Chapter

Scaling Mechanization and Profitability in Maize Cultivation through Innovative Maize Planters along with Agroforestry Approach Sustainable and Climate Smart Approach to Diversify Rice Based Cereal Systems in Various Regions

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Abstract

Keeping in view declining water tables in India and across the world, low greenhouse gas (GHG) emission and global warming potential (GWP) for maize as compared to rice a study was done on maize planters along with agro forestry concept. The yield for inclined and vertical plate mechanism ranged between 4.96–7.71 t.ha^{-1} and 6.75–8.61 t.ha^{-1}, respectively. The increase in maize yield in raised bed planters varied between 0.48–2.57 t.ha^{-1}. The maximum yield was recorded from pneumatic raised bed planter with bed of 150 mm height and 711 mm top width (2 rows on each bed). The saving of irrigation water ranged between 9.68–23.69% for raised bed planting (150–290 mm) as compared to flat planting. The specific energy was found minimum for pneumatic raised bed and flat planter as 7.02 and 7.38 MJ.kg^{-1}. The energy productivity was found maximum for pneumatic raised and flat planter as 0.14 Kg.MJ^{-1} (cost $12.60 per ha and $9.33 per ha) followed by raised bed inclined plate planter as 0.13 Kg.MJ^{-1} and were found economical as compared with ridger+manual sowing method (cost $77.62 per ha).

Keywords: energy, maize crop planter, water savings, raised bed, pneumatic, maize yield

1. Introduction

Maize due to its various uses in feed (61%), industry (22%) and food sectors (17%), is considered as an internationally important commodity driving world agriculture.

Globally, it is grown in 193.7 million hectare across 170 countries (**Figure 1**), with total production of 1147.7 million metric tonne and average productivity of 5.75 t ha^{-1}. It has attained a position of industrial crop globally as 83% of its production in the world is used in feed, starch and bio-fuel industries [1, 2]. It has emerged as the most cultivated grain in the world, surpassing rice and wheat in 1996 and 1997, respectively [3]. Largest grain crop in India, after rice and wheat is Maize (*Zea mays* L.). It is cultivated in an area of 9.09 million hectares (M ha), with an annual production of 24.26 million metric tonnes (MMT), and an average national productivity of 2.56 metric tonnes per ha (t ha^{-1}) [4]. In US and China are the leading producer accounting for about 38% and 23% respectively and India contributes around 2% of this production chart (26 million MT) in 2016–2017. In the Indian context it generates employment for more than 650 million person-days at farming and the businesses related to it. States such as Karnataka, Rajasthan, Andhra Pradesh and Madhya Pradesh, Bihar contribute towards almost 2/3rd of the national maize production [5]. It is grown in India during rainy (*kharif*), winter (*rabi*) and spring seasons, but major production is in the rainy season [6]. Area under Rabi Maize (>400 thousand ha) is larger than that under *Kharif* maize (>230 thousand ha) in Bihar due to low infestation of insect, pest and diseases as well as slow growth of weeds [7]. The abiotic and biotic stresses listed in descending order of importance are: caterpillars, water stress, stem borers, weevils, zinc deficiency, rust, seed/seedling blight, cutworm, leaf blight and technological parameters. A potential solution for organic maize is to apply the biological control agent Trichogramma strips at around 10 and 17 days crop (100–125 no ha^{-1}; size 5×1.50 cm). A study revealed that that by application of Trichogramma pretiosum, 79.2% of egg masses were parasited and maize yield increased by (701 kg ha^{-1}) 19.4% [8].

Water stress during the growing season can decrease grain yields [9]. The FIRB technique save the resources like water, nutrients and labour and also facilitates the greater diversification of the rice-wheat cropping systems and improve the physical properties of soil [10]. The raised-bed planting may enhance maize productivity in part by increasing availability of essential crop nutrients by stimulating microbial activity. Raised-bed planting yielded mean saccharase, urease, protease and phosphatase activities across sampling times in 2006 of 2.3 mg glucose $g^{-1} h^{-1}$, 0.8 mg NH_3–N $g^{-1} h^{-1}$, 10.5 mg glycine $kg^{-1} h^{-1}$, and 0.4 mg nitrophenol $g^{-1} h^{-1}$, 6, 18, 34, and 31% higher than those in flat planting, respectively [11]. It was reported that wide (180 cm) beds produced higher wheat (15%) and maize (26%) yields whereas narrow (65 cm) and medium (130 cm) width beds produced higher maize yields (10%) while wheat yields were only marginally (<5%) higher than the basin treatment. The narrow beds used 3–7% while the medium and wide beds used 16–17% and 18–22% less water than the basins [12]. A 3–4 inch bed height is necessary for maintaining

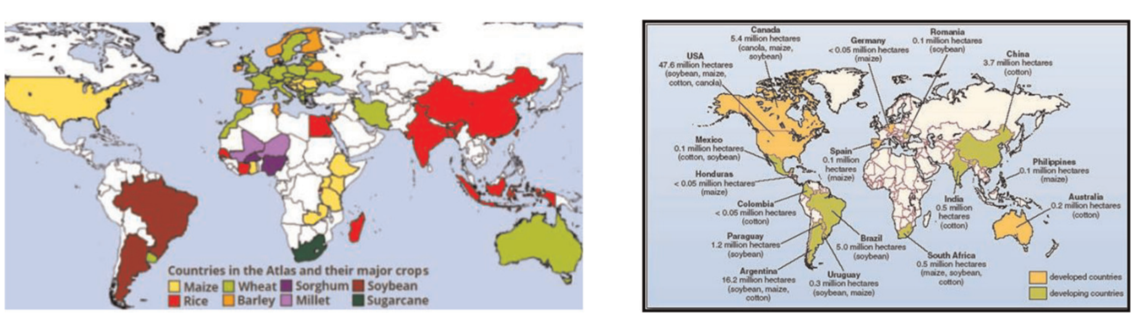

Figure 1.
Worldwide distribution of Major crops.

maximum yield for both corn and soybeans [13]. There was water saving of about 20.4% for wheat crop (for wide beds (107 cm furrow centre gap) and about 16.5% for narrow beds (37 cm furrow centre gap) with grain yield increase of about 13.5% (5.13 and 4.44 t ha^{-1}) and 11.8% (4.33 and 3.82 t ha^{-1}) for maize crop with precision land leveling and raised bed planting compared to traditional land leveling with flat beds planting [14]. Increasing the compost from 5 to 10 ton ha^{-1} increased the yield, protein and K contents in maize crop. The interaction between compost manure (10 ton ha^{-1}) and nano-potassium (500 cm^3 ha^{-1}) or humic acid (10 ton ha^{-1}) recorded the highest mean values for all parameters during both harvest seasons [15]. A study was done for maize (PMH-1) grain in the moisture range of 10–18% wet basis (w.b.), the length of wetted grain increased from 10.01 to 10.65 mm, width increased from 8.57 to 8.70 mm, thickness ranged from 4.63 to 4.97 mm and the angle of repose varied from 23.36° to 28.55° [16] and hue angle (z%) decreased from 14.59 to 14.06 [17]. Maize sown on ridges resulted in greater seed emergence of 89%, plant height of 155.1 cm, and greater grain yield of 6.35 t ha^{-1} [18]. The manual punch planter recorded 61–64% singles, 17–19% multiples, 17–22% missing for speed ranging between 0.5–0.7 km h^{-1} and for soil with 69% clay, 16% silt and 15% sand [19]. A punch planter for corn was evaluated for no-till conditions at the vertical position with 2.5 kPa of vacuum and at a 22° incline with 4.0 kPa of vacuum. Only small changes occurred in the seed meter performance when speed varied from 1 to 3 m s^{-1} [20]. The best seed spacing uniformity and seed emergence ratio were obtained with the no-till planter, and the best seed depth uniformity was obtained with the precision vacuum planter. As forward speed increased, mean emergence time decreased ($p < 0.05$) [21]. The time required to plant one hectare of farmland with manual planter was determined as 3.7 hours [22]. A small maize planter with an independent driving wheel and stationary firming wheels was specially designed and was found suitable as compared to ordinary seeders for complex terrain and heavy soil surface condition [23]. The data showed that planter performance in terms of emergence and plant spacing coefficient of variation (CV) was comparable for most of the meter speeds (17.4–33.5 rpm) among the two seed meters (variable depth and variable seed rate) utilized in the study [24]. For common grain drills, a CV of 20% is an acceptable accuracy achieved by mechanical and pneumatic machines when they are performing well [25]. Panning et al. [26] evaluated a vacuum metering general purpose planter designed for shallow planting of small seeds for sugar beet crop. The most uniform seed spacing occurred at the lowest speed of 3.2 km h^{-1} and decreased as the forward speed increased from 3.2 to 8.0 km h^{-1}. The seed spacing uniformity was not affected by planter forward speed between 4.8 and 11.2 km h^{-1} [27]. A population of 90,000 plants ha^{-1} had the highest grain yields than lower populations for adequate nutrients and water supply. When density/population of plants increases, stalk lodging will increase due to smaller stalk diameter and a slight gain in grain test weight was observed [28–30]. It was reported that as plant population increased, the yield and kernel numbers increased but weight of kernels decreased [9, 31]. Yield reductions from uneven plant distributions ranged from 0 to 31% and averaged 10% [32]. The part of sowing depth real-time control included the module of collect pressure information and the module of sowing depth adjustment and the part of precise control of the sowing spacing included the module of speed acquisition and sowing motor control in a developed intelligent detection and control system for corn precision planter [33].

In a tillage study soil conditions induced fall moldboard plow, spring disk, and no-till were measured and the effects of tillage-induced soil conditions on planting depth, seedling emergence, and early growth of four maize hybrids grown continuously were evaluated on a poorly drained, moderately permeable soils. Surface residue cover averaged 10, 39, and 68% for the moldboard-plow, spring-disk, and no-till tillage systems, respectively. The study revealed that the residue from the previous maize crop remaining on the soil surface had a greater effect on plant growth than did the other soil physical properties measured. Seed placement was shallower and more variable on tillage systems with greater surface residue cover and early growth was delayed by systems with a large percentage of surface residue cover. Tillage systems with the best early growth tended to have the greatest yield, however, yields of hybrids were not always correlated with early growth The increase in seed depth with increasing amounts of tillage may result from decreasing soil strength or from decreasing surface residue cover. The final emerged plant population was least for the no-till system. Populations were similar in the spring disk and fall moldboard plow systems. Populations may have been reduced in the no-till system because of seed decay before germination or because seed was planted near residue pressed into the soil by the planter. Residue near the seed could reduce soil-seed contact and produce an allelopathic effect that can stunt or prevent early seedling growth [34, 35]. Compared with strip-rotating maize no-tillage planter, the maize no-till planter could not only seed and fertilize at the suitable depths, but also decrease soil disturbance and fuel consumption by 69.7% and 19.3%, respectively [36].

