

# Global overview of research progress and development of precision maize planters

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**Abstract:** Maize is the most important crop for food and widely used for industrial materials, leading to its increasing demand all over the world. Precision planting is the effective method to increase maize yield. To meet the agronomic requirement of precision planting, different kinds of precision maize planters were developed. However, because of the difference of geographical environment, cropping system, farm scale and economic status among different countries, types of maize planters are various and the technologies involved are at different levels. This paper summarizes the precision maize planters currently available in the world and classifies them into four types: precision planters for tilled-land, minimum/no tilled-land, hilly & small land, and cold & arid land. Detailed characteristics have been provided for some typical precision planters and comparisons were made as to their suitability under particular working conditions. High-efficiency and high-accuracy are the main features of precision planters for tilled-land, while the ability to clean residue from seed rows and prevent planters to be blocked are the important function of precision planters for minimum/no tilled-land. To fit for hilly & small land, planters should be light-weighted and small-sized, and to warm up soil and keep moisture, planters for cold & arid land should be equipped with plastic-film mulching mechanism. Finally, developing trend of precision planting technology was analyzed and suggestions, including policy support and technical improvement, were made for developing countries to make suitable precision maize planters according to the local geographical conditions and cropping systems.

**Keywords:** precision planter, maize, cropping system, research progress, overview

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## 1 Introduction

Maize is more and more widely used in food, medicine, chemical and industry with its ever-increasing demands in recent years. In 2013, maize has become the No.1 crop in the world and its global production is more than one billion tons according to the data of FAO.

Maize output is of strategic significance to ensure food security, promote animal husbandry industry and increase peasantry income<sup>[1,2]</sup>.

The major maize producers in the world are USA, China, Brazil, Mexico and Argentina, which contribute to 70% maize output of the whole world<sup>[3]</sup>. However, maize yield varied greatly in different countries. For

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example, in 2013, the maize yield of USA reached  $9.97 \times 10^3$  kg/hm<sup>2</sup>, while the data were  $6.0 \times 10^3$  kg/hm<sup>2</sup> in China and only  $2.45 \times 10^3$  kg/hm<sup>2</sup> in India. There are a lot of factors affecting maize yield and precision planting technology is considered as one of the important factors<sup>[4]</sup>. Precision planting can save seeds of 22.5 - 30.0 kg/hm<sup>2</sup> and increase output of 1.5 t/hm<sup>2</sup><sup>[5]</sup>. In recent decades, with the improvement of seed quality, germination percentage and emergence rate of maize seeds can be guaranteed, and as a result precision planting has become the main direction for seeding maize<sup>[6,7]</sup>.

Precision planters are crucial machines to implement precision planting<sup>[8]</sup>. In general, precision planter consists of furrow opener, fertilizer device, depth control unit, power transmission system, seed meter, press wheel and covering device. However, the actual structure and working principle of maize planters are various due to the difference of geographical environment, climate condition, cropping system and farm scale among different countries and areas. For tilled land with flat surface and appropriate planting condition, high-efficiency and high-speed precision planters are usually applied. As for no/minimum-tilled land, because of the existence of residue, anti-blocking devices are necessarily mounted on planters to cut or clean residue. In some hilly region or small land, small-sized and light-weighted planters are usually used due to the constraints of working condition. With regard to cold and arid areas, in order to maintain soil moisture and to increase soil temperature, plastic film mulching planters have been developed. This paper introduces currently available precision planters in the world and classifies these planters into four types: precision planters for tilled-land & scaled farm, minimum/no tilled-land, hilly & small land, and cold & arid land according to distinct regions and methods of soil preparation.

## 2 Precision planters for tilled-land and scaled farm

Tilled-land refers to the farmland after tillage and soil preparation. The objective of soil tillage is to provide high quality seedbed. Different countries usually adopt different soil tillage methods. Subsoiling and power harrow combined tillage are generally used in Europe,

while combined tillage machine with the multi-function of cutting stubble, sub-soiling and harrowing are mainly adopted in USA. However, rotary tillage is very popular in China. Since the soil surface is smooth, loose and no residue covered after tillage (Figure 1), planters will not encounter the trouble of blocking and weak penetration ability, so high precision, high-speed and high-efficiency are the main features of maize planters for tilled-land. To satisfy the requirements mentioned above, innovations on seed meter, seed delivery mechanism, intelligent monitoring and control system are occurred more and more frequently on precision maize planters.



Figure 1 Soil surface of tilled-land and seedlings after emergence

### 2.1 Precision seed meter

Seed meter is the most crucial component on planter to ensure seeding performance. To fit for precision planting under high working speed, different kinds of seed meters with each individual working principle were developed (Table 1).

#### 1) Finger pick-up seed meter

For finger pick-up seed meter (Figure 2a), spring-loaded fingers are mounted on a vertical disk, which rotates in a seed hopper. Fingers ride on a stationary disk, as they travel to the bottom of the hopper, fingers will open in sequences, and each finger picks up one or more seeds. With further movement, the finger passes across an opening in the stationary disk and the seed is ejected into the seed placement belt for transport to the seed tube. Due to its mechanical structure, there is a limitation of operation speed about 7-9 km/h. Searle et al.<sup>[9]</sup> evaluated the effects of field slope on planter seed spacing uniformity for three different seed metering units (cell plate, finger pick-up, and flat plate) operating with medium round corn seed in laboratory. Results showed that the finger pick-up was the least affected by slope, but affected by seed size. Real large seed can cause some under population, as the seed size gets smaller the characteristic of the finger pickup meter is to

overpopulate<sup>[10]</sup>. A finger pick-up precision seed-meter was studied by Wang et al.<sup>[11]</sup> based on the theory of discrete element method (DEM). The simulation results showed that as the rotational speed was between 15-45 r/min, the seeding quantity of medium-size grains was the best, and the qualified index was greater than 84%, followed by that of large-size grains. The seeding quantity of small-size grains was the worst and its qualified index was greater than 80%. Wang et al.<sup>[12]</sup> built a mathematical model based on the test of quadratic general rotary unitized design. The optimal wire diameter of spring and rotational speed of seed meter were obtained. Meanwhile, seeds damaged likely to occur during the picking up process. Under the background of high working speed and efficient modern agricultural development, they will be replaced in the longer term<sup>[13]</sup>.






