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Development of Furrow Opener for Liquid Fertilizer Application in Soil

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ABSTRACT

Designing a furrow opener for the simultaneous placement of seed and liquid fertilizer posed a challenge due to the toxic effects of liquid fertilizers like UAN on seeds. To address this, furrow openers were developed to place fertilizer at a deeper depth and seeds at a shallower depth, with horizontal spacing between the respective delivery tubes. Two types of furrow openers—hoe and shovel—were designed and tested in a soil bin to evaluate soil spread width, backfill cover, draft, and vertical separation between seed and fertilizer. Among the tested parameters, backfill cover and draft were key selection criteria. Results showed greater backfill cover with shovel-type openers (6.33 cm) compared to hoe-type (5.77 cm) at 11% soil moisture and a working depth of 9 cm. At 6% moisture content, backfill cover increased due to reduced cohesion between soil particles, with values of 7.63 cm and 7.93 cm for hoe and shovel types, respectively. Draft requirement was lower for shovel openers (132 N) than hoe types (148 N), attributed to their lower rake angle. Overall, the shovel-type opener exhibited better performance in terms of backfill and lower draft, indicating its suitability for efficient seed and liquid fertilizer application in varying soil conditions.

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INTRODUCTION

Due to the limitations of prilled urea, liquid fertilizers are popular in foreign countries viz. USA, European Union, Australia and many more. The most widely used nitrogen based liquid fertiliser is in these countries are Urea Ammonium Nitrate (UAN) which is an aqueous solution of urea [CO(NH2)2] and ammonium nitrate [NH4NO3]. It contains nitrogen (N) between 28 to 32 per cent. The NO3- portion (25 % of the total N) is immediately available for plant uptake. The NH4+ fraction (25 % of the total N) can also be assimilated directly by most plants, but is rapidly oxidized by soil bacteria to form NO3- (nitrate). Soil enzymes hydrolyse the remaining urea portion (50 % of the total N) to form NH4+, which subsequently transforms to NO3- in moist soil conditions. Solutions of UAN are extremely versatile as a source of plant nutrition. Its chemical properties make UAN compatible with many other nutrients and agricultural chemicals and can be mixed with solutions containing phosphorus, potassium and other essential plant nutrients. Also, liquid fertilizers can be blended to precisely meet the specific needs of a soil or crop. UAN solutions are commonly injected into the soil beneath the surface, sprayed onto the soil surface, dribbled as a band onto the surface, added to irrigation water, or sprayed onto plant leaves as a source of foliar nutrition.

In spite of number of benefits of liquid fertilizers for manufacturers' as well for farmers, the use of liquid fertilizers did not pick up in India due to lack of appropriate liquid fertilizer application technology. Application of liquid fertilizer alongside the seed needs a precise and proper method to avoid contact of seed with liquid fertilizer. The precise placement of fertilizer and seed is critical for the efficient use of fertilizer and for enhanced plant growth. Fertilizer placed in high concentrations next to the seeds can result in toxic effects to the seedlings. If the concentration of fertilizer is too high close to the developing seedling, germination and emergence can be adversely affected. If seed and fertilizer are separated appropriately, fertilizer banded vertically below or laterally at some depth below the seed can efficiently provide nutrients to the seedling and without any damage to the roots. Simultaneous placement of seed and liquid fertilizer requires the development of liquid fertilizer (UAN) application system that can facilitate the differential depth application of seed and liquid fertilizer for proper seed emergence and root establishment.

For development of liquid fertilizer (UAN) application system, furrow opener design, appropriate liquid fertilizer metering system and optimum placement depth of liquid

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fertilizer are of critical importance. For design of furrow opener, type, size and material need to be given due consideration.

MATERIALS AND METHODS

A furrow opener is an important component of a seed drill or a planter. It cuts a furrow and allows the seeds or seedlings to be deposited before being partially covered with soil. Zero-till seed cum fertilizer drill places both granular fertilizer and seed simultaneously using inverted-T type furrow opener. Aqua ferti seed drill enabled the user to apply aqueous fertilizer alongside the seed in moisture deficit fields at the time of sowing using shovel type furrow opener (Kant, 2008). The simultaneous placement of seed and fertilizer had the advantage of making efficient use of fertilizer, improving crop production, and reducing the number of field operations. The major challenge in using the existing furrow openers for liquid fertilizer application was the simultaneous placement of liquid fertilizer vertically below the seed.