Field test shows that the planter has a good performance of trafficability with the ratio of sheering off corn stubble 85% and anti-blocking capacity, thus to finish wheat and maize no-till planting. The variation coefficient of seed depth was 19.4% and 23.4% for wheat and maize, respectively [37]. A rotary drum-type anti-blocking mechanism was developed and mounted in front of each opener shank of the maize planter and the drum was rotated driven by ground wheel at a certain speed. The result showed that the speed ratio was the most significant factor that affecting anti-blocking performance. Based on the results of simulation, the speed ratio of 1.24, the drum diameter of 150mm and 5 bars were the optimum parameters [38]. Ultra high precision placement of seed was also established. Mechanisms that ensure that the seeds planted has zero ground velocity [39].

Apart from planting/sowing technique, the crop selection and rotation, tillage practices have a significant effect on GHG emissions and resource conservation. The 24.8% of global greenhouse gases (GHGs) are emitted by "Agriculture, Forestry and Other Land Use (AFOLU)", including 0.5 Gt carbon dioxide equivalents (CO_2e) yr^{-1} from enteric fermentation and 1.2 Gt CO_2e yr^{-1} from agricultural soils [40]. The principal emissions from agricultural practices consist of (1) methane (CH_4) from enteric fermentation, (2) carbon dioxide (CO_2) from decomposition of soil organic carbon (SOC), and (3) nitrous oxide (N_2O) from synthetic fertilizer and manure [40]. The global warming potential (GWP) of each gas differs, however, with CO_2e values of 34, 3.7, and 298 for CH_4, SOC, and N_2O, respectively [41] (Intergovernmental Panel on Climate Change).

Results show that the GWP of CH_4 and N_2O emissions from rice (3757 kg CO_2 eq ha^{-1} $season^{-1}$) was higher than wheat (662 kg CO_2 eq ha^{-1} $season^{-1}$) and maize (1399 kg CO_2 eq ha^{-1} $season^{-1}$). The yield-scaled GWP of rice was about four times higher (657 kg CO_2 eq Mg^{-1}) than wheat (166 kg CO_2 eq Mg^{-1}) and maize (185 kg CO_2 eq Mg^{-1}), suggesting greater mitigation opportunities for rice systems [42]. Intermittent irrigation in rice reduced methane emissions by 40% whereas application of farmyard manure in rice increased the GWP by 41% [43]. However, practice of mid-season drainage has reduced green house gases equivalent to 270 million tonnes of carbon dioxide and increased the release of nitrous oxide, by about 20,000 tonnes for the same period [44]. It was estimated that CH_4 emissions from global rice fields varied from 18.3 ± 0.1 Tg CH_4/yr (Avg. ±1 SD) under intermittent irrigation to 38.8 ± 1.0 Tg CH_4/yr under continuous flooding [45]. Around 30% and 11% of global agricultural CH_4 and N_2O, respectively, emitted from rice fields and A recent study based on the database from different states in India documented national CH_4 budget estimate of 4.09 ± 1.19 Tg year^{-1} [46]. Open-burning of straw residues also contributes to global warming through emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) [41, 47, 48]. The carbon (C) and nitrogen (N) in the burned straw are emitted as CO_2—C (57–81%), CO—C (5–9%), CH_4—C (0.43–0.90%), and N_2O—N (1.16–1.50%) [49]. The global warming potential for CO_2 is 1 (100 years period), CH_4 is 27–30 (12 years in atmosphere), N_20 is 273 (109 years). Another potent green house gas carbon monoxide reacts with hydroxyl (OH) radicals in the atmosphere, reducing their abundance. As OH radicals help to reduce the lifetimes of strong greenhouse gases, like methane, carbon monoxide indirectly increases the global warming potential of these gases [50]. This means that a methane emission is projected to have 28 times the impact on temperature of a carbon dioxide emissions of the same mass over the following 100 years assuming no change in the rates of carbon sequestration. More than half of the South Asian population's livelihood capabilities are at risk due to rising temperature, droughts, erratic and isolated rainfalls, floods resulting in decline of crop yield, water logging/water scarcity, reduced farm income and migration [51]. Growing rice in rotation with soybean and planting hybrid cultivars, drainage twice may result in reduced CH_4 emissions. However, mineral-soil dressing on peat could have a significant impact on suppression of CH_4 emissions from beneath the peat reservoir [52, 53]. The study suggests that adoption of rice-rice-rape (*Brassica napus* L.) cropping system would be beneficial for greenhouse gas emission mitigation and as good cropping pattern in double rice cropped regions [54]. The monoculture in any cropping system causes more insect-pest attack, depletion of soil organic carbon, underground water, more use of fertilizers etc. Therefore crops should be grown in rotation specially with legumes to maintain soil health, reduce use of fertilizers, break insect-pest cycle thereby reducing use of chemicals, pesticides etc. A study revealed that crop residue return might be most effective in increasing crop yields and WUE in corn crops with a tillage depth > 20 cm, for cold conditions (<10°C), moderate nitrogen fertilization (0–150 kg ha^{-1}), growth of a single crop per year and high soil organic matter content (>15 g kg^{-1}) [55]. By assuming, the crops which had C:N ratio more than the threshold C:N ratio (50) and plant biomass higher than the threshold biomass (25 g/plant) were considered as having higher carbon sequestration potential. Based on these, the carbon sequestration potential of maize, sorghum and pearl millet was higher as compared to rice, finger millet and soybean [56]. Croplands worldwide and specially in intensively cultivated regions such as North America, Europe, India and intensively cultivated areas in Africa, such as Ethiopia could sequester between 0.90 and 1.85 Pg C/yr, i.e. 26–53% of the target of the "4p1000 Initiative: Soils for Food Security and Climate". Soil carbon sequestration and the conservation of existing soil carbon stocks is an important mitigation pathway to achieve the less than 2°C global target of the Paris Climate Agreement [57]. The crop water productivity for maize (1.80 kg m^{-3}) is higher as compared to wheat (1.09 kg m^{-3}), rice (1.09 kg m^{-3}), $cotton_{seed}$ (0.65 kg m^{-3}), $cotton_{lint}$ (0.23 kg m^{-3}) [58]. The carbon dioxide sequestration potential of corn is 20 tonne ha^{-1}. Depending upon location and the specific management practices implemented, the Climate Exchange bases Michigan carbon payments on approximately 1.0–1.5 tons of carbon dioxide equivalent per ha per year [59]. Soil biota includes earthworms, nematodes, protozoa, fungi, bacteria and different arthropods. Detritus (plant leaves, roots, stubble mulch etc.) resulting from plant senescence (final stage of plant growth) is the major source of soil carbon and above micro organisms decomposes these materials to help maintain nutrient cycling and organic carbon in soil. The organic matter content, especially the more stable humus, increases the capacity to store water and store (sequester) C from the atmosphere. The fastest way to gain soil carbon is to convert to long term no till, adding high carbon crops (corn and wheat) and adding cover crop mixture high in carbon (grasses primarily but also legumes to stabilize soil carbon). Along with GHG emissions, the depletion of ground water table under the existing 'Rice-Wheat' rotation in the erstwhile food bowl (Indo-Gangetic Plains) of the country has also alerted the state governments to diversify the cropping system and maize is a promising substitute. The wheat and paddy requires respectively 3–4, 30–35 irrigations per crop cycle where as maize crop requires 8–15 irrigations (depending upon rainfall) per crop cycle (each irrigation 50 mm). However, national productivity of maize is considerably lower than the global standards and there lies immense scope for improvement in farming technologies. Thus planters especially raised bed planters play a crucial role in achieving optimum maize crop stand, plant spacing, planting depth and higher yields in a sustainable way. Therefore, the feasible low cost flat and raised bed row crop precision planters were evaluated for sowing of maize crop and yield, energetic, irrigations aspects were studied.

2. Material and methods

2.1 Experimental site and maize variety description

The two raised bed planters with inclined and vertical metering plate mechanism, manual planter, flat inclined plate planter and pneumatic raised bed/flat planters were used for this study and the manual sowing on ridges was taken as control plot. The various field and crop parameters are shown in **Table 1**. The experiments were conducted at Department Farm Machinery and Power

Parameters	Detail/Value
Soil type	Sandy loam (2014–2017)
Soil type	Arid brown soil (2017–2020)
Longitude	75°49″09.082″ E, 75.4216702° E
Latitude	30°54′39.286″ N, 31.1797347° N
Mean monthly rainfall, mm	130.88
Mean maize seed characteristics L, B, T, mm	9.0, 7.8, 5.6
Degree of sphericity	0.0670452846592
1000 seed weight, g	286.0
Angle of repose	27.64

Table 1.
Soil type and location, mean rainfall for experimental areas and maize seed parameters.

Engineering Research Farm and farmer's fields during 2014–2020. The field was prepared with mould board plough, two operations of disc harrow followed by two operations of cultivator and one operation of planker and laser leveler to get the best sowing uniformity, the most uniform sowing depth, and maximum emergence percentage with various planters [60]. The various specifications of planters used for this study are shown in **Tables 2** and **3**. The maize crop was sown with various planters during 2014–2020 and sowing was done in East-West direction and North South directions. The seed rate was kept as 20 kg ha^{-1} and 275 kg ha^{-1} urea and 137.5 kg ha^{-1} DAP (N, P & K as 125, 60, 30 kg ha^{-1}), 50 kg ha^{-1} muriate of potash was applied. The weeds were controlled by chemical attrazine which was applied for weeds control (within 10 days of sowing) @2000 g ha^{-1} in 500 l water and mechanically by tractor operated 3-row sweep type weeder when crop height was 300 mm and during further stages of growth. Urea was applied in three splits 1/3 rd at sowing, 1/3 rd at 300 mm height and rest at silking stage. For fall armyworm insect control 1.0 ml corazen 18.5 S.C. per litre was applied for 20 days crop in 300 l water and later on according to stage of maize crop water upto 500 l was used (per ha area).

Parameters	**Raised bed inclined plate planter P_{rbip}**	**Raised bed vertical plate planter (P_{rbvp})**	**Flat Inclined plate planter P_{fip}**	**Pneumatic raised bed P_{prbvp}/flat planter P_{pfvp}**	**Ridger + manual sowing R_{ms}**
Required tractor power, KW	33.60	33.60	26.11	29.84 (dual clutch)	33.60 + 0.60H. E.[*]
Size of machine, L × B × H, mm	1670 × 3040 × 1250	1460 × 2050 × 1220	1350 × 2470 × 1065	2032 × 1524 × 1219	1000 × 2000 × 1200
Number of rows	4	4	4	4	2
Furrow opener type	Reversible shovel type	Reversible shovel type	Reversible shovel type	full runner type	Ø
Bed maker	Plough type	Plough type	Ø	Plough type	Plough type
Bed/ridge height/ top width, mm	230/350	150/350	Ø	150/711	290/Ø
Row spacing, mm	675	675	675	675	675, 600
Metering plate(mp) material	Aluminum	Mild steel	Mild steel	SS-304	Ø
Metering plate diameter, mm	160	180	160	215	Ø
Seed metering mechanism	Inclined plate with cells on periphery	Vertical plate with spoons on periphery	Inclined plate with cells on periphery	Vertical plate with holes on periphery	Manual
No. of cells/spoon on each plate	8	12	24	26 (5mm hole)	Ø
Adjacent cell/spoon spacing, mm	55	50	12	—	Ø
mp inclination with horizontal	45°	90°	45°	90°	Ø
Height of seed drop, mm	740	970	940	100	Ø

Parameters	Raised bed inclined plate planter P_{rbip}	Raised bed vertical plate planter (P_{rbvp})	Flat Inclined plate planter P_{fip}	Pneumatic raised bed P_{prbvp}/flat planter P_{pfvp}	Ridger + manual sowing R_{ms}
Ground wheel (gw) diameter, mm	508	400	420	356	Ø
Speed ratio gw:mp and mode of power transmission to metering plate	1.25:1 chain sprocket and bevel gear	1.25:1 chain sprocket	1.25:1 Chain sprocket and bevel gear	Chain and sprocket	Ø
Weight, kg	515	315	250	300	175
Seed covering device	Mild steel Strips	Cast Iron Roller	No device	Fiber plastic wheels/zero pressure pneumatic press wheel	Manual

H.E.—human energy, KW [61].