2) Vacuum seed meter

In vacuum seed meter (Figure 2b), the vacuum created by an air pump holds the seeds in the seed cells on the rotating seed disk. The vacuum is blocked as the cells reach a point above the seed tube and the seeds fall into the tube by gravity. A seed cutoff wiper is used with the vacuum system to eliminate extra seeds which may have been trapped in a hole in the seed metering disk. Hydraulic-driven vacuum pump could be used to create a consistent vacuum to each metering unit. Gil et al.<sup>[14]</sup>

found that pneumatic seeders provided better results than mechanical seeders in terms of within row uniformity. Turan J found that pneumatic seed meter depends less on seed shape, uniformity of seed size and operating speed than mechanical seed meter<sup>[15]</sup>.

The performance of vacuum seed meter is mainly affected by seed size, seed shape, number of holes on seed plate and working pressure. Singh et al.<sup>[16]</sup> investigated the performance of the seed-meter of a pneumatic planter under laboratory and field conditions. It was observed that the planter disc with a 120° entry cone angle gave superior performance at all speeds and operating pressures. Yazgi et al.<sup>[17]</sup> evaluated the performances of vacuum plates with different number of holes in the laboratory. The highest performance was determined when 36 holes were used on disc for corn. The optimum vacuum pressure was determined as 4.0 kPa for maize by Karayel in 3.5 mm holes diameter<sup>[18]</sup>. Chen et al.<sup>[19]</sup> did simulation and experiment on the sucking nozzle air field, which affected sucking effect of air-suction seeder. The results showed that the bigger of the sucking nozzle diameter, the better of the sucking effect. Because of the stable operation performance, vacuum seed meters are widely used by many international agricultural machinery enterprises, such as John Deere, Kinze, Case IH, Precision Planting, Horsch, Moneson and so on.

Table 1 Comparison of different kinds of seed meter

Seed meter type	Picture	Working principle	Features
Finger pick-up seed meter		Spring-loaded fingers open in sequences to pick up one or more seeds from the bottom of seeds hopper, and release seeds across the opening on the top of stationary disk into the seed placement belt for transporting seeds to the seed tube.	Seeds are easily damaged by fingers at high working speed
Vacuum seed meter		Seeds are held in cells on rotating disc by negative pressure, and dropped into seed tube with the assistance of a cutoff wiper which blocks the vacuum as soon as the seed arriving at the outlet.	Wear gasket need to be replaced frequently.
Air pressure seed meter		Positive pressure provided by a blower hold the seed in cell located around the circumference of the disk. As seeds near the seed tube, a soft brush cuts off the air supply, and then seeds fall into the seed tube	Seed can be damaged when being shoot at high speed. Seed tube is easily blocked.
Air blowing seed meter		A cellular wheel with funnel-shaped cells rotates inside the metering house. Each cell is filled with several seeds. When the filled cells come to the seed hopper, surplus maize seeds are blown out of the cell by an air nozzle, and then the only single seed remains in the cell until it arrives at the outlet.	No requirement for seeds grading. Seeds are easily to be stuck between the seed plate and shell.
Centralized pneumatic seed meter		As the drum rotates, differential pressure holds seeds against each hole around the drum circumference. As the seeds are moved close to a seed tube, a row of external rollers near the seed tubes block the holes momentarily. Air then carries the seeds to the planting units and deposits them into the rows.	High requirement for air pressure.

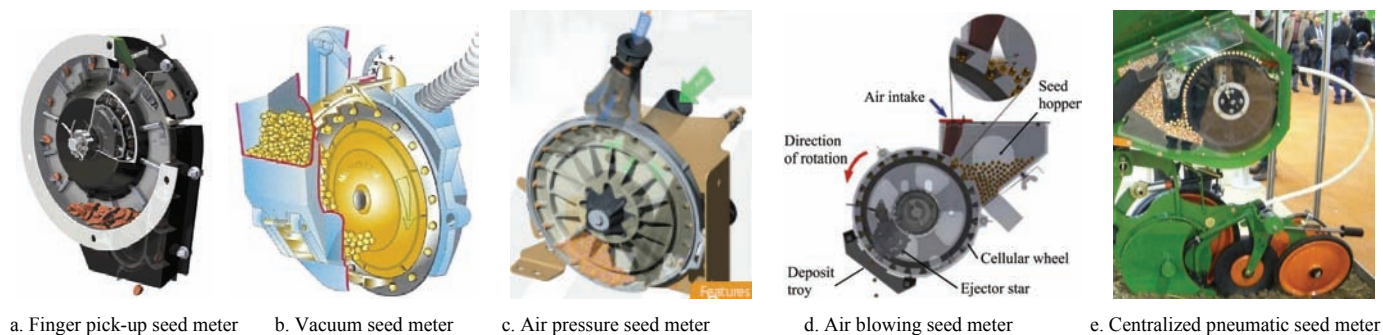


Figure 2 Precision seed meters for maize

### 3) Air pressure seed meter

For air pressure seed meter (Figure 2c), gravity moves the seeds from the hopper to the metering unit, positive pressure provided by a blower hold the seed in pockets located around the circumference of the disk. As each pocket nears the drop tube, a soft brush cuts off the air supply to the pocket and the seed falls into the seed tube and then into the soil by gravity. Most air pressure seed meters are broadly classified as ‘dropped type’ and ‘shot type’ according to the way the seeds enter into the tube. Seed meters produced by Great Plains<sup>[20]</sup> and White Planter<sup>[21]</sup>, are known as dropped type and tempo seed meter produced by Vaderstad is shot type. It is also the one with highest working speed of 15.8 km/h<sup>[22]</sup>. Shi et al.<sup>[23]</sup> had designed an air pressure seed meter for maize. The field test revealed that the qualified index rose steadily up to 97% with the operation speed of 7.89 km/h.

### 4) Air blowing seed meter

A cellular wheel with funnel-shaped cells rotates inside the metering house at the base of the seed hopper, individual cells are filled with several maize seeds. Once the filled cells emerge from the seed hopper, any surplus maize seeds are blown out of the cells by an air nozzle so that only one single seed remains at the bottom of the cells by air pressure till the cells reach the point where the seed is to be placed into the soil (Figure 2d)<sup>[24,25]</sup>.

There is no requirement for graded maize seeds for this kind of seed meter, and it is also better able to plant non-spherical shaped seeds. This simple system prevents significant wear-and-tear to the seed-sowing system. Mursec et al.<sup>[26]</sup> conducted a test of quality of sowing in five different working speeds by the air

blowing seed meter (Aeromat-Becker) for sowing sugar beet. The optimum sowing speed turned out to be 10 km/h according to the test.

