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# AMA

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# EDITORIAL

In spring 1971, AMA was first published under the title of "Agricultural Mechanization in South East Asia". A total of 10,000 issues were sent to all over the world, government agencies, universities and related agricultural engineering research institutes. As a result of this, there were many reactions from many Asian countries, and they requested to include all Asian area in AMA not only southeast Asia. Then the title was changed from the second issue to "Agricultural Mechanization in Asia ". After 10 years, AMA became the journal that was read by the people not only in Asia but in Africa and Latin America. Then Dr. Moens who was a professor at Wageningen University and the key person of agricultural machinery research in those days, advised that the title of AMA should include all the world. From that time AMA has been titled as "Agricultural Mechanization in Asia, Africa and Latin America".

Since then we have continued to publish AMA for more than 30 years. Still in the world, farmers in developing countries are poor and there are innumerable tasks for improving their situation through agricultural mechanization. Global cooperation of the people involved in research, production and extension of the agricultural machinery is greatly needed. Earth has become smaller due to the development of communication and transportation. Under current situation, expansion of economic gap makes it difficult to make a peaceful society. We have to work actively with the aim that farmers of developing countries will become rich by themselves by using new and improved technologies.

In February, I visited ISAE 49th Annual Convention held at Punjab Agricultural University, Ludhiana, India where I spent a great time to meet many Indian Co-editors again who have a longstanding relationship with me. From them, I learnt that in India AMA has acquired the highest reputation. In NAAS, the AMA took 6.06 score, (ICAR Journal 6.0, ISAE journal 4.27 and AAAE Journal 2.75), which is the highest score among the journals of agricultural technology that are published in ASIA. Thank you from the bottom of my heart and I think that this is the result of cooperation of many Co-editors.

With the situation that world population is growing to be 9 billion, promotion of agricultural mechanization is becoming more and more important. Let's do our best for agricultural mechanization in the world by cooperating with each other and communicating more closely.

**Yoshisuke Kishida**
**Chief Editor**

April, 2015

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## AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

**Vol.46, No.2, Spring 2015**

# Development and Evaluation of Zone-till with Subsurface Fertilizer Applicator for Unpuddled Transplanting Rice Cultivation


by

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## Abstract

Tillage, fertilizer placement and water are the most important for sustainable and economical agriculture. Therefore, a zone-till subsurface row fertilizer applicator was developed and evaluated at Harbin, China. The system of the applicator ($T_1$) was compared with traditional rice practices ($T_2$). The performance tests of the applicator were promising. The system ($T_1$) saved water, reduces costs and desired transplanted seedling depth compared to $T_2$. The new system can enrich soil temperature, crop growth rate, yields and increased the residual retention of nutrients (N, P, K) in soil. The applicator and the system could be offered as an alternative for future pattern of rice cultivation.


## Introduction

Rice is a primary food, contributing to food security and income in Asia. But challenges in maintaining the sustainability of rice farming have been increasing with increased scarcity of water, declining soil health and increasing costs. In Asia, the most common traditional tillage (TT) for rice is to grow in puddled soil. Unfortunately puddling destroys the ecological environment which can be avoided without any penalty in rice production. On the face of limited resources when future production is under threat, conservation tillage (CT) may be suggested for future changes in cultivation to produce more rice with less tillage, water, fertilizer and keep the sustainability of cropland (Smith *et al*., 2012). In this study, zone till (ZT) is considered as one of the many types of CT for row crops. The concept of ZT, strip tillage and band tillage (BT) are synonymous terms with CT (Mclaughlin, 2011). Fertilizer placement is the most important for efficient use and yield responses in CT. Trends in fertilizer consumption is highest in China than other countries. However, more fertilizer does not mean more profit. Manual fertilizer broadcasting is not uniform and unevenly distributed to the field which is a time consuming, unpleasant, arduous work and costly. Linquist *et al*. (2012) suggested for future work to investigate the deep fertilizer placement into the soil for the utilization and economic viability. The earlier findings indicated that applying fertilizer with floodwater for placement, covering and maintaining adequate soil barrier is little complex although fertilizer losses could be reduced (Khan *et al*., 1985), and interest in the application may be increased when the fertilizer prices are up day by day. Some prototypes have not been tested extensively and have not reached commercial production, also may not be suitable for CT system. The recent findings from pot study indicated that deep fertilizer placement reduced ammonia volatilization rate in transplanted rice than with direct seeding (Xu *et al*., 2013). Applying liquid fertilizers need high technical equipment which are expensive, complex to match fertilizer solution rate (kg ha$^{-1}$). However, experimental evidence on ZT with subsurface application of fertilizer for unpuddled transplanting rice in CT systems is still scarcely reported. Therefore, on these aspects and to address the issues on interacting machine-soil-plant-water-nutrient-economic for the desirability of alternative rice technology, the specific objectives of this study were: (1) to develop and evaluate a ZT with sub-surface row fertilizer applicator (2) to compare the field performances with TT under transplanted rice cultivation with regard to water saving, planting depth, soil temperature, crop growth rate, yield, partial unit production cost and NPK residual retention in the soil.

## Materials and Methods

**Development of the Applicator**

The applicator (**Fig. 1c**) was consisted of mainly three parts: (1) rotary blade arrangement (2) fertilizer metering devices and system, and (3) hoe type narrow opener.

***Rotary Blades Arrangement***

The C-type sharpened rotary blade was used. Six blades of 5 mm thick each blade per flange was arranged for desired ZT. Five sets of blades in one pass were implemented (**Fig. 1b**). Blades were oriented at 600 apart in the plane perpendicular to rotor shaft. The spacing between two rows adjacent blade sets was 16cm. The soil shield, cover guard and cover plate of flange was attached to give a fairly fine zone tilth, and proper backfill soils for favorable rice planting.

***Fertilizer Metering Devices and System***

The fertilizer unit consisted of a drive wheel, chain, sprockets, metering device, rotary shaft, adjusting meter, delivery tubes and fertilizer box (**Fig. 1a**). The common fluted roller fertilizer meter and plastic tubes were used. Total 10 fluted rollers were assembled on the shaft. The fertilizer rate on the fluted meter was adjusted relative to ground speed. A control handle adjusting meter was placed to the side of fertilizer box to handle the position and calibrated the fertilizer rate. The fertilizer box was fabricated to cover nearly the full width of the

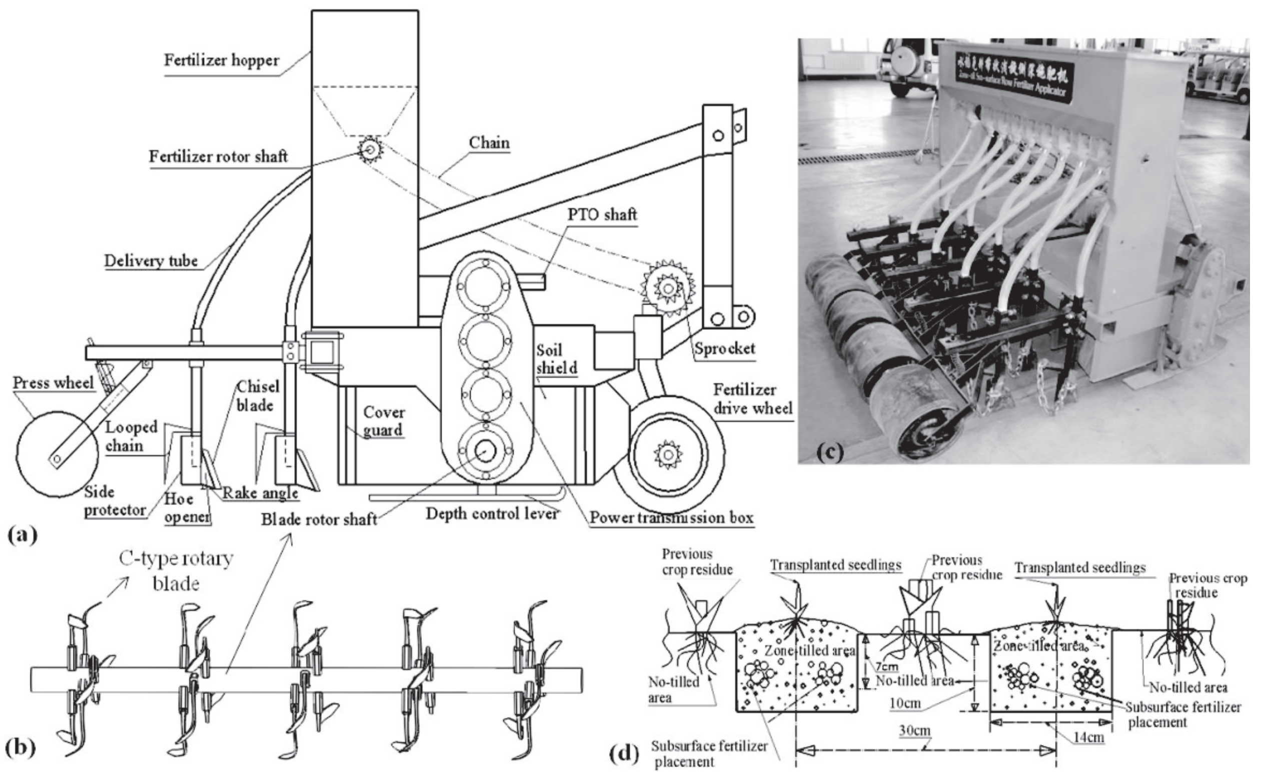


**Fig.1(a)** Schematic presentation of hoe opener with press wheel and ZT rotary blade assembly attached to tractor-mounted toolbar for vertical and horizontal separation of fertilizer placement into soil. **(b)** Schematic diagram of rotary blade arrangement, **(c)** Photographic view of newly developed ZT with subsurface row fertilizer applicator, **(d)** Schematic geometry and working principle of zone-till with subsurface fertilizer placement for unpuddled transplanting rice cultivation where 54 % of the field area is no-tilled and remained covered with protective residue while the planting zone is shallow zone tilled machine.

***Hoe Openers Arrangement***

The locally produced geometry of the narrow hoe opener was considered to construct the structure. The new opener was a straight axis, ending with a front of chisel cutting blade and rear side 3 cm wide and 10cm height (**Fig. 1a**). The chisel blade (1mm thickness) was attached in front of the opener to cut easily and prevent blockage. The opener front side was slightly angled (250) towards the direction of machine operation. Each opener was attached to an individual frame section that is attached to the machine's toolbar by a parallelogram linkage. Opener depth was changed by moving the opener up or down relative to the frame. Opener with looped chain furrow closer and fertilizer tube was attached to the flat shank.

***Working Principles of the Applicator***

The applicator (**Fig. 1c**) fabricated of the frame on which blade rotors and fertilizer meter were installed, and the frame on which hoe openers were attached. The frames were bolted together. The power from the tractor was transferred to the gear box via the power take off shaft that would drive the blade rotors via rotor shaft. Blade arrangement was attached in front of opener for ZT. When the machine was operated, rotary blade would cut and loosen soil at desired depth and width. The cutting depth was controlled by gauge levers mounted on both sides of the frame. The inter-row zone was left undisturbed and protected by previous residues (**Fig. 1d**). One pass process ZT with fertilizer was drilled into the soil uniformly with openers and soil packed to minimize fertilizer tie up with looped chain attached to the opener. The fertilizer shaft was operated at a constant speed by a drive wheel through roller chains and sprockets. This unit was adjusted and engaged or disengaged when the drive wheel was raised or lowered with the machine. The metal roller type drum wheel covered with plastic film used for pressing ZT area firming and leveling simultaneously.

***Experimental Site and Treatment***

The experiments were conducted at Harbin in north east of China in 2011 and 2012. The coordinates of the study site are 45048/N and 128052/E. The experiment was designed in strip plots with three replications; where treatment $T_1$: Inter-row ZT (14 cm width and 10 cm depth) +fertilizer placement nearly 7 cm below the soil surface by the newly developed machine (**Fig. 1c**) +unpuddled irrigation water+ transplanting in ZT area; treatment $T_2$: Dry tillage+ flooding irrigation+ manual broadcasting fertilizer+ puddling+ leveling (by indigenous machine) +transplanting. Seedling spacing was 30 × 15 cm. Unit plot size was 59 × 9 m, each levee was covered with10mm thickness plastic sheet to the total height of 35 cm, and 20 cm and 15 cm height was placed below and above the soil surface, respectively. The local recommended fertilizer dose (300 kg ha$^{-1}$) (N-$P_2O_5$-$K_2O$:13-18-15) was applied during land preparation. Two split broadcasting of prilled urea (60 kg ha$^{-1}$) was applied on 7 and 30 days after transplanting (DAT) for both treatments. Intermittent irrigation and PVC tubes method was followed for irrigation. Seedlings age and average height of the Chinese hybrid rice variety (Jia He no.1) was 30 days and 11.91 cm, respectively. After transplanting, all inter cultural practices were similar for both treatments.

***Observed Test Parameters***

The applicator was first tested in the workshop to examine the fertilizer uniformity rate and stability from the each opener. The tractor forward speed was measured. Vertical and horizontal fertilizer distribution uniformity was evaluated to determine the pattern of fertilizer drop into the soil at field conditions. Every 10 mm thick soil slices samples were collected one by one using soil cutting blade (1mm) to locate the trace of fertilizer in each soil slice using measuring scale. Standard deviation (SD), coefficient of variation (CV) and coefficient uniformity (CU) were determined according to Karayel and Ozmerzi (2007). Water requirement for wet land preparation was measured using water flow meter and saving of water was computed. Transplanted seedling depth was assessed by the following way:

$$P_{ad} = (\sum p_t - p_h) / n$$

Where, Pad is the average planting depth, Ph is the height of protruding length above the soil; Pt is the total length of seedling, n is the total number of measurement. Partial labor productivity and unit production cost was considered based on tillage, fertilizing and irrigation for wet land preparation. Crop growth rate (CGR) was taken for several stages and calculated as proposed by Akram (2011):

$$CGR = (W_2 - W_1) / (t_2 - t_1)$$

Where, $W_1$ is the first dry weight, $W_2$ is the second dry weight, $t_1$ and $t_2$ is the time interval days between first and second sampling. The dry weight of crop aboveground and root dry matter (g m$^{-2}$ D$^{-1}$) was observed (70° to constant weight) on 33, 63, 98 and 124 DAT from 9 hills in 90 × 45 cm under each treatment with three replications. At the same DAT, each 2 hrs interval from morning to evening (12 hrs) soil temperature was also recorded to 0-5 cm, 5-10 cm and 10-15 cm depth of soil by LCD long stem digital thermometer. Root samples were collected using core sampler (8 cm diameter) to a depth of 0-15 cm. Yield contributing characters were observed from randomly selected 9 hills from 18 hills and total yield was measured from 18 hills in each plot with three replications, and adjusted at 12 % moisture content. After harvesting the crop, soil samples were collected to 0-5.0, 5-10.0 and 10-15 cm depth of soil. Total N concentration was determined by Kjeltec auto system. Available P and K were measured by Mehlich 3 method using AA3 Continuous Flow Analytical System and UV-visible spectrophotometer atomic adsorption. Data were analyzed using SPSS17. Duncan's multiple range tests were used to identify significantly different means with dependent variable at $p \leq 0.05$.

## Results and Discussion

The variation of fertilizing stability and evenness between rows and openers is shown in **Table 1** and **2**, respectively. The uniformity of distribution rate of fertilizer was not significant ($P \leq 0.05$) among the rows. The average SD of fertilizing stability was 2.45 that varied from 2.09 to 3.31 (**Table 1**). The average evenness of CV was 2.39 with variation from 0.76 to 3.35 % (**Table 2**). The neglecting variation in the uniformity of fertilizer stability and evenness was occurred due to improper and non-uniform granular sizes of fertilizers, metering mechanism along the path of the machine and ground speed acquisition unit. Nevertheless, the variation was considered and coincided with results reported by Kim *et al.* (2008) and Honglei *et al.* (2007).

**Table 1** Variation of fertilizer stability between rows and openers

| | Operation speed (km h$^{-1}$) | Mean (g) | SD | CV (%) | Fertilizer rate (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| | 2.62 | 182.02 | 2.14 | 1.18 | 303.4 |
| | 3.58 | 179.06 | 2.09 | 1.17 | 298.4 |
| | 3.32 | 182.52 | 3.31 | 1.81 | 304.2 |
| | 3.1 | 178.02 | 2.27 | 1.28 | 296.7 |
| Average | 3.16 | 180.41 | 2.45 | 1.36 | 300.68 |

**Table 2** Evenness of fertilizer rate between rows and openers

| | Mean (g) | SD | CV (%) |
|---|---|---|---|
| | 89.13 | 2.08 | 2.33 |
| | 89.0 | 2.33 | 2.62 |
| | 92.13 | 0.70 | 0.76 |
| | 89.63 | 2.28 | 2.54 |
| | 90.10 | 3.02 | 3.35 |
| | 90.95 | 1.67 | 1.84 |
| | 90.65 | 2.78 | 3.07 |
| | 89.25 | 2.57 | 2.88 |
| | 91.33 | 1.24 | 1.36 |
| | 89.88 | 2.80 | 3.12 |
| Average | 90.20 | 2.22 | 2.39 |

**Table 3** abridges the vertical and horizontal placement fertilizer when used in the no-tilled field conditions. The average CV of the vertical placement was 7.15 % that varied from 6.53 to 8.28 %, and the CU was more than 95 %. The average CV of the horizontal spacing was 10.04 % with variation from 8.67 to 11.71 % and the CU of the horizontal separation more than 90 %. Closed uniformity of spacing to desired depth indicated that narrow width with cutting blade of the hoe opener presumably allowed quickly dropping of fertilizer almost at the same depth and was quickly covered by loosening soil into the furrow. Rear press wheel and depth control components also affected the distribution uniformity (Roufat and Mahboei, 2007).

Nearly 27.6 % water was saved in $T_1$ compared to $T_2$ (**Table 4**). More water was required in $T_2$ compared to $T_1$ due to excess puddling and leveling, evaporation, surface runoff and percolation and no residue on soil surface which supported by the report of Friedrich (2012). The mean seedling depth of $T_2$ was found significantly ($P < 0.01$) greater than $T_1$ (**Table 4**). The $T_2$ system created more puddled layer, dispersed the fine particles to the upper layer and the soil was transferred into flowing slurry during transplanting. Therefore, the observed results implied that intensive ploughing, puddling and levelling were not necessary for agreeable rice production (Qin *et al.*, 2010). In $T_1$, the partial labor productivity for wet land preparation was 63.6 % higher and input production cost was 64.9 % lower

**Fig. 2** Effect of treatment on soil temperature (ST) during different growth stages of rice

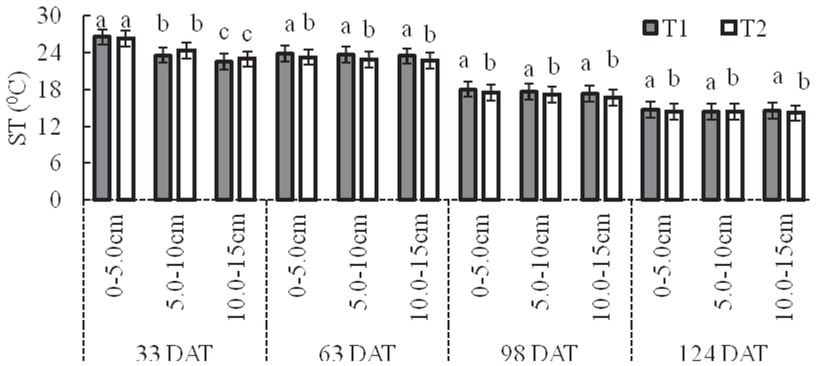

**Table 3** Equalization of vertical and horizontal placement separation of fertilizer spacing in zone-tilled area

| ZT rows | 1 | 2 | 3 | 4 | 5 | Average |
|---|---|---|---|---|---|---|
| Mean vertical depth (cm) | 7.20 | 7.42 | 7.26 | 7.36 | 7.48 | 7.34 |
| SD | 0.47 | 0.54 | 0.48 | 0.52 | 0.62 | 0.52 |
| CV (%) | 6.53 | 7.27 | 6.61 | 7.06 | 8.28 | 7.15 |
| CU (%) | 95.8 | 97.5 | 97.4 | 98.9 | 99.4 | 97.8 |
| Mean horizontal spacing (cm) | 10.14 | 10.95 | 10.50 | 10.56 | 11.09 | 10.64 |
| SD | 0.95 | 0.95 | 1.23 | 1.0 | 1.2 | 1.07 |
| CV (%) | 9.37 | 8.67 | 11.71 | 9.46 | 11 | 10.04 |
| CU (%) | 99.8 | 90.86 | 90.47 | 96.4 | 98 | 95.1 |

**Table 4** Effects of tillage on comparative water saving, transplanted seedling depth, partial labor productivity and unit input costs

| Treatment | Water saving (%) | Planting depth (cm) | Partial labor productivity (ha $d^{-1}$) | Partial unit cost (*Yuan $ha^{-1}$) |
|---|---|---|---|---|
| $T_1$ | 27.6 | 2.59a | 0.154 | 852 |
| $T_2$ | - | 3.57b | 0.056 | 2432 |

*US $1 is equal to 6.34 Yuan

**Table 5** Comparison of yield attributing characteristics

| Yield characteristics | $T_1$ | $T_2$ | P-value |
|---|---|---|---|
| Effective spike per hill | 21.33a | 19.1b | 0.01 |
| Spikelet per spike | 9.78a | 8.8ab | 0.07 |
| Effective gain per spikelet | 9.43a | 8.07b | 0.06 |
| Effective gain per spike | 91.30a | 71.53b | 0.01 |
| TGW | 26.5a | 25.9a | 0.48 |
| Total yield (kg $ha^{-1}$) | 10,443a | 9,648a | 0.174 |

than $T_2$ (**Table 4**) due to greatly decreasing the number of field operations from intensive to one, less uses of water, fuel, labor and reducing operating time and costs without compromising yield (Sorenssen and Nielsen, 2005).