Table 2.
Specifications of machines used for raised bed planting of maize crop and their operational parameters.

Particulars	Unit	Energy equivalent MJ unit^{-1}	References
Human labor	h	1.96	[62, 63]
Machinery	h	62.70	[63]
Diesel fuel	L	56.31	[62, 64]

Table 3.
Various energy equivalents for input operations and sources.

2.2 Meteorological data

The average minimum and maximum temperatures were 17.59°C and 29.67°C, respectively, whereas the mean temperature was 23.53°C based on meteorological data. The average annual rainfall was 653.84 mm. The mean sunshine duration was 7.43 h, mean number of rainy days recorded was 1.91 and mean wind speed was 3.53 km h^{-1} (**Figure 2**).

2.3 Planter dimensions, specifications and material description

The specifications of various planters are shown in **Table 2**. The inclined plate with cells and vertical plate with spoons/holes were used as metering mechanisms for seed metering. The furrow openers of planters were made of steel alloy hard. The power transmission to metering plate was given through bevel gear for raised bed inclined plate and flat plate planter and was through chain for raised bed vertical plate planter. In case of raised bed vertical plate planter the hopper size was 140 × 300 mm (l × b) and horizontal distance between inner side of plate to outer side of spoon/spoon length/diameter were 35/15/Φ11 respectively. The hopper size for flat plate planter was 100 × 110 mm (1 hole Φ30mm).

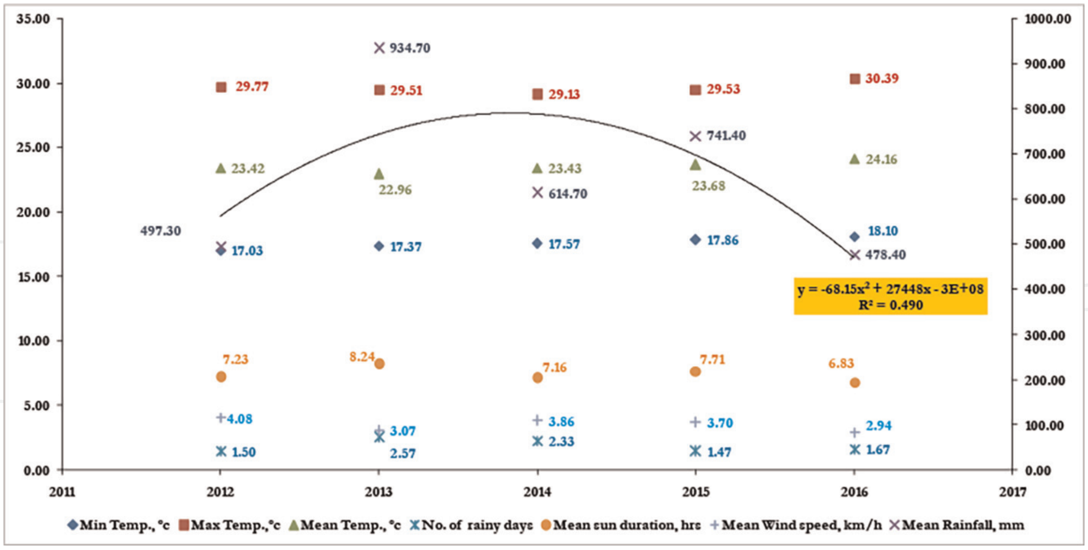

Figure 2.
Mean annual meteorological data from 2012 to 2016.

Runner type opener was used as the fields were well prepared, comprising of sand to loam soils and free from weeds and residue etc. The front section of the opener is 'V'-shaped (in transverse cross section) and extends below the wider rear portion (**Figure 3**). Runner openers are not used in soils with high clay content as the sliding action of the opener causes 'smearing' along the base and walls of the furrow which severely restrict subsequent root development. Similarly reversible shovel type furrow openers causes less disturbance in soil, requires less draft and are easy in construction, cheaper and easily repairable. The seed covering device like mild steel strip (light weight), cast iron roller (for seed covering and bed shaping), zero pressure pneumatic press wheel were used. Zero pressure pneumatic press wheels are continual flexing which makes them self cleaning. The function of covering device in planter is to place the seed in contact with the moist soil, cover them to the proper depth, press the soil firmly around the seeds and leave the soil directly above the row loose enough to minimize crusting and promoting easy emergence. Agitator & sliding orifice type metering mechanism was used for fertilizer metering. Material used for ground wheel, bed former and fertilizer metering mechanism was mild steel. The material used for Pneumatic raised bed/flat planter was mostly Aluminum to make it light weight and cause less compaction of soil. The germination data were recorded for the different rows planted by planters/method and were analyzed for quality, missing, multiples and precision indices. The data was also analyzed statistically. Similarly maize yield and water requirements were also recorded during these experiments. The raised bed inclined plate (**Figure 4**) planter (4-row), raised bed vertical plate planter (2-row) (**Figure 5**) were designed to sow one line of maize on each bed. The mean maize grain length, width and thickness were 9.0, 7.80 and 5.60 mm, respectively. Therefore, cell radius in planter plate was kept as 10 mm and thickness as 8 mm. The angle of repose was 27.64° [16]. Therefore, plate was inclined at 45° i.e. more than angle of repose for free fall of maize seed during field operation. The flat inclined plate planter (**Figure 6**) and pneumatic planter were able to sow 4 rows of maize at a spacing of 675 mm. The ridger was used to make ridges at 600 mm and 675 mm distance and manual plating of maize was done at plant to plant spacing of 200 mm. In case of manual planting around 160 man-h ha^{-1} were involved in sowing operation.

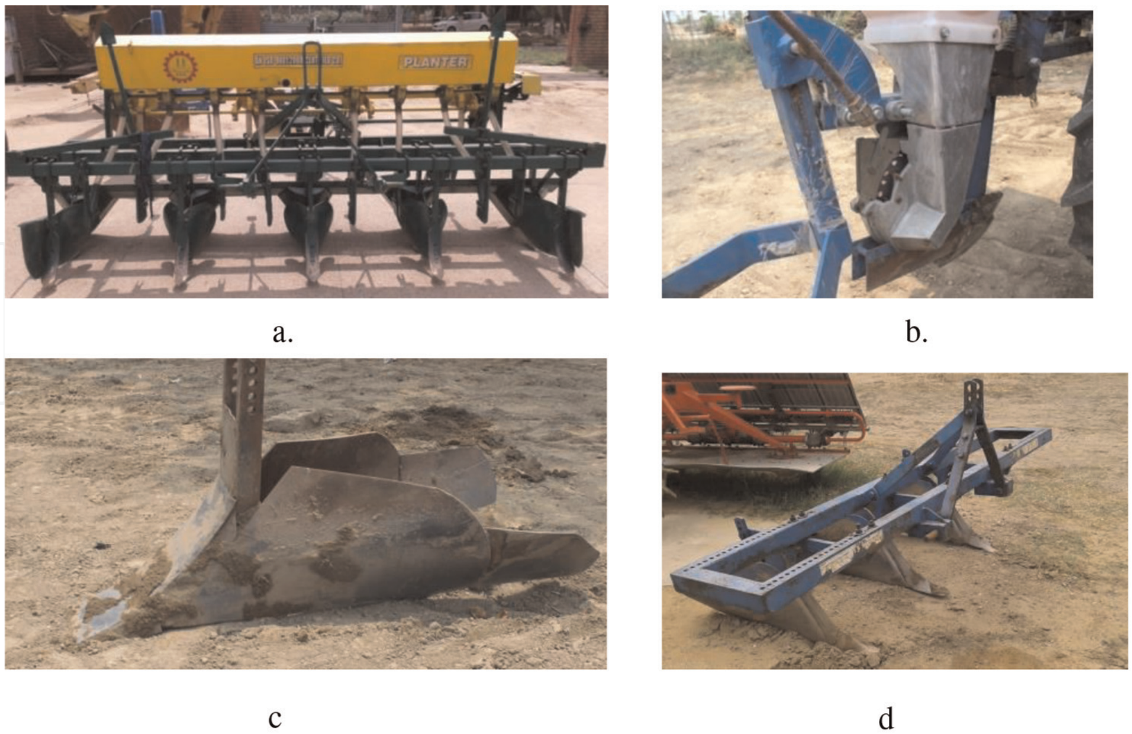

Figure 3.
(a) A view of reversible shovel furrow opener in inclined plate planter, (b) metering plate and full runner opener for pneumatic planter, (c) bed former for pneumatic raised bed planter and (d) ridger.

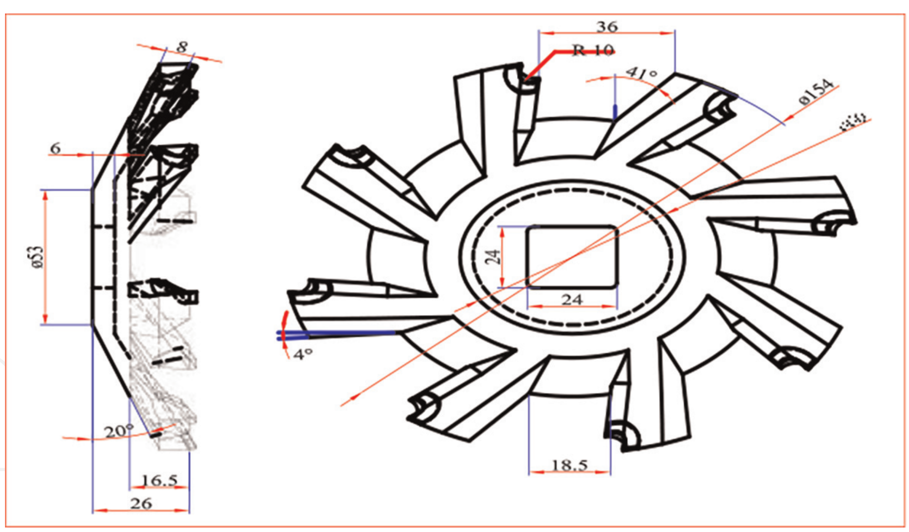

Figure 4.
Line diagram for metering plate of raised plate planter.

