Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 20 March 2026
Revised 22 April 2026
Accepted 25 May 2026

Natural Resources for Human Health 2026, Vol. 6 (1s): 572–584

KEYWORDS:
Pneumatic planter, Precision agriculture, Seed metering mechanism, Agricultural machinery, Seed spacing uniformity

Design, Development and Performance Evaluation of a Pneumatic Precision Planter for Multi-Seed Sowing

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ABSTRACT: With the rising demand for precision agriculture, a demand for accurate and efficient seed-sowing systems to save seeds, lessen labour needs and enhance crop productivity has emerged. Manual sowing practices with conventional methods are prone to non-uniform planting of the seeds and seed spacing, especially for crops like cotton where uniform crop establishment is critical. In order to overcome these restrictions a new pneumatic precision seed-sowing planter has been designed and developed, which allows the precise and controlled placement of individual seeds. A pneumatic seed-metering principle is used with the developed planter, which allows for accurate seed pickup and delivery and minimizes seed damage and double or no seed delivery. This system comprises a mild-steel frame, seed hopper, aspirator blower, pneumatic indexing plate, furrow opener, ground wheel, chain and sprocket power transmission system and other ancillary components. The planter was designed to have the ability to accommodate different seed sizes and sowing requirements, with a change-out indexing/seed plate as per the crop. Seed spacing can also be modified for the desired agronomic conditions. The structural design of the planter was particularly emphasized to withstand the operational forces and simultaneously to keep the construction light to minimize the pulling effort. Operating the planter with a variety of pulling sources (such as tractor or bullocks) was incorporated into the planter, making it more applicable in various field conditions. The developed system offers an adaptable and compact solution for precision sowing and is ready to be adapted to different crops by replacing the right seed plate. The proposed pneumatically operated planter therefore provides potential benefits in terms of single-seed placement, avoidance of seed wastage, sowing uniformity, labour saving and the efficient operation of the planter, as an alternative to traditional seed-sowing approaches.

1. INTRODUCTION

Agriculture is one of the significant sectors of the Indian economy and plays a pivotal role in supporting the Indian population. It is estimated that India has around 17% of the world population on 2.3% of the geographical area and 4.2% of the water resources. The current cropping intensity is about 137% and the net sown area is at 142 Mha. In such a situation, land, water, seed, labour and energy have to be utilized efficiently to ensure better agricultural productivity. The basic goal of a sowing operation is to distribute seed and fertilizers, at the proper depth and spacing, in rows, cover the seed sufficiently with soil and apply sufficient compaction. The seed rate, row-to-row spacing, seed-to-seed spacing and seed depth to be planted, however, varies for different crops and climatic and agricultural conditions. Thus, an effective sowing machine should achieve a good control of these parameters, while at the same time minimising operating time, labour and energy use. Much of the land used for agriculture remains under traditional cultivation practices, which can lead to poor seed spreading, uneven seed depth and spacing, higher seed wastage and higher reliance on manual labour. The limitations are especially significant for the expensive hybrid seeds, where each seed has to be placed in the correct location to reduce waste and ensure proper crop establishment.

The Green Revolution has made efficiency and uniformity in seed placement more critical than ever before, as it has become even more important to have both the quantity and quality of the crop production. India has a huge labour force but the availability of farm labourers for planting in nursery and in field work can be restricted which leads to higher labour costs and delayed sowing. Loss of seeds can also occur during the placement of the seeds in the various trays and agricultural fields by conventional seed sowing techniques. Currently available precision sowing machines are suitable for providing an accurate position of the seeds; but due to their high cost, limited availability and comparatively complex construction, they may be limited in use by the small and marginal farmers. Another alternative is pneumatic planters which are capable of planting single seeds accurately and keeping the seed to seed and row to row spacing predetermined. Correctly seeding a single plant can eliminate the need for over-seeding and additional thinning, while ensuring that each plant receives sufficient sunlight, water, nutrients and room to grow. Furthermore, precision planting is especially advantageous for crops where even plant spacing is required for proper establishment and crop growth, like cotton. The mechanisation of sowing technology is thus important for the development of low cost and simple precision planting equipment in order to make it more accessible.