The effect of treatments on ST had no significant in early stage of 33 DAT. The effect of depth had highly significant ($P < 0.01$) on 63, 98 and 124 DAT (**Fig. 2**). Average 0.3 °C ST was greater in $T_1$ than $T_2$ through the crop season due to desired soil loosening and less compact soil in zone-tilled area which increased air pockets and changed the air to soil particles, and heating air can enter quickly to the soil that enhanced the heating process (Sarkar and Singh, 2007).

**Fig. 3** Influence of tillage and fertilizer placement on crop growth rate (CGR) during different growth stages of rice

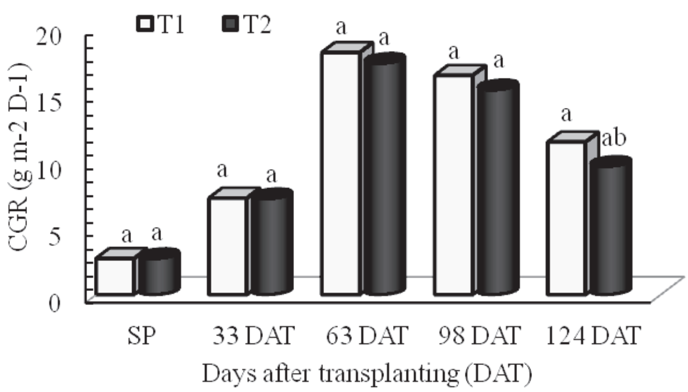


**Fig. 3** and **Table 5** present the crop growth performances and yield contributing related components. CGR had no significant ($P \leq 0.05$) between the treatments. On average CGR was greater by 7.1 % in $T_1$ than $T_2$ (**Fig. 3**) due to slightly warm soil conditions, root and crop growth development. Total crop yield was not influenced significantly ($P \leq 0.05$) by the treatments (**Table 5**). Total yield was greater by 7.6 % (on average) in $T_1$ than $T_2$. CGR and yield affected by the tillage and fertilizer placement which helps to increase the effective filled grain per spike and yield. The results are agreement with the findings of Jian (2010). Additional observations of crop lodging and soil crack were observed that were higher in $T_2$ at grain maturity stages which presumably detrimental effect of crop growth and yield.

**Table 6** shows the total N, available P and K retention in the soil. Total N, available P and K were not significantly influenced by the treatments, but the treatments resulted in slightly higher N, P and K in $T_1$ by 10.11, 6.78, 2.67 %, respectively, compared with $T_2$ due to reduce tillage, crop residue and subsurface fertilizer placement due to minimizing ammonia volatilization, leaching, runoff, and increasing residual

**Table 6** Influence of tillage and fertilizer placement on total N, available P and K residual retention in the soil

| Mean nutrient | Treatment | | P-value | Increased of $T_1$ over $T_2$ (%) |
|---|---|---|---|---|
| | $T_1$ | $T_2$ | | |
| Total N (g $kg^{-1}$) | 0.98a | 0.89a | 0.280 | 10.11 |
| Available P (mg $kg^{-1}$) | 14.49a | 13.57a | 0.802 | 6.78 |
| Available K (mg $kg^{-1}$) | 89.88a | 87.54a | 0.227 | 2.67 |

retention and favorable nutrient balances in the soil for greater plant stability and next succeeding crop cultivation (Peng *et al*., 2011).

## Conclusions

The study revealed that all parameters reached and met the agronomic requirements, and are in agreement with the related past research findings. The observation tests on the machine were primarily satisfactory. About 27.6 % water was saved and planting depth had significant in $T_1$ compared to $T_2$. This method is economically viable. Combined application of zone tillage with subsurface fertilizer placement increased ST, CGR, and yields compared with $T_2$. The residual retention of nutrients slightly increased in $T_1$. The short-term findings suggested that the new system could be used an alternative rice cultivation instead of traditional practices.

**Acknowledgements**

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# Determination of Spring Rigidity and Fruit Detachment force in Yomra Variety Hazelnut Trees

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## Abstract

The objective of this study was to determine Fruit Detachment Force/Fruit Weight (FDF/W) ratios of fruits and spring rigidities of Yomra variety hazelnut limbs. With this objective, changes in detachment forces and weights of fruits according to the maturity time of fruit ripening periods and changes in spring rigidities according to the limb diameters and limb connection points were determined. FDF/W ratios were found as 1.21-3.59 $Ng^{-1}$ on August 28th, 0.78-3.09 $Ng^{-1}$ on September 7th and 0.57-2.16 $Ng^{-1}$ on September 15th. Spring rigidities varied between 0.13-2.51 $Nmm^{-1}$ depending on increase in limb diameters and decrease in limb connection points.

***Key Words:*** Hazelnut trees, fruit detachment force, spring rigidity.

## Introduction

Hazelnut is one of the major agricultural products in Turkey. Hazelnut is mainly cultivated in Black Sea Region of Turkey and it has been reported that almost 600,000 tones of hazelnut per year is produced on 432,439 ha in Turkey. This amount is equal to nearly 70 % of total world hazelnut production (Anon, 2012). For harvesting this much of amount 306 LUH/ha (labour unit hour/hectare) are needed in Turkey. This amount stands for 71 % of total working time and 55 % of production costs. As usual the higher labour requirement increases the production costs, therefore, the labour costs must be decreased in hazelnut production. It is possible to decrease production costs by mechanization. In mechanical hazelnut harvesting, all of the fruits are dropped from the tree and then they are collected by picking machine (Beyhan, Yıldız, 1996; Yıldız, 2000). Hence, efficiency of mechanical harvesting depends on percentage of fruit dropped from the tree (Beyhan, 1996).

Mechanically shaking of trees is the most widespread harvesting technique. Both limb and trunk are being shaken. Limb shaking is slower, but the fruit removal is better (Lang, Z., 2008). The violence of forces produced by shaking exceeds the detachment force of the fruit; consequently the fruits are removed and fall to the ground (Erdoğan, 1988). In mechanical fruit harvesting with shaker, the efficiency depends on the shaking parameters such as frequency, amplitude, shaking direction and limb connection point (Tuncer, Özgüven, 1989).

Dynamic characteristics of limbs are required to be known for designing of an appropriate shaker. The most important of these characteristics is the spring rigidity which is defined as the ratio of the applying force to the displacement of limb (Gezer, 1999; Civil, Hacıseferoğulları, 2010). Spring rigidity affects the amplitude, frequency, dissemination and resonance of shaking force (Tuncer, Özgüven, 1989). Spring rigidity, which might vary according to the distance between limb connection points and stem or limbs, increases with decreasing distance between limb connection points and stem. Furthermore, shaking frequency increases with increase in spring rigidity. Spring rigidity of limbs is used for calculation of shaking frequency (Lenker, Hedden, 1968).

Variation in the Fruit Detachment Force/Fruit Weight (FDF/W) ratio is considered as one of the most important factors affecting efficiency of shaker in mechanical harvesting of fruit trees (Beyhan, 1996). FDF/W ratio has a significant effect on rate of fruit removed from the limb by shaking. FDF/W ratio decreases with increasing maturity time thus fruit falls to the ground easily (Erdoğan 1988; Beyhan 1996). In other words, FDF/W ratio is considered as a criterion on whether fruits are easy or difficult to detach (Keçecioğlu, 1975).

Some studies have been conducted on spring rigidity and FDF/W ratio at some fruit trees. Polat and Ülger (2000) determined the FDF/W and limb spring rigidity of pistachios. The FDF/W ratio and spring rigidity values were found to vary among 346.03 and 52.67 $Ng^{-1}$ and 219.38 and 416.41 $Ncm^{-1}$ for some varieties of pistachio. The FDF/W ratio values for different hazelnut varieties (Palaz, Tombul, Sivri and Kalınkara) were found as 82.99, 65.75, 92.05 and 72.62 $gfg^{-1}$ respectively (Beyhan, 1996). For almond tree, FDF/W ratio values varied from 1.39 to 4.53 $Ng^{-1}$ with the mean value of 2.42 $Ng^{-1}$ during the harvesting season (Loghavi *et al.* 2011). In another study conducted with apricot, spring rigidity was found between 58 and 200 $kpcm^{-1}$ according to the age of the tree and 31 to 238 $kpcm^{-1}$ according to the limb diameter (Gezer, 1999). For plums, FDF values and limb spring rigidities were found as 6.40 and 12.67 N and 151.72 and 326.10 $Ncm^{-1}$ for Angeleno and President varieties, respectively (Civil, Hacıseferoğulları, 2010).

This study was conducted to determine the limb spring rigidity and FDF/W ratio values in Yomra hazelnut variety.

## Materials and Methods

Experiments were conducted between August 28th, 2010 and September 15th, 2010 in a private farm in Emiryusuf village of Çarşamba town in Samsun, Turkey. (**Fig. 1**). Yomra variety was used as research material. Some characteristics of hazelnut orchard are given in **Table 1**.

FDF values were measured with a force gauge (MACRONA, capacity: 500 N, resolution: 0.1 N). A special apparatus, which can hold the fruits, was attached to the measuring end of the force gauge with the aim of measuring FDF of fruits. An increasing force was applied to the fruit in direction of its stem up to time it (fruit) was detached. Maximum FDF value at the separating moment was read from the scale indicator. The weights of detached fruits (W) were determined with an electronic scale (measuring range: 2 kg, 0.01 g division). FDF/W ratio

**Fig. 1** Hazelnut orchard

**Table 1** Characteristics of hazelnut orchard

| | |
|---|---|
| Orchard establishment age (year) | 10 |
| Orchard area (da) | 11 |
| Planting system | Brush (in Turkish ocak) |
| In and between row spacing (m × m) | 6 × 3 |
| Average limb number | 13 |
| Average limb length (mm) | 298 |
| Average orchard yield (kg/da) | 180-200 |

**Fig. 2** Change in FDF/W ratio depending on maturity time of fruit ripening period in Yomra variety

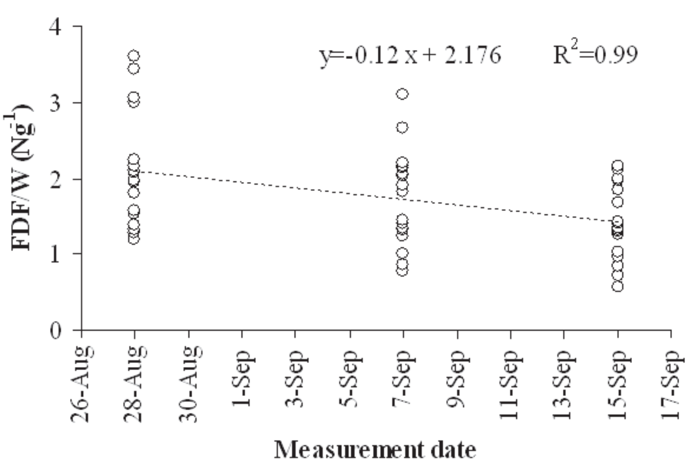



**Table 2** Spring rigidities and Standart Deviations of Yomra hazelnut variety

| Mean diameter of limbs (mm) | Limb connection points (mm) | Spring rigidity ($Nmm^{-1}$) |
|---|---|---|
| 22.21 | 2000 | 0.14 ± 0.01 |
| | 1500 | 0.42 ± 0.02 |
| | 1100 | 0.66 ± 0.05 |
| 25.88 | 2000 | 0.18 ± 0.01 |
| | 1500 | 0.70 ± 0.05 |
| | 1100 | 1.23 ± 0.04 |
| 32.53 | 2000 | 0.38 ± 0.04 |
| | 1500 | 1.06 ± 0.02 |
| | 1100 | 2.32 ± 0.16 |

values were determined by using these values. FDF measurements were made at three maturity time of fruit ripening periods (August 28th, September 7th, and September 15th, 2010) with 20 replications.

This force gauge was also used for determining the pull force of hazelnut tree limbs. Limbs were pulled perpendicular to their axes at the 40, 60, 80, 100, 120, 140, 160 mm and 1100, 1500 and 2000 mm heights from the orchard ground and then maximum pulling forces were recorded. Limb diameters at these connection points were measured with digital caliper. The calculated force (F) values and displacement of limb (x) were used in the equation below and spring rigidities were determined (Gezer, 1999).

$C = F / x \ (Nmm^{-1})$

Where;

$C$: Spring rigidity ($Nmm^{-1}$),

$F$: pulling force (N),

$x$: Displacement quantity of limb (mm).

## Results and Discussions

The results showed that maturity time of fruit ripening time had significant effects on the FDF values of fruits. The change of FDF/W ratio values depending on maturity time of fruit ripening period in Yomra variety is given in **Fig. 2**.

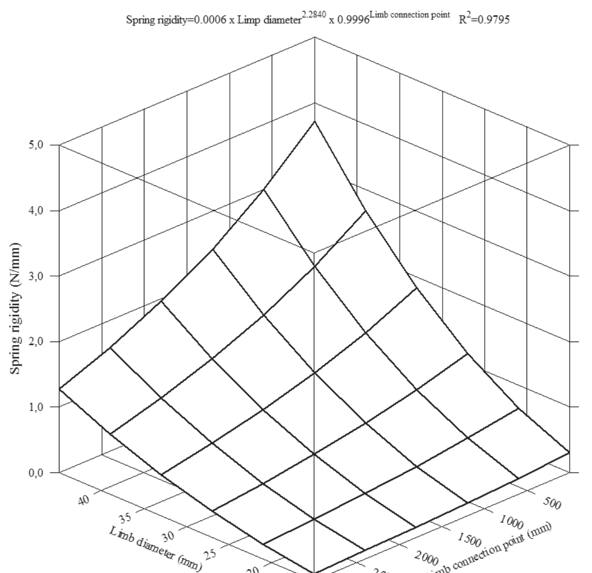
As seen in **Fig. 2**, FDF/W ratios of fruits changed with wide limits. Also, the increase of maturity time of fruit ripening periodindicates that husky hazelnut fruits can be easily removed from the layer of rupture (Beyhan, 1996). FDF/W ratio values were found as 1.21-3.59 $Ng^{-1}$, in August 28th, 0.78-3.09 $Ng^{-1}$ in September 7th and 0.57-2.16 $Ng^{-1}$ in September 15th, 2010. These results are consistent with results from some previous literatures (Keçecioğlu, 1975; Beyhan, 1996; Polat *et al.*, 2011). Average FDF/W ratio values decreased with increasing maturity time of fruit ripening period. Husky hazelnut fruits join the limb with a thick stem. Higher forces are needed initially to detach the husky hazelnut fruits. The situation in question is said to be due to immature detached layer by August 28th and weak detachment force applied onto separating layer, which was still flexibly linked to the maturity level of the fruits. It is seen that, during August 28th, the stem and fruit limbs connecting the husky hazelnut did not cause a complete separation layer; husky hazelnut to be more flexible depending on the state of maturation of stem breakage, can be said to be due to less force acting on the layer. Husky hazelnut and attached stem lose moisture and become reddish when matured, and consequently stem lose its flexibility (Beyhan, 1996).

Spring rigidity values depending on limb diameters and limb connection points (**Table 2**) and changes in coefficient of spring rigidity with limb diameter and limb connection points (**Fig. 3**) showed that spring rigidities were changed within large limits.

Increases in limb diameters and decreases in limb connection points increased average limb spring rigidities. The spring rigidity values as depending on average limb diameters were found 0.14, 0.42, 0.66 $Nmm^{-1}$ for average diameter group of 22.21 mm at limb connection points of 2000 mm, 1500 mm 1100 mm, respectively. The other spring rigidity values for average diameters group of 25.88 and 32.53 mm were also measured as 0.18, 0.70, 0.23 $Nmm^{-1}$ and 0.38, 1.06, 2.32 $Nmm^{-1}$ at the same limb connection points, respectively. Ranges between spring rigidities at the lowest parts of limbs with different diameters are higher, but ranges are narrowed at the upper parts of the limbs. This finding is confirmed by studies conducted with other some fruit trees (Keçecioğlu, 1975; Beyhan, 1996; Gezer, 1999; Polat *et al.*, 2011).

Trees are dynamic structures which can give different responses against various forces formed by complex movements when they are shaken. For this reason, these different responses given by trees depend on some characteristics (damping, hardness, mass etc.) of different tree parts as well as magnitude and distribution of force. Vibration event is

**Fig. 3** Changes in coefficient of spring rigidity depending on limb diameter and limb connection points



determined by the natural frequencies and the dynamic properties of limbs. Mass distribution of tree, which varies according to the growing type of tree, has a significant role in its dynamic characteristics. Such parameters as ripening index and FDF are required to be known for determining most appropriate mechanical harvest period. Different maturity time of fruit ripening periods can be seen even within the same fruit varieties.

In conclusion, the fruit trees are planted with different growing methods in all around the world. Naturally, this leads to some differences in harvesting technologies and equipment in practice. Therefore, it is important to determine the particular problems and their solutions. Finally, it is essential to define the most optimal parameters prior to the mechanical harvesting in terms of agricultural mechanization.

**Acknowledgements**

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# Studies on Effectiveness of Electrostatic Spraying for Cotton Crop


by

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## Abstract

Evaluation of an electrostatic sprayer was conducted 75 Days after Sowing (DAS) of the cotton crop, when there was full coverage of the canopy over the ground. Different spray parameters are spray deposition, droplet density and size, spray loss/drift and bio-efficacy of the sprayer were measured under field condition and contrasted with the performance of a conventional knapsack sprayer. The statistical analysis was done by using SAS 9.3 software. It was found that spray deposited over the top, middle and lower level of the plants by electrostatic sprayer was 34.8, 57.1 and 38.6 % higher as compared to the knapsack sprayer respectively. Similarly, spray deposition on the underside of leaves of the top and middle of the plant by electrostatic sprayer was 77.6 and 61.5 % higher as compared to knapsack sprayer respectively. The droplet density of the upper and under sides of leaves by electrostatic sprayer was significantly ($p = 0.0001$) higher than knapsack sprayer by 90.4 and 95.7 % respectively. The ground loss for electrostatic sprayer was significantly ($p = 0.0001$) less than knapsack sprayer by 62.4 %. The vertical loss for electrostatic sprayer was significantly ($p = 0.0001$) less than knapsack sprayer by 69.4 %. It was also observed that insects killed during spraying by an electrostatic sprayer were 85.3 % and that by the knapsack sprayer 66.6 % in 48 hours after spraying. Overall, the results showed that the performance of an electrostatic sprayer was distantly better than the conventional knapsack sprayer.



***Key Words*:** Electrostatic spraying, Droplet Density, Bio-efficacy, Drift losses.


## Introduction

Cotton is an important cash crop of India grown in approximately 9 million hectares by over 40 million farmers (Majumdar, 2010). It accounts for about 5 percent of the total cultivated area. Of the total pesticide uses, nearly 50 percent is used for cotton alone. Knapsack sprayers are widely used for applying pesticides and plant growth regulators. More than 90 % of these pesticides are applied by hydraulic sprayers especially knapsack sprayers (Lalitha, 2008). This method is simple but has several disadvantages. Spray distribution is poor and labour costs are high. More than 80 % of pesticides are deposited on the ground by using these sprayers (Zhou & He, 2010).

Electrostatic spraying technology is an established technology for spraying chemicals. It is considered to be simple, safe, and easy to use along with minimum spray loss deposition characteristics of spray are better from environmental pollution point of view apart from effectiveness (Elmoursi; 1992). Charged spray particles have reduced the drift by about 40 % by using an electrostatic hydraulic nozzle (Sharp, 1984). The reduction in drift is due mainly to higher electrostatic force leading to smaller droplets as compared to the gravitational force. For electrostatic spraying, the average cumulative mortality of pests is 94.5 % as compared to an average cumulative mortality of 76.7 % with the conventional sprayer (Zhou *et al*., 2009). Reduction in spray volume from 250 to 1 l/ha did not alter the bio-efficacy in electrostatic spraying (Hislop *et al*., 1983).

Hence, electrostatic spraying technology scores higher over the conventional spraying technology in respect of spraying efficiency with low spraying cost. Electrostatic spraying technology has so far been used mainly for orchard & green houses. But it has not been adopted so far for broad-leaf crops like cotton. Hence, the present study was undertaken to evaluate the performance of an engine operated electrostatic sprayer on the cotton crop.

## Materials & Methods

### Electrostatic Sprayer Used

An electrostatic sprayer (Make ESS, USA) powered by a 6.5 hp engine with an on-board compressor and spray gun (**Fig. 1**) was used in the study. For charging the spray particles in the nozzle, two 9 V rechargeable batteries have been provided. The nozzle assembly was located at the end of the spray gun wand. The spray gun was hand triggered by the operator during spraying. Air and liquid entered separately at the rear of the nozzle. Just before leaving the nozzle, the air hit the liquid stream to atomize it into spray droplets that passed through the charging ring.

Electric charge is applied to the spray particles by the charging the ring (**Fig. 2**). The charged spray particles are blown out of the nozzle and moved into the plant canopy, where these get attracted to plant leaves & foliage by the electrostatic force. The negatively charged droplets attracted by the positively charged leaf surface. The charged spray particles bend the underside of the leaf surface upward (**Fig. 3**).

### Field Evaluation Protocol

Electrostatic sprayer was evaluated on cotton crop (variety MRC 6303) grown at the Research Farm of Department of Farm Machinery & Power Engineering, Punjab Agricultural University, Ludhiana (India). Row to row and plant to plant spacing for the crop were 90 and 75 cm respectively. Evaluation of the sprayer was done at 75 Days after Sowing (DAS) of the crop, when there was full coverage of the ground by plant canopy. Various parameters were measured during the evaluation of the electrostatic sprayer and compared with hydraulic knapsack sprayer. Knapsack sprayer (Make ASPEE) manually operated with average working pressure 350 kPa and minimum discharge rate 550 ml/min was used. All the experiments were replicated three times. Following instruments/equipments were used for measuring various parameters; listed in **Table 1**.

