Identifying potential field sites for production of cellulosic energy plants in Asia

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Abstract: Cellulosic bioethanol produced from non-edible plants avoids food-fuel competition. Growing such plants on marginal non-arable lands also avoids the use of farmland. In this study, attempts were made to identify potential field sites for cellulosic bioethanol production in Asia. In this study, GIS databases containing information about requirements such as land use, landform, and climate were superimposed. Areas with terrestrial constraints were then removed from the candidate field sites using a terrain slope database. The remaining lands were evaluated using a net primary production (NPP) database. Of these areas, southern and eastern India, northeastern Thailand, and southern Sumatra (Indonesia) had high NPP. In the 2nd phase, local information regarding infrastructure, and agriculture were analyzed. Field-establishment feasibility was high for eastern India and southern Sumatra. Potential field sites were then located in satellite images of these two areas. In the 3rd phase, soils around potential sites were evaluated. Local residents were interviewed to estimate the cost of producing plants for biomass energy. Sites selected using this simple method are suitable for biomass production.

Keywords: bioethanol, biomass, cellulosic energy plants, geographic information system, unused land
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1 Introduction

Production of bioethanol as an alternative to fossil fuel and a countermeasure against global warming has been increasing rapidly. However, increases in global food prices have led to concern that production of food crops is being undermined by cultivation of biomass crops[1]. As a result, cellulosic bioethanol produced from non-edible plants or plant parts is currently attracting attention[2], and major bioethanol-producing countries are attempting to increase the proportion of cellulosic biomass produced [3,4].

In Japan, a number of projects have been implemented to establish a national cellulosic bioethanol industry[5-7], including our project: "the Development of Technology for High-Efficiency Conversion of Biomass and Other Energy"[8]. This project aims to develop a system for producing 2 × 10^5 kL of ethanol annually at a cost of less than 40 JPY per liter. To create a stable

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supply of low-cost materials throughout the year, it plans to grow energy plants rather than to depend on crop residues that are available only during harvest seasons or on woody materials that have high transportation costs. Then, Napier grass (*Pennisetum purpureum*) was selected as the energy crop because it can produce large quantities of biomass and tolerates biotic and abiotic stresses[2,9].

As previously pointed out[2], there are some important aspects that should be considered when selecting a field site for energy plants production. First, energy plants should not replace food crops in farmlands because the main purpose of switching from sugar- or starch-based biomass to cellulosic biomass is to avoid the use of food crops. Second, climatic conditions such as temperature and rainfall must be favorable for plant growth. Third, social conditions, such as land rent, wages, road networks, and markets should also be appropriate. Finally, environmental degradation and CO_2 emissions should be also minimized[10].

The biomass and ethanol yields of Napier grass are estimated to be 50 t/ha and 250 L/t respectively, and thus approximately 1.6×10^4 ha are required to meet our ethanol production target. The important question here is whether a field site of this scale that satisfies a number of criteria as described above is available in Japan. In addition, the production cost of bioethanol in Japan is much higher than imported ones mainly due to expensive land usage[6,7]. Under such circumstances, the government defined the imported bioethanol produced in Asian countries using Japanese technologies as the "quasi-domestic product" in an attempt to promote the cellulosic bioethanol industry in Japan[7].

To this end, this study has decided to expand the target region beyond Japanese territory, and to employ a 3-phase method to identify potential field sites for biomass production (Figure 1). The method consists of GIS analysis, local information gathering, and field surveys. As demonstrated by some researchers[11-13], the GIS analysis identifies some potential areas that satisfy all the geographic criteria of land use, land form and climate described above. The local information gathering reveals environmental and/or social constraints specific to each potential area based on which all identified potential areas are ranked. The field surveys in highly ranked areas evaluate the feasibility of growing Napier grass there.

