Mechanization technology: The key to sugarcane production in China

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Abstract: Sugarcane is an important cash crop in southern China now planted on about 1.5 million ha in the main production areas in Guangxi, Zhuang Autonomous Region and Yunnan, Guangdong, and Hainan Provinces. Since the cost of labor in China is increasing rapidly and the price of local sugar is uncompetitive with the product from mechanized international producers, China needs to change its sugarcane production methods from manual work to mechanization in order to catch up with international trends in this global industry. Although a lot of effort in China have gone into sugarcane mechanization since the 1960s, the overall level of mechanization in sugarcane production is still only approximately 30%, which is about 20% lower than that achieved in the other main field crops. Almost all of the sugarcane grown in China is still harvested by hand. In order to summarize past experience and promote the mechanization of sugarcane production in China, this paper reviews the whole process of developing mechanization since 1960s and describes the current state of sugarcane mechanization in China. The research currently being undertaken and the main obstacles to be overcome in developing a mechanized sugarcane production system, are described. The design and testing of sugarcane harvesting machinery and its key components has been a significant research area by some Chinese universities, research institutes, and manufacturing companies in these past decades. This paper reviews that research and outlines the main achievements which have been made in this area. Mechanized harvesting systems for sugarcane, and the appropriate harvesting patterns suitable for different growing conditions applying in China, have also been studied. The paper concludes with some comments on the future directions for progress in China's mechanization of sugarcane production and some policy suggestions to facilitate the industry's transition.

Keywords: mechanization technology, sugarcane production, sugarcane harvester, sugarcane machinery, development pattern
DOI: 10.3965/j.ijabe.20130601.001

Citation: Ou Y G, Wegener M K, Yang D T, Liu Q T, Zheng D K, Wang M M, et al. Mechanization technology: The key to sugarcane production in China. Int J Agric & Biol Eng, 2013; 6(1): 1－27.

1 Introduction

As an important cash crop in China, around 1.5 million ha of sugarcane is planted in the main production planted areas in Guangxi Region (1.04 million ha), Yunnan (0.3 million ha), Guangdong (0.15 million ha), and Hainan Province (0.07 million ha) (Figure 1)[1-3].

Received date: 2013-01-29 **Accepted date:** 2013-03-04

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A substantial proportion of the sugarcane produced in China comes from mountainous areas, particularly in Guangxi Region and Yunnan Province. The sugarcane crop usually remains in the field for several years, and can be harvested several times from the original planting (ratooned) if the yield in the subsequent crops does not decline too rapidly. The average sugarcane yield in China is around 60 tonnes per hectare. Planted area per household is less than 0.33 hectare.

Figure 1 Map of sugarcane production areas in southern China

In these circumstances therefore, sugarcane production in China remains a labor intensive industry. There is a heavy demand for labor throughout its crop cycle. In the present situation with globalization as a powerful economic force, sugarcane production in China is facing two main challenges:

1) With China's economy being transformed from a predominantly agricultural base to substantially a manufacturing base, this has created an unprecedented demand for factory labor so that high wage rates apply and less labor is available for manual farm work[4].

2) The other challenge comes from abroad. In China's manual production system, labor productivity is low, the process is slow and costly, and producers are facing the increasing cost of labor. All these factors caused the cost of sugar to increase to around 4 000 RMB/tonne in the recent crushing season. Compared with the cost of sugar of around 2000 RMB/tonne from the mechanized producers in Australia, Brazil, and even Thailand, China's sugar cost is much higher. At the same time, the research and application of high level technologies such as electronic measurement, automatic control, and precision farming have been the developing trends in sugarcane production in many countries. Compared to those countries, China's production system is poorly competitive in the international market[5-13].

China needs to change its sugarcane production system from manual work to mechanization in order to keep pace with international trends, while also recognizing that population growth will put increasing pressure on preserving soil and water resources[14].

Already a high proportion of land preparation prior to planting sugarcane is mechanized, but almost all harvesting is still done by hand. Mechanization of sugarcane harvesting remains a serious challenge. With sugarcane usually grown in small plots at close row spacing around 0.7 m to 0.9 m, using varieties adapted to that planting configuration, and much of the crop grown on hillsides, the challenges to mechanize sugarcane production, especially harvesting, are significant and different from other parts of the world. While the experience of Australia, USA, and Brazil in regard to the kinds of machinery systems they use is relevant, and the economic analyses of their systems are of interest, only about 10% of the current sugarcane area in China could be cultivated with the same large-scale machines used in those countries. If Chinese industry is successfully converted to mechanized production, more than one type of system may be needed. Besides the big machines, smaller machines developed specifically to suit Chinese local conditions, with small farms, steeply sloping land, relatively low sugarcane yields, and less developed transport infrastructure, are required. Much innovation including research, design and testing of alternative machines, especially harvester components, is currently occurring in China. While the evolutionary pathway, from manual to mechanized production methods has some similarity to what happened in developed countries, there are distinctly different aspects to be addressed in China[15,16].

In the following sections of this paper, the review will focus on the state of the art of sugarcane mechanization in China, the research into mechanization systems and their development pattern, and the main obstacles to be overcome in developing a mechanized sugarcane system for China. The research being conducted on sugarcane harvesters and their key components will be reviewed. Finally, the directions for further progress in China's mechanization of sugarcane production will be proposed.

2 Stage of sugarcane mechanization in China and development process

2.1 Role of mechanization in sugarcane production

Mechanization of sugarcane production means adopting mechanized operations in the sugarcane production system, which includes mechanized soil preparation, furrowing, planting, cultivation with fertilizer application, plant protection, harvesting, loading and transportation (Figure 2). These mechanical operations may be continued at ratooning with shredding leaves to leave them in the field as mulch, stubble shaving to keep the ridge flat for ratoon sugarcane, or deep ripping of the row interspaces to apply fertilizer, as typical operations[17,18].

Mechanization of sugarcane production is the inevitable choice in order to reduce production costs, improve labor productivity, and reduce the intense demands for farmers' labor. It is the most important measure to promote development of the sugar industry in China.

Figure 2 Mechanized operations in the sugarcane production system

2.2 Historical review

2.2.1 Investigation of medium and small scale sugarcane mechanization

China started to investigate sugarcane production machinery as early as the 1960s. From then to the end of the last century, the level of sugarcane mechanization in China was very low. Manual work was the basic manner of sugarcane production. The early research work was on animal-drawn machines. From the mid-1970s to mid-1980s, the institutions concerned carried out research work on tractor-powered sugarcane machines and they developed more than 40 machines and tools for soil tillage, deep ripping, sugarcane planting, field management, sugarcane harvesting, and transportation. In general, from the 1960s to the end of last century, sugarcane mechanization in China was mainly based on tool development, and performance and adaptability tests. Some small- and medium-sized machines for tillage, field management and transportation were developed and mature enough for extension and utilization. Mechanization of sugarcane harvesting however was at zero level[19-22].

Since the 1990s, more institutions, including universities, scientific research institutions and production companies, started a new round of research on sugarcane harvesters and planters. A number of new machines were in use and others were being tested. Most of the harvesters developed in China were small and medium size except for the 4GZQ-260 and 4GZQ-180 combine sugarcane harvesters developed by Guangxi Academy of Agricultural Machinery, and the 4GZ-260 and 4GZ-180 sugarcane combine harvesters were developed by Guangxi Yunma-Hansheng Machinery Manufacture Company. These small and medium size machines are suitable for small and medium scale mechanized systems[23-31].