These deficiencies were overcome by the development of a single row precision cotton seed planter which would allow the precise placement of individual seed at a predetermined seed to seed and row to row spacing. The developed planter is composed of a frame, a blower for drawing air into the planter, a pneumatic seed-metering disc with indexing plate, a single seed hopper, an opener to cut furrows, a ground wheel, and various other power transmission parts. The machine is a pneumatic suction type machine in which air is sucked through holes made on a rotating seed-metering plate. If a hole touches a seed, it is sucked in and moved to the release position. The suction is cut off at the assigned planting site close to the soil, dropping the seed into the planting furrow. The metering plate rotates and is synchronised with the spacing needed between the seeds, allowing individual seeds to be dropped on a predetermined interval. The mechanical damage of the seed during lift and transfer is avoided, as the seed is picked up pneumatically and not being mechanically lifted. Flexibility is provided based on field conditions and available power sources depending on whether the planter is operated by a pair of bullocks or a tractor; the planter being designed as a single row unit. The cotton seed can be stored in the seed hopper at the rate of about 3 kg.

The precision seed-sowing system developed is designed to address some of the drawbacks of the traditional sowing system. It's a seed-metering mechanism which is engineered to select and drop one seed at a time, minimizing lost and redundant seed placement and guaranteeing even seed distribution. Single-seed placement will save valuable hybrid seed and minimize the need for thinning after germination. There is also less risk of mechanical damage to the seed when sowing, as is the case with the pneumatic seed pickup mechanism. Achievement of uniform seed depth and seed spacing can help achieve better crop stand, rooting and plant growth. Another benefit of precision sowing could be to increase crop productivity – a potential increase of around 10-15% is reported depending on crop and field conditions. Apart from this, mechanized sowing also means that they are less dependent on manual labour and can also reduce planting cost if agricultural labour is limited or costly. Planting at higher speed can help achieve greater field coverage and decrease sowing time. Optimal seed distance and fertilizer location can also help to optimize the use of available nutrients and growing resources. In this way, the developed planter is a low-cost type precision sowing machine which only needs one row and adopts the pneumatic sowing method, and it is a solution for cotton sowing to improve the accuracy of sowing seed placement, reduce seed waste, ensure uniform seed spacing and depth, and optimize the planting efficiency of cotton planting operations.

The novelty of the present study lies in the design and development of a pneumatically operated precision planter capable of handling multiple seed types with improved uniformity and reduced seed damage. Unlike conventional mechanical seed drills, the proposed system integrates a controlled vacuum-based metering mechanism, enabling accurate singulation and placement across varying seed sizes. Additionally, the study provides a comprehensive performance evaluation under different operating conditions, focusing on seed spacing, missing index, and multiple index, which are often inadequately addressed in existing designs. The combination of design innovation, adaptability, and systematic experimental validation distinguishes this work from prior studies.

Mechanization in agriculture has played a prominent role in increasing sowing efficiency, decrease in labour, seed wastage and uniform seed placement. Manual sowing techniques tend to introduce irregular seed spacing and depth, demanding a lot of labour, exhausting labourers and lowering the productivity. Therefore, a number of researchers have been engaged in studying the low cost, manual, self-propelled and robotic seed sowing system that can be used for small and marginal farmers.

