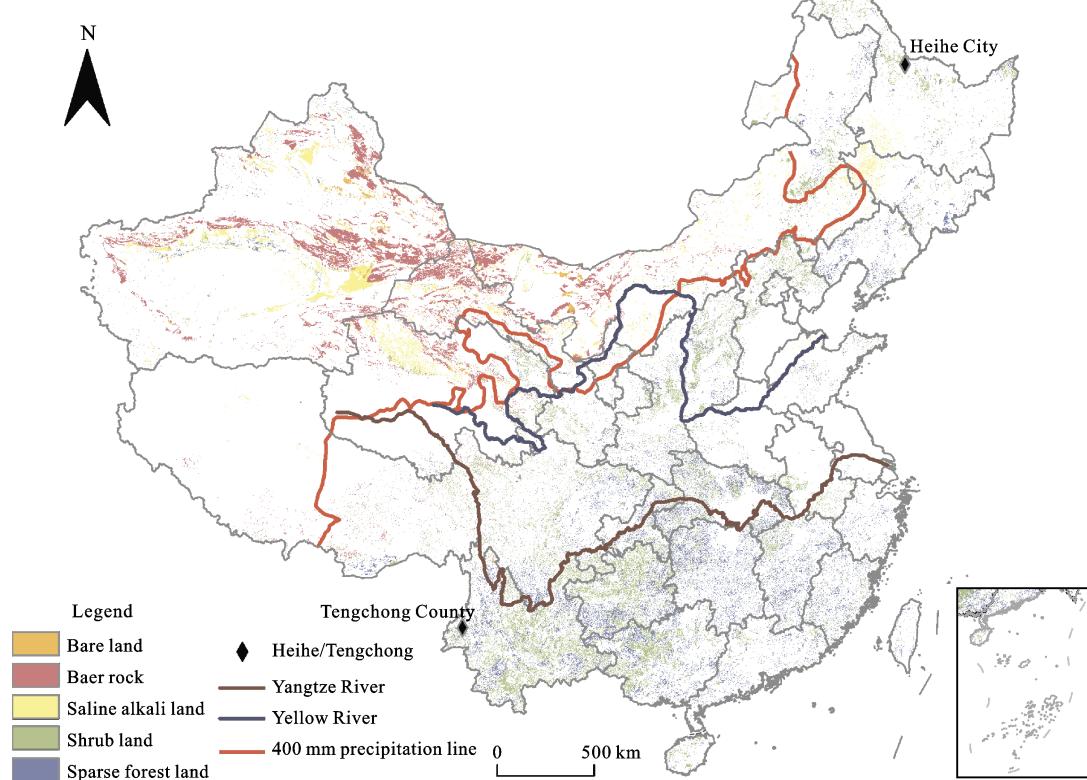


Fig. 2 Distribution of marginal land in China in 2010

Table 4 Area of each type of marginal land in China in 2010

Marginal land type	Area (10^6 ha)	Percentage (%)
Shrubland	36.31	34.66
Sparse forest land	28.57	27.26
Saline alkali land	11.74	11.21
Bare land	2.64	2.52
Bare rock	25.51	24.35
Sum	104.78	100.00

clearly agglomerated distribution. Generally, they were distributed in three main regions: *X. sorbifolia* and *C. humilis* were mainly found in north China; *J. curcas* and *C. wilsoniana* were mainly found in southwest and southeast China, respectively; and *P. chinensis* was mainly located in central China, and also displayed a northeast–southwest zonal distribution.

In terms of quantity, the total area suitable for the planting of woody energy crops is 55.82×10^6 ha, with the area suitable for each species descending in the order of *P. chinensis* > *C. humilis* > *C. wilsoniana* > *J. curcas* > *X. sorbifolia*. The suitable planting area for each province could be categorized into four groups. The first group was only Inner Mongolia, with an area of 9.30×10^6 ha; the second was in Guizhou, Yunnan, Xinjiang, and Guangxi with area of 4.50×10^6 – 5.50×10^6 ha; the third was in Hunan, Hubei, Shaanxi, Sichuan, Shanxi, Jiangxi, Heilongjiang, Fujian, Chongqing, Hebei, Gansu, and Guangdong provinces, with area that ranged from 1.20×10^6 ha to 3.00×10^6 ha; and the fourth was in Anhui, Zhejiang, Jilin, Tibet, Liaoning, Henan, Beijing, Ningxia, Hainan, Jiangsu, and Shandong, with an area less than 6.00×10^5 ha.

