Design and development of subsoiler-cum-differential rate fertilizer applicator

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Abstract: A subsoiler-cum-differential rate fertilizer applicator was designed and developed by selecting the best parameters from previous studies. The equipment consisted of a rectangular frame, a main winged tine, two shallow leading winged tines, a depth control device, a fertilizer box of 100 kg capacity, positive feed type fertilizer metering devices and a ground wheel with chain and sprockets for transmitting power to the metering mechanism. The equipment had the option to place fertilizers up to a 500 mm soil depth by the main winged tine and delivering fertilizer up to 250 mm deep using the leading tines, thereby helping place fertilizer at different depths in vertical soil profile in a single pass. All three tines had independent metering systems. Options were provided to meter and deliver either 33.3% or 25.0% or 20.0% of the total recommended fertilizers with the main tine and the remaining amount through two shallow leading tines. The laboratory evaluations indicated a coefficient of uniformity of more than 90% for application rates of 250, 500, 750 and 1,000 kg/ha. The equipment was tested in the field to observe its performance on sugarcane with results showing an increase of 16.2%, 16.4% and 35.4% in yield as compared to conventional ploughing with in-furrow fertilizer application (Control). Subsoiling alone increased the cane weight, number of millable cane and cane yield by 4.3%, 11.4% and 15.9% compared to the control.

Keywords: Subsoiling, differential rate fertilizer placement, sugarcane

Citation: Mandal S., and T. C. Thakur. Design and development of subsoiler-cum-differential rate fertilizer applicator. Agric Eng Int: CIGR Journal, 2010, 12(1): 74－83.

1 Introduction

In India, the estimated annual food grain requirement for the year 2010 will be 300 million tones. To meet the demand of food grain, there will be a requirement of 45 million tones of inorganic fertilizers for growing the grain crops. Despite that most of the fertilizer used in India is imported, the usage of fertilizers per unit area is higher than the world average (Survey of Indian agriculture 2006). Therefore, measures should be taken to increase the fertilizer use efficiency. For maximum efficiency of applied fertilizer, it is essential to deliver nutrients to the root zone of plants at a rate which is sufficient for maximum uptake while avoiding fixation with clay particles. The attention should, therefore, be given towards addition of fertilizer in subsoil to increase its nutritive status. In situations where deep loosening was required, the incorporation of fertilizer has been found to be beneficial (Godwin and Spoor, 1981).

Hence, it is important to incorporate P fertilizers into the soil especially when using low water soluble phosphates. By increasing the efficiency, the same level of yield could be obtained with fewer amounts of

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Received date: 2009-05-09 **Accepted date:** 2010-03-04

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fertilizer and vice-versa (Cooke, 1982). In developing countries, a lot of work has been conducted on deep tillage with results showing substantial increases in crop yields.

Earlier experiments (McEven and Johnston, 1979; Rowse and Stone, 1980; Godwin and Spoor, 1981 and Liu et al., 1988) highlighted the potential yield increase for different crops, which could arise from amelioration of compaction and the incorporation of granular phosphate (P) and potassium (K) fertilizers into the subsoil. Therefore, incorporation of granular fertilizers with subsoiling operations for deep loosening and hard pan breaking may be effective and beneficial. Fertilizers may be placed either in continuous or intermittent bands as per the cropping pattern, root density of crops and metering system available. The evenness of placement should be maintained in vertical and horizontal soil profiles. Limited research has been conducted on subsoil delivery of fertilizers and tillage to reduce compaction while improving nutrient uptake. Subsoiling and fertilizer application by making two different passes across a field may not prove to be economical therefore combining into one pass is desired. Keeping the above points in view, the present investigation was carried out with the following objectives:

1) To design and develop a subsoiler-cum-differential rate fertilizer applicator for carrying out subsoiling and application of fertilizers in one pass.

2) To evaluate the developed machine on performance of sugarcane crop.

The application of fertilizers is usually accomplished by methods such as manual spreading, broadcasting, placement or mixing in upper soil layer of 20-50 mm only. Broadcasting of fertilizers, especially P and K, produces fixation problems due to more soil contact, whereas volatilization of N results in reduction of applied N content to the soil. Only 40% to 50% of N fertilizers, 20% to 30% of P and K fertilizers are effectively used by crops while the remaining become volatilized, leached to groundwater, or fixed within the soil as per the properties of their contents (Olsen et al., 1971; Rowse and Stone, 1980). Contrary to this loss, the basal application of fertilizers using planters and seed-drills has been found to be effective, but still not able to distribute fertilizers evenly as per the needs of roots. Therefore, more research efforts are needed on these aspects.

It is essential to consider the following requirements for achieving maximum effectiveness of mineral fertilizers concerning their techniques of application:

1) Uniform distribution of fertilizer on the desired area of the field,

2) Shortening the duration between the application of fertilizer and the start of intake by the plants,

3) Optimum depth of application of fertilizer in soil, and

4) Optimum spatial distribution of fertilizer based on planted rows and the crop root system (Cooke, 1982).