At present, influential companies and organizations which are involved in promoting the adoption mechanization in the Chinese sugarcane industry are shown in Table 1.

2.2.2 Investigation of large scale fully mechanized sugarcane

The expansion of mechanized sugarcane production in China over the past three decades has reflected the transformation of the systems of production in countries like Australia, Brazil and the United States[33,34]. It has been accompanied by a shift in the centre of technology development to China. The investigations into large scale fully mechanized sugarcane production in China started in the 1970s. In 1974, a team led by an Australian cabinet minister and including a sugarcane breeder visited China when variety exchange and other

Table 1 Leading institutions in mechanization of sugarcane in China

Institution	Location	Operational level	Functions
Chinese Academy of Agricultural Mechanization Sciences	Beijing	National	Information about policy. Import technology. Conduct research on sugarcane machinery
College of Engineering, South China Agricultural University (SCAU)	Guangzhou	Provincial	Research and scholarship. Testing and design of sugarcane machinery, Farm demonstrations of sugarcane mechanization
Guangxi Academy of Agricultural Machinery	Nanning	Provincial	Development and testing of sugarcane harvesters. Farm demonstrations of sugarcane mechanization.
Guangxi Provincial Extension and Appraisal Station for Agricultural Mechanization	Nanning	Provincial	Machinery testing, evaluation and extension.
Sugarcane Research Institute, Fujian Agriculture and Forestry University	Fuzhou	Provincial	Research on cooperation between farm machinery and agronomy technology
Guangxi University	Nanning	Provincial	Research and scholarship
Zhanjiang Agricultural Reclamation Bureau	Zhanjiang city	Local	Diversified group that includes large farm and sugar mill. Leading organization in mechanization of sugarcane
Guangdong Guangken Group (A division of Zhanjiang Agricultural Reclamation Bureau)	Zhanjiang city	Local	Set up farm demonstration plots, Undertake experiments in mechanized sugarcane farming in conjunction with SCAU staff.
Sugarcane Research Institute, Yunnan Academy of Agricultural Science	Kaiyuan city, Yunnan	Provincial	Land suitability and agronomy study for mechanized sugarcane production
Guangdong Kolea Agricultural Machinery Company	Guangzhou	Local	Machinery manufacturer. Manufacture medium size sugarcane chopper harvester.
Guangxi Yunma-Hansheng Machinery Manufacture Company	Liuzhou city, Guangxi	Local	Machinery manufacturer. Manufacture medium size whole stalk and chopper sugarcane harvesters
Zhejiang Sanjia Agricultural Machinery Company	Ninghai city, Zhejiang	Local	Machinery manufacturer. Developed whole stalk harvester in collaboration with Zhejiang University

Source: adapted from Wegener et al.[32].

matters were discussed. Australia was one of the main sugarcane machinery producing countries at the time, where sugarcane growers started to use harvesting machine 100 years ago[35], and the government and the industry recognized that China was a potential market of sugarcane machinery. The Australian Prime Minister Mr. Frazer subsequently visited Beijing when cooperation in sugarcane production was discussed. In 1978, the first Australian machines were displayed at the Agricultural Machinery Exhibition, Beijing and the Director of Sugar Experiment Stations was invited to deliver a lecture on mechanized sugarcane production. In 1979, a group of experts from Australia visited China. After conducting an investigation, they suggested importing Australian sugarcane machinery and establishing an experimental farm in the area managed by the Zhanjiang Reclamation Bureau. In the same year, a Chinese delegation visited Australia. After their investigation and approval by the Ministry of Agriculture, they decided to import a set of Australian sugarcane farming equipment (including ploughs, planters, multi-row weeders, irrigation equipment and a harvester) to China[32,36].

In 1982, a fully mechanized sugarcane farm based on the imported Australian machinery was established on Qianjin Farm, by the Zhanjiang Farm Reclamation Bureau, Guangdong Province. The aim was to test the performance of the imported Australian machinery, and to explore the route to large scale sugarcane mechanization in China. There were 150 ha of sugarcane land on the experimental farm. After six years of experimentation, they believed that large scale fully mechanized sugarcane production using the Australian machinery system in China was possible, although it needed serious improvements in production conditions and management systems[36,37].

In 1996, with the help of South China Agricultural University (SCAU), a new phase in the investigation of mechanized sugarcane production was started, again on Guang Qian Farm in the area of Zhanjiang Reclamation Bureau, in cooperation with several foreign companies. The features of this cooperation were that the foreign companies managed the whole experiments, while the Chinese side supported their work. That meant that not only the machinery, but also the whole system including the agronomy and management processes were introduced. It was a research project on sugarcane mechanization which focused on introducing the combination of overseas machinery and complete technology systems into the production situation in China. Academic staff from SCAU and Massachusetts State University (UMAS) played the role of judges to evaluate the results of these experiments[38-40].

These experiments started in early 1997 and ended in April 2000. The scale of these experiments extended over 260 ha and they indicated once again that mechanized production was highly efficient, and incomparable with the system of using human labor[41,42].

In 2003, for the third time, the Zhanjiang Agricultural Reclamation Bureau introduced a whole set of foreign sugarcane machines, and conducted an experimental and demonstration project on sugarcane mechanization on the company’s Fengshou Farm. It became a national “demonstration area for agriculture (sugarcane) patternization”. In recent years, Fengshou Farm introduced more than 70 sets of different kinds of advanced large machines and tools, and set up 1 000 ha of mechanized sugarcane production as an experimental base and basically achieved mechanization of the whole sugarcane production system. Subsequently, Zhanjiang Agricultural Reclamation Bureau established Guang Ken Agri-Machinery Company which unified the development and management of sugarcane mechanization work in the whole reclamation area. It is planned to achieve mechanized sugarcane production on 6 500 ha of land by 2015[36,43,44].

In the same period, under the guidance of the Guangxi Academy of Agricultural Machinery, Guangxi Agricultural Reclamation Bureau also carried out large scale sugarcane mechanization experiments on Jinguang Farm, Nanning, Guangxi Region. They also have made some progress towards mechanized production[45].

2.3 State of the art in the mechanization of sugarcane production in China

The area for planting sugarcane in the sugarcane-crushing season of 2011-2012 in China was approximately 1.56 million ha. At present, the overall level of mechanization in sugarcane production is approximately 30%, which is about 20% lower than that achieved in the other main crops. This has restricted the development of the sugarcane industry. In 2011-2012, about 0.07% of the sugarcane in China was harvested mechanically, about 0.05% in Guangxi, 0.47% in Zhanjiang district of Guangdong, and almost none in Yunnan and Hainan Provinces.

Sugarcane production has recently attracted the concern and attention of state leaders, in conjunction with the governments at all levels. In July 2010, "The opinions of the State Council on promoting the rapid and healthy development of agricultural mechanization and agricultural machinery industry" (Document No. 22, 2010) put forward the strategic goal in developing sugarcane mechanization, which is to "breakthrough the bottleneck in sugarcane harvesting mechanization", by 2020, to "mainly solve the key technical problems in mechanizing sugarcane planting and harvesting"[46]. In June 2011, the Ministry of Agriculture issued "The guiding opinion on mechanization technology in sugarcane production", putting forward guiding opinions on using different patterns of mechanized production and the technical routes by which they might be achieved, according to different local conditions and ways of doing things[47]. In March 2011, the Ministry of Industry and Information issued "The farm machinery industry development plan (2011-2015)", and the sugarcane harvester has been included among the key construction projects[48]. In 2009, the Ministry of Agriculture approved a research organization named National Sugarcane Industry Technology System, which includes sugarcane mechanization research. The establishment of that system further promoted the development of sugarcane mechanization.