### 5) Centralized pneumatic seed meter

The centralized pneumatic seed meter (Figure 2e) can be designed to serve four, six, or eight rows, depending on the number of rows of perforated holes that are provided. As the seed meter drum rotates, differential pressure holds seeds against each hole around the drum circumference. When the seeds are moved close to seed tubes, a row of external rollers near the seed tubes block the holes momentarily, thus removing the differential pressure and allowing the seed to fall into the seed tubes. Air then carries the seeds to planting units and drops them into seed bed of each row. The seed meter is widely applied on Amazone Xpress series planter, and the operation speed is up to 15 km/h<sup>[27]</sup>. Zhao et al.<sup>[28]</sup> designed a circular tube slit pneumatic precise wheat seed meter and did a contrast experiment with the existing mechanical seeder for wheat. The experiment indicated that seeding uniformity was significantly improved. Qi et al.<sup>[29]</sup> developed a centralized pneumatic seed meter for maize and carried out double factors equal repeated trials on a seed meter test-bed PS-12. The test results showed that, as the working speed was between 4 km/h to 10 km/h, the average single rate of the filling hole in a 4.5 mm diameter was 97.9%.

To evaluate the performance of different seed meters, researchers conducted a lot of comparison experiments. Pioneer Inc.<sup>[30]</sup> compared the performance of air pressure, vacuum, finger pick-up and plate seed meters and results showed that seed meter types do affect maize yield and air pressure seed meter was most suitable one for maize

precision planting. Pedro et al.<sup>[31]</sup> compared the performance of pneumatic seed meter and horizontal perforated disc with and without ramp and results showed that there was no significant difference between seed meters.

**2.2 Electrical driving system for seed meter**

Seed meters of conventional precision corn planters are usually driven by ground wheel and chain and sprocket system, and as a result, planting accuracy cannot be ensured because of the existence of ground wheel slippage and chain vibration, especially in higher forward speed. To solve the problems mentioned above, an alternative power transmission method which adopted electrical motor replacing mechanical driving system to drive seed meters was developed<sup>[32]</sup>. The electrical motor driving systems are divided into two types: driving system in axial direction and in circumferential direction.

Driving system in axial direction is a mode that the shafts of seed meters are driven by motors directly or indirectly. Seed meters do not need to be modified but high torque motors are required. So, gear reducers are usually installed at the output end of motors to increase the motor torque. Therefore, lateral size of seed meters becomes larger. Horsch and Vaderstad (Figures 3a and 3b) have developed a direct-driving method by installing motor with gear reducer directly on the shaft of seed meter, which results in larger lateral size of seed meters<sup>[33,34]</sup>.



Figure 3 Seed meter driven by motor with gear reducer on shaft

Monosem and Becker (Figures 4a and 4b) developed a driving method by installing motor with gear reducer at the front or rear end of seed meter to avoid over-large size. Transmission between motor and seed meter is done by synchronous belt or sprocket chain<sup>[35,36]</sup>. Relative studies were also made by Tang in Hebei

Agricultural University<sup>[37]</sup>, Li in Gansu Agricultural University (Figure 5a)<sup>[38]</sup>, Wang in Nanjing Agricultural University<sup>[39]</sup> and Northern Rongtuo Inc.<sup>[40]</sup> (Figure 5b). In those studies, high-torque motor without gear reducer was applied to drive seed meter on shaft directly. Although the whole system is simple in structure, the energy consumption is high.

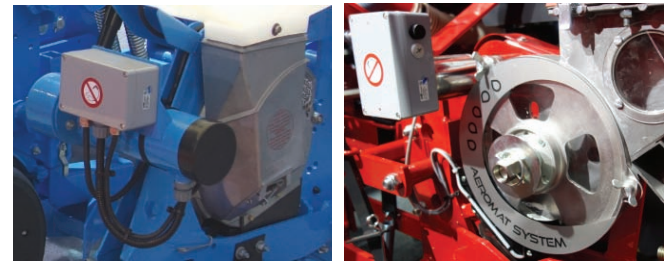


Figure 4 Seed meter driven by motor with gear reducer through chain-sprocket or synchronous belt



Figure 5 Seed meter driven by high-torque motor on shaft without gear reducer

Driving system in circumferential direction was developed to solve the problem of over-large lateral size and high requirement for motor torque. Power was transmitted from motor to seed meter through the meshing between gear and outer gear ring on the edge of seed plate. This driving method requires low torque motor and also has the merits of compact structure and smooth transmission. However, structure of seed plate is needed to be improved. Precision Planting Inc.<sup>[41]</sup> developed a seed plate (Figure 6a) with its circumference designed to be outer gear wheel which meshed with a small gear installed on the shaft of a motor. Kinze<sup>[42]</sup> designed a seed plate with an inner gear ring which meshed with a small gear installed on the shaft of a moter (Figure 6b). Yang et al.<sup>[32]</sup> developed a seed plate with an outer gear ring fixed on its back (Figure 6c). Moreover, in order to install motors conveniently, improvements are also needed on structures of seed meter shells.

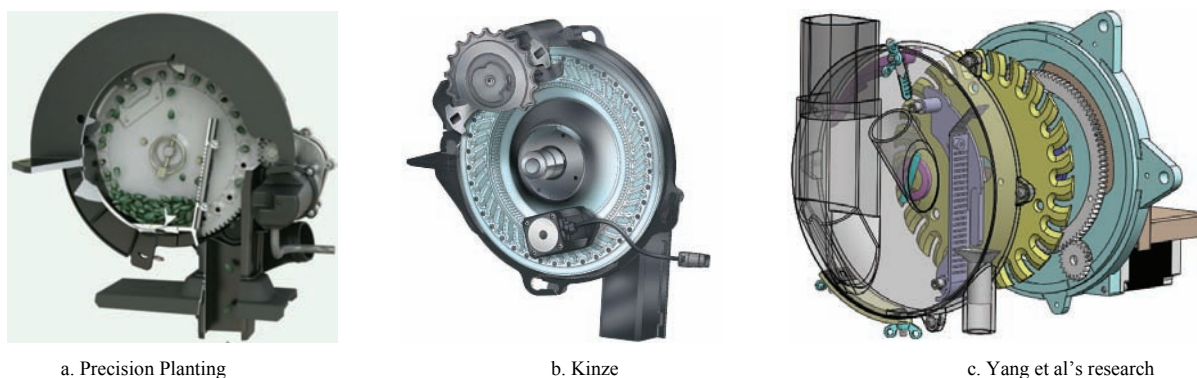


Figure 6 Driving system in circumferential direction

### 2.3 Seed delivery mechanism

Seed delivery mechanism is mounted at the outlet of seed meter, which is used to guide seeds to furrow smoothly. Seed delivery mechanisms are divided into three types: round seed tube, square seed tube and belt delivery system.