Design criteria for furrow opener

To design a furrow opener for liquid fertilizer placement, following were the important considerations:

i. Seed should be placed at the desired depth below the seedbed surface. Permissible deviations from the given depth of drilling were ± 5 mm, ± 7 mm and ± 10 mm for sowing depths of 30-40 mm, 40-50 mm and 60-80 mm, respectively (Darmora and Pandey, 1995).
ii. Liquid fertilizer and seed should be placed at the optimum separation distance vertically, i.e. close enough to maximize the beneficial effects of the fertilizer on the seed and emerging seedling and far enough to minimize the toxic effects of the fertilizer on the seed or seedling. A desired vertical and lateral separation should be maintained between the seed and fertiliser. For most cereal crops, placement of fertilisers about 30 mm to the side and 20 mm deeper than the seed was recommended (Choudhary et al., 1985; Baker and Afzal, 1986).
iii. Liquid fertilizer and seed should be placed at the optimum separation distance horizontally so that there is enough time for the soil to fall back in the furrow made by the shovel before placing the seed.
iv. The volume of soil disturbed during placement of fertilizer and seed should be minimum so that the draft of the machine is less.
v. It should be easily modified and attached with the existing shanks of seed drill.

Selection of material of furrow openers

The purpose of furrow opener was to cut open the soil and placed the liquid fertilizer in the sub-soil. There after the seedhad to be placed at shallow depth. A prototype furrow opener was designed with a hole drilled in the centre across the width of shank (Fig. 1). The purpose was to use the hole inside shank as a conduit to pass the liquid fertilizer. However, corrosion was observed inside the shank hole only after 24 hours of passing Urea ammonium nitrate through it. In order to selected the corrosion resistive material for the shank, necessary corrosion test was conducted. applications.

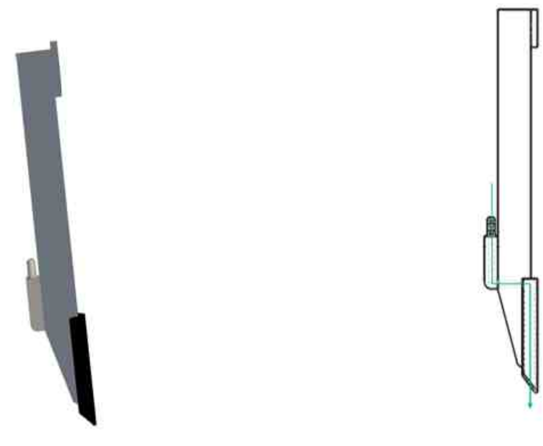

Fig.1: (a) Furrow opener prototype and (b) direction of flow of liquid fertilizer

Based upon the observed results of corrosiveness of the liquid fertilizer, it was decided to use narrow PVC tubes for conduit of liquid fertilizer in order to avoid contact between UAN and the furrow opener surface. Therefore, a narrow tube commonly used in reverse osmosis water purifiers which was easily available in the local market was used for the purpose. A groove of cross section 7 x 7 mm was made in the lower front shank to fit the selected delivery pipes for liquid fertilizer.

Two furrow openers viz. hoe and shovel type were designed and fabricated in the Division of Agricultural Engineering, ICAR IARI workshop. Hoe and shovel type furrow openers were selected as they are the most common type of furrow openers used in conventional tillage (Chaudhuri, 2001). For placement of seed, the boot of the conventional seed drill was modified by split opening the lower part into two halves and shaping it with the help of hammer in the form of small furrow opener (Fig. 2 , 3 & 4).

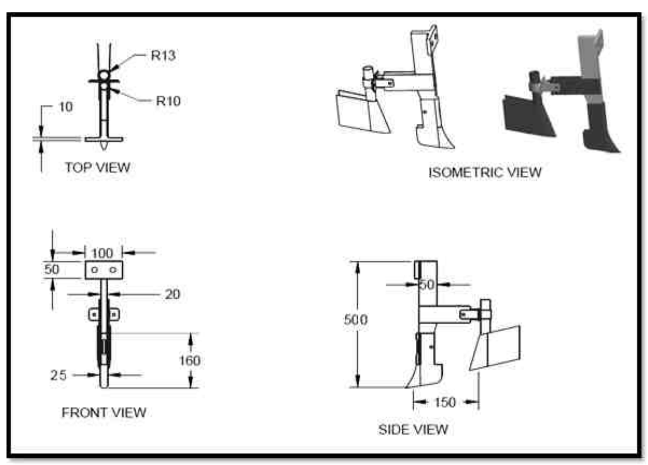

Fig. 2: Hoe type furrow opener (T1)