At present in China, the household responsibility contract system controls land allocation. It means the peasants can use the land as a household unit, and each household can now decide what and how to produce. In recent years, the government found this is a constraint on mechanization. They introduced a new policy to allow the peasants to rent out their land for farming. Therefore, some peasants can control more land, which is called "land circulation", and those peasants or companies that control these larger areas can level the land and join small pieces into larger areas suitable for machine operations. This is called "land regulation". Although the government encourages land circulation, under the household responsibility contract, the peasants have the right to decide whether they keep their small piece of land for themselves or rent it out.

Under these circumstances, sugarcane mechanization needs to be given priority for a few more years while it remains in the developmental stage of experiment and demonstration. During this time, experience with machine operations and mechanized production of sugarcane will be accumulated. We are confident that significant progress in sugarcane mechanization will occur in the near future and that the bottlenecks to sugarcane mechanization, especially the mechanization of harvesting, will be overcome.

2.4 Development situation in different operations[2]

2.4.1 Mechanized land preparation

The main achievement in sugarcane mechanization in China to date is in land preparation with the mechanization level of that operation now around 80%. The equipment mainly used includes cultivators and harrows. Tillage equipment developed and produced in China has been widely used for deep ripping, plowing, rotary hoeing, harrowing, furrow preparation, sugarcane leaf shredding and ratooning operations. More efficient tillage equipment, including multi-operation equipment, is also regularly appearing[49].

2.4.2 Mechanized planting and crop management

Some planters have been developed and successfully demonstrated, and there is small scale application in the field. These planters are "chop and drop" types. Another most useful method recently developed is the use of tractor mounted ridgers for opening the furrows while the rest of the operations involved in sugarcane planting are still done manually[50].

In crop management, there are limitations due to a lack of high clearance tractors and matching implements, and most of the machines being used are low horsepower types, so the intensity of labor use is still high when using them in the growing season. The quality of cultivation, especially in rows spaced 1-1.2 meters apart, is usually not reaching the required standards[51].

2.4.3 Harvesting

Mechanized harvesting of sugarcane in China is still in the experimental and demonstration stage.

In recent years, large combine sugarcane harvesters have been imported from abroad (originally from Australia, more recently from USA and Brazil), and are currently on trial mainly in the Zhanjiang area by the local agricultural reclamation company[44,52].

From the domestic point of view, there are some combine sugarcane harvesters including whole stalk and chopper types developed by Chinese companies being tested in the field, but none of these machines have been sold commercially. More work is needed to make the breakthrough to successful mechanized sugarcane harvesting[53].

2.4.4 Complementarity between machinery and crop agronomy

There is preliminary consensus on the need for complementarity between agricultural machinery and agronomic technology. “The fusion between agricultural machinery and agronomy technology is necessary for achieving agricultural mechanization” has been accepted as an important objective, and is starting to be put into practice in the consolidation of land, planning of roads for machine operations, construction of irrigation systems, adoption of sub-soiling technology, wider row spacing (1.2-1.4 m), and sugarcane breeding technology. A lot of improvements have been made, and a significant increase in efficiency has been affected[54-57].

2.5 Sugarcane production in the main provinces

2.5.1 Guangxi Zhuang Autonomous Region

Sugarcane is the second largest crop in Guangxi agriculture, with the planting area being around 1 million ha. Total production of sugarcane is 56.70 million tonnes, which accounts for more than 60% of the total output of the whole nation. The production conditions in Guangxi, however, are poor. The sugarcane is mainly planted in hilly and mountainous areas, field blocks are usually small and sloping, and the economic foundation of the industry is weak, as the farmers’ ability to purchase equipment is limited. The development of mechanization is very challenging although, in recent years, mechanization of sugarcane production in Guangxi has developed rapidly. Total mechanization level in 2010 was about 39%, and is expected to be 45% by 2015[58-63].

2.5.2 Yunnan Province

Yunnan’s sugarcane planting area is 0.15 million ha, ranks second nationally, and is a very important industry for Yunnan’s economic development. The basic conditions for sugarcane production in Yunnan are also poor. The main fields for sugarcane are located in mountainous and hilly areas, and account for around 80% of the total sugarcane planting area. The transport conditions are also poor, with a sugarcane transportation radius of 50 kilometers on average, three times more than the national average. The transportation cost, therefore, is high.

Yunnan’s mechanization level in sugarcane production has been very low. Besides soil preparation, cultivation, and transport, the utilization of machinery in planting and harvesting is almost zero. In the past two years, Yunnan’s mechanization of sugarcane production has gained momentum. Some companies, such as the Yingmao Industry Group .Ltd began paying attention to sugarcane mechanization and explored the mechanization route to the mill. In addition to land preparation machines, sugarcane planters, cultivators and harvesters were introduced and are on trial[2,64].

2.5.3 Guangdong Province

There are approximately 0.147 million ha of sugarcane planted in Guangdong Province, which ranks third in the national list of producers. The industry is mainly located in Zhanjiang area, west Guangdong Province, where about 0.133 million ha of sugarcane are planted. Zhanjiang Agricultural Reclamation Bureau is the most important guiding force in sugarcane mechanization in China. Although it has only 27 000 ha of sugarcane, it has been vigorously developing sugarcane mechanization, and after 20 years of effort, mechanized land preparation, planting, and transportation have reached a higher level than anywhere else in China. Mechanized harvesting level, however, remains very low.

The company expects to have 6 500 ha of mechanized sugarcane by 2015[2,15,36].

2.5.4 Hainan Province

Hainan's sugarcane area ranks fourth in China and the tax from the sugar industry is a large proportion of local fiscal revenue. In recent years, the provincial government has promoted sugarcane sub-soiling and furrowing, and has obtained good results. Hainan's mechanization level in sugarcane production, however, is still low with no mechanized sugarcane planting or harvesting recorded[65-67].

3 Research on sugarcane harvesters and their components

3.1 Research and manufacture of sugarcane harvesters in China

There is a long history to the study and manufacture of sugarcane harvesters in China which started in the 1960s. The vastly different harvesting conditions existing in China generated a set of early innovations and encouraged the manufacture of sugarcane harvesters. Many early models were designed with features considered to suit China's small fields and steeply sloping land. Unfortunately, those models no longer exist. Only a few models made in Guangxi followed the design and size of the Australian machines. The first attempts were made in the early 1980s when a 104 kW chopper harvester was developed in Guangxi. Two 104 kW chopper harvesters were sent to Indonesia for trial in 1982[32].

Typical models produced in the past decade have been as follows:

4GZ-9 whole stalk harvester, mounted on 11-14.7 kW hand tractor, which was developed in 2002 by Guangxi Institute of Agricultural Machinery. The sugarcane stalks are laid down on the ground beside the machine after cutting. It can be used when the sugarcane is not seriously lodged. Its productivity is 0.1-0.15 ha/h, and it is adapted to row spacing ≥1.0 m.

4ZZX-48 whole stalk harvester, mounted on the side of a 48 kW four-wheel-drive tractor, was developed in 2006 by SCAU. It is driven by the hydraulic system and can be used when the sugarcane is not severely lodged. Its productivity is ≥0.2 ha/h, and it is adapted to row spacing ≥1.2 m. The 4GZX-45 model developed by SCAU and Guangxi Institute of Agricultural Machinery in 2006 is similar to the 4ZZX-48 except it is mounted on the front of the tractor.

