Characteristics of sugarcane production in the State of São Paulo, Brazil

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Brazil is the largest producer of sugar and ethanol made from sugarcane. It is well known that automobiles in Brazil run on ethanol, but the current conditions of sugarcane production have not yet been explained from the viewpoint of human geography. To present basic data pertaining to sugarcane production, this study reconsiders its characteristics by examining the production elements such as land use, cultivation methods, and the management of cases involving farms, custom harvesters, agricultural cooperatives, machinery manufacturers, and sugar factories. The main data used were obtained from fieldwork conducted in the State of São Paulo. The results show that the vast amounts of land used in Brazil for sugarcane production have developed around the sugarcane production centers, especially those in the State of São Paulo. In this area, the scale of production has grown through the introduction of new technology, mechanization, tenant farming, and single-crop production. The structure of sugarcane production that comprises these elements is complex, but it can be rationalized in terms of economy. With respect to environmental load, there are anxieties about the amount of industrial materials being applied in the course of land use.

Keywords: sugarcane, land use, production element, sustainability, Brazil

I Introduction

1. Purpose

Brazil is the world's largest producer of sugarcane *(Saccharum officinarum* L.). In 2001, according to FAOSTAT (Food and Agriculture Organization Corporate Statistical Database), the harvested area of sugarcane was 9.6 million ha; this amount was more than twice that of India, the second-largest producer of sugarcane. The sugarcane produced in Brazil is processed mainly into ethanol and sugar, but besides these products, the spirit called cachaça has also been traditionally made from sugarcane. Recently, the bagasse (*bagaço*) — sugarcane waste left after extracting the juice — has been burned to generate electricity (Luo et. al., 2009).

Especially, the ethanol produced in Brazil has a worldwide appeal, as that biofuel is considered an environmentally friendly energy source.[1)] In what is known as "carbon neutral" circumstances, the carbon dioxide emissions that stem from burning biofuels are considered zero, as they are "cancelled out" by the sugarcane plants' active reduction of carbon dioxide during their growing period (Figueiredo and La Scala, 2011). Especially in urban areas, ethanol is considered an ideal energy source, and certainly preferable to fossil fuels, as its consumption discharges low volumes of toxic substances (Goldemberg et. al., 2008).

Brazil is ranked as the world's second-largest producer of ethanol, after the United States. Gas stations in Brazil sell ethanol (*álcool*) for automobile consumption, and gasoline contains 20–25% ethanol. Government laws regulate the gasoline–ethanol ratio, and thus promote the consumption of domestic ethanol (Moreira, 2000). Flexible-fuel vehicles that run on ethanol and gasoline mixed at any ratio have gained popularity in recent years; the export of ethanol has also increased year by year. Although ethanol is considered an environmentally friendly energy source, the accelerated demand for energy will inevitably result in an expansion of sugarcane production in Brazil's rural areas (Koizumi and Ohga, 2007; Giesecke et. al., 2009).

Sugarcane is not produced throughout Brazil; rather, its production is concentrated in the southeast (*Sudeste*) and northeast (*Nordeste*) regions. The modernization of sugarcane production and sugar mills in the northeast region was reported by Yagasaki and Saito (1992). In that region, sugarcane has been produced since the late 16th century, and it is considered a crop whose continuous cropping does not injure the land (Eida, 2003). Sugarcane is a C_4 plant, and as such, it efficiently produces glucose through photosynthesis and yields a high amount of sugar.

Nonetheless, sugarcane is today produced through the extensive use of industrial products, including chemical fertilizers and agricultural machinery. Cultivation methods that make extensive use of modern technology may cause soil erosion and water contamination. Recently, vinasse (*vinhoto or vinhaça*), a by-product of ethanol production, has been used as fertilizer. Liquid vinasse works as a potash fertilizer, but it may cause leaching and soil hardening as it changes the soil's chemical components (Nakamura and Matsumoto, 2003). While observing the vast and monotonous land use relating to sugarcane and which is extending from the sugarcane production centers, we consider how the continuous production of a single crop can create problems in terms of both the environment and sustainable development.

Nonetheless, the current conditions of sugarcane production in Brazil remain unexplained from the viewpoint of human geography. In this study, to present basic data regarding sugarcane production, we reconsider its characteristics by examining the production elements that relate to land use, cultivation methods, and the management of cases involving farms, custom harvesters, agricultural cooperatives, machinery manufacturers, and sugar factories. To fulfill this purpose, we first review spatial and temporal changes in Brazilian sugarcane production by creating maps and graphs that are based on data obtained mainly from government bodies (section II). The elements relating to sugarcane production will then be explained in detail (section III). Data were obtained from fieldwork in the State of São Paulo, from 2011 to 2012. Our intention in picking up the cases is to show, as much as possible, the various management conditions therein. During the interviews with production bodies such as farms and factories, we emphasized especially the cultivation methods used. Detailed documentation relating to cultivation methods will be useful in interdisciplinary settings and contexts. Please note that this study also applies italics to both the scientific names of crops and Portuguese terms.

2. Study area

The State of São Paulo is located in the southeast region of Brazil (Figure 1). This state has the largest population and economy of all the states in the country. Its capital is São Paulo City, which has a population of 20 million, including the metropolitan area of Greater São Paulo; it is also the largest city in the southern hemisphere. Compared to the coastal cities in the northeast region and Rio de Janeiro, the development of São Paulo City has lagged behind. The city started in the mid-17th century as a base community for interior expeditions (*bandeirantes*), and its hinterland was developed in the late 19th century as the world's largest coffee production center (Yagasaki, 1988). The city then became the distribution center, and Santos was the outer port used in shipping exported goods.

At present, sugarcane production has expanded

Fig. 1 Study area

in the hinterland of São Paulo City because the geographical conditions are suitable for production. Located along the Tropic of Capricorn, a Cwa climate (humid subtropical with dry winter) extends the middle part of the state. The sugar content of sugarcane increases in the dry winter, after a warm and humid summer. Greater São Paulo is a huge consumption center for ethanol, and Santos is the port through which both sugar and ethanol are exported.

We did fieldwork in the central part of the state. The study area extends to the city of Piracicaba (population: 365,000 in 2010), and its neighboring cities of Rio Claro (186,000) and Pirassununga (70,000). The municipalities constitute one of the conventional production centers of sugarcane in the state. Sugarcane land use has expanded in the rural areas. The main city, Piracicaba, is located about 150 km northwest of São Paulo City. The place name signifies "fish" (*pira*), "stop" (*syk*), and "place" (*aba*) in the Tupi language. There are rivers and waterfalls in the city, including the Piracicaba River—one of the main branches of the Tietê River. The city was developed as a traffic terminal, and the old-city center and riverside parks attract tourists and fishers, respectively.

3. Overview of sugarcane production

According to FAOSTAT, the main crops produced in Brazil are soybeans (*Glycine max* (L.) Merr.) (24.0 million ha of harvested area in 2011), maize (*Zea mays* L.) (13.2), sugarcane (9.6), kidney beans (*Phaseolus vulgaris* L.) (3.7), paddy rice (*Oryza* spp., 2.8), coffee (*Coffea* spp.) (2.2), wheat (*Triticum* spp.) (2.1), cassava (*Manihot esculenta*) (1.7), cotton (*Gossypium* spp.) (1.4), and oranges

(*Citrus* spp.) (0.8). The following production volumes are cited: sugarcane (734 million t in 2011), soybeans (75), maize (56), cassava (25), and oranges (20).

Thus, the average sugarcane yield reaches around 76.5 t/ha, which is the highest value among all the crops, including root and tuber crops. Sugarcane is produced by sugar factories and the farms that sell sugarcane to sugar factories. Sugarcane produced by factories is called *cana própria* (own sugarcane), while that produced by farms is *cana de fornecedor* (sugarcane of suppliers). According to the Annual Statistics of Agri-Energy (*Anuário Estatístico da Agroenergia*) by MAPA (*Ministério da Agricultura, Pecuária e Abastecimento*), *cana própria* accounted for 57% of all sugarcane in 2010.

According to the Annual Statistics of Agri-Energy, the average sugar content of sugarcane (ATR: *Açúcar Total Recuperável*) in the 2000s was 144 kg/t. This figure is a marked increase from 109 kg/t in the 1970s, 123 kg/t in the 1980s, and 137 kg/t in the 1990s. The sugar content varies from 120 to 160 kg/t during the harvest season (April–November), and peaks in the middle of the dry season (August–September) (Research Policy Planning Division, Research Council Secretariat, Ministry of Agriculture, Forestry and Fisheries, 2007). The sugarcane yield has also increased. According to Statistics of the Twentieth Century (*Estatísticas do Século XX*) by IBGE (*Instituto Brasileiro de Geografia e Estatística*) and SIDRA (*Sistema IBGE de Recuperação Automática*), the average yield in the 2000s was 74.1 t/ha; previous values were 49.1 t/ha in the 1970s, 60.6 t/ha in the 1980s, and 65.8 t/ha in the 1990s.

A large proportion of the sugar produced in Brazil is exported. According to UNICA (*União da Indústria de Cana-de-açúcar*), in 2010, 27,500 t (66%) of all sugar was exported, and 14,000 t was earmarked for domestic consumption. The amount exported accounted for about 50% of the world's sugarcane trade. The main export destinations were Russia (13%), India (8%), Iran (6%), United Arab Emirates (5%), and Saudi Arabia (5%). As for ethanol production in 2010, 1.9 billion L (liter, simply L) (7%) was exported, whereas 25.5 billion L was set aside for domestic consumption. The main export destinations were the European Union (22%), South Korea (10%), the United States (16%), Japan (14%), and Caribbean countries (8%). In Japan, imported ethanol was used as industrial material to make soy sauce, miso, liquor, antiseptic, and disinfectant.