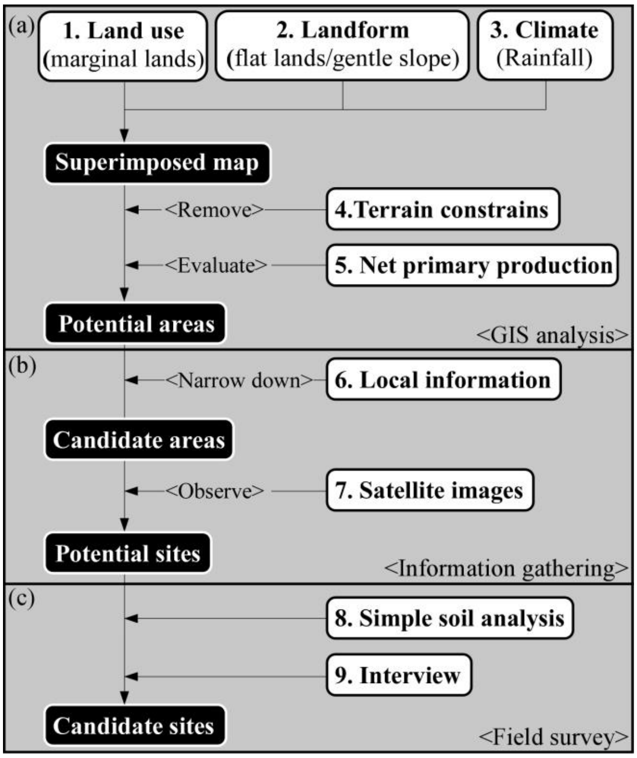

Figure 1 Schematic diagram of the method used to identify potential cellulosic energy plant production sites

2 Materials and methods

2.1 GIS analysis

The target region was located between 0–55°N lat and 70–150°E long. All geographic information was obtained from freely available data sources between December 2007 and February 2008 and was processed using GIS software (ArcGIS, Esri, California, USA). The goal of GIS analysis was to identify potential areas in which energy plants could be grown at high rates of productivity and without disturbing food-crop production (Figure 1a). Thus, first, marginal lands were identified to avoid the disturbance of food-crop production from the Eurasia Land Cover Characteristics Data Base and the Asian Association on Remote Sensing (AARS) Asia 30-second Land Cover Data Set, which were downloaded from websites maintained by the U.S. Geological Survey (USGS) and Chiba University, respectively. Marginal lands were identified by excluding cities, agricultural lands, forests, and water from the target region. Because irrigation significantly increases production costs and

CO_2 emissions, biomass energy crops should be grown under rain-fed conditions. Flat lands and gentle slopes are expected to allow efficient use of rainfall by reducing surface runoff, and also minimize soil erosion. Thus, second, gradient data was obtained to find slopes of <5° by converting the elevation data in the Global Land One-km Base Elevation (GLOBE) database downloaded from the National Oceanic and Atmospheric Administration (NOAA). Then, marginal lands with slopes of <5° were selected for further analysis. Third, the International Institute for Applied System Analyses (IIASA) Climate Database, downloaded from a United Nations Environmental Programme (UNEP)/the Global Resource Information Database (GRID) website, was used to identify areas with >500 mm rainfall during the growing season (from May to September). For reference, the extracted lands were divided into tropical, subtropical, temperate, and continental climatic zones following the Köppen climate classification system. Subtropical climates were defined as having an average temperature between 0 and 18℃ in their coolest months. Here, potential field areas were found that had gentle slopes, were marginal, and received at least 500 mm of rainfall during the growing season. Then, fourth, lands with terrestrial constraints were removed from those potential field areas using the terrain slope constraints map of the Global Agro-Ecological Zones (GAEZ) that was downloaded from the Food and Agriculture Organization (FAO)/IIASA website. Finally, the Terra/MODIS Net Primary Production Yearly L4 Global-1km (MOD17A3) was downloaded from a USGS website and potential field areas with relatively high NPP in 2006 were selected for further evaluation.

2.2 Local information gathering

Local information was gathered to identify potential field sites (Figure 1b). First, a number of web sites were visited to obtain relevant information, based on which potential areas were ranked (Table 1). General public security information was collected because the 2008 Mumbai attacks created great security concerns. Potential areas having public security problems were then ranked low. Infrastructure information on road networks, harbors, and power and water supplies was collected. Potential areas having large distances from field sites to harbors, and from harbors to Japan were ranked low to avoid the increase in costs and CO_2 emissions during ethanol transport. Thereafter, agricultural information was searched for on Google using several keywords such as agriculture, land use, crop, water resources, soil, fertility and biomass. The collected agricultural information was then analyzed to extract some keywords that characterize local agriculture. Using those keywords, relevant scientific literatures were searched for on Web of Science and local research institutes. The collected literatures were reviewed to further understand local agriculture. Potential areas having problems in agricultural production, such as soil salinity and acidity and water scarcity were ranked low.