The manual planter (**Figure 7**) is cheap, suitable for hilly/plain regions or for land with undulating topography. One persons pulls this machine from front with the help of a rope and other person pushes it from ergonomically designed handle for uniform movement of metering plate and placement of maize seed in soil at proper depth. The physical power output of a male agricultural worker is approximately 75 W and for female worker is 60 W sustained for an 8–10 hours work per day [61]. A furrow opener is provided for opening of soil in manual planter (M_{vp}) and ground wheel is provided for easy movement of planter. The metering plate is driven by it through

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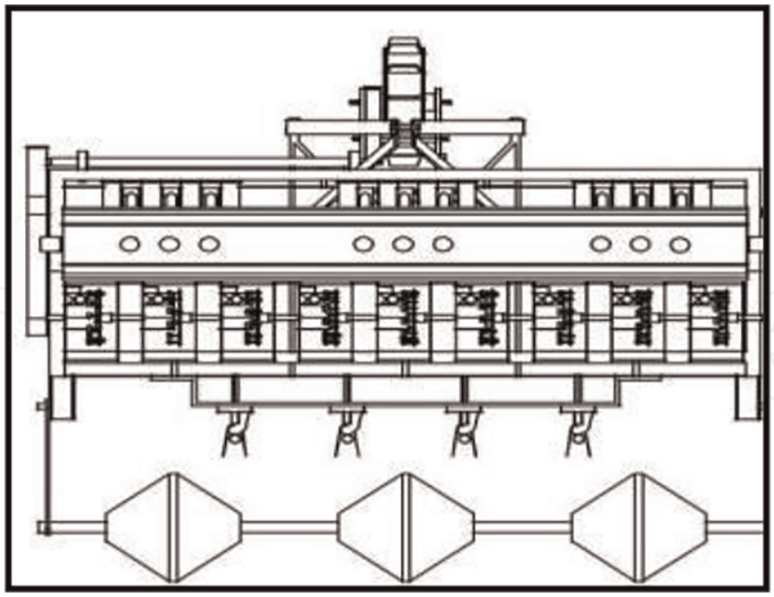

Figure 5.
Raised bed vertical plate planter and bed inclined spoon type vertical metering plate.

Figure 6.
Flat inclined plate planter with U shaped inclined plate planter.

Figure 7.
Manual planter with spoon type vertical metering plate.

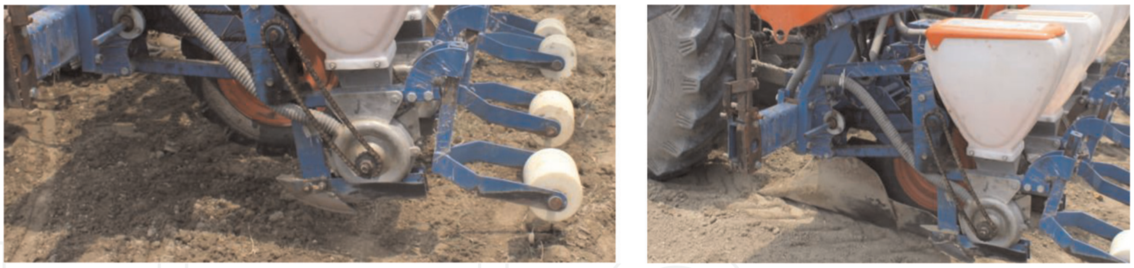

Figure 8.
View of chain transmission system, press wheel and bed maker for low cost Pneumatic precision planter.

Figure 9.
Chain and sprocket mechanism for varying plant to plant spacing.

chain sprocket transmission. In this planter the metering system used is vertical plate with spoons system. The approximate weight of manual maize planter is 20 kg and mean depth of seed placement was 22.35 mm. The view of chain transmission system to metering plate, press wheels, bed former for pneumatic raised bed planter are shown in **Figures 8** and **9**.

Indices for planter performance analysis—All the row crop planters were calibrated in lab for desired seed rate and plant to plant spacing and variation in field was compared with theoretical spacing.

Various indices were used to calculate accuracy of planting of various planters, the description of each index is given below.

2.3.1 Multiple index

Multiple index (D) is the percentage of spacing that are less than or equal to half of the theoretical spacing. D, is an indicator of more than one seed dropped within a desired spacing.:

$$D = N/n_1 \quad (1)$$

where N = total number of observations and n_1 = number of spacing's in the region less than or equal to 0.5 times of the theoretical spacing.

2.3.2 Quality of feed index

It is the percentage of spacing that are more than half, but not more than 1.5 times the theoretical spacing. Quality of feed index, A, is the measure of how often the seed spacing were close to the theoretical spacing [65]. The quality of feed index is mathematically expressed as follows:

$$\mathrm{A} = N/n_2 \tag{2}$$

where N = total number of observations and n_2 = number of spacing's between 0.5 times the theoretical spacing and 1.5 times of the theoretical spacing.

2.3.3 Miss index

It is the percentage of more than 1.5 times the theoretical spacing. Miss index, M, is an indicator of how often a seed skips the desired spacing and expressed as:

$$\mathrm{M} = N/n_3 \tag{3}$$

where N = total number of observations and n_3 = number of spacing in the region more than 1.5 times of the theoretical spacing.

2.3.4 Precision Index

Precision Index, C, is a measure of the variability in spacing after accounting for variability due to both multiples and skips. The degree of variation is the coefficient of variation of the spacing that are classified as singles, and expressed as:

$$\mathrm{C} = ref\ X/S_2 \tag{4}$$

where, S_2 = sample standard deviation of the $n2$ observations and $Xref$ = Theoretical spacing.

Energy input calculations—The various energy equivalents are shown in **Table 3** and energy indices were calculated using following formulae.

- Fuel energy consumption $\mathrm{MJ\ ha^{-1}} = \text{fuel consumption}\ (\mathrm{l\ h^{-1}}) \times \text{fuel energy equivalents}\ (\mathrm{MJ\ l^{-1}})/\text{effective field capacity}\ (\mathrm{ha\ h^{-1}})$ (5)

- Human energy consumption $\mathrm{MJ\ ha^{-1}} = \text{no. of human labour used} \times \text{time}\ (\mathrm{h}) \times \text{human energy equivalent}\ (\mathrm{MJ\ h^{-1}})/\text{area covered}\ (\mathrm{ha})$ (6)

- Energy embodied in machinery $\mathrm{MJ\ ha^{-1}} = \text{weight of specific machine}\ (\mathrm{kg}) \times \text{energy equivalent of machinery}\ (\mathrm{MJ\ kg^{-1}})/\text{wear out life of machine}\ (\mathrm{h}) \times \text{effective field capacity}\ (\mathrm{ha\ h^{-1}})$ (7)

The energy involved in various planters, mechanical weeders, field preparation, combine harvester, biocides, fertilizer, electricity was considered for energy calculations. The various forms of direct and indirect energy were also calculated for row crop planters and other sowing methods.

2.4 Analysis and economics

Analysis of maize crop yield was done for various planters. The saving in irrigation water, CO_2 emissions were recorded and compared for all the planters. The economics was calculated for all planters using fixed and variable costs for each planter and energy calculations were also done.

3. Results and discussions

The sowing of maize was done with various planters (**Figures 10–12**) and techniques. The operational parameters were recorded for various planters and shown in **Table 4**. The fuel consumption and field capacity for raised bed inclined plate planter were 7.92 l ha^{-1} and 0.60 ha h^{-1}. The mean standard deviation in spacing was 0.92 cm for raised bed inclined plate planter whereas it was 1.67 cm (+0.75 cm) for raised bed vertical plate planter.

The view of ridge formation for manual sowing is shown in **Figure 12**. The field operational parameters of the various row crop planters/methods are shown in **Table 4**.

The maize sowing with pneumatic raised bed planter and pneumatic flat planter is shown in **Figures 13** and **14** respectively. The emergence of maize crop sown with raised bed inclined plate planter and pneumatic raised bed planter is shown in **Figure 15**.

The field observations revealed that higher missing index was either due to higher speed or the 'U' shaped design of metering plate which lead to stucking of two seeds in one cell. Thus this planter design requires human intervention and more human energy for planting accuracy. The design of plate of raised bed inclined plate planter was like 'open loop' (**Figure 10**) which encountered no stucking of seeds in the field operation.

The various parameters recorded at germination stage are shown in **Table 5** and represented in **Figure 16**.

Standard deviation remains a widely used standard of measure for within-row plant spatial variation, and targets the mechanics of the planter as causative for non-uniformity. The grain yields appeared to increase 110 kg ha^{-1} for every 1 cm decrease in standard deviation and change in yield per 1 cm improvement in plant spacing uniformity ranged from 27 to 152 kg ha^{-1}; respective to location [66]. The correct seed metering unit setup is very critical to obtain expected performance from planting technology [24]. The planters were operated between speed range of 1.87–3.79 km h^{-1}. The low speed of planter minimizes the Intra-row spacing by reducing the creation of skips and multiple-plant hills that cause, more so the latter, barren stalks and reduced grain weight per ear [66, 67]. The lowest standard deviation in spacing was achieved by raised bed inclined plate planter design (0.92 cm), which shall lead to higher yield returns. However quality of feed index

Figure 10.
Maize sowing with raised bed inclined plate planter and view of metering plate.

Figure 11.
Maize sowing with raised bed vertical plate planter.

Figure 12.
Ridge formation with ridger for manual sowing.

Operational parameters	Raised bed inclined plate planter	Raised bed vertical plate planter	Flat inclined plate planter	Pneumatic raised bed planter	Manual flat planter	Ridger + manual sowing	Pneumatic flat planter
F_C, l ha^{-1}/human energy KW	7.92	10.10	9.27	7.50	0.15 KW*	8.03	6.25
S, km h^{-1}	3.24	2.64	3.79	1.87	0.46	2.21(R) +0.11 (MS) 1.16″	2.22
C_e, ha h^{-1}	0.60	0.49	0.48	0.50	0.23	0.0061	0.60
d, mm	40.26	40.10	33.63	35.16	23.33	23.45	35.25

F_C, *fuel consumption;* S, *forward speed;* C_e, *effective field capacity;* d, *depth of seed placement.*
*[61]—"Mean speed of ridger + manual sowing technique".

Table 4.
Field operational parameters for various row crop planters.

Figure 13.
Maize sowing with pneumatic raised bed planter.

Figure 14.
Maize sowing with pneumatic flat planter during 2017.

Figure 15.
Emergence of maize crop sown with raised bed inclined plate planter (left, 1-row/bed) and pneumatic raised bed planter (right, 2-rows/bed).

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Parameters	Raised bed Inclined plate planter	Raised bed vertical plate planter	Flat Inclined plate planter	Ridger + manual Sowing		Pneumatic raised bed planter	Pneumatic flat planter	Manual planter	p-value	*f*-value
				60.00	**67.5**					
QFI, %	67.44a	48.04a	41.09a	55.22a	39.29a	87.99a	85.25a	76.85a	0.176*	1.965
MI, %	19.00ab	17.52a	30.28ab	44.78ab	53.57b	7.64ab	10.97a	12.75a	0.024*	4.501
MUI, %	13.63a	34.33b	21.46a	0.00c	0.00c	4.37a	3.79a	10.61a	0.002*	31.438
Intra-row spacing, cm	0.92a	1.67a	1.35a	3.40b	2.14a	1.27a	1.55a	2.36a	0.001*	12.332
C, %	4.63a	8.34bc	6.74ab	16.95d	10.69c	6.35a	7.74a	11.82a	0.003*	61.155
PTP spacing, cm	19.35a	18.69a	19.16a	27.87b	27.10b	18.52a	18.92a	18.24a	0.000*	54.035

**Significant at 5% level.*

Table 5.
Performance of raised bed inclined plate and vertical plate planter based on germination data attributes.