#### 1) Round seed tube

Round seed tube is flexible hose, which is mainly used in air pressure seed meter (Figure 7a). A kind of round seed tube, which was mounted at the outlet of air pressure seed meter, was developed by Vaderstad Inc. When working, seeds are “shot” through the seed tube because of the force of air flow and therefore it is insensitive for both slopes and vibrations<sup>[43]</sup>.

#### 2) Square seed tube

Square seed tube (Figure 7b) is used for keeping seeds dropped from seed meter along its wall to maintain uniformity of seed spacing. The shape of square seed tube is designed based on the trajectory of seed flow. When the rotation speed of seed plate is less than 30

r/min, square seed tube performs well and uniform seed spacing can be kept. However, when the rotation speed of seed plate is more than 30 r/min, bounce and roll of seeds aggravate when they go through square seed tube, which leads to worse uniformity of seed spacing<sup>[44-46]</sup>. A square seed tube called BullsEye was developed by Precision Planting Inc., which could keep seeds in a direct path to seed trench and would not change the previous distance between adjacent seeds<sup>[47]</sup>. Liu et al. conducted a contrast experiment using a designed seed tube, imported seed tube and without seed tube and results showed that seed tube can effectively improve seeding quality and the performance of the designed seed tube is equivalent to the imported one<sup>[48]</sup>. Kocher et al.<sup>[49]</sup> evaluated variation of corn seed spacing for two seed tube conditions (new or worn) with two corn seed shapes (round or flat). Results indicated that the new seed tube had better seed spacing uniformity than the worn one and the round corn seeds had better seed spacing uniformity than the flat ones.

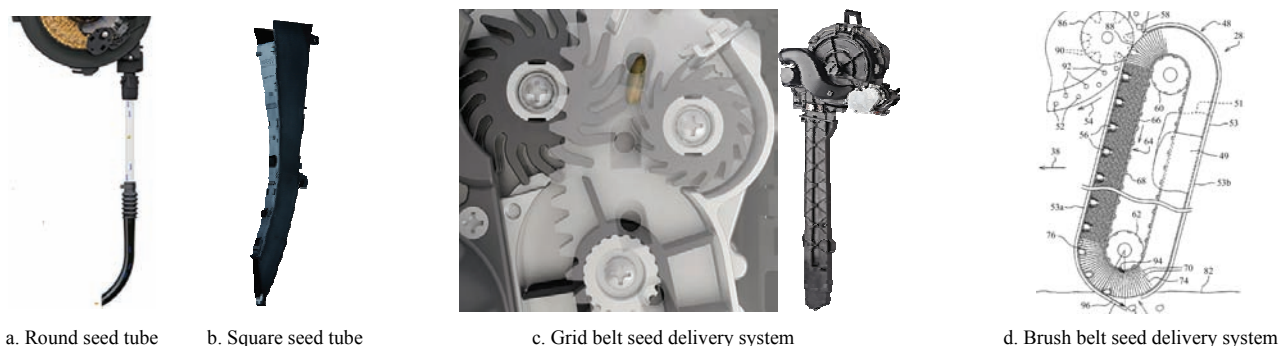


Figure 7 Seed delivery mechanism

#### 3) Belt delivery system

Belt delivery system was developed to ensure the uniformity of seed spacing when planters worked at high speed. A belt delivery system called Speed Tube was

developed by Precision Planting Inc. (Figure 7c) which could grab seeds from seed plate and hold seeds all the way to seed bed by a grid belt<sup>[50]</sup>. A brush belt delivery system (Figure 7d), which could take seeds from seed

meter and move seeds to seed bed by a brush belt, was developed by John Deere Inc.<sup>[51,52]</sup> The delivery system can improve working speed of planters to a fastest speed of 10-16 miles per hour.

### 2.4 Intelligent monitoring and control technology

Seed sensors used for monitoring seeds are the key component of intelligent monitoring and control system. Opto-electronic sensor is widely researched and used due to its low cost. Dickey-John Inc. developed an opto-electronic sensor in 1966, which could monitor seeds in real-time<sup>[53]</sup>. Lan et al.<sup>[54]</sup> designed a sensor system with 24 phototransistors and 24 light-emitting diodes to measure seed spacing uniformity. Shi et al.<sup>[55]</sup> adopted red laser diode (RLD) to transmit and silicon-photocell to receive light source, which could cover the profile of seed tube perfectly. Zhang et al.<sup>[56]</sup> designed a new sensor with high detection accuracy. Due to opto-electronic sensors could be easily made in a variety of shapes based on working conditions, the installation of opto-electronic sensors is quite flexible and sensors could be mounted at the outlet of seed meter (Figure 8a), in the middle of square seed tube (Figure 8b) or round seed tube (Figure 8c)<sup>[57-59]</sup>.

However, opto-electronic sensors are susceptible to

interference from dust in field<sup>[60]</sup>. To solve this problem, Zhou et al.<sup>[61]</sup> designed a capacitive sensor to receive and process capacitance signal of maize seeds. Wang et al.<sup>[62]</sup> researched a sensor based on sensor's voltage changing caused by seed hitting sensor surface, but it did not perform well at high working speed. Precision Planting Inc.<sup>[63]</sup> developed a radio wave sensor (Figure 8d) to detect seed mass instead of seed shape to eliminate the interference from dust in field.

According to signals received from seed sensor, the monitor controller calculates population per hectare and time interval among adjacent dropping seeds, and displays relative parameters on screen. If seeds are not detected in expected time, alarm will work. Changzhou Jade Electronics Inc. developed a BJ8 monitoring system (Figure 9a) for detecting dropping seeds based on opto-electronic sensor, which could monitor 8 planting rows at the same time<sup>[64]</sup>. New methods combining seed detecting sensors with radar ground speed sensor or GPS developed by Precision Planting (Figure 9b), Agleader (Figure 9c), John Deere (Figure 9d) and other companies could measure the seed spacing as well as the quality of feeding index, missing index, multiple index and Precision index<sup>[65-69]</sup>.