Table 1 Web sites and their URLs visited for local information gathering

Information	Web sites	URL
Security	Ministry of Foreign Affairs (Overseas Safety HP)	www.anzen.mofa.go.jp/riskmap/asia_1.html
	CNN	www.cnn.com[e.g. 14]
	BBC	www.bbc.co.uk[e.g. 15]
Infrastructure	Government of Orissa (Departments of Commerce & Transport, Energy, Water Resources etc.)	www.orissa.gov.in (www.odisha.gov.in)
	Thai government links	www.eppo.go.th/link_thaigov.html#220
	Ministry of Foreign Affairs (Regional Affairs, Asia)	www.mofa.go.jp/region/index.html#asia
	Japan International Cooperation Agency (Countries & Regions, Asia)	www.jica.go.jp/regions/asia/index.html
Agriculture	Google	www.google.co.jp
	Web of Science	thomsonreuters.com/thomson-reuters-web-of-science/[India: 16–32, Indonesia: 33–45, Thailand: 46–60]
	Government of Orissa (Departments of Agriculture, Science & Technology etc.)	www.orissa.gov.in (www.odisha.gov.in)[61–63]
	Central Rice Research Institute	crri.nic.in[64–69]
	Indonesian Investment Coordinating Board	regionalinvestment.com[70]
	Statistics Indonesia	www.bps.go.id[71–73]

Second, satellite images and farm-system maps of highly ranked areas were obtained from Google Earth and the FAO respectively. By comparing images from the two sources, marginal lands along main roads connected to major cities or harbors were identified as potential field sites.

2.3 Field surveys

Field surveys were conducted in February 2009 (Figure 1c). Each potential site was identified using a GPS (GPSMAP 60CSx, Garmin, USA), and geographical coordinates obtained from Google Earth. The landscape at each site was confirmed by visual observation. Simple soil analyses were conducted. pH value and soil nutrients were measured using a portable pH meter (HI 99121, Hanna Instrument, USA) and a soil test kit (Midorikun, Fujihira Industry, Japan), respectively. Local residents, including farmers and agrochemical retailers, were interviewed to estimate the costs involved in crop production. Local government offices and academic institutions were also visited to evaluate local policies toward bioenergy and foreign direct investment.

3 Results and discussion

3.1 GIS analysis

From the land-use databases, marginal lands were identified including grasslands and areas with barren, sparsely vegetated, and bare ground (Figure 2a). Marginal lands were generally most dense in inland regions, whereas urban or built-up areas, agricultural lands, and forests were found in coastal regions. The landform database indicated that flat lands or gentle slopes were distributed throughout our target region, with the exception of the Tibetan and Himalayan regions (Figure 2b). Appropriate climatic zones were mainly found in coastal regions (Figure 2c). After superimposing all data (Figure 2d), large areas were removed from consideration in the highlands in China and Myanmar, due to terrain slope constraints (>8%) (Figure 2e). Lands with few terrain slope constraints (0–8%) were identified and evaluated in terms of NPP; we selected 4 potential areas containing sites with relatively high NPP (25–50 t C/ha) in southern and eastern India, northeastern Thailand, and southern Sumatra (Indonesia) (Figure 2f).