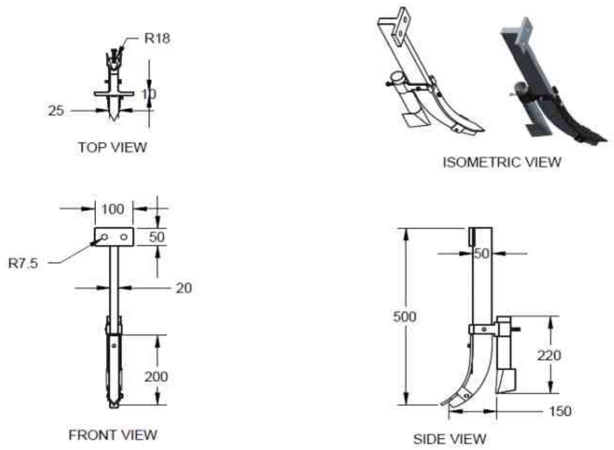

Fig. 3: Shovel Type furrow opener (T2)

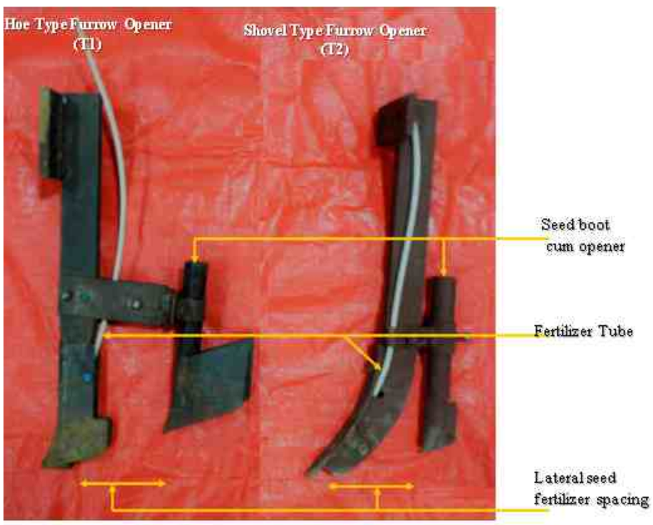

Fig. 4: Developed prototype furrow openers

The specifications of designed furrow openers test are listed below, Table 1.

Table 1: Design values of selected hoe type and shovel type furrow opener

Description	Furrow openers	
	Hoe typeT1	**Shovel Type T2**
Seed/fertilizer tubes	Dual	Dual
Working width, mm	25	25
Diameter of seed boot/opener, mm	30	30
Diameter of fertilizer tubes, mm	4	4
Furrow opener and seed opener Spacing, mm Horizontal Transverse	Adjustable Min=100, Max=150 Max=100	Adjustable Min=100 ,Max=150 Max=100
Rake anglea (degree)	45	40

Performance evaluation of furrow openers

To know the best suitable furrow opener for liquid fertilizer application, it was necessary to investigate the effect of different independent parameters viz. furrow opener type, soil moisture content, operational speed and depth of operation on soil spread width, furrow backfill cover, draft, and maximum vertical movement of liquid fertilizer. The test set-up was fabricated for soil bin study consisting of seed and fertilizer metering unit. Seed metering unit had a seed hopper with a single unit of fluted roller. It was calibrated for a seed rate of 120 kg/ha. Fertilizer metering unit contained a small PVC tank of 30 litre capacity, a DC motor with diaphragm pump of 4 litres per minute capacity, a control valve and a RO pipe for conduit of liquid fertilizer (Fig. 5). The flow rate of the liquid fertilizer was controlled by a control valve. The flow rates were theoretically calculated at three different speeds of soil processing carriage. The flow rate was calculated for100 % basal dose of N fertilizer at UAN concentration of 1:10.

The soil bin experiment was conducted in two parts. During the first part of experiment only the furrow opener was attached in the experimental set up and the seed opener was removed. This was done to prevent the disturbance of soil profile after passage of furrow opener so that furrow backfill depth could easily be measured. During the second part of experiment both furrow opener as well as seed opener were attached in the experimental setup and seed as well as liquid fertilizer were delivered during forward motion of the whole set up. The experiment was conducted according to the experimental plan, Table 2 and each experiment was replicated thrice and average values of measured parameters were computed.