HSM1000 self-propelled wholestalk combine harvester, is a 42 kW machine, developed in 2004 by Liuzhou Hansheng Machinery Manufacture Ltd, Guangxi Region. Its productivity is 0.13-0.20 ha/h.

All these models are still in the development stage, and none have been sold. In recent years, the research work on sugarcane harvesters in China has made great progress. More researchers are involved in the development of sugarcane harvesters, and the main ones are shown in Table 2 below.

From the table it can be seen that while development has concentrated on billet harvesters, whole stalk machines are still being tried in China[68]. Whole stalk harvesting may offer benefits for some areas in China, where there are no efficient transport systems to take sugarcane from the field to the mills. All of the mills are equipped to handle whole stalks of sugarcane, and deterioration in chopped sugarcane could be a serious problem under Chinese harvesting and processing conditions.

Some theoretical research has also been carried out on design of sugarcane harvesters.

Using Visual Studio.net as a tool, Yang[69] developed an integrated design platform, and the functions of the platform were validated by designing an example of a wheeled sugarcane harvester. The use of the platform shows that it can significantly speed up the design process and could shorten the development cycle.

Based on the related theory of humanization of design and the design development of a sugarcane harvester, some humanization design factors which deal with certain requirements, such as environmental factors, physical factors, and sensibility level factors, were analyzed and researched. In addition, the layout, shape, and color of the sugarcane harvester were designed by humans, which made the function and the form come together harmoniously. Several modeling schemes with practical reference values were developed[70].

Table 2 Research institutes and the sugarcane harvesters they have developed

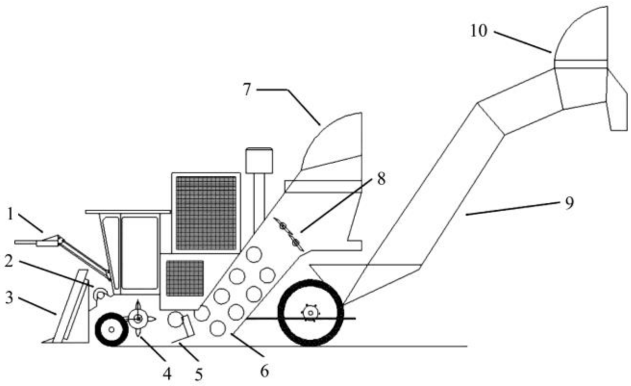
Institution	Location	Functions	
Chinese Academy of Agricultural Mechanization Sciences	Beijing	Research on whole stalk harvester mounted on four wheel tractor (48 kW), and combine chopper harvester (90 kW)	
College of Engineering, SCAU	Guangzhou	Research on whole stalk harvester, mounted on 4 wheel tractor (48 kW), Cooperation with Guangdong Kolea company to develop combine chopper harvester (56 kW, 91 kW)	
Guangxi Research Institute of Agricultural Machinery	Nanning	Research on combine Chopper harvester (132 kW, 190 kW)	
Guangxi Wuling-Guihua Machinery Manufacture Company	Nanning	Manufacture small size whole stalk harvester, mounted on hand tractor (11-14 kW)	
Guangdong Kolea Modern Agricultural Machinery Company	Guangzhou	Manufacture combine chopper harvester (56 kW, 91 kW)	
Guangxi Yunma-Hansheng Machinery Manufacture Company	Liuzhou city, Guangxi	Manufacture combine whole stalk and chopper harvesters (132 kW, 190 kW)	

Institution	Location	Functions	
Zhejiang Sanjia Agricultural Machinery Company	Ninghai city, Zhejiang	Manufacture combine whole stalk harvester (50 kW)	
Henan Kunda Machinery Manufacture Company	Luoyang city, Henan	Manufacture Combine whole stalk harvester (90 kW)	

Fu[71] studied the optimization of sugarcane harvesting machinery using the multidisciplinary optimization modeling method and its data transmission and information exchange, based on a virtual prototyping environment. Using a Product Data Management System (PDM), unified management of model data was achieved and information on design optimization was obtained. A multidisciplinary intelligent design optimization platform for a sugarcane harvester was built.

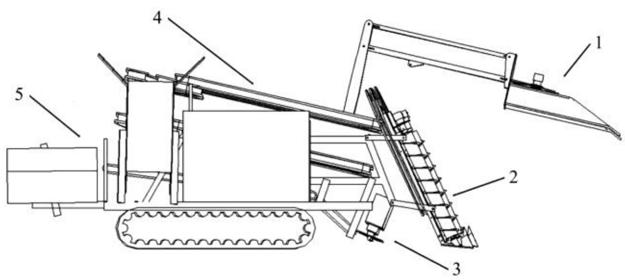
3.2 Progress in research on key components of sugarcane harvesters and harvesting technology in China

There are two main types of sugarcane harvesters researched in China: Wholestalk harvester and chopper harvester. Figure 3 shows the main components of these two main types of sugarcane harvester.



1. Topper 2. Knockdown roller 3. Crop divider 4. Fin roller 5. Base cutter 6. Feed roller 7. Primary extractor 8. Choppers 9. Elevator 10. Secondary extractor

a. Large combine sugarcane harvester



1. Topper 2. Crop divider and lifter 3. Basecutter 4. Conveying devices 5. Collector

b. Medium size wholestalk harvester

Figure 3 Main components of sugarcane harvesters

3.2.1 Research on sugarcane growth characteristics and physical properties

Liu et al.[72] reported that sugarcane is anisotropic, non-uniform, qualitatively elastic-plastic material. Sugarcane cutting is a complicated mechanical process and research into the process and its underlying theory should be combined with the physical and mechanical properties of sugarcane stalk material.

Liu et al.[73] also conducted research to study the mechanical properties of sugarcane under bending stress. The results showed that under a bending load, sugarcane stalks have four failure forms: breaking at a neutral layer, breaking transversely, breaking in the axial direction, and irregular breaking. Samples from the base or the top of the sugarcane stalk mainly showed transverse breaking, others were inclined to break at the neutral layer. The Yong's modulus of sugarcane stalks at the base position was distinctly different when the stalk was peeled, and it was larger than the values without peeling. The bending strength between the peeled and unpeeled stalk at its base was not significantly different. Similar research has also been carried out on the lodging potential of sugarcane in the field, to investigate the mechanical properties of sugarcane under torsional and compression stresses[74-76].

In order to study the damage to sugarcane leaf sheaths under the action of flexible leaf-stripping elements in the leaf-stripping process of a wholestalk sugarcane harvester, Mou used high-speed photography to record the damage. The damage process was analyzed using a simplified mechanical model based on the properties of the sugarcane leaf sheath. The different damage forms were related to the growth characteristics and mechanical properties of leaf sheaths. When the moisture content of the leaf sheath was less than 20%, the abscission of leaf sheath from stalk was the main form of damage but if the moisture content ranged from 20% to 50%, tearing of the leaf sheath occurred. If the moisture content was greater than 50%, the sheath appeared to separate more easily from the stalk[77,78].

Song et al.[79] developed a force-predicting model for sugarcane stalks based on theoretical analysis and field tests. The root stress and flexibility were obtained using the model and SOLIDWORKS simulation. The results showed that root stress and flexibility increased as distance between root and action point increased.