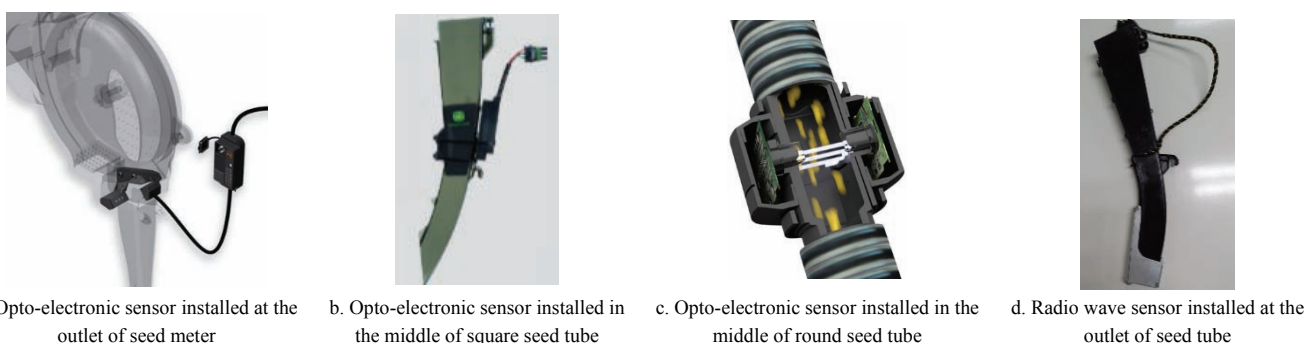


Figure 8 Different kinds of seed sensor for monitoring planting quality

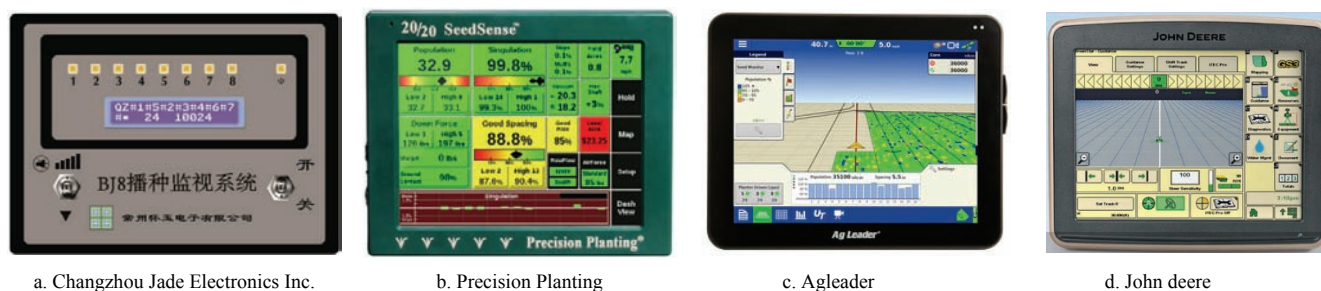


Figure 9 Variable monitor controllers

Based on the innovations and high techniques mentioned above, many typical planters for tilled-land

and scaled farm are developed (Table 2).

**Kinze 3110 Planter** (Figure 10a) is equipped with an

improved finger pickup seed meter which makes it more suitable for a wide variety of seed shapes and sizes. A Bolt-On Height Adjustable Wheel Modules is used to adjust toolbar height for flatland planting or different heights for beds. However there is a limitation of operation speed, due to speed above 8 km/h will lead to a significant decrease of planting quality<sup>[70]</sup>.

**John Deere 1725NT** (Figure 10b) is the latest precision planters at present. High precision vacuum seed meter, with a new mini-hopper to receive seeds from CCS tank, is mounted on each row unit. Touch screen and control system are located in the cab, so that the operator can easily setup or adjust the wanted working

parameters. 1725NT precision planter is also equipped with brush belt delivery system, it can work at high speed of 16 km/h with high planting accuracy<sup>[71]</sup>.

**Vaderstad Tempo series planter** (Figure 10c) is equipped with an electrical driven air pressure seed meter and trailed carrying wheels. The electric drive of all seed meters makes it possible to shut off the row units one at a time. The great advantage with trailed carrying wheels is that the machine has lower inertia. In addition, the carrying wheels are mounted on a bogie unit, which maintain more uniform drilling depth in uneven field conditions<sup>[72]</sup>.

**Table 2 Comparison of precision maize planters for tilled-land and scaled farm**

Machine name	Row number	Type of seed meter	Type of fertilizer opener	Matched power /hp	Working width /m	Working speed /km·h <sup>-1</sup>	Working efficiency /hm <sup>2</sup> ·h <sup>-1</sup>
Kinze 3110	6/8	Finger pickup seed meter	Double-disc	80-120	4.5-6	6-8	2.7-4.8
John Deere 1725NT	8/12/16	Vacuum seed meter	Double-disc	>180	7.3-12.16	16	11.6-19.4
Vaderstad Tempo series	4-12	Air pressure seed meter	Double-disc	>100	2.8-9.12	15.8	4.4-14.4
HORSCH Maestro RC	8	Vacuum seed meter	Double-disc	180	5.6	12	6.7
Amazone EDX6000-TC	8	Central drum seed meter	Single-disc	170	4	15	9



a. Kinze 3110 Planter



b. John Deere 1725NT precision planter



c. Vaderstad Tempo series planter



d. HORSCH Maestro RC



e. Amazone precision planter

Figure 10 Precision planters for tilled-land and scaled farm

**HORSCH Maestro RC** (Figure 10d) driven by tractors with 180 horsepower, can till soil and plant maize at the same time. Soil preparation is completed by notched-discs which mounted in front of planting apparatus, while planting apparatus is installed at the rear.

The distinguishing feature of Maestro RC is the intellectualized precision planting system which consists of electrical motor driven seed meter and monitoring

system. The pneumatic seed meter driven by electrical motor has the merits of small size, high planting precision and high working speed of 12 km/h. Further, seed spacing and seeding rate can be adjusted and switched individually. The electronic monitoring system can detect the amount of missing and double seeds and at the same calculate the qualified feeding index, missing-seeding index, multiple index, and coefficient of



variation of each row. When planting issues come up, the alarm system will be activated to guarantee a stable performance in high-speed working condition<sup>[73]</sup>.

**Amazon EDX6000-TC precision planter** (Figure 10e) consists of a centralized pneumatic seed meter, a single-disc fertilizer opener and a double-disc coulters for seeds with sliding knife being mounted between the discs. Its typical characteristic is that seeds are carried by air and delivered directly into the rows. After dropping, press wheel is used for placing and firming seeds immediately to prevent seeds bouncing on seed bed and to improve the planting precision. The highest planting speed is up to 15 km/h<sup>[74]</sup>.

In some cold areas (for example, northern areas of Heilongjiang Province, China), ridge planting pattern is mainly applied to raise soil temperature in early spring and to prevent waterlogging in wet-season<sup>[75-77]</sup>. After harvesting in autumn, soil was tilled by sub soiling or deep-plowing. Next spring, rotary tillage and ridging were applied and then seeds were planted directly on ridges, or the procedure of rotary tillage and ridging was done in previous year and only planting was carried out in next spring (Figure 11). Hayhoe et al.<sup>[78]</sup> found that low seedbed temperatures at planting season reduce rate of corn germination, emergence and final stand establishment at many corn locations in Canada. Jabraeil et al.<sup>[79]</sup> compared the different performance of soybean planting methods in North-West Iran and results indicated that ridge planting had maximum percentage of seed germination and highest yields. Kumar et al.<sup>[80]</sup> carried out some research on feasibility and economic viability of ridge planters in western plane zone of Uttar Pradesh, India. The research indicated that the ridge planter can be used for wheat successfully, and an efficient ridge planter with multi-crop seed metering mechanism can also be used for planting other bold and small seeds.