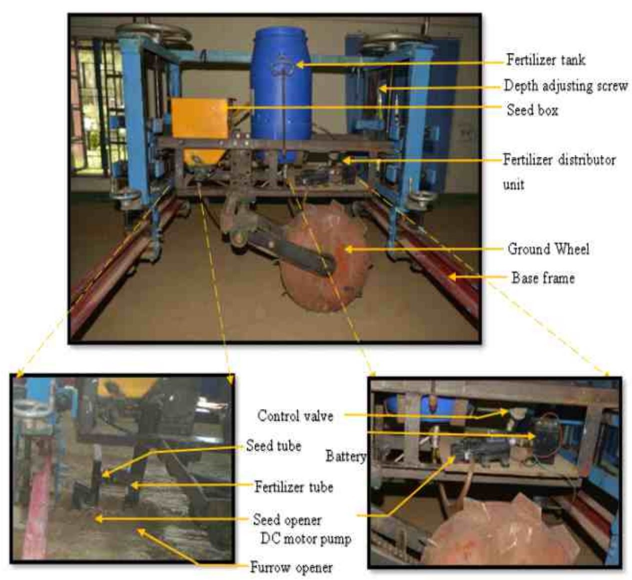

Fig. 5: Experimental setup for soil bin study of furrow openers

Table 2: Experimental plan for performance evaluation of furrow openers under soil bin study

Independent Variables	Levels	Details	Measured parameters
Furrow opener type	2	T1: Hoe type T2: Shovel type	a. Soil spread width (cm) b. Furrow Backfill cover (cm) c. Draft (N) d. Space between seed and liquid fertilizer
Soil moisture, (% db)	2	11±1.5 and 6±0.9	
Operational speed, (kmh-1)	3	1.23,1.56 and 1.80	
Operating depth, (cm)	3	7, 9 and 11	

Test procedure for soil bin study of furrow openers

After preparing the soil bed, the test furrow opener was mounted on the base frame. Each test was conducted on the 20 m long soil bed. Using depth adjusting screws, the furrow opener was set at desired depth and the experimental setup was levelled with the help of spirit level. UAN with water (1:10) was used as liquid fertilizer to check the dispersion pattern of fertilizer in the soil. The seed box containing wheat seed was connected to the seed boot/opener through transparent plastic tubes. The base frame was coupled with soil processing carriage with the help of load cell. The observation of draft was recorded on the laptop kept on the base frame (Fig. 6).

Fig. 6: Draft measurement of furrow openers using load cell

The soil processing carriage was operated at selected speed by an operator and the wheat seed as well as liquid fertilizer dropped through respective delivery pipes. Liquid fertilizer was driven through the PVC made narrow delivery pipe in to the soil by switching on the battery of the DC pump simultaneously. A 254 mm long soil sampler trough with cross sectional area of 220 x 220 mm was developed for study of liquid fertilizer spread and actual seed placement depth (Fig. 7).