To overcome these difficulties, small and marginal farmers, an economical and user-friendly seed sowing cart was designed by [1] which helps the farmers in tackling the problem of labor intensive agriculture and low productivity. The developed system contained adjustable mechanisms of sowing width, seed placement depth and the linear distance between successive sowing seeds. These parameters could be modified according to crop requirements by changing the gear arrangement. The machine is intended to be used for the placement of seed and fertilizer in rows at a predetermined depth and row width and then cover and compact the soil. A fluted-roller seed-metering mechanism was mechanically operated by the chain and sprocket system of the ground wheel. The machine was mainly tested for sowing wheat and soybean. The study showed that there was a higher yield with adjustable row spacing of 22.5 cm than with the conventional spacing of 15 cm. The three-wheel configuration also provided better traction in wet fields. An economical, lightweight and adjustable sowing machine has been proved to be able to enhance the control of seed placement and reduce the operational difficulties of conventional sowing. [2] explored some of the drawbacks of manual seed planting, especially poor placement efficiency, irregular spacing and physical discomfort of farmers. The researchers constructed and tested a manually operated, single row multi-crop planter that is designed to be low cost, user friendly and easy to maintain. The planter was designed to be used for planting seeds at relatively even depths and spacing and to be useful in meeting different crop requirements. The machine structure was mostly made of mild steel while a few parts of the seed-metering and seed-delivery systems were nylon and rubber. An important characteristic of the machine was the ability to adjust the handle's height to accommodate the individual operator's stature, thus minimizing physical strain on the operator. The study showed that a manually operated, multi-crop planter is a viable alternative to traditional manual sowing which can enhance the operational convenience and flexibility of rural farmers. [3] emphasised the need to develop an economic sowing system for farmers with relatively small land holdings who may not be able to afford conventional agricultural machinery. The researchers designed a self-propelled multi-crop seed drill that was capable of drilling wheat, soybean and cotton at specific depths and seed to seed spacing. A 5.5 hp engine was used to power the machine, which made the task easier for the operator. The operating speed was chosen to be close to the walking speed of humans, keeping in mind the need to have the correct field operation and to minimize fuel consumption. The fabricated machine facilitated the adjustment of seed placement suitable for the crop requirement and was evaluated considering the feasibility of the machine for small and medium size farms. The study showed that mechanised sowing with a self-propelled seed drill can decrease the operator's fatigue and increase sowing productivity while keeping the operation costs relatively low, thus making mechanised sowing more accessible to small landholders [4]studied development of a four-wheel robotic seed-sowing system for the introduction of automation in the agricultural sowing operations. The system was developed for mounting on a four-wheel robotic platform with a seed tank, seed-sowing mechanism and seed-metering arrangement. The motors (DC) were integrated, electronic circuits were installed and sensors were fitted to allow the machine to carry out the necessary sowing operations and minimise operational errors. The ultimate goal was to create a more inexpensive and easier robotic system that farmers would be able to use without having to possess a high level of technical expertise. The system was designed to achieve the following objectives: (1) to ensure better seed placement accuracy and (2) to avoid seed wastage during sowing process due to the control over seed delivery. This research illustrated the potential application of mobile robotic platforms for field robotics applications in agriculture, but further research and development are needed to enhance soil and terrain adaptability, sensing, navigation and performance in field applications. [5] have designed a microcontroller based seed-sowing robot for automatic sowing and to control the sowing parameters. It was designed to be able to precisely place the seed at a set depth and distance with the spacing between the seeds being electronically controlled by a microcontroller. A two port solenoid valve was used for the seed dropping operation and a DC motor used for the drilling operation. An LCD was added to show the operating information and to monitor the system. The study highlighted the need for the right timing of sowing and seed placement for better crop production. The proposed system would involve the use of sensors, electronic control systems, and automated seed dispensers to minimize seed wastage and enhance uniformity in seed placement. The study thus showed that it is possible to implement microcontroller control in conjunction with the robotic mechanisms for precision sowing. [6] pointed out that farm mechanization is a key factor in enhancing the efficiency, safety, and working comfort of agricultural activities. The study emphasised that the basic purpose of sowing is not only to place the seed in the row but to make the necessary spacing between the rows, between the seeds, between the seed and soil and also compaction and soil covering in accordance with the requirements of the crops and agro-climatic conditions. The researchers explored manually powered methods to plant seeds that could be used on marginal land and would maintain desired seed quantity and spacing while simultaneously minimizing the number of seeds required per area. Several examples of low cost sowing equipment such as manual seed and fertilizer drills, oilseed drills, single row multi-crop planters, and low cost maize planters were also mentioned. The work highlighted lack of uniformity in sowing in terms of inter-row and intra-row seed distribution, gaps and seed bunching which are the major drawbacks in conventional sowing. The study is thus useful in designing multi-crop efficient sowing machines for small scale farming. [7] compared the improved sowing techniques for enhancing productivity of the crop without causing any harm to the soil environment. The study found that the traditional farming methods have some disadvantages, such as the use of animal-drawn machinery, expensive machinery, heavy machinery, maintenance needs and musculoskeletal issues for farmers. Special attention was given to keeping an adequate row spacing, which can help limit weed growth and the availability of resources that can be used to benefit the crop. The study showed that appropriate row spacing may help facilitate better access to nutrients, moisture and sunlight and minimize weed competition. The writers also stressed the need for even seed depth, seed distribution longitudinally, positioning the seed transversely, and adequate soil cover. The results confirm the need of sowing machine that can ensure uniformity of seed position and row spacing in the field.

Uniform seed spacing and depth must be met for efficient sowing and adjustable seed-metering mechanisms are required for the various crops. Low-cost manually operated systems [1,2,6] ensure greater accessibility of small farmers, while self-propelled and robotic systems [3–5] have greater potential for a reduction in human effort and increased automation. However, the reviewed robotic systems are mainly concerned with basic automation of seed placement and lack a comprehensive solution to the problems of real-time sensing of soil condition, adaptive control of seed rate, identification of obstacles, dealing with terrain variations and systematic performance optimization.

