Exploitation and application of improved farming-systems technologies in sugarcane production in China

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Abstract This paper summarizes the achievements in exploiting and comprehensively applying modernized sugarcane farming-systems technologies in China. Since the 1980s, China has developed a series of advanced and appropriate farming technologies in commercial sugarcane production, and has adopted these practices since the 1990s. These technologies include deep-ploughing and soil preparation, plastic-film mulching, a prescription fertilizer system, trash retention in fields, water-efficient irrigation, use of pathogen-free healthy seed-cane, rationalised application of vinasse, chemical ripening, in-field machine operation, and comprehensive control of diseases, pests, weeds and rats. The exploitation and comprehensive application of the new sugarcane farming-systems technologies have promoted the Chinese sugar industry to new levels of production every 5 years, and made China the third-largest sugar-producing country. However, the sugar industry has been experiencing difficult times in the recent two milling seasons because of the worldwide low sugar price and the high production cost at the domestic level. This has led to a substantial reduction in sugarcane-growing areas and sugar production. Mechanization and the related sugarcane variety selection and farming technology development have become a bottleneck for sustaining the development of the sugar industry in China.

Key words China, sugarcane, farming technology, development

INTRODUCTION

The sugar industry in China has been developing rapidly since the 1980s. China currently produces about 13 Mt sugar annually under normal climatic conditions. During the past decade, more than 90% of the sugar produced was from sugarcane, with the balance from sugarbeet (Fig. 1). Sugarcane is grown mainly in Guangxi, Yunnan and western Guangdong provinces. Guangxi is the largest sugar producer, contributing more than 60% of the total Chinese production. The contribution from Guangxi has made China the third largest sugar producer in the world after Brazil and India (Li and Yang 2008, 2009, 2015; Li 2010; Wei and Li 2006).

![Fig. 1. Sugar production from milling years 2004/05 to 2014/15 in China.](image-url)
Sugar production in China increased markedly during the 2006/07 and 2007/08 milling seasons compared to the 2005/06 production. China produced 11.99 Mt of sugar in 2006/07. This was 36% higher than that achieved in 2005/06. The 14.87 Mt produced in 2007/08 was 24% higher than that in 2006/07. The cane sugar production reached 10.75 Mt in 2006/07, which was about 90% of the total sugar production and 13.67 Mt in the milling year 2007/08, which was 92% of the total sugar production. Sugarcane productivity and sugar recovery in China have improved significantly since the 1980s. The average annual cane productivity increased from about 55 t/ha in 1990s to about 65 t/ha in 2000s. In recent years, yields have increased to about 75 t/ha per annum. Average sugar recovery has increased from about 10% in 1990s to about 12% in recent years.

The increasing improvement in sugarcane production and productivity is mainly attributed to continuous success in breeding and developments of appropriate farming technologies for rain-fed upland sugarcane production (Li and Solomon 2004, 2006; Li and Wei 2006; Li et al. 2008, 2011; Li 2010).

In recent years, a group of new elite GT varieties have been released. Varieties GT21, GT29, GT31, GT32, GT40, GT42, GT43 and GT46 have performed well in several districts. Compared to ROC22, they show higher productivity and stronger ratooning ability. We strongly recommend the use of multiple sugarcane varieties for each sugar mill, at least 8-10 varieties in ratios of 30:50:20% for early, intermediate and late maturing varieties, respectively. We also recommend that cold-tolerant varieties such as GT21, GT29, GT32 and GT40 be used in the northern areas such as Hechi, Laibin, and Liuzhou districts in Guangxi.

Apart from breeding and encouraging the adoption of new varieties, we have also exploited a series of advanced appropriate farming technologies in commercial sugarcane production. These technologies include deep ploughing and soil preparation, use of plastic-film mulching, prescription fertilizer application, trash retention in fields, efficient irrigation practices, pathogen-free healthy seedcane, rationalised application of vinasse as a liquid fertilizer, chemical control of weeds, machine operation for sugarcane management, and comprehensive control of pests and diseases (Li et al. 2014; Li and Yang 2015). This paper describes the application of these improved farming-systems technologies in sugarcane production in China.