Band placement of fertilizer in sub-surface zones has been established as an effective method to increase the fertilizer use efficiency. Deep placement in band is also a similar and an advanced practice with the concept of applying fertilizer within root zone (Nathan, Singh and Thakur, 1990). Lee (1926) found that irrigated cane generally had more than 50% of the roots developed in the upper 200 mm of the soil profile and 85% in the upper 600 mm. Root distribution profiles of other crops are presented in Table 1. It is clear from these data that roots of these crops reach nearly 1.5 m in depth within the soil profile. Depth-wise, root distributions showed that more than 20% of roots grow vertically beyond a depth of 300 mm. Therefore, attention should be given to the nutrient availability below 300 mm. The concept of differential rate fertilizer application in which fertilizer is applied in bands according to the distribution of root could make sense in order to maximize nutrient availability at these root depths. The necessary depth of application could be important and vary with crop types and soil conditions. It is de after the study of the hard pan that is generally developed below the normal ploughing depth. During subsoiling operations to breakup compacted layers, fertilizer also could be applied and delivered to the depths where roots could utilize the nutrients. So by studying the root distribution above and below the plough pan differential rates can be de i.e. if *x* % of roots are below this pan, *x* % of fertilizer will be applied with the subsoiler at the same zone. In *Tarai* region of Uttarakhand (India), the study revealed the presence of hard/plough pan below a depth of 300 mm. So the subsoiling depth was decided at 500 mm whereas leading tines were operated at a depth of 250 mm.

Table 1 Quantitative information on specific root length and root length density

Crops	Age	Depth/m	L/Y_D^*	L_{ra}	L_{rv}I	L_{rv}II	L_{rv}III	L_{rv}IV
Wheat	126 d	1.50	—	223	1.5	4.6	1.7	0.8
Maize	12 w	1.45	30	—	—	4.2/8.2	3.0/.88	2.1/.4
Cotton	14 w	1.80	96	—	0.9	2.9	1.8/.9	1.6

(*Source*: McMichael and Persson, 1991)

*L/Y_D = specific root length, [m/g]; L_{ra} = total root length per unit soil surface area, [m/m^2], d = Day, w = Week, yr. = Year, L_{rv} = root length density, [m/m^3]: I = average over rooted zone, II = 0-0.3 m, III = 0.3-0.6 and IV = 0.6-0.9 m depths.

2 Materials and methods

The complete machine is shown in Figure 1. The first prototype of Subsoiler-cum-differential rate fertilizer applicator consisted of two main units i.e. a subsoiling unit and a fertilizer application unit. The subsoiling unit consisted of mainly a rectangular frame, a main winged tine, two shallow leading winged tines, a depth control device, and a hitching system. The fertilizer application unit consisted of a fertilizer box with the metering system for individual tines, a ground drive wheel for power transmission and its accessories. The design procedure followed for the main parts is given in the subsequent sections:

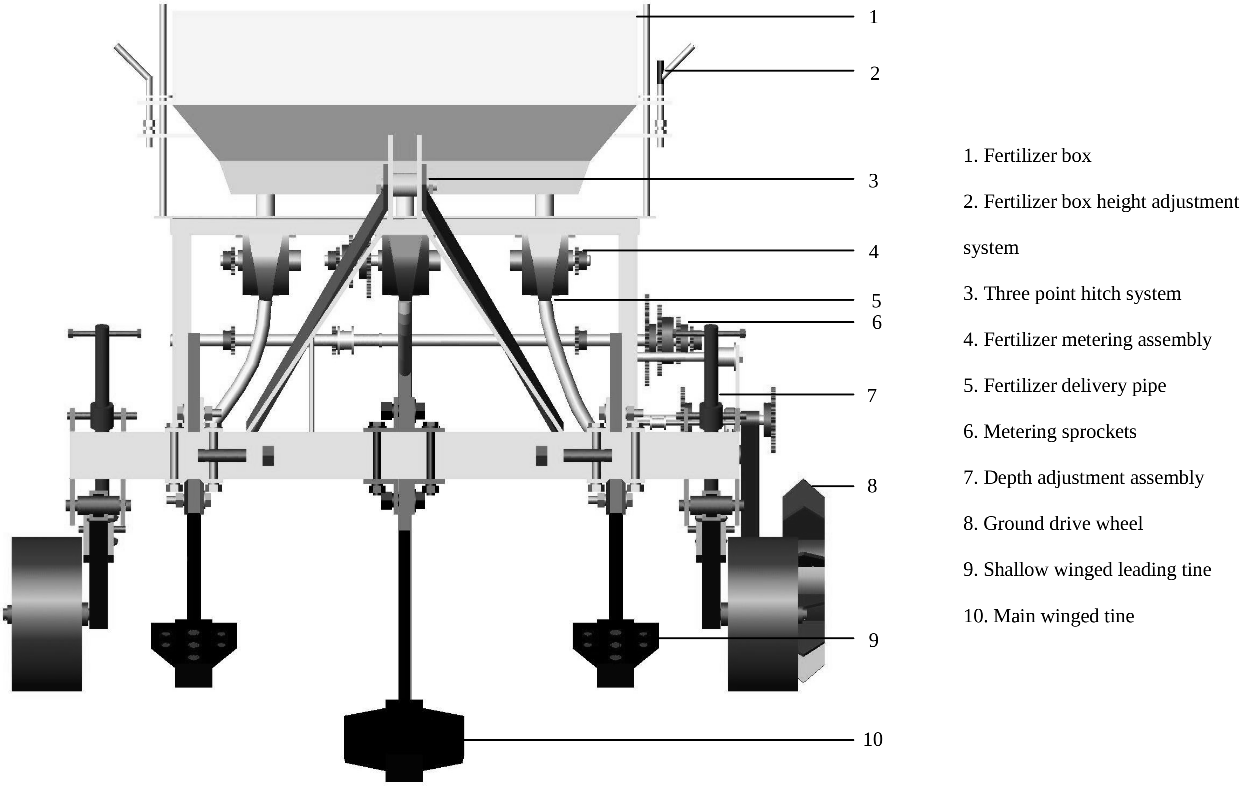


Figure 1 Front view of the subsoiler-cum-differential rate fertilizer applicator

2.1 Soil cutting mechanisms

Mathematical models of soil cutting postulated by different researchers, either two or three dimensional, have assumed that soil is moved upward over the entire working depth range of the cutting tool, which is not true at all time. Below certain working depths termed as 'critical depths', the soil movement changes from a predominantly forward and upward manner (crescent failure) to a mainly forward and sideways movement known as the 'lateral failure'. A mathematical model was postulated by Godwin (1974) in which the regime of forces in the soil can be analyzed when a critical depth is present. There are two types of soil failure mechanism as given below:

a) Crescent soil failure

The soil above the critical depth fails in brittle manner during the crescent failure. The models suggested for the crescent soil failure make three assumptions as given below:

1) Yielding of soil in shear obeys the Mohr-Coulombs failure criterion.

2) A distinct rupture surface is formed in front of the tine, bounding a volume of soil in a state of plastic equilibrium.

3) Rate effects on the relevant soil parameters are negligible.

The magnitude of the resultant passive force (P) can be calculated from the equation given by Hettiartchi et al. (1966):

$$P= [\gamma z^2 N\gamma + czN_c + c_a zN_a + qzN_q]w \qquad (1)$$

$$H_1=P\sin(\alpha+\delta) \qquad (2)$$

Where, γ = Bulk density of soil, kN/m^3; z = Depth of operation, m; c = Soil cohesion, kN/m^2; c_a=Soil adhesion, kN/m^2; q = Surcharge load, kN/m^2; w = Width of tool, m; H_1= Horizontal component of passive force i.e. draft; α = Rake angle of tine, degree; δ= Angle of soil-metal friction, degree; φ = Angle of internal friction, degree.

The N-factors are dimensionless numbers and depend upon the magnitudes of α, δ and φ.

b) Lateral soil failure

The soil below the critical depth fails in a two-dimensional manner within the horizontal plane regardless of the rake angle of tine (Figure 2). The soil moves to the lateral sides of the tool at a depth greater than the critical depth, along logarithmic spiral paths, similar to the deep foundation model postulated by Meyerhof (1951) and the resultant stress on the tine can be obtained using:

$$q' = cN'_c + P_0 N'q \qquad (3)$$

$$P_0 = \gamma zK_0 = \gamma z[1-\sin\varphi] \qquad (4)$$

Where, φ = Angle of internal friction of soil, degree; K_0 = Ratio of horizontal to vertical stress on the soil at rest; = $[1-\sin\varphi]$ after Lambe and Whitman (1969).

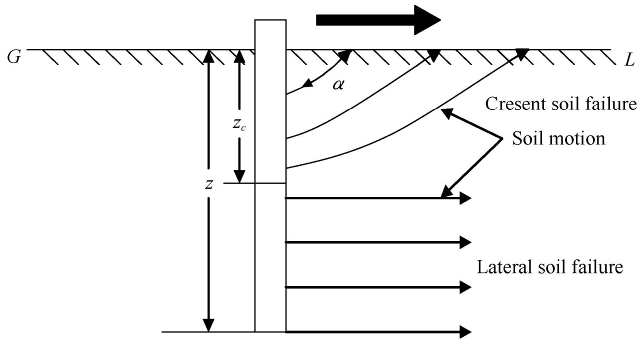


Figure 2 Soil movement for a very narrow cutting tool

Therefore, the total force, Q, on the tine face width of w below critical depth, is given by integrating equation 3 between limits of critical depth (z_c) and total working depth (z) by neglecting tine roughness and multiplying by 'w' as:

$$Q = [cN'_c\,(z-z_c) +\gamma/2K_0N'q(z^2-z_c^2)]w \qquad (5)$$

Where, z_c = Critical depth of operation, m.