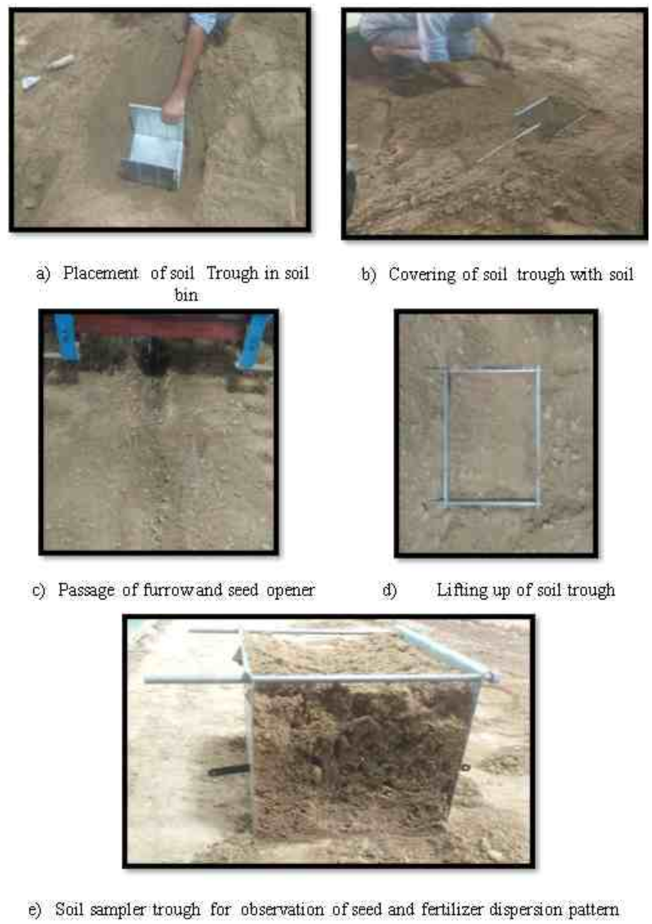

Fig. 7: Different activities involved in Soil sampler trough

The specifications were selected according to the soil spread width obtained in the trial run of the furrow opener in soil bin. The depth of the sampler was decided on the basis of maximum depth of operation of the furrow opener during the experiment. The trough was also fitted with lifting mechanism in the form of end-to-end handle. Before operating the soil processing carriage at selected speed, the soil sampler trough was put inside the soil. Its mid axis plane was kept in line with the furrow opener, so that seed and liquid fertilizer get placed in the middle of the sampler after the passage of furrow opener. Various unit operations related with soil sampler trough are illustrated in fig. 7 (a-d). The soil surface on both the sides of soil trough was carefully cut by serrated blade, Fig. 7(e). Different response parameters were measured after taking out the soil sampler trough from the soil.

Performance Parameters for evaluation of furrow openers

Experimental set up was mounted on the base frame and was attached with Soil processing carriage. The soil processing carriage was run by motor powered drive mechanism. Following performance parameters were evaluated during soil bin study of furrow openers.

Soil spread width

Soil spread width was measured as the maximum width of soil throw. As the furrow opener moved in the soil bin, the soil got disturbed as it was cut and spread to the sides of the furrow opener. Less soil spread width during the tillage operation was desirable. Width and shape of furrow opener along with speed of operation played an important role in soil spread width. It was measured by measuring scale.

Furrow backfill cover

The passage of furrow opener through the soil created a deep furrow. The furrow cross sectional area got backfilled with the loosened soil from side of the furrow. This depth/height of backfill was a measure of furrow backfill cover (Fig. 8). For liquid fertilizer application, the furrow backfill cover was of utmost importance. Since, furrow opener and seed opener were in tandem, the seed should fall on the soil backfilled. If the soil backfill cover were less, there was chance of contact between seed and liquid fertilizer.

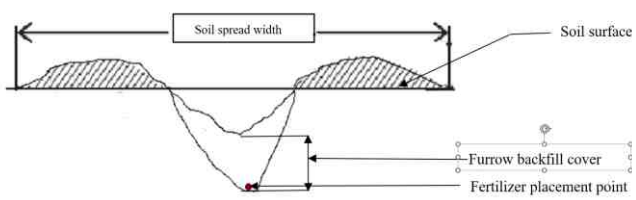

Fig. 8: Pattern of soil disturbance

Draft

The liquid fertilizer had to be placed at appropriate depth than the seed in the subsoil during tillage; hence draft was an important factor in deciding the power requirement of the power source. Draft was measured by "S" type load cell and data logger was attached to the Arduino circuit to record data. Arduino was programmed and load cell was calibrated before measurement of draft for instantaneous data display and recording. A Dry run of experimental setup was performed without load and with load. The difference between the two observations was the measure of draft force exerted by furrow opener.

Vertical spacing between seed and liquid fertilizer (Liquid fertilizer spread)

After placing liquid fertilizer through furrow opener, downward movement of liquid fertilizer took place due to gravity and upward movement caused by capillary action It was not possible to locate the exact placement point of the liquid fertilizer inside the soil. Hence only lateral and vertical movement of liquid fertilizer were quantified in terms of their maximum value (Fig. 9).