Figure 11 Ridging and seedlings on ridge

In order to fit for ridge cultivation, a number of precision planters have been developed (Table 3).

**2BYQC-7 air-blowing precision planter** (Figure 12a) is a kind of planter fitting for planting maize on prepared ridge bed, which is very popular in northeast China. Air-blowing precision seed meter was adopted to maintain uniform seed distribution and press wheels which are as wide as ridge are used for smoothing ridge bed. The planter is suitable for precision planting under the working speed of 8 km/h.

**2BQD-12 vacuum precision planter** (Figure 12b) was developed to adapt to big ridge cultivation model in China's Heilongjiang reclamation area. The planter can plant 12 rows at each time, with 2 rows on one big ridge and the distance between adjacent ridges of 1.1 m. The adjacent planting units are mounted in staggered orders. The dry topsoil is cleared away and thus seeds can be planted in wet deeper soil. The highest working speed of this planter is 6 km/h.

**Maschio MT-6 precision planter** (Figure 12c) is a precision planter for planting maize on ridges with width of 1.1 or 1.3 m. Vacuum seed meter is used and high accuracy with planting speed of 8 km/h can be obtained. A new seed meter driving method with steering drive shaft and bevel gear replacing chain driving makes power transmission more reliable and stable<sup>[81]</sup>.

Since tilled-land is smooth, soft and operating conditions are better, high-precision and high-speed planters have been the developing trend of maize planting. Therefore, the stability of transmission, the accuracy of seed meter, electrical-driven or hydraulic-driven transmission, down force control are becoming the main research subjects.

**Table 3 Comparison of precision maize planters for ridge cultivation**

Machine name	Row number	Type of seed meter	Type of fertilizer opener	Matching power /hp	Working speed /km·h <sup>-1</sup>
2BYQC-7 air-blowing precision planter	7	Air-blowing	Sliding knife	80	8
2BQD-12 air-suction precision planters	12	vacuum	Single-disc	120	6
Maschio MT-6 precision planter	7	vacuum	Shoe type	85	8



Figure 12 Precision planters for ridge cultivation

### 3 Precision planters for minimum/no tilled-land

Minimum-tillage and no-tillage are the methods that need not turn soil over and try to reduce tillage times<sup>[82]</sup>. In single cropping areas such as America and Australia, no-tillage planter works on land covered with crop residues from the previous year<sup>[83-85]</sup>, while in double cropping areas in Asia, no-tillage planter works directly on land with heavy residues just after harvesting, so anti-blockage devices, such as pulling and cutting wheels, are necessarily mounted on planters. To enhance the ability of anti-blocking, positive and negative anti-blockage mechanisms are respectively developed. Minimum/no-tillage precision planters are divided into two parts as follows: planters for single cropping areas and planters for double cropping areas.

#### 3.1 Minimum/no-till precision planters for single cropping areas

In single cropping areas, crop residues decomposed in last autumn and winter (Figure 13), therefore, different kinds of disc coulters (Figure 14) are usually applied to cut crop residues by self-weight<sup>[86]</sup>. Wang et al.<sup>[87]</sup> optimized the parameters of residue cutting disc. Zhao et al.<sup>[88]</sup> found that the forward speed of planter and the in-soil depth of cutting disc were the main factors affecting residue cutting performance. Lin et al.<sup>[89]</sup> designed a notched cutting disc with Archimedes spiral which effectively improve the planting effect. A finger wheel row preparation device (Figures 14f, 14g) is also used in front of the coulters to remove residue from seed rows. Fallahi et al.<sup>[90]</sup> had proved that row cleaner increased the qualified feed index and decreased missing and precision indices based on the test in NW Shiraz, Iran.

The benefit of no-till seeders had also been proved. He et al.<sup>[91]</sup> conducted a field trial to assess the effects of

three typical row cleaners (powered-chopper, powered-cutter and powered-disc) on no-till seeders and compare with a traditional seeder. The results indicated that the no-till seeder with powered-disc promoted crop emergence and growth, and improved 1.8%-6.9% of spring maize and wheat yields as compared to powered-chopper and -cutter.



Figure 13 Residue on single cropping fields

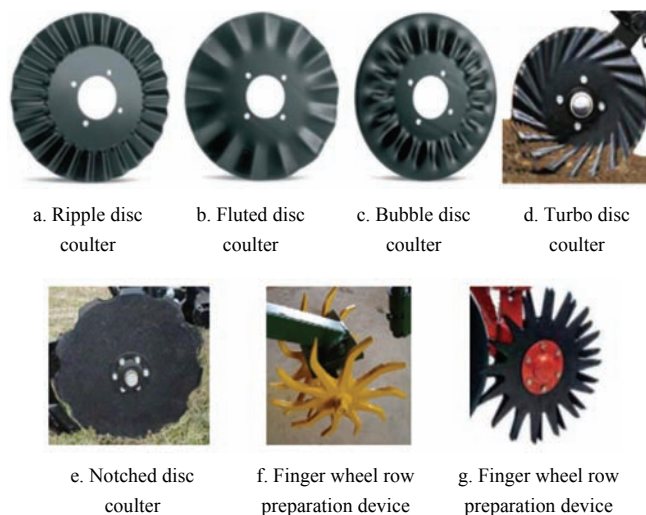


Figure 14 Different types of row cleaner

Some planters associated with the technologies mentioned above are as follows (Table 4).

**Kinze 3500 series no-till precision planter** (Figure 15a) installed a ripple-edge disc coulters in the front of the planter to cut crop straws and residues, and then the following opener can easily make furrow for seeding. Vacuum seed meters are applied for precision planting and the working accuracy can be up to 99% at the forward speed of 12.9 km/h.

**Kuhn MAXIMA2 no-till planter** (Figure 15b) adopts finger-wheel row cleaners to remove residues on seed rows. To work successfully at land boundary where row numbers on plot are less than that of the planter, each seeding unit can be individually shut off and raised up.

The highest speed of this planter is 8-9 km/h<sup>[92-94]</sup>.

**DEBONT 2605 vacuum no-till planter** (Figure 15c) applies notched disc in the front of the planter to cut residues and make furrow for fertilizer application with a top forward speed of 9 km/h<sup>[95]</sup>.