The N'_c and $N'q$ can be determined from expressions provided below or from graphical presentation (Meyerhof, 1951).

$$N'_c = \cot\phi\left[\left[\frac{1+\sin\phi}{1-\sin\phi}\right]e^{2\left(\frac{\pi}{2}+\phi\right)\tan\phi}-1\right] \qquad (6)$$

$$N'_q = \left[\frac{1+\sin\phi}{1-\sin\phi}\right]e^{2\left(\frac{\pi}{2}+\phi\right)\tan\phi} \qquad (7)$$

The total horizontal force component (H_1) of P in the direction of travel including interface adhesion above the critical depth is represented by:

$$H_1 = P\sin(\alpha+\delta)+c_a z_c w\cot\alpha \qquad (8)$$

Thus, the total horizontal component (Draft force), D in the direction of travel is the sum of Q below critical depth and H_1 above it, can be expressed by:

$$D = Q + H_1 \qquad (9)$$

2.2 Design of main tine

The main tine is the central tine with its primary purpose of applying fertilizer as well as to perform subsoiling up to a depth of 500 mm. A 75 mm wide share was selected for the central tine from the previous research completed by Arun Kumar (2003). Thus, to design the different parts, the determination of the draft force was required.

Tool parameters:

Width of share (w) = 75 mm

Rake angle of share (α) = 22^0

Depth of operation (z) = 500 mm

Aspect ratio (z/w) = 500/75 = 6.67

Soil parameters:

Cohesion (c) and angle of internal friction (ϕ) of soil layer having the maximum density of 17 kN/m^3 was taken as 17 kPa and 25^0, respectively as found by Arun Kumar (2003).

Soil to metal friction (δ) = 2/3$^{rd}\phi$= $16.6^0 \approx 17^0$

Bulk density of soil (γ) = 17 kN/m^3

Soil adhesion (Ca) = 0 (assumed).

According to Spoor and Godwin (1978), the critical depth (z_c) of a conventional straight leg subsoiler ranged between the aspect ratios of five and seven. Therefore, taking z_c/w=5, the critical depth was computed at 375 mm. For α =22^0, z_c/w = 5, δ = 17^0, ϕ = 25^0, z =500 mm, the values of N_γ and N_c were found as ten and nine, respectively from graph presented by McKyes (1985) and N'_c = 40 and N'_q =20 were found from graphical relation of ϕ and N factors provided by Meyerhof (1951). Further, the addition of wings added 30% more to the total draft (Spoor and Godwin, 1978). Substituting these values and considering addition of wings, the total draft force (D) on the leg of subsoiler was calculated as 14.3 kN and rounded up to 15.0 kN.

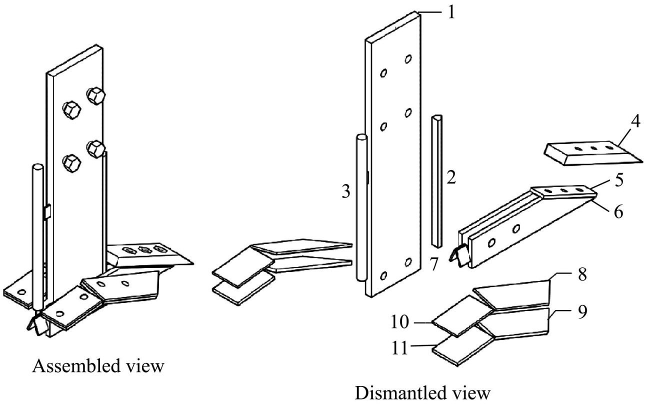
The different components of the main winged tine for both subsoiling and deep placement of fertilizers were the leg, shin, share, wings, gusset plates, and side plates (Figure 3).

1) Leg and foot

The leg of the subsoiler was made from flat mild steel of size 900 mm×200 mm×25 mm. The lower end of the leg was sandwiched between two side plates of 100 mm×15 mm called the ‘foot’ and tapered at 22^0 for mounting the share. The lateral portion of the side plates provided space for attachment of gusset plates for mounting of wings of the subsoiler.

2) Shin

The subsoiler generally operated at depths greater than 250 mm, resulting in heavy wear on the front side of the leg. To avoid this wear, a high carbon steel shin measuring 25 mm×25 mm in cross-section was welded to the front side of the leg. It was tapered in the front at 90^0 cone angle and was replaceable after wear.



1. Leg 2. Shin 3. Fertilizer tube 4. Share 5. Base plate 6. Side plate 7. Deflector plates 8. Wing 9.Gusset plate 10.Cover plate 11. Cover plate support

Figure 3 Isometric view of main winged tine

3) Share

The share was the main component of the subsoiler which opened the soil. It had the highest wear potential thus was made of high carbon steel (EN 31). The share tip was mounted at a rake angle of 22^0 for easy penetration and to minimize draft. The share was hard surfaced by depositing wear resistant material in the form of a grid to enhance its wear life. The length of the share was adjusted such that when one side of the share was worn-out, the other end could be tapered to 22^0 and used for successive work.