3.3 Evaluation of potential productivity of target woody energy crops

Based on the mechanistic model and the effective coefficient of soil given in Table 3, a map showing the distribution of the potential productivity of woody energy crops in China was obtained in Fig. 4. After taking the maximum value of the overlapping areas, the yield of woody energy crops in China in 2010 was 3.263×10^7 t. For each species, without considering the overlapping areas, the potential productivity was 6.81×10^6 t/yr for *X. sorbifolia*, 8.86×10^6 t/yr for *C. humilis*, 7.18×10^6 t/yr for *J. curcas*, 9.55×10^6 t/yr for *P. chinensis*, and 7.78×10^6 t/yr for *C. wilsoniana*.

Lu et al. (2012) reported a *P. chinensis* biomass of

56.85×10^6 t/yr, with a 20% oil yield, the potential productivity of *P. chinensis* is 11.37×10^6 t/yr, being similar to the 9.55×10^6 t/yr reported in this study. The total biomass of energy plants was 135.21×10^6 t/yr reported by Xue et al. (2016), and by taking an oil yield range of 20%–30%, the total annual potential productivity was determined to range from 27.04×10^6 t/yr to 40.56×10^6 t/yr, while the total annual potential productivity in this study was 32.63×10^6 t/yr. However, the total annual potential productivity is 20.65×10^6 t/yr according to Xu et al. (2013). The difference between the values reported by Xu et al. (2013) and the 32.63×10^6 t/yr found in this study maybe because that we selected different species of energy crops (Xu et al. selected *P. chinensis*, *J. curcas*, *Manihot esculenta*, *Vernicia fordii*, and *Helianthus tuberosus*, i.e., only the first two were evaluated in this study). The potential productivity of energy crops in this study was close to similar studies, while the use of different target plants caused major differences in the results.

In terms of the annual potential productivity per unit area of woody energy crops (Fig. 4), the areas with highest annual potential productivity per unit area (700–800 kg/(ha·yr)) were mainly in central and north China, specifically with a cluster around the Gurbantünggüt Desert in Xinjiang, central and eastern Inner Mongolia, the Da Hinggan Mountains and Heihe areas of Heilongjiang, the Changbai Mountains area of Jilin, northern Hebei, central-north Shaanxi, and most of Shanxi. The areas with the second highest annual potential productivity per unit area (600–700 kg/(ha·yr)) were concentrated and contiguously distributed around the Sichuan Basin, northwestern Hunan, and the whole territory of Guizhou and Guangxi. Some of these areas were sparsely distributed in Guangdong, Jiangxi, Fujian, Hami Prefecture of Xinjiang, and western Inner Mongolia. The areas with a medium annual potential produc-

Table 5 Area suitable for planting each woody energy crop in China

Woody energy crop	Area (10^6 ha)	Percentage (%)
<i>Cornus wilsoniana</i>	16.14	18.25
<i>Pistacia chinensis</i>	22.28	25.20
<i>Jatropha curcas</i>	16.51	18.67
<i>Cerasus humilis</i>	19.99	22.61
<i>Xanthoceras sorbifolia</i>	13.50	15.27
Sum*	55.82	100.00