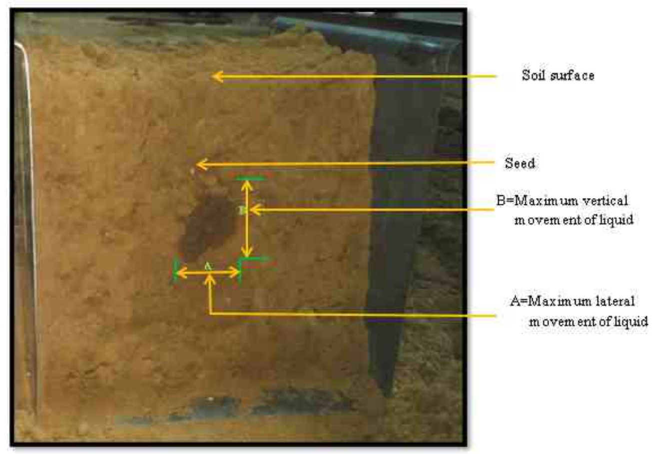

Fig. 9: Measurement of vertical spacing between seed and liquid fertilizer

Maximum vertical movement of liquid was of critical importance to decide the actual distance between seed and applied liquid fertilizer. It was observed that after 25 minutes the increase in wetted surface area became stagnant. Hence, measurements were made after 30 minutes of application of liquid fertilizer in the soil. The wetting front boundary was delineated on a transparency to measure the minimum spacing between seed and fertilizer after stabilization. A graph paper was put below the transparency sheets and scanned. The vertical distance between seed and top of the wetting front (Fig. 10) was measured by measuring scale with 1 mm least count.

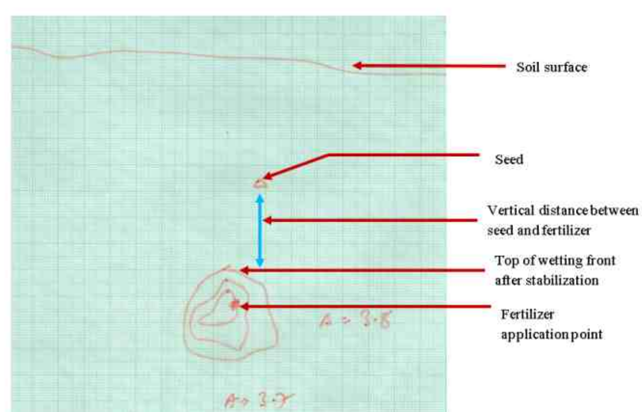

Fig. 10: Delineation done to measure the minimum distance between seed and fertilizer after stabilization

RESULTS AND DISCUSSION

Effect of operational variables on soil spread width Less soil spread width during fertilizer application was desirable to avoid fertilizer exposure (Hasimu and Chen, 2014). The soil spread width ranged from 11.20 to 22.57 cm at different operational speed, soil moisture content and furrow operational depth, Fig. 11. The range of soil spread width for hoe type and shovel type furrow opener was observed as 13.90 cm to 22.57 cm and 11.20 cm to 20.50 cm, respectively. The minimum soil spread width of 11.20 cm was observed in case of shovel type furrow opener attained at a forward speed of 1.23 kmh-1, soil moisture content of 11 % and at 7 cm depth of operation. All the operational variables significantly contributed to variation in soil spread width. In general, higher the soil moisture content, lower the throw of soil, hence lower the soil spread width. Similarly, soil spread width increased with the depth of operation due to larger lifted soil volume. In fact, shovel type furrow opener created narrow soil spread as compared to hoe type furrow opener.