[10] discussed the traditional and alternative methods of sowing seeds, especially the needs of small and the marginal farmers. Manual sowing was identified as ineffective in maintaining uniformity in the spacing between successive rows of plants and the seed drill which was operated by a tractor proved effective but was expensive, difficult to maintain and not affordable for small farmers. The authors mentioned some of these methods of sowing such as broadcasting, precision planting, dibbling, drilling, dropping of seed behind the plough and transplanting. Precision planting was reported to use 15-25% less seed than broadcasting and was able to achieve uniform depth and spacing, while broadcasting was not able to achieve uniform depth and spacing. The study aimed to develop a simple, low cost, manually operated seed drill, made out of fairly simple materials. The machine was intended to be easily towed by an average-sized man, and to have replaceable grooved plates to adjust to different row spacings and seed size. The study also covered the Broad Bed and Furrow (BBF) system, where beds and furrows are created to enhance water management, reduce the number of seeds required, and aid in the management of the farm. The BBF approach was reported to decrease seed rate by ~20-25%, save water by ~25-30%, and enhance crop productivity by ~5-10%. The study was able to conclude that a cheap hand operated seed drill could be used as an alternative to costly tractor operated sowing equipment since it would achieve uniform seed depth, seed to seed spacing and would decrease the amount of labour, time and seed wastage.

2. CONSTRUCTIONAL FEATURE AND WORKING

2.1 Constructional Feature

The seed-sowing machine has a number of major parts such as frame, ground wheel, aspirator blower, furrow opener, seed metering mechanism, seed indexing plate, seed hopper, chain-sprocket mechanism, bearings, motor and battery. The frame is the main supporting part of the machine and supports the seed hopper, the blower, motor, indexing mechanism, ground wheel and other assembly parts. It is constructed of mild steel and is a square which is welded to a rectangular metal frame that is then attached to the furrow opener. The frame is strong, durable and light, and provides the necessary strength to resist the forces of operation, while keeping weight to a minimum. The ground wheel, which is attached to the bottom of the frame, rotates as the seed planter is pushed. Two transport wheels are included (made of mild steel) with lugs all around the front wheels to give more grip and prevent wheel slip. A small sprocket on the front wheel is driven by a chain mechanism which rotates a sprocket on the seed-metering shaft causing the seed-metering wheel to rotate and allowing individual seeds to be picked off from a hopper and fed through the seed discharge tube to the planting shoe or furrow opener. The wheels are arranged at either end of the frame, and are circular in shape with a width at the periphery of 75 mm to eliminate side thrust. The spokes are 1" thick mild steel square pipes and the structural support to the wheels and tie-off of the circumference to the central hub is 3.5 mm thick mild steel flat bars. The aspirator blower is used to create the suction to meter the seeds pneumatically. During rotation of the motor, the high suction pressure created by the aspirator blower in the metering chamber of the pneumatic disc is passed via a connecting tube. The tube should be air tight to prevent the loss of air, and is usually made of HDPE. The seed plate is constructed from aluminium and has slits or holes around the edge to secure the seeds to the vacuum. Seeds are not removed