**Table 4 Comparison of no/minimum-till precision planters for maize**

Machine name	Areas	Types of seed meter	Anti-blocking mechanism	Anti-blocking method	Working speed/km·h <sup>-1</sup>
Kinze3500	Single cropping areas	Finger pickup seed meter	Ripple-edged disc	Negative anti-blocking	12.9
Kuhn MAXIMA2 series	Single cropping areas	Vacuum seed meter	Cutting disc+ Star-shaped residue remover	Negative anti-blocking	8-9
DEBONT 2605 series	Single cropping areas	Air-blowing seed meter	Ripple-edged disc	Positive anti-blocking	9
2BMF-4 no-till precision planter	Double cropping areas	Air-blowing seed meter	Powered roller	Positive anti-blocking	7
2BMFY-4 no-till precision planter	Double cropping areas	Vacuum seed meter	Powered roller	Positive anti-blocking	7
2BMY-3 no-till precision planter	Double cropping areas	Scoop-wheel seed meter	Anti-blockage roller	Negative anti-blocking	5
2BYF-4 no-till precision planter	Double cropping areas	Scoop-wheel seed meter	Row clearance device	Positive anti-blocking	5-6



Figure 15 No-till precision planters for single cropping areas

**3.2 Minimum/no-till precision planters for double cropping areas**

In double cropping areas, annual wheat-maize cropping system is usually adopted and maize is directly planted after wheat harvesting without tillage. Wheat straws are in high moisture content and tough, so the row cleaners mentioned above are not available in this area. Residues need to be pushed aside instead of being cut to avoid blocking (Figure 16). To solve the problems, negative vertical drum, positive vertical drum and horizontal rotary blade row cleaners are developed. Negative vertical drum is used for less residue condition, while positive vertical drum and horizontal rotary blade are used for heavy residue conditions.

Researchers have done a lot of anti-blocking studies. Gao et al.<sup>[96]</sup> designed a positive anti-blocking mechanism combined with residue separating device. Field experiments showed that passing ability and planting quality satisfied the requirements of precision planting. Based on this design, further contrast test indicated that the anti-blocking mechanism performed better regarding to residue removal compared to the inactive row cleaner<sup>[97]</sup>. Li et al.<sup>[98]</sup> designed a rotary cutter which is installed in front of fertilizing opener. The cutter can work well at rotation speed of 380 r/min. Some planters based on the technologies mentioned above are as follows (Table 4).



Figure 16 Heavy wheat residues on double cropping fields

**2BMF-4 no-till precision planter** (Figure 17a) and **2BMFY-4 pneumatic no-till planter** (Figure 17b) equipped with positive anti-blocking drum in front of fertilizer opener could remove crop residues from seed belt. Residue separating device is also used behind the drum to prevent straws from falling back to seed belt. Working speed of these planters can reach 5-6 km/h under heavy wheat residue conditions<sup>[99]</sup>.

**2BMY-3 no-till planter** (Figure 17c) installed negative anti-blocking roller in front of fertilizer opener. When straws on the roller accumulated to a certain amount, rollers would lose force balance and start to rotate to push aside the residues. Scoop-wheel seed meters were used and the maximum speed of this planter is not more than 5 km/h.

**2BYF-4 no-till precision planter** (Figure 17d) mounted horizontal rotary blades in front of the fertilizer openers. Powered rotary blades, which do not disturb

soil, cut and throw residues forward to either side of seed belts. Scoop-wheel meters are applied. Working speed of this planter is 5-6 km/h<sup>[100]</sup>.

In single cropping areas, it is easier to deal with residues just by mechanical cutting device. Therefore, cutting disc, ripple-edged disc or finger-wheel residue cleaner can meet planting requirement. While in double cropping areas, more methods and high efficiency row cleaners are needed to be developed. Usually, positive anti-blocking cleaners perform better than negative ones.



Figure 17 No-till precision planters for double cropping areas

#### 4 Maize planter for hilly and small land

Small sized, simple structure and light-weight planters are needed in hilly areas since complicated landform, wavy terrain and poor traffic conditions<sup>[101]</sup>. Some typical small planters for maize are reviewed as follows (Table 5).

**2BYJLS-2 precision maize planter** (Figure 18a) is a 2-row scoop-wheel planter that matches to small wheeled tractor. To solve the problem of planting skips caused by slippage, a special driving wheel for seed meter, separated from press wheels, was designed. The qualified feeding index can reach 93% at speed of 5 km/h.

**2BMY-2 planter** (Figure 18b) is a 2-row maize planter that matches to wheeled tractor. The front two depth wheels are installed to balance the whole machine and control planting depth. Press wheel is at the rear to drive seed meter, fertilizer device and press soil. The working speed of this planter is 3-5 km/h.

**Mini-type maize planter** (Figure 18c) driven by mini-tiller is small-sized and light-weight for working on small farms. Socket seed meter is usually applied hence the planting accuracy is relatively low. The working speed of the planters is 2-3 km/h with the qualified feeding index of 88% and missing-seeding index of 4%.

**Manual single-row planter** (Figure 18d) is man handled planter. The planting efficiency is 0.2 hm<sup>2</sup>/h, single seed rate is 90% and missing seeding index is 2% approximately.

Mechanized farming is relatively difficult due to hills and complex terrains, thus mechanization level is still low. In addition, manual operation is still popular leading to high labor cost, so appropriate agricultural implements are in urgent need in these areas. In rural China at present, small 4-wheel tractors and mini tillers are the main power source. Consequently, it is particularly essential to develop new small-sized maize planters fitting for complex conditions.

Table 5 Comparison of maize planters for hilly and small lands

Machine name	Row number	Type of seed meter	Matched power/hp	Working efficiency/hm <sup>2</sup> ·h <sup>-1</sup>
2BYJLS-2 precision maize planter	2	Scoop-wheel or Finger pickup seed meter	Four-wheel tractor below 20 hp	0.84
2BMY-2 no-till fertilization planter	2	Scoop-wheel or Finger pickup seed meter	Four-wheel tractor below 20 hp	0.72
Mini-type planter driven by mini-tiller	2	Outer-fluted seed meter	Mini-tiller or walking tractor	0.24-0.36
Manual planter	1	Scoop-wheel seed meter	Manpower	0.2



Figure 18 Maize planter for hilly and small lands

### 5 Maize planters for cold and arid land

In cold and arid areas, in order to maintain soil moisture, raise soil temperature and speed up seeds germination, mulching planting pattern has been widely accepted and plastic-film mulching planter is mainly used<sup>[102]</sup>. Two ways of mulching planting, seeding-mulching (SM) and mulching-punch-seeding (MPS), are applied according to the working sequence. SM needs to break film manually during emergence period, while the MPS does not need, but needs special duck-mouth punch openers (Figure 19).

