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A review of methodologies and influencing factors in planter performance evaluation for higher maize yield

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Abstract
Maize, a versatile crop with a wide range of uses, holds a pivotal position in ensuring global food security. The key to maximizing maize production lies in adopting effective planting methods, where the use of maize planters plays a significant role in determining crop establishment and overall yield. As precision agriculture continues to evolve, the performance evaluation of planters plays a critical role in optimizing crop production processes. This paper provides a review of the existing literature on the methodologies, metrics, and technologies employed in the performance evaluation of planters. By assessing the current state of research, this paper aims to identify key factors influencing planter performance, challenges faced, and propose recommendations for future research directions.

Keywords: Planter, performance evaluation, seed spacing, depth control, precision planting

1. Introduction
Maize (*Zea mays* L.) has played a pivotal role in global agri-food systems since its domestication 9,000 years ago. Currently holding the position as the leading cereal in terms of production volume, maize is poised to become the most widely cultivated and traded crop in the coming decade. This versatile and multi-purpose crop serves as a primary feed globally, crucial for livestock and poultry nutrition. Additionally, it plays a vital role as a food crop, especially in sub-Saharan Africa and Latin America [1]. In 2020, maize was cultivated in nearly 200 million hectares of land in the world, and it had a production of 1163 million metric tonnes with a yield of 5815 kg/hectare. India was ranked sixth in production of maize with 28.77 million metric tonnes from a cultivated area of nearly 9.57 million hectares and a yield of 3006 kg/hectare [2].

Planting stands as a critical agricultural activity indispensable for successful crop production, conducted subsequent to seed bed preparation. This operation entails the careful consideration of key parameters, including seed spacing, row spacing, sowing depth, and seed rate. These factors are intricately linked to soil type, crop variety, and the prevailing climatic conditions, emphasizing the importance of meticulous planning and execution in the planting process for optimal crop development [3]. In the process of planting, a planter plays a crucial role by creating furrows at the desired depth, precisely measuring the seed, and then depositing the seed in an appropriate pattern within the furrow. Once the seed is placed, the planter covers it and ensures the soil is compacted around it to promote proper germination [4].

A planter can be viewed as a collection of components, each designed to fulfil a specific function. These functions include activities such as opening a furrow, metering the seed, transporting the seed to the furrow, closing the furrow, and firming the seedbed. Planter components can be organized based on their functions into distinct categories, which include soil-engaging components, furrow opener depth control components, seed metering components, and seed delivery components [5].

Metering device serves as the central component of any planter, responsible for placing seed at a predetermined depth and spacing interval. This ensures that seed-to-seed distances are maintained in the planter, providing adequate space for the proper growth of individual plants. Additionally, this spacing facilitates easier intercultural operations, ultimately contributing to higher production per unit area. The effectiveness of a planter hinges on the uniform distribution of seeds in furrows, a factor challenging to assess in field conditions due to soil coverage post-planting. Consequently, the design of the metering device significantly influences the overall performance of the planter [6].

In the market, there are various types of seed metering devices available to accomplish this task. Some seed metering devices are designed with cells on a moving component. These cells can carry either a single seed or multiple seeds, depending on the specific planting requirements. On the other hand, there are force feed type devices equipped with a moving component that efficiently removes the seeds from the hopper. In certain stationary opening metering devices, an agitator is often incorporated above the opening. This agitator serves to ensure a smooth and consistent flow of seeds, enhancing the accuracy and precision of the planting process [7]. The presence of a variety of seed metering devices offers the flexibility to choose the most appropriate equipment for specific crops and planting techniques. These devices play a crucial role in enhancing the efficiency and effectiveness of the planting process, leading to better crop establishment and increased overall productivity in agriculture.

Due to the inconsistent seeding performances exhibited by planter under varying forward speeds and other conditions, issues such as miss-seeding, reseeding and uneven seeding commonly arise. Miss-seeding has the potential to diminish overall production, while reseeding not only leads to seed wastage but also increases labour costs associated with thinning out seedlings. Concurrently, non-uniform seeding poses a threat to the precise control of seed quantities. To achieve improved planting uniformity, it is essential to study influence of some factor including forward speed, planting unit, the structure of the seed meter, and the seeding's driving method [8].