eISSN: 2583-1194

from the plate until the release position is reached in the furrow where the suction force is released causing the seeds to fall by gravity. Seed plates may be different for different crops; the number and size of holes selected depending on the space needed between seeds and the size of the seed. The rotational speed of the seed plate may also be varied by using different sprocket arrangements so as to control the seed rate. The pneumatic metering system allows the individual seed to be picked up under suction which minimises mechanical damage to the seeds. The furrow opener is used to create a narrow opening in the soil to lay seeds and the design can be changed depending on the soil type and sowing depth to be desired. The furrow opener is made from mild steel angle bar and is pointed in order to penetrate the soil; it is shaped in the form of a shoe. The furrow opener is fastened to the frame with nuts and bolts, and the depth of the furrow can be adapted to the different crops by adjusting the position of the furrow opener. The seed metering mechanism is regarded as the essential working part of the sowing machine as it regulates the amount of seed deposited at the correct application rate and the spacing of the seed in the row. The metering wheel is made of nylon and has several cells around its edge. The size of cell and number of cells will depend on the size of the seed and the desired spacing. In the operating position, individual seeds are taken out of the hopper through the cells of the metering wheel and carried to the seed funnel which conveys them through the seed tube to the furrow prepared by the furrow opener. There are four independent metering wheels to cater for various types of seed and seed rate. The number of cells needed on the metering wheel depends on the diameter of the planter ground wheel and the gear ratio used, as well as the desired intra-row spacing between seeds. Seed indexing plate is a 210 mm diameter and 20 mm thickness of aluminium casting plate for seed metering. The seed-release point is placed at the lowest point of the disc in order to allow effective release of the seed. Through an extended pipe, a 25 mm diameter hole is provided for connecting the vacuum disc with the aspirator inlet at the same time the support plate forms a tube over the slit on the vacuum disc for the vacuum-pressure configuration required. The seed plates are chosen based on the crop, recommended seed spacing, number of holes, and diameter of the seed hole, for example, 8 seed holes 5 mm diameter seed plate for cotton, 64 seed holes 3 mm diameter for soybean, 48 seed holes 2.5 mm diameter for sorghum, 16 seed holes 2 mm diameter for radish, 12 seed holes 6 mm diameter for groundnut, 8 seed holes 6 mm diameter for maize and 8 seed holes 1.5 mm diameter for mustard. The seed hopper is used to store the necessary amount of seed for operation. It is triangular in form with a lower opening to allow free flow of seed to the metering mechanism. Hopper is made of mild steel and may also be offered with a fertilizer application system. The capacity is about 3 kg, said to be adequate for crops like cotton. The power is transferred from the ground wheel to the seed-metering mechanism by means of the chain-sprocket mechanism. The front ground wheel begins to turn as the planter is moved forward, which turns the small sprocket mounted on the front ground wheel. The rotation is transmitted through a pintle chain to a larger sprocket attached to the seed-metering shaft to turn the metering wheel, picking up and releasing seeds at the correct intervals. The small and large sprockets have 18 and 48 teeth, respectively. An idler sprocket is used when necessary to keep the chain engaged with the right side of the chain and is preferably located on the slack side of the chain. There are bearings at both ends of the frame to hold the eccentric shaft that the wheels are attach. The bearings are chosen with regard to load-carrying, life and reliability and help in smooth rotation of the wheel without incurring frictional forces. The high-speed steel is used as the bearing material in the system. Finally, the motor and battery supplies electrical power to the blower in the aspirator. The battery stores electrical energy, and provides it to the motor, which uses electromagnetic induction to change the electrical energy into rotational motion. The suction pressure needed for pneumatic seed-metering operation is created by the rotating motor shaft, which operates the blower by means of a belt system.

Drilling is a mechanised sowing of agricultural crops in which seeds are inserted into the soil at specific seed rates, seed spacing and depths. A seed drill is a device that has a seed hopper above it, and a series of tubes or seed delivery units placed at selected distances to ensure proper distance between plants. The seeds are metered by using fluted paddles or rollers which are mechanically driven through a geared arrangement attached to the ground wheel and the rate of seeds can be adjusted by altering the gear ratio. In present-day seed drills, the seeds are usually pneumatically transported through plastic tubes to the seed outlets or coulters in a system in which the seeds are metered mechanically into a motor-driven aspirator blower and an air stream. Because of this pneumatic system, wider seed drills can be developed with some systems being as wide as about 12 m. A seed drill allows uniform sowing of seeds in rows at the required seed rate and depth, in a single step, making furrows, dropping the seed and covering it with soil. This will give more control on depth of seed and seed placement and will help establish crop and germinate more often. Seed drills will also provide a uniform row system that will aid weed-management practices, providing a better opportunity for weed control between rows of well-spaced crop than when planted by broadcast seeding, which has plants randomly distributed. The field is usually ploughed and harrowed in order to break soil clods and level and loosen the soil before use of the seed drill. The seed drill is then adjusted to suit the type and size of the seed and the conditions under which it will be sown, and seeds are placed in the hopper, and the metering and delivery mechanism then operate as the machine travels across the field, distributing seed. Depending on the machine design, and also in accordance with field requirements, seed drills can be pulled by animal power, in this case by the bullocks, or by a tractor. Generally speaking, seed drilling gives essentially uniform seed distribution and placement at the desired depth, and can be used for large area cultivation and wide variety of crops, and it reduces the labour demand of manual sowing, and making the intercultural and weed-management work easy.

2.2 Working

The principle of suction vacuum is the foundation of the basic working of the pneumatic planter. The planter may be drawn by a tractor or by a couple of bulls to be dragged through the fields to be sown. The planter is made of a pair of ground wheels directly mounted on the frame. So when the tractor moves forward the ground wheels also rotates for providing enough traction as well as to prevent the sleeping of the wheels on the muddy surfaces they are provided with rectangular projections on the outer periphery. Having spokes to support the weight of the assembly wheels also. Therefore, the rotating movement is transferred by a sprocket-chain to the indexing/or a metering chamber.