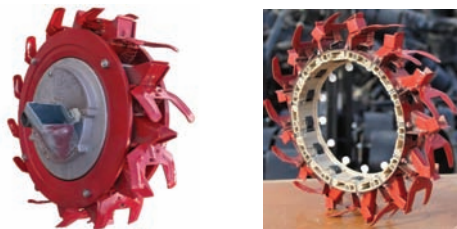


Figure 19 Duck-mouth seed meter

Yang et al.<sup>[103]</sup> designed a precision maize planter with whole plastic-film mulching on double ridges. The planting depth under the film could be ensured by a bidirectional parallelogram linkage. Yu et al.<sup>[104]</sup> designed a mechanical assisted duck-mouth seed meter and Cheng et al.<sup>[105]</sup> designed a vacuum plastic-film mulching planter. The two types use the same duck-mouth punch opener but different seed meters. To

ensure plastic-film being placed smoothly, working speed of this kind of planter is not more than 3 km/h.

Some typical plastic-film mulching planters are reviewed as follows (Table 6).

**2BYHF-2 plastic-film mulching planter** (Figure 20a) is a SM type planter, which uses spoon-wheel seed meter driven by depth-control wheel. Mulching device is mounted behind the planting unit. During the next emergence period, plastic-film must be broken manually for releasing seedlings.

**2BQP-6 vacuum plastic-film mulching planter** (Figure 20b) is a MPS type planter, which uses vacuum seed meter. To satisfy precision planting and plastic-film mulching quality, the working speed should be controlled under 1 km/h and the air pressure of seed meter should be up to 4.5 kPa, and better planting performance can be obtained with qualified feeding index of 94% and missing-seeding index of 3.2%.

**2BJQM-2 water-saving precision planter for maize whole plastic-mulching** (Figure 20c) is a combined machine with multi-functions including fertilizing, spraying, laying drip lines, mulching and planting. Chemicals and drip lines are both put under film. Further, seeds are planted by punching on the film surface with a duck-mouth seed meter with the missing-seeding index of 3%.

Table 6 Comparison of maize planters for cold and arid areas

Machine name	Row number	Type of seed meter	Main structures	Features	Qualified feeding index/%	Missing-seeding index /%
2BYHF-2 planter	2	Mechanical seed meter of duck mouth type	Two front furrow openers; A rear packing auger; Film pressing roller	Sufficient soil for covering	-	-
2BQP- 6 planter	6	Vacuum seed meter of duck mouth type	Scrapping disc; Six soil retaining plate	High planting precision; Good uniformity of planting depth	94%	3.2%
2BJQM-2 water-saving planter	2	Mechanical seed meter of duck mouth type	screw conveyer; Two wide depth wheels	Powered soil coverer; Sufficient soil for covering; Good uniformity of planting depth	-	3%
SGTN-160Z4A2 water-saving planter	4	Mechanical seed meter of duck mouth type	A front rotary tiller; Film pressing roller	Soil preparation and planting at one time; High work efficiency	97%	-



a. 2BYHF-2

b. 2BQP- 6

c. 2BJQM-2

d. SGTN-160Z4A2

Figure 20 Maize planters for cold and arid lands

**SGTN-160Z4A2 water-saving rotary planter for maize plastic-film mulching** (Figure 20d) can complete rotary tillage, fertilizing, plastic-film mulching and planting in one operation. The qualified feeding index of this planter is 97% when it is working at 2.5 km/h.

Though maize planters for cold and arid areas are developed, disadvantages still remain including complex structures, low efficiency and labor assistant in processes of plastic-film mulching and drip pipe laying.

## 6 Conclusions and recommendations

(1) Currently with the importance of planting process in maize production increasing, more and more innovations have being made on precision planters.

① To obtain better uniformity of seed spacing, different optimum design and simulation methods are used on seed meters to ensure their planting quality more accurate. Moreover, driving system for seed meters is changed from ground-wheel and chain-sprocket to electrical motor to eliminate the effects of ground-wheel slippage on planting quality and get more uniform seed spacing. In addition, seed delivery system which transports seeds from seed meter to seed-bed is being developed to prevent bump and skip between seeds and seed-tube, and as a result to maintain the uniformity of seed distribution.

② More attention are paid on the effects of seeding depth on maize yield. Different kinds of depth control units were developed to enable precision planters to have contour following capability, and therefore to keep uniform seeding depth and get more consistent emergence. Hydraulic driving depth control unit, with the ability of real-time and precision, will be the focus of future research.

③ High speed and high efficiency are the farmer's

requirement for precision planters, because seeds need to be planted within 7-10 d, which is the best optimal planting period. To meet this demand, new precision planters with faster speed of 16-20 km/h and wider breadth of 48 m are being developed recently.

④ The latest developing trend of precision maize planter is that more and more automation and intelligent technologies are equipped on planters to obtain more precise planting quality and enable them easier to be used. For example, newly developed variable planters can change seeding population promptly according to different soil fertility conditions and as a result to excavate maximum yield potential and save seeds.

(2) Although precision planters made in developed countries are modern, advanced, and some types have been introduced to developing countries, their usage in these areas are limited because of the differences of cropping systems, geographical or environmental conditions, as a result each area has to develop their own precision planters according to the local conditions. Therefore policy supports, including providing adequate research projects and funds, should be supplied to encourage local researchers to study progressive precision planting technologies and develop suitable precision planters to meet the requirement of local precision planting. Moreover, a specific targeted subsidy system should be founded to ensure these hi-tech precision planters being affordable by local farmers.

(3) Technically, in order to develop suitable precision maize planters to adapt to local geographical conditions and cropping systems, developing countries should make efforts on planting technology according to their actual circumstances.

① For hilly and mountainous areas, because of the limitations of farm size and rough surface, maize planters

need to be light-weighted, small sized and suited to low horsepower tractors. In this case, seed meters are especially crucial, and therefore more attention should be paid to developing precision seed meters fitting for small size planters.

② For medium-sized farms, because working efficiency and planting quality are both required, middle size planters with precision seeding performance and high speed should be developed.

③ For double cropping areas, because of the existence of wheat residue, anti-blocking mechanisms are the key components of maize planters. Researchers should adopt different methods to clean residue from seed rows according to the amount of wheat residue to obtain better effects and at the same time to save energy.

(4) Research institutions and universities should cooperate closely with agricultural machinery companies and extension departments to enable their new research achievements to be manufactured and applied in maize production in time.

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