3.2.2 Research on harvester components

1) Sugarcane dividers and lifters

In the sugarcane harvesting process, dividing the intertwined sugarcanes of different rows and lifting up fallen sugarcane stalks from the ground may be the first procedure, depending on lodging state of the crop which is affected by the sugarcane variety and planting mode, its growth status, and other constraints that have affected its growing conditions[80].

There are two kinds of crop lifting mechanisms, the screw type, and finger chain type. Due to the thickness of sugarcane stalks, and that they are often tangled on the ground, finger chain type sugarcane lifting mechanisms have limited use in sugarcane harvesting machines.

The screw type mechanism is now widely used because of its main advantages: the compact structure, its easy to implement power transmission, and their higher efficiency. For seriously lodged sugarcane, however, the lifting effect of screw-type crop lifters is still less than ideal. Its main role in severely tangled sugarcane is, instead, to take the intertwined sugarcane apart. Some people therefore prefer the name "crop divider".

Some of the early research work done on crop lifters in China is described as follows.

Lao[81] analyzed the relationship between the movement parameters of the sugarcane lifting screw and its rotating speed. He also analyzed the relationship between the speed of the screw lifter and the forward speed of the sugarcane harvester.

In a study to determine the movement parameters for screw lifters on sugarcane harvesters, Peng[82] found that there was a close relationship between the rotating speed of the screw lifter with the machine's forward speed and sugarcane lodging status.

By undertaking motion analysis of the crop lifter, Wang[83] deduced the appropriate design principles of the screw lifter. Ye[84] also made contributions to determining the working principles and design parameters of the sugarcane crop lifter.

Some of the more recent research has been on the performance of sugarcane lifters:

Song[85,86] conducted indoor simulation tests on a single segment screw sugarcane lifter. By studying the sugarcane lifting process in detail, he analyzed the impact of the structure parameters of a single segment screw lifter, ratio parameters, and sugarcane growth status on its lifting capacity.

Zhang et al.[87,88] designed a finger type chain lifter for a sugarcane harvester, and tested its structural and working parameters as well as developing a kinematics model. They also used high-speed photographic records, conducted a virtual prototype test, and tested a physical prototype as part of their research into the sugarcane harvesting and movement process.

Finite element modeling and dynamic simulations have been made of the stress deformation caused in the crop lifting process. Research showed that the crop lifter cannot pick up sugarcane with side angle less than or equal to 15°. The lifter which is installed as a crop divider can help the machine to lift up sugarcane stalks with elevation 15° and side angle 60° to 65° and 29°, respectively[89].

In order to improve the lifting ability of whole stalk harvesters in lodged sugarcane, Song and Xie et al.[68,85,90-92] designed a crop-lifter composed of a spiral roller and chain-lifter. It can lift lodged sugarcane into the entrance of the conveyor system. By analyzing the movement of the conical spiral roller, which is the key component of the combined device, the relationship between the parameters, and a reasonable estimate of the appropriate angle of the conical spiral roller were obtained. Using the optimal parameters, the results showed that up to 90% of the sugarcane stalks could be picked up with the combined lifter.

2) Base-cutters

Yang et al.[93,94] developed a modal model for the main structure of a small sugarcane harvester and a finite element model for the disc-blade base-cutter. Using the mixed modal synthesis method, they considered the main structure and the base-cutter structure, and created a dynamic model of the whole system using generalized coordinates. Based on this model, a dynamic structural design for the base-cutter of a sugarcane harvester was undertaken. The dynamic performance of the base-cutter was improved. Huang et al.[95] also used a finite element model to study the disc-blade base-cutter.

Wang et al.[96] used the 4GZ-9 type sugarcane harvester as the test prototype to conduct both theoretical studies and field experiments. They optimized the parameters for the base-cutter, and the ratio of broken rootstock in ratoon sugarcane declined to 2.11%.

More researchers conducted research on the cutting mechanism of a single disc base-cutter when it was set to cut and not cut the soil, respectively[97-105]. The kinematics and dynamics analysis of the base-cutter and the influence of factors causing root damage were also analyzed.

Liu et al.[73] carried out experiments to test the mechanical characteristics and failure of sugarcane stalks under bending load. The results showed that the sugarcane stalks mainly displayed four kinds of damage under bending load: neutral layer cracking, transverse cracking, bottom longitudinal cracking, and irregular cracking. These results are significant for research on the sugarcane cutting process, and blade design.

Zheng[106] studied the matching problem between forward speed of the sugarcane harvester and base-cutter rotating speed. Chen and Yang[107-110] studied the factors influencing and mechanism causing sugarcane root breakage from a single disc base-cutter. The results showed that the frequency and amplitude have significant influence on root breakage. By optimizing the working parameters, the extent of broken roots caused by the base-cutter was reduced to less than 14%, and this improved the quality of cut sugarcane stalks.

The combine sugarcane harvester usually uses a dual base-cutter system but this research was all done with single base-cutters. Using quadratic regression and an orthogonal rotary design, an indoor experiment was carried out by Lin et al. on the factors affecting quality of the base cut, including rotating speed of the base-cutter, harvester forward speed, blade number, cutter obliquity, cutting angle, and blade-edge angle. Synthesized optimal values were obtained in both wet and dry soil conditions. The results showed that the rate of broken roots could be reduced to less than 8.18%[111].

3.2.3 Research on conveying devices

The conveying devices in sugarcane harvesters can be divided into two main kinds, grip conveyers and roller train conveyers. Grip conveyers use two grip chains with fingers which are fixed on to the conveyor chains. The extrusion pressure between two grip chains carries the stalks into and through the machine. The grip chains on sugarcane harvester usually use fingers of soft material such as rubber to avoid damage to the stalks. Roller train conveyors are composed of a set of rollers, which convey the sugarcane stalks by the tangential force generated when they are rotating. The grip chain conveyors are usually used on wholestalk harvesters, while the roller train is usually part of the chopper harvester. Besides conveying the sugarcane, the grip chain also has the function of holding the sugarcane stalks while the base-cutter is cutting them at their base. The gripping device, therefore, is not only one part of the conveyor, but also part of the topper.

(1) Grip conveyors

There are two typical grip conveyor devices. One is a trackless grip conveyor, with the soft grip components fixed onto the conveyor chains which is tensioned by two gears. Since the chain is running in a horizontal plane and there is no track to hold it, this kind of device needs high tensile strength to keep the chain in its running position. The Model 4ZZX-48 sugarcane harvester built by SCAU used this kind of device, composed of two sets of grip chains to form an L-shape allowing the sugarcane stalks to be lifted and then conveyed to the lateral position. Experiments showed that this device was structurally strong and had good ability as a conveyor, but it also had heavy resistance and needed considerable power to run it. Furthermore, this type of conveyor chain dropped easily out of position[112].

Another type of device is the tracked grip conveyor, with the conveyor chain running in a track. Li et al.[113] designed a circular track grip conveyor, and the experimental results showed that this could run stably with little tensile force and less power was needed.

(2) Roller train conveyors

Roller train conveyors are widely used on all chopper harvesters, such as the various Case and John Deere models. The sugarcane is fed uniformly into the chopper system by the roller train.

Chen[114] applied for a patent on a roller train conveyer which can strip sugarcane leaves from the stalks while conveying them through the machine. Li et al.[115] designed a roller conveyor, and conducted simulation and physical experiments on its performance.

Zhou et al.[116] did research on a front mounted whole stalk sugarcane harvester in which he used a roller conveyor system to move the sugarcane stalks. The 4GZ-56 combine chopped sugarcane harvester, which was collaboratively designed by SCAU and Kolea Ltd, also utilized this roller train conveyor device. The performance of these two machines was very good when they were tested in the field.