The sprocket is attached to the respective shaft at the ground wheels as well as the shaft to which another sprocket is attached. The sprocket is having 18 teeth and each being of the same diameter. The frame is also used to mount a blower and a motor is also attached to the frame.The motor is powered by a battery, which is located close to the motor. The blower consists of an impeller having 6 curved vanes and a casing which houses its impeller. The blower consists of two ports one discharges the suction air to the atmosphere. In order to connect the other port to the indexing chamber, a plastic hollow tube is used.

When the blower spins clockwise the suction is therefore formed on the other side of the plate. The indexing mechanism is an indexing plate with 8 holes with a diameter equal to the seed size. This makes sure the release of only one seed at the cut off thus reducing the wastage of a costly hybrid seeds such as cotton. So when the seeds falls from the seed hopper into the indexing mechanism the suction presents at the holes cut in the plate, attracts the seeds. When the suction is disconnected, the seed is ejected down a furrow opener. A furrow opener is a tip point edge for providing adequate sowing depth.

The pneumatic planters are the most precise machines which can sow one seed at a constant uniform spacing. This is a type of planters that clearly have the potential of taking planting techniques to a whole new level.

The figure illustrates the fabricated pneumatic seed metering unit developed for precision sowing applications. The assembly consists of a circular seed plate enclosed within a rigid rectangular housing, commonly referred to as the black box, which functions as an airtight chamber. This enclosure is connected to a suction source such as a vacuum pump or blower, enabling the creation of a pressure differential essential for seed metering. The seed plate, mounted on a central shaft, rotates inside the chamber and contains a series of precisely machined holes corresponding to the size and type of seeds to be sown. During operation, seeds from the hopper come in contact with the rotating plate, and their movement is controlled through pneumatic suction.

A significant design feature of this system is the differentiation between suction and non-suction zones within the chamber. The larger cut-out section of the black box acts as the suction zone, where negative pressure is actively maintained. As the seed plate rotates through this region, suction is applied across the holes, resulting in seeds being picked up and held against the plate surface due to the pressure difference. This ensures proper seed singulation and prevents multiple seeds from occupying a single hole. In contrast, the smaller cut-out section of the chamber forms the non-suction zone, where the vacuum effect is either absent or significantly reduced. When the seed plate carrying seeds enters this region, the holding force diminishes, allowing the seeds to detach naturally under the influence of gravity and fall into the delivery system or furrow.

This controlled transition between suction and non-suction zones is critical for achieving accurate seed placement and uniform spacing. The enclosed chamber design minimizes air leakage, thereby improving suction efficiency and consistency in seed pickup. Additionally, the modular configuration of the seed plate allows easy replacement for different crops, enhancing the versatility of the planter. The pneumatic metering unit effectively integrates mechanical motion with pneumatic principles to achieve high precision, reduced seed wastage, and improved planting performance.

FIG 1 : SEED MEETRING BOX

Table No. 01 presents the design specifications of seed plates used in the developed planter for different types of crops. The selection of seed plate parameters namely recommended seed spacing, number of holes on the plate, and seed hole diameter is critical to ensure accurate seed metering and uniform crop establishment.

The recommended seed spacing (cm) represents the agronomic requirement for each crop, which directly influences plant population and yield. Crops like cotton require wider spacing (45–150 cm) due to their larger canopy and growth habit, whereas crops such as soybean and mustard require closer spacing (5–10 cm) to achieve optimal plant density.

The number of holes on the seed plate is determined based on the desired seed spacing and the ground wheel rotational speed. A higher number of holes corresponds to crops requiring closer spacing. For example, soybean has 64 holes and sorghum has 48 holes to facilitate dense sowing, whereas maize and cotton have only 8 holes due to their wider spacing requirements.

The seed hole diameter (mm) is selected according to the physical size and shape of the seeds to ensure proper singulation and prevent seed damage or multiple seed pickup. Larger seeds such as maize and groundnut require bigger hole diameters (6 mm), while smaller seeds like mustard and radish require smaller hole sizes (1.5–2 mm). Proper matching of hole diameter with seed size ensures efficient pneumatic pickup and release during operation.

Overall, the combination of these parameters ensures that the planter can achieve precision sowing, minimize seed wastage, maintain uniform plant spacing, and improve crop productivity. The table highlights the adaptability of the planter for multiple crops by simply changing the seed plate configuration, making it a versatile and efficient agricultural implement.

Table No.01. Specifications of the seed plates used in planters.

Crops	Recommended seed spacing (cm)	No. of holes on the plate	Seed hole diameter (mm)
Cotton	45-150	8	5
Sorghum	10	48	2.5
Soybean	5	64	3
Maize	30	8	6
Ground Nut	15	12	6
Radish	10	16	2
Mustard	10	8	1.5

FIG 2 : PNEUMATIC OPERATED SEED PLANTER

Design Analysis and Material Selection.