**DEVELOPMENTS IN SUGARCANE FARMING-SYSTEMS IN UPLAND AREAS IN CHINA**

Deep-ploughing and fine preparation of soil

Deep-ploughing and soil preparation have become increasingly popular since the early 1990s, and more than 90% of the sugarcane fields are now ploughed by tractor-drawn implements (Fig. 2). Field trials have shown that deep-ploughing to 45-60 cm and appropriate soil preparation increases soil moisture, which is good for germination and emergence, root development, tillering and enhanced growth (Ye et al. 1995; Liao et al. 2010). It has also contributed to increased cane yields, thicker and longer stalks, improved resistance to lodging and increased sugar accumulation in the crop. This resulted in >20% increase in cane and sugar productivity in rain-fed upland fields (Liang 2004; Wei 2006; Liao et al. 2010; Li et al. 2014). Deep-ploughing and appropriate soil preparation are now considered key farming technologies for upland sugarcane production in China.

![Fig. 2. Deep-ploughing and soil-preparation operations in China.](image-url)
Plastic-film mulching

Use of plastic-film mulching (Fig. 3) preserves soil moisture and nutrients (Li 2010; Li et al. 2014; Li and Yang 2015). It also contributes to higher soil temperature when seed-cane is planted in the winter and spring and results in germination and emergence 10-20 days earlier than before. Emergence rate is improved by 15-26% and the number of viable plants increased from 15,000 to 30,000 plants/ha (Li 2010). The latter increased cane productivity by 15%, and improved sucrose content by 0.53% (Li 2010). Plastic-film mulching has become one of the major farming practices in upland sugarcane farming. This practice was adopted on more than 221,000 ha in Guangxi in 2011, representing 52% of the total plant cane area at that time.

Prescription fertilization

A prescription fertilizer system based on collated data was established in the 1990s. This has resulted in decreased use of fertilizer that, in turn, has led to a decreased cost of production and improved cane productivity and increased sucrose content by 10-25% and 0.4-0.8%, respectively (Li 2010). As a result, fertilizer use efficiency increased by 4.5-8.2%. This technology, popularized in the 1990, has now been developed into an 'intelligent' expert system. In 2011, the prescription fertilization system was used in 172,000 ha of sugarcane fields.

Trash retention in-field

Sugarcane trash retention in-field leads to improved soil structure and physico-chemical properties, increases the organic matter content, and improves the soil fertility (Li 2010; Li et al. 2014; Li and Yang 2015). In China, two methods of trash retention are used (Fig. 4). One involves shredding the trash (Fig. 4A) and mixing it with the soil (Fig. 4B), and the other involves collecting the trash and placing it on alternate rows (Fig. 4C). Experiments from 1987-2010 showed that trash retention in-field improved soil structure and physico-chemical properties (Li 2010). Average soil organic matter increased from 1.79% to 2.60%, total nitrogen (N) from 0.09% to 0.14%, available phosphorus (P) from 13.37 mg/kg to 43.25 mg/kg, and available potassium (K) from 79.63 mg/kg to 233.33 mg/kg. These results confirmed that sugarcane trash is an important source of N, P, K, and reportedly calcium (Ca), magnesium (Mg) and micronutrients (Li 2010). Results from the trials showed that the average cane productivity improved by 7.7%. Trash retention also has the ability to lead to increased microbe populations. Liao et al. (2014) reported increases in bacteria, fungi and actinomycetes by 2.38, 1.80 and 2.74 times, respectively, in trashed systems compared to conventional untrashed soil. Addition of trash to fields also has a positive effect on soil moisture and contributes to weed control (Li 2010). In recent years, sugarcane trash retention has been adopted on over 300,000 ha annually.
Fig. 4. Sugarcane trash retention in fields: top, grinding the trash and mixed with soil; bottom, collecting the trash and placing it on alternate rows.

Water-efficient irrigation

Water-efficient irrigation systems, including spray, micro-spray (Fig. 5) and drip irrigation, have been developing quickly in China in recent years. Use of these technologies, especially fertigation, saves water, fertilizer and labor, and improves fertilizer utilization efficiency. Experimental results showed that fertigation improved cane productivity by 19-56%, improved fertilizer use efficiency by 90%, and gave water savings of up to 60% in dry upland sugarcane areas in China since the 2000s (Li 2010; Xu et al. 2010, 2011; Chen et al. 2012). Water-efficient irrigation systems have been in use on 18,867 ha in Chongzuo City since 2001.