Note: *The sum of the areas does not contain overlapping areas

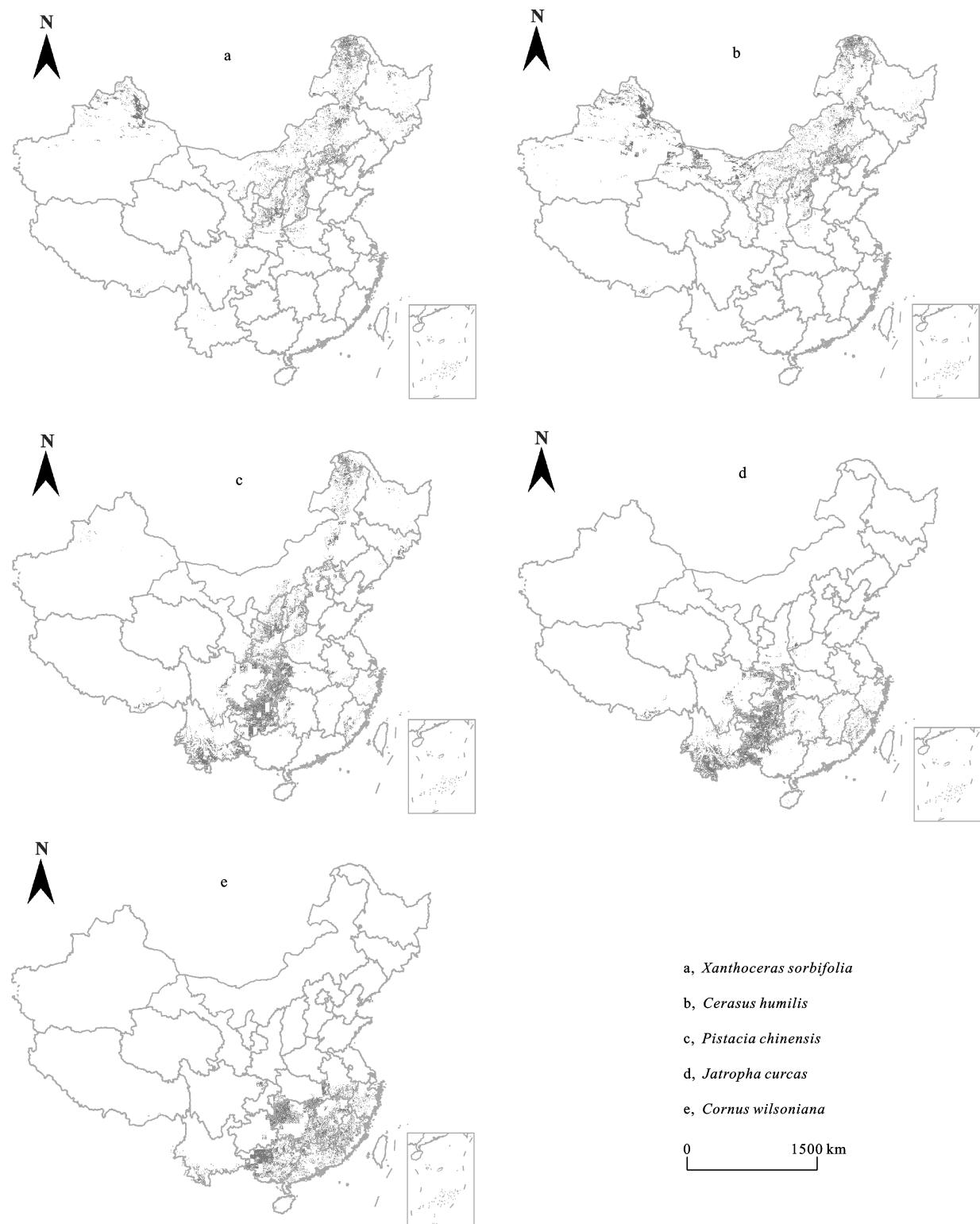


Fig. 3 Distribution of woody energy crops in China in 2010

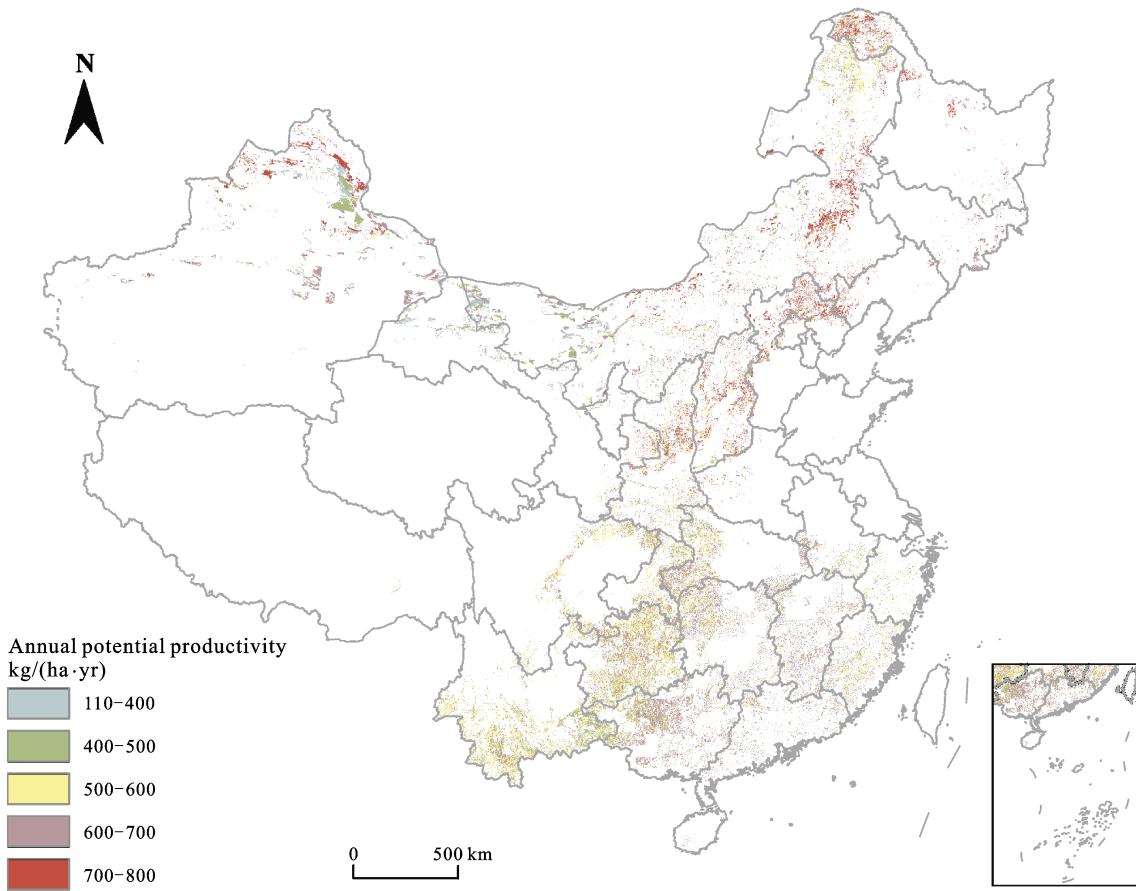


Fig. 4 Distribution of annual potential productivity per unit area of woody energy crops in China

tivity per unit area ($500\text{--}600 \text{ kg}/(\text{ha}\cdot\text{yr})$) were mainly situated around the Sichuan Basin, Guizhou and central-south Yunnan, with a large overlap with the second highest yield areas. The areas with lowest annual potential productivity per unit area (below $500 \text{ kg}/(\text{ha}\cdot\text{yr})$) were mainly located in western Inner Mongolia and northeastern Xinjiang.

Generally, the yield per unit area of woody energy crops in China is higher in the north than in the south, while the density of the species investigated is higher in the south than in the north, which suggests that the best planting strategy is to develop forest farms in the northern high-yield areas and to promote a small-scale village planting model in the southern densely-distributed areas.

In certain provinces, woody energy crop plantations will also generate considerable ecological benefits, such as suppressing desert expansion in the Gurbantünggüt Desert, Hexi Corridor, and western Inner Mongolia; reducing soil erosion in the Loess Plateau of Shaanxi and Shanxi provinces; and enhancing the ecological

barrier around Beijing.

4 Conclusions

By analyzing temperature, precipitation, slope of terrain, soil texture, degree of erosion, nutrient content, pH, and other physical and chemical conditions, we evaluated the potential productivity of *X. sorbifolia*, *C. humilis*, *P. chinensis*, *J. curcas*, and *C. wilsoniana*. The results were as follows:

(1) China has rich marginal land resources, with a total area of $104.78 \times 10^6 \text{ ha}$. Generally, the 400-mm precipitation boundary line divides the marginal land into two regions, with shrub land and sparse forest land on the southeast side and bare land, bare rock land, saline alkali land on the northeast side. Saline alkali land and bare rock land were aggregated around north Xinjiang, central-north Qinghai, most of Gansu, and central-west Inner Mongolia, which accounted for 35.56% of the total area. Shrub land and sparse forest land were mainly