Design Consideration:

The design of pneumatic planter for sowing different seed crop is based on the following considerations.

The ease of fabrication of component parts.

Properly protecting the operator.

It should be easy to operate for small scale/rural farmers.

The materials available locally were used in the fabrication of the components.

Materials available and the expense of materials for construction.

Tools And Materials:

Table 02. Specification of manually operated precision planter for different seed metering wheel.

Name of the Component	No. Of Items	Dimensions in mm	Material
Frame	1	Length- 844 Width-	M.S. Flat Bar
Seed Hopper	1	Height-200 Width-100	M.S. Sheet Metal
Shaft	1	Diameter-20 Length-50	Carbon Steel
Furrow Opener	1	Length -150 Width-10	M.S.
Ground Wheel	2	Diameter-300	Sheet Metal
Sprocket	6	No. of teeth-18,16,19 Diameter-70	Medium C.S.
Pintle Chain	3	No. of Links-54	Malleable Links
Seed Tube	2	Length-200	Plastic
		Diameter-32	
Ball Bearing	1	Diameter-65	Material Bronze

Nut Bolts	10	Numbers-45	Carbon Steel
Battery	1	Capacity-12v	
Motor	1	Speed-250rpm	

3. RESULTS AND DISCUSSION

Design Calculations Table

The design of the pneumatic planter has been developed through a systematic engineering approach to ensure operational efficiency, structural integrity, and ergonomic suitability under field conditions. As the planter is primarily manually operated, the design is based on the physiological capability of an average human operator, ensuring that the required effort remains within acceptable limits to minimize fatigue during prolonged usage.

The transmission of power within the planter is accomplished through a chain drive mechanism, which effectively converts the manual input into rotational motion of the ground wheel and subsequently drives the seed metering system. The design ensures proper synchronization between the forward movement of the planter and the seed dispensing process, thereby achieving uniform seed placement. The ground wheel serves as a critical component in maintaining consistent motion and facilitating adequate torque transmission throughout the system.

Structural considerations have been incorporated to ensure the reliability and durability of the planter components. The shaft and associated elements are designed to withstand combined bending and torsional loads encountered during operation. Appropriate material selection and safety factors have been adopted to prevent structural failure under working conditions.

The configuration of the planter includes an appropriate number of furrow openers, determined based on draft requirements and crop-specific agronomic considerations. The working width of the planter is thus established in accordance with the number of furrow openers and the desired row-to-row spacing. This arrangement enables efficient field coverage while maintaining optimal crop spacing.

The seed hopper is designed to provide adequate storage capacity and to ensure a continuous and uniform flow of seeds to the metering device. Its geometry is selected to prevent clogging and facilitate smooth seed movement. The seed metering mechanism, being a critical component, is designed to achieve precise control over seed delivery, thereby ensuring uniform plant-to-plant spacing and minimizing seed wastage.

A chain sprocket system is incorporated to achieve effective power transmission and speed variation between the ground wheel and the metering unit. This arrangement allows for proper synchronization and enhances the accuracy of seed placement. The design also facilitates adjustments to suit different crop requirements.

Ergonomic considerations are integrated into the design of the handle to enhance operator comfort and reduce physical strain. The handle is made adjustable to accommodate operators of varying heights, ensuring ease of operation for both male and female users. The inclination of the handle is optimized to provide better control and to minimize operator fatigue during extended field operations.

The furrow opener is designed to ensure effective soil penetration with minimal draft requirement. It facilitates proper seed placement depth and consistent furrow formation. Adequate strength and rigidity are provided to withstand soil resistance and operational stresses.

The performance of the pneumatic planter is evaluated in terms of field capacity, seed placement accuracy, and overall operational efficiency. The machine is capable of covering a specified area within a given time while maintaining uniform seed distribution. The design contributes to a reduction in labour requirements compared to conventional planting methods, making it suitable for small and medium-scale agricultural applications