4) Gusset plates

Gusset plates were made from mild steel flat of 300 mm (length)×100 mm (width)×10 mm (thickness) to support the wings on the foot. The gusset plate of each tine had 22^0 lift angle from front side in horizontal plane and 12^0 in the vertical plane for proper upheaval of soil. These plates were cut on front side at 40^0 to obtain an included angle of 80^0 while the rear sides were left as such to match the covering plates provided at the rear of tines.

5) Wings

Wings were made from high carbon steel. They will encounter excessive wear due to the the depth and interaction with the soil. For easy penetration and minimum draft while cutting the soil with wings, the edges were tapered at 40^0 from the front side and supported on the gusset plates as described above. They were mounted on the gusset plates with countersunk bolts.

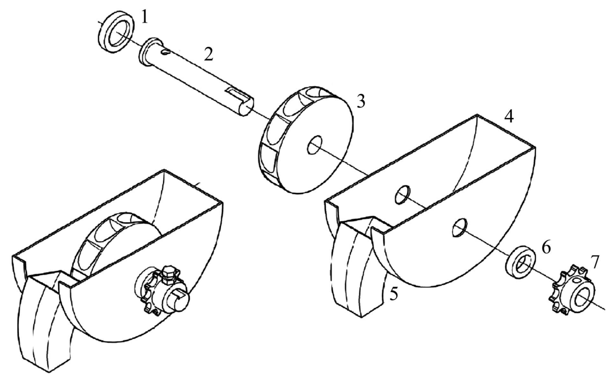
2.3 Design of shallow leading tines

The shallow leading tines operate at half the depth of operation of main tine (deep tine). Therefore, the maximum depth of operation of shallow leading tines (z) was 250 mm for 500 mm depth of operation of the main tine. All other tool and soil parameters remained the same as mentioned above. The N-factors such as $N\gamma$ and N_c for $\alpha = 22^0$, z/w =3.33, $\delta = 17^0$ and $\phi = 25^0$ were found as $N\gamma$ =7 and N_c = 7 (Mckyes, 1985). Substituting these values in equations (1) and (2), and considering 30% more draft for the wings, the total draft force (H_1 was computed as 2.3 kN but rounded up to 2.5 kN for the design analysis.

The shallow leading tines also consisted of a share, leg, wings, shin etc. as that of the main tine (Figure 3). The leg of leading tine was made from m.s. flat of 750 mm×80 mm×25 mm size. The lower end was sandwiched between two side plates of 300 mm×75 mm×15 mm size tapered at 22^0 in the front and joined by nuts and bolts to form a foot. A share of 270 mm×80 mm×25 mm size is bolted on the tapered portion of foot by countersunk nuts and bolts. The share has a tip angle of 22^0 and made of high carbon steel (EN 31) to give maximum worn-out life and is reversible. Wings of the same material having dimensions of 225 mm×65 mm×5 mm were attached to both sides of the foot at a distance of 20 mm from its centre. The remaining portion of foot was covered by a steel plate of 80 mm (length)×5 mm (thickness) for easy fertilizer distribution in bands after falling over the deflector plates. Gusset plates of 5 mm thickness supported the wings. A high carbon steel replaceable shin which was tapered at the front to a 90^0 cone angle was attached to minimize wear of the front side of leg.

2.4 Metering mechanism

A two stage fertilizer metering system was used to achieve accurate rates of application - a free fall unit with adjustable height of the hopper within a range of 0-200 mm and an edge cell roller type metering mechanism were provided for the metering of fertilizer. By changing the height of the hopper, the fall of fertilizer from the box could be controlled and thereby the rate of application. The main components of this unit are shown in Figure 4.



1. Bush 2. Shaft 3. Roller 4. Hopper 5.Bush 6. Sprocket

Figure 4 Illustration of the fertilizer metering unit assembly

1) Physical properties of fertilizers

Shinde (2004) conducted an experiment to find out the physical properties of fertilizers mixture of DAP, MOP and SSP which have been reported in Table 2. These data were used to design the components of the fertilizer metering unit.

Table 2 Physical properties of fertilizers

S.N.	Fertilizers	Moisture conten /%	Bulk density /mg • m^{-3}	True density /mg • m^{-3}	Angle of repose /degree	Angle of inter-granular friction/degree	Particle M.W.D. /mm	Fineness modulus
1	DAP	6.28	1.087	2.035	35.74	38.4	1.831	5.999
2	SSP	7.02	1.206	2.148	33.68	36.8	0.576	3.679
3	MOP	7.20	1.020	1.818	39.34	33.7	0.890	3.888
4	NPK Complex	5.98	1.080	1.870	37.87	38.2	1.222	4.912

Source: Shinde, 2004.

2) Fertilizer box and box height adjustment assembly

The box was designed for 90-95 kg capacity to minimize the number of refills for the box on a per hectare basis. This box was fabricated in three sections i.e. upper rectangular section with the cross section of 1,000 mm×350 mm, the first trapezoidal section with an inclination angle of 40^0, and the bottom section of a 20^0 inclination from the vertical. The whole box assembly could be lowered or raised by 150 mm to vary the rate of application.