The efficiency and accuracy of planting operations are pivotal for achieving optimal crop yields and resource utilization in modern agriculture. The evaluation of planter performance is essential for ensuring precision in seed placement, spacing, and depth, directly impacting crop uniformity and overall productivity. As precision agriculture continues to evolve, the performance evaluation of planters plays a critical role in optimizing crop production processes. This review paper provides an in-depth review of the existing literature on the methodologies, metrics, and technologies employed in the performance evaluation of planters. By assessing the current state of research, this paper aims to identify key factors influencing planter performance, challenges faced, and propose recommendations for future research directions.

2. Key Metrics and Criteria for Performance Evaluation of Planter

Performance evaluation of a planter is crucial for optimizing agricultural operations and ensuring efficient crop management. Key metrics and criteria play a pivotal role in assessing the effectiveness and productivity of planters.

In the performance evaluation of a planter, several critical factors require consideration. Planting accuracy is paramount, encompassing seed spacing and depth control, ensuring uniform placement for proper crop development and reduced plant competition. Seed singulation is vital for preventing doubles or skips, enhancing plant stand and maintaining optimal spacing. Speed and efficiency assessments evaluate the planter's performance at different operating speeds, crucial for covering more acres without compromising accuracy. Seed population and rate comparisons gauge the planter's success in achieving targeted plant populations, maximizing yield potential. Row spacing flexibility is crucial for meeting crop-specific requirements, and down force control evaluations focus on maintaining consistent seed depth and preventing soil compaction. The accuracy of the metering system, the planter's capability for real-time monitoring and data collection, and compatibility with precision farming technologies contribute to informed decision-making. Evaluations of maintenance requirements, adaptability to diverse soil types and field conditions, and versatility in seed handling ensure optimal performance across different terrains and crops.

Earlier researchers used mean and standard deviation for summarizing distributions of plant spacing. The mean and standard deviation were not found suitable for effectively summarizing plant spacing distributions. Instead, four alternative measures named miss index, multiple index, quality of feed index and precision were explore based on the theoretical spacing, finding that these alternatives provided satisfactory results when summarizing distributions of plant spacing [9].

The miss index represents the percentage of spacing exceeding 1.5 times the predetermined seed spacing, while the multiple index indicates the percentage of spacing falling below or equal to half of the set seed spacing. The quality of feed index corresponds to the percentage of spacing that falls between half and 1.5 times the set seed spacing. Precision, in this context, is determined by the coefficient of variation of seed spacing within a row, excluding missing values and multiples.

Generally theoretical field capacity, Effective field capacity and Field efficiency are considered while evaluating the performance of the planter in the field. The theoretical field capacity refers to the rate of coverage of an implement when operating at its rated speed and covering its entire rated width for 100% of the time. In essence, it represents the maximum potential efficiency of the implement under ideal conditions, assuming continuous operation at the specified speed and width without any interruptions.

Effective field capacity is a measure that takes into account real-world factors and operational constraints, providing a more practical estimate of the productivity of an agricultural implement. Unlike theoretical field capacity, effective field capacity considers factors such as downtime, turning time, and other non-working periods that may occur during actual field operations. In summary, effective field capacity provides a more realistic assessment of an implement's performance in practical farming conditions, acknowledging the interruptions and inefficiencies that can occur during real-world operations.

Field efficiency is the ratio of the effective field capacity to the theoretical field capacity

2.1 Cost economics of the planter

The cost economics of a planter encompasses various factors crucial to evaluating the overall financial impact of utilizing this agricultural equipment. Initial purchase costs involve the acquisition of the planter machinery and related expenses. Operational costs, including fuel, labour, and consumables, play a role in day-to-day planting activities. Maintenance and repair costs ensure the planter's reliability and performance over time. Seed and fertilizer costs are influenced by the type and quantity of inputs required. The integration of technology and precision agriculture features may incur additional expenses but can enhance efficiency. Labour efficiency, field performance, and resale value also contribute to the economic considerations. Ultimately, a comprehensive analysis of these factors enables farmers and agricultural businesses to make informed decisions about the cost-effectiveness of a planter in

their operations.
According to Indian standard, the cost of using planter consisted of expensed for ownership, operation and overhead charges. Ownership costs are independent of use and are often called as fixed costs. Cost of operation vary directly with use and are referred as variable cost. Fixed costs include depreciation, interest on investments, housing, insurance and taxes. Variable cost includes fuel cost, repair and maintenance; and wages and labour charges.