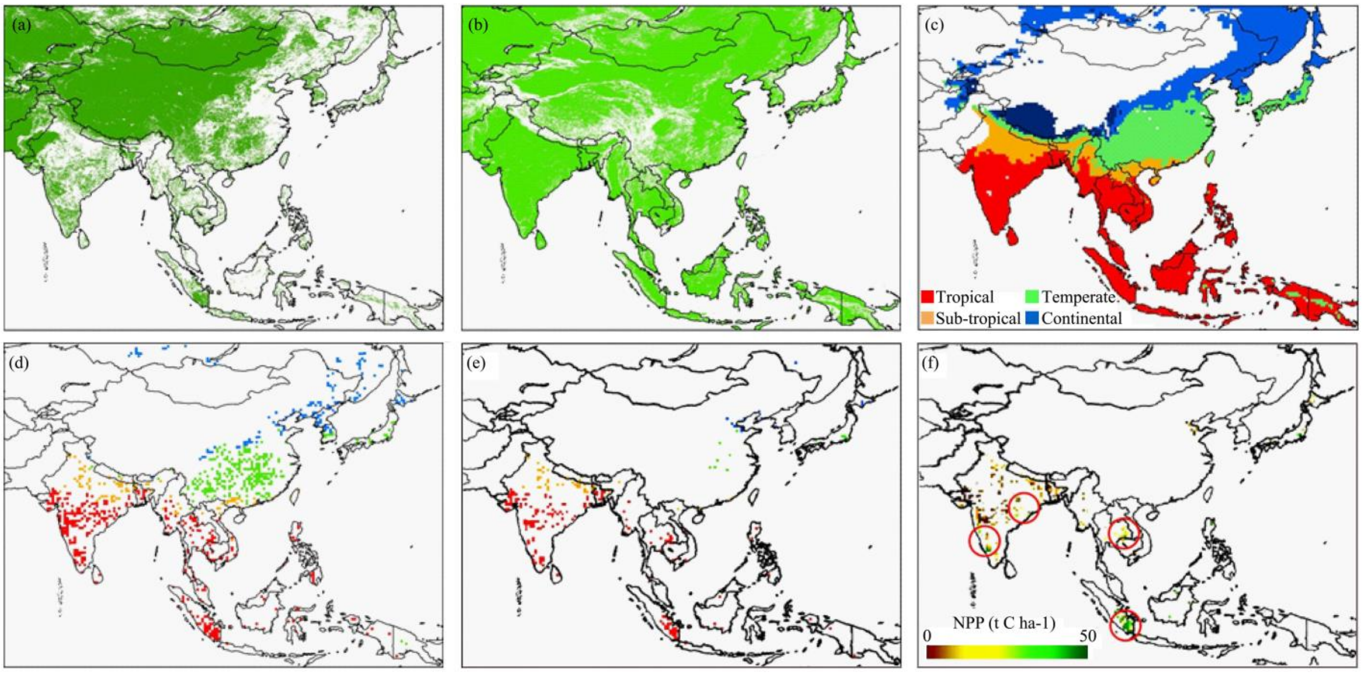

Figure 2 Identification of potential areas for energy plant production. Geographic information on land use (a), landform (b), and climate (c) were superimposed (d). Terrestrial constraints were then removed from the superimposed map (e). NPP of the remaining lands was evaluated, and four potential areas were selected (red circles) that had relatively high NPP (f). In map (a), green indicates marginal lands. In map (b), light green indicates flat lands or gentle slopes. In maps (c), (d), and (e), red indicates tropical climate; orange indicates sub-tropical climate; light green indicates temperate climate; and blue indicates continental climate, respectively. Climate zones were defined following the Köppen climate classification system. Color figures are available online (http://www.ijabe.org/).

3.2 Local information gathering

Southern India received the lowest ranking among the 4 potential production areas because the 2008 Mumbai attacks created security concerns, even though the potential production areas were not very close to Mumbai (500–600 km to the south). In addition, it was furthest from Japan and the relatively large distance was expected to increase costs and CO_2 emissions during ethanol transport. The potential areas in northeastern Thailand received the second-lowest rank because agriculture in this region has been severely affected by soil salinity, making crop productivity very low[47,49–52,56–58,60]. No major security problems were identified in the remaining two areas: eastern India (Orissa State) and southern Sumatra (Lampung Province, Indonesia). Both were situated along the coast and had access to large harbors. Therefore, they were ranked high and were selected for further analysis.

On the basis of satellite images and farming-system maps, four sites in Orissa State and five sites in Lampung Province were selected as having potential as biomass-production areas (Figure 3 and Table 2).