**Table 1** Instruments used for measuring various parameter

| Parameter | Instrument |
|---|---|
| Parameter | Instrument |
| Transmittance | UV-VIS Spectrophotometer (190 to 1100 nm) |
| Spectral reflectance | Spectral tester (650-960 nm) |
| Average diameter (micron) | Droplet analyzing system (microscope, CCD camera, PC and a monitor) |
| Optical density | UV-VIS Spectrophotometer (190 to 1100 nm) |

### Spray Deposition

Spray deposition was used as the measure for spray coverage and penetration on crop canopies by using both the sprayers. Two methods selected to measure the spray deposition were Leaf Wash Method & Spectral Reflectance Method.

In the *leaf wash method*, cotton plots were sprayed with Methylene blue dye. Leaves from the top, middle and bottom of the plants were picked from the sprayed areas randomly. Within 24 hour dye residues were washed with 40 mL of methanol from the upper and underside of the leaves with a dual-side leaf washer (Gupta & Duc 1996). A UV-VIS spectrophotometer (190 to 1,100 nm) was used for measuring transmittance and optical properties within visible spectral range of electrostatic spray deposition. The transmittance through washed solutions from leaves with known deposits of dye had logarithm relationship with the amounts of dye deposited (**Fig. 4**). Dye solutions washed from the top and undersides of the leaves evaluated for transmittance with a UV-VIS spectrophotometer and compared with a calibration from known washed deposits to determine dye deposition for both leaf sides along with location within the plant canopy.

In spectral reflectance method, cotton crop

**Fig. 1** Engine operated Electrostatic sprayer

**Fig. 2** Charging Method

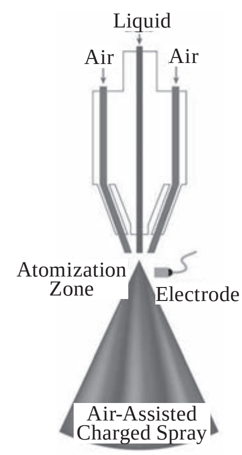
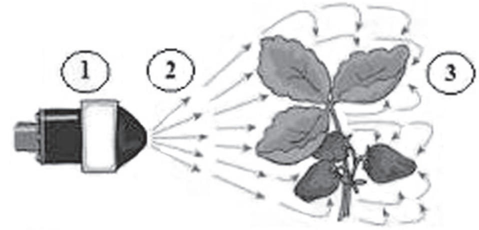



**Fig. 3** Electrostatic Spraying to the Plant




1. Nozzle, 2. Spray Particles, 3. Plant Canopy

was sprayed by using Methylene blue dye. After spraying the leaves, the dye was collected from the top, middle and bottom heights of the plants. Within 24 hour the spectral reflectance was measured by using a Spectral tester (Make YARA) having the spectral range of 650-960 nm. The spectral reflectance of sprayed leaves was compared with that of the spectral transmittance of un-sprayed leaves.

### Measurement of Droplet Density and Size

Water-sensitive papers (cards 76 × 26 mm) were attached on the upper and under side of the leaves at three different heights of cotton canopy (Top, middle and bottom) (**Fig. 5**). After the spray, the cards (60 samples) were collected and placed into Zip-Lock® bags. The cards were evaluated for percentages of card area covered with spay patches and its diameter. Spray coverage and size distribution of spots on the cards were determined by using droplet analyzing system (Make Radical Scientific Equipments). Average diameter of each droplet and its density were calculated. The droplet analyzing system consisted of a microscope, CCD camera, PC and a monitor to control the analyzed image. The software used to analyze the droplets was USB digital scale.

### Spray Loss/Drift

Drift is the carrying away of spray particles by wind stream during and after application. In general, spray particles of all size classes are capable drifting away from target. However, the smallest particles move the farthest before setting on to the ground (Allan & Felsot, 2005). Spray loss measurements were carried out by using Methylene blue dye and placing the collectors outside the field. Ground loss was measured by horizontal collectors placed at a distance of 50, 100 & 200 cm from the last cotton row (**Fig. 6**). Vertical loss was measured on vertical collectors placed at heights of 50, 100 & 150 cm at 100 cm distance from last row. Collectors were made of synthetic clothe (Technofil TF-290) with dimensions of 50 × 10 cm for measurement of ground loss and 100 × 10 cm for measurement of vertical loss. After spraying, within 24 hour the dye was extracted from the collectors by using 50 ml of Methanol. The optical density of the solution was measured by UV-VIS spectrophotometer (nm) and compared with optical density of known solution.

### Bio-efficacy of Sprayer

Bio-efficacy is a measure of pest mortality and diseases control. An experiment was conducted in the field to evaluate the bio-efficacy of both the electrostatic and conventional knapsack sprayer. Three replications by selecting an area of 5 m × 5 m each were used for the experiment. An area 5 m × 5 m was selected as a block. Imidacloprid 200 SL (CONFIDOR) insecticide 42 ml/acre was sprayed with an electrostatic and knapsack sprayer. Observations on numbers of insects (Jassids, Scientific name: Amrasca devastans and whitefly, Scientific name: Bemisia tabaci Genn) in the selected area were recorded before and 48 hrs after application of the pesticide (**Fig. 7**). The average values of these observations were taken to assess the overall impact on pest suppression and mortality.

### Statistical Analysis

The factorial experiment was conducted using randomized block design. General Linear Model (GLM) procedure was used for statistical analysis with the help of SAS 9.3 software. Tukey method was used for multiple comparisons

**Fig. 4** Relationship between transmittance and percent dye concentration in Methanol

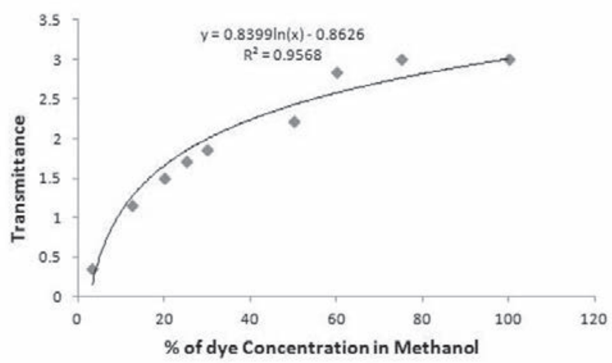



**Fig. 5** A view of water sensitive paper stapled on to cotton canopy

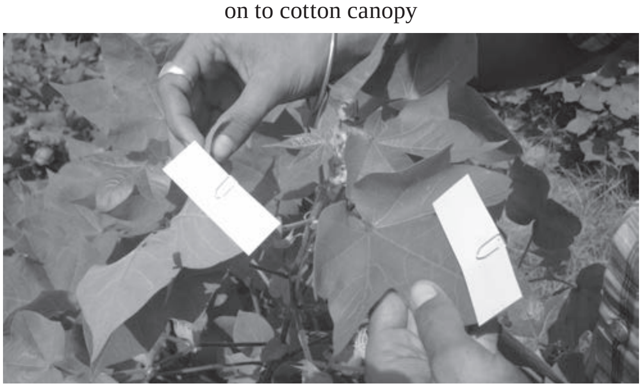
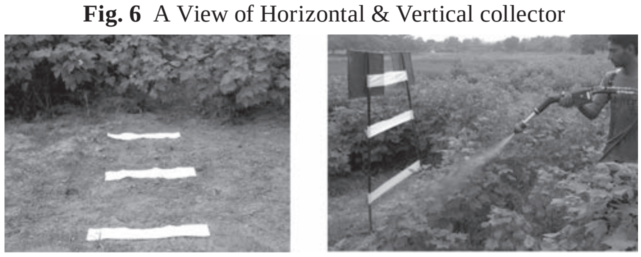


**Fig. 6** A View of Horizontal & Vertical collector



of variables. Least Squares Means and probability (p) values were calculated for comparison of sprayers electrostatic and knapsack sprayer variables. The p values of different parameters are shown in **Tables 2** and **3**.

## Results and Discussion

### Spray Deposition

***Leaf Wash Method***

The results of spray deposition measured by leaf wash method are depicted in **Fig. 7**. Spray deposited by the electrostatic sprayer was 80.6, 42.4 and 17.8 % on upper side of the leaves respectively at the top, middle and bottom levels of the plants. Spray deposited by knapsack sprayer was 54.9, 13.3 and 4.9 % at the top, middle and bottom levels of the plant on upper side of the leaves respectively. Spray deposited by electrostatic sprayer was 19.9 and 10.1 % observed at the top and middle levels of the plants at underside of the leaves respectively. Spray deposited by knapsack sprayer was 4.5 and 3.9 % observed at the top and middle levels of the plants on the underside of the leaves respectively. The spray deposited at the top, middle and bottom levels of the plants by electrostatic sprayer was significantly higher than knapsack sprayer by 31.8, 68.7 and 72.6 % respectively. Similarly, spray deposited on the underside of top and middle levels of the plant leaves by electrostatic sprayer was 77.6 and 61.5 % more as compared to knapsack sprayer respectively. But there was non-significant difference (p = 0.2059) for spray deposited at underside leaves attached at middle level of the plant. The overall results revealed that spray deposited on the upper and under sides of leaves by electrostatic sprayer was significantly (p = 0.0001) higher than knapsack sprayer by 48.1 and 72.2 % respectively.

***Spectral Reflectance Method***

The results of the spray deposition measured by spectral reflectance method are shown in **Fig. 8**. The spray deposits by both sprayers on the plant leaves decreased at different levels of the leaves from top to bottom levels of the plants. Spray deposited by electrostatic sprayer was 64.9, 52.2 and 13.2 % observed at the top, middle and bottom levels of the plant leaves respectively. Spray deposited by knapsack sprayer was 42.4, 22.4 and 8.1 % at the top, middle and bottom levels of the plant leaves respectively. The spray deposited at the top, middle and bottom levels of the plants by an electrostatic sprayer was significantly higher than knapsack sprayer by 34.8, 57.1 and 38.6% respectively. The overall results revealed that spray deposited on the leaves by electrostatic sprayer was significantly (p = 0.0001) higher than knapsack sprayer by 44.1 %.

### Droplet Density and Size

***Droplet Density***

The results of droplet density measured by water sensitive paper are shown in **Fig. 9**. The statistical analysis showed that there was significant difference at 1 % level of significance for the droplet density at the top, middle and bottom levels of the plants between both of the sprayers' except at the underside leaves attached at bottom level of the plant. The droplet density measured in the laboratory on the upper side of top, middle and bottom leaves were 472, 364 and 324 drops/cm$^2$ respectively for the electrostatic sprayer. The droplet densities for knapsack sprayer on the upper side of top, middle and bottom leaves were 50, 32 and 29 drops/cm$^2$ respectively. On an average, only 14 drops/cm$^2$ were observed at the underside of top, middle and bottom leaves for knapsack sprayer, but the electrostatic sprayer deposited 411, 310 and 195 drops/cm$^2$ at the underside of top, middle and bottom leaves respectively. The overall results revealed that on an average, droplet density of the upper and under sides of leaves by electrostatic sprayer was significantly (p = 0.0001) higher than knapsack sprayer by 90.4 and 95.7 % respectively.

***Droplet Size***

Sprayer performance based upon the droplet size on water sensitive paper is depicted in **Fig. 11**. As evident, the maximum droplets, i.e. 87

**Fig. 7** Spray deposition in Leaf Wash method

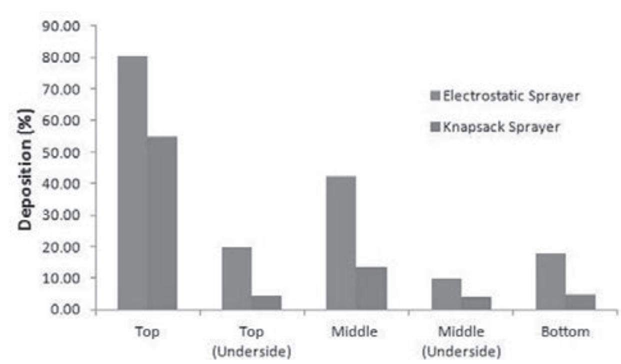
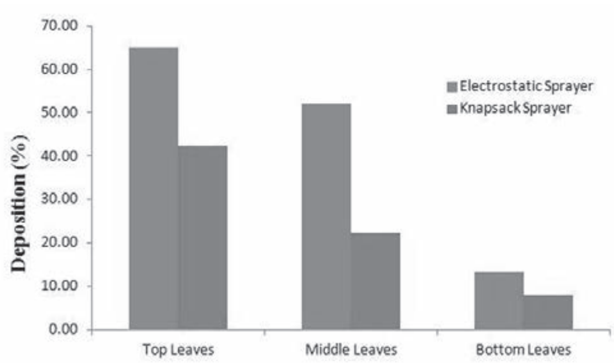



**Fig. 8** Spray deposition in spectral reflectance method



numbers were of size 40 microns observed for the electrostatic sprayer. The droplet size for 99 percent droplets were below 120 micron for electrostatic sprayer, but in case of knapsack sprayer, the maximum droplets, i.e. only 10 number of drops were of 240 microns and the broader droplets were observed in the range of 40 to 340 microns.

**Table 2** P Value of comparison between electrostatic and knapsack sprayers for droplet density and deposition

| Place | Droplet Density | Deposition | |
|---|---|---|---|
| | | Leaf Wash Method | Spectral Reflectance Method |
| Top | 0.0001 | 0.0001 | |
| Top (Underside) | 0.0001 | 0.0006 | 0.0007 |
| Middle | 0.0004 | 0.0001 | 0.0004 |
| Middle (Underside) | 0.0017 | 0.2059 | |
| Bottom | 0.0001 | 0.0024 | 0.0008 |
| Bottom (Underside) | 0.1457 | ------- | |
| Average | 0.0001 | 0.0001 | 0.0001 |

**Table 3** P Value of comparison between electrostatic and knapsack sprayers for horizontal and vertical loss

| Distance | Horizontal Loss | Height | Vertical Loss |
|---|---|---|---|
| 50 | 0.0001 | 50 | 0.0001 |
| 100 | 0.0001 | 100 | 0.0001 |
| 200 | 0.0001 | 150 | 0.0001 |
| Average | 0.0001 | Average | 0.0001 |

## Drift/Spray Loss

### *Horizontal (Ground) Loss*

The evaluation of total ground loss percent at different distances, i.e. 50, 100 and 200 cm is shown in **Fig 11**. It was also observed that electrostatic sprayer had less ground loss as compared to the knapsack sprayer at all distances. Ground loss of electrostatic sprayer was 14.8, 8.52 and 6.4 % at 50, 100 and 200 cm distances respectively. Ground loss of knapsack sprayer was 43.1, 20.9 and 15.2 % for the same distances respectively. The ground loss at distances 50, 100 and 200 cm by an electrostatic sprayer was observed to be 65.6, 59.1 and 57.8 % less as compared to knapsack

**Fig. 9** Droplet density on water sensitive paper

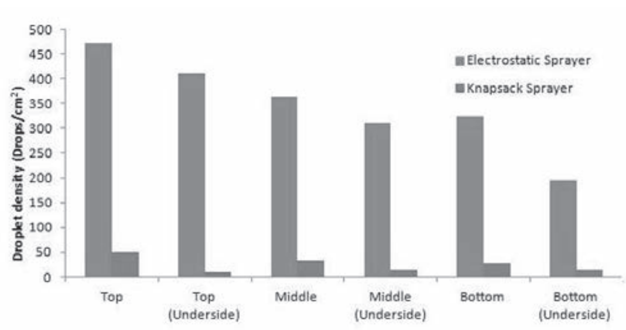



**Fig. 10** Sprayer Performance in water sensitive paper

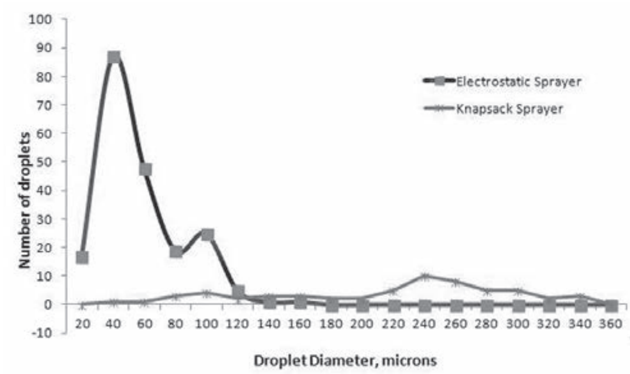



**Fig. 11** Horizontal ground loss

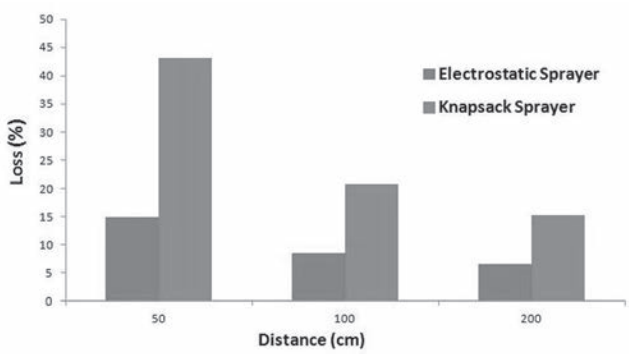
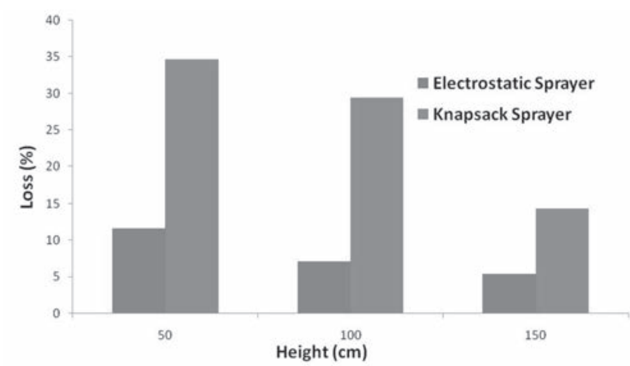



**Fig. 12** Vertical ground loss



sprayer respectively. The results showed that ground loss for electrostatic sprayer was significantly (p = 0.0001) less than knapsack sprayer by 62.4 %. It may be due to the larger electrostatic force present on smaller droplets as compared to the gravitational force.

***Vertical Loss***

The evaluation of total vertical loss percent at different plant heights, i.e. 50, 100 and 150 cm is shown in **Fig. 12**. It was also observed that electrostatic sprayer had less vertical loss as compared to the knapsack sprayer. Vertical loss of electrostatic sprayer was 11.5, 7.1 and 5.4 % observed at 50, 100 and 150 cm height above the ground respectively. Vertical loss of knapsack sprayer was 34.7, 29.4 and 14.3 % observed at 50, 100 and 150 cm height respectively. The vertical loss at heights of 50, 100 and 150 cm by an electrostatic sprayer was 66.7, 75.9 and 62.6 % less as compared to knapsack sprayer respectively. The results showed that vertical loss for electrostatic sprayer was significantly (p = 0.0001) less than knapsack sprayer by 69.4 %.

### Bio-Efficacy of Sprayer

Bio-efficacy of a sprayer is specified in terms of insects mortality for a given crop. The insects killed by spraying by an electrostatic sprayer were 85.3 % in 48 hours after spraying (**Table 4**). The insects killed by a knapsack sprayer were 66.6 %. The results showed that insects killed by an electrostatic sprayer were significantly (p = 0.0047) higher than knapsack sprayer by 22 %.

**Table 4** Insects mortality of sprayers

| Sprayer | Avg. No. of Insect Before Spraying | Avg. No. of Insect left After Spraying | Insect mortality % | p Value |
|---|---|---|---|---|
| Knapsack Sprayer | 487 | 162 | 66.6 | |
| Electrostatic Sprayer | 538 | 81 | 85.3 | 0.0047 |

## Conclusions

The following conclusions are drawn from the study:

- The statistical analysis showed that there was significant difference at 1% level of significance for all the parameters between electrostatic and knapsack sprayers.
- In the leaf wash method, the results showed that on an average, spray deposited on the upper & under sides of leaves by an electrostatic sprayer was 48.1 and 72.2 % higher as compared to the knapsack sprayer.
- In spectral reflectance method, the results showed that on an average, spray deposited on the leaves by an electrostatic sprayer was 44.1 % higher as compared to the knapsack sprayer.
- The droplet density of the upper and under sides of leaves by electrostatic sprayer was 90.4 and 95.7 % higher than that of the knapsack sprayer respectively.
- The results showed that, on an average, ground loss for an electrostatic sprayer was 62.4 % lesser as compared to the knapsack sprayer. It can be attributed to larger electrostatic charge held on smaller drops as compared to the gravitational force.
- The results showed that, on an average, vertical loss for an electrostatic sprayer was 69.4 % lesser as compared to the knapsack sprayer.
- It was observed that insects mortality by spraying with an electrostatic sprayer was 22 % more as compared to the knapsack sprayer


### Acknowledgements

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# Need of Ergonomically Mechanized Interventions in Selected Farm Operations in Hills of Himachal Pradesh


by

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## Abstract

Himachal Pradesh, a mountainous state of India where 71 % of the population depends on agriculture and horticulture, located on a sloping terrain of great Himalayas with snow clad mountains, rolling hills and valleys. Elevation of the state widely ranges from 350 m to 6,975 m above mean sea level. The major agricultural crops grown in the state are maize, paddy, wheat, potato, barley and horticultural crops are apple, citrus and nut & dry fruits. The state produced around 6 lakh tonnes of apple per annum, accounting for more than 80 percent of the total fruit production of the state. The undulating topography and small-sized terraced fields with high vertical intervals are the major constraints in adoption of modern agricultural & horticultural equipment prevalent in the plains. Small and marginal farmers dominate in the state having average land holdings 0.6 ha. At present power availability per hectare in the state is about 0.6 kW/ha out of which about 80 % came from animate power. The use of mechanical power source like tractor and power tiller is on limited scale in some plain and valley areas. Women participation in most of the farm operations is in the


**Fig. 1** Agro-climatic zones of Himachal Pradesh


**Table 1** A view of four agro-climatic zones of Himachal Pradesh

| Particulars | Overall view | Agro-climatic zones | | | |
|---|---|---|---|---|---|
| | | Sub montane and low hills sub-tropical | Mid hills sub humid | High hills temperate wet | High hills temperate dry |
| Geographical area, 000 ha | 5567.3 | 913.2 (16.4 %) | 1,183.2 (21.3 %) | 1,280.9 (23.0 %) | 2,190.6 (39.0 %) |
| Total cropped area, 000 ha | 956.8 | 335.1 (38.0 %) | 383.4 (41.0 %) | 171.8 (18.4 %) | 24.3 (2.6 %) |
| Elevation (amsl), m | - | < 650 | 651-1,800 | 1,801-2,200 | > 2,201 |
| Irrigated area, % | 101.9 | (16.6 %) | (17.3 %) | (7.8 %) | (10.6 %) |
| Rainfall, mm | - | 1000 | 1500-3000 | 100 | 250 |
| Field crops | - | Wheat, Maize, Rice, Pulses | Rice, Wheat, Maize, Barley, Pulses | Wheat, Maize, & Potato | Barley, Potato & Wheat |
| Fruit crops | - | Subtropical fruits. | Apple, Other temperate fruits, Stone fruits, Nuts, Mango & Litchi | Apple, Other temperate fruits & Nuts | Nuts, Dry fruits & Apple |

range of 50-80 %. The agricultural operations such as clod breaking, transplanting/sowing, weeding, harvesting, threshing/shelling, transportation all requires ergonomic intervention as these are mostly done by women with traditional tools. The horticultural operations such as land preparation, pit digging, pruning, plucking/harvesting and material handling are also being done manually with age old tools. These operations are resulting in lot of drudgery and increased cost of operation with very low productivity.