3. Methodologies for Performance Evaluation
The performance evaluation of a planter in agriculture involves assessing its effectiveness, efficiency, and overall functionality. Various methodologies have been employed by researchers for evaluating planter performance, including laboratory testing and field trials.

3.1 Laboratory testing
Laboratory testing is essential for assessing seed planter performance. It helps determine the rate of seed discharge, ensuring efficient operation. The uniformity of seed spacing along the planting row is rigorously examined. Additionally, the testing evaluates potential seed damage during the planting process. This data guides the optimization of seed planter design for improved efficiency in agricultural applications.
The sticky belt test is a frequently utilized technique among researchers to assess seed spacing for different planter configurations. In this method, the planter unit is positioned on a moving belt coated with an adhesive substance, typically grease. This causes the seeds to adhere to the grease upon impact. The sticky belt is widely used among the researchers for the laboratory evaluation of the seed metering mechanism. It a time and labour-intensive technique including limitations imposed by the restricted belt length and issues arising from the skidding and bouncing of seeds along the belt [10].
some of the alternative methods (Opto-electronic system, machine vision techniques, computerized measurement system and acoustic technique) developed to measure seed spacing uniformity are integrated with sticky belt, they also have the same disadvantages as that of the sticky belt [11].
Singh *et al*. [12] assessed how a pneumatic planter's disc's operating speed, vacuum pressure, and seed hole design affected the mean seed spacing, precision in spacing, miss index, multiple index, and quality of feed index. For a desired seed spacing of 25 cm, the entrance cone angle of the hole, speed, and vacuum pressure were changed. The laboratory evaluation was carried out on a sticky belt and the seed spacing with misses and multiples were measured of 30 seeds on the sticky belt. Reduced miss indices were noted when operating at elevated pressures and lower speeds, while reduced multiple indices were observed under lower pressure and increased speeds.
Reddy *et al.* [13] evaluated the performance of seed planter metering mechanisms and optimized the parameters using grease belt test rig. The existing inclined plate metering mechanism and newly developed horizontal metering plate were tested for comparative performance at three speeds, 2.5, 3.5 and 5 km/h using the test rig. The average number of seeds metered at different forward speeds for selected variety of maize were measured and compared to theoretical metered seed. It was concluded that, correct seed rate can be achieved with the selected speed ranges by re-designing the seed cells in horizontal plate rotor.
Cay *et al.* [11] developed an opto-electronic measurement system for the measurement of seed spacing for performance evaluation of precision planter during the laboratory tests. The experiment stand consists of an opto-electronic measurement system, sticky belt and seed metering units. The developed system was tested by comparing the measurements on the sticky belt using 10 different seeds with different physical properties. The system yielded accurate results quite fast and there was no need for complex calibration and adjustment processes. Time and labour requirement could be reduced by using developed system on the place of sticky belt apparatus.
Van Loon *et al.* [14] developed a low-cost standard methodology for evaluation of mechanical maize seed meters for smallholder farmers. Performance of ten seed meters was evaluated using two test-bench setups. A conveyer-belt setup was used for seed distribution analysis and the influence of vibration and topography on the seed singulation. The angle of the plate influenced the distribution, with fewer seeds distributed at smaller angles and higher speeds for the inclined plate meters. The working angle of 45° was recommended for general use but the precision could be improved by decreasing the angle compared to this intermediate position. The 20 revolutions per minute was found to be optimum for most of the meters. The developed low-cost methodology could easily be replicated and implemented which had potential to be used as a baseline for continued research on seed meter evaluation.