II Development of sugarcane production in Brazil

1. Yield changes

In Brazil's agricultural history, the period from the late 16th to the 18th century is known as "the age of sugar." Brazil became a major sugar-exporting country, to satisfy the demand for sugar in England and other European countries (Monbeig, 1976). During that time, the main sugarcane production centers were located along the coastal ranges in the States of Pernambuco and Bahia, in the northeast region. Sugar was produced at sugar mills (*casa de engenho*) located at the sites of large farms. The competitiveness of Brazilian sugar was stagnant from the late 18th century, given Antilles' and India's increased sugarcane production. In the late 19th century, Brazilian sugar production fell with the abolition of slavery and the expansion of sugar beet production, especially in the United States.

In 1900, Brazil produced 183,000 t of raw sugar; this accounted for 3.5% of the world's production, after India, Java, Antilles, and the United States (Geerligs, 1912). The main commercial crop of Brazil changed to coffee, and from the late 19th century to the mid-20th century, coffee became the country's main export. This period saw a monocultural economy and featured what was called "the cycle of coffee."

As shown in Figure 2, the sugarcane yield in 1920 was 14 million t. To cope with oil-price fluctuations after the Great Crash of 1929, the presidential decree (*Decreto-lei* 19.317) mandated in 1931 a 5% mixture of ethanol with gasoline. The government established the Sugar and Alcohol Institute (IAA: *Instituto do Açúcar e do Álcool*) in 1933, at which point the production of ethanol and sugar was controlled through government purchases. The sugarcane yield increased in 1940 to 18 million t.

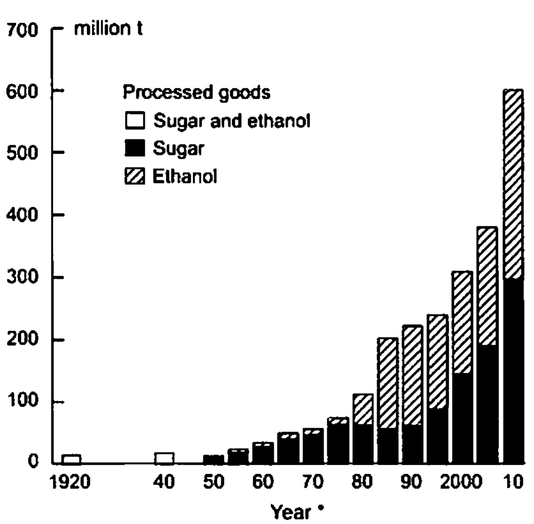

Fig. 2 Changes in sugarcane yield in Brazil
The values after 1950 are based on the crop year (from April to March).
Sources: *Censo Agropecuário* by IBGE (*Instituto Brasileiro de Geografia e Estatística*) in 1940 and 1950, and *Anuário Estatístico da Agroenergia* by MAPA (*Ministério da Agricultura, Pecuária e Abastecimento*) after 1950.

After the oil crisis in the early 1970s, the government supported the production of ethanol through the creation of the National Alcohol Program (*Pró-Álcool*) in 1975. The law offered subsidies for sugarcane production not only through government purchases, but also by the allocation ratio of ethanol production, and by offering financial supports for modernizing sugar mills. The proportion of ethanol mixed into gasoline increased to 10% by law. Fiat Automobiles sold cars powered by ethanol in Brazil in 1979. The sugarcane yield exceeded 203 million t in 1985, of which 72% was processed into ethanol.

The increase in sugarcane production slowed between the late 1980s and the mid-1990s. This slowing is largely attributed to the hyperinflation and debt crisis seen in the 1980s, and the abolition of the Sugar and Alcohol Institute—the latter of which was consistent with the new industrial and trade policies adopted by the Collor regime (1990–92). The allocation ratio of ethanol production that had been made by law were also abolished in the early 1990s, and the price of ethanol was liberalized in 1997. Even after the liberalization of sugarcane production in the 1990s, the law that regulated the mixture of ethanol in gasoline continued to be enforced.

The sugarcane yield increased to a great extent in the 2000s. It reached 602 million t in 2010, of which 51% was processed into ethanol. The liberalization of sugarcane production attracted foreign investments and, as a consequence, sugar factories enlarged their facilities and started to produce sugar and ethanol at lower costs. The members of BRIC (i.e., Brazil, Russia, India, and China) have seen recent economic growth, and this has created an explosion in vehicle ownership and a consequential increase in ethanol consumption. The Volkswagen group was the first to release flexible-fuel vehicles, in 2003.

2. Change of production center

The harvested sugarcane area in Brazil in 1990 comprised 4.3 million ha. As Figure 3 shows, that production was distributed among the State of São Paulo (42%), three states in the northeast region (Alagoas, Pernambuco, and Paraiba: 28%), and the States of Minas Gerais (7%) and Rio de Janeiro (5%). The main production centers of sugarcane in 1990 were located in the central part of the State of São Paulo and the coastal part of the northeast region.

The harvested area increased to 9.1 million ha in 2010. In that year, production was distributed among the State of São Paulo (55%), the three aforementioned states in the northeast region (10%), and the States of Minas Gerais (8%), Paraná (7%), and Goiás (6%). The area from the western part of the State of São Paulo to the central-west (*Centro-Oeste*) region became the frontier of sugarcane production. The development of cultivation methods—such as new seed varieties, irrigation systems, and mechanization—have allowed the production of sugarcane in the outer regions, under a climate of Aw (tropical savanna).

The Brazilian government launched the National Agro Energy Policy (*Plano Nacional de Agroenergia*) in 2005 to promote the exportation of ethanol, as well as the Agroecological Zoning System of Sugarcane (*Zoneamento Agroecológico da Cana de Açúcar*) in 2009 to regulate the expansion of sugarcane production into interior areas. To protect the natural environment, the latter law allows for the veto of sugarcane production in the Amazon, Pantanal, and Upper Paraguay River

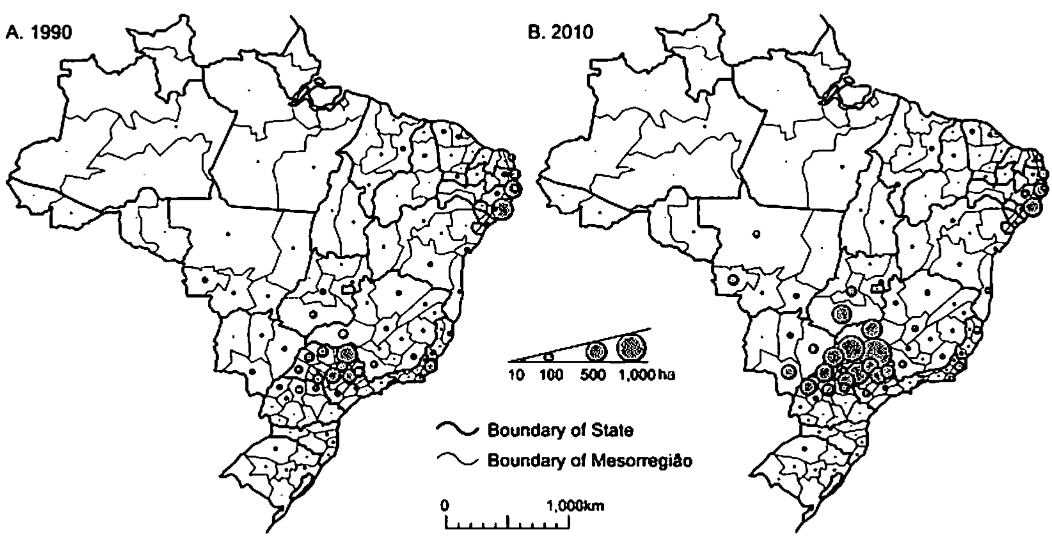

Fig. 3 Brazil's harvested sugarcane area, 1990 and 2010

Source: IBGE (*Instituto Brasileiro de Geografia e Estatística*).

Basin areas, but promotes production in the states of the Cerrado region (i.e., the west of the Minas Gerais and São Paulo, the north of Parana, the east of Mato Grosso do Sul, and the south of Goias) (Koizumi, 2011; Nakatsuka and Hidaka, 2010).

Figure 4 shows changes in agricultural land use in the State of São Paulo after the 1980s. The land use types that saw the greatest increase in area were those devoted to sugarcane and oranges. Especially, the sugarcane land use area increased significantly after the late 2000s. With respect to fluctuations in land use, pasture was mainly converted into sugarcane production areas in the 2000s. The area devoted to orange production increased from the 1980s to the 1990s, in inverse proportion to the area devoted to coffee and savanna (*cerrado*). Ultimately, Brazil became the world's largest exporter of orange juice; according to Census of Agriculture data, 80% of the harvested oranges area in 2006 was concentrated in the State of São Paulo.

The land use types that have remained steady in terms of area are those devoted to eucalyptus (*Eucalyptus spp.*), soybeans, and forestry (*cerradão*). Eucalyptus is used in wood pulp, charcoal, construction material, and herbal oil. The eucalyptus area increased after the 2000s. In the State of São Paulo, paper companies produce eucalyptus in large-scale artificial forests, and have increased their exports of wood pulp and paper. In the State of São Paulo, soybeans are produced in crop rotation after maize or sugarcane, and the area fluctuates. Soybeans are a major agricultural export of Brazil, and the production centers are located in the central–west and south regions. Forest areas tend to be left intact at sites unsuitable