So, there is an urgent need to study these operations ergonomically so that the drudgery involved could be minimised with enhanced productivity by introducing/providing some improved tools or job aids.

## Introduction

Himachal Pradesh is a small hill state of India located in the western Himalayas situated between 30.3 and 33.3º North Latitude and 75.3-79.0º East Longitude. The elevation of the state widely ranges from 350 m to 6,975 m above mean sea level. On account of wide variations in altitude and topography, the state has broadly been classified into four agro-climatic zones (**Fig. 1** & **Table 1**), i.e. sub montane and low hills sub-tropical, mid hills sub humid, high hills temperate wet and high hills temperate dry.

The land under cultivation is 10 % of geographical area and about 82 % of net area sown is rain-fed. The total population of state is 60.7 lakh with 9.14 lakh land holdings (**Table 2**). The 71 % population of state depends on agriculture & horticulture. The average size of operated land holding in state is 1.1 ha which is 32 % less than average operated holding size in India (1.68 ha). About 86.4 % operational holdings fall under marginal and small category. The improvement of the agricul-

**Table 2** Distribution of Land Holdings

| Size of Holdings (ha) | Category (Farmers) | No. of Holdings (in lakhs) | Area (in lakhs ha) | Av. Size of Holding (ha) |
|---|---|---|---|---|
| Below 1.0 | Marginal | 6.15 (67.3%) | 2.52 (25.8%) | 0.4 |
| 1.0-2.0 | Small | 1.74 (19.1%) | 2.45 (25.0%) | 1.4 |
| 2.0-4.0 | Semi Medium | 0.90 (9.8%) | 2.43 (24.8%) | 2.7 |
| 4.0-10.0 | Medium | 0.31 (3.4%) | 1.76 (18.0%) | 5.7 |
| 10.0-Above | Large | 0.04 (0.4%) | 0.63 (6.4%) | 15.7 |
| Total | | 9.14 | 9.79 | 1.1 |

**Fig. 2** Gender participation in farming operations

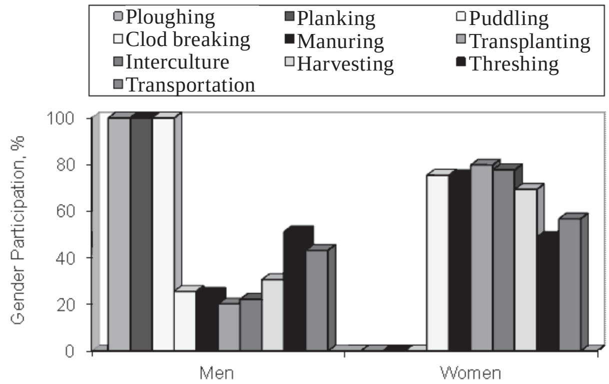



**Table 3** Performance of traditional tools and equipment

| Name of tools | No. of farmers using (%) | Source of power | Field capacity, ha/h |
|---|---|---|---|
| Indigenous Plough | 11 | Bullocks | 0.020 |
| Soil stirring plough | 89 | Bullocks | 0.023 |
| Planker | 100 | Bullocks | 0.20 |
| Wooden clod breaker | 76 | Manual | 0.009 |
| Khuntee | 100 | Manual | 0.003 |
| Sprayer | 22 | Manual | 0.06 |
| Sickle | 100 | Manual | 0.008 |

**Fig. 3** Terraced view of fields

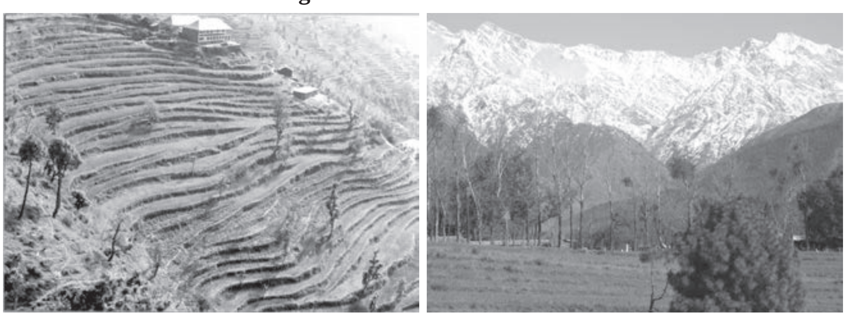


**Table 4** Field size and vertical interval in the terraces

| Size of field, $m^2$ | % of fields | Av. Length, m | Av. Width, m | Av. Interval, m |
|---|---|---|---|---|
| < 50 | 12 | 7 | 4 | 1.0 |
| 50-100 | 36 | 13 | 5 | 0.8 |
| 100-200 | 27 | 24 | 5 | 0.8 |
| 200-300 | 11 | 30 | 7 | 0.6 |
| 300-400 | 8 | 36 | 9 | 0.5 |
| > 400 | 6 | 46 | 11 | 0.4 |

tural production and productivity depends not only on the availability of improved seeds and fertilizer but also on the timeliness of agricultural operations.

Out of total agricultural workers (20.49 lakh) in the state, 57 % are women. Most of the farm operations are performed by women and their involvement is in the range of 50-80 % (**Fig. 2**). Traditional manual tools and animal drawn implements form the mainstay of tools in the state that results in very low output, higher drudgery and cost of operations (**Table 3**). The state topography and small sized & vertical interval between terraces (**Table 4** & **Fig. 3**) makes it difficult for the use of heavy mobile machinery on steep slopes of hills. More than 68 % area is having steep and very steep slope (**Table 5**). Lack of accessible roads to the fields has aggravated this problem.

**Table 5** Percentage distribution of area according to slope in HP

| Slope Classes | Slope, (%) | Area (000' ha) | Area (%) |
|---|---|---|---|
| Nearly level | 1 | 14 | 0.3 |
| Very gentle | 1-2 | 309 | 5.6 |
| Gentle | 3-5 | 348 | 6.3 |
| Moderate | 5-8 | 453 | 7.2 |
| Moderately steep | 8-15 | 629 | 11.2 |
| Steep | 15-30 | 1,214 | 21.8 |
| Very steep | 30 & > | 2,592 | 46.5 |
| Total geographical area | | 5,559 | |

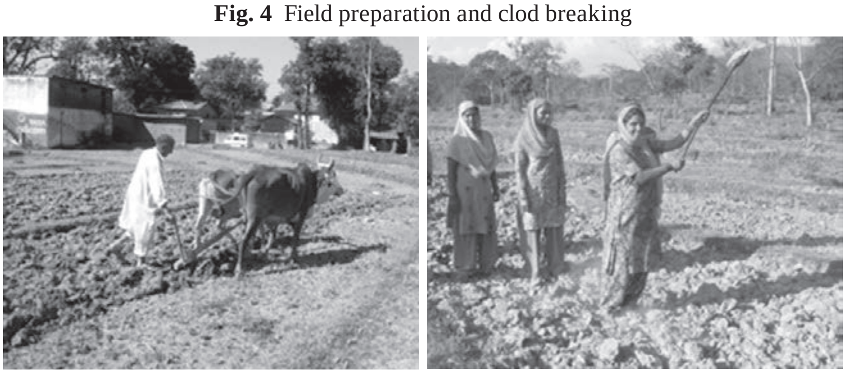
**Table 6** Farm power availability in Himachal Pradesh

| Power Source | Number, lakh | Available power, kW/ha |
|---|---|---|
| Human | 29.90 | 0.220 |
| Draught Animals | 7.033 | 0.181 |
| Power tillers | 0.001 | NG |
| Tractors | 0.070 | 0.180 |
| Diesel Engines | 0.037 | 0.025 |
| Electric motors | 0.073 | 0.0108 |
| Total | 0.609 | |

**Table 7** Area and production of major crops in Himachal Pradesh

| Crop | Area (000' ha) | Production (000' MT) |
|---|---|---|
| Wheat | 366.59 | 562.01 |
| Maize | 300.15 | 682.62 |
| Rice | 78.57 | 121.45 |
| Barley | 23.51 | 30.67 |
| Other crops (millets, cereals & pulses) | 41.7 | 42.54 |
| Total food grains | 811.98 | 1440.66 |
| Apple | 94.8 | 592.57 |
| Citrus | 21.4 | 24.67 |
| Nuts & Dry fruits | 11.18 | 2.90 |
| Other fruits | 73.22 | 92.70 |
| Total fruit crops | 200.50 | 712.84 |

**Fig. 4** Field preparation and clod breaking



The power availability in Himachal Pradesh is only 45 % (0.60 kW/ha) of India's 1.35 kW/ha (**Table 6**). Presently, the share of animate power in the state is 67 %. For increasing the production, there is a need for increased farm power up to 2.0 kW/ha (Srivastava, 1999). The major agricultural and horticultural crops grown in the state are wheat, maize, paddy, barley, apple, citrus, mango, nuts & dry fruits (**Table 7**).

## Present Status and Level of Mechanization

### *Field Preparation and Clod Breaking*

For raising crops, a well-ploughed bed is the pre-requisite for all crops. Seed-bed preparation for nursery and growing other crops is the most time and energy consuming as well drudgery oriented operation that are performed by manual or bullock power (**Fig. 4**). The indigenous/desi (wooden) ploughs and soil stirring (iron) ploughs are most commonly being used by the farmers (Vatsa et. al., 2003). The clod formation after opening land is a severe problem in some of the regions, particularly after harvesting paddy. The wooden hammer is used for breaking of clods by women involving lot of drudgery and energy. Spade is used for this purpose manually. The ridge and furrow formation is also accomplished manually by spade.

### *Sowing/Transplanting*

The sowing of wheat, maize and soybean is normally done by broadcasting/seed dropping behind plough manually which not only uses more labour but it adversely affects the crop stand resulting in poor yield. Paddy sowing is also performed by conventional methods resulting in lot of drudgery and cost (**Fig. 5**). Most of the vegetable crops are sown on ridges manually and ridges are being prepared manually with spade or kudali. Sowing and dibbling of all vegetables crops are done manually which utilizes a lot of labor ultimately increasing the cost of operation.

***Pit Digging***

The pits for planting the tree sampling are dug manually with spade. On an average, a man can dig hardly 3 to 4 pits of size 1 × 1 v 1 m in a day (Singh Sukhbir et.al. 2007). Pits for erecting bower or trellises for kiwis and other fruit crops are dug manually and wires of bower or trellises are also drawn manually.

***Weeding and Earthing up***

Weeding and intercultural operations are being performed manually by majority of the farmers using khunti (local name) with very low efficiency and high labour, drudgery and cost of operation.

Earthing up operation in case of potato and other ridge sowing vegetable crops is done manually with spade. Frequent weeding is required in vegetable crops. Weeding is done manually with conventional weeding tools like khunti or kudali/ kudal (**Fig. 6**).

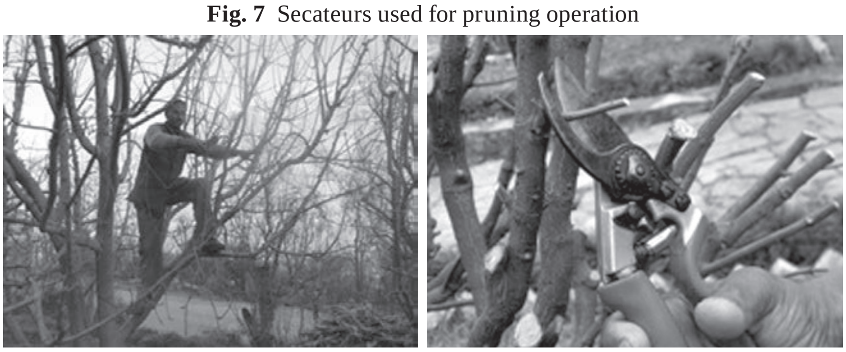
***Basin Preparation and Fertilizer Application***

In orchards, plants need well-ploughed basins. In fruit crops, basin preparation is mostly done with spade, which is very labour intensive and drudgery-oriented operation. On an average, a man can prepare 2.2 basins per hours of 1.5m radiuses in mango crops.

**Fig. 5** Broadcasting of seeds and hand transplanting

**Fig. 6** Weeding tools used by the famers

**Fig. 7** Secateurs used for pruning operation



***Pruning***

Pruning is the removal of any excess or undesirable branches, shoots, roots or any parts of a plant so as to allow the remaining parts to grow normally or according to the desire of the pruner. Most of the fruits needs regular pruning. Pruning of trees is mostly done with pruning saw or secateurs by climbing on trees or ladder (**Fig. 7**).

***Spraying/ Plant Protection***

Spraying the fruit and vegetable plants against timely control of insect-pests and diseases is the important horticultural practices. Spraying of different fruits and vegetable crops is done by hand sprayer, knapsack sprayer and power sprayer.

***Harvesting/Digging***

For harvesting of crops and fodder grasses, farmers use plain sickles having very low capacity because of easy accessibility and availability at low cost. The farmers have their own traditional ways of harvesting. Harvesting of all the fruits are being done manually by hand picking or by climbing on tree directly or sometimes directly beating the branches with the long bamboo. Apple is harvested by hand picking with some twisting action by climbing on tree or by using ladder (**Fig. 8**). For harvesting of Mango, some people use conventional harvester with a hook or frame and net at the end of a long bamboo pole. Techniques for harvesting of mango and citrus are available elsewhere in the country. However, no such techniques have been standardized for harvesting of fruits in the state. Harvesting of pecan-nut is done manually by beating the fruits with a bamboo. Litchis are harvested by their stalks (bunches) manually. Likewise, digging of potato, onion, ginger, garlic and turmeric are done manually by kudali or khurpa. The dug out materials are picked manually from fields. Harvesting/plucking of different vegetables such as peas, tomato, chilies, french bean, brinjal etc. are done manually.

***Threshing/Shelling***

Wheat threshing is almost mechanized but for threshing of paddy crop still the traditional method i.e. bullock treading is in practice and this method requires lot of drudgery and cost of operation with low output (**Fig. 9**). Maize shelling is also performed by beating with stick or by fingers resulting in injury.

***Material Handling***

In hills, material handling is a very big problem. There are many orchards, remote villages or areas where there are no approach roads for transportation of fruits or vegetables to the nearby market. So, material is to be carried manually on the back in the Kiltas from orchards to the storage/packaging point near to the roadside. Some farmers have made their own traditional rope ways to carry their produce from higher reaches of mountains to the roadsides (**Fig. 10**). They also use rope ways to transport other things up and down viz. construction material etc. on custom hiring basis and generate income. These are crudely made and needs lot of improvement.

**Need of Ergonomically Mechanized Intervention**

From the above, it is clear that most of the operations are performed with the help of traditional tools with very low output and higher drudgery. No systematic study has been carried out till now to reduce the drudgery involved in the various operations in hills. Anthropometry is fundamental to any successful design of tool/machine. The man-machine interface decides the ultimate performance of the equipment/work-system. To achieve enhanced performance and efficiency of the man-equipment system along with better comfort and safety of operators, it is necessary to design various tools, equipment and work places keeping in consideration the anthropometric data of agricultural workers. Further the ergonomic characteristics and physiological cost of male and female workers are different in terms of anthropometric data, muscular strength, maximum aerobic capacity and heart rate. Thus there is need to gather comprehensive anthropometric data on male and female farm workers in the hilly state of Himachal Pradesh which would meet the needs of the local manufacturers of farm equipment. It would also be helpful in compilation of data at the national level for preparing comprehensive data-base. The operation which needs mechanized interventions are discussed as-

***Field Preparation and Clod Breaking***

A systematic ergonomic study is required in both traditional method of field preparation by spade/bullocks plough and improved system by power tillers. For steep and very steep slopes (> 15 %) in hills, there is need to provide some lightweight power tiller (weight around 80-100 kg) which could be lifted by two or three persons from one terrace to another for doing field work. The rotary motion of blades cuts the soil very efficiently and destroys the chances of clod formation. Also there is need to provide some improved clod breaker with minimum fatigue.

**Fig. 8** Plain sickle and harvesting of apple

**Fig. 9** Conventional paddy threshing practice

**Fig. 10** Kilta used for carrying apples & conventional rope way

***Pit Digging***

Manual pit diggers developed by various Institutes and commercially available tools could be taken for ergonomic study as to improve the efficiency and save energy.

***Sowing/Transplanting***

As there is lot of drudgery in paddy sowing/ transplanting, ergonomically evaluated lightweight paddy drum seeder and 2 or 4-rows paddy transplanter could be the solution for hills. Small and lightweight seed drill or planter may be considered for ergonomic study.

***Weeding***

Maximum labor is involved in weeding operations performed manually by women. There is need to introduce manual weeder, hoe, long handle hoe, hand rake etc. in hills so that drudgery could be minimized. There is also a need to study critically various tools used by the farmers for weeding and then introducing energy efficient, drudgery reducing improved tools.

***Pruning***

To improve efficiency of pruning, there is need in design refinement related to grip of handle, quality of blade etc. in existing pruner and some improved pruner may be taken for ergonomic study.

***Harvesting/Digging***

Serrated sickles could be provided to improve efficiency of harvesting of crops. For fruits harvesting, some manual harvester and lightweight ladder could be developed and studied to improve the efficiency of the person during plucking of fruits.

***Threshing/Shelling***

Manual/power operated light weight thresher and sheller developed by many institute may be taken for ergonomic study and also there is need of design refinement based on the anthropometric data.

***Material Handling***

Some design refinement is required in Kilta for easy transportation of fruits and other materials. There is also need of design refinement in traditional rope ways for safety purpose and improving efficiency. Improvements are required in many parts such as breaking system, trolley, trolley stopper, and pulley needs in rope ways used by the farmers.

## Conclusion

There is tremendous scope of introduction of ergonomically evaluated gender friendly tools and equipment in various agricultural and horticultural operations in hills of Himachal Pradesh as most of these operations are being carried out by traditional system involving higher labour, drudgery and cost of operation.

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# Book


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Feasibility Survey Project on Agricultural Mechanization for the Small Scale Farmers in Sub Sahara Africa
-Acceleration of Agri-Business -

Final Report –Second Year-

March 2015

JAICAF

Japan Association for International Collaboration of Agriculture and Forestry

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Final Report —Second Year

by Japan Association for International Collaboration of Agricultural and Forestry

**http://www.jaicaf.or.jp/reference-room/publications/detail/article/492.html**

# Design and Optimization of a Double-Concave Rocker Seedmeter for Precision Seeding

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## Abstract

A new type of seedmeter for soybeans was designed, and its working principle was analyzed and illustrated. The structural parameters of the key component of the seedmeter, the double-concave seed-taking block, were optimized. To meet the requirements for adjusting seeding rate by changing the rotational speed and to offer a theoretical basis for the design of a high-speed, high-performance planter, a rotary speed combination design was developed, with the rotational speed of the seedmeter and the tilt angle of the seed-cleaning ring as experimental factors and the single-seeding rate as the experimental index. A mathematical model based on the experimental data was developed using the Design-Expert software. The experimental results showed that at the optimal tilt angle of 65º and at a rotational speed between 21 rpm and 55 rpm, the seed-cleaning ring can achieve a single-seeding rate of over 95 %.

***Key Words:*** seedmeter, double-concave seed-taking block, tilting seed-cleaning ring.

## Introduction

Precision seeders have become more widely used as agricultural technology has developed. (Chen Lidong *et al.*, 2006; Jia Xiuzhi *et al.*, 2007) The seedmeter is the most important component of a precision seeder because its performance has a direct effect on the performance of the precision seeder. (Sun Yujing *et al.*, 2009; Liao Qingxi *et al.*, 2003). The currently available wheel seedmeter and spoon seedmeter cannot satisfy the seeding requirements of high precision, high efficiency and high stability. (Luo Xiwen *et al.*, 2008; Chen Lidong *et al.*, 2006). An urgent market demand exists for a new type of seedmeter with low rates of miss-seeding, multiple-seeding and seed-hurting. (Liao Qingxi *et al.*, 2009; Liao Qingxi *et al.*, 2003). This paper presents the design of a double-concave-surface rocker seedmeter that is capable of meeting the requirements of high single-seeding rates, high seed flow evenness, high speed and low seed-damage by seed filling, cleaning and dropping through a double-concave-surface seed-taking block and a tilting seed-cleaning ring. (Liao Qingxi *et al.*, 2009; Liao Qingxi *et al.*, 2003). This paper also presents the design of a double concave-surface rocker seedmeter, which is capable of seed filling, cleaning and dropping, through a double concave-surface seed-taking block and tilting seed-cleaning ring to meet the requirements of high single-seeding rate, high seed flow evenness, high speed and low seed-hurting.