3.1.2 Simulation model
Simulation models are valuable tools for the performance evaluation of planters in agriculture. These models allow researchers and farmers to assess the impact of various factors on planter performance in a controlled and virtual environment. Here are some key simulation models used for the performance evaluation of planters:
Anantachar *et al.* [15] developed feed forward artificial neural network (ANN) models and statistical models for the prediction of the performance parameters of an inclined plate seed metering device and determined optimum values of design and operational parameters by using the developed ANN models in a reverse direction. A sticky belt test stand along with seed metering device and opto-electronic seed counter was used for the performance evaluation of metering plates. The optimal number of hidden layers and neurons in each of them were obtained through genetic algorithm as single objective constrained optimization problem. The results show that the ANN model predicted the performance parameters of the seed metering device better than the statistical models.
Anantachar *et al.* [16] developed ANN model for the prediction of the seed rate, seed spacing and percent seed damage of the inclined plate seed metering device. A sticky belt test stand along with seed metering device and optoelectronic seed counter was used in the laboratory to evaluate the performance of the metering device. The mean absolute generalization error for the prediction of individual performance parameter by the best ANN for each was found to be varying from 1.38 to 3.29%. The prediction of performance parameters by ANN models were found to be consistent. The result of the sensitivity analysis indicates that the forward speed of the planting equipment had the highest influence on seed rate followed by peripheral speed of the metering plate. The seed rate was negatively correlated with forward speed and positively correlated with peripheral speed

of the metering plate.

Ramesh *et al.* [17] used Computational fluid dynamic (CFD) software tool to optimize design and operational parameters of pneumatic seed metering mechanism. Vacuum pressure and cell diameter were simulated through ICEM CFD software and precision pneumatic seed planter was developed. Experiments were designed using response surface methodology (RSM) to optimize design and operational parameters (vacuum pressure, rotor speed and cell diameter). Results of simulation showed that the predicted responses of miss index, multiple index and precision index were 6.76, 3.89 and 10.81%, respectively with combined desirability of 0.88. The simulation results were validated by testing developed metering unit under lab setup using instrumented test rig and was also evaluated under actual field conditions.

Han *et al.* [18] performed simulation of the gas-solid flow in an inside-filling air-blowing maize precision seed-metering device by coupling approach of the discrete element method and CFD. EDEM software was used to depict the discrete particle phase and to create Maize particles using the bonded particle while ANSYS Fluent software was used to describe the continuous gas phase. The effects of the positions, the width and the average arc length of the lateral hole were examined and analyzed in terms of gas field and seed movement. the factors and parameters of the maximum evaluation index affecting the working performance of a seed-metering device were assessed using an orthogonal experimental design. The ideal lateral hole was found 1.5 mm wide with an average arc length of 10 mm long.

Bhimani *et al.* [19] optimized the operational parameters of a picking-type pneumatic planter under laboratory conditions using rotatable central composite design of RSM. The independent parameters taken for study were hole diameters for the nozzle, forward speed and vacuum pressure while miss index, multiple index, quality of feed index and precision parameters were taken as dependent parameters. The combination of hole diameter of nozzle and vacuum pressure acted as the most important variable that affected planting. The optimum settings were tested in the field condition and the result were found in accordance with the model.

Pareek *et al.* [20] used a technique based on the integrated artificial neural network - particle swarm optimization (ANN-PSO) approach for optimization of the seed-cell filling performance of an inclined plate seed metering device. The forward speed of operation, the seed metering plate inclination and the seed level in the hopper were taken as independent parameters. the cell fill of inclined plate seed metering device was considered as the dependent parameter. A 3–5-1 artificial neural network ANN model was developed for predicting the cell fill of inclined plate seed metering device and then PSO algorithm was applied to get the optimum values of the operating parameters corresponding to 100% cell fill. The proposed integrated ANN-PSO approach was capable of predicting the optimal values of operating parameters with a maximum deviation of 2% compared to the experimental results, thus confirmed the reliability of the proposed optimization technique.

Pareek *et al.* [21] used ANN and multi-objective particle swarm optimization (MOPSO) to maximize the quality feed index and minimize the precision index. The seeding performance test setup was composed of a pneumatic seed metering device, an electric motor, a motor controller, a vortex blower, a vacuum gauge, a gate valve, and a sticky belt-type seeding test bed. The independent variables taken for testing were the entry shape of the suction hole, size of suction holes, vacuum pressure and forward speed of operation. For the prediction of the quality feed index and precision index, the multilayer perceptron (MLP) and radial basis function (RBF) neural network models were developed. The RBFNN (4-15-2) model was coupled with the MOPSO algorithm for getting optimum values of the design and operational parameters as it performed better than the MLPNN (4-7-2) model. The validation results showed a variation of -2.11 and +5.40% between the observed and predicted values of the quality feed index and precision index, respectively.