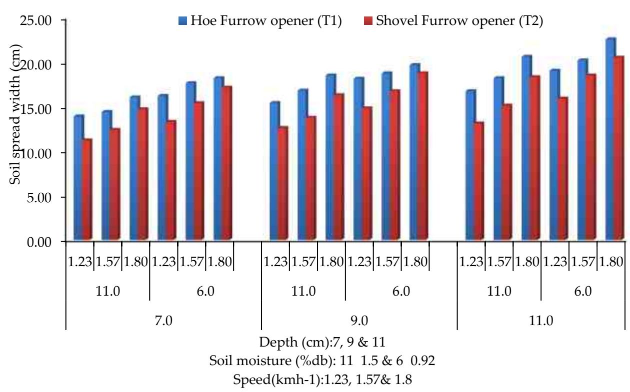

Fig. 11: Variation in Soil spread width at selected operational variables

Effect of operational variables on furrow backfill cover

The advance of furrow opener, for liquid fertilizer placement into the soil, resulted into narrow opening which was backfilled with the loosened soil creating a contact barrier between seed and fertiliser. The depth of backfilled soil determined the vertical spacing between liquid fertilizer locus and seed placement. The greater backfill cover indicated greater seed-fertilizer spacing, thus, reducing the chances of seed and liquid fertilizer contact. The operational parameters (speed, soil moisture content and operational depth) significantly affected the soil backfill cover. The soil back fill cover varied from a minimum value of 3.03 cm observed for hoe furrow opener to the maximum value of 9.33 cm in case of shovel type furrow opener (Fig. 12). As the forward speed increased from 1.23 kmh-1 to 1.80 kmh-1, the average backfill depth increased from 4.76 cm to 7.54 cm for Hoe type furrow opener and 5.41 cm to 7.67 cm for Shovel type furrow opener. Lesser the soil moisture content, higher was the soil back fills at all operational depths. The increase in operational depth resulted in increased soil disturbance leading to more back fill cover.

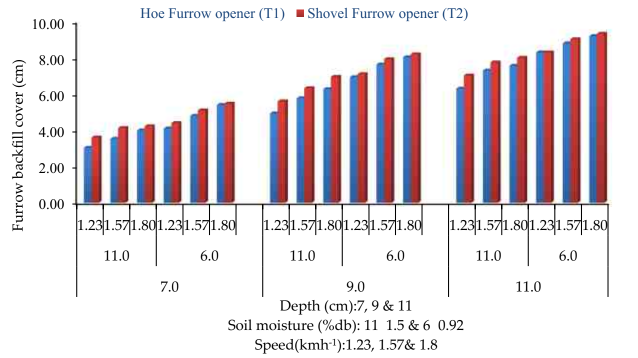

Fig. 12: Variation in furrow backfill covers with selected operational parameters

Effect of operational variables on draft of furrow openers

The draft requirement of the selected furrow openers was evaluated at different moisture contents (6%, 11%), operational speeds (1.23, 1.57 and 1.8 kmh-1) and operational depths (7, 9 and 11 cm) in order to select optimum operating conditions for minimum draft. The soil type used for the study was of sandy loam texture. Draft requirement of selected furrow openers (hoe and shovel type) was determined with S-type load cell using Arduino Software. A mean draft of 148 N and 132 N was developed by hoe type and shovel type furrow opener, respectively. The draft increased significantly with speed and depth of operation and soil moisture content (Fig. 13). Minimum draft requirement of 82 N and 105 N by shovel and hoe type furrow opener, was observed respectively at a forward speed of 1.23 kmh-1, soil moisture content of 6 % and 7 cm depth of operation.

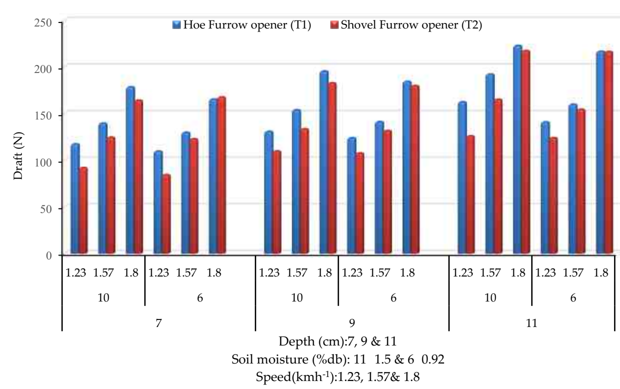

Fig. 13: Variation in draft at selected operational variables

Effect of operational variables on vertical spacing between seed and liquid fertilizer

The fertilizer should be optimally placed from the seed close enough to supply nutrients and distant enough to avoid seed injury. In case of granular fertilizers, the seed and fertilizer spacing remains constant with time. However, in case of liquid fertilizer, upward movement due to capillary action might bring the liquid fertilizer in close proximity of seed causing seed damage. Vertical spacing between seed and liquid fertilizer after stabilization (30 minutes from application time) was analysed by delineating the wetting front boundary of liquid fertilizer on a transparency sheet. The mean vertical spacing observed for hoe type and shovel type furrow opener at 11 % soil moisture was 32 mm and 42 mm, respectively. The same increased to 37 mm and 45 mm, respectively at a soil moisture content of 6 per cent. For both the furrow openers, the results revealed less value of vertical spacing may be advantageous at moisture content of 11 % than that of 6 % of soil moisture content (Fig 14).