### Structure and Working Principle of the Seedmeter

#### *Structure of the Seedmeter*

The double-concave-surface rocker seedmeter consists primarily of the shaft, double-concave seed-taking blocks, seed-taking block rings, a rotor plate, and crank arm rings. The structure of the seedmeter and its key parts are shown in **Fig. 1**. The shaft$_{(1)}$ is welded to the rotating disc$_{(6)}$, which is welded to the seed-taking block rings$_{(5)}$ and crank arm rings$_{(7)}$. The double-concave seed-taking block$_{(4)}$ is connected to the seed-taking block ring$_{(5)}$ through a bolt$_{(2)}$, and the crank arm$_{(8)}$ is connected to the crank arm ring$_{(7)}$ through a bolt$_{(3)}$. The seed-taking block$_{(4)}$ and crank arm$_{(8)}$ can rotate counterclockwise with respect to the shaft$_{(1)}$. The seed-taking block$_{(4)}$ is connected to the crank arm $_{(8)}$ through a connecting rod$_{(9)}$, forming a crank-rocker mechanism that can make the seed-taking block$_{(4)}$ swing with the rotation of the crank arm$_{(8)}$. The torsion spring mounted on the bolt$_{(3)}$ enables the seed-taking block$_{(4)}$ to rotate clockwise around the bolt$_{(2)}$.

The seedmeter cup$_{(10)}$ is fixed to the seedmeter cup cover$_{(13)}$ through bolts. The inclined plane$_{(11)}$ in the seedmeter cup serves as a seed-cleaning ring. The tilting cleaning ring$_{(11)}$ is equipped with a seed-cleaning brush$_{(12)}$. There is a tiny gap between the seedmeter cup$_{(10)}$ and the rotating disc$_{(6)}$ to reduce frictional resistance. The cam$_{(18)}$ is connected to the seedmeter cup cover$_{(13)}$ through the connecting rod$_{(16)}$ to ensure that the cam does not rotate$_{(18)}$. The cam$_{(18)}$ and the seedmeter cup cover$_{(13)}$ are connected to the shaft$_{(1)}$ by the deep groove ball bearing$_{(17)}$ and bearing end cover$_{(15)}$. The key part —the double-concave seed-taking block$_{(4)}$ has two concave surfaces. The concave surface farther from the bolt$_{(2)}$ is called the first concave surface, and the other one is called the second concave surface.

***Working Principle***

The shaft is connected to the motor shaft, which makes the disc rotate counterclockwise, thus driving the crank arm, connecting rods and seed-taking block in a uniform counterclockwise rotation. When the seed-taking block rotates close to the seed-filling area, the cam forces the crank arm to rotate counterclockwise around the bolt, putting the crank arm into the far repose and driving the seed-taking block to rotate counterclockwise around the bolt through the connecting rod. This forms a certain flare angle between the concave surface of the seed-taking block and the seed-cleaning ring, making seeds enter the first concave surface. When the joint of the two concave surfaces of the seed-taking block enters the seed-filling area, the crank arm terminates the far repose and begins its return trip and enters the near repose. When the second concave surface enters the seed-filling area, the seed-taking block rotates clockwise due to the torsional force of the torsion spring, thus reducing the flare angle, which prevents seeds from entering the second concave surface and holds seeds in the first concave surface. At this point, the seed is in a balanced state under the action of the holding force from the seed-taking block, centrifugal force and the supporting force from the tilting seed-cleaning ring, and the gravity force of the seed itself, and evenly rotates counterclockwise with the seed-taking block. In most cases, the seed-taking block takes one seed or two seeds at a time; it seldom takes three seeds at a time. When it takes more than one seed, the seeds will come into contact with the cleaning brush and will be obstructed by it, and a relative movement will occur between the obstructed seeds and the seed-taking block. The seed closest to the second concave surface enters it first, increasing the flare angle of the seed-taking block. At that moment, the seed remaining in the first concave will no longer be held by the seed-taking block, and the cleaning ring has a certain tilting angle that makes the axial forces on the seedmeter unable to achieve a balance, causing axial displacement and making the seed leave the seed-taking block and return to the seed-taking area. The tilting seed-cleaning ring also provides a space limit for the seed-taking block. The seed-taking block will stop when it comes into contact with the seed-cleaning ring on the smaller-radius side, thus protecting the seed from damage caused by flare angles of the seed-taking block that are too small.

**Design of the Double-Concave-Surface Seed-Taking Block**

The key part of the soybean seedmeter is the double-concave seed-taking block. A space rectangular coordinate system O-XYZ is established, where point O represents the rotating center of the double-concave seed-taking block, the Z-axis represents the axial direction of the seedmeter, the X-axis represents the instantaneous velocity direction of the rotation center of the double-

**Fig. 1** Structure of the seedmeter

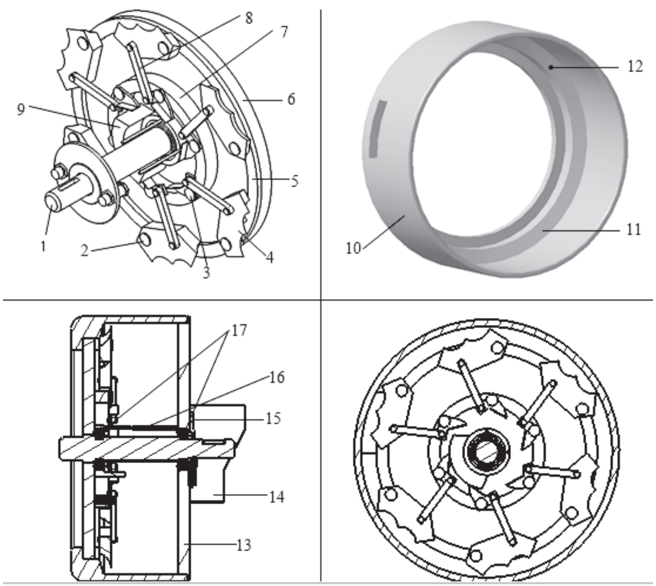



**Fig. 2** 3D diagram of double-concave-surface seed-taking block

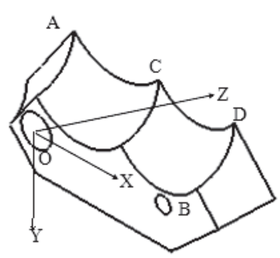
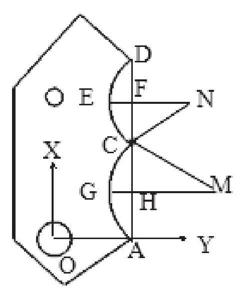


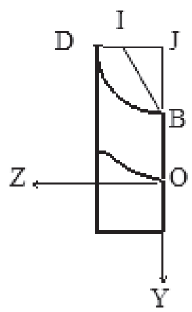

**Fig. 3** Side view of concave-surface seed-taking block



concave seed-taking block, and the Y-axis represents the radial direction of point O of the seed-taking block, which moves in a circular motion around the seedmeter shaft, as shown in **Fig. 2**. The design of two concave surfaces can be accomplished by establishing the parameter equations of eccentric arcs AC and CD parallel to plane XOY and eccentric arc AB parallel to plane YOZ. The surface of a soybean can be considered a sphere because the spherical rate for soybeans is more than 90 %. (Yu Jianqun *et al.*, 2008). In this study, the maximum radius of a soybean was assumed to be 3.5 mm, and the minimum radius was assumed to be 2 mm. Considering the overall structure of the seedmeter, it was assumed that the distance between points O and A in the Y-axis direction is 9 mm.

**Fig. 3** is the side view of the double-concave seed-taking block. M and N represent the centers of eccentric arcs AC and CD, respectively. H and F represent the midpoints of chords AC and CD, respectively. G and E represent the intersections of line MH with eccentric arc AC and line NF with eccentric arc CD, respectively. The eccentric arc AC of the concave-surface seed-taking block plays a role in seed taking during operation. To ensure that the largest seed can be held by the seed-taking block, the radius $r_{CD}$ of the eccentric arc profile CD should be greater than or equal to the maximum radius $r_{\max}$ of a soybean. If $r_{CD}$ is too large, too many seeds will be taken at one time, decreasing the single-seeding rate; thus, $r_{CD}$ is assumed to be equal to $r_{max}$. To ensure that the flare angle of the double-concave-surface seed-taking block is always greater than zero when any seeds of different sizes enter the seed-taking block, the length of the line segment EF should be less than or equal to the minimum radius $r_{\min}$ of a soybean seed. If EF is too short, the radian of the eccentric arc profile CD will be too flat, decreasing the effect of seed-holding, so EF is assumed to be equal to $r_{\min}$. From **Eqn. 1**, the length of chord CD is 6.4 mm.

**Fig. 4** Front view of concave-surface seed-taking blockave-surface seed-taking block




$$r^2_{CD} = (r_{CD} - r_{min})^2 + (L_{CD} / 2)^2 \quad (1)$$

where $L_{CD}$ is the length of chord CD in mm.

Therefore, the parameter equation of the eccentric arc profile CD can be written as follows:

$$(x - 11)^2 + (y - 10.5)^2 = 12.25;\ 7 \leq y \leq 9,\ 7.8 \leq x \leq 14.2 \quad (2)$$

When seeds come into contact with the seed-cleaning brush, the closest seed enters the eccentric arc AC first. Because a soybean seed can be considered approximately spherical, the flare angle of the double-concave seed-taking block will become larger first and then smaller as the seed enters more inside, and the flare angle will be greatest when the seed is halfway through the eccentric arc AC. To ensure that all seeds can enter the eccentric arc AC and that the flare angle can become as large as possible after the seeds enter, the eccentric arc profile AC must satisfy the requirement that the largest seed should be held exactly at its midpoint. From **Eqn. 3**, the length of chord AC is $\sqrt{5}r_{max}$.

$$L^2_{AC} = r^2_{\max} + (2r_{\max})^2 \quad (3)$$

where $L_{AC}$ is the length of chord AC in mm.

When the size of the seed entering the eccentric arc profile AC is smaller than the maximum seed size, the flare angle of the concave-surface seed-taking block will decrease. To ensure that the flare angle is greater than zero when any seed enters the seed-taking block, the length of line segment GH should be less than or equal to the minimum soybean seed radius $r_{min}$. However, if GH is too short, the radian of the eccentric arc profile CD will be too flat, decreasing the effect of seed holding, so the length of EF should be equal to $r_{min}$. The equation for calculating $r_{AC}$ can be written as follows:

$$(r_{AC} - r_{min})^2 + (\sqrt{5}r_{max} / 2)^2 = r^2AC \quad (4)$$

where $r_{AC}$ is the radius of eccentric arc profile AC in mm.

From **Eqn. 4** it was determined that $r_{AC} = 4.8$ mm.

The parameter equation of the eccentric arc profile AC can be written as follows:

$$(x - 3.9)^2 + (y - 11.8)^2 = 23.04;\ 0 \leq x \leq 7.8,\ 7 \leq y \leq 9 \quad (5)$$

**Fig. 4** is the front view of the double-concave seed-taking block. J is the center of eccentric arc BD, BI is the tilting seed-cleaning ring, ∠BIJ is the tilt angle $\beta$ of the tilting seed-cleaning ring, and ∠BJD is the central angle $\alpha$ of the eccentric arc profile. To ensure that all seeds of any size can enter the seed-taking block, the radius of the eccentric arc DB should be equal to the maximum seed radius $r_{max}$. As the seeds rotate with the seed-taking block, the components of the gravity force of seeds in the X and Y directions are constantly changing, so the seeds will constantly slide along the eccentric arc DB to keep them in a force balance. To ensure that the seed is held at any position of the eccentric arc DB after entering the double-concave-surface seed-taking block, the distance between DI on the eccentric arc profile and the seed-cleaning ring should be less than or equal to the minimum seed diameter ($2r_{min}$). If DI is too small, it will decrease the seed-holding effect; thus, the length of line segment DI should be equal to $2r_{min}$. The relationship between $\alpha$ and $\beta$ can be deduced from **Eqn. 6**. Tests showed that $\beta = 65^{\circ}$ and $\alpha = 97^{\circ}$.

$$[(2r_{\max} - 2r_{\min}) / \sin(\pi / 2 - \beta)] = 2r_{\max} / [\sin(\pi/2 - \alpha + \beta)] \quad \text{......(6)}$$

The parameter equation of the eccentric arc profile DB can be written as follows:

$$Z^2 + (Y + 8.6)^2 = 12.25;\ 0 \le Z \le 3.5,\ 5.1 \le Y \le 9 \quad \text{......................(7)}$$

## Experimental Design and Methods

### *Test Platform*

Experiments were conducted on a 30-m test bench equipped with a conveyor belt and speed-adjusting motor. Other testing devices used included a hand-held digital tachometer, a meter stick and 5 different seedmeters. Both the seed-cleaning ring and the double-concave-surface seed-taking block of each seedmeter had different tilt angles $\beta$ and central angles $\alpha$ of the eccentric circular arc DB. The parameters $\beta$ and $\alpha$ of each seedmeter satisfied **Eqn. 6**.

### *Selection of Test Factors and Test Index*

The centrifugal force acting on the seed is determined by the rotational speed of the seedmeter when the seed rotates with the double-concave seed-taking block. When the seed is not clamped by the double-concave seed-taking block, the force acting on the seed in the Z direction is determined by the tilt angle and centrifugal force of the seed-cleaning ring. The greater the force acting on the seeds is, the more easily the seeds fall back to the seed-taking area. The smaller the central angle $\alpha$ of the eccentric circular arc DB is, the smaller the probability is of too many seeds being blocked in the Z direction by the double-concave-surface seed-taking block. When the flare angle of the seed-taking block increases, the seeds fall back to the seed-taking area more easily. Thus, the rotational speed of the seedmeter, the tilt angle $\beta$ of the seed-cleaning ring and the central angle α of the eccentric circular arc DB all have an effect on the single-seeding rate. The angles $\beta$ and α should satisfy **Eqn. 6**. Because there is always one angle $\alpha$ value that corresponds to each angle $\beta$, the values of $\beta$ and α should be considered as one factor. Therefore, the rotational speed of the seedmeter and the tilt angle $\beta$ were selected as the experimental factors, and the single seed rate of seedmeter was selected as the experimental index.

### *Test Method*

In the experiment, the speed-regulating motor was used to drive the seedmeter shaft rotating synchronously, and a hand-held digital tachometer was used to determine whether the rotational speed of the motor had been adjusted to the $N_1$ required in the test plan. After the rotational speed was determined, the seedmeter cup selected in the experiment was installed on the seedmeter. Seeds were then put into the seedmeter, which dropped the seeds for one minute onto the conveyor belt under the seedmeter. The conveyor belt was covered with a layer of sand to ensure that the seeds fell to the conveyor belt without bouncing. Measurements showed that the spacing of most seeds was basically equal, and the seed spacing d was measured. The seedmeter was operated again for two minutes each time and measured the seed spacing $L$. If $L$ was significantly greater than d, the miss-seeding times between two seeds was taken as the rounded value of $(L - d) / d$. If this case occurred times, the miss-seeding times were taken as the rounded value of $[n_1 (L - d)] / d$. If L was significantly less than $d$, one reseeding time exists. If this occurred $n_2$ times, there were $n_2$ reseeding times. Total seeding times should be based on the single-seeding rate and can be written as follows:

$$\{[6N_1 - n_1 (L - d) / d - n_2] / 6N_1\} \times 100\ \% \quad \text{.................................(8)}$$

We repeated the tests up to 5 times and determined the average values of the results. In the single-factor test, 5 levels of the experimental factors were considered. The other factor was fixed at the zero level for repetition of the above steps at each level of the other factor. In the rotation test, the levels of the rotational speed and tilt angle of the seed-cleaning ring were selected in accordance with **Table 4**. Tests were conducted by repeating the above steps for each combination of factor levels.

### *Design of Single Factor Experiment and Analysis of Test Results*

In the single-factor test, the 5 levels of rotational speed of the seedmeter were selected, and the tilt angle was held constant. F-test results showed that $F > F_{1-0.05}$ (4, 16), indicating that the rotational speed of the seedmeter had a significant effect on the single seed rate. The response curve obtained using the Design-Expert software is shown in

**Fig. 5** The response curve for the rotational speed

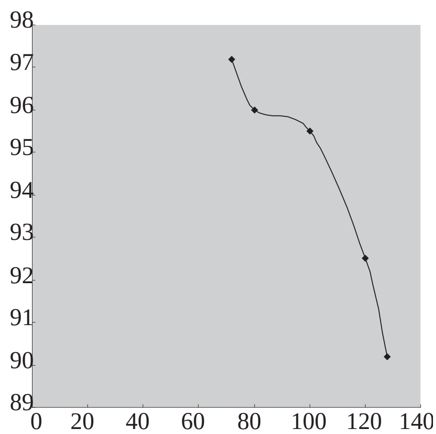



**Fig. 6** The response curve for the tilt angle

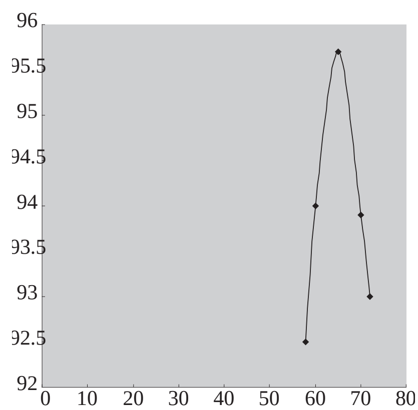


**Fig. 5**. The response curve shows that the single seed rate decreases when the rotational speed increases.

The single-factor tests of tilt angles of the seed-cleaning ring were conducted with the rotational speed of the seedmeter was fixed at the zero level for each of the five seedmeters. F-test results showed that $F > F_{1-0.05}$ (4, 16), indicating that the tilt angle of the seed-cleaning ring had a significant effect on the single seed rate. The response curve obtained using the Design-Expert software is shown in **Fig. 6**. The response curve shows that the tilt angle first increases and then decreases as the single seed rate increases.

***Design of Rotation Combination Experiment and Analysis of Test Results***

A rotary quadratic combination design with two factors and five levels was adopted in the experiment. The Design-Expert software was used to conduct a regression analysis of the test data. A mathematical model relating the test factors to the test index was established. The test factors were the rotational speed of the seedmeter and the tilt angle of the seed-cleaning ring, and the test index was the single-seeding rate.

Based on the test results given in **Table 4**, the Design-Expert software was used to conduct an analysis of variance of the regression equation coefficients. The results, which are shown in **Table 5**, indicated that the coefficients of $x_2$ and $x_1x_2$ were not significant, so the mathematical modeling was conducted again after removing $x_2$ and $x_1x_2$.

A new regression **Eqn. 9** was obtained using the Design-Expert software. Its response surface is shown in **Fig. 7**. The coefficients of the new regression equation are all significant.

$$y_1 = 96.10 - 2.24x_1 - 1.30x_1 2 - 1.92x_2 2 \quad (9)$$

The maximum value of $x_2$ can be calculated from **Eqn. 9**, and the optimal value of $x_2$ is 0. The optimal tilt angle is 65º.

Therefore, at the optimal tilt angle of 65º. It was conclude from **Eqns. 10** and **11** that a single seed rate of over 95 % can be guaranteed when the rotational speed $N_1$ of the seedmeter is between 21 and 55 rpm.

$$96.10 - 2.24x_1 - 1.30x_1^2 \geq 95 \quad (10)$$

$$x_1 = (N_1 - 50) / 1.414 \quad (11)$$

***Validation Test in Field***

The seed device was installed on the machine for validation test in field, The experimental factors was Selected the best parameters. The test results as shown in **Table 7**, prove that the selected job parameters conform to the requirements of the job.

**Table 1** Design of the single-factor experiment and test results for rotational speeds

| Levels | Test results (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 78 | 89.3 | 88.0 | 90.2 | 89.6 | 89.4 |
| 70 | 92.3 | 91.7 | 92.5 | 92.2 | 91.0 |
| 50 | 96.0 | 95.3 | 95.5 | 95.8 | 96.2 |
| 30 | 96.5 | 96.8 | 95.0 | 97.1 | 97.2 |
| 21 | 98.0 | 98.6 | 97.2 | 98.5 | 98.6 |

**Table 2** Design of single-factor experiment and test results for tilt angles

| Levels | Test results (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 72 | 92.1 | 92.5 | 93.0 | 91.8 | 91.6 |
| 70 | 94.3 | 94.1 | 93.9 | 94.2 | 93.7 |
| 65 | 96.0 | 95.8 | 95.7 | 96.3 | 96.2 |
| 60 | 94.5 | 93.9 | 94.0 | 94.1 | 94.2 |
| 58 | 92.6 | 93.2 | 92.5 | 93.0 | 92.7 |

**Table 3** Code table of experimental factors and levels

| | Experimental factors | |
|---|---|---|
| | Rotational speed (rpm) | Angle of seed-cleaning ring (degree) |
| 1.414 | 78 | 72 |
| 1 | 70 | 70 |
| 0 | 50 | 65 |
| −1 | 30 | 60 |
| −1.414 | 21 | 58 |

**Table 4** Experimental design and results

| Factors | | Indexes |
|---|---|---|
| 1 | 1 | 91.0 |
| 1 | −1 | 91.6 |
| −1 | −1 | 94.3 |
| −1 | 1 | 93.6 |
| 1.414 | 0 | 89.3 |
| −1.414 | 0 | 98.2 |
| 0 | 1.414 | 92.2 |
| 0 | −1.414 | 92.8 |
| 0 | 0 | 96.5 |
| 0 | 0 | 96.3 |
| 0 | 0 | 95.6 |
| 0 | 0 | 96.2 |
| 0 | 0 | 95.9 |

Notes: $x_1$ = rotational speed, $x_2$ = tilt angle of seed-cleaning ring, $y_1$ = single seed rate

**Table 5** Analysis of variance of the regression equation coefficients

| | Mean sum of squares | F value | P value |
|---|---|---|---|
| $x_1$ | 39.99 | 36.54 | 0.0005 |
| $x_2$ | 0.58 | 0.53 | 0.4914 |
| $x_1^2$ | 11.76 | 10.74 | 0.0135 |
| $x_2^2$ | 25.78 | 23.55 | 0.0019 |
| $x_1x_2$ | 2.500E − 003 | 2.284E − 003 | 0.9632 |

## Conclusions

The structural parameters of the double-concave seed-taking block significantly affect the operational performance of the double-concave rocker seedmeter. These structural parameters were optimized in this study.