3) Metering roller

The metering roller was an edge cell type and designed considering the free flow of fertilizer during delivery. Therefore, the angle of the base of the cell was maintained at 52^0 for easy flow of material as shown as Figure 5. The diameter of roller was 130 mm with ten cells in the periphery. Cells were cylindrical in shape with a diameter of 18 mm and a height of 35 mm, thus giving a capacity of 4.75×10^{-6} m^3 which can deliver 4.75×10^{-5} m^3 of fertilizer equivalent to 51.30 g of NPK complex with a bulk density (ρ) of 1080 kg/m^3 in one revolution. The core diameter of the metering roller was 25 mm. Three independent metering assemblies were provided one for each tine. A ground wheel attached at the back side of the implement was provided to drive the metering assembly. Four sprockets were provided to vary the application rate from 250 kg/ha to 1,000 kg/ha.

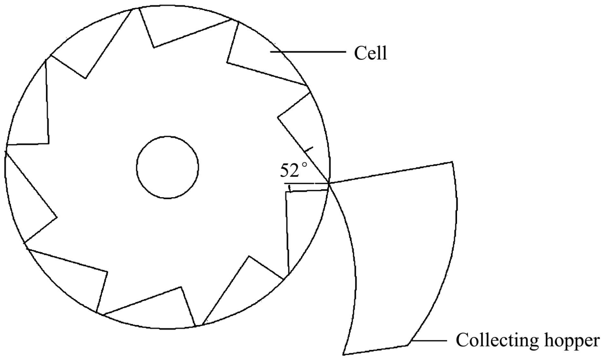


Figure 5 Metering roller

4) Deflector plate

Two deflector plates were provided below the fertilizer delivery pipe behind each tine. The main function of these plates were to place fertilizers in band uniformly which depends upon the included angle between two deflector plates. Figure 6 shows that the 60^0 deflector plate angle gave the maximum co-efficient of uniformity for most of the fertilizers. Therefore, a 60^0 angle between the two plates was selected.

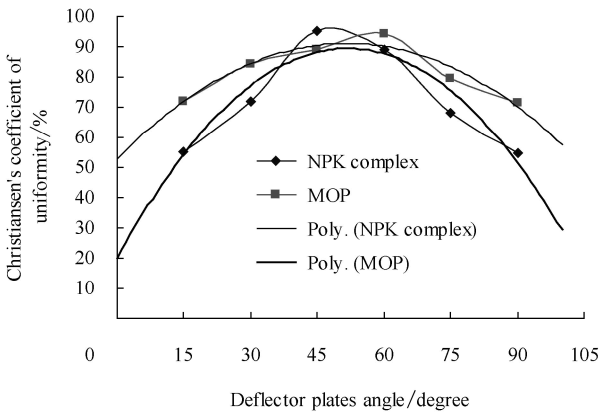


Figure 6 Relationship between included angles of deflector plates and co-efficient of uniformity (Shinde, 2004)

2.5 Distribution pattern of fertilizers

For precise quantitative analysis of distribution pattern, 32 collection boxes of 100 mm (length)×50 mm (width)×40 mm (depth) were fixed on the conveyor belt of experimental set-up suggested and used by Nathan (2000) shown in Figure 7. The conveyor belt was run at constant speed of 0.55 m/s. In order to collect the uniform and steady flow of fertilizer in boxes from fertilizer tube, the fertilizer was dropped up to 2 m length on the belt every time. The fertilizer from each box was collected in small butter paper bags, which were then kept in polythene bags to keep away from atmospheric moisture. The samples were then weighed on electronic balance having 0.001 g least count. The data were noted in series, which were then analyzed to find the uniformity of distribution.

Figure 7 Experimental set-up used for studying the distribution pattern of fertilizers

2.6 Experimental design and data analysis

2.6.1 Laboratory test

The experiments were planned in randomized block design (RBD) with eight replications and four treatments to evaluate the distribution pattern in laboratory for NPK complex and MOP fertilizers.

Reed and Wacker (1970) determined coefficient of variation of distribution pattern to test the uniformity of placement of dry fertilizer spreaders. Later on Bansal and Thierstein (1984) also determined coefficient of variation as an index for analyzing distribution patterns of oscillating trough type applicator. Davis (1966), however, presented the uniformity of water distribution from sprinkler. He used Christensen's coefficient of uniformity, coefficient of variation and pattern efficiency as indices. It was, therefore, decided to analyze the uniformity of distribution of fertilizers using standard deviation, Christensen's coefficient of uniformity and coefficient of variation by using the developed statistical software for analysis of variance (ANOVA) with F-test at 5% level of significance.