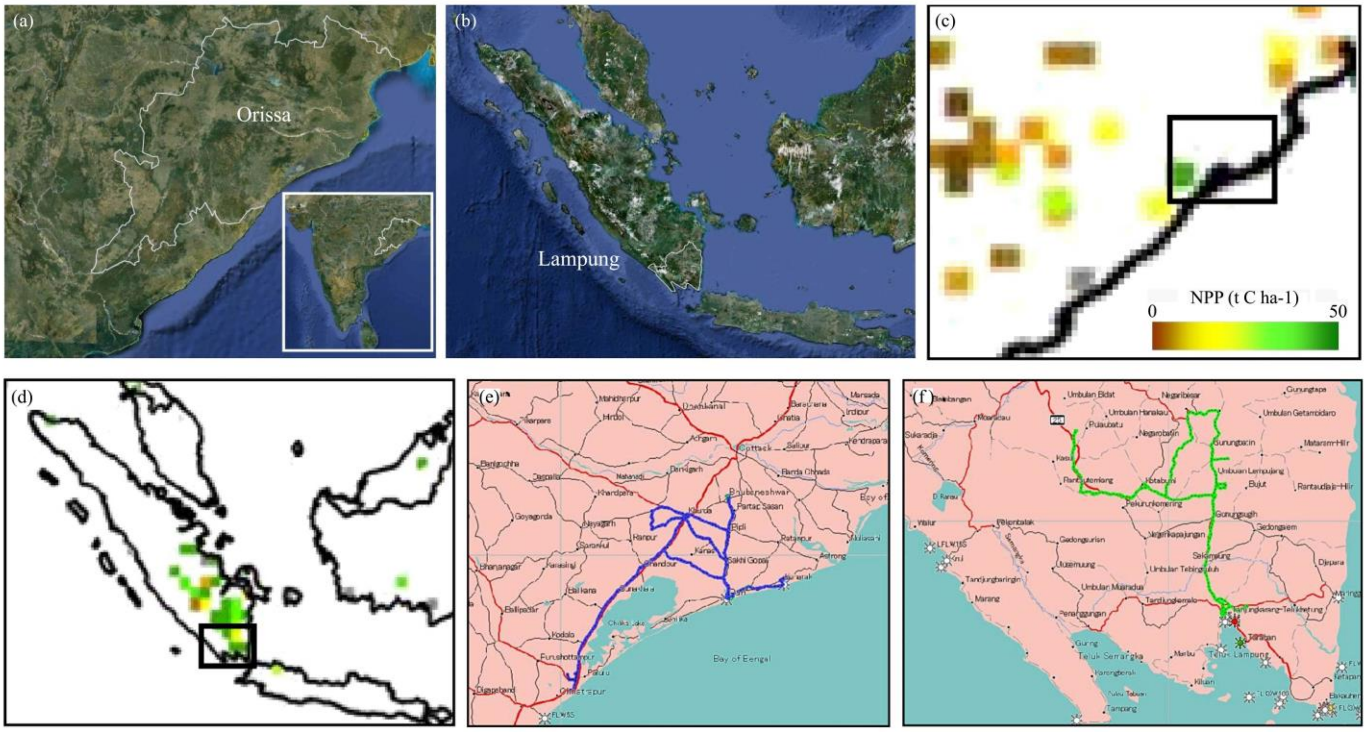

Figure 3 Two of the potential sites for production of vegetation for biomass energy: Orissa State in eastern India (a, c, e) and Lampung Province in southern Sumatra (b, d, f). Satellite images (a, b) were obtained from Google Earth. NPP evaluations (c, d) are enlargements of Figure 1f. Field survey routes (e, f) were retrieved from a GPS device. The rectangles in (c) and (d) correspond to maps (e) and (f), respectively. Color figures are available online (http://www.ijabe.org/).

Table 2 Sample soil analyses conducted near potential cellulosic energy plant production sites in Orissa (eastern India) and Lampung (Indonesia)