The rotational speed of the seed-meter and the tilt angle of the seed-cleaning ring both have a significant effect on the rate of the seedmeter. These two factors are independent.

A regression equation for the test index (the single-seeding rate) as a function of the test factors (the rotational speed of the seedmeter and the tilt angle of the seed-cleaning ring) was obtained using the Design-Expert software. The optimal tilt angle of the seed-cleaning ring was found to be 65º. At this tilt angle, a single-seeding rate of over 95 % can be achieved when the rotational speed $N_1$ of the seedmeter is between 21 and 55 rpm.

**Table 6** Analysis of variance of new regression equation coefficients

| | Mean sum of squares | F value | P value |
|---|---|---|---|
| $x_1$ | 39.99 | 36.54 | 0.0005 |
| $x_1^2$ | 11.76 | 10.74 | 0.0135 |
| $x_2^2$ | 25.78 | 23.55 | 0.0019 |

**Table 7** Result of experimental

| Angle of seed-cleaning ring (degree) | Rotational speed (rpm) | Single grain rate (%) |
|---|---|---|
| 65 | 70 | 98.6 % |
| 65 | 80 | 97.2 % |
| 65 | 90 | 96.3 % |
| 65 | 100 | 95.9 % |
| 65 | 110 | 95.2 % |

**Fig. 7** Response surface

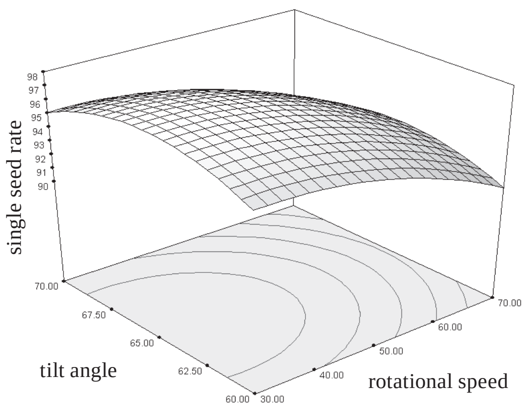



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**Fig. 8** The moment of seeding in test bench

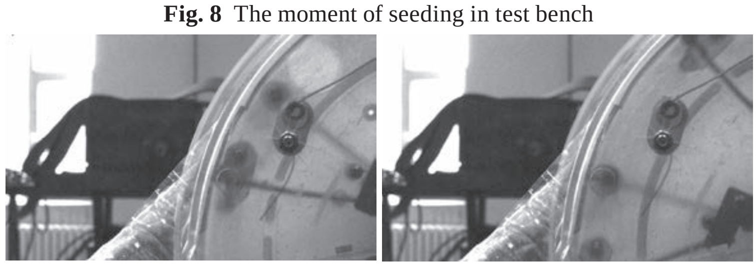
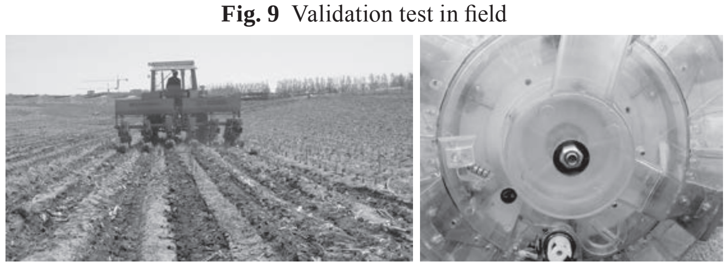


**Fig. 9** Validation test in field



Machine operation in field　　Seeder

# Developing Countries in Africa and Priorities towards Implementation of Agricultural Mechanization



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## Abstract

Although agriculture is the driving force of every economy in developing countries, the existing farming system that is at its initial stage, is totally inadequate to alleviate poverty as expected. Farmers use constantly unproductive ways to cultivate. Hence, agricultural system needs to be modernized. Modern Agriculture starts with manpower training which undoubtedly means education. Apparently educated or trained manpower increases the level of agricultural productivity. Moreover, proper mechanization which is a technical approach towards productivity, needs training. Therefore, committed officials and good government policies are the bases and key factors towards its realization. This paper highlights the importance of manpower training in vocational schools, transformation of government policies in agriculture and attitude of the population towards the agriculture sector.


## Introduction

The importance of vocational trainings is not given proper attention by government officials due to the fact that such trainings are vital to the development of agriculture in developing countries. Government officials of developing countries have no adequate approach and attitude to manpower training.

The use of agricultural machineries and equipment has increased in this 21st century and developing countries are of no exception (FAO, 2008). The world population is growing and agriculture and food production cannot be based entirely on manual labour (Oni, 2011a). Farming on a large scale and improved production of agriculture products can be achieved only when there is a gradual transition to modern agriculture using mechanization (Kic, Zewdie, 2013). Despite all the effort made by developing countries to improve on agricultural production to reduce the rate of hunger and food insecurity, success has become far cry. This is because farmers in developing countries continue to practice old way of farming although agricultural mechanization has been introduced. The complication is to identify the major problems as to when and where to begin utilizing farm machinery and equipment in developing countries. This can be reached when issues like manpower training, government policies, varieties, and composition of farm machineries and equipment are critically examined. Above all the core problems, manpower training (initial preparation) for maintenance, and servicing of farm machinery should be taken into greater consideration. For Ghanaian case which is similar to developing countries, manpower preparation has been neglected due to the negative attitude and perception of the population (Wallace, 2014). Experience shows that a lot of students prefer to pursue Management courses rather than engineering that is also an important part of manpower training. A large number of graduates want white collar work i.e. work in office which they think earn better pay than being in the agricultural industry (blue collar work). Still, lots of people are of the view that "He who is dealing in the agriculture sector is incompetent" (Wallace, 2014). The idea and perception that agricultural which manpower training is for those who are not academically good should be changed as it is the backbone for efficient and effective agricultural mechanization. These above facts will remain a problem unless and until the mentality of the population towards agriculture is changed.

### Government Policies in Developing Countries towards Agricultural Mechanization

A considerable number of heads of states in developing countries are not democratically elected and think of staying in power rather than focusing on agricultural development, which is the driving force of the economy. In many developing countries, head of states seize power by undemocratic manner which leads to poor management and embezzlement of state funds. Government allocates small amount of funds in agriculture in the state budget and gives priority to "tanks than agricultural machineries." Number of lobbyists and the brokers play a significant negative role in deciding the direction of development of the countries where their priority is only profits. Lobbyists mislead government officials to import different brands and models of farm machineries which are not suitable for the agricultural needs of the country and complicate the spare parts availability. As a result, precious time is wasted on training and retraining of personnel that leads to low agricultural productivity.

Competent and progressive leaders advocate the necessary experiences and know how's from developed countries to boost the level of productivity. Such experiences can be in the form of sandwich training (short-term programs) organized by the government for both operators and service men to adopt modernization of agricultural production. This can lead to efficient utilization of farm machinery and reduction of post-harvesting losses. In addition, governments in developing countries should allocate funds that should motivate small scale farmers to accomplish by importing farm machineries and accessories on credit or at a subsidized cost. Through time, farmers gradually acquire their own tractors. The initial solution can be achieved through custom hiring services at early stage to facilitate the low income small farmers.

### Importance of Manpower Training in Agricultural Mechanization

The initial stage of agricultural mechanization in developing countries has to start not only with purchase of machinery but also with manpower training. The key factor to modern agriculture is the transformation of education, which developing countries cannot catch up with the technological advancement. This is because of outdated curriculum and training facilities, poor infrastructure condition, inappropriate teaching methods both in the practical and theoretical realm. Thus, the priority comes in realizing the educational transformation which starts in allocating a budget for vocational schools.

Manpower training for technical condition of agricultural equipment can be divided into two categories of workers. The first group is trained to operate farm machinery and equipment which means operators, drivers, and other similar professions. The other group is in charge of maintaining and restoring the technical conditions, i.e. servicemen and repairmen. This can be achieved by restructuring the syllabus which is suitable to the condition and policy suitable to a given country. The authors of this paper recommend two years of vocational training unlike the sandwich program stated above. Beyond that, pilot projects should be adopted in major regions where agriculture is intensive and the need of manpower training is essential. The authors strictly recommend a modern layout for schools with necessary teaching aids, teachers (foremen), and teaching materials. International and local donors are advised to give priority in realizing the concrete projects. The pilot projects are supposed to promote the role of training centres as well as maintenance and servicing sites.

The authors propose the following structural transformation policies in modern agriculture for developing countries;

Every government is supposed to guarantee allocation of enough budget for implementing agricultural

**Table 2** Import and export commodities of three African Countries

| | CAMEROON | GHANA | MALI |
|---|---|---|---|
| Import commodities | Maize, millet, sorghum, sugar, pig meat, beef meat, poultry | Rice, maize, sorghum, poultry | Rice, millet, sorghum, milk |
| Export commodities | Cocoa, coffee, cotton, palm oil | Cocoa | Cotton |

Source: Dewbre, J. and A. Borot de Battisti (2008)

**Table 1** Distribution of currently Agricultural Industry employed population in Ghana aged 15-64 years (percent)

| Industry | Urban | | | Rural | | | Ghana | | |
|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | All | Male | Female | All | Male | Female | All |
| Agriculture | 20.8 | 16.6 | 18.6 | 79.4 | 71.3 | 75.3 | 59.1 | 52.7 | 55.8 |
| Fishing | 1.3 | 0.2 | 0.7 | 2.9 | 0.6 | 1.7 | 2.3 | 0.5 | 1.4 |

Source: Ghana Statistical Service, 2008 (Modified by authors) mechanization especially manpower training. Private sectors are expected to be active and called upon to work hand to hand with the government in training apprentices and building vocational and technical training school with soft loans so that developing countries will have basic food consumption.

The field of vocational education is expected to play a vital role in transforming the curriculum which is practical and enables students to perform other practical life support and different branch of the country´s economy. Vocational education is the key factor which drives the economy of a country and in this case a practical student is more valuable than an engineer. The perception that an engineer must have a perfect knowledge of all elements of lower categories of staff is currently completely naive and outdated. Each category has its own special status. To a certain extent it may be correct to educate skilled workers in abundance and have a shortage of engineers than vice versa. An excellent engineer without a skilled maintenance worker is unlikely to be of good use. It offers, therefore, to consider whether it would be effective to secure for mechanization of agriculture in general and for the maintenance, repairs and diagnostics particularly education mainly of blue-collar workers.

Research centres are parts and parcels in agricultural promotion and modernization. The relationship must be continuous and practical-farmer and research centre, farmer, and extension workers. Governments should frequently train extension staff on modern farm mechanization so that they give technical advice on proper selection, use, and management of farm machinery and equipment rather than farmers relying on sales persons. Research centres and Universities which can play a vital role, should cooperate in training individuals so that locally designed simple machines are used by small-scale farmers (Betru and Sidahmed, 1999).

## Discussion

**Tables 1, 2, 3** and **4** clearly indicates that developing countries are not self-sufficient in food security of their inhabitants because of lack of farm technology and skilled manpower. **Table 1**. Emphasize the population employed in the agricultural industry both in urban and

**Table 4** Estimated available power for agriculture in Ghana in 2002

| Major source | Number of units | Power per unit, kW | Total power, kW | Percentage of total |
|---|---|---|---|---|
| Human | 7,200,000 | 0.01 | 720,000 | 51.73 |
| Bullock | 970,000 | 0.5 | 485,000 | 34.85 |
| Tractor | 4,000 | 46.7 | 186,800 | 13.42 |
| Total | | | 1,391,800 | 100 |

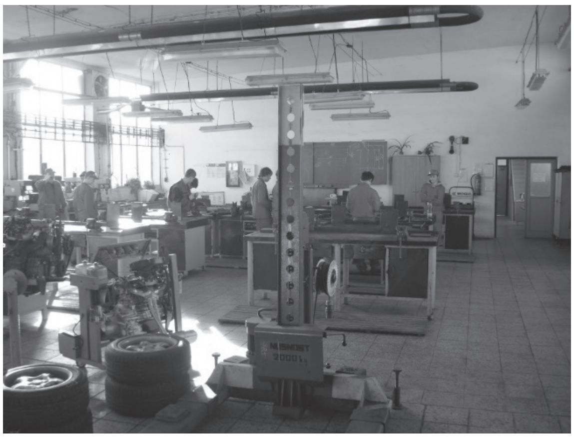
Source: Josiah *et al.* (2008)

**Table 3** The distribution of various power source used for land preparation in Mali, 2005

| | Types of power source and percentage use | | | | | |
|---|---|---|---|---|---|---|
| | Manual | Animal traction | Mechanized | Partly animal traction and mechanized | Partly manual and animal traction | Partly manual and mechanized |
| National weighted average | 17.00 | 71.98 | 0.94 | 0.09 | 9.93 | 0.06 |

Source: DNA *et al.* 2007 (Modified by authors)

**Fig. 9** Typical maintenance centre at local plant in Ghana



Source: http://mofa.gov.gh/site

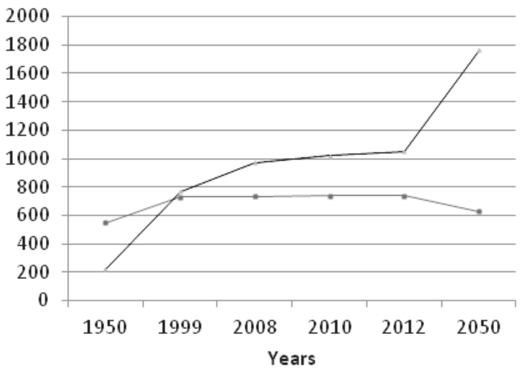
**Fig. 10** Typical class of modern Vocational School in Czech Republic

Source: Wallace, 2014

rural areas in Ghana; which are significant indicators of livelihood for the rural population as agriculture and fisheries. From the **Table 2**, it is clearly seen that, those three countries (Cameroon, Ghana, and Mali) give priorities to cash crops than consumer commodities. The production of agriculture is not adequate which results in rather import than produce. The climatic conditions are suitable to cultivate those imported commodities, but the wrong government agricultural policies towards modern Agriculture (the authors are only in assumption), led to those specified facts. Those facts are illustrated on **Figs. 7** and **8**. **Table 3** represents the distribution of powers in Mali; where the national weighted average of mechanical power (farm machinery and equipment) is less than 1 percent. However, greater numbers of Malian farmers (nearly 72 percent) use animal draught power and 17 percent manual technology. Similarly, from **Table 4**, only 13 percent of Ghanaian farmers practise farm mechanization which is relatively in a better level than farm practises in Mali. The above two tables (**Tables 3** and **4**) indicate the amount of agricultural machineries utilise in developing and developed countries. This shows the agricultural machines energy per hectare as entirely different level; which of course can be taken as a cardinal issue to the influence on productivity.

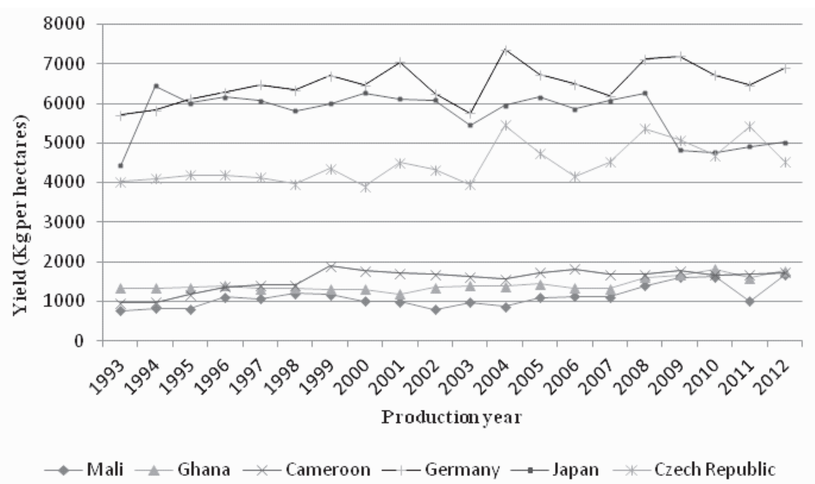
The population growth rate estimation in Africa is rapid compared to Europe (**Fig. 1**). Due to this fact, the food security of the continent is increasing rapidly and traces the actual population growth. The farm machineries in developing countries are far beyond its expectation when compared to the developed countries (**Figs. 3** and **4**) and as the result is clearly demonstrated on the production which is indicated in **Fig. 2** because of the low energy applied on the farm. A good example of maize and wheat yields is demonstrated on **Figs. 5** and **6** respectively. The

**Fig. 1** Population growth prediction for Africa and Europe



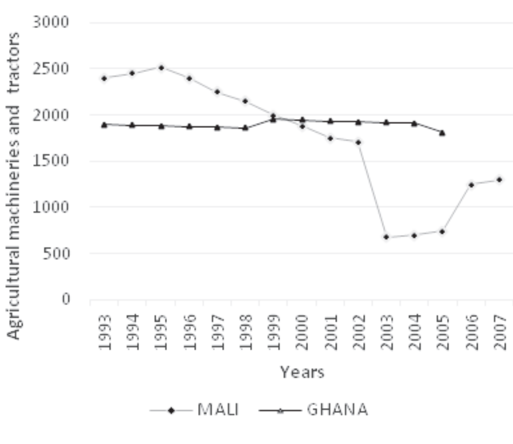

Source: http://en.wikipedia.org/wiki/World_population

**Fig. 2** Cereal production in developing and developed countries



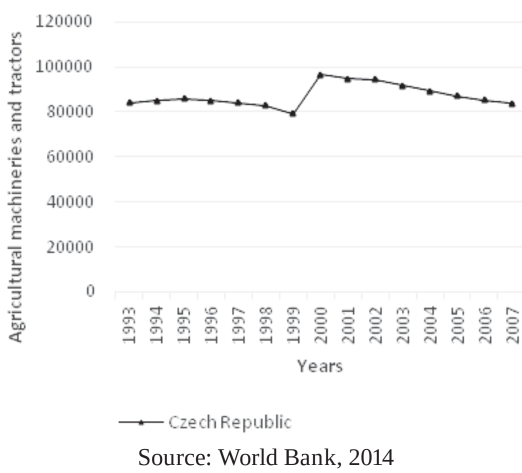

Source: FAOSTAT, 2014

**Fig. 3** Number of farm machineries in Mali and Ghana




Source: World Bank, 2014

**Fig. 4** Number of farm machineries in Czech Republic




Source: World Bank, 2014

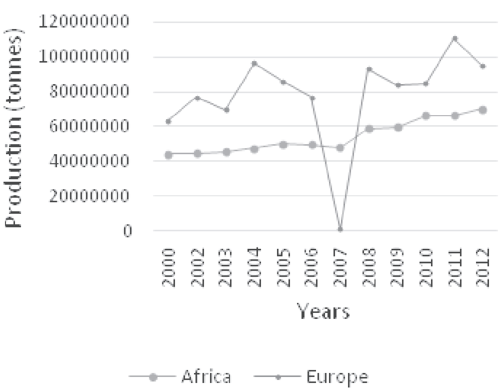
indicated maintenance area shows the standard at the local level in Ghana is illustrated on **Fig. 9**; which is inadequate both technically and ecologically. On **Fig. 10**, the modern vocational school in Czech Republic can be taken as a demonstrative standard to developing countries. From the above discussion and argument and facts, the authors deduced that agricultural in developing countries is in its initial stage. Therefore the authors strictly recommend application of modern farming system. This of course will be achieved only through skilled manpower training which is supposed to include a government restructure policy in the field of agriculture, education and transformation towards mentality of its inhabitants.

## Conclusions

In this paper, the authors have defined the priorities in addressing some fundamental questions about the importance of modern agriculture concerning serious deficiencies of trained manpower.