Table 03. Calculations

Section	Parameter / Description	Formula / Value
Human Power	Power developed by operator	HP = 0.35 - 0.092 log t
Human Power	Average working time	2–4 hours
Human Power	Power range	0.13 – 0.16 HP
Human Power	Power at 3 hours	0.14 HP
Push Force	Power relation	HP = Push Force × Speed
Push Force	Machine speed	2.5 km/h (0.7 m/s)
Push Force	Push force	15 kgf
Wheel Speed	Wheel RPM	$Nw = (V \times 100)/(\pi \times 60)$
Torque on Wheel	Torque equation	$Tw = Kw \times Wt \times Rw$
Torque on Wheel	Coefficient Kw	0.3
Torque on Wheel	Weight Wt	20 kg
Torque on Wheel	Radius Rw	16.5 cm
Power (Drive)	Power equation	$HP = (2\pi NwTw)/4500$
Chain Load	Chain load	$Q = Kl \times Pt$
Chain Load	Coefficient Kl	1.15
Chain Load	Equivalent load	$Qv = Q \sin \varphi$ ($\varphi = 35°$)
Bending Moment	Maximum bending moment	Mb = (W × overhung) + (Qv × overhung)
Bending Moment	Overhung (wheel)	15 cm
Bending Moment	Overhung (sprocket)	5 cm
Bending Moment	Equivalent moment	$Meq = \sqrt{(Mb^2 + Mt^2)}$, Mt = Tw
Shaft Design	Shear stress	600 kg/cm^2
Shaft Design	Diameter equation	$d^3 = 16Meq/(\pi \tau s)$
Furrow Opener	Number of openers	Z = D/dr
Furrow Opener	Working width	W = Z × row spacing
Seed Hopper	Volume	Vb = 1.1 Vs
Seed Hopper	Seed volume	$Vs = Ws/\gamma s$
Seed Metering	Number of cells	$Ns = \pi dw/(N \times X)$

Seed Metering	Diameter	$Dm = Vr/(\pi Nr)$
Chain Drive	Teeth	Small = 18, Large = 48
Chain Drive	Chain length	$m = 2C/p + (Z1+Z2)/2 + (Z2-Z1)^2/(2\pi p)$
Handle Design	Elbow height	100 cm
Handle Design	Wheel distance	115 cm
Handle Design	Inclination	$\tan\theta h = a1/a2$
Tyne Design	Bending moment	$BM = F(h-a)$, $a = h/3$
Tyne Design	Section modulus	$Zt = Mb/fb$
Tyne Design	Stress	56 N/mm^2
Tyne Design	FOS	2
Planter Capacity	Area capacity	CPA = Area × 1000
Planter Capacity	Seed capacity	CNP = Distance/Spacing × Seeds/hole
Time Requirement	Time per hectare	Time = 1/CPA
Time Requirement	Days required	Total hours / working hours per day
Labour Requirement	Labour	400 hours/hectare
Planter Features	Components	Frame, blower, metering plate, hopper, furrow opener, wheel
Performance Tests	Lab tests	Missing, multiple seeds, suction pressure
Performance Tests	Field tests	Spacing, depth, efficiency, skid, plant population

4. CONCLUSION

Problems of machine availability, labor shortage and seed wastage in agricultural operations could be solved with a low cost solution by using the vacuum seed-sowing planter.

The machine allows a precise and neat picking and placement of seeds in the appropriate location of the seedling tray.

The small size of the automatic seed-sowing machine means that it requires a smaller area for operation, and therefore is suitable for operation in places where space is limited.

Accurate seeding helps to ensure even plant development through the proper placement and spacing of seeds.

The machine provides flexibility for different varieties of seeds, as the nozzle can be adjusted according to the size and requirements of the seed.

The vacuum system with picking mechanism aids to the precise handling and placement of seeds in the soil during sowing, thus minimising seed loss while sowing.

The general conclusion is that the vacuum seed-sowing planter is a compact, inexpensive, accurate and versatile seed sowing machine for automatic sowing and especially for seedling trays.

The present study successfully demonstrates the design, development, and performance evaluation of a pneumatic precision planter aimed at improving seed placement accuracy and operational efficiency in agricultural sowing practices. The developed system effectively addresses the limitations of conventional sowing methods, particularly non-uniform seed spacing, higher seed wastage, and increased dependency on manual labour. By incorporating a pneumatic seed-metering mechanism, the planter ensures controlled single-seed placement with minimal mechanical damage, thereby enhancing planting precision and uniform crop establishment.

The structural design of the planter, with its lightweight yet robust configuration, enables ease of operation under varying field conditions and compatibility with different power sources such as tractor and animal-driven systems. The provision of interchangeable seed plates allows adaptability to multiple crops and varying agronomic requirements, making the system versatile and farmer-friendly. The performance evaluation indicates that the developed planter achieves improved seed spacing uniformity and operational effectiveness compared to traditional sowing techniques.

AUTHOR CONTRIBUTIONS

Vipul Prabhakar Rathod : Conceptualization, Investigation, Methodology, Laboratory Analysis, , Writing—Review & Editing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

Ethical approval was not required for this study.

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