Xie et al.[117] added a fan into the roller conveyer system and improved the trash cleaning performance of the harvester.

3.2.4 Research on leaf striping technology and its key components

The components for stripping leaves from the sugarcane stalks are a key part of the small scale leaf stripper. The materials and shape of the components have a significant influence on the quality of stripping and life of the working parts[118]. Much research has been done in China on the appropriate materials for the stripping brushes[119-122]. The materials used more popularly now are nylon and rubber.

At the same time, many studies have been undertaken on the influence of arrangement pattern, structure, and motion parameters of the stripping brushes on stripping force and trash left after stripping[122-124, 153].

Curved sugarcane stalks, especially those bent into S and V shapes, need to be broken before stripping because they are difficult to be fed through the machine and will even block it. Some research has been done on the structure of the stripper to improve performance[25,125].

Meng et al.[123] analyzed the working principles of the brushes which are arranged in a non-linear pattern, and established a force model. Zhang[126] studied the force imposed on the stem during stripping. Mou et al.[77] recorded and analyzed the failure of the leaf sheath under the action of the flexible stripping element. Mou et al.[127] also did research on a leaf stripper with flexible brushes.

3.3 Modeling and computer simulation

Sugarcane harvesting is a complex system and while research in China started in the previous century, around 1960, there are still many problems to be solved. One of the important reasons for this is that there are complex kinematic and dynamic relationships operating between the machines and the sugarcane during the harvesting process. Many of them are not easy to observe but have a serious influence on the quality of the harvested sugarcane. Computer simulation technology therefore supplies a new method for research work in sugarcane mechanization[128,129].

Sugarcane is anisotropic, non-uniform elastic-plastic material[73,130]. It is necessary to propose the proper hypotheses and make appropriate simplifications while modeling the crop and the harvesting process[131,132]. Gao[133,134] studied the mechanical properties of sugarcane while growing in the field, and established an anisotropic physical model. He developed a sugarcane harvester-sugarcane simulation system which was based on the physical mode, and conducted simulations to assist the design of a screw-type crop lifter. Liu et al.[132] and Pu and Wu[135] studied the modeling methods for different materials.

The application of modeling and virtual simulation technology requires the integration of some software to establish a virtual design platform, which can then be used to modify an existing sugarcane harvester, or to develop new machines[136,137]. Deng et al.[138-140] established a virtual model for lodged sugarcane after analyzing the real situation in the field. By using the Engineering Software I-DEAS to do simulation analysis on the sugarcane crop lifter, they obtained some important parameters (the lift trajectory, lift speed, and acceleration speed) and were able to analyze the performance of the lifter with this approach. Based on the methods for component modeling, Deng et al. also proposed the “concept design and creative design” methods for designing sugarcane machinery components.

For lifter mechanisms, the main modeling and virtual simulations were on screw lifters[131,132,135,138,141,142]. Gao et al.[133] conducted theoretical and virtual simulations on the lifting process by the screw lift mechanism. Zhang et al.[143] designed a finger-bar chain mechanism to study the problems in harvesting lodged sugarcane. Virtual machinery experiments for lifting sugarcane were conducted, and the results coincide with the results of theoretical analysis.

The research on base-cutters comprised much of the virtual simulation research[100]. Research has also been conducted on the treatment of sugarcane stems[72,102], the influence of sugarcane size, and the dynamic response of the hydraulic system[86], as well as the influence on the number of broken roots caused by vibration, speed ratio, blade numbers, and inclination angle of the base-cutter[144,145]. Using Object ARX MFC technology, without considering the random vibration caused by terrain surface roughness, Liu conducted three dimensional simulations of blade trajectory using the AutoCAD2000 platform, and explored the mechanism of blade space kinetic trajectory and multi-blade cutting[146]. Zhao et al.[147] conducted simulations considering the random vibration caused by terrain surface and came up with much the same answers roughness (amplitude A = 50 mm, frequency f = 0.5).

The sugarcane harvester frame is a structure which holds the base-cutters, crop lifters, chopper mechanism and conveyor system in their respective places. It is subject to considerable vibration during operation, and its mechanical model, therefore, is forced vibration[148]. Using cutting blades as the input excitation source, Dan and Li built a virtual machine dynamics model for the harvester frame, and conducted the dynamic, virtual analysis[149].

In investigating optimum frame design, Hu et al. used AN-SYS software to carry out simulations with a virtual model of a sugarcane harvester frame[150,151]. Zhang et al.[152] built a finite element model for the frame of a leaf stripper, and carried out modal analysis and dynamic response analysis by simulation.

Feeding and trash separation (leaf stripping) are key steps in the sugarcane harvesting process. The performance of these components has potentially serious impact on the productivity of the machine and the trash content of the harvested sugarcane. Zhang did virtual leaf stripping experiments[153]. Pu et al.[154,155] built a virtual model for a finger-bar type sugarcane feeding mechanism, and also conducted simulation studies.

Using the hydraulic analysis module in ANSYS software, Meng et al. conducted simulations and analysis of the air flow inside the leaf stripper, and optimized the structural parameters for the leaf stripping component[137,156-158].

There is more work that can be reported using modeling and computer simulation methods on sugarcane harvester design, components research, sugarcane-soil system properties, etc[5, 10, 146,155,159-167].

To summarize, the modeling and computer simulation work has shown the advantages of kinetic and dynamic research, and have helped make progress in sugarcane mechanization research in China. More research is necessary in the following aspects:

1) Improving the accuracy of key components of these models using the real data from field and laboratory experiments.

2) Based on the virtual models of the various components, building simulation models for whole machines and developing the evaluation models and methods to evaluate the performance of whole machines.

3) Conducting system dynamics simulation research on sugarcane-soil-harvester systems[128].

4 Research into sugarcane mechanization systems and production patterns in China

It has been mentioned that more than one type of mechanization system may be needed in China. It has been estimated that only 10 percent of the existing sugarcane growing area could be handled efficiently by large machines such as those used in Australia, the United States, and Brazil. Smaller machines suitable for small farms, steeply sloping land, relatively low sugarcane yields, and less developed transport infrastructure, need to be developed[5,15]. Following the usual adoption process of machinery application, much testing of innovations and theoretical research of alternative mechanized production systems has been conducted and the main issues addressed by these systems research projects will be described in this part of the paper.

4.1 Research on sugarcane mechanization systems

4.1.1 Partial mechanization of key processes in the production system

In the early years of this century, many researchers in China believed that priority should be given to the development of small and medium-sized mechanization systems, because of the complex terrain and undeveloped infrastructure in sugarcane areas. These put the emphasis on the development of key processes which were seen as more important in improving the economic efficiency of the whole system, and were adapted to the existing situation in most countryside areas. They included land preparation, cultivation and fertilizing, ridging for planting, simple wholestalk harvesters, and leaf strippers[168-173].

Up to now, these points of view have been held by many researchers and government departments[16,174,175].

Zhang et al.[176] compared the cost of activities in sugarcane production using machines and human labor. The results showed that the mechanized system costs 14.19% less than the manual system. Among all of the activities, harvesting cost more than any other operation in the mechanized system, while planting potentially saved more than any other activity. Zhang suggested that planting and harvesting were two operations that needed early mechanization.

4.1.2 Large scale fully mechanization system

As mentioned previously, the machinery for large scale fully mechanized sugarcane production systems has been introduced and tested at three different locations and over three period of time (1980-1986, 1996-2000, and after 2003) on the large farms in Zhanjiang. SCAU participated in these attempts to evaluate the process and the results of various mechanization projects have been previously reported[38,41,42].