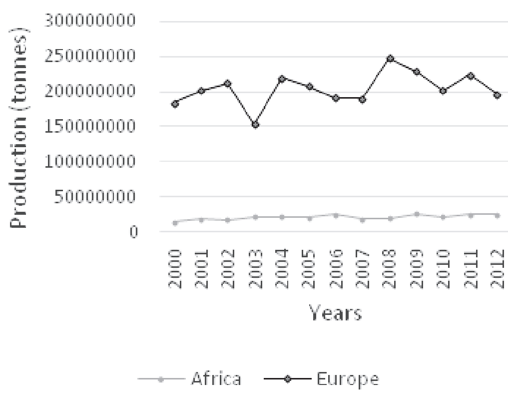
- Preparation of blue-collar workers (manpower training) for industry is lagging in developing countries which have led to high rate of failure, premature depreciation, and inefficient use of machinery. Therefore, a new and reformed school syllabus which replaces the boring theory which is impractical for the livelihood of the population is expected to improve the productivity in agriculture.
- All vocational schools in developing countries should be upgraded to have modern facilities to create a good environment for manpower training. Layout of vocational training is recommended to include the following sections; maintenance hall, welding mechanical shop, trivial mechanical, oxy-acetylene, lathe machine, electrical shop, classroom blocks, car wash, diagnostics centre, vulcanizing, oil drawn centre, dressing room(washroom, tool box),

**Fig. 5** Maize production in Africa and Europe



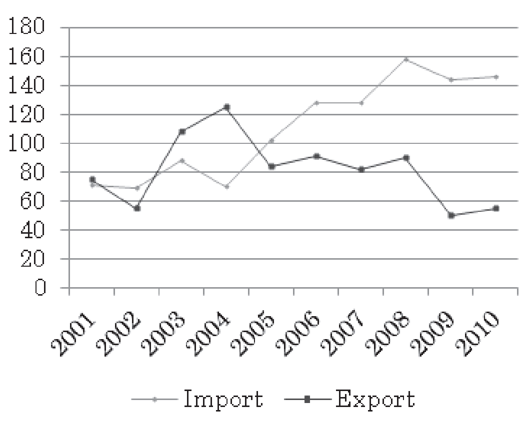

Source: FAOSTAT, 2014

**Fig. 6** Wheat production in Africa and Europe



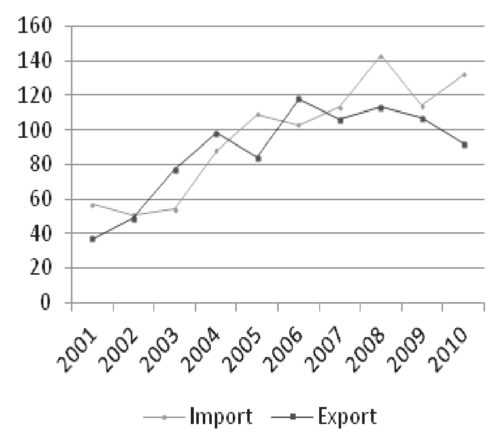

Source: FAOSTAT, 2014

**Fig. 7** Import and export of agricultural products, Mali




Source: FAOSTAT, 2014

**Fig. 8** Import and export balance of agricultural Products, Ghana




Source: FAOSTAT, 2014

and parking area.

• Minimum brands of farm machinery and spare parts policy. Such policy can be implemented by government to establish business relations with more than one or two manufacturer or representatives of agricultural equipment and systematic import of spare parts. This will encourage technical documentation to detect and improve the conditions of operation, service, and maintenance of machines. In addition, prolong machine life, ease nursing units, and last not least, saves foreign exchange.

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# News

### Prof. Li Shujun (co-editor of AMA) was elected the Incoming President (2017-2018) of CIGR

Prof. Li Shujun, Former President of AAAE (2010-2011, 2012-2013), the Vice President of AAAE, was elected the Incoming President of CIGR (2017-2018) by voting and approved by the CIGR Presidium, CIGR Executive Board and CIGR General Assembly which was held during the 18th World Congress of CIGR in Beijing.

He is the first President from China during the 85 years history of CIGR. He has been playing an important role in promoting the agricultural and biosystems advancement.

### **AAAE 25th Anniversary** at the 18th World Congress of CIGR

The AAAE 25th Anniversary was successfully held on September 17th, 2014 during the 18th World Congress of CIGR. AAAE was established in 1990 at Asian Institute of Technology, Bangkok, Thailand with the purpose of general advancement of the agricultural engineering profession and for the practices of agricultural engineering in all its aspects, and for promoting the academic and technological exchanges. By means of organizing biennial academic conferences and publishing IAEJ, AAAE made contributions to the promotion of agricultural engineering in Asian area. By way of publishing and circulating the AAAE newsletters and recruiting new members, AAAE maintained close ties with its members and kept the association growing. Now AAAE has grown into an international academic association with professional impact in agricultural scientists and engineers around the world.

The leaders of other international academic societies all expressed their congratulations on AAAE 25th Anniversary. They gave the best wishes to AAAE. They had the common vision that with the efforts of all experts and agricultural engineers, the human beings would be free from hunger and malnutrition, where food security and agriculture contribute to improving the living standards of all, in an economically, socially and environmentally sustainable manner.

# Status of Agricultural Mechanization in Lesotho

by

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## Abstract

Lesotho is a mountainous high altitude Southern African country, landlocked within the Republic of South Africa. It has a total land area of 30,355 km². Agriculture is the main source of employment to rural people. Agricultural mechanization is dominated by animal draught power. The status of agricultural mechanization in Lesotho was determined by, firstly, carrying out an inventory of farm machinery and equipment using secondary data from the Ministry of Agriculture and Food Security (MoAFS), and secondly, by matching farm power and implements with available arable land to be effectively and efficiently operated in a timely manner. The results showed that the country has a shortfall of tractors and tractor drawn implements for summer agronomic operations. There are sufficient numbers of tractors and tractor drawn implements for winter operations, primarily for winter wheat. In the case of animal draught, the available power is adequate for timely field operations for both summer and winter. The limitation is, however, on the numbers of animal drawn implements, as they cannot cover available summer agronomic operations within the desirable optimal window.

## Introduction

Lesotho is a mountainous Southern African country, landlocked within the Republic of South Africa (RSA) (**Fig. 1**). It lies between latitudes 28ºS and 31ºS, and longitudes 27ºE and 30ºE. The country's total area is 30,355 km² and it is divided into four ecological zones, namely lowlands comprising 17 %, foothills 15 %, mountains 59 % and Senqu River Valley with 9 %. The mountain zone is the largest and it is characterized by very cold winters, yet suitable for grazing and water resource development. The lowlands are densely populated and intensively cultivated, while the foothill zone is less populated. Lesotho is a high altitude country, with the lowest point being Senqu River at 1,388 m above sea level, while Thabana-Ntlenyane which is the highest part is 3,482 m above sea level. According to Lesotho Meteorological Services (2011), average rainfall ranges between 600 - 700 mm from October to April and this summer rainfall is often marked by heavy floods, which are associated with severe soil erosion. Snowfall occurs in the mountains during winter months of May to July. The country has four perennial rivers, namely Makhaleng, Mohokare, Senqu and Phuthiatsana, all of them draining into the Republic of South Africa.

Lesotho Bureau of Statistics (BoS) (2012) indicated that agricultural mechanization is dominated by animal draft power, which cultivates 181,136 ha while tractors cultivate 61,884 ha. The government of Lesotho introduced tractors and implements in 1954 to improve agricultural production, but to date the government has only 89 tractors, 13 maize planters, 11 boom sprayers and 10 combine harvesters, which are operational (MoAFS, 2012). These are expected to serve the whole farming community within the country. There is no continuity in increasing the number of agricultural equipment in the country because of different models introduced by donors which disappear immediately after the termination of donations and subsidies due to unavailability of spares. Since 2001, the government has sold 233 new tractors at subsidized prices to farmers. The intervention by the government brought the total number of private tractors to 1,751 of which 1,508 were operational (MoAFS, 2012). Most of the tractors are used

**Fig. 1** Map of Lesotho

for primary land preparation and the rest for towing trailers and light implements because of their age and condition.

Despite government interventions, food production has been declining for the past ten years. Maize production as a staple food to Basotho has been declining from 158,189 metric tones in 2000/2001 to 128,213 metric tones in 2009/2010. BoS (2011) reported that the main contributing factors for the decline in production include poor land preparation, untimely and poor planting methods, inadequate weeding and delayed harvesting.

The objective of this paper is to determine the status of agricultural mechanization in Lesotho based on inventory of agricultural machinery and equipment, and matching farm power and implements with available arable land to be effectively operated in a timely manner.

## Materials and Methods

The status of agricultural mechanization was determined by procedures as described below.

An inventory of agricultural machinery and equipment in Lesotho was carried out using secondary data from the Ministry of Agriculture's Department of Crops as the main source of data for both government and privately owned farm machines and implements. Other sources of data included Lesotho Bureau of Statistics, Lesotho's Department of Planning and Policy Analysis and farm machinery extension officers. Reports on available farm power sources and implements were reviewed as a basis of the inventory of farm power and implements. The inventory included the common sources of farm power in Lesotho such as tractors, combine harvesters, draught animals and their implements.

Annual agricultural activity reports, in the form of farm data statistics were assessed for determination of total arable land ploughed, how much of arable land is fallow and how much has had a failed crop because of factors such as poor methods of land preparation, untimely planting, inadequate weeding, frost and late harvesting.

Matching farm power and implements with the available arable land to be operated effectively within a specific operational window, completed the determination of the status of agricultural mechanization in Lesotho. This entailed calculations of effective field capacities of tractors and animal drawn implements using their operating speeds, rated widths and field efficiencies. Each draught power source and implement was allotted unique field efficiency and operating speed based on its operational condition.

In the case of animal drawn implements, consideration was given to the fact that in Lesotho a single animal drawn mouldboard plough is pulled by a span of six animals harnessed together, because of their poor body condition. The total ploughed area using animal draught power was determined by the product of number of implements used, effective field capacity of the implement used and total operational hours. Based on the available arable area to be ploughed and the number of draught animals and implements available, a decision was made as to whether there was enough draught power and implements to optimally perform the necessary agronomic operations of ploughing, harrowing and planting.

The optimal ploughing window is influenced by the onset of frost which begins at the end of February, making it imperative to start ploughing during the first week of October, when early rains start. The ploughing ends after 27 days at the end of October, with an operational window of 162 hours for animal power and 216 hours for tractor power. The difference in operational hours between the two modes of draught power emanates from the fact that animals work for only 6 hours per day as they have to be released for grazing, while tractors can work up to 8 hours per day. Harrowing and planting activities are carried out during November with an operational window of 186 hours for animal power and 248 hours for tractor power. Wheat harvesting is carried out using self-propelled combine harvesters during the third week of November to the last week of December. This provides an operational window of 387 hours.

## Results and Discussion

**Major Crops and Cropping Intensity**

Agriculture is the main source of employment for rural people who are engaged in crop and animal husbandry. Lesotho farming system comprises of crop and livestock production, with cropping seasons being mainly summer and winter. Summer cropping season commences from August and ends in January, while winter cropping season starts in February and ends in July. The

**Table 1** Crop production for 2009/2010 Lesotho Agricultural Census

| Year | Name of the crop | Area planted (ha) | Production (metric tones) |
|---|---|---|---|
| 2009/10 | Maize | 151,717 | 128,213 |
| 2009/10 | Sorghum | 36,572 | 23,830 |
| 2009/10 | Beans | 30,364 | 8,899 |
| 2009/10 | Peas | 3,990 | 1,373 |
| 2009/10 | Wheat | 14,088 | 20,119 |

Source: Bureau of Statistics, 2009/2010 Lesotho Agricultural Census, 2012.

planted area under the main cultivated crops is indicated in **Table 1** (BoS, 2012). The total arable land has decreased by 19.7 percent in 2009/2010 Agricultural Census from that of 1999/2000. In 1999/2000 Agricultural Census, arable land was 406,500 ha and maize production was 277,626 metric tones; while in 2009/2010 Agricultural Census, the total cultivated arable land was 324,835 ha with an estimated maize production of 128,213 metric tones (BoS, 2012).

Marake *et al.* (1998) noted that agriculture is the key sector and major source of employment within the country, with 80 percent of the population obtaining income from agriculture, inspite of erratic and declining production and productivity. The share of agriculture to Gross National Product (GNP) fell from 9.3 % to 7.1 % during the period of 2003 to 2009 (BOS, 2011). The decline has been influenced by both crops and livestock subsectors as crops moved from 2.9 % to 1.6 %, while livestock changed from 5.1 % to 4.3 %. The decline results from fluctuations in the output of agriculture, which is closely associated with climatic and other agro-ecological conditions [Ministry of Natural Resources (MNR), 2000]. Crop failure is the main contributing factor for the decline in production as shown in **Table 2**. The causes for crop failure include frost, hail, drought, pests, weeds, untimely planting, poor planting methods and delayed harvesting. During the 2009-2010 cropping season, 243,835 ha of arable land were cultivated, but only 220,313 ha were harvested, while 23,557 ha failed due to frost, hail, drought and late planting according to BoS (2012).

**Table 2** Agricultural Statistics, 2009/2010 Lesotho Agricultural Census

| Description | Area (ha) |
|---|---|
| Total land area | 3,035,500 |
| Arable area | 324,767 |
| Total cultivated area (planted) | 243,835 |
| Total harvested area | 220,313 |
| Total failed area | 23,557 |
| Total fallow area | 81,165 |
| Average individual land size | 5 |

Source: Department of Planning and Policy Analysis and Bureau of Statistics, 2012.

### Tractor Power Situation

The Government of Lesotho introduced tractors and implements in 1954 to improve agricultural production. These machinery and equipment carry out specialized operations such as planting, spraying and harvesting for farmers for a fee, while private sector carries out primary field operations such as primary and secondary tillage. The current inventory from MoAFS (2012) shows that the government has 89 tractors, 13 maize planters, 11 booms prayers and 10 combine harvesters (**Table 3**).

Mantovani *et al.* (2003) stressed that without capital for investment in updated agricultural farm machinery and cut of agricultural subsidies, small-scale farmers struggle to remain in agricultural business. In order to increase and promote private sector capacity, the government of Lesotho has been engaged in selling farm machinery and equipment at subsidized prices to farmers. According to MoFS (2001), farmers are given farm equipment upon the payment of 10 % deposit on ex-Bauer schemes equipment and 25 % on Kennedy Roundtable II (KRII) and Indian Credit Dollar Line (ICDL) equipment. The balance of the loan is paid within the period of 48 months in three monthly installments. According to an agreement contract, the equipment must strictly be used for crop production, failing of which, the government repossesses the equipment without re-reimbursing the farmer the already paid-up amount. Since 2001-2005, the government sold 233 new tractors to farmers with the aim of improving agricultural production. Apart from the government interventions, farmers acquire second hand tractors and implements from the Republic of South Africa and through government public auctions. The total number of privately owned tractors and implements for 2005/2006 is shown in Table 4. These machinery and equipment are expected to cover 324,767 hectares within a ploughing and planting operational window of 396 hours (49.5 days) per year (**Table 4**).

The effective field capacity for field operations using tractor power was determined using the formula by Hunt (2001):

$C = Swe / c$

Where:

$C$ = Effective field capacity, (ha/h)

$S$ = Speed, (km/h)

$w$ = Rated width of implement, (m)

**Table 3** Inventory of government machinery and implements, 2011/2012

| District | Tractors | Ploughs | Discs | Maize planters | Boom sprayers | Combine harvesters |
|---|---|---|---|---|---|---|
| Butha-Buthe | 9 | 9 | 2 | 2 | 2 | 1 |
| Leribe | 11 | 11 | 1 | 2 | 2 | 2 |
| Berea | 11 | 11 | 1 | 3 | 2 | 2 |
| Maseru | 9 | 9 | 1 | 2 | 2 | 2 |
| Mafeteng | 6 | 6 | 2 | 1 | 1 | 1 |
| Mohale's Hoek | 10 | 10 | 2 | 1 | 1 | 1 |
| Quthing | 5 | 5 | 1 | 1 | 1 | - |
| Qacha's Nek | 6 | 6 | 2 | 1 | - | - |
| Thaba-Tseka | 6 | 6 | 1 | - | - | - |
| Mokhotlong | 6 | 6 | 1 | - | - | - |
| Total | 89 | 89 | 15 | 13 | 11 | 10 |

Source: Ministry of Agriculture and Food Security, Department of Crops Services: Agricultural Engineering Division, 2012.

*e* = Field efficiency as a decimal
*c* = Constant, 10

Field efficiencies and operational speeds of most of the tractor drawn implements are low because of old-age tractors (more than ten years), and poor maintenance. For summer cropping, 1,508 tractors and 1,682 mouldboard ploughs can manage to plough only 162,864 ha out of 310,912 ha for 27 days, at 8 hours per day, leaving 148,048 ha unploughed (**Table 5**). This implies that there is a shortfall of 1,580 tractors and 1,406 mouldboard ploughs at the current working rates. Although other implements have higher effective field capacities compared to mouldboard plough, they do not cover 324,767 ha over optimal operational window. The total number of 21 boom sprayers can cover 4,351.2 ha instead of 310,912 ha over a period of 14 days, at a working duration of 4 hours per day. Operational hours for spraying are low because spraying is carried out only during morning hours when wind speeds are low (< 2.2 m/s) in order to avoid wind drifting. Ten combine harvesters with an effective field capacity of 1.6 ha/h each can harvest 6,192 ha of wheat, while the 7,896 ha of wheat requiring to be harvested in Lesotho cannot be harvested on time. There is a shortfall of 13 combines for wheat harvesting.

## Animal Power Situation

The use of animals for land preparation, planting and weeding is still dominating in Lesotho despite that their increased usage is limited by several factors, which include:

- Poor and declining rangeland conditions which lead to lack of pastures for free grazing;
- Insufficient supplementary feeding especially for subsistence farmers;
- High cattle mortality due to poor body conditions which make animals susceptible to diseases;
- High rate of stock theft.

Animal traction is; however, made attractive by the low cost of acquiring and maintaining animals and implements. The number and uses of cattle in Lesotho are shown in **Table 6**.

The number of animal-drawn farm implements in Lesotho is shown in **Table 7**. Animals work for 6 hours per day because they depend on free grazing, as most of the subsistence farmers are not able to provide supplementary feeding.

As far as timeliness using animal

**Table 4** Inventory of privately owned machinery and implements, for 2005/2006

| District | No. of tractors | | Mould-board Ploughs | Disc harrows | Maize planters | Wheat drills | Boom sprayers | Area (ha) |
|---|---|---|---|---|---|---|---|---|
| | Operational | Non-operational | | | | | | |
| Butha-Buthe | 116 | 15 | 127 | 18 | 18 | 3 | 1 | 11,076 |
| Leribe | 392 | 45 | 434 | 104 | 88 | 22 | 5 | 50,554 |
| Berea | 386 | 51 | 393 | 46 | 65 | - | 3 | 45,526 |
| Maseru | 190 | 85 | 274 | 61 | 40 | 16 | 7 | 45,257 |
| Mafeteng | 217 | 28 | 246 | 47 | 15 | 9 | 2 | 49,583 |
| Mohale’s Hoek | 131 | 10 | 128 | 28 | 31 | 15 | 3 | 41,606 |
| Quthing | 34 | 3 | 32 | 3 | 4 | - | - | 19,000 |
| Qacha’s Nek | 20 | 5 | 25 | 5 | 5 | - | - | 10,130 |
| Thaba-Tseka | 11 | 1 | 12 | 1 | 3 | - | - | 15,869 |
| Mokhotlong | 11 | 0 | 11 | - | 2 | - | - | 36,165 |
| Total | 1,508 | 243 | 1,682 | 313 | 271 | 65 | 21 | 324,767 |

Source: Ministry of Agriculture and Food Security, Department of Crops Services: Agricultural Engineering Division, 2012.

**Table 5** Capacities of tractors and tractor-drawn implements to the national arable agricultural production requirements

| Operation | Equipment | Arable area (ha) | No. of equip. | Effective field capacity (ha/h) | Daily oper. hours | Annual oper. days | Covered area (ha) |
|---|---|---|---|---|---|---|---|
| Tillage | Tractors (summer) | 310,912 | 1,508 | 0.5 | 8 | 27 | 162,864 |
| | Tractors (winter) | 14,088 | 1,508 | 0.5 | 6 | 30 | 135,720 |
| | Ploughs (summer) | 310,912 | 1,682 | 0.5 | 8 | 27 | 181,656 |
| | Ploughs (winter) | 14,088 | 1,682 | 0.5 | 6 | 30 | 151,380 |
| | Harrows (summer) | 310,912 | 313 | 1.5 | 8 | 16 | 60,096 |
| | Harrows (winter) | 14,088 | 313 | 1.5 | 6 | 15 | 42,255 |
| Seeding | Planter | 310,912 | 271 | 1.6 | 8 | 15 | 52,032 |
| | Wheat drill | 14,088 | 65 | 1.6 | 6 | 13 | 8,112 |
| Spraying | Boom sprayer | 310,912 | 21 | 3.7 | 4 | 14 | 4,351.2 |
| Harvesting | Combine (wheat) | 14,088 | 10 | 1.6 | 9 | 43 | 6,192 |

**Table 6** Number of cattle and their purpose, 2009/2010 Lesotho Agricultural Census

| Type of animal | Purpose | Number | Percentage |
|---|---|---|---|
| Cow | Milk | 5,743 | 1.84 |
| | Meat | 293 | 0.09 |
| | Draught & milk | 306,601 | 98.07 |
| Total | | 312,636 | 100.00 |
| Ox | Meat | 1,522 | 0.99 |
| | Draught | 151,532 | 99.01 |
| Total | | 153,054 | 100.00 |

Source: Bureau of Statistics, 2009/2010 Lesotho Agricultural Census, 2012.

**Table 7** Number of animal-drawn farm implements, 2009/2010 Lesotho Agricultural Census

| District | Mouldboard ploughs | Harrows | Maize planters | Row cultivators | Area (ha) |
|---|---|---|---|---|---|
| Butha-Buthe | 772 | 91 | 583 | 383 | 11,076 |
| Leribe | 787 | 176 | 671 | 187 | 50,554 |
| Berea | 1,081 | 2,814 | 2,838 | 318 | 45,526 |
| Maseru | 1,400 | 630 | 253 | 420 | 45,257 |
| Mafeteng | 48 | 51 | 182 | 195 | 49,583 |
| Mohale's Hoek | 1,414 | 197 | 241 | 170 | 41,606 |
| Quthing | 1,334 | 181 | 877 | 78 | 19,000 |
| Qacha'sNek | 4,380 | 581 | 291 | 581 | 10,130 |
| Thaba-Tseka | 928 | 252 | 178 | 197 | 15,869 |
| Mokhotlong | 3,233 | 1,267 | 47 | 115 | 36,165 |
| Total | 15,377 | 6,240 | 6,161 | 2,644 | 324,767 |

Source:Bureau of Statistics, 2009/2010 Lesotho Agricultural Census, 2012.

draught power is concerned, effective field capacities of animal drawn implements are low because of low field efficiencies. In Lesotho, six cattle are harnessed together to make one team or span for pulling a single furrow mouldboard plough because of their poor body conditions. According to Makungu and Dihenga (1995), using two or more animals harnessed together results in an efficiency loss of 37 % for a six animal span.

