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Design, development and evaluation of furrow opener for differential depth fertilizer application

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ABSTRACT

A differential depth furrow opener for tractor-drawn seed-cum-fertilizer drill under raised beds sowing was designed, developed and evaluated at ICAR-Central Institute of Agricultural Engineering, Bhopal, MP, India. The basic aim of this development was to apply fertilizer at different depth in crop root zone to enhance the fertilizer use efficiency. The furrow opener was evaluated based on draught and power requirements under soil bin at four depths (5, 10, 15, and 20 cm), four forward speeds (1.8, 3.2, 4.3 and 5.4 km/h) and three compaction level (200, 400 and 600 kPa). The field performance evaluation of furrow opener was done in two wheat crop varieties; HI-1544 (*Triticum aestivum* L.) and HI-8663 (*T. durum*) under raised beds. The experiment consisted of different fertilizer placement depths, i.e. application of NPK mixed fertilizer on surface (T1) and 5 cm (T2), 10 cm (T3), 15 cm (T4) and 20 cm (T5) below the surface in split-plot design. The root weight/plant shows significant results under all treatments, maximum and minimum root weight/plant were observed 16.01 and 9.63 g in T3 and T5, respectively. Highest grain yield was observed in treatment T4 (6 048 kg/ha) followed by T3 (5 611), T2 (5 223), T1 (4 739) and T5 (4 493 kg/ha). Higher NDVI values were observed in T3 (0.95) and T4 (0.96) at heading stage of wheat crop. From crop attributes point of view, parallel results were observed for T3 (10 cm) and T4 (15cm). But considering the draught and power requirement, 15 cm deep fertilization required 47% and 42% higher draught and power, respectively as compared to 10 cm deep fertilization.

Key words: Differential depth fertilizer placement, Furrow opener, NDVI, Raised beds, Wheat

Various studies have been reported on the effects of different fertilizer application methods on plant emergence, root growth, plant stand, fertilizer use efficiency, nutrient loss and crop productivity. Rochette *et al.* (2009) reported broadcast urea lost the greatest proportion of applied nitrogen (64%) followed by banded (2 cm) urea (31%). Su *et al.* (2015) concluded that fertilization at 10 cm and 15 cm soil depth produced greater root length and dry weight than fertilization at 0 cm and 5 cm. Trapeznikov *et al.* (2003) found that higher wheat yield achieved in the banded placement of granular NPK fertilizer at 8-10 cm depth compared with homogeneous application of fertilizer in the 0-18 cm. Malhi and Nyborg (1991) concluded that band placement of urea in barley under zero and conventional tillage systems resulted better yields as compared to broadcasted urea application. The effect of banding fertilizer on crop growth, nutrient uptake and yield significantly varied with the change of fertilizer placement depth, suggesting determining the proper placement depth is an effective approach for further improving the effect of banding fertilizer (McConnell *et al.* 1986, Murphy and Zaurov 1994).

Raised beds farming adopted in agriculture at large scale in developed countries and have proven to be an excellent option for raising the productivity of wheat. Raised beds are formed by moving soil from the furrows to the area of the bed, thus raising its surface level. Generally, two to six rows are planted on the top of each bed for rice crop (Naresh *et al.* 2011). Permanent raised beds, merge the concepts of zero tillage, bed sowing, furrow irrigation, and controlled traffic farming, which ensures the beds and furrows are permanently in the same position and repaired only once a year before the next crop is seeded (Singh 2003). A change from growing crops on the traditional flat-bed to the raised bed offers change in fertilizer requirements by plants. Reduce soil compaction and increase aeration in the root zone for raised beds farming will help the roots to penetrate more deeply into the soil, also the location of fertilizer placement under raised beds is different from flat-

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bed sowing.