Fig. 5. Micro-spray irrigation system in use in a sugarcane field in China.
Healthy seed-cane production and utilization

Pathogen-free healthy seed-cane technology has been developed and applied in China since the 2000s. Experimental results showed that use of pathogen-free healthy seed-cane improved cane productivity by 15.1-52.1% and sucrose content by 0.12-1.71% because of the removal of diseases such as ratoon stunting disease, mosaic viruses and yellow leaf disease (Li 2010). The use of a temporary immersion bioreactor system (TIBS) improved the propagation rate of seed-cane by up to 40 times compared to the traditional tissue culture method (Yang et al. 2011a). However, in many districts, the use of pathogen-free healthy seed-cane of sugarcane variety ROC22 did not result in yield increases because the large-scale monoculture of variety ROC22 had already caused substantial accumulation of pathogens and insect pests in the growing environment (Li 2014; Li and Yang 2015). This experience contributed to the realization that pathogen-free healthy seed-cane technology should be used mainly in propagation of newly released elite sugarcane varieties to accelerate the adoption.

Vinasse as a liquid fertilizer

Vinasse is the liquid by-product of molasses fermentation for alcohol production in many sugarcane mills. Its chemical components are solely derived from sugarcane and the milling process and consist mainly of soluble inorganic and organic nutrients that are nontoxic to plants and animals (Li et al. 2007, 2008; Li 2010; Jiang et al. 2012). Vinasse has been shown to be a useful liquid fertilizer for use in sugarcane (Chapman et al. 1992; Li et al. 2007; Li 2010; Jiang et al. 2012) and other crops. However, vinasse does contain relatively large amounts of proteins that are easily oxidized and capable of producing odours (Li et al. 2007; Li 2010). It also contains high concentrations of soluble ions that have the potential to harm crops if applied inappropriately.

![Fig. 6. Vinasse as a liquid fertilizer applied in sugarcane. Top, pumping vinasse into tank; bottom left, applying vinasse in a plant-cane field; bottom right, applying vinasse in a ratoon-cane field.](image-url)
An environment-friendly technology system has been developed for application of vinasse in both plant and ratoon crops of sugarcane in China (Li et al. 2007; 2014; Li 2010; Li and Yang 2015) and transformed vinasse from a so called ‘pollutant’ into a useful product. This development has been supported by extensive research that included determining the effects of vinasse application rates on soil properties and sugarcane growth associated with different soil types and farming conditions. The physico-chemical properties of vinasse, movements of different vinasse components in soil, and soil adsorption characteristics of vinasse after application have been evaluated (Li 2010; Li et al. 2007; Zhu et al. 2009; Jiang et al. 2012; Su et al. 2012; Yang et al. 2012, 2013). These investigations showed that applying 75 t/ha vinasse with a Brix reading of 6-8 onto plant cane, and 105 t/ha vinasse with a brix reading of 8-9 (Fig. 6) and covered with a plastic film without further chemical fertiliser, resulted in improved cane productivity (10-30%) and sucrose content (0.2-1.0%) compared to traditional fertilizer practices (Li 2010; Li et al. 2007; Zhu et al. 2009; Jiang et al. 2012; Su et al. 2012; Yang et al. 2012, 2013). Spraying vinasse with high pressure spray guns has enabled very good soil coverage on newly planted seed-cane (Fig. 6B) and ratoon cane (Fig. 6C). Continuous application of vinasse year by year on the Changling Farm in Guangxi has resulted in an average cane yield over 120 t/ha/annum since 2005. This technology is now extensively used. It has ‘solved’ the previous vinasse ‘pollution’ problem, but also provided a superior liquid fertilizer for crop production that improves soil fertility, yield and quality of cane, and reduces sugarcane production costs.