There is a shortfall of 16,610 mouldboard ploughs and excess of 44,369 spans because the draught animal population in Lesotho can only make 15,377 spans which can cover only 149,464 ha out of 310,912 ha for 162 hours in summer (**Table 8**). For planting operation, 6,161 single row planters can manage to cover 121,988 ha in 75 hours out of 310,912 ha and leaving 188,924 ha unplanted.

**Table 8** Capacities of animals and animal-drawn implements to the national arable agricultural production requirements

| Operation | Equipment | Arable area (ha) | No. of equip. | Effective field capacity (ha/h) | Daily oper. hours | Annual oper. days | Covered area (ha) |
|---|---|---|---|---|---|---|---|
| Tillage | Spans (summer) | 310,912 | 76,356 | 0.06 | 6 | 27 | 742,180 |
| | Spans (winter) | 14,088 | 76,356 | 0.06 | 4 | 30 | 549,763 |
| | Ploughs (summer) | 310,912 | 15,377 | 0.06 | 6 | 27 | 149,464 |
| | Ploughs (winter) | 14,088 | 15,377 | 0.06 | 4 | 30 | 110,714 |
| | Harrows (summer) | 310,912 | 6,240 | 0.37 | 6 | 16 | 221,644 |
| | Harrows (winter) | 14,088 | 6,240 | 0.37 | 4 | 15 | 138,528 |
| Seeding | Planter (summer) | 310,912 | 6,161 | 0.22 | 6 | 15 | 121,988 |
| | Planter (winter) | 14,088 | 6,161 | 0.22 | 4 | 13 | 70,482 |
| Weeding | Cultivator | 310,912 | 2,644 | 0.20 | 6 | 27 | 85,666 |

**Table 9** Tractor and implement adequacy for the arable agricultural operations of Lesotho

| Operation | Equipment | Area to cover (ha) | Actual covered area (ha) | Excess | Shortfall |
|---|---|---|---|---|---|
| Tillage | Tractors (Summer) | 310,912 | 162,864 | 0 | 1,580 |
| | Tractors (winter) | 14,088 | 14,088 | 1,340 | 0 |
| | M/ board plough (summer) | 310,912 | 181,656 | 0 | 1,406 |
| | M/board plough (winter) | 14,088 | 14,088 | 1,529 | 0 |
| | Disc harrow (summer) | 310,912 | 60,096 | 0 | 1,330 |
| | Disc harrow (winter) | 14,088 | 14,088 | 240 | 0 |
| Seeding | Planter (summer) | 310,912 | 52,032 | 0 | 1,320 |
| | Wheat drill | 14,088 | 8,112 | 0 | 50 |
| Spraying | B/ sprayer | 310,912 | 4,351.2 | 0 | 1,491 |
| Harvesting | Combine (wheat) | 14,088 | 6,192 | 0 | 13 |

**Status of Agricultural Mechanization**

A comprehensive gauging of draught power and available implements for agronomic operations of crop production in Lesotho using tractor revealed that there is a shortfall of tractors and implements such as ploughs, harrows, planters, sprayers and harvesters, particularly for summer operations (**Table 9**). There is; however, adequate draught power and implements for winter operations, due to small area covered in winter operations for wheat production only.

Lesotho has adequate animals for provision of draught power for both summer and winter agronomic operations (**Table 10**). However, there is a shortage of implements, such as ploughs, harrows, planters and cultivators for summer operations.

## Conclusions

**On the Basis of Results, The Following Conclusions are Drawn:**

Lesotho is under mechanized in terms of tractor power and implements because the available tractors and implements cannot optimally perform all the required agronomic operations of ploughing, planting, harrowing and cultivation within an available operational window for the summer operations. Summer operations are crucial for the growth and development of most crops such as maize, beans and sorghum. There is however adequate tractor power and implements for winter operations, primarily for wheat production.

In the case of animal power, there are sufficient numbers of animals for all the animal powered operations, but the limitation is on inadequate animal drawn implements. The shortage of animal drawn planters is so critical that there is a shortage of these even for winter planting operations. Winter wheat is desirably planted using planters instead of broadcasting to facilitate the use a combine harvester for harvesting.

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**Table 10** Animal power and implement adequacy for the arable agricultural operations of Lesotho

| Operation | Equipment | Area to cover (ha) | Actual covered area (ha) | Excess | Shortfall |
|---|---|---|---|---|---|
| Tillage | Spans (Summer) | 310,912 | 742,180 | 44,369 | 0 |
| | Spans (winter) | 14,088 | 14,088 | 74,399 | 0 |
| | M/ board plough (summer) | 310,912 | 149,464 | 0 | 16,610 |
| | M/board plough (winter) | 14,088 | 14,088 | 13,421 | 0 |
| | Harrow (summer) | 310,912 | 221,644 | 0 | 2,513 |
| | Harrow (winter) | 14,088 | 14,088 | 5,605 | 0 |
| Seeding | Planter (summer) | 310,912 | 121,988 | 0 | 9,542 |
| | Planter (winter) | 14,088 | 14,088 | 4,929 | 0 |
| Weeding | Cultivator | 310,912 | 85,666 | 0 | 6,952 |

# Effect of Deep Placement of Vermicompost and Inorganic Fertilizers in Subsoil at Different Depths on Mustard (*Brassica Juncea*) Crop

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## Absract

A "field pot experiment" was conducted during 2007-08 by digging 2 × 2 m size field pots and packing vermicompost (organic) and NPK (inorganic) fertilizers up to 400 mm depths as per treatment to study the effect of deep placement of fertilizers on mustard crop (var: Kranti). A total of ten different treatments were laid out at the experimental site in randomized block design with three replications each. Application of vermicompost and fertilizers at different depths increased all the crop growth parameters at all the growth stages, and yield attributes over control. Significantly maximum seed yield (2.418 t/ha) was obtained with the application of 50 % N (inorganic) placed at 200 mm + 50 % N (organic) placed at 400 mm, but was at par with treatments i.e. application of 80 % (inorganic) placed at 200 mm and 20 % (inorganic) placed at 400 mm (2.185 t/ha), and also with 100 % (inorganic) placed at 200 mm exactly below the line of sowing (2.166 t/ha). The seed yield was found higher by 35.92 % in the best treatment in comparison to conventional method of broadcasting and mixing of 100 % inorganic fertilizers in top 100 mm depth of soil (1.72 t/ha). However, the fertilizers placement methods did not have significant effect on oil content.

***Key Words:*** Subsoil health management, Subsoiling, Vermicompost placement, Fertilizer placement in subsoil, Mustard crop response

## Introduction

Soil health including subsoil has been presumed of great importance in recent years. Declining subsoil health due to soil compaction, reduction in soil organic matter, occurrence of multi-nutrient deficiencies and indiscriminate use of chemical fertilizers along with many other factors have resulted in stagnation of yield of crops over the years. The fertilizer application is generally accomplished by manual spreading, broadcasting and placement or mixing in upper soil layers of 20-50 mm only (Chauhan and Kumar, 1972; Chichester *et al.*, 1985). The most serious shortcoming of all centrifugal broadcaster is the excessive unequal distribution of fertilizers on the surface of the field as the coefficient of variation even under ideal condition seldom comes within 20-25 % and also the spacing between passes cannot be maintained. 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 and 20 to 30 % of P and K fertilizers are effectively used by crops and the remaining gets evaporated, volatilized, leached to groundwater or fixed with soil as per the properties of their contents (Olsen *et al.*, 1971; Rowse and Stone, 1980). Hence, increasing the fertilizer use efficiency is of paramount importance in reducing the expenditure on fertilizers. The incorporation of P and K in subsoils has positive results as reported by many researchers (McEwen and Johnston 1979; Rowse and Stone, 1980; Godwin and Spoor, 1981; Rababi, 2006 and Mandal, 2007). The relative level of available K in the subsurface layers also influences the availability of K to the crop since roots of various crops penetrate to 1m or even more into many soils, thereby suggesting the application of fertilizers in varying amounts as per the root density (Van Noordwijk and Brouwer, 1991).

Agricultural production has been found to increase with increasing assimilation of inorganic, organic and bio-fertilizers in suitable manner and in proper proportion with proper technology because of non-availability of costly commercial fertilizers.

The deep placement of organic fertilizers either in solid or liquid forms would all together eliminate the losses due to soil erosion or otherwise and enrich the subsoil with organic matter. This would enhance the proliferation of roots and increase the microbial activities which would improve the subsoil health on long term basis. At present, the technologies for application of organic manures and amendments into subsoil are not available in India and need to be developed. Organic matter has a strong positive effect on infiltration of water into the soils. This effect is mainly due to decrease in bulk density and improvements in aggregation and structure (MacRae and Mehuys, 1985). Bulk density has direct correlation with compacted stress. However, incorporation of organic matter in a compacted soil lowers its bulk density and increase the electric charge, thus increasing the repulsive forces between soil particles and improvement in soil aggregate strength (Soane, 1990). This area of research has not attracted the attention of scientists. Thus, keeping in view the above problems, the present 'field pot' study was conducted to examine the response of deep placement of organic manure and inorganic fertilizers including subsoil on mustard crop.

## Materials and Methods

The experiment was conducted at Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (India) in the year 2007-08. The experimental field is situated at latitude of 29º *N* and longitude of 79.3º *E* at 243.84 m above mean sea level and lies in a narrow belt in Tarai region of Uttarakhand in the foothills of Shivalik ranges of the Himalayas. The silty clay loam soil had neutral pH, 0.89 % organic carbon, 216 kg/ha available *N*, 20.5 kg/ha available P, 306 kg kg/ha available *K* and 24.9 kg/ha available *S* (Singh *et al*., 2005). The following ten treatments were selected for experimental study:

$T_1$ = 100 % (inorganic)[*] + Mixing in 100 mm, depth (Control)

$T_2$ = 50 % (inorganic) + 50 % (organic)[**] + Mixing in 100 mm, depth

$T_3$ = 100 % (inorganic) placed at 100 mm, depth

$T_4$ = 100 % (inorganic) placed at 200 mm, depth

$T_5$ = 80 % (inorganic) placed at 200 mm and 20 % (inorganic) placed at 400 mm, depths

$T_6$ = 50 % *N* (inorganic) placed at 200 mm + 50 % *N* (organic) placed at 400 mm, depths

$T_7$ = 100 % (inorganic) + Mixing (100 mm) and hard pan formed manually at 150 mm, depth

$T_8$ = 100 % (inorganic) + Mixing (100 mm) and hard pan formed manually at 250 mm, depth

$T_9$ = 50 % *N* (inorganic) + 50 % *N* (organic) placed at 200 mm, depth and

$T_{10}$ = 100 % (inorganic) placed at 200 mm exactly below the line of sowing

[*]*Inorganic*: *N*, *P* and *K* @120:40:20 kg/ha through Urea, SSP and MOP

[**]*Organic:* Vermicompost (*N:* 2.4 %, *P:* 1.1 %, *K:* 1.0 %, *Organic carbon:* 10-20 %, *Na:* 0.2 %, *Mg:* 0.6 % etc.)

**Fig. 1** Manual digging and removal of soil from pits for placement of fertilizers as per treatment

**Fig. 2** Experimental field at 50 DAS

The soil from each plot of 2 × 2 m size of ploughed land was dug manually as per treatment and removed (**Fig. 1**). Known quantities of vermicompost or inorganic fertilizers or their combination were placed at the desired depths as per treatment and covered with loose soil for preparation of seed and root beds. The seeds were sown in rows at 300 mm apart and after about 15 days of germination, thinning of plants was carried out to maintain 20 plants in each row with a total of 120 plants in each pot of 2 × 2 m size. The soil samples were collected from three different locations of the field for determining the initial moisture content and dry soil bulk density at various depths. Full dose of *P* and *K*, and 50 % of *N* was mixed with the soil in top 100 mm depth in treatments $T_1$ and $T_2$. For other treatments, full dose of P and *K*, and 50 % of *N* was placed as per experimental design while 25 % of *N* was mixed in the top soil for initial vigour of plants. The remaining 50 % *N* in treatments $T_1$ and $T_2$ was applied in two split doses during first and second irrigations, whereas

**Table 1** Initial soil moisture content and dry bulk density of experimental field before digging the field pots

| Depth, mm | Moisture content, % (d. b.) | Dry bulk density , Mg/m$^3$ |
|---|---|---|
| 0 - 100 | 11.37 | 1.54 |
| 100 - 200 | 14.38 | 1.89 |
| 200 - 300 | 17.74 | 1.91 |
| 300 - 400 | 17.68 | 1.76 |
| 400 - 500 | 21.00 | 1.60 |
| 500 - 600 | 25.00 | 1.39 |
| Sem± | 0.26 | 0.03 |
| CD at 5 % | 0.82 | 0.08 |

the remaining 25 % *N* in other treatments was applied through top dressing during second irrigation. All the crop growth parameters and yield attributes were noted as per standard procedures recommended for field experiments. A view of experimental field is shown in **Fig. 2**.

## Results and Discussion

The initial soil moisture content and dry bulk density at various depths are presented in **Table 1**. The moisture content and bulk density were found to vary from 11.37 to 25.00 % and 1.39 to 1.91 Mg/m$^3$ for depth range of 0-100 to 500-600 mm, respectively. The soil moisture content at the time of harvesting varied significantly in different layers and treatments (**Table 2**). For a particular treatment, the moisture content was found to increase with the depth. In top 0-100 mm depth, the minimum moisture content (11.39 %) was found in $T_1$ and the maximum was 13.19 % in $T_2$ due to mixing of vermicompost with

**Table 2** Variations in soil moisture content and bulk density at different depths in various treatments at harvest

| Treatment | Depths of soil, mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0-100 mm | | 100-200 mm | | 200-300 mm | | 300-400 mm | |
| | Moisture content, % | Bulk density, Mg/m$^3$ | Moisture content, % | Bulk density, Mg/m$^3$ | Moisture content, % | Bulk density, Mg/m$^3$ | Moisture content, % | Bulk density, Mg/m$^3$ |
| $T_1$ | 11.39 | 1.47 | 14.32 | 1.59 | 17.61 | 1.77 | 17.63 | 1.71 |
| $T_2$ | 13.19 | 1.44 | 14.80 | 1.58 | 17.65 | 1.78 | 17.67 | 1.67 |
| $T_3$ | 12.34 | 1.48 | 14.42 | 1.51 | 17.61 | 1.74 | 17.65 | 1.67 |
| $T_4$ | 12.61 | 1.46 | 14.84 | 1.57 | 17.96 | 1.76 | 17.98 | 1.69 |
| $T_5$ | 12.23 | 1.46 | 15.15 | 1.56 | 17.65 | 1.58 | 18.26 | 1.56 |
| $T_6$ | 12.39 | 1.45 | 15.65 | 1.51 | 17.80 | 1.54 | 18.50 | 1.52 |
| $T_7$ | 12.42 | 1.46 | 14.35 | 1.52 | 17.63 | 1.84 | 17.72 | 1.75 |
| $T_8$ | 12.25 | 1.45 | 14.79 | 1.55 | 17.65 | 1.65 | 17.66 | 1.75 |
| $T_9$ | 12.60 | 1.48 | 15.85 | 1.52 | 18.45 | 1.72 | 18.50 | 1.74 |
| $T_{10}$ | 12.05 | 1.47 | 14.92 | 1.48 | 17.63 | 1.76 | 17.65 | 1.77 |
| Sem± | 0.26 | 0.02 | 0.10 | 0.03 | 0.11 | 0.02 | 0.06 | 0.02 |
| CD at 5 % | 0.77 | NS | 0.27 | NS | 0.32 | 0.07 | 0.18 | 0.04 |

**Table 3** Growth parameters of mustard crop as affected by application of vermicompost and inorganic fertilizers at different depths

| Treat-ment | Average plant height, m | | | Average plant girth, mm | | | Average number of branches | | | | | | Av. root length, mm | Date of flower-ing |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | At 45 DAS | At 90 DAS | At harvest | At 45 DAS | At 90 DAS | At harvest | At 45 DAS | At 90 DAS | | At harvest | | | | |
| | | | | | | | P | P | S | P | S | T | | |
| $T_1$ | 0.818 | 1.717 | 1.827 | 7.8 | 12.3 | 12.3 | 5.8 | 5.8 | 8.3 | 5.7 | 7.7 | 3.3 | 162 | 02.12.07 |
| $T_2$ | 0.982 | 1.792 | 1.897 | 9.1 | 12.0 | 12.4 | 7.9 | 5.9 | 7.0 | 6.1 | 7.2 | 3.9 | 186 | 02.12.07 |
| $T_3$ | 0.783 | 1.794 | 1.947 | 10.3 | 12.8 | 12.9 | 7.8 | 6.9 | 8.0 | 6.6 | 7.1 | 4.5 | 183 | 04.12.07 |
| $T_4$ | 0.778 | 1.954 | 2.000 | 14.3 | 14.6 | 14.8 | 10 | 9.3 | 8.0 | 8.7 | 8.6 | 3.4 | 262 | 05.12.07 |
| $T_5$ | 0.728 | 1.977 | 2.090 | 15.2 | 16.5 | 16.7 | 9.5 | 9.8 | 14.3 | 9.7 | 14.5 | 5.6 | 368 | 13.12.07 |
| $T_6$ | 0.796 | 2.061 | 2.210 | 16.1 | 17.5 | 17.7 | 9.3 | 9.3 | 13.8 | 9.0 | 13.7 | 6.4 | 371 | 13.12.07 |
| $T_7$ | 0.617 | 1.839 | 1.910 | 8.2 | 12.7 | 12.9 | 7.2 | 7.7 | 7.7 | 8.3 | 10.0 | 5.9 | 167 | 11.12.07 |
| $T_8$ | 0.764 | 1.850 | 1.957 | 13 | 14.4 | 14.9 | 8.2 | 8.1 | 11.4 | 8.3 | 13.1 | 4.9 | 190 | 11.12.07 |
| $T_9$ | 0.762 | 1.918 | 1.950 | 14.7 | 15.4 | 15.7 | 9.2 | 10.5 | 11.9 | 7.3 | 13.6 | 6.7 | 240 | 05.12.07 |
| $T_{10}$ | 0.648 | 1.953 | 1.976 | 14.2 | 16.3 | 16.5 | 9.3 | 8.5 | 14.2 | 7.9 | 14.2 | 6.9 | 243 | 13.12.07 |
| Sem± | 20.26 | 0.015 | 0.007 | 0.21 | 0.43 | 0.14 | 0.44 | 0.21 | 0.15 | 0.15 | 0.18 | 0.12 | 13.69 | - |
| CD at 5 % | 60.19 | 0.05 | 0.02 | 0.61 | 1.27 | 0.40 | 1.30 | 0.62 | 0.46 | 0.45 | 0.53 | 0.37 | 40.67 | - |

P = Primary, S = Secondary, T = Tertiary inorganic fertilizers which retained more water. Similarly for 100-200 and 200-300 depths, it was found significantly maximum as 15.85 and 18.45 % in $T_9$, respectively. However, for 300-400 mm depth maximum moisture content (18.50 %) was obtained in case of 50 % *N* (inorganic) placed at 200 mm + 50 % *N* (organic) placed at 400 mm depths ($T_6$). The moisture content was found higher by 1.8, 1.53, 0.84 and 0.87 percentage units for 0-100, 100-200, 200-300 and 300-400 mm depths, respectively in the treatments in which vermicompost was applied either separately or in combination with inorganic fertilizers as compared to Control ($T_1$). It is also evident from **Table 2** that the bulk density of soil reduced to a maximum of 6.92 % in case of 100% (inorganic) placed at 200 mm exactly below the line of sowing ($T_{10}$) for 100-200 mm depth, and 12.99 % and 11.11 % in case of 50 % *N* (inorganic) placed at 200 mm + 50 % *N* (organic) placed at 400 mm depths ($T_6$) for 200-300 and 300-400 mm depths, respectively as compared to Control ($T_1$).

The growth parameters of various treatments are presented in **Table 3** and visuals at 65 DAS are illustrated in **Fig. 3**. It is vividly clear that there is a significant increase in all the growth parameters, viz. plant height, plant girth and number of branches with deep placement of inorganic and organic fertilizers ($T_5$ and $T_6$) in comparison to Control ($T_1$). It is also clear that the date of flowering has been delayed by 10-12 days in treatments having deep placement of fertilizers. It is clear from **Fig. 4** that the application of vermicompost and inorganic fertilizers had highly significant effect on root length of mustard crop.

The root length obtained in treatment $T_6$ (371 mm) was significantly higher but was at par with treatment T5 (368 mm). However, significantly lower root length of 162 mm was obtained in treatment $T_1$ (Control). The yield attributes of various treatments presented in **Table 4** revealed that the number of siliquae per plant (409.2) and test weight (5.10 g) were significantly higher in case of treatment ($T_6$) in comparison to treatment $T_1$ with values of 263.8 and 4.11 g, respectively. The seed and stover yields varied significantly in various treatments. The highest seed yield (2.418 t/ha) and stover yield (8.355 t/ha) were obtained with 50 % N (inorganic) placed at 200 mm + 50 % N (organic) placed at 400 mm ($T_6$) in comparison to treatment $T_1$ (Control) having the lowest seed yield of (1.779 t/ha). The oil content was not affected significantly in different treatments, but the oil yield was significantly influenced by different application methods of fertilizers. It is also clear from data in **Table 4** that the oil yield was found to be maximum (0.976 t/ha) in $T_6$ which was significantly higher by 32.79 % with that of control treatment $T_1$ (0.735 t/ha).The study further revealed that the treatments $T_5$, $T_{10