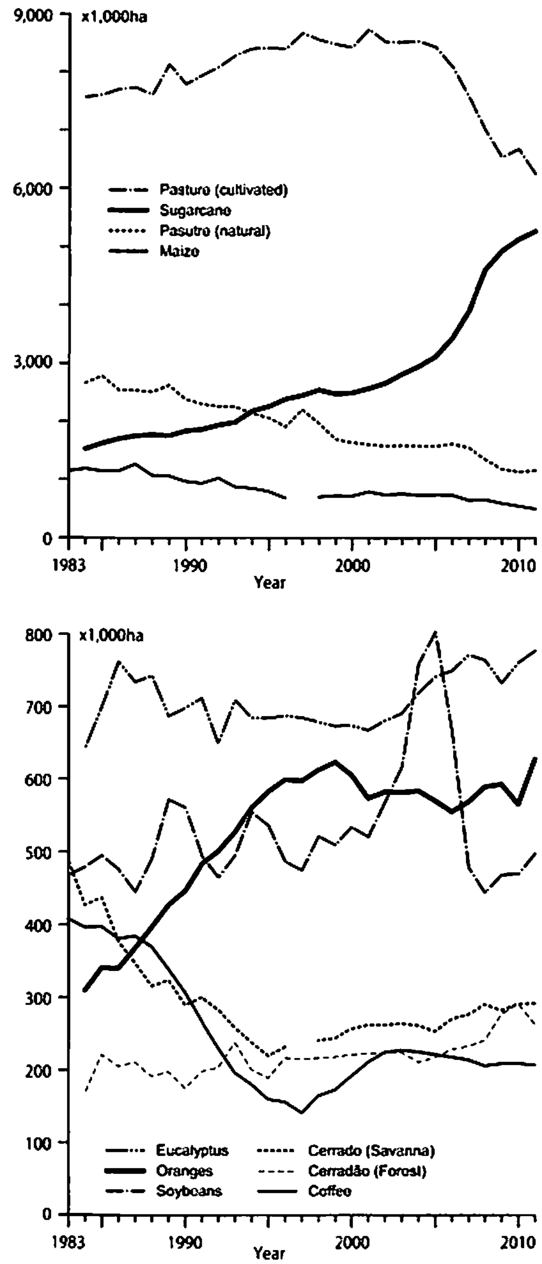

Fig. 4 Changes in the land use of agriculture and forestry in the State of São Paulo

The values of sugarcane from 1983 to 2000 and oranges from 1984 to 2011 are estimated by the length of ridge (i.e., 1,000 *pés* of coffee correspond to 0.51 ha, and 1,000 *pés* of oranges correspond to 3.1 ha).

Source: *Instituto de Economia Agrícola, São Paulo.*

for crop production, such as steep slopes and wetlands. The total forest area increased slightly after the 2000s; this increase is attributed to the enactment of the Brazilian Forest Code, which regulates the development of forest and savanna. The law stipulates that landowners set aside up to 20% of owned land for forest reserves.[2]

The land use types to have seen a decrease in area are pasture, maize, coffee, and savanna. Although the pasture area greatly decreased in the 2000s, it still occupies the largest agricultural land use form in the state. More than 80% of pasture land comprises artificial grasslands, in which gramineous plants are grown to fatten beef cattle. Maize is mainly produced near the border with the State of Paraná, in the south (*Sul*) region—Brazil's largest state, in terms of maize production. The main maize production region moved in the 2010s from the south to the central-west region. The area devoted to coffee production, meanwhile, declined significantly between the late 1980s and the early 1990s. The coffee production centers moved to the States of Minas Gerais and Espírito Santo. Compared to the State of São Paulo, those states are located at lower latitudes, and contain a lot of sloping arable land. The savanna area decreased until the early 1990s, but it slightly increased after the 2000s; as with the forest area, this increase is attributed to laws that protect natural vegetation.

Ⅲ Characteristics of sugarcane production

1. Land use

By undertaking a landscape survey in and around Piracicaba, we confirmed that sugarcane production was the dominant agricultural land use form there. Other notable land use types were pasture, orange orchards, cassava fields, and trees of eucalyptus and Para rubber (***Hevea brasiliensis*** Muell.-Arg.). Some orange orchards remained full ripen fruits.[3] Forest and savanna areas proliferated, mainly at sites unsuitable for arable land; these included valleys and water source areas. Some farm sites were divided lineally to conserve forest lands as per law. Some fences and palm trees were left in the sugarcane fields that were once pasture land, although those along federal roads are found in both national and private lands.

Sugar factories were located in lowlands along rivers, because they use considerable volumes of water during processing. During processing, sugar factories can be spotted at a distance by virtue of their smoking chimneys. Modern factories are made of reinforced concrete and located at large sites that feature cooling ponds. Old sugar mills made of bricks are no longer used, and their abandoned columnar chimneys, as seen in the fields, mark their former sites. One ranch retained an old sugar mill with a quadrilateral chimney; it had been powered by slave labor in the 19th century.

Table 1 shows the land use area in agriculture and forestry within three cities in the study area. Sugarcane accounts for 75% of crop production (annual and perennial crops) and 73% of sales. The sales of major crops per production area are as follows: oranges (R$8.2 thousand/ha [about 328 thousand yen/ha]), cassava (5.9), sugarcane (5.0), maize (2.4), and soybeans (1.7). Sales of sugarcane are relatively high among the annual crops. According to Census of Agriculture data, 369 farms produced sugarcane in Piracicaba in 2006, when their average sugarcane production area was 108 ha each.

The amount of wood used to produce paper and cellulose is equivalent to the amount of eucalyptus produced in the area. Eucalyptus is produced only in Piracicaba, which contains a considerable amount of sloped land that is not suitable for machinery-based crop production.[4] For the same reason, the pasture and firewood areas in Piracicaba are large. Horticultural crops such as watermelon (*Citrullus lanatus* (Thunb.) Matsum. et Nakai), mango (*Mangifera indica* L.), banana (*Musa* spp.), and avocado (*Persea americana* Mill.) are produced mainly in Piracicaba, the most populous municipality in the area.

According to interviews with the Cooperative of Sugarcane Producers in the State of São Paulo (COPLACANA: *Cooperativa dos Plantadores de Cana de Estado de São Paulo*), sugarcane is produced on both owned land and leased land.

Table 1. Production of agriculture and forestry in the study area

	Piracicaba		Rio Claro		Pirassununga	
Area of municipality (km²)	386		498		727	
Population (2010)	364,571		186,253		70,081	
Annual crops (2011)	ha	1,000 real	ha	1,000 real	ha	1,000 real
Sugarcane	59,644	327,684	9,100	23,887	21,000	96,390
Maize	1,325	4,029	1,300	912	5,000	13,500
Soybeans	272	466	200	241	1,200	2,184
Cassava	150	1,165	65	429	300	1,425
Watermelon	290	5,220	-	-	-	-
Rice	50	81	50	81	100	120
Cotton	-	-	-	-	125	900
Kidney beans	-	-	30	33	-	-
Sorghum	-	-	-	-	30	16
Perennial crops (2011)	ha	1,000 real	ha	1,000 real	ha	1,000 real
Oranges	2,070	11,882	2,000	20,880	11,600	95,839
Lemon	16	368	3,099	210	-	-
Tangerine	140	1,268	100	1,168	-	-
Banana	50	580	3	40	15	337
Mango	50	605	16	310	-	-
Abocado	50	586	10	175	-	-
Coffee	6	28	40	120	-	-
Palmito	-	-	-	-	27	250
Passion fruit	3	72	6	135	2	4
Para rubber	-	-	792**	2,178	80**	240
Pasture (2011)	40,000	n.d.	15,133	n.d.	1,700	n.d.
Forestry (2010)	m³	1,000 real	m³	1,000 real		
Wood*	65,078	2,810	-	-	-	-
Firewood	56,202	1,952	7,490	206	-	-

*For paper and cellulose, **t

Source: IBGE (*Instituto Brasileiro de Geografia e Estatística*).

Within the study area, the latter is cultivated by sugar factories and farms, and it occupies more than 50% of all such land. The rent of the leased land is 20% of sales, generally speaking. The landlords of leased land consist not only of farms, but also of the managers of companies and hospitals. The farms that produce sugarcane are not large; in fact, about 80% of them contain fewer than 25 ha each. It is estimated that in the study area, 60% of sugarcane is produced by sugar factories.

2. General cultivation methods

Figure 5 shows the general crop calendars for sugarcane production. There are two types of new planting—namely, winter planting and summer planting. Winter planting occurs between early August and September (Figure 5-A). Before planting, the soil's pH is adjusted through the application of lime or calcium sulfate. Chemical fertilizer is then put in the furrows at depths of 10–15 cm. The fertilizer is applied at a rate of 400–600 kg/ha, and the N–P_2O_5–K_2O ratios therein are 10–30–10, 5–30–5, and 5–30–24, for example.

Just before planting, seed stems (*tolete*) are cut to a length of 20–30 cm; doing so leaves two or three nodes for budding. Between 3.0 and 3.5 t/ha of seed stems are used in planting. Seed stems are placed by hand or by planting machines, into ridges at a depth of 20 cm. There are generally two patterns in making ridges. In one, there is a ridged row with a 1.3-m furrow; in the other, two rows are adjoined and feature 1.5-m furrows. For both patterns, the ridge width is 0.5 m. The use of the latter pattern proliferated after 2007 with the diffusion of harvest machinery (*colhedora*) and planting machinery (*plantadora*). Although the stem diameters have become thinner, use of the latter pattern precludes soil hardness and reduces damage to subterranean areas, because the agricultural machines move less.

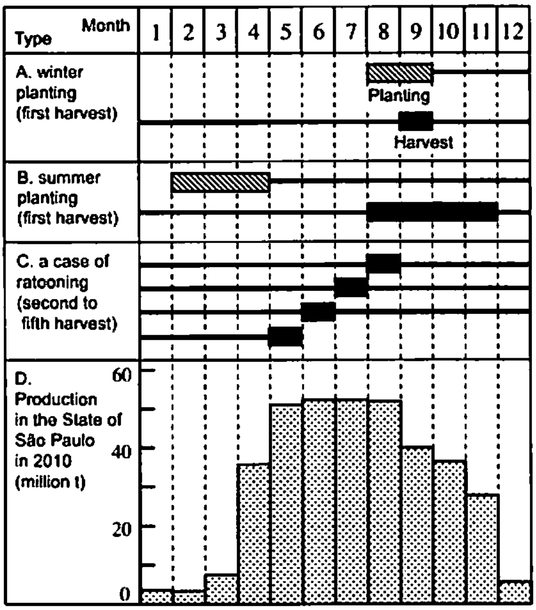

Fig. 5 Crop calendar of sugarcane in the State of São Paulo

Source: Crop calendar is drawn from the authors' interview with COPLACANA (*Cooperativa dos Plantadores de Cana de Estado de São Paulo*) and farms in 2011 and 2012. The amount of production is obtained from UNICA (*União da Indústria de Cana-de-açúcar*).