In the experiments run over the1996-2000 period, a complete set of sugarcane machinery was imported from Australia together with the appropriate production technology to make a large scale test of sugarcane mechanization. Those experiments into sugarcane mechanization were evaluated and the economics analyzed by a research group from SCAU and UMAS, USA[42,177-179].

The experimental process indicated that mechanized production is a complicated engineering system, that needs advanced machines and agricultural technology as well as the close coordination of many factors such as field conditions and the weather, the level of management and service, and the cooperation of all sides (growers and the mill) in the process. Lack of cooperation by any partner in the process could affect the working efficiency of the whole system. To evaluate and summarize these experiences in large scale mechanization experiments was important to promote the development of sugarcane mechanization and improve the standard of agricultural mechanization in China. Any delay in carrying out any of these tasks could affect the working efficiency of the whole system. To develop mechanization of the sugar industry in China, socialization of farm machinery services may be required and a strict management system should be established. Land selection, machine coordination, harvesting management, and personnel training are all problems that should be solved properly and synchronously. Economic analysis of the experiments showed that although there were about 300 ha of land involved, the scale was still too small compared with the capacity of the set of machines used. The economic efficiency achieved in these experiments did not reach the desired level[180].

Mechanized production can lead to high economic returns if adopted on a large scale. Small-scale operation does not take advantage of the machines' working capacity and benefits from scale of operations could not be obtained. Hunt[181] indicated: "Profit is the reason why an agricultural system exists." The objective of mechanization should be to improve working efficiency and gain profit, but in the Guang Qian mechanization test, yield was strongly emphasized and profit from scale of operations was relatively ignored. When dealing with mechanization, it is necessary to change the way of thinking from increasing yield to increasing profit.

According to the experiments, the machinery used must be carefully selected to operate efficiently and rationally. For example, large tractors could do heavy duty jobs, but small Chinese tractors used to do some light duty work would not only enhance their availability but also reduce production cost. Harvester and transporters must combine as part of a rational system to make the large scale machinery work efficiently. It would be much more risky to import whole sets of machinery from overseas to carry out a complete sugarcane mechanized program while the mechanization route that combines imported and domestic machinery, technology, and management would be feasible.

Zeng et al.[44] described the whole mechanization system for sugarcane on Fengshou Farm. They undertook a systems analysis of the whole system's operations, and found that the experiments were running well and that there was a need to continue the investigations. Huang et al.[182] confirmed that it is necessary to match machines according to the operating program, power required, and agronomic requirements. Chen[36] pointed out that after investigating sugarcane mechanization on their large farms, they could reduce the cost of sugarcane production, reduce labor intensity, and increase profit, concluding that it was desirable to develop sugarcane mechanization in China.

As mentioned previously, Jinguang Farm, part of Guangxi Agricultural Reclamation Bureau, provided an excellent demonstration of a large scale sugarcane mechanization system. In 2008, they established a mechanization service team, run from a base on Jinguang Farm. They created an industry management pattern that involved the large farms, machinery bases, and sugarcane growers. They have made significant progress with this style of industry management[45].

4.1.3 Mechanized harvesting systems

Ou et al.[168] and Liang[171] proposed that it was necessary to develop three kinds of mechanized harvesting systems simultaneously in China, namely large, medium, and small sized harvesting systems. Many authors[59,171,172,183-186] have pointed out the problems with sugarcane harvesting systems in China, and proposed the development of countermeasures. Some other authors offered suggestions for the development of sugarcane mechanization in Guangxi which as pointed out earlier has a high proportion of steeply sloping land under sugarcane[58,60,61,187].

The mechanized sugarcane system based on imported large-scale harvesting machinery was studied[36,38,42,168]. The performance of the Case chopper harvester and its complementary mechanized sugarcane farming system was tested and compared with manual work and the small scale sugarcane harvesting system. The results indicated that the introduced large-scale harvesting system provided higher working efficacy and the economic benefit was significantly higher than manual work. This system is suitable for large areas and large scale sugarcane production, while the small domestic machines are suitable for small scale household cane growers. Liao et al.[188] analyzed the present situation with large scale sugarcane harvesting in China, noting its slow development, and put forward some alternative ideas.

For harvesting sugarcane in the hilly areas, Zhang et al.[87] proposed that it was better to develop both a small wholestalk harvester and a medium size combine harvester simultaneously in order to promote the whole development and working efficiency of sugarcane harvesting in those areas. Wang et al.[189] did an analysis of the economic efficiency of the small sugarcane harvesting system and found that it was feasible to use the small chopped sugarcane harvesting system in present circumstances in China.

Huang et al.[174] considered the circumstances which applied to sugarcane production in Nanning, Guangxi, as well as how to extend the adoption of sugarcane harvester system.

In order to optimize machinery selection and scheduling for a mechanized sugarcane farm using a large harvesting-transport system, a non-linear programming analysis for machinery selection and an integer programming analysis for machinery scheduling were developed by Yu[190]. It showed that simulating the decision problem was a good way to optimize the machinery selection issue and scheduling harvest-transport operations for a large mechanized sugarcane farm[190].

4.2 Research into mechanized patterns of sugarcane production

Similar to the concept of “pattern analysis” in statistics, “pattern” is also used in mechanization research. **“**Pattern” means a typical style (or representative state) of something, or a standard way of behaving. In agricultural mechanization, “pattern” is used to describe a typical style of mechanization for one crop in a particular area and situation. “Pattern” research is very important in academic research and also in government policy making in China. It can guide the actions of the government, for instance, in establishing research projects. Following the advance of agricultural mechanization, the pattern of mechanized sugarcane production is increasingly valued. In 2012, for the first time, the No.1 Document from the central authorities contained the words “explore the production pattern for full agricultural mechanization”. It means that the importance of designing mechanized production systems has been acknowledged by the Chinese leadership[191].

4.2.1 Review of the main factors impacting on pattern research into mechanized sugarcane production in China

Ou et al.[168] put forward the suggestion to conduct research on mechanized patterns for sugarcane production, and proposed some preliminary ideas. You and Yao[162,192] analyzed the main factors which restricted the development of mechanized sugarcane systems. Liang[16] analyzed the suitability and economic efficiency of sugarcane machinery, and proposed a development pattern which was suitable for the situation in Guangxi Region. He suggested that the developmental plan for Guangxi should put the emphasis on small- and medium-sized machinery which could improve the production conditions and promote economic efficiency. He suggested developing deep ripping, cultivation, irrigation, and simple harvesting technologies in order to reduce the production cost and increase the yield[171].

Yunnan Sugarcane Research Institute organized an investigation into the location of land cultivated for sugarcane in that province. Using satellite remote sensing technology, they have assessed the terrain of the sugarcane fields according to the gradient. This work gave a solid scientific basis to guide the development of sugarcane mechanization in Yunnan province. Guangxi Academy of Agricultural Machinery Research did similar work[15, 64].

4.2.2 Research on mechanized production patterns for sugarcane using terrain, landform, and the sugarcane harvesting system as the main criteria

On the basis of previous research work, Ou et al.[15] proposed a classification method for land suitable for mechanized sugarcane production using the terrain and landform data, together with the potential sugarcane harvesting system, as the main criteria. Research indicates that essential factors in any mechanized system of sugarcane production include the machinery selected and the related agriculture. Thus terrain and landform of each area, block size, and management system all influence the type of machines that can be used. Ou et al.[15] proposed four different patterns for sugarcane mechanization following the classification method described above to meet the situation in China: large scale fully integrated mechanization, medium scale fully mechanized, small scale partially mechanized, and mini scale semi-mechanized systems.