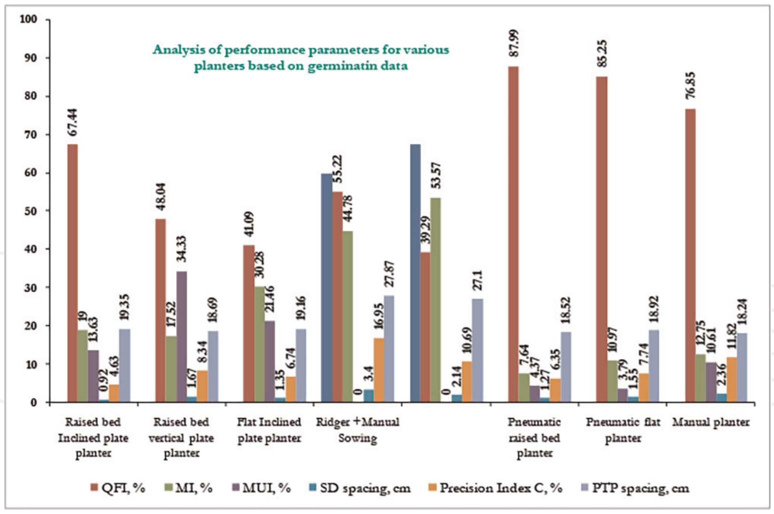

Figure 16.
Graphical representation of various performance parameters for maize planters based on field germination data of maize crop.

was higher for pneumatic raised bed planter (87.99%) and pneumatic flat planter (85.25%). The lowest missing index (7.64%) was recorded for pneumatic raised bed planter and lowest multiple (3.79%) index was observed for pneumatic flat planter. The precision indices for raised bed inclined plate planter, pneumatic raised bed and flat planters were 4.63%, 6.35%, 7.74% respectively. The intra-row spacing for pneumatic raised bed and flat planter were 1.27 cm and 1.55 cm which resulted in higher grain yield. The Intra-row spacing of raised bed vertical plate planter, inclined plate planter were 1.67 cm, 0.92 cm and that of flat planter was 1.35 cm. The forward speed for vertical plate planter was 2.64 km h^{-1} and intra-row spacing was observed as 1.67 cm. The forward speed for raised bed inclined plate planter was 3.24 km h^{-1} and Intra-row spacing was observed as 0.92 cm. The SD increased at faster planting speeds but variation of intra-row spacing with change in forward speed of planter was low in case of inclined plate as compared to vertical plate. Thus sowing with different mechanical planters certainly affected plant population, stand uniformity with mean standard deviation (SD) of within-row plant spacing and consequently maize yield [68]. A view of mechanical weeding operation in raised bed maize crop with sweep type weeder and crop at growing stage are shown in **Figures 17** and **18** respectively. After maturity, maize harvesting was done and yield data was recorded which is shown in **Figures 19** and **20** and represented in **Table 6**.

The yield for ridger + manual sowing method was found more for 60.0 cm spacing (5.38 t ha^{-1}) and lower for 67.5 cm spacing (4.56 t ha^{-1}). The optimum bed design, exposed bed area to sunlight is necessary for better root formation, canopy formation, irrigation water productivity and water drainage.

The maximum cob grain weight of 0.117204 kg (at 10% m.c., w.b.), grain yield of 8.61 t ha^{-1} was observed for pneumatic raised bed planter with number of grains per cob as 410, plant population as 84,095 [9, 69] and 1000 grain weight as 285.86 (at 10% m.c., w.b.), owing to highest QFI as 87.99%, appropriate seeding depth of 35.16 mm and wider row spacing of 67.5 cm appropriate spacing between plants (row spacing and plant to plant spacing) resulted into non overlapping of inter row maize canopies, uniform exposure for all plants to sunlight, higher grain filling and grain weight. The higher yield for pneumatic raised bed planter with 2-rows of maize per bed revealed that 2-rows per bed for 150 mm bed height to be optimum for better crop growth and yield. The difference between QFI for pneumatic raised bed and flat

Figure 17.
Mechanical weeding operation in raised with 3-row sweep type weeder.

Figure 18.
A view of maize crop at growing bed maize crop stage.

planter was found as 2.74% and corresponding yield increase for pneumatic raised bed planter was 3.14% .

The flat inclined plate planter had lower yield of 4.98 t ha^{-1} owing to high missing index and multiple index and low QFI as 41.09%. Due to more multiples, 1000 grain weight per cob was low as 267.40 g because of more competition among plants for nutrients [70]. The grain yield and QFI for raised bed vertical plate planter was 6.75 t ha^{-1}, 48.04% and for manual flat planter was 7.42 t ha^{-1}, 76.85% respectively. In mechanical vertical plate mechanism a slight jerk in field resulted in skip of seeds at various points and more multiples/missings at other points [22]. The difference in QFI for raised bed inclined plate planter and flat inclined plate planter was 26.35% and yield increase for raised bed inclined plate planter was 35.41%. The manual flat planter

Figure 19.
A view of maize crop at maturity stage.

Figure 20.
A view of maize grain samples from various trials.

is economical, easy to operate and suitable for maize planting by small and hilly area farmers [22].

The raised bed inclined plate planter had plant population as 63,623 and cob grain weight as 0.010109 kg. But due to highest precision index 4.63% and more accurate plant to plant spacing 19.35 cm, seed placement at appropriate depth of 40.26 mm, the maize plants sown with this planter recorded maximum 1000 grain weight as 286.57 g and higher grain yield as 7.71 t ha^{-1} [9]. Due to lower missing index, better crop stand and canopy formation it lead to more sunlight exposure and healthy grains with a recorded more maize yield [25, 71].

In case of manual and raised bed vertical plate planter the QFI was higher (76.85%) for manual planter and missings, multiples were higher in raised bed vertical plate planter as 17.52%, 34.33% respectively. The missings may be attributed to higher speed in case of raised bed vertical plate planter (2.64 km h^{-1}) as compared to manual planter (0.46 km h^{-1}). The difference in QFI for manual flat planter and

Maize crop parameters	Raised bed vertical plate planter	Raised bed inclined plate planter	Ridger +manual sowing		Flat Inclined plate planter	Pneumatic raised bed planter with press wheel	Pneumatic flat planter with press wheel	Manual planter
			60.0	67.5				
Varieties	PMH-1, PMH-2	PMH-1, DKC-9108, 1844	PMH-1, DKC-9108	PMH-1	PMH-1, PMH-2	DKC-9108, DKC-9164, Pioneer-1899, 1844	DKC-9108, DKC-9164, Pioneer-1899, 1844	PMH-2, DKC-9108, DKC-9164, Pioneer-1899, 1844
Area, ha	7.0	18.0	8.2	8.2	7.2	195.0	195.0	5.0
Period	07/2014, 07–10/2015	07–10/2015, 6/2016, 02–06/2017, 02/2017	07–10/2015, 02–06/2017, 07–10/2019	07–10/2015	07/2014, 07–10/2015, 02–06/2017	07–10/2019, 02/2020	07–10/2019	07/2014, 07–10/2019
Mean ± S.E. p-value 0.001, f-value 10.629	6.75 ± 0.09	7.71 ± 0.17	5.38 ± 0.56	4.56 ± 0.0	4.98 ± 0.51	8.61 ± 0.26	8.34 ± 0.1.07	7.42 ± 0.82
1000 grains weight (m.c. w.b.10%)	275.40	286.57	220.90	249.40	267.40	285.86	282.31	269.40.0
Plants per ha	71,394	63,623	30,581	26,073	68,171	84,095	79,065	73,154
No of grains per cob	359	353	396	395	318	410	402	405
Cob grain weight after moisture correction (at 10% mc w.b.), kg	0.098995	0.10109	0.0795555	0.10709	0.0710895	0.117204	0.113489	0.098745

Table 6.
Results obtained for maize yield (t ha^{-1}) (at 10% m.c., w.b.) sown with various planters during different year experiments.

raised bed vertical plate planter was 28.81% and yield increase for manual planter was 9.03%.

The more height of bed (290 mm) and low depth of sowing in manual method (23.45 mm) lead to lower germination/plant population and lower yield (4.56–5.38 t ha^{-1}). It may be attributed to fact that seed was placed close to soil crust and in low moisture, rapid drying zone and root formation was not appropriate. The difference in maize yield between manual flat planter and manual sowing method (2.04–2.86 t ha^{-1}) also shows the importance of initial soil tillage. However seed metering mechanism in planter is most crucial to obtain optimum plant population, crop stand, growth and yield [24, 72]. The seeding depth for full runner type furrow opener and reversible shovel type furrow opener were 35.16 mm and between 23.33 and 40.26 mm respectively and corresponding plant emergence ranged between 79,065–84,095 and 63,623–73,154 respectively due to low soil resistance. The full runner type furrow opener and reversible shovel type furrow opener were found suitable for sandy loam soil [73, 74]. The depth of seed placement can be attributed to furrow opener type, depth setting, downforce (applied due to weight of planter), pull force, weight of machine, bed maker attachments. The bed maker attachments facilitates tillage in front of furrow opener by cutting, breaking and moving of soil and facilitated deeper placement of seed [34] due to friable condition of soil, which ultimately resulted in maximum plant emergence. The plant population among various planters also showed the benefits of light weight covering device like M.S. strips and zero pressure pneumatic wheels behind the seeding line. The light weight covering device enables furrow closure and seed soil contact for maximum germination and minimal compaction of seeds [75] as low weight covering device leaves the soil in crumbly condition which enables germinated seed to emerge from soil crust with lowest force. The effect of various planting mechanisms (metering, furrow opener and soil covering device), planter speed was found significant on SD value, precision index and maize yield ($p < 0.05$).

The saving in water with raised bed inclined plate planter, raised bed vertical plate planter, ridge planting, pneumatic raised bed planting was 31.25 cm, 15.87, 18.62, 38.85 cm ha^{-1}, respectively as compared to flat planting (**Table 7**). The saving of irrigation water ranged between 9.68 and 23.69% for raised bed planting as compared to flat planting [14]. The CO_2 emissions in kg ha^{-1} for raised bed inclined plate planter, raised bed vertical plate planter, ridge planting and flat planting were found to be 20.91, 26.66, 24.73 and 21.20, respectively and for pneumatic raised bed planter was 19.80 kg ha^{-1}. The maize yield increase were found to be 3.98, 3.39 and 1.33 t ha^{-1} for raised bed inclined plate planter, raised bed vertical plate planter, ridge planting as compared to flat planting. The data collected from sub-mountainous rainfed area revealed that under rainfed conditions (rainfall between 150–950 mm, yearly 944.87 mm, *Kharif* 770.21 mm June-October, *Rabi* 186.89 mm October To February) the maize crop yield lied in between 3.5 and 4.0 t ha^{-1} during *Kharif* season.