Chemical regulators

Use of chemical regulators provides an effective means of promoting plant growth and improving sugar productivity in sugarcane production (Li and Solomon 2003, 2006). For example, different concentrations of ethephon have been shown to cause different physiological effects in sugarcane (Li 2006; Li and Solomon 2003, 2006). These include promoting plant growth, improving drought and cold tolerance, and increasing cane and sugar productivity (Jian et al. 2012; Li 2004, 2010; Li and Solomon 2003, 2006). Chemical ripening with glyphosate-borate complex and high concentration of ethephon has also been shown to promote sugar accumulation in sugarcane and improve sugar productivity (Li and Solomon 2004, 2010). In the past, the biggest limitation for using chemical regulators on a large scale was the foliar spray operations. This was initially done by man-operated airplanes (Fig. 7A) over wide areas (Yang et al. 2011b). Unmanned aerial vehicles (Fig. 7B) have been found to be better, and have been developing rapidly in recent years.

![Fig. 7. Foliar spray of chemicals by airplanes in sugarcane: left, man-operated airplane operation, and right, unmanned aerial vehicle operation.](image)

Mechanization for field management

With increasing urbanization in China, the availability of farm labourers has decreased and labour costs are increasing rapidly. This trend has promoted the developments of mechanization for in-field management in sugarcane production (Li 2010; Li et al. 2014; Li and Yang 2015). Machinery is now used in almost all soil preparation and is common in most other field operations such as planting, fertilizing, soil and plastic film coverage, and weed and pest control. The exception is harvesting which is still mainly done by hand (Li 2010; Li et al. 2008, 2011).
Comprehensive control of diseases, pests, weeds and rats

The Chinese industry uses comprehensive controls of diseases, pests, weeds and rats (Li 2010; Li et al. 2014; Li and Yang 2015). These include selecting resistant sugarcane varieties, using pest and pathogen-free seed-cane, sterilization of seed-cane, removing sources of diseases, pests and rats, control of infectious sources and on-farm controls such as field trapping (Fig. 8A). There is also biological control of borers using pheromone, Trichogramma and Cuban flies (Li 2010; Li et al. 2014), underground insect control with Metarhizium (Li 2010; Li et al. 2014), and light trapping of borers and longhorn and scarab beetles (Fig. 8B). Weed control is undertaken with pre- and/or post emergence herbicides (Li 2010; Li et al. 2014).

Fig. 8. Insect pests control by: left, field trapping of longhorn beetle, and right, light trapping for many kinds of pests.

MAJOR CHALLENGES FOR FARMING-TECHNOLOGIES IN CHINESE SUGARCANE PRODUCTION

China faces several major challenges in adopting farming-systems technologies:

- The most important issue relates to the development of machine harvesting of cane. The reasons for this are complex, but primary considerations relate to existing farm size and cane-quality requirements imposed by sugar mills. To address these issues, it will be necessary for small farms to be combined into larger management units, for field sizes to be enlarged, and for sugar millers to address the cane-quality requirements and improve their cane-cleaning systems.
- Soil preparation is being compromised by the lack of power in tractors currently used in most sugarcane growing areas (>120 kW (160 horsepower) tractors are rare). The resulting limited plough-depth (about 30 cm) is affecting water-holding capacities and limiting root systems. These, in turn, contribute to drought stress, lodging and lower yields of cane and sugar.
- Growers are generally over-applying fertiliser because they believe that more fertiliser will result in higher yields. Experimental results have indicated that N, P and K applications have been 75, 50 and 30%, respectively, more than sugarcane requires for optimum growth (Li et al. 2014; Li and Yang 2015). This is leading to low fertiliser-use efficiencies.
- Growers have tended to prolong the life of the main sugarcane variety ROC22 by removing stools of disease-affected cane. However, due to the susceptibility of this variety to cold, borers and smut, yields have declined. Anecdotal evidence also suggests that ROC22 is not a good ratooning variety.
- The sugarcane crop-cycle is too short in China and usually only covers a plant crop and two ratoon crops or fewer. This leads to high production costs compared to most other countries, such as Brazil, that have crop-cycles in excess of 5 years. Ratoon performance may also be negatively affected by dry conditions in winter and spring in the upland sugarcane-growing areas that comprise about 80% of the total sugarcane growing area. Water is therefore a major limiting factor. Field management practices need further improvement.
PROSPECTS FOR THE CHINESE SUGAR INDUSTRY

Based on the reality of high production costs and international competition, mechanization of in-field management is urgently needed in China. This is coupled to the need to merge smaller farms and consolidate farmland, to provide sugarcane varieties and farming practices suited to the operation of machinery, and update requirements for millable cane.