Herbicides are sprayed just after planting. Seedlings germinate 45 days after planting and grow to 1 m in height three months after planting. Additionally, chemical fertilizer is applied at the rate of 300 kg/ha. The N–P_2O_5–K_2O ratio of that fertilizer is typically 20–0–20. Not only quick-acting nitrogen fertilizer but also slow-release types are used. Pesticide is then sprayed to control termites and nematodes. The harvest season of winter planting is the following September. Just before harvest, the stem length reaches 2–2.5 m.

Some varieties of sugarcane do not bloom in the harvest season in the State of São Paulo, because the precipitation levels and temperatures are lower than those in the northeast region.[5]

All of the varieties of sugarcane are F1 hybrids. There are three main variety series (i.e., the RB series developed by the Agricultural Science Center in UFSCar [*Universidade Federal de São Carlos*], and the CTC series and the SP series developed by the Sugarcane Technology Center [*Centro de Tecnologia Canavieira*]). According to the Variety Census (*Censo Varietal*) by UFSCar, the main variety series used in new planting in the State of São Paulo in 2011 were RB (61%), SP (22%), and CTC (13%). Among them, the main varieties were RB867515 (27%) and SP81-3250 (11%). Most of the producers purchase seedlings from the producers of clone seedlings, or agricultural cooperatives.

Summer planting takes place from February to April (Figure 5-B), and the harvest season for summer planting begins 1.5 years after planting. The sugar content of summer planting is higher than that of winter planting, because it involves a longer growing period that includes two rainy seasons. The summer-planting yield reaches 130–150 t/ha; as such, it is about 40 t heavier than the winter-planting yield. Although summer planting brings about a higher yield, it is not widely adopted, because the long growing period is not conducive to an increase in land productivity through ratooning (*cana-soca*) and crop rotation.

With ratooning, buds are grown from stumps after the harvest (Figure 5-C). To initiate ratooning, chemical fertilizer is applied to stumps 30–60 days after harvest, while avoiding the days just before and after rainfall. Between 400 and 500 kg/ha is applied, and examples of the N–P_2O_5–K_2O ratios are 18–0–7, 20–5–20, and 25–0–25.

The ratooning harvest begins 10–12 months after the previous harvest. The ratooning yield under the conditions of sandy soil (*solo arenoso*) and hand-cutting is expected to be 80–90 t/ha after 12 months of cultivation, and 120–130 t/ha after 18 months. If it is harvested by machines, the yield decreases to 80% of that with hand-cutting. Machine harvesting reduces the yield by 20%, because harvest machines cut stems at higher positions than is the case with hand-cutting. The vibration caused by heavy harvest machines (15–20 t each) also reduces the budding ability of subterranean stems and roots. Recently, producers have been harvesting sugarcane five to six times per stalk, whereas they used to harvest 12 times by ratooning. After ratooning, other crops such as soybeans, maize, and green manure are immediately planted, prior to the next cultivation of sugarcane.

Harvest peaks from May to August (Figure 5-D). That peak used to be apparent in August, when the sugar content would be at its highest in the middle of dry season. There are other advantages to harvesting during the dry season. Harvest machines, tractors, cargo handlers, and trucks can more easily access the fields, and there are plenty of migrant workers available for hand-cut harvesting, because it is the off-harvest season in the northeast region. The harvest season has been prolonged since new early-ripening (April–July), medium-ripening (July to September), and late-ripening (August–November) seed varieties have been bred. Producers do not harvest between

December and May, but since a few sugar factories with the latest machinery have begun to operate all year round, a little sugarcane is harvested even during the rainy season.

Sugar factories harvest sugarcane with their own machinery (Figure 6). The machines are so expensive that only farms that manage more than 1,000 ha can make use of machine harvesting. Most farms leave the harvest work to custom harvesters and sugar factories. Custom harvesters hire workers who hand-cut the harvest—and, as mentioned, a considerable number of workers are temporary migrants from the northeast region. Although about 60% of sugarcane in Piracicaba in 2008 was harvested by hand-cutting, the amount harvested by mechanical means has increased rapidly. In the new production centers—such as the States of Mato Grosso do Sul and Goiás—the proportion of harvesting done with machinery has reached 80–95%.

One of the reasons for the spread of mechanical harvesting is legal regulations regarding the burning of sugarcane before harvest. Previously, sugarcane leaves were burned to improve efficiency in hand-cutting. The sugarcane harvested after burning is called ***cana queimada*** (burned sugarcane), and that harvested without burning is called ***cana crua*** (raw sugarcane). The latter is harvested in inclined fields with a grade exceeding 12%, where machinery cannot harvest. Burning in fields near residential areas and power cables is prohibited, to prevent the spread of fires.

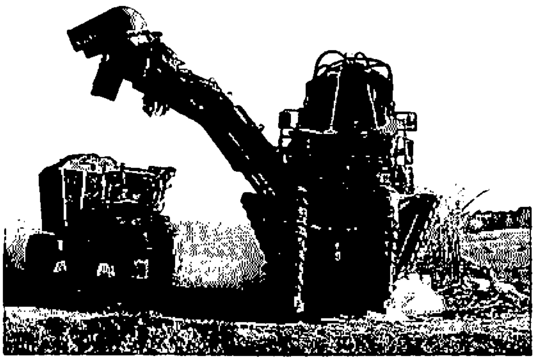

Fig. 6 Mechanical harvest of sugarcane by a sugar factory

Source: Taken by Nihei, August 2012.

If a producer wishes to burn a sugarcane field, he or she must submit a plan to the city office with respect to the burning area, the date of burning, and the address of the landlord. Producers can burn up to 80% of their fields. As of June 2012, the Federal Court (*Justiça Federal*) has prohibited burning in 20 municipalities around Piracicaba.[6] The reasons for that prohibition are the possibility of fire spreading in the dry season and health hazards that are created or exacerbated by smoke emissions.

3. Case of farms

1) Large farms

Farm "V" produces 3,000 ha of sugarcane and 200 ha of groundnuts. All crops are cultivated on leased land. The farm sells 70% of the sugarcane to a distillery of spirits, and 30% to a sugar factory. There are no differences among the purchasers in terms of cultivation methods or varieties. The sugarcane price is determined by the weight and sugar content, and there are no differences in the price standard among the purchasers. The farm manager is in his thirties. The number of employees is 300 during the harvest season (April–November) and 60 in the off-harvest season (December–March).

The farm does not purchase its own tractors;

instead, it rents about 20 of them. The manager understands that agricultural machinery is expensive, their prices fluctuate, and they are not always dependable. The firm leaves the harvest on an equal basis to a sugar factory and to custom harvesters. The mechanical harvest undertaken by the sugar factory reduces the yield by up to 10 t/ha, compared to that derived through hand-cutting by custom harvesters. In 2012, the proposed harvested area would be reduced, given the burning prohibition.

For new planting, the soil conditions are adjusted in terms of manganese, molybdenum, zinc, and boron levels; chemical fertilizers are then applied. The chemical fertilizer applied, in terms of $N-P_2O_5-K_2O$, at 50–250–120 kg/ha. With ratooning, sugarcane is cut from a stalk five or six times; with ratooning, the weight of the chemical fertilizer applied, in terms of $N-P_2O_5-K_2O$, is 100–0–120 kg/ha. The weight values are averages, and are based on the case where the yield of the previous harvest reached 100 t/ha. [Interviewed in August 2012]

Farm "S" owns 1,500 ha of land. It produces 800 ha of sugarcane, 400 ha of oranges, and 50 ha of Para rubber, and has some palm trees (Figure 7). It is a traditional *fazenda* (farm) of the region. Four related families managed the farm and employed 50 workers. Among the crops, oranges have required the most labor.

Sugarcane occupies all the arable land from the central to eastern parts, where the topography is relatively flat. Adjacent to the farm is a sugar factory to which the farm sold sugarcane until the 1990s. Currently, the farm sells to another sugar factory located 12 km away, because the factory handles the farm's harvest.

The western hilly area is occupied by orange groves and a forest reservation. Oranges were planted from the 1980s to the early 1990s, after the coffee trees were cut down. All varieties of oranges are processed. The in-farm forest reservation area is 200 ha in size; it extends to valleys, water sources, slopes, and the area within 30 m of the riverbanks.

Para rubber is grown in the lowlands along the valleys. Mature Para rubber trees comprising 30 ha were planted in 1985; another 20 ha of young trees were planted in the late 2000s. The farm increased its Para rubber crop, because its price has gone up compared to those of other crops.[7] The main variety of Para rubber is PRIM600, which was developed by the Rubber Research Institute of Malaya. The Para rubber yield reaches 3,000 kg/ha on average, and it commands a price of R$3.0–4.5/kg. Although Para rubber is native to the Amazon region, the climate of the State of São Paulo is suitable for its cultivation, as outbreaks of diseases such as leaf blight are lessened in the dry season. However, producers cannot collect latex in the dry season, when leaves fall. Para rubber trees are planted at 7-m intervals, and palm trees are planted between the rows.