It is clear from the graphical representation that the highest irrigation water requirement (656 mm/acre) was for flood irrigation (**Figure 21**). The prediction equation for irrigation water (cm/ha) as a function of height of bed (cm) was obtained as:

$$y = 0.091x^2 - 3.339x + 164.3 \quad (8)$$

The prediction equation for maize yield (t ha^{-1}) as a function of height of bed (cm) and planter design was obtained as:

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Planting method	Height of bed	Diesel consumption (l ha^{-1})	Irrigation water (cm ha^{-1})	Cost of operation (Rs/ha)	Yield (t ha^{-1})	1 l diesel equiv. kg CO_2 (g)	CO_2 emissions (kg ha^{-1})	Saving in water (cm ha^{-1})	% saving in water as compared to flat planting	% Yield increase per ha compared to flat planter	Yield increase per ha compared to flat (t ha^{-1})
Raised bed inclined plate planter	230	7.92	132.75	1170.03	7.71	2640	20.91	31.25	19.05	+31.53	+1.98
Raised bed vertical plate planter	150	10.10	148.13	1646.26	6.75	2640	26.66	15.87	9.68	+8.60	+0.54
Ridge planting	290	9.27	145.38	6209.70	4.56	2640	24.73	18.62	11.35	+7.64	+0.48
Flat Planting	0	8.03	164.00	1590.24	4.98	2640	21.20	0.00	0.00	0.00	0.00
Pneumatic raised bed planter	150	7.50	125.15	1022.35	8.61	2640	19.80	38.85	23.69	+40.92	+2.57

Table 7.
Irrigation water requirement, maize yield and CO_2 emissions with various planters.

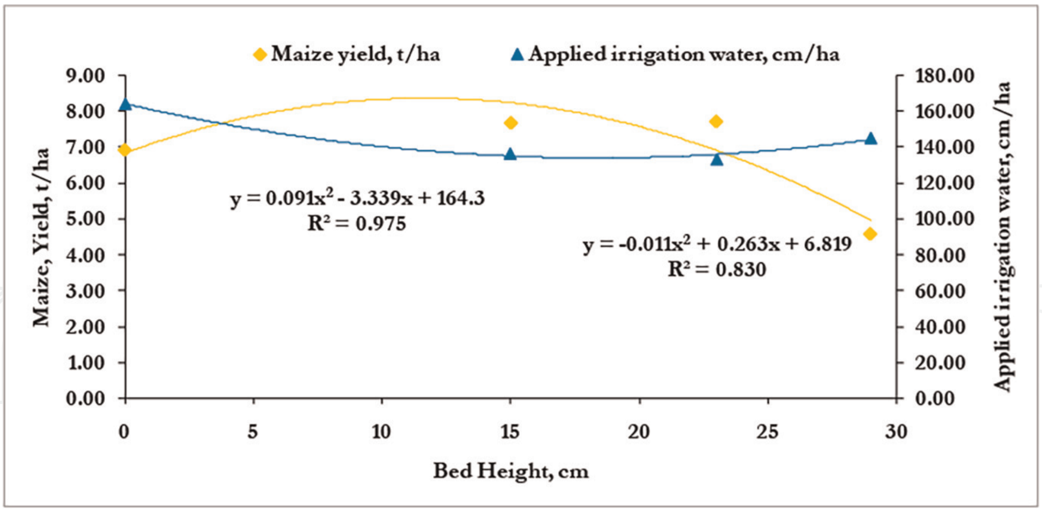

Figure 21.
Maize yield attributed to planter parameters, bed applied irrigation water for various sowing methods.

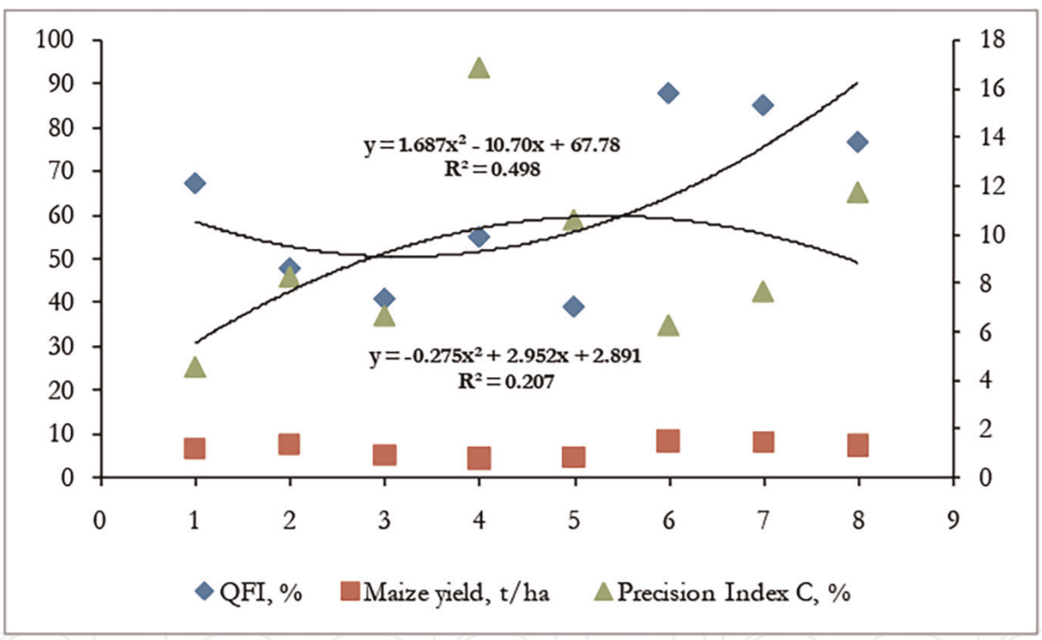

Figure 22.
Maize yield attributed to planter height, parameters like quality of feed index and precision index.

$$y = -0.011x^2 + 0.263x + 6.819 \quad (9)$$

The graphical relation between maize yield and quality of feed index and precision index is shown in **Figure 22**. The prediction equation between quality of feed index (%) and maize yield (t ha^{-1}) was obtained as

$$y = 1.687x^2 – 10.70x + 67.78 \quad (10)$$

The prediction equation between precision index (%) and maize yield (t ha^{-1}) was obtained as

$$y = -0.275x^2 + 2.952x + 2.891 \quad (11)$$

The irrigation water was certainly affected by height of bed and plant population which was related to type of planter used. From all the planters under experiment the pneumatic raised bed (125.15 cm ha^{-1}) and raised bed inclined plate planter (132.75 cm ha^{-1}) recorded minimum water requirement. Thus bed height ranging between 150 and 230 mm (6″–9″) was optimum for irrigation water saving and optimum yield. The highest irrigation water requirement (164.00 cm ha^{-1}) was observed for flood irrigation under flat planting system and lowest yield was recorded for flat planting system (4.98 t ha^{-1}). Raised bed vertical plate planter observed higher irrigation water (148.13 cm ha^{-1}) and lower yield (6.75 t ha^{-1}) than raised bed inclined plate planter practice (132.75 cm $ha^{-1}$and 7.71 t ha^{-1}). The ridge planting method had water requirement of 145.38 cm ha^{-1} and lower yield. Generally it was found that that more applied irrigation water has inverse relation on maize yield i.e. water at root zone must be not more than sufficient for optimum crop establishment, growth and higher yield. Along with this alternate irrigation ensures more soil aeration and better root growth and underground water saving. Groundwater accounts for 99% of all liquid freshwater on Earth and is present beneath Earth's surface in rock and soil pore spaces and in the fractures of rock formations. Therefore it is very important to make smarter use of the potential of still sparsely developed groundwater resources, and protecting them from pollution and overexploitation and it is essential to meet the fundamental needs of an ever-increasing global population, to address the global climate and energy crises". To achieve the Sustainable Development Goals (SDGs) by 2030 we have to improve the ways for using and managing groundwater efficiently with minimum waste and pollution [76]. Among many contributors to the Polar motion (PM) excitation trend, groundwater storage changes are estimated to be the second largest (4.36 cm/yr) toward 64.16°E [77]. The unregulated anthropogenic activities (like municipal, industrialization, pollution, deforestation, urbanization, building dams, improper landfill practices improper chemical, product, fuel storage causing leaks in soil, agricultural, marine dumping, oil leaks and spills, radioactive waste, global warming killing water animals and thus water pollution, etc.) have drastically increased groundwater depletion and resultant pollution. Groundwater quality monitoring should be done, especially by industries to measure groundwater parameters like Ph, TSS, water level, flow rate, etc. through a telemetry system and if any problem is observed, prompt action should be taken. Climate change will further exacerbate groundwater challenges by affecting aquifers both quantitatively and qualitatively. Geogenic factors such as salinity, fluoride, arsenic and iron in groundwater affect the resource and cause significant long-lasting, intergenerational health detriment. Metals such as cobalt (Co), copper (Cu), iron (Fe), molybdenum (Mo), manganese (Mn) and zinc (Zn) are critical for plant growth and are classified as essential micro nutrients. Other metals that are commonly found as contaminants, and are non-essential for plants, include arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), uranium (U), vanadium (V), Wolfram (W). Metals can have toxic effect on plants even at low concentration. The pollution and depletion of groundwater notoriously violate the right to access water and, in turn, the right to life, recognized as a human right by numerous judicial pronouncements. Water pollution laws must create sufficient legal safeguards against groundwater pollution. The water crises, draught are becoming more common place around the world as billions of people (approx. 6.04 bn) continue to suffer from a lack of access to clean water, sanitation and hygiene in the event of natural water resources scenario in world disasters and increasing global water withdrawals due to growing demand. Projected global water consumption by 2040 is 1.72 trm^3 and highest water consuming sector worldwide by 2050 will be irrigation to agricultural crops. Maize being a C4 plants, has a competitive edge over C3 plants. C4 plants use 3-fold less water, allowing them to grow in conditions of drought, high temperature, and carbon dioxide limitation. Along with this the resource conservation techniques like raised bed planting of crops on raised bed, drip/sprinkler irrigation systems, underground pipeline system (to save evaporation, seepage losses as compared to open channels), crop rotations, rooftop (on building roof) and on farm rainwater harvesting structures (for underground water recharge as well as for use in agricultural lands, industrial, rural and urban area), crop diversification (pulses, sugarcane, maize, etc., in place of rice), agro-forestry, etc. will play a crucial role in preventing over-exploitation of existing water resources and saving of underground water and mitigating climate change. Over-exploitation or pumping groundwater aggressively may release arsenic into the water and also cause land subsidence (sudden sinking of land). Arsenic is mainly present in clayey layer of underground surface and little of it seeps into the water, while groundwater is pumped. But if overdone, a substantial amount may get entered into aquifers due to high hydraulic gradient created. Similarly, phytoremediation

Title	Tractor 45-50HP	Raised bed vertical plate planter	Flat inclined plate planter	Raised bed inclined planter	Pneumatic raised bed/ flat planter	Ridger + manual/ manual planter	Pneumatic flat planter
New cost, P, Rs Cost, USD	550,000 **$6875.00**	60,000 **$750.00**	50,000 **$625.00**	80,000 **$1000.00**	200,000 **$2500**	15,000 **$187.50**	180,000 **$2250.00**
Life (yrs), L	15	10	10	5	10	10	10
Avg. use/yr (h)	700	700	700	300	700	250	700
Rate of interest (%), i	12	12	12	12	12	12	12
Field capacity, ha/h	Of implement	0.49	0.48	0.60	**0.50**	0.56	0.6
Salvage value, S = 10% of P	55,000	6000	5000	8000	20,000	1500	18,000
Total fixed costs (Rs/h)	114.71	15.09	12.57	70.93	50.29	10.56	42.56
Total variable cost (Rs./h)	77.41	446.34	408.62	443.58	297.54	474.75	215.11
Total cost (fixed + variable) (Rs/h)	192.12	461.42	421.19	514.52	347.82	485.31	260.36
Total cost, Rs/ha including tractor		1333.76	1277.74	857.53	695.64	1209.70	433.94
Labour required off machine operation, man-h/ha		10	10	10	10	160	10
Grand total machine cost, Rs/ha Cost, USD*		1646.26 $20.58	1590.24 $19.88	1170.03 $14.62	1008.14 $12.60	6209.70 $77.62	746.44 $9.33

https://www.xe.com/currencyconverter/convert/?From=USD&To=INR (1USD = 80.00 inr)

Table 8.
Cost economics calculations for various row crop planters.