Utilization of biological N-fixation characteristic of sugarcane and the ability of soil microbes to fix N and release P and K could decrease dependency on chemical fertilisers in sugarcane production, decrease production costs and improve fertilizer-use efficiency while assuring high cane and sugar productivities.

Application of pathogen-free healthy seedcane should be combined with propagation of new elite sugarcane varieties to accelerate the extension of new sugarcane varieties and improve seed-cane quality for commercial production.

Deeper ploughing and soil preparation are important. Use of larger tractors could extend the plough depth to 50-70 cm. This is the important foundation for high and stable productivity and improved lodging resistance in rain-fed upland sugarcane growing areas.

Increased use of sugarcane varieties with strong disease-resistance and ratoning ability (e.g. GT29, GT32, GT40) and updated farming-systems technologies could assist in prolonging the production cycle from 3 years to 5 years or longer. This would also help to decrease costs and improve the efficiency of Chinese sugarcane production.

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REFERENCES


**Exploitation et mise en œuvre d’itinéraires techniques améliorés en culture de canne à sucre en Chine**

Résumé. Ce papier présente les réalisations de l’exploitation et de la mise en œuvre de techniques agricoles nouvelles en culture de canne à sucre en Chine. Depuis les années 1980, la Chine a développé une série de techniques agricoles modernes et adaptées pour la production de canne à sucre puis les a adoptées à partir des années 1990. Ces techniques comprennent le labour profond et la préparation du sol, le recouvrement du sol par des films plastique, le conseil en fertilisation, une irrigation efficiente, l’utilisation de boutures saines, l’application raisonnée de vinasse, les maturateurs chimiques, la mécanisation, et une gestion raisonnée de la maladie, des maladies, des insectes, des mauvaises herbes et des rats. L’exploitation et l’application complète des nouvelles technologies agricoles en canne à sucre ont conduit l’industrie sucrière chinoise à de nouveaux paliers de production tous les 5 ans, faisant de la Chine le troisième pays producteur mondial de sucre. Cependant, l’industrie sucrière a connu des moments difficiles ces deux dernières campagnes de récolte en raison du faible prix du sucre sur le marché mondial et du coût élevé de la production locale. Cela a conduit à une baisse substantielle des surfaces sous canne et de la production de sucre. La mécanisation, la sélection de variétés et le développement de techniques agricoles sont devenus les points essentiels pour assurer le développement de l’industrie sucrière en Chine.

**Mots-clés:** Chine, canne à sucre, techniques agricoles, développement

**Explotación y aplicación de tecnologías de sistemas de cultivo mejoradas en la producción de caña de azúcar en China**

Resumen. Este artículo resume los logros obtenidos en la explotación y aplicación de forma integral de las tecnologías modernas de cultivo en China. Desde las ochentas, China ha desarrollado una serie de tecnologías adecuadas y avanzadas para la producción de caña de azúcar y las adoptó en la década de los noventa. Estas tecnologías incluyen el arado profundo y preparación del suelo, acolchado con película plástica, un sistema de fertilización por prescripción, retención del trash en los campos, riego eficiente, uso de semilla de caña libre de patógenos, aplicación racionada de vinaza, maduración química, manojo de maquinaria en campo y control integral de enfermedades, plagas, malezas y ratas. La explotación y uso integral de estas nuevas tecnologías del sistema de cultivo ha promovido que la producción de la industria llegue a nuevos niveles cada 5 años y ha hecho de China el tercer país con más producción de azúcar. Sin embargo, la agroindustria azucarera ha estado experimentando tiempos difíciles en las dos últimas zafra debido al bajo precio del azúcar y debido a los altos precios de producción local. Esto ha causado la reducción substancial de la áreas de producción de caña. La mecanización y la subsecuente selección de variedades y desarrollo de tecnologías de campo han producido un cuello de botella para el desarrollo de la industria azucarera en China.

**Palabras clave:** China, caña de azúcar, tecnología de campo, desarrollo