Sprouts of palm trees (*palmito*) are harvested four to five years after planting. The farm produces two varieties of palm—namely, *palmeira real* (*Roystonea* spp.) and *pupunha* (*Bactris gasipaes*). Both sprout types are packaged at 300 g and sold at neighboring markets. Market prices are R$11 for the former variety and R$8 for the latter one. Compared to the Amazon region, palm cultivation is difficult in the state, given the lower precipitation

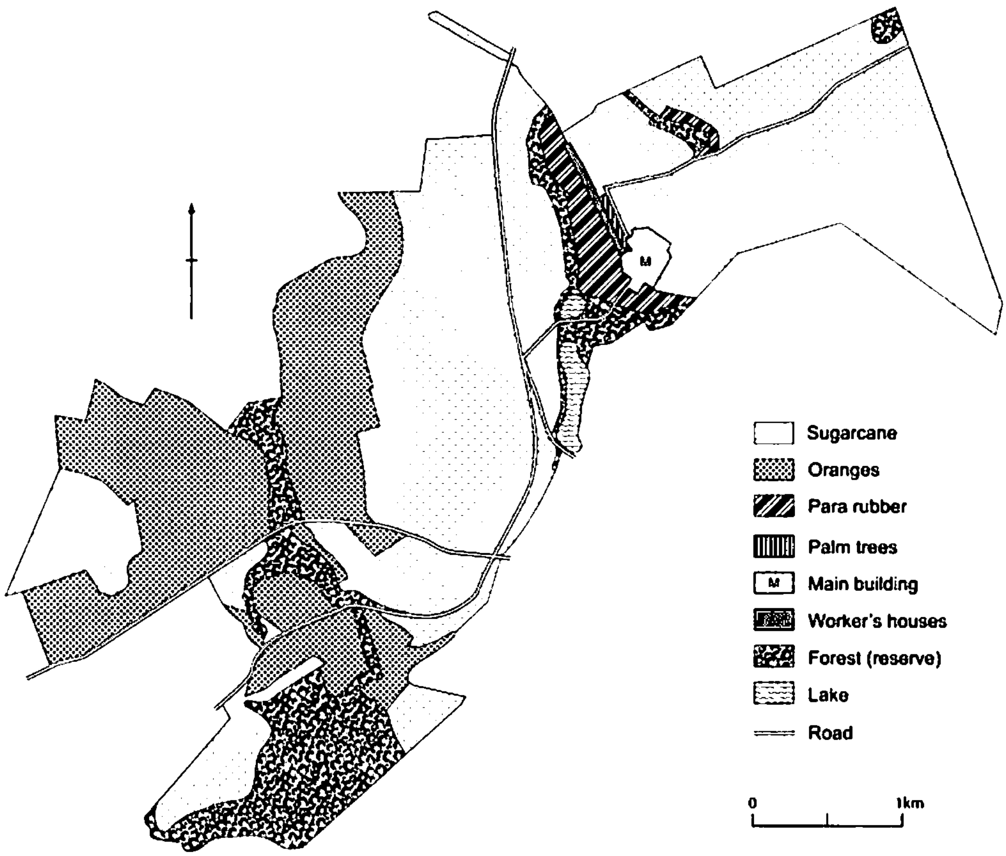

Fig. 7 Land use of farm "S" in the State of São Paulo, 2012

Source: Field survey.

levels there.

The main farm building is located to the east of the lake. Next to the main building are 15 houses for farm workers, which extend along a long lot; these houses were used when the farm produced coffee. Adjacent to the houses is a 2-ha palm field. The farm once bred freshwater fish such as *pacu* (*Colossoma macropomum*) and *piauçu* (*Leporinus macrocephalus*), until the 1990s. [Interviewed in August 2012]

Farm "G" produces 350 ha of sugarcane, of which 230 ha are leased and 120 ha are owned. The farm also manages a tractor-rental business and is a fertilizer retailer. The manager, who is in his forties, is a second-generation sugarcane producer. He intends to expand sugarcane production, and has been searching the lowlands for more land to lease. Tenant farming in the lowlands is competitive, as sugar factories also seek out lowlands, which tend to be flat, humid, and fertile.

The harvest period continues from April to December. Sugar factories undertake 60% of the harvest, and custom harvesters undertake the other 40%. The farm sells 60% of its sugarcane to a factory of a major group in Rio das Pedras, 30% to a factory of a mid-scale company in Santa Bárbara d'Oeste, and 10% to a factory of a major group in Piracicaba. After harvest, lime (*calcario*), calcium sulfate (*gesso*), and phosphorus (*fósforo*) are applied to adjust the soil conditions for purposes of ratooning. There are typically five or six harvests prior to new planting.

The manager expected the cost of harvest to increase with the prohibition in 2012 of burning. Hand-cutting the harvest without burning costs 35% more than a harvest with burning, because the speed of mowing falls by one-quarter; additionally, workers dislike working with the sawtooth leaves, which often inflict minor injuries. The custom harvester that the farm contracts employs 10–15 workers to hand-cut the harvest; that harvester undertakes not only the harvesting but also planting.

The main work in the rainy season is new planting and the maintenance of agricultural machinery. The planting period begins in February and ends in May. Before planting, phosphoric acid is applied at the rate of 400 kg/ha; chemical fertilizer is also applied, at the rate of 500 kg/ha and at an $N\text{–}P_2O_5\text{–}K_2O$ ratio of 5–25–25. The farm plants five varieties—namely, CTC15, CTC11, RB6928, CTC14, and RB7515—with the main varieties being CTC15 (40% of area), CTC11 (20%), and RB6928 (20%). The harvest season of RB6928 runs approximately from April to July, while those of CTC11 and CTC15 are from July to August, and after September, respectively. The farm purchases seedlings from an agricultural cooperative, and sugar factories advise on combinations of varieties and on land conditions.

The farm owns three tractors for its own use, six tractors for rent, and loaders and cargos. The sizes of the tractors for their own use are 70 hp, 100 hp, and 150 hp, while that of each of the tractors for rent is 100 hp. Loaders are used not only to move sugarcane to the cargo pulled by tractor, but also to unload stems from the cargo prior to planting. The manager measures the temperature and humidity at the farm, and sends those data by a certain time to an agricultural cooperative. [Interviewed in August 2012]

Farm "P" produces 150 ha of sugarcane and 30 ha of sweet potatoes. The leased land area is 165 ha and that of the owned land is 15 ha. The main farm workers are the manager, who is in his fifties, and his four brothers. They employ six workers in the harvest season, from April to November. Their main agricultural machines are two tractors, two loaders, and a dump truck.

Ridges of sugarcane are planted at 1.3-m or 1.0-m intervals. The former is suitable for increasing the overall yield, but it is not convenient for mechanical harvesting. The manager intends to adopt a new pattern of ridges suitable for mechanical harvesting—namely, making two adjoining ridges 90 cm in width, and 1.5-m intervals between the sets of two ridges.

Custom harvesters undertake 80% of the harvest, and a sugar factory undertakes the other 20%. The cost of harvesting is R$12/t by mechanical harvesting, R$14/t by hand-cutting with burning, and R$18/t by hand-cutting without burning. The progress of harvest in August 2012 was 70% of that which had been expected, because of the prohibition of burning. [Interviewed in August 2012]

Farm "A" produces 93 ha of sugarcane and 11 ha of eucalyptus; it also raises eight cows and 22 goats in one *alqueire* (2.4 ha) of pasture. All fields comprise owned land. The main workers are the manager, who is in his fifties, and two employees. The manager lives in the town center, which is about 6 km from the farm. In 1999, he converted the farm's production from grazing beef cattle on pasture, to sugarcane and eucalyptus.

The sugarcane fields are distributed across three sites. One is located next to the main house, where sugarcane has been cultivated continuously for 11 years by ratooning. Sugarcane is replanted when the yield falls under 83 t/ha. All sugarcane is harvested by hand-cutting, because the land features a lot of slope. Ridges of sugarcane are made at 1.45-m intervals. After the sugarcane harvest, kidney beans *(feijão)* are produced at once as a green manure. The beans are not harvested, but rather plowed into the soil.

For ratooning, chemical fertilizer is applied every year at the rate of 54 kg/ha; its N-P_2O_5-K_2O ratio is 19–4–19. As a substitute for phosphorus, poultry manure is applied every year at the rate of 2 t/ha; lime is applied once every four years, at the rate of 2 t/ha. The farm purchases chemical fertilizer directly from a factory, and poultry manure from the neighboring poultry farms. Herbicides are sprayed every year, because pasture grasses such as Brachiaria (Brachiaria spp.) still bud in the sugarcane fields. Pesticides are sprayed only after new planting. [Interviewed in August 2011]

2) Small farms

Farm "K" produces sugarcane on 8.5 ha of its own land, and it distills spirits. The number of harvests before replanting, on average, is seven to eight; depending on the field, however, that number can vary from five to 10 or more. The growing period is 12–18 months long for ratooning, and 12 months for new planting. The farm generally allows growth for more than 14 months, in order to increase the per-area yield. In the last ratooning harvest, the period is shortened to 12 months, to cultivate another crop. After sugarcane, the farm usually produces maize for one year, but sometimes produces sugarcane again.

For a new planting of sugarcane, chemical fertilizer is applied at a rate of 1,300–1,500kg/ha, and its N-P_2O_5-K_2O ratio is either 20–5–20 or 19–5–19. It is applied in two or three stages, while avoiding the days before rain (e.g., 900 kg/ha after the first rainfall, and 400 kg/ha after the second rainfall). Pesticides that keep termites and beetles in check are also sprayed. The farm owns a tractor and a loader. The tractor is a 150-hp Massey Ferguson model that can spray 650 L of herbicides or 500 kg of fertilizer at a time.

The managers of the farm are two brothers in their forties; their father started sugarcane production in 1974. Before the introduction of sugarcane, the farm produced maize, rice (*Oryza sativa* L.), and cotton (*Gossypium* spp.). Among those former crops, the maize-related income was stable. The current managers took an interest in distilling spirits, and started doing so in 2005.

Spirits are distilled in a shed adjacent to the main house. The distillation process starts inside a fermentation tank filled with juice that features a 17–18-degree sugar content. Water is not added during distillation. As fermentation progresses in the tank, the sugar content decreases and alcohol is brewed. When the sugar content becomes zero, the liquid from the top layer is transferred to another tank. The yeast that remains 20 cm from the bottom of the tank is left for another fermentation. In heating the top liquid to 85°C by burning eucalyptus firewood, three types of spirits (with alcohol content of 40%, 44%, or 48%) are distilled. Pouring the 48% spirit into a cup will result in the formation of a few bubbles.