The selection of a furrow opener of a combined seed drill depends upon its draught requirement; sub-soil placement of seed and fertilizer inputs at desired separations and depths from the soil surface and create an optimum physical environment around the seed for germination and plant growth (Darmora 2007). Many researchers (Lindwall and Anderson 1977, Singh *et al.* 1983, Dubey and Srivastava 1985 and Choudhary *et al.* 1985) used plant emergence and grain yield to assess grain drill opener performance. Furrow openers that place the fertilizer directly below the seed should improve fertilizer use efficiency. However, good seed-fertilizer separation is difficult to maintain with this type of openers. Placement of seed and fertilizer in separate bands and at different depth has been a difficult design parameter for seed-cum-fertiliser drill. Therefore, the differential depth furrow opener was designed and developed to apply fertilizer at different depths in vertical bands. Furrow openers were evaluated in field to investigate the proper fertilizer placement depth for wheat crop under raised beds farming. Soil bin studies were conducted with the furrow opener to establish the draught requirement and match the equipment requirement with available power source.

MATERIALS AND METHODS

A differential depth furrow opener of seed-cum-fertilizer drill was designed and developed at ICAR-Central Institute of Agricultural Engineering, Bhopal. It consisted of front fertilizer tine, furrow opener, fertilizer boot, covering device, seed tine, seed furrow opener, seed boot and depth adjustment arrangement. Two tines were attached one behind other, front tine having a shovel type furrow opener which opens a furrow and placed the fertilizer at appropriate depth and a covering device covers the furrow opened by front tine. Placement of the seed in furrow at recommended depth was done by rear furrow opener.

In case of differential depth furrow opener a shallow tine (seed) operating behind a deep tine (fertilizer), have no additional soil disturbance due to shallow tine. There is no change in the draught force compared with the deep tine alone (Godwin *et al*. 1984). Therefore, draught force calculated for deep tine was considerd as total draught of differential depth furrow opener.

Draught exerted due to the opener was calculated by the following equation (Sharma and Mukesh 2013)

$$D = K \times w \times d \tag{1}$$

where, D is the draught on furrow opener (N), k is the specific soil resistance (N/cm^2), w is the width of furrow opener (cm) and d is the depth of sowing (cm).

Bending moment of shank was calculated by the following equation (Kurtz *et al*. 1984)

$$M = D \times 1 \tag{2}$$

where, M is the bending moment (N-cm), D is the draught (N) and l is the moment arm length of shank (cm).

The section modulus of the shank was computed from the classical flexure formula (Seely *et al*. 1952, Timoshenko *et al*. 1964) as given in equation.

$$\delta = \frac{MC}{1} \tag{3}$$

where, δ is the bending stress (N/mm^2), M is bending moment (N-mm), *C* is distance from the neutral axis to the point at which stress is determined (mm) and *I* is moment of inertia of the rectangular section (mm^4). The section modulus (z) axis was computed by using the formula,

$$Z = \frac{1}{C} \tag{4}$$

From equations (3) and (4),

$$Z = \frac{M}{\delta} \tag{5}$$

Section modulus of rectangular section is

$$Z = \frac{t \times b^2}{6} \tag{6}$$

where, t is the thickness of shank and b is the breadth of shank in mm.The shank of the front tine was made of 500×50×20 mm mild steel flat.Furrow opener were of shovel type made of medium carbon steel with a 35 mm cross section. The boot wedge and rake angle were 40° and 30°, respectively.

The soil bin comprised a stationary bin, a tool bar frame, implement and test trolleys, a power transmission system, a control unit and instrumentation. The bin was 10.0 m long, 2.5 m wide and 1 m deep. Soil bin was filled with vertisol up to a depth of 0.9 m. Soil compaction was measured using cone-penetrometer. The tool was mounted on a test trolley fitted with S type load cell data acquisition system. Campbell scientific CR3000 micro logger was used to take data. The operating software includes measurement, processing, and output instructions for programming the data logger, triggering the sensors and save the online data during each run of tool. Experiments were conducted in soil bin at four depths (5, 10, 15 and 20 cm) varied using the tool bar frame, four forward speeds (1.8, 3.2, 4.3, 5.4 km/h) using 15 kW AC drive and three compaction levels (200, 400, 600 kPa).Draught requirment and cross section of tine going deep in the soil was major consideration.