located in the provinces that intersect with the Heihe-Tengchong Line and the southern Yangtze River region, which accounted for 61.92% of the total area.

(2) The plants selected as energy crops in this study were representative of various environmental conditions. Among the five woody energy crops, *X. sorbifolia* and *C. humilis* have a strong tolerance to cold and drought, and are suitable for planting in northwest China. *Jatropha curcas* and *C. wilsoniana* both require plentiful water and heat, and should be planted south of the Yangtze River. *P.chinensis* has a wide spatial distribution, but mainly grows in central China.

(3) The mechanistic model could be used to evaluate the potential productivity of energy crops. Based on the yield formation process and the indicators of elevation, temperature, precipitation, slope, soil texture, pH, organic matter, reference soil depth, and the degree of erosion, by increasing the hierarchies of model indicators, a realistic potential productivity could be evaluated.

(4) After taking the maximum value of the overlapping areas, the yield of woody energy crops in China in 2010 was 32.63×10^6 t. For each species, without considering the overlapping areas, the potential productivity was 6.81×10^6 t/yr for *X. sorbifolia*, 8.86×10^6 t/yr for *C. humilis*, 7.18×10^6 t/yr for *J. curcas*, 9.55×10^6 t/yr for *P. chinensis*, and 7.78×10^6 t/yr for *C. wilsoniana*. The potential productivity of energy crops in this study was close to similar studies, while the use of different target plants caused major differences in the results.

(5) The development and utilization of energy crops is not only related to the natural conditions, but also to the ecological and socio-economic situation. In this study, the potential productivity was mainly considered to be derived from woody energy crops and natural resources, with less consideration given to socio-economic factors (e.g., traffic, energy demand, and the level of industrialization) and ecological factors (e.g., plant adaptability, landscape patterns, and the prevention of desertification). The evaluation of natural resources is the basis for the determination of the potential productivity of energy crops, but socio-economic and ecological factors should also be considered in future studies.

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