According to the investigations in Yunnan and Guangxi, only 10% of the current sugarcane planting area is suitable for the large scale mechanization pattern, and 40% is suitable for medium scale mechanization[15,64, 193].

The emphasis on developing mechanized sugarcane production, therefore, lies in giving priority to large- and medium-scale mechanization systems. For the large scale pattern, the mature experience of foreign countries can be followed together with the features of the agricultural reclamation system in China. This style of mechanization has been demonstrated and could be adopted, although restricted to 10% of the area. Medium-scale mechanization which can work on 40% of the area, is the key to sugarcane mechanization in China. In both the large- and medium-scale systems, the emphasis should be put on the development of the harvesting part of the system, especially the chopped sugarcane harvesting system[2,15].

The mechanization of sugarcane harvesting in China should aim to select an optimal harvesting system, introduce timeliness of operations, reduce human drudgery, and improve overall production efficiency. As stated previously, this will involve a mix of large-, medium-, and small-scale harvesting systems.

4.2.3 “Agricultural Industry Special Project” on sugarcane mechanization

As part of the 12th National Five-Year Plan introduced in 2010, the Agricultural Mechanization Bureau of the Central Government Ministry of Agriculture established a five year project “Agricultural Industry Special Project” named “Technology and equipment development on fully-mechanized sugarcane production”. The objective was to do practical research on the various patterns of sugarcane mechanization. Eight institutions take part in this project, with SCAU as the lead agency for the project.

The project set up six production bases to demonstrate mechanized sugarcane production in Guangxi, Guangdong, and Yunnan provinces. These experimental demonstrations of the technology and key equipment required for completely mechanized sugarcane production on a large scale, medium scale, small-medium scale, and for the partially mechanized sugarcane production systems with small scale and mini scale equipment suitable for mountainous areas, have being conducted now for more than two years.

5 Development trends and policy suggestions

5.1 Harvesting problems and development trends

1) Development stage

Sugarcane mechanization in China is still in the experimental and demonstration stage. This will continue for a few more years. Government and relevant institutes will put more emphasis on this work.

2) Development pattern

Since the conditions for sugarcane mechanization in China are so complicated, more than one type of mechanized system is needed in China. Recall the discussion about patterns of harvesting systems when the options for large, medium sized, small, and micro mechanized systems were discussed. In the No.1 Document of the central government for 2012, the authorities put forward the idea “explore the production patterns for fully mechanized agriculture”, so the investigation of various types of sugarcane production and harvesting systems that involve the full use of machinery will continue.

3) Achieving scale of operations and socialized machinery services in sugarcane production.

The small scale of household sugarcane growers’ businesses in China restricts the application of mechanization technology in sugarcane production and the achievement of intensive management advantages. To improve the scale of operations, some form of socialized machinery service is necessary as the next step. There is considerable discussion at present on the best way to provide these services, whether it should be through existing government agencies (e.g. agricultural machinery bureaus) or whether the development of private contractors to provide these services ought to be encouraged.

4) Lack of mature machines suitable for most of the sugarcane production situations in China is a significant limitation. The large, foreign-made chopper harvesters are adapted to only a few places in China. The introduction of advanced foreign machines will only solve a small part of the sugarcane mechanization task. Domestic machines, however, are not mature enough at this stage. As the labor shortages grow and labor prices continue to increase, sugarcane growers need mechanization urgently. The R&D and demonstrations to solve this urgent need for mature sugarcane planting and harvesting machines in the domestic market will be given more emphasis and there should be some significant break-throughs in the near future.

5) Research into and application of technologies such as electronic measurement, automatic control, and precision farming has been part of the developing trends in sugarcane production in many countries. As we have seen in other industries in China, and in agriculture in other parts of the world, these technologies will also be ultimately adopted in Chinese farming and are part of the development trends.

6) Coordination within the sugarcane production system

The mechanization of sugarcane production is a complex systems engineering task, which requires cooperation between the sugar mill, sugarcane growers and sugar companies, as well as the other parties who are involved. Establishing a management pattern which is adapted for China's national conditions is essential.

7) Coordination between machinery and agriculture

The coordination between machinery and agriculture is poor at the present time in China and causes serious problems. A typical case is that mechanized production requires wider row spacing (wider than 1.2 m), while the traditional row spacing in China is about 0.8-0.9 m. It is essential to solve this coordination problem which may involve developing new varieties suitable for mechanized farming. Serious lodging of sugarcane does cause many difficulties for field management and mechanized harvesting. Breeding new varieties of sugarcane with lodging-resistance and suitability for mechanized production and harvesting will be important for widespread adoption of mechanized operations and more work will be necessary on this aspect in coming years.

5.2 Policy suggestions

1) It is essential to publicize information about the current stage of sugarcane mechanization so that everyone understands fully that the present stage of development in sugarcane mechanization is experimental and demonstration. Thus it is essential to establish appropriate policies according to the situation and needs of the current stage of development. It is also important to have a clear view of where this development could ultimately lead so that current policies do not adversely affect achieving the best long term position for the sugar industry.

2) China should strengthen inputs into the experiments and demonstrations of full-scale, integrated mechanization of sugarcane production, and investigate the different routes to sugarcane mechanization that could be available, recognizing that several patterns of mechanized production will be needed to meet the requirements of the different production situations in the country.

3) More support from government for coordination between the development of agricultural machinery and agricultural technology will be essential in the future.

4) Appropriate research groups should organize and conduct more surveys of the conditions of terrain and land form in sugarcane production areas, to provide a better basis for policy making and appropriate development of mechanized systems.

5) More land renovation and amalgamation needs to occur, and it might be appropriate to give a financial subsidy for this work.

6) The attitude of sugar enterprises to mechanization is one of the key issues to influence the process of mechanization in sugarcane production. The experience in Australia and other countries shows that it is important to have the appropriate legislation in place to spell out

clearly the interests and relationships between the sugar mill, sugarcane growers, and management authorities so that all share appropriately in the rewards to be gained from mechanization. China will need to pay more attention to this issue.

7) Finally, China should continue to strengthen theoretical research into sugarcane mechanization systems and production patterns under modern agricultural conditions as well as making practical investigations of how to implement this enormous change in one of its important agricultural industries.

8) It might be appropriate to provide more financial assistance for research on highly sophisticated new technologies (such as electronic measurement, automatic control, and other elements of precision farming). Just as these technologies have been adopted in other Chinese industries, and are becoming part of farming in other countries, they will eventually be adopted in Chinese agriculture and the research is needed to prepare for that eventuality.

Acknowledgements

This research was financially supported by the following projects: The project on special scientific research fund of agricultural public welfare profession: Production technology and equipment development for full sugarcane mechanization (Grant No. 201003009); The National Five-Year Plan for 2011 to 2015 project on rural areas science and technology plans: The research and integrated demonstration of self-propelled sugarcane combine harvesting equipment (Grant No. 2011BAD20B05-3); the Ministry of Science and Technology Project on International Cooperation; the development of key technology and equipment for full sugarcane mechanization (Grant No. 2011DFB70350); and the National Technology System for Sugarcane Industry: Annual research fund. The authors would like to acknowledge the assistance of all the people who have contributed to this review paper.

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