The furrow opener was evaluated in the research field of ICAR-Central Institute of Agricultural Engineering, Bhopal (23°28' N Latitude, 77°40' E Longitude) for its performance in winter wheat crop varieties *Triticum aestivum* HI-1544 and *Triticum durum* (HI-8663) under raised bedsin vertisols (34% sand, 22% silt and 44% clay). The bulk density of soil varied from 1.21 to 1.25 g/cc. Crop was sown in November 2012 and 2013 and harvested in April 2013 and 2014 (Fig 1). The experiment consisted of different fertilizer placement depth, i.e. application of NPK mixed fertilizer on surface 0 cm (T1), and 5 cm (T2), 10 cm (T3), 15 cm (T4), 20 cm (T5) below the surface in split-plot design. Wheat was sown (seed rate 100 kg/ha) with the developed machine on raised bed of 15 cm height and 120

Fig 1 Wheat sowing with differential depth furrow opener on raised bed

cm width and 30 cm furrows, formed by tractor drawn raised bed maker. Five rows of wheat were sown on each bed with row-row spacing 22.5 cm.

The irrigation was applied in the furrow during wheat growth.Samples for measuring the crop attributes, i.e. plant height, plant weight and root weight were measured randomly in the field, all the parameters were recorded at regular interval from DAS. The yield of wheat was estimated at different random locations from 1 m^2 area.Spectral reflectance of crop canopy was collected using ASD FieldSpec®3 spectro-radiometer (Analytical Spectral Devices Inc., Boulder, CO, USA) having 350—2500 nm wavelength. The observations were taken along the nadir view under clear sky condition and appropriate sun shine between 11:00 to 14:00 IST. Data was processed using ViewSpec™ Pro application and Normalized Difference Vegetation Index (NDVI) was calculated using equation (Sellers 1985).

$$NDVI = \frac{NIFR - Red}{NIR + Red} \qquad (7)$$

The analysis of data was done by using SPSS (v-10) software and values were arranged according to Duncan Multiple Range Test.

RESULTS AND DISCUSSION

Laboratory performance of differential depth furrow opener

The effect of different depth on draught (Fig 2) of the furrow opener was examined for four different speeds and three different compaction level 200, 400 and 600 kPa. The draught was minimum (156.96 N) at depth of 5 cm for 1.8 km/h speed and 200 kPa soil compaction level. It was found that the draught on the tool increased with depth of operation, the reason being that at higher depth more soil volume comes in contact with tool and soil becomes denser. The increase became higher as the depth increased due to