3.3 Field testing

Field testing of a planter is a crucial step in assessing its real-world performance and effectiveness in different agricultural conditions. Field testing provides valuable insights into a planter's performance under actual farming conditions, helping farmers and researchers make informed decisions about equipment selection, configuration, and operational practices.

Stone *et al.* [22] examined the effects of row spacing and plant population on maize yield and quality at three different locations. Jab planters were used for sowing two seeds per position. Two maize hybrid varieties differing in maturity were grown at two row spacings and seven populations. The plant population had affected yield and quality significantly. For crops cultivated at typical plant populations, row spacing had no significant impact on any aspect of yield or quality. The effect of row spacing on maize output was found negligible. Plant population had a significant and typically predictable impact on yield. The yield, quality, and profitability of maize were all significantly impacted by plant population, although row space had minimal impact on any of these factors.

Barut and Özmerzi [23] analyzed the effects of hole shape, peripheral velocity and hole area of the seed plate, vacuum pressure, and thousand grain weight on the seeding quality of a pneumatic single seed planter with a vertical seed plate for three maize varieties. The test unit consisted a single seed planting unit with a vacuum and hole plate, a fan, an electronic counter, a tractor and an electric engine for the power source. The impacts of the independent factors on the seed holding ratio were investigated. It was found that the shape, peripheral velocity, vacuum pressure, hole area, and thousand grain weight of the seed all had an impact on the seed holding ratio. The oblong shape of the hole in the seed plate proved ideal for maize seeds. When the seed plate's peripheral velocity rose, the seed holding ratio fell, but it increased in tandem with an increase in vacuum pressure. A greater hole area was required to keep seeds on the plate holes due to an increase in the thousand grain weight of the seed.

Staggenborg *et al.* [24] evaluated the effects of planter speed and a seed-firming device on the grain yield and maize stand establishment. Calculations were made for the mean plant spacing, standard deviation in spacing, miss index, multiple index, quality of feed index, and precision index to assess the plant spacing data. Planter performance decreased as measured by these indices and standard deviation in plant spacing with increase in planter speed. Crop yield decreased with increased planter speed at one location, but not at the other locations. The yield of maize was unaffected by the seed firmer. According to the findings, planter performance in the field should be more concentrated on determining the right seeding rate and subsequent plant stands rather than on exact plant spacing.

Matin *et al*. [25] tested a multicrop power tiller operated inclined plate planter for maize establishment. The effectiveness of the planter was assessed, and its economic viability was contrasted with conventional practice. The seed rates for planting by machine and the conventional method were 21.7 and 26.5 kg/ha, respectively. The average field capacity was 0.19 ha/h which helped in saving 32.8% in total cost and 79.2% in labour expenditures in comparison to traditional practice. The use of planter improved yield by 18% due to consistent seed placement.

Karayel [26] evaluated the effectiveness of a modified precision vacuum seeder used for planting maize. Three forward speeds and two different types of furrow openers were used to sow the seeds. Multiple index, miss index, quality of feed index, uniformity of sowing depth, mean emergence time, and% emergence were calculated as dependent parameters. Increasing forward speed resulted in a decrease in sowing depth uniformity, mean emergence time, and percent emergence as well as an improvement in the precision of seed dispersal along the length of the row. The double disc-type opener of the seeder performed better than the hoe-type opener in terms of seed distribution along the length of the row, consistency of sowing depth, and percent emergence. Based on the dispersion of the seeds over the length of the row, sowing depth uniformity, and percent emergence, the modified precision vacuum seeder performed best while utilizing the double disc-type furrow opener at the forward speed of 1.0 m/s.

Gill *et al.* [27] conducted field experiment to evaluate the efficiency of two row maize planter. The independent parameters for the testing were seed rates, row to row distance, forward speed and fertilizer rate. The data regarding row-to-row distance, fertilizer rate, seed rate, machine forward speed, maize dry biomass and emergence rate index were analyzed. Maize dry biomass and emergence rate index were not affected significantly by machine forward speed. Best results regarding dry biomass and emergence rate index were recorded when seed rate was 35 kg/ha, row to row distance was 80 cm and fertilizer rate was 60 kg/ha. Average field efficiency of two row maize planter was calculated to be 73.8%.