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(with poplar and other trees, etc.) technique can be used which involves use of plants and associated microbes to reduce the concentrations or toxic effects of contaminants in the environment. However, it is limited to root zone of plant and has limited application where the concentrations of contaminants are toxic to plants. The processes affecting the quality are dissolution, hydrolysis, precipitation, adsorption, ion-exchange, oxidation, reduction and bio-chemical mediated reactions. In general, the reactions that control the chemistry of ground water are:

- Introduction of CO_2 gas into the unsaturated zone.
- Dissolution of calcite and dolomite and precipitation of calcite.
- Cation-exchange.
- Oxidation of pyrite and organic matter.
- Reduction of oxygen, nitrate and sulfate with production of sulphide.
- Reductive production of methane.

Particulars	Raised bed vertical plate planter	Flat inclined plate planter	Raised bed inclined plate planter	Pneumatic raised bed planter	Ridger + manual	Manual	Pneumatic flat planter
	P_{rbvp}	P_{fip}	P_{rbip}	P_{prbvp}	R_{ms}	M_{VP}	P_{pfvp}
Biocides	500.00	500.00	500.00	500.00	500.00	500.00	500.00
Fertilizer	11217.50	11217.50	11217.50	11217.50	11217.50	11217.50	11217.50
Electricity	5737.50	6324.75	5130	4826.25	5602.50	6324.75	6324.75
Seed	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Human energy	237.52	237.60	236.79	235.15	531.03	373.92	236.79
Machine energy	3443.92	3430.40	3467.80	3400.38	3400.38	3372.67	3430.40
Diesel fuel	39372.48	39325.67	39249.42	39225.96	39256.12	38803.63	38803.63
Total energy MJ ha^{-1}	61508.92	62035.92	60801.51	60405.24	61507.53	61592.47	61513.07
GJ ha^{-1}	61.51	62.04	60.80	60.41	61.51	61.59	61.51
Yield kg ha^{-1}	6750	4980	7710	8610	4970	7420	8340
Specific Energy, MJ kg^{-1}	9.11	12.46	7.89	7.02	12.38	8.30	7.38
Energy productivity, EP, kg MJ^{-1}	0.11	0.08	0.13	0.14	0.08	0.12	0.14

Machine equivalent 133 MJ/kg (Source: CIGR Handbook of Agricultural Engineering Volume V Energy and Biomass Engineering, p. 18).

Table 9.
Energy consumption in maize production.

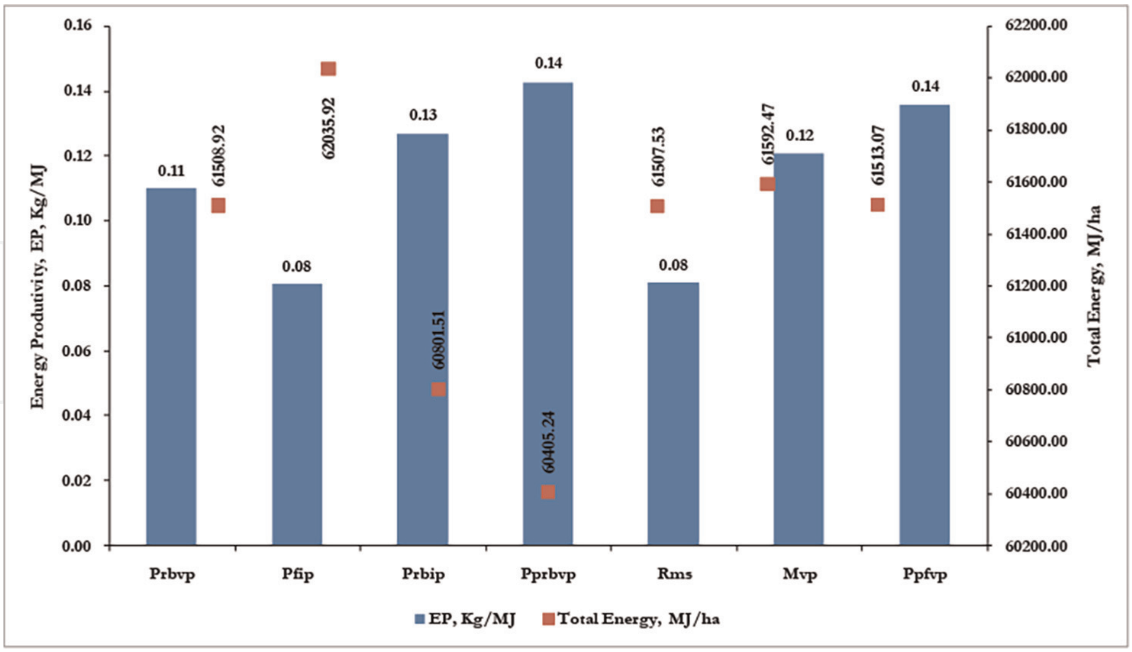

Figure 23.
Total energy and energy productivity associated with various maize sowing planters/techniques.

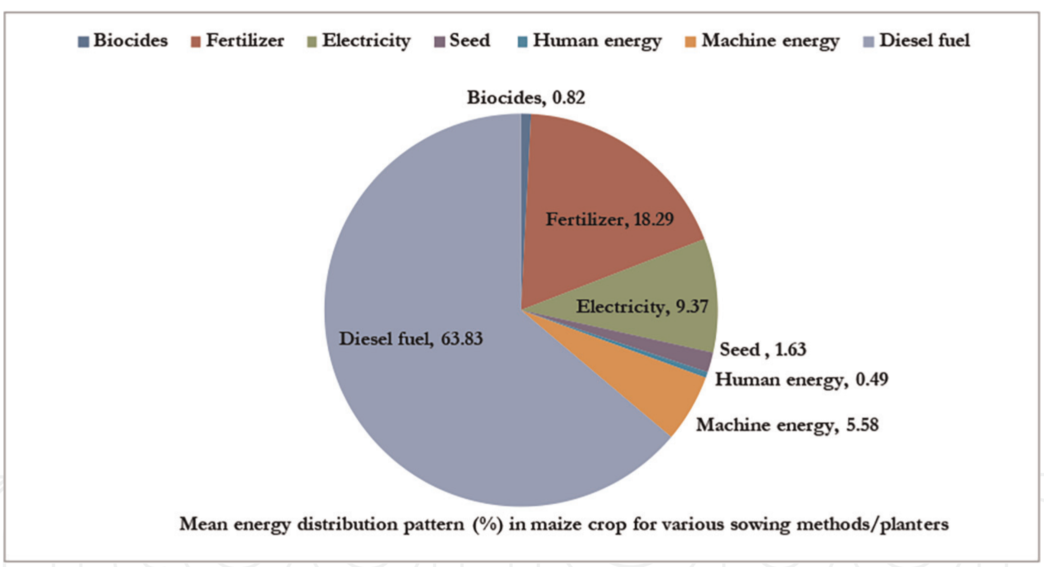

Figure 24.
Maize energy distribution pattern (%) in maize crop for various sowing methods/planters.

- Dissolution of gypsum, anhydrite and halite.

- Incongruent dissolution of primary silicates with formation of clays.

Ground water that is in perpetual motion, acquires various physical, chemical, and biological characteristics as it flows from recharge area to the discharge area. The factors that influence ground water quality are: local geology, land use, climatic conditions particularly pattern and frequency of rainfall and anthropogenic activities such as use of fertilizers and pesticides in agriculture, disposal of domestic sewage and industrial effluents and extent of exploitation of ground water resources.

3.1 Cost economics

The cost economics of the different methods were worked out for pneumatic raised bed planter, vertical plate bed planter, flat inclined plate planter, raised bed inclined plate planter and ridger + manual which are presented in **Table 8**.

The cost of maize sowing operation was found highest for ridger and manual sowing method showing a cost value of Rs. 6209.70 per ha ($ 77.62 per ha) and lowest for pneumatic flat planter showing a cost value of Rs. 746.44 per ha ($ 9.33 per ha) followed by pneumatic raised bed planter as Rs. 1008.14 per ha ($ 12.60 per ha).

The energy calculation for various row crop planters/sowing techniques is shown in **Table 9** and energy productivity is shown in **Figure 23** and pattern is represented in **Figure 24**.

The energy involved was found maximum as 62.04 $GJ.ha^{-1}$ for flat inclined plate planter and energy productivity was lowest for ridger+manual method and flat inclined plate planter as 0.08 kg MJ^{-1} . The specific energy was found minimum for pneumatic raised bed planter as 7.02 MJ kg^{-1} followed by pneumatic flat planter as 7.38 MJ kg^{-1} and raised bed inclined plate planter as 7.89 MJ kg^{-1}. The specific energy for maize sowing was found maximum for flat inclined plate planter as 12.46 MJ kg^{-1}. The energy productivity was found maximum for pneumatic raised bed planter, pneumatic flat planter as 0.14 kg MJ^{-1} followed by raised bed inclined plate planter as 0.13 kg MJ^{-1}.