The mean vertical spacing observed at a depth of 7, 9 and 11 cm was 18, 36 and 54 mm, respectively. The mean vertical spacing at different depths of operation and soil moisture content observed for hoe type and shovel type furrow opener was 35 mm and 43 mm, respectively. The vertical distance between seed and fertilizer at 6 % soil moisture content for hoe type furrow opener was nearly equal to the value observed for shovel type furrow opener at 11 % moisture content (Fig. 14). In general, at a given moisture content the vertical spacing observed for shovel type furrow opener was more as compared to hoe type furrow opener.

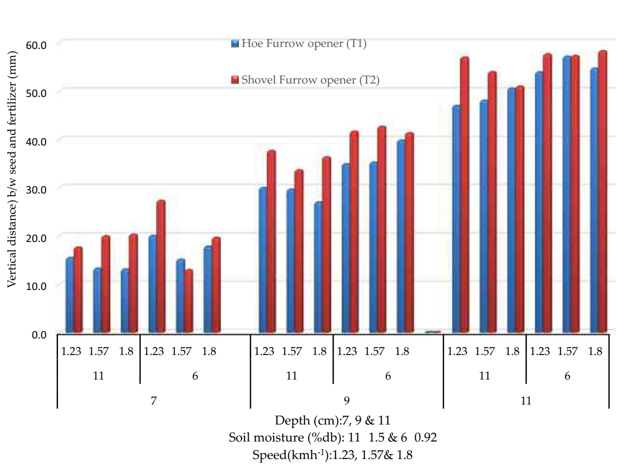

Fig. 14: Vertical distance between seed and fertilizer as affected by different parameters

The soil bin study for comparative performance evaluation of shovel type and hoe type furrow openers at different operational variables (speed, soil moisture and depth) revealed added advantage with shovel type furrow opener in terms of lower spread width, higher back fill cover, less draft and more vertical spacing after stabilization.

CONCLUSIONS

Designing a furrow for simultaneous placement of seed as well as liquid fertilizer was the foremost challenge. As seeds were sensitive to the toxic effect of liquid fertilizer (UAN), both seeds and liquid fertilizer had to be placed at different depth in the soil. Furrow openers were designed such that the front part placed the liquid fertilizer at deeper depth and seeds were placed in tandem at a shallower depth. A horizontal spacing was maintained between both the fertilizer tube and seed tube. Hoe and Shovel types of furrow openers were designed and their effectiveness was studied in soil bin in terms of soil spread width, furrow backfill cover, draft and vertical distance between seed and liquid fertilizer. Furrow backfill covers as well as draft were the main criteria for selection of the furrow opener. The furrow backfill cover was more in shovel type furrow opener as compared to how type furrow opener. When furrow openers advanced at a speed of 1.57 kmh-1 through the soil at 11 % (db) moisture content and at a depth 9 cm, the average soil back fill cover was observed as 5.77 cm and 6.33 cm for hoe type and shovel type furrow opener, respectively. The higher furrow backfill cover observed in shovel type furrow opener compared to hoe type was probably because of difference in the shape of soil advancing part of the furrow opener. The lateral sides of the hoe type furrow opener acted as an elongated base for soil flow leading to greater soil spread and less backfill. At lesser soil moisture content (6%), the soil backfill cover increased for both the furrow openers across all the selected speeds. This was attributed to the fact that water in the soil acts as a binding element. As the moisture content of soil decreased the force required to break the cohesion among soil particles decreased (Kemper, 1984) leading to more backfill cover. This was evident when furrow openers advanced at a speed of 1.57 kmh-1 at 6 % (db) moisture content and at a depth 9 cm, the average soil back fill cover was 7.63 cm and 7.93 cm for hoe and shovel type furrow opener, respectively.

The draft requirement of furrow openers at soil moisture content of 6 % was found significantly less as compared to the draft requirement at 11 % moisture content at all depths of operation. The average draft requirement of hoe type and shovel type furrow opener was observed as 148 N and 132 N, respectively. Although both openers had the same working width, their difference in draft force would be due to the lower rake angle of the shovel type furrow opener (400) as compared to hoe type furrow opener (450). McKyes (1985) reported less draft for lower rake angle furrow opener. The results imply that the shovel furrow openers will require less tractor power to operate. The draft increased significantly with speed and depth of operation. Soil moisture content was also found to significantly affect the draft requirement for shovel type and hoe type furrow opener. The draft requirement for hoe furrow opener at 6 % and 11 % soil moisture content was 147 N and 164 N, respectively. While for shovel furrow opener it was 127 N and 144 N.

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