Location	Site	Land use	Texture and color	pH[a] (H_2O)	NO_3-N[b]/kg ha^{-1}	P_2O_5[c]/kg ha^{-1}	K_2O[d]/kg ha^{-1}
Orissa	Khurda-Begunia	Grassland (grazing)	Clay, Hard, Yellow	6.5	0-50	250	50-100
		Grassland (partly cultivated)	Clay, Hard, Reddish yellow	6.5-7.0	n.d.	200	0-50
	Begunia	Savanna	Sandy loam, Soft-Hard, Yellow	6.0-6.5	0-50	200-250	100
	Paluru	Mountain slope	Sandy loam, Soft, Yellow	5.0-5.5	0-50	250-300	150-200
Lampung	Menggala	Pineapple plantation	Clay, Soft, Brown	4.0	0-50	50-100	750<
		Sugarcane plantation	Clay, Soft, Reddish brown	5.8	0-50	50-100	750<
		Cassava (small scale)	Sand, Soft, Brown	4.3	n.d.	50-100	100-250
	Way Kanan Regency	Unused land (Previously cassava)	Sandy clay loam, Soft, Brown	5.0	0-50	100-250	100-250
		Corn	Sandy clay loam, Soft, Brown	5.5	0-50	100-250	50-100

Note: [a] Soil pH in Orissa State was measured using the phenol red test while that in Lampung Province was measured using a portable pH meter.
[b, c, d] NO_3-N, P_2O_5 and K_2O were measured using the Griess-Romijm reagent, the molybdenum blue and the crown ether methods, respectively. n.d.: not detected.

3.3 Field surveys

The results of simple soil analyses are shown in Table 2. Soil pH value in Orissa State ranged from 5.0 to 7.0 and was favorable for plant production, whereas soil in Lampung Province was relatively acidic (4.0–5.8). Nitrate-N was low in both regions (0–50 kg/ha), and soluble phosphate and potassium were fairly high, with the exception of Khurda-Begunia, a partly cultivated grassland in Orissa State. These results suggest that the application of nitrogen fertilizer would be required for biomass production in both regions. In addition, energy plants should be able to tolerate the acidic soils of Lampung Province. Napier grass is capable of growing under a wide range of environmental stresses that may include acidic soils[75].

Cost estimates of crop production indicate that total costs per ha field would be approximately 112 000 and 201 000 JPY in Orissa and Lampung respectively (Table 3). Assuming that production of Napier grass biomass in both regions is similar to that reported previously (50–55 t/ha)[9], the unit production costs would be 2.04–2.24 and 3.65–4.02 JPY/kg dry biomass in Orissa and Lampung respectively. These estimates were below our target of 5.0 JPY/kg dry biomass, which was calculated based on the national target of 40.0 JPY/L of ethanol.

Table 3 Cost of cellulosic energy crop production in Orissa and Lampung estimated based on interview with farmers and agrochemical retailers

Location	Item		Requirement	Unit cost (JPY)	Cost[a] (JPY ha^{-1})
Orissa	Materials	Fertilizer (N:P:K=15:15:15)	800 kg ha^{-1}	11	8 800
		Herbicide	6 L ha^{-1}	700	4 200
		Fuel for pumping	800 L ha^{-1}	85	25 500
		Others (seedlings, contract etc.)			17 500
	Labor	Management	0.667 Farmer ha^{-1}	84 000	56 000
	Total				112 000
Lampung	Materials	Fertilizer (N: 46%)	260 kg ha^{-1}	17	4 420
		Fertilizer (P_2O_5: 44%)	91 kg ha^{-1}	80	7 280
		Fertilizer (K_2O: 50%)	100 kg ha^{-1}	73	7 300
		Herbicide	10 L ha^{-1}	583	5 830
		Fuel for pumping	300 L ha^{-1}	50	15 000
		Others (machinery etc.)			11 170
	Labor	Management	1 family ha^{-1}	150 000	150 000
	Total				201 000

Note: [a] Cost is expressed in Japanese Yen (JPY) per hectare. Exchange rates of JPY/INR (Indian Rupee) and JPY/IDR (Indonesian Rupiah) were 1.8778 and 0.0078, respectively.

4 Conclusion

Based on our findings, a series of field experiments have been conducted in Lampung Province in collaboration with The Research Association of Innovative Bioethanol Technology (RAIB)[76,77]. The experiments have demonstrated that Napier grass can be harvested on abandoned lands three times per year with a total biomass yield of approximately 50 t/ha.

The combination of GIS analysis and local information gathering made it possible to identify potential sites for cultivation without making a number of visits to potential areas. Then, the simple field survey could assess the feasibility of cultivation in potential sites. As a result, candidate sites for cultivation of plants for cellulosic bioethanol production were identified at low cost.

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