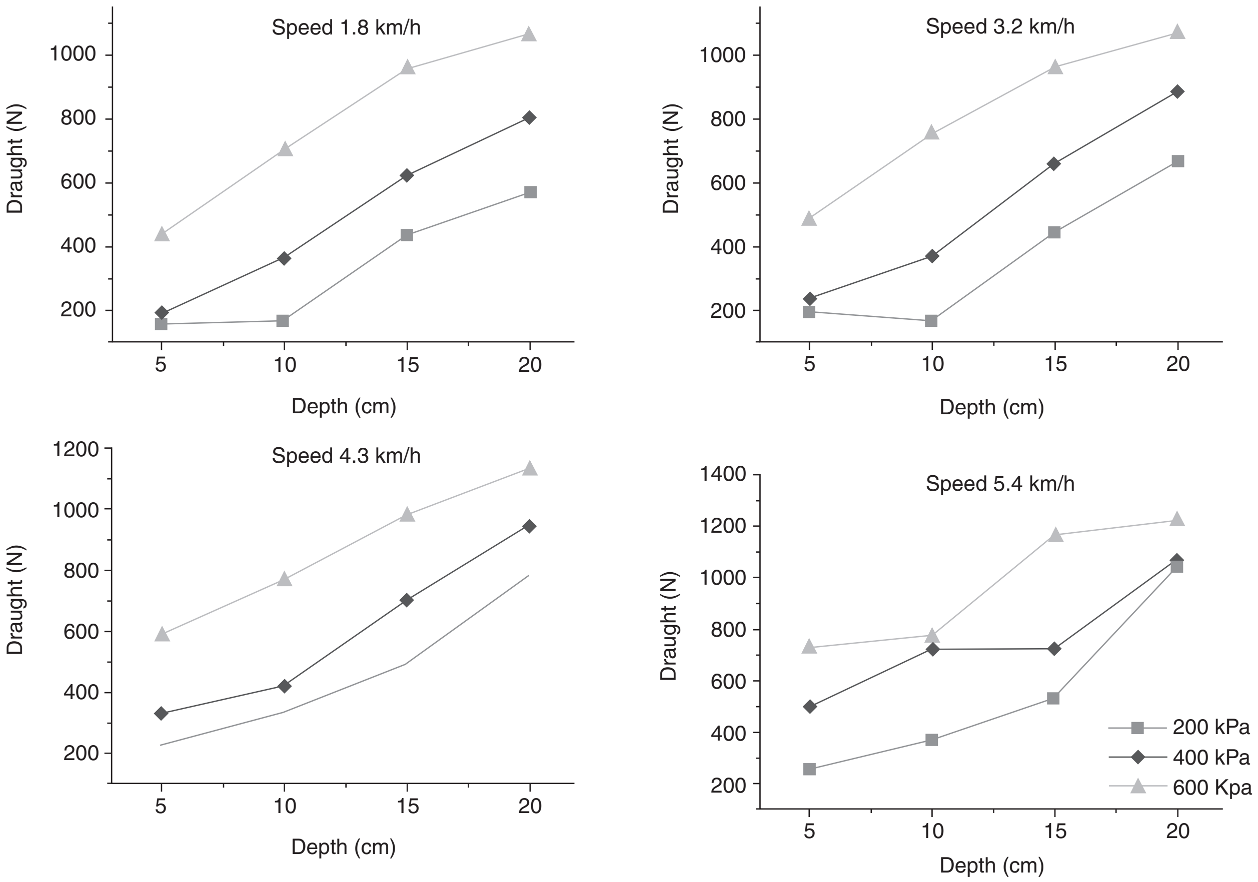

Fig 2 Effect of depth on draught for different forward speed

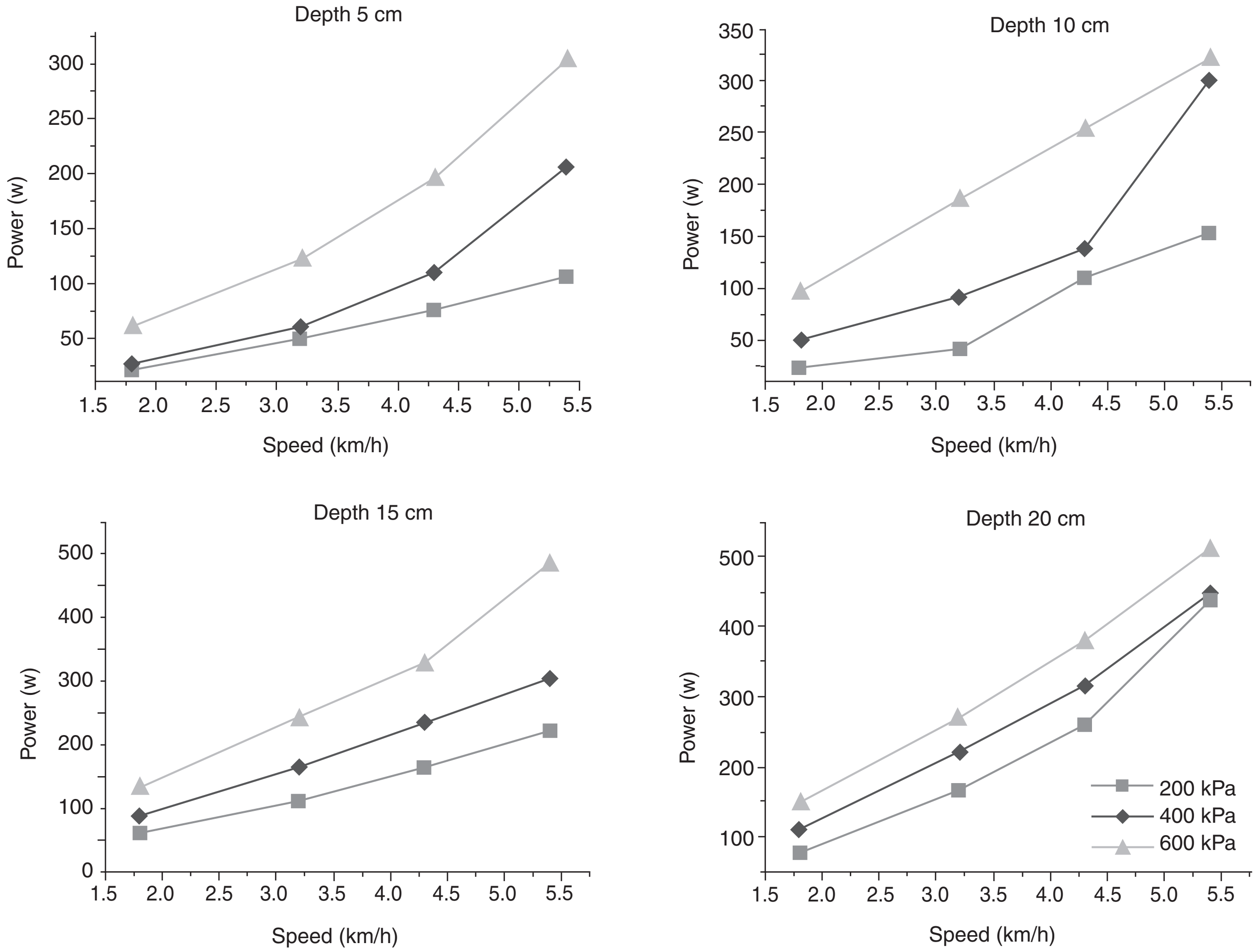

Fig 3 Effect of forward speed on power for different depth of operation

the increase of bulk density with depth. Within a practical range of field operating speed of tillage or sowing implement is pulled through soil has a relatively small influence on draught (Telischi *et al.* 1956, Schaaf *et al.* 1979, Stafford 1979). In present study a significant linear increased in draught had produced with the speed and each degree of soil compactions. The maximum draft was found to be 1226.25 N at 20 cm depth on soil compaction of 600 kPa at 5.4 km/h.

Effect of forward speed, depth and compaction level on power

The effect of different forward speed on power at different depth and compaction level of soil was found increasing linearly (Fig 3). All soil compaction levels show sudden increase in power requirement with change in speed from 4.3 km/h to 5.4 km/h at all depths. The maximum power 509.43 W was found for 5.4 km/h at 20 cm operating depth and 600 kPa compaction level where maximum draught achieved, as the power is directly proportional to the draught on tool. Results showed that at higher speed, magnitude of forces that act on soil engaging tools are also higher that require more draught which ultimately increases the power requirement of tool. Similarly lowest power 21.8 W was achieved at 5 cm depth for 1.8 km/h and 200 kPa compaction level of soil.

Crop attributes

The data of split plot design experiment for crop attributes were analysed and presented in Table 1. It revealed that crop varieties significantly ($P<0.01$) influences the root weight per plant and seed weight per ear head. Whereas crop varieties had no significant ($P<0.01$) effect on plant height, plant weight, grain and straw yields. Differential depth fertilizer application shows significant influence on plant height, plant weight and root weight/plant, grain and straw yields. Plant height was significantly higher 96.73 cm in *Triticum aestivum* than 94.94 cm in *Triticum durum*. Treatment wise maximum plant height 99.50 cm was achieved in T5 followed by 98.00, 97.50, 96.17, 88.00 cm in T4, T2, T1, and T3, respectively, also dry weight of plants were significant in the same order as plant height but maximum and minimum dry weight/plant was observed 57.68 and 38.03g in T4 and T3, respectively. The root weight per plant in T3 and T4 were significant while the maximum and minimum weight of root per plant were observed 16.01 and 9.63 g in T3 and T5, respectively.