The major % contribution factor for total energy was diesel fuel (63.83%) in various row crop planters followed by fertilizer (18.29%) and electricity (9.37%). The higher diesel fuel energy is due to more mechanized operations involved in maize cultivation. The machine energy contributed 5.58% in total energy as shown in **Figure 24**.
The variation in electricity energy required for irrigation can be attributed to design of planters and bed shapes variation in various planters. The energy associated with weedicide can be reduced by use of mechanical weeders. Similarly fall armyworm and other insects can be controlled naturally by birds. To give birds a shelter 5–10% of cultivable land should be permanently brought under tree like *Neem* (*Azadirachta indica*), Ashoka tree (*Asopalav*), Tamarind, Jamun tree (*Syzygium cumini*), Banyan (*Ficus benghalensis*), fast growing bamboo (*bambusa vulgaris, Bambusoideae*), Stone apple or aegle marmelos (*bilwa or bael*), Moringa oleifera (drought tolerant), *amla* or Indian gooseberry (*Phyllanthus emblica*), Sal (Shorea robusta), Cedrus deodara, the deodar cedar, Himalayan cedar and Teak (Tectona grandis) tropical hardwood tree species, orchard (mango, guava, apple, kinnow, etc.), etc. Moreover tree act as a carbon capture and storage (CCS) and carbon capture and utilization unit (CCU). Bamboo plants have potential to convert barren lands into a fertile forest. The researchers, from the Mizoram University in Aizawl, India, found that above-ground biomass in the stands of two bamboo species—Bambusa tulda (BT) and Dendrocalamus longispathus (DL)—have

Figure 25.
*Maize crop intercropped with Poplar (*Populus deltoides*) as a mitigation to heavy rainfall, cyclones and floods and also as a diversification option to rice crop in coastal areas.*

Figure 26.
View of agriculture and forest land (Agroforestry) and on-farm rainwater water harvesting and recharging structure (for hilly and flat terrains).

high potential for storing atmospheric carbon. On an average, one hectare of bamboo stands absorbs about 17 tonnes of carbon per year [78]. If planted at optimum distance, tree also helps in natural groundwater recharge. In a study field data from wick lysimeters revealed that the percentage of the yearly rainfall percolating to 1.5m soil depth reached its maximum of 16% of the annual rainfall around the edge of the tree canopy, 4.4m from the nearest tree stem, and decreased to 1.3% in open areas, 37 m away from the nearest tree. The model was run repeatedly and valid for a tree density of 20 trees ha^{-1}, average tree size (67 m^2 canopy area), and 50% water uptake below 1.5 m soil depth [79]. Also during cyclones, storms, trees can protect the properties from debris attack and protect the structures situated downwind from damage . So selection of proper cyclone resistant tree species like *Terminalia arjuna*, *Azadirachta indica*, *Millettia pinnata* (L.) Panigrahi etc. is necessary in coastal areas [80]. Some farmers are practicing maize crop intercropping with poplar (*Populus deltoides*) tree for timber purpose which yields timber around after 5–6 years and good profit to farmers (**Figure 25**). A view of agro forestry concept and rainwater storage and harvesting structure is shown in **Figure 26**. On-farm rainwater harvesting structure can be used at hilly terrains at higher altitude than fields, or in flat terrains if the agricultural land is under organic practices.

The plants are planted at a spacing of 600 cm × 180 cm (20′ × 6′) and with a population of 1000–1250 per ha if grown alone and 750 per ha if grown with some field crops like maize, wheat or turmeric etc. The cost of planting is 25,000 per ha (USD 313 \$ ha^{-1}) and net returns vary between 10.0 and 12.5 lakh per ha (USD 12,500–15,625 \$ ha^{-1}) depending upon growth and girth of plant. Normally this tree grows to height of 85 feet and 36 inches in diameters and average weight of tree ranges between 80 and 120 kg (0.08–0.12 tonne). The average selling price ranges between Rs 12,000–13,000 per tone (USD 150–162 \$ ha^{-1}).

Maize grown in this way can be used for both grain and silage purpose. The populous deltoids tree can tolerate annual precipitation in the range of 600–1500 mm and more making it suitable for flood tolerance [81]. This means that the maize crop intercropping with high water requiring plants like Populus deltoids can be a good mitigation measure in heavy rainfall, flood prone, coastal areas like north-east, north-west and other zones in India and other regions. The water use of a Eucalyptus (2500 l/year) plantation and other tree species such as *Acacia auriculiformis* (1200–1300 litres/year), *Dalbergia sissoo* (1400–1600 litres/year), *Albizzia lebbek* (1200–1300 litres/year) is high. Permanent plantation of such high water demanding tree along with agricultural crops or as plants alone (in 5–10% of cultivable land by every farmer) can help mitigate the climate change effects in flood prone, coastal

Figure 27.
Maize crop is commonly sold on roadside after heat processing and is a good nutrition source.

areas. Farmers can take advantage by selling timber also but plantation area should be maintained by again planting tree on same or new location of cultivable land for combating heavy rainfall, floods etc. Similarly eco friendly technique helps natural control of insects and pests. The eco friendly "Push-pull climate smart" technology entails using an attractive trap plant (Napier/Brachiaria grass as a "pull") and a repellent intercrop (Desmodium as a "push"). Around maize farms, the Napier grass is which attracts stemborers and fall armyworm (FAW) to lay eggs on it but it does not allow larvae to develop on it due to poor nutrition; so very few larvae survive. At the same time, Desmodium, planted as an intercrop emits volatiles that repels stemborers or FAW [82]. Thus energy associated with machine, diesel, electricity and various other inputs can be reduced by selection of appropriate maize planter, climate smart technologies like Push-pull along with Agro-Forestry concept and total energy involved in maize production can also be reduced in a sustainable way and also organic concept can be boosted. Maintaining Agro forestry, birds i.e. biodiversity concept can be useful for other fields crops also. They can protect field crops from excessive heat waves occurring due to climate change and from various insect pests through increased birds population, thus increasing economy of small and marginal farmers. The maize crop can be economical as it creates opportunity from low income families and they buy it from local market and sell them as roadside food on good prices between Rs 20–60 (0.25–0.75 US$) (**Figure 27**).

4. Conclusions

The result reveals that optimum height of bed for better maize crop stand shall range between 150 and 230 mm with a top width of 350 mm bed at a row spacing of 675 mm. The planter plate design geometry has an important role in achieving accurate plant to plant spacing. The yield for inclined and vertical plate mechanism ranged between 4.96–7.71 t ha^{-1} and 6.75–8.61 t ha^{-1} respectively. The saving in water was 9.68–23.69% with bed heights ranging between 150 and 290 mm. The maximum saving in water of 38.85 cm per ha was found for bed height of 150 mm (for 2 rows on as compared to flat planting method. The precision indices for inclined and vertical plate mechanism varied between 4.63–6.74% and 6.35–11.82% respectively. The pneumatic raised bed and flat planter recorded highest yield as 8.61 t ha^{-1} and 8.34 t ha^{-1} respectively. The energy productivity was found maximum for pneumatic raised bed planter, pneumatic flat planter as 0.14 kg MJ^{-1} Maize residue can be collected with balers for use in biomass co generation plants, bio CNG plants, biomass pallet industry as maize crops residue has higher gross calorific value (17.0 MJ kg^{-1}) than paddy crop residue (14.5 MJ kg^{-1}).

Maize crop residue can be used to promote silage industry as farmers usually require silage for feeding animals. The maize crop sowing, weeding and harvesting operations are fully mechanized whereas in case of rice crop manual transplanting is mostly followed in rice growing regions though harvesting is done with combine harvesters. Also the in-situ management of paddy crop residue is energy intensive and maize crop residue can be easily chopped and incorporated with disc harrows, rotary tillers or super seeders facilitating timely and easy sowing of next crops. Among plant-based foods, rice is largest contributor of green house gas emissions, because it can grow in water, so many farmers flood their fields to kill weeds, creating ideal conditions for certain bacteria that emit methane. Rice produces 12 percent of the total greenhouse gas emissions from the food sector, followed by wheat (5%) and sugar cane (2%) [83]. Although burning of straw residues emits large amounts of CO_2, this component of the smoke is not considered as net GHG emissions and only concludes the annual carbon cycle that has started with photosynthesis. At constant straw moisture of 10%, the mass-scaled emission factors (EF_m) were 4.51 g CH_4 and 0.069 g N_2O per kg dry weight (kg^{-1}dw) of straw. This corresponds to 1.05% and 0.29% of the total C and N released from straw burning, respectively and subsequent area-scaled emissions (Ea) that were 10.04 kg CH_4 ha^{-1} and 0.154 kg N_2O ha^{-1} as averages for both seasons [60]. Methane in the Earth's atmosphere is a strong greenhouse gas with a global warming potential (GWP) 84 times greater than CO_2 in a 20-year time frame. Methane primarily leaves the atmosphere through oxidization, forming water vapor and carbon dioxide. So, not only does methane contribute to global warming directly but also, indirectly through the release of carbon dioxide. Moreover CH_4 production from rice fields and burning of rice residues also creates breathing problems to local people. The puddled rice also hinders natural recharging of underground water during rainy season (especially *monsoon* period) due to presence of hard pan beneath soil. However strategically diversifying rice area partially to maize crop especially in *Kharif* season can help maintain underground water as well as facilitate recharging also and reducing GHG emissions from its cultivation and residue burning. Maize crop can be sown in *Kharif* (period June-July to October) to diversify rice, *Rabi* season (October to November sowing and harvesting April to June), Spring (sowing-January end to February and harvesting in June-July) and can also be intercropped with Populus deltoids in flood, heavy rainfall prone areas. *Rabi* season or winter maize takes more time to mature as in winter growth of maize is slow but it is less infested with insects, pest, weeds and ensures more efficient use of resources, higher yield than *Kharif* maize and also allows maize-maize system intensification. The rice is grown mainly in *Kharif* season, therefore maize crop can be grown in *Kharif* season to save water. Moreover winter and spring maize have irrigation requirement higher than *Kharif* crop. Also by changing metering plates of pneumatic raised bed planter and inclined plate planter along with some adjustments these planters can be used for sowing of wide row crops like peas, gram, canola etc and narrow row crops like onion, radish, carrot etc. in subsequent winter (*Rabi)* season. With appropriate raised bed maize planter selection, maize sowing operation can be done with precision and lower energy input while maintaining crop yield and saving energy and irrigation water especially for arid and tropical regions. More if agroforestry concept is scaled up, it will help improve water quality, as trees improve water quality by slowing rains as it falls to earth, and helping it soak into the soil. Trees then serve as natural sponge, collecting and filtering rainfall and releasing it slowly into streams and rivers. Trees are the most effective land cover with various benefits such as maintenance of water quality, recharging of water table, reduced drinking water treatment costs, removal of nitrogen and phosphorus leaching from adjacent agricultural land uses into streams by acting as a filtering sediment and also tree can help control the effects of climate change by capturing green house gases and controlling the rise in temperature of earth. Moreover less water requiring crops like pulse, sugarcane, maize, etc. in place of rice will need less irrigation water and more trees can help lower down the environment temperature and more rainfalls. Thus, all these will lead to less pumping of water and saving of underground water as well as natural recharging of underground water.

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Competing interests

This is to certify that all authors do not have any conflict of interest in publishing paper entitled "Scaling mechanization and profitability in maize cultivation through innovative maize planters along with Agroforestry approach -Sustainable and climate smart approach to diversify rice based cereal systems in various regions-" in New Prospects of Maize.

Abbreviations

FIRB	furrow irrigated raised bed
PRB	permanent raised bed
GNSS/IMU	Global Navigation Satellite System
GHG	green house gas
GWP	global warming potential

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