Ani *et al.* [28] tested a vertical plate maize seed planter which was adapted for gardens and small holder farmers. Results showed that the planter has a metering efficiency of 88.94%, effective field capacity of 0.27 ha/h and field efficiency of 71.86%. The time required to plant one hectare of farmland was determined as 3.7 hours. The average number of seeds planted per stand was determined as two and percentage seed damage was determined as 1.71%. Planter was found economical and could be adopted for maize planting by small holder farmers.

Singh *et al.* [29] evaluated the performance of a manual/bullock operated multi-crop planter for hilly region. The machine performance parameters like effective field capacity, field efficiency, speed of operation, depth of sowing and labour requirements were determined as per the standard procedure and compared with the conventional practice. The power and pull requirements were found 74.6 W and 12 kgf, respectively. Two persons are required to operate the machine manually by one using handle and one with bullocks. The cost of operation was observed 42% less in multi-crop planter with 21-33% increase in yield as compared to traditional broadcasting method.

Yang *et al.* [8] accessed the performance of two different types of maize precision planters fitted with motor-driven planting devices. As simulated speed increased, test findings showed that the quality of feed index of the two planters declined, while the miss index increased. In the simulation experiment and the field trial, the two planters' average reductions in the quality of feed index were 13.34 and 10.32%, respectively which was close to each other. The quality of feed index of the two types of planters in the field trial was found lower than that in the simulation speed experiment at the same speed level.

4. Future Research Directions

Future research directions in the performance evaluation of planters may involve the integration of precision agriculture technologies, such as GPS, sensors, and data analytics, to enhance planting precision and efficiency. Taylor *et al*. [30] used GPS technology to evaluate corn planter performance. He *et al*. [31] designed a GPS-based turn compensation system for improving the seeding uniformity of maize planter.

A mechatronics system resolves challenges in precision planters, addressing issues like ground wheel skidding. It utilizes variable rate technology and modified pulse width modulation to enhance transmission ratios, resulting in improved seeding uniformity and increased productivity. The innovation tackles existing problems, ensuring more precise and efficient planting operations. Researcher have been working to build an electric drive metering system to more precisely drive the seed metering units without the need of mechanical transmission systems, in order to provide uniform seed delivery at quicker operating rates and to address other limitations [32].

Researchers may explore the potential of automation and robotics in planters to reduce labour requirements and improve overall efficiency. Researchers around the globe have developed the remote-controlled and GPS guided robots for sowing operations for different crops. Lohan *et al*. [33] designed and developed a remote-controlled system consisting of an electronic control unit to control the various hand-control levers of a walk-behind paddy transplanter through linear actuators, sensors, and wireless receivers. Obialor *et al*. [34] designed and developed a remote-controlled seed sowing machine for crops such as maize, beans, and other grains. Unal and Topakci [35] designed and developed a robot which was both GPS-guided and remote-controlled and in addition it could be controlled via the internet for field applications.

Advanced sensor technologies, including machine vision and artificial intelligence, could be developed and tested for real-time monitoring of soil conditions, seed placement, and plant health during planting. Energy efficiency and sustainability of planters may be investigated, with a focus on alternative energy sources like solar or battery power. Adaptive planting strategies, guided by machine learning algorithms and real-time environmental data, could offer dynamic adjustments to optimize planting decisions. Multi-crop planting, user-friendly interfaces, economic analyses, and considerations for climate change resilience may also be key areas for future exploration in the quest for more efficient, sustainable, and resilient planting practices.

5. Conclusion

The review of maize planter performance in modern agriculture underscores the pivotal role that advanced planting technologies play in shaping the landscape of contemporary farming practices. The evaluation has provided valuable insights into the efficiency, precision, and sustainability aspects of maize planters, shedding light on their impact on crop yield and overall agricultural productivity.

The technological advancements witnessed in seed metering systems, precision agriculture, and data-driven approaches have significantly contributed to the evolution of maize planting methodologies. These innovations have not only enhanced the accuracy of seed placement but also improved overall planting uniformity, resulting in more consistent crop emergence and higher yields.

Looking ahead, it is evident that the journey towards precision planting and sustainable agriculture is ongoing. Future research and development in maize planter technologies are expected to focus on addressing the evolving needs of farmers, incorporating artificial intelligence for real-time decision-making, and promoting practices that contribute to long-term environmental stewardship. In essence, this review not only serves as a comprehensive assessment of the current state of maize planter performance but also as a guide for future advancements in agricultural technology.

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