The statistical parameters which were used for comparing the uniformity of distribution patterns are described as below:

1) Standard deviation

$$\sigma = \sqrt{\frac{1}{N}\Sigma X^{2}\,\frac{(\Sigma X)}{N}}^{2} \qquad (10)$$

where, σ = Standard deviation; N = Total number of observations; X = Weight of fertilizer in each box, g.

2) Christensen's coefficient of uniformity

$$C_U = 1 - \frac{\Sigma(\left|X - \overline{X}\right|)}{n\overline{X}} \times 100 \qquad (11)$$

where, C_U = Christensen's coefficient of uniformity, %; $\overline{X}\Big|$ = Mean weight of fertilizer, g; X = Weight of fertilizer in each box, g; N = Number of fertilizer boxes.

2.6.2 Field test

The machine was further tested in the field to determine the effect of deep and differential rate placement of fertilizer on sugarcane crops. The experiment was laid out in Two Factor Randomized Block Design with two fertilizer doses and four tillage and fertilizer application methods with three replications (2×4×3), which are as follows:

Fertilizer doses:

F_1 : Recommended NPK of sugarcane crop (120 kg N, 60 kg P_2O_5 and 40 kg K_2O)

F_2 : 80% of recommended NPK of sugarcane crop (96 kg N, 48 kg P_2O_5 and 32 kg K_2O)

Tillage and fertilizer application methods:

T_1 : Plough x 1 + Harrowing x 4 + Furrow application of fertilizer

T_2 : Subsoiling by the developed machine (400 mm) + Harrow x 2 + Furrow application of fertilizer

T_3 : Subsoiling-cum-deep placement at 300 mm depth by the developed machine + Harrow x 2

T_4 : Subsoiling-cum-differential rate placement (80% at 250 mm and 20% at 400 mm) by the developed machine + Harrow x 2

The level of significance in the statistical analysis was chosen as 5%. Standard measurement technique was followed to take the data of various crop parameters regarding growth and yield.

3 Results

The machine was first tested in the laboratory to examine the uniformity of application rate from each tine as discussed above. The result showed that coefficient of uniformity for all the application rates viz. 250, 500, 750, and 1,000 kg/ha, was over 90% with a range of 93.7% to 98.8%. The variation in the uniformity was due to improper mixing of the powder form of MOP with the granular form of other fertilizers. However, this variation was considered small and coincided with results reported by Walker (1957).

The results of crop performance in terms of yield attributes and the yield of sugarcane recorded during the experiment were analyzed by standard statistical technique applicable for two-factor RBD. Mean values and SEm and CD from the ANOVA table are presented in Table 3. It showed that subsoiling-cum-deep placement (1,430 g), being at par with subsoiling-cum-differential rate fertilizer placement method (1,419 g) reported significantly higher cane weight than subsoiling with in-furrow fertilizer application (1,274 g) and ploughing with in-furrow fertilizer application methods (1,222 g).

Subsoiling-cum-deep fertilizer placement and subsoiling with in-furrow fertilizer application methods reported a significantly higher number of millable canes than ploughing with in-furrow fertilizer application. Significant differences in yield were found due to different tillage and fertilizer application methods. Subsoiling-cum-deep fertilizer placement method showed a 17.0% increase in cane weight, a 15.8% increase in the number of millable cane and a 35.6% increase in cane yield. In another case, subsoiling-cum-differential rate fertilizer placement method reported 16.2%, 16.4% and 35.4% increasees in cane weight, the number of millable cane and the cane yield, respectively due to placement of fertilizer in subsoil or within the crop roots. Subsoiling-cum-differential rate fertilizer placement gave the maximum juice extraction of 36.9% whereas the ploughing with furrow fertilizer application method reported the least juice extraction of 34.9% (Table 3).

Table 3 Yield and yield attributes as influenced by fertilizer dose, methods of tillage, and fertilizer application

Treatments	Cane weight/g	NMC/000 ha^{-1}	Yield/t • ha^{-1}	Juice extraction/%	Brix/%	Sucrose content/%
F1	1367	67.0	94.6	36.6	20.5	18.7
F2	1306	69.1	90.6	35.8	20.0	18.5
SEm	24	1.0	1.9	0.6	0.1	0.1
CD	NS	NS	NS	NS	0.4	NS
T1	1222	62.2	76.0	34.9	19.9	18.5
T2	1274	69.3	88.0	36.6	20.1	18.6
T3	1430	72.1	103.0	36.7	20.7	18.7
T4	1419	72.5	102.9	36.9	20.4	18.8
SEm	35	1.4	2.7	0.8	0.2	0.2
CD	145	4.2	8.3	NS	NS	NS

Subsoiling-cum-deep placement method reported the maximum brix value of 20.7% followed by subsoiling-cum-differential rate fertilizer placement (20.4%), subsoiling with furrow fertilizer application method (20.1%) and the minimum brix value was recorded in ploughing with furrow fertilizer application (19.9%).

The subsoiling-cum-differential rate fertilizer placement recorded maximum sucrose content (18.8%) followed by the subsoiling-cum-deep placement (18.7%), subsoiling with furrow fertilizer application (18.6%), and ploughing with furrow fertilizer application (18.5%) methods.