Table 1 Wheat crop attributes influenced by wheat varieties and differential depth fertilizer application

Treatment	Plant height (cm)	Plant weight (g)	Root weight /plant(g)	Seed weight /ear head (g)	Grain yield (kg/ha)	Straw yield (kg/ha)
Main plots HI-1544 (*T. aestivum)*	96.73	47.3	10.29	1.90	5275	6740
HI-8663 (*T. durum)*	94.94	51.89	15.38	2.85	5170	6590
LSD(P=0.01)	NS	NS	6.68	0.24	NS	NS
Sub plots						
T1	96.17	50.51	11.40	2.26	4739	6060
T2	97.50	47.50	11.58	2.41	5223	6500
T3	88.0	38.03	16.01	2.45	5611	7240
T4	98.0	57.68	15.55	3.32	6048	6900
T5	99.50	54.54	9.63	2.45	4493	6630
LSD(P=0.01)	3.39	5.63	1.77	NS	239	240

NS: Non-significant at 1% significant level

Grain and straw yields

There was no significant effect of varieties on grain yield but differential depth fertilizer application shows significant effect on grain yield in all treatments. Highest average grain yield 6 048 kg/ha was observed in T4, followed by 5 611, 5 223, 4 739, 4 493 kg/ha in T3, T2, T1, and T5, respectively. There was no significant (P<0.01) effect of wheat varieties on straw yield. While there was significant effect of differential depth fertilizer application on straw yield. Higher straw yield was observed in T3 (7 240 kg/ha), followed by 6 900, 6 630, 6 500 and 6 060 kg/ha in T4, T5, T2 and T1, respectively. Thus, T4 (15 cm fertilizer application depth) was the optimum placement zone for obtaining higher grain and straw yields in wheat crop.

Effect of NDVI values on plant growth

Table 2 shows the effect of treatments on NDVI values at different growth stages of wheat crop. Wheat varieties shows significant (P<0.05) difference for NDVI values. Treatments shows significant difference at heading and milking stages, whereas in rest of stages no significant difference were observed. NDVI values of T4 in both wheat varieties were observed significantly (P<0.05) higher as compared to other treatments.

Table 2 Effect of NDVI values on wheat growth stages under treatments

Treat-ment	Tillering	Stem extension	Booting	Heading	Milking
Main Plots					
HI-1544	0.52 a	0.55 a	0.64 a	0.89 a	0.85 a
HI-8663	0.68 b	0.6 b	0. 77 b	0.97 b	0.97 b
Sub plots					
T1	0.581725[ab]	0.600925[a]	0.700025[a]	0.9069[a]	0.8887[a]
T2	0.6506[b]	0.59345[a]	0.695275[a]	0.9355[b]	0.8910[a]
T3	0.57[ab]	0.563075[a]	0.73875[a]	0.9516[bc]	0.9385[bc]
T4	0.555875[a]	0.597985[a]	0.72145[a]	0.9600[c]	0.9553[c]
T5	0.550475[a]	0.655625[a]	0.750525[a]	0.9566[bc]	0.9270[b]

Means within a column followed by the same letters are not significantly different (P= 0.05)

Effect of reflectance measurements at different growth stages of wheat on plant performance

The variation in the reflectance for the treatments were observed under differential depth fertilizer application. The reflectance at heading stage for the wheat crop was higher at all wavelengths under the T4 for both crop varieties and followed by T3, T2, T1 and T5. An increase in chlorophyll concentration due to higher nitrogen uptake by the plant causes increased reflectance in the visible regions. Low reflectance in T5 was due to the unavailability of nutrients to the plant during growing period. Reason was, at early stage roots did not reach to fertilization depth of 20 cm for nutrient uptake, result in lower chlorophyll content in the plant. It was observed that increased pattern of reflectance at heading stage under all treatments were similar to yield of crop.

The draught and power of the furrow opener for different speeds and different compaction level was increased with depth. Differential depth fertilizer application shows significant influence on plant height, plant weight and root weight/plant, grain and straw yields. Grain and straw yields of wheat crop achieved at 10 and 15 cm depth fertilizer placement were at par and higher as compared to other placement depths in both varieties. However the draught and power requirements for 15 cm fertilizer placement were 47% and 42% higher as compared to 10 cm fertilizer placement depth. NDVI values at 10 and 15 cm depth fertilizer placement in both wheat varieties were at par and higher as compared to other treatments. Therefore, fertilizer placement at 10 cm depth was found optimum for wheat crop under raised beds cultivation.

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