Spirits are matured for more than a year in a warehouse, under trees. Ninety-five percent of spirits are matured in plastic barrels, and the other 5% in wooden barrels. The spirits matured in plastic barrels taste mellow, and that matured in wooden barrels feature the milder flavor of wood. The managers prefer the taste of the former spirits. The spirits are colored a pale yellow with the nuts of Jatobá (*Hymenaea courbaril* L.). The good-quality spirits leave membranes on cup surfaces after drinking that resemble an oil film. Spirits are put in 4.5 L bottles and sold for R$12 each. There are no differences in price among the different percentages of alcohol. Sales of spirits increase in the cold season, from June to July. [Interviewed in August 2011]

Farm "D" produces sugarcane seedlings on 5.1 ha of owned land; it also raises dairy cows in a pasture in front of the main house. The managers of the farm are an elderly man and his son. Their land used to be grazing pasture, but sugarcane production was initiated around 1980. Sugarcane seedlings are harvested by hand-cutting, without burning. Seedlings are sold to a major sugar factory in a nearby city.

In a sugarcane field that was harvested in mid-June 2011, by early August, new buds were already growing about 20 cm high. At that time, chemical fertilizer was applied at the rate of 500 kg/ha, and its N P_2O_5-K_2O ratio was 20-5-19. Then, poultry manure that had been matured for six months was applied at the rate of 1,250 kg/ha. [Interviewed in August 2011]

4. Case of agricultural cooperative

The Cooperative of Sugarcane Producers in the State of São Paulo was established in Piracicaba in 1948. This is one of the biggest agricultural cooperatives in the state. In 2011, it had 4,500 members across 35 municipalities in the central part of the state. The harvested sugarcane area reached 120,000 ha, and the yield in 2010 amounted to 10 million t. Its main business is the trade of sugarcane, but it also deals in the sale of agricultural materials such as fertilizers and pesticides, the management of a repair shop, the operation of grain bins for maize and soybeans, and financing and mutual aids. The cooperative operates, on an experimental basis, a refinery facility of biodiesel made from soybeans, a beef-cow feedlot, and a eucalyptus plantation.

The management areas of the members are not large; 60% of the members have holdings of between 5 and 45 ha; 20%, of between 45 and 150 ha; and 20%, of more than 150 ha. The members pay R$1-2/t when they sell agricultural products. The members are categorized as *ativo* (active) or *passivo* (passive), in terms of their land ownership: the former produces sugarcane mainly on their owned land, and the latter produces it mainly on leased land. The members are also categorized as *fornecedor* (suppliers of sugarcane to sugar factories) or nonsugarcane producers. Most of the members are *fornecedor*; the others are farms that do not produce sugarcane, but rather soybeans, maize, and other crops. The prices of agricultural materials and services are the same across the different types of members.

The headquarters of the Association of Sugarcane Suppliers of Piracicaba (AFOCAPI: *Associação dos Fornecedores de Cana de Piracicaba*) and the office of the rural union (*sindicato rural*) are located in the cooperative's building. The former instructs producers on the various technical methods of cultivation, sugarcane burning, and environmental conservation. The branches of the Association are located in the States of São Paulo, Mato Grosso do Sul, Minas Gerais, and Goiás. The latter union deals in tax procedures, labor problems, and government negotiations.

The problems the cooperative considers are low sugarcane prices, a shortage of farm successors, and a lag in mechanization. The price of sugarcane has fallen recently: in the 1980s, the sale of 800 t of sugarcane generated enough revenue to buy a truck, but in the 2010s, the sale of that same volume declined around to R$50,000, or enough to buy a passenger car. Namely, the value had declined to between one-third and one-quarter of that in the 1980s. The decrease in the selling price is linked directly to the shortage of successors, especially in small farms. It is difficult to increase around Piracicaba the amount of arable land devoted to sugarcane production, because it has been produced for decades, and the yield on a per-land-unit basis needs to be increased. Mechanization is also a challenge for small farms and elderly farmers; the farms that do not stay abreast of new agricultural machinery tend to quit sugarcane production and shift to pasture or eucalyptus production.

5. Case of custom harvester

The following case was obtained from an interview with a custom harvester in August 2011. The company undertakes the harvest of sugarcane mainly in Rio Claro, which is located in the north of Piracicaba. The company's harvest season continues from April to November. They employ 34 workers for hand-cut harvesting, as well as a measurer (*fiscal*) and a bus driver. The measurer is the workers' foreman.

This company is one of five custom harvesters in the city. There are 30 custom harvesters in Ipeúna, which is located in the west of Rio Claro. The number of custom harvesters is lower in Rio Claro, because the field is so hilly that grazing cattle on pasture has been the main form of production.

On one Saturday morning, we observed within the field 14 workers who were taking part in hand-cutting; five of them were women. The company harvested the area of three alqueires (7.3 ha) over two days. The field was burned on the following Thursday night; at that time, several workers carrying propane gas cylinders and burners burned the field. The time of burning is limited by law to between 20:00 and 05:00, and the company must have ready a truck or a tractor with a water tank, to keep the fire from spreading. The hand-cut harvesting started at 11:00 on Friday, and finished a day later, at 10:30 on Saturday. Workers usually harvest until 15:30 on weekdays, and until 12:00 on Saturdays. Work finishes 30 minutes earlier on paydays, which is the 5th of each month.

Workers use machetes (*facão*) to cut sugarcane and rakes (*gancho*) to gather the stems and leaves. Each worker wears boots, gloves, shin guards, and a chest protector (Figure 8). Their clients—such as producers and landlords—pay for this protective gear; they also pay for medical checks of workers, which cost about R$100 per worker. After the hand-cut harvesting, sugarcane stems are piled on the ground, whereupon another company loads them into trucks by using loaders. (Custom-harvest workers used to load stems into trucks manually, by using ladders.)

There are no differences in the standard of workers' wages by gender. The longer the ridge they cut, the higher the payment they receive. Their monthly wages are about R$1,400 (R$50–60/day) for men and R$700 for women. Women can earn here higher salaries than through part-time jobs in urban areas, most of which pay minimum wage (about R$500/month). Another advantage is that they can have days off as they like, and they receive wages in the form of checks, as cash might be stolen. All workers are experienced and middle aged, because young people cannot carry out harvesting labor over multiple days. In the off-season, some workers will work at planting, while others will return to their hometowns. Recently, considerable numbers of migrant workers have

Fig. 8 Harvest of sugarcane by hand-cutting
Source: Taken by Nihei, August 2011.

quit, and subsequently stayed in the Piracicaba area to work in the factories.

The measurer records the length of the ridge, using a meter-width compass to calculate the workers' payments. In the field, ridges were lined at 1.5-m intervals, and 7,000 m of ridge corresponded to 1 ha. The yield of the 1-m ridge would be calculated as a little less than 15 kg. Even in sandy soil, the yield through hand-cutting would increase by 80 t/ha in the seventh harvest, but the yield through mechanical harvesting could fall to 70 t/ha in the third harvest. Although the sugarcane leaves weigh 8–10 t/ha, almost no leaves are shipped to sugar factories after hand-cutting and burning have taken place. Hand-cut harvesting can take place in steep fields, and in muddy fields just after rain. Only sugar factories operate harvest machines in Rio Claro.

After the harvest day finished, the measurer asked workers if they could work on Sunday, because the landlord wanted to harvest another field along a valley. The measurer expected 20–25 workers to accept the offer, as the payment doubles on Sundays. The landlord would sell the sugarcane to a sugar factory in a nearby city.

The bus driver woke at 05:00, picked up workers at various bus stops, and arrived at the field at 07:00. He works for a transportation company, but has served since 1974 as a driver exclusively for this custom harvester; it was about that time that sugar factories became equipped with modern facilities. At the rear of the bus, he installed a 30-L tank of drinking water that cost R$15,000. Before the installation of the water tank, there were health problems among the workers from consuming river water. He worked as a driver for years, but his wife never came to the field; if she were to come, the labor union could consider it "labor padding" and levy a fine. Custom harvesters and clients must monitor such labor issues.

6. Case of machinery manufacturers

The first agricultural machinery manufacturer to arrive on the Brazilian market was Ford, from the United States, in the 1950s. Subsequently, Case and New Holland from the United States, Valmet from Finland, and Massey Ferguson from Canada entered the Brazilian market. Ford launched a local factory in the State of São Paulo in 1975, and when it acquired New Holland in the 1980s, it stopped selling Ford brand tractors. Other manufacturers also started to engage in local production, and the grouping of manufacturers progressed.

At present, the dominant manufacturers of agricultural machinery in Brazil are the AGCO group, the CNH group, and John Deere. The AGCO headquarters are located in the United States; its main brands are Massey Ferguson, Valtra (former Valmet), Fendt, and Challenger. The CNH group is affiliated with the Fiat group in Italy, and its headquarters are located in the United States; its main brands are Case and New Holland. According to Anfaeva (*Associação Nacional dos Fabricantes de Veiculos Automotores*), the top sellers of tractors in Brazil in 2011 were Massey Ferguson (20,689 units, including imported tractors), New Holland (13,359), Valtra (13,107), and John Deere (9,956). In this section, we refer to the use of agricultural machinery in sugarcane production, based on information captured during interviews in August 2012 with two machinery dealers.

1) The group

The group "A" sells a brand that used to belong to a national Finnish company; the brand has been sold in Brazil since the 1960s. The factory is located in Mogi das Cruzes, about 50 km east of São Paulo City. The brand is popular among sugarcane producers, and farmers have used the tractors since the 1970s. Producers rely on the group dealer, as it opens at 07:00, the employees are knowledgeable about agricultural machinery, and they can repair most troubles within one day.

The tractors are known for their easy maintenance, long durability, and affordability; additionally, many other companies supply parts that are compatible with these tractors. Especially, the engine of the tractor wears more 14,000 hours' operation without a large repair, because of its simple structure. Engines made after 2006 can use fuel mixed with 25% biodiesel oil. The efficiency of fuel consumption is the same between diesel and biodiesel, but the supply of biodiesel is now insufficient in Brazil.

Producers of sugarcane generally use three sizes of tractor. The small one ranges from 75 to 95 hp and is suitable for planting, soil covering, and gathering leaves after harvest. The middle one ranges from 100 to 160 hp (mainly 150 hp) and is suitable for fertilization. The large one ranges from 160 to 215 hp and is suitable for pulling harvest cargo. Huge tractors—such as the 370-hp ones—have been imported from Finland; these are not used by sugarcane producers but by soybeans producers in the State of Mato Grosso, because it can plow 17 ridges at once.

Sugarcane harvest machinery used to be imported from Australia. At present, three companies produce harvest machines in Brazil. The group purchased one of the companies, and the dealer began to sell harvest machines in 2012. The harvest machine is powered by a 336-hp motor, weighs 20 t, and costs R$750,000. The company that produced the harvest machine also developed a self-propelled planting machine that can make ridges, plant buds, cover soil, and fertilize, all in a single pass. The dealer is ready to sell this planting machine.

The dealer sold 120 tractors in 2011, and between April and August 2012 it sold two harvest machines. The best-selling tractor among sugarcane producers is the 180-hp model, which costs R$180,000; the second-most popular one is the 78-hp model. The prohibition of burning sugarcane in 2012 would not have influenced harvest machinery sales in that year, as producers would already have decided the quotas for hand-cutting versus mechanical harvest prior to the harvest season.

2) The company

The company "J" used to sell tractors imported from Argentina, where it established the first factory in South America. In 1998, the company set up an assembly plant through a joint venture with a Brazilian company in the State of Goiás. The factory produced five models of agricultural machinery, including tractors and sugarcane harvest machines. The company also constructed a factory in Porto Alegre in the south region, and began in 2010 to produce construction machinery in collaboration with a Japanese company.

The main machinery used in sugarcane production are tractors, planters, and harvesters. There are 18 models of tractor available, and they range from 55 to 225 hp. The largest tractors—which range from 230 to 470 hp—are imported from the United States. The producers of sugarcane typically purchase four models of tractor, and the most popular one is the 6180J type.[8)] It weighs about 7.5 t, and at its basic price costs about R$190,000. A GPS navigation system is an option that costs R$40,000; this expense pays for itself within 1.5 years, given the cost-saving precision it allows.

There are variations in sugarcane harvest machinery (e.g., one-row versus two-rows cut, and caterpillar treads versus rubber tires). The most popular harvester is the 340-hp, one-row cut machine, which weighs about 16 t when outfitted with rubber tires; at its basic price, it costs R$900,000. The company also sells sugarcane planters made by a domestic company. Hauled by a tractor, the planter plants the mericlone seedlings, whose length is only about 4 cm. The seedlings are cultivated with plant tissue in the biotechnology branch of the company at Itápolis, in the middle part of the state.

The company developed an irrigation system that uses GPS, for use in sugarcane production. It is a drip-irrigation system that supplies vinasse through pipes buried in 20 cm of soil. In the irrigated fields, tractors and harvest machines must be guided by GPS so as not to break the pipes. Despite the viscosity of vinasse, the pipes never clog, because of its high acidity. The irrigation system is sold mainly in the State of Goiás, whose climate is drier than that of the State of São Paulo.

In 2012, there were 47 dealers of the company in Brazil. One of the dealers opened in the study area in 2000. In 2011, it sold 310 tractors, 25 sugarcane planters, 10 sugarcane harvest machines, and 12 grain harvest machines. The dealers adopted a uniform display-rack design within their retail space. In the racks nearest to the entrance, consumption goods such as oil, oil filters, and batteries are displayed. Beside them, clothes, key chains, mini-tractors, and maté tea utensils (*cuia and bomba*) are displayed. The inner floor area features business booths, offices, and a repair shop. In the backyard, there are machines used to perform repairs, service cars used to perform repairs in the fields, and a large stove for barbecue parties (*churrasco*). The company provides services not only to producers but also to their families.

7. Case of sugar factories

According to UDOP (*União dos Produtores de Bioenergia*), there were 450 sugar factories in Brazil in 2011; 193 of them (43%) are located in the State of São Paulo. Many of the large factories belong to foreign groups (e.g., major oil companies from the United Kingdom and the Netherlands, grain companies from France and the United States, and a construction company from Spain). In this section, we refer to the production of sugarcane by factory "B," and the use of vinasse by factory "C." The former is the main factory of a mid-scale company, whose personnel we interviewed in August 2012. The latter belongs to a major group that operates 21 factories in the State of São Paulo; we interviewed their personnel in August 2011.

1) Sugarcane production

Factory "B" was founded in 1956 as a distillery of spirits that consumed 1,000 t/year of sugarcane. In the 1970s, the son of the founder enlarged the distillery into a modern sugar factory that produced not only spirits but also syrup and ethanol, using 600,000 t of sugarcane each year. The sugar factory was rebuilt in 2009 and the company enhanced its ethanol and sugar product offerings. In 2011, it produced 250,000 t of sugar and 60,000 m^3 of ethanol from 2.5 million t of sugarcane. The company sells sugar to food and beverage companies—including one from Japan—and ethanol to a major liquor company in Brazil. It employs 770 individuals in the farming section, 130 in the manufacturing section, and 20 in administration.

The factory cultivates 12,000 ha of sugarcane on leased land, and suppliers cultivate 18,000 ha. The contract period for leased land is typically five years, but it is sometimes extended to six. The main variety the company cultivates is the medium-ripening CTC2. The yield amounts to 85 t/ha in general, but it fell to 75 t/ha in July 2012 because of frost damage. The sugarcane cultivated by the company is cut by 330-hp harvest machines. During the harvest season, harvest machines move 24 hours per day, under the guidance of three shifts of workers. The sugarcane carried to the factory amounts to 12,000 t/day. After the harvest, fertilizer for ratooning is applied three times, at the rates of 120 kg/ha, 100 kg/ha, and 70 kg/ha. As well as vinasse, the filter cake—which is the fine solid residue obtained by filtration—is used as fertilizer in sugarcane production.

All sugarcane fields are distributed across nine municipalities, within a 45-km radius of the factory. Half of them are located within the same municipality, within a 25-km radius; 10 other sugar factories are found within a 50-km radius.

The logistics of sugarcane shipping constitute an important factor regarding the location of the sugar factory, because the sugar content begins to fall just after cutting, and so a long transportation distance would result in substantial energy loss.

The factory is located in a suburb along a federal road. The site extends across a 120,000-m^2 area, including 213 m^2 of ponds for cooling and purifying. A large measure is set in front of the processing plant, and in the processing season, trailers carrying sugarcane form lines. Each trailer is called a ***rodotrem*** (road train) because it is long and is equipped with two produce beds. Sugarcane is cut into short stems (about 40 cm) by machine harvesting, and so the two beds weigh 60–65 t—about 1.5 times heavier than that from hand-cut harvesting. At the unloading site, a large hoist overturns the trailer bed to drop the sugarcane onto a large conveyer belt. Not only stems but also leaves are carried into the processing plant. Sugar factories will be able to produce sugar and ethanol from leaves in the near future.

The sugarcane is washed with sugarcane juice that contains bagasse, in order to remove mud and leaves. Water is not applied, as it dissolves sucrose. After washing, the sugarcane is ground and divided into bagasse and juice. Bagasse is burned to make hot steam that is used to concentrate juice and generate electricity. Two generators whose annual production reaches 160,000 MWh generate electricity; surplus electricity is sold to an electric company. After filtration, juice is crystalized into brown sugar by heat treatment; juice is also brewed and distilled into ethanol. The company sells brown sugar in 1,200-kg bags. Depending on buyer requests, the company will process white sugar, and make syrup by adding water to it.

2) Vinasse spray

Factory "C" gathers 4 million t of sugarcane from 48,000 ha; from it, the factory produces 300,000 t of sugar and 160,000 m^3 of ethanol. This facility, started in the 1930s, used to be a traditional sugar refinery. Seven kilometers north of the current factory is an abandoned refinery made of brick, as well as houses for workers.

The factory sprays vinasse on the fields that are within 15 km of the factory. The spray system is composed of pipelines (***tubo***), a reservoir, and a sprinkler. It has the capacity to spray 150,000 L/h of vinasse. The thickest pipeline stretches to the reservoir, which is 3 km from the factory. Attached to the reservoir is a pump shed (***casa de bomba***) from which vinasse is conveyed to fields in pipelines that spread out like tree branches. The pipeline system from the pump shed is composed of 6 km of large-diameter pipes, 3–4 km of middle-diameter pipes, 1 km of small-diameter pipes, and 150 m of mini-diameter pipes. Pump cars (***motobomba***) are set up at sites where pipelines cross rural roads.

For more distant fields, tank trucks carry vinasse. Spraying vinasse near residential areas has been prohibited by law since 2001, as it has a strong and foul odor. Vinasse is sprayed on both the leased and owned land of the factory. The farming sections of the factory do not cultivate the suppliers' land, nor do they lease owned land to suppliers. However, they do contract the harvest of suppliers, and lease the land after ratooning for one year, to produce another crop.

The in-field vinasse sprinkler system consists of an automatic hose hoist (***hidro roll***) and a blast nozzle (*canhão*), as shown in Figure 9. The hose hoist moves parallel to a rural road while pulling the blast nozzle. The hose length ultimately reaches 60 m in length. The blast nozzle sprays vinasse at 180 degrees in the opposite direction of the hose, although it can potentially cover 360 degrees. Once vinasse is sprayed before the plantation of sugarcane—at the rate of 300–400 m^3/ha —no fertilizer is applied until the next planting.[9] The sprinkler system operators work between 09:00 and 0:00 during mid-April to mid-December. It takes 2.5 days to spray a 10-ha field.

The factory makes sugar and ethanol from April to December. During the production season, employees work full-time for five continuous days and take one day of holiday. During the off-production season, employees work full-time for 5.5 days per week, and take off 1.5 days. The main work in the off-production season consists of machinery maintenance and overhauls to the processing plant.

Ⅳ Discussion

Considering the information in the sections above, we can discuss the characteristics and problems of sugarcane production in terms of (1) the emergence of monotonous land use, (2) environmental load, and (3) future challenges.

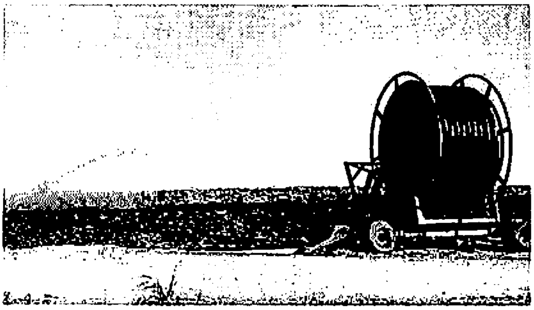

Fig. 9 Spray of vinasse by a sugar factory
Source: Taken by Nihei, August 2011.

Monotonous land use in sugarcane production has proliferated outward from the sugarcane production centers. Since the government deregulated ethanol production in the 1990s, foreign investments in sugar industries have increased, and the production costs of sugar and ethanol have fallen. Both products became important exports for Brazil, and the country's harvested sugarcane area increased rapidly after the 2000s.

The State of São Paulo holds 55% of the harvested sugarcane area in Brazil. As the harvested sugarcane area increases, the pasture area within the state has decreased drastically. New sugarcane production centers have emerged from the north to the western part of the state, and in the central-west region. In those regions, producers can convert pasture to sugarcane by introducing agricultural innovations such as an irrigation system and precision agriculture that makes use of GPS.

The conventional sugarcane production centers are located in the central part of the state. Vast and monotonous land use for sugarcane is proliferating there: sugarcane now occupies more than 90% of the arable land in the study area. A large amount of sugarcane is produced within a complex structure that comprises various elements. It is being developed through the introduction of new technology, such as different varieties, agricultural machines, and fertilization. The production scale of farms and sugar factories has also been enlarged, through tenant farming. The fact is that sugar factories produce only sugarcane on several tens of thousands of hectares. Monotonous land use may relate to problems vis-à-vis not only ecological diversity, but also food production. From the viewpoint of food miles, vast land use for industrial crops in the hinterland of huge cities will result in increased environmental load.

A second concern about environmental load relates to fertilization and mechanization. The high productivity of sugarcane (80–150 t/ha) is made possible with the input of fertilizer. Fertilizer is applied at the rate of 400–1,500 kg/ha (500 kg/ha on average)—a weight which, in itself, exceeds the amount of soybean and maize production.[10] Fertilization, in terms of the N–P_2O_5–K_2O ratio, especially requires nitrogen and potassium. Brazil is one of the major importers of fertilizer: according to the IFA (International Fertilizer Industry Association), of the 10.1 million t of fertilizer consumed in Brazil in 2010, 74% of it was imported. In particular, the ratio of imported nitrogen and potassium reached 76% and 97%, respectively.

The efficiency of fertilization will be improved with the diffusion of tractors that move precisely under the guidance of a GPS system. However, it will be difficult to practice sustainable agriculture if production depends overly much on the use of foreign materials. The spraying of vinasse also attracts a great deal of attention because it helps to simultaneously manage waste treatment and fertilization; however, as its practice was embraced in the late 20th century, its long-term effects are not yet known. There have been warnings against the spraying of vinasse, suggesting that it is the equivalent of spraying acid rain; indeed, it may cause soil acidification and leaching (Matsumoto, 2012).

It is well known that continuous cropping in sugarcane production creates no injury, as its cultivation has a long, four-century history. In terms of Brazil's enormous territory, however, the region with such a long history of cultivation is limited to coastal areas of the northeast region. Even within that region, land devastation has progressed in the sugarcane fields (Yamamoto, 1982). At present, soil fertility is maintained by deep-plowing and upside-down plowing. The treatment of soil with agricultural machines could give rise to the problems of soil erosion and groundwater pollution.

The mechanization of harvesting also poses environmental and social problems. Although the environmental load of sugarcane production has been under examination by other studies from our study group (Tase et. al., 2013), the use of heavy harvest machines and large tractors will no doubt cause soil compaction. There is also the problem of increased fossil fuel use, as well as how social aspects of mechanization are associated in rural areas with rapid changes in employment (Nishijima, 2009; Martinelli et. al., 2011). Sugarcane has been traditionally harvested by hand-cutting after burning; although burning has advantages in terms of pest control (e.g., *Mahanarva fimbriolata*) and therefore reducing the use of pesticide (Eida, 2003), it has received severe criticism, given its negative influence on health by virtue of particulate emissions (Uriarte et. al., 2009).

A third concern, regarding future challenges, relates to agricultural policies and sustainable land use. The state's ordinance, revised in 2007, enacted the gradual prohibition of the preharvest burning of sugarcane. It proclaimed that in-field burning at inclines under 12% would be prohibited until 2014, and that in fields with inclines exceeding 12%, or cultivated by farms with fewer than 150 ha, it would be prohibited until 2017.

The ordinance was modified several times to accelerate the prohibition, and the burning of sugarcane was suddenly prohibited in certain cities in 2012. Although the prohibition was cancelled in that year, judicial decisions have a considerable effect on rural areas. A similar case was reported in the tropical wetlands, where a law prohibited artificial changes in river flows (Maruyama, 2011). Rural and urban residents should have a substantial dialog with policy-makers about the endogenous development of rural areas.

The expansion of sugarcane production is regulated by the Agroecological Zoning System of Sugarcane, as mentioned in section II. The law prevents the sprawl of sugarcane production in tropical forest areas, but further sugarcane production expansion is expected in the new production centers in the Cerrado region. Not only in that region but also in the conventional production centers in the State of São Paulo, there is a need to consider the issue of sustainable land use. Although environmentally vulnerable sites such as valleys and water resources are protected by the forest reserve, a more direct relationship between agricultural land use and protected areas will be requested. This is feasible, depending on a producer's consciousness and the government supports that are in place.

To address these problems, we must pay close attention to land use consequences. As Pinto et. al. (2005) suggests, the agroforestry of sugarcane and eucalyptus will have an effect on the sustainability of land use. Eucalyptus, for example, grows so swiftly that it can absorb surplus fertilizer if it is planted downstream from sugarcane fields. However, because eucalyptus is also produced in a monotonous land use fashion by firms, there is little relationship between the land use of sugarcane and that of eucalyptus.

V Conclusions

The State of São Paulo has certain geographical advantages with respect to sugarcane production (e.g., a climate with distinct dry and rainy seasons, a huge demand for ethanol for automobiles, and the existence of export ports). Investments in sugar and ethanol industries increased after the government deregulated the production of ethanol in the 1990s; after the 2000s, the harvested sugarcane area in the State of São Paulo increased significantly. In the conventional production centers where we conducted our fieldwork, sugarcane occupied more than 90% of the arable land.

The production structure of sugarcane is complex, but it is progressing rationally in terms of economy. For example, major companies lead the country's sugar industry and expand monotonous land use, while small farms tend to shift part-time management or discontinue farming. Sugarcane yields are sustained by large inputs of industrial goods, such as chemical fertilizers and agricultural machinery. The producers of sugarcane—which consist of sugar factories and farms—tend to enlarge the scale of production by adopting mechanization, introducing new varieties, and renting land.

Concerning the environmental aspects of sugarcane production, there are anxieties regarding the amount of fertilizer applied in the course of vast and monotonous land use. According to a report from our study group (Tase et. al., 2013), at present, there are no concerns about the leaching of fertilizer and agricultural chemicals from sugarcane production. However, in the long term, the use of fertilizers and agricultural machinery may cause environmental problems such as soil erosion and groundwater contamination. Agricultural land use consequences, such as the combined production of sugarcane and eucalyptus, will naturally have an effect on sustainable development in rural areas.

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Notes

1) Besides ethanol made from sugarcane, biodiesel is also created from soybeans, oil palm (*dendê: Elaeis guineensis*), and castor (*mamona: Ricinus communis* L.). The diesel oil sold in Brazil contains 5% biodiesel.
2) The Brazilian Forest Code regulates the percentage of protected area in tropical forest states such as Pará and Amazonas (i.e., 20% for the Atlantic Forest Zone [*Mata Atlantica*] in coastal states such as São Paulo and Paraná, 35% for the Savanna Forest Zone [*Cerrado*] in inland states such as Goiás and Mato Grosso, and 80% for the Amazonas Zone [*Selva Amazonica*]).
3) It is said that the decline in the price of oranges is due to the increased demand for mineral water in developed countries.
4) Eucalyptus for pulp is extensively produced in Mogi Guaçu, a city located in northeast Piracicaba. Wood production in the city amounted to 487 million m^3 in 2010, according to the IBGE's *Cidades*. One particular firm produces eucalyptus on 100,000 ha of city land.
5) It is generally believed that when sugarcane blooms, prices decline, and that the sugar content decreases after blooming. According to interviews with producers, the timing of blooms owes to the variety of sugarcane grown, and not to price, and sugar content does not change after blooming, because it is then that plant growth ceases.
6) The prohibition in 2012 of burning came into effect in the following municipalities: Águas de São Pedro, Americana, Analândia, Araras, Charqueada, Cordeirópolis, Corumbataí, Ipeúna, Iracemápolis, Itirapina, Leme, Limeira, Nova Odessa, Piracicaba, Rio Claro, Rio das Pedras, Saltinho, Santa Bárbara d'Oeste, Santa Gertrudes, and São Pedro.
7) The State of São Paulo has become Brazil's largest producer of Para rubber. According to the IBGE's *Estados*, the state's harvested area reached 52,455 ha in 2012.
8) The four digits and letter printed on the machinery body together signify the model number ("6" means two-shift gears with frames), horsepower ("180" means 180 hp), and the degree of specialization ("J" is a more specialized model than "D" or "E," and can work with new devices such as GPS navigation systems).
9) The number of vinasse applications varies among sugar factories. Another sugar factory that we interviewed in 2013 sprays every year, at a rate of 60–80 m^3/ha.
10) Data pertaining to maize and soybean of fertilization were obtained from AgroByte (http://www.agrobyte.com.br) [last accessed 24 June 2013].

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