4 Conclusions

Subsoiling is a well established practice in agriculture. Deep placement of fertilizer in bands is also fruitful to reduce fixation. To combine these two operations, a subsoiler-cum-differential rate fertilizer applicator was designed and developed. As results indicated, this equipment performed well in laboratory and also in the field. The land profile after the operation of the implement was quite flat compared to the ploughed field by mould board plough. It can simultaneously perform subsoiling and fertilizer application in the subsoil which ultimately saves fuel and time. Both subsoiling-cum-deep placement and subsoiling-cum-differential rate placement methods were found equally effective in substantially increasing the yield of sugarcane crops. These two methods would also save around 20% of fertilizers due to increased fertilizer use efficiency. However, the experiments need to be conducted for confirmation of results by measuring the nutrient status of soil and the uptake of nutrients by plants.

References

Arun K., and T. C. Thakur. 1999. Effect of subsoiling and tillage methods on yield of wheat crop. *J. Agric. Engg.*, 36(3): 51－54.

Arun K. 2003. Design and development of winged subsoiler with leading tines and maize crop response to subsoiling. Unpublished Ph.D. Thesis, G. B. Pant University of Agriculture and Technology, Pantnagar, p 167.

Bansal, R. K., and G. E. Thierstein. 1984. Metering granular fertilizer with an oscillatory mechanism. *J. Agric. Engg.*, 21(1 and 2): 1－8.

Cooke, G. W. 1982. *Fertilizing for maximum yield*. English Language Book Society and Granada, London, 3rd ed. p 7－8.

Davis, J. R. 1966. Measuring water distribution for sprinkler. *Transactions of ASAE*, 9(1): 94－97.

Fertilizer News. 2005. ICAR, New Delhi, India.

Godwin, R. J., and G. Spoor. 1981. The design and performance for the subsoil placement of fertilizer. *ASAE Paper* No., 81－1091.

Godwin, R. J. 1974. An investigation into the mechanics of narrow tines in frictional soils. Ph. D. thesis, Univ. of Reading, U.K.: 248.

Hettiaratchi, D. R. P., B. D. Witney, and A. P. Reece. 1966. The calculation of passive pressure in two-dimensional soil failure. *J. of Agril. Engg. Res.*, 11(2): 89－107.

Lambe, T. W., and R. V. Whitman. 1969. *Soil mechanics*. John Wiley and Sons, Inc., New York.

Lee, H. A. 1926. Progress Repot on the distribution of cane roots in the soil under plantation conditions. *Haw. Plant. Rec.*, 30: 511－519.

Liu, F., H. Jha, C. Zhang, and H. Zhang, et al. 1988. Improvement of planosol solum. Part 9: fertilizer distributor for subsoil. *J. Agric. Engg. Res.*, 71(3): 213－221.

McEwen, J., and A. E. Johnston. 1979. The effect of subsoiling and deep incorporation of P and K fertilizers on the yield and nutrient uptake of barley, potatoes, wheat and sugarbeet grown in rotation. *J. Agric. Sci. Cambridge*, 92: 695－702.

McKyes, E. 1985. *Soil cutting and tillage*. Elsevier Science Publishers. Amsterdam, The Netherlands.

McMichael, B. L., and H. Persson. (ed). 1991. In: Plant roots and their environment, Elsevier Science Publishers B.V.

Meyerhof, G. C. 1951. The ultimate bearing capacity of foundations. *Geotechnique*, 2(4): 310－332.

Nathan, S. K., B. Singh, and T. C. Thakur. 1990. Laboratory studies on performance of positive fee metering devices for band placement of fertilizers. *J. of Agric. Engg.*, 37(2): 1－14.

Olsen R. A., T. J. Army, J. J. Hanway, and V. J. Kilmer. 1971. Fertilizer Technology and Use. (2nd ed.), *Soil Science Society of America*, Inc. Madison, Wisconsin (USA).

Reed, W. B., and E. Wacker. 1970. Determining distribution pattern of dry fertilizer applicators. *Transactions of ASAE* 13(1): 85－89.

Rowse, H. R., and D. A. Stone. 1980. Deep cultivation of a sandy loam, I. Effects on growth, yield and nutrient content of potatoes, broad beans, summer cabbage and red beet in 1977. *Soil and Tillage Research*, 1(1): 57－68.

Shinde, A. T. 2004. Design, development and performance evaluation of a Subsoiler-Cum-Fertilizer Applicator. Unpublished M. Tech. Thesis, G. B. Pant University of Agriculture and Technology, Pantnagar.

Spoor, G., and R. J. Godwin. 1978. An experimental investigation into the deep loosening of soil by rigid tines. *J. of Agril. Engg. Res.*, 23(3):243－258.

Survey of Indian agriculture. 2006. The Hindu, New Delhi, India.

Walker, H. B. 1957. Engineering problems in fertilizer placement. *Agric. Engg.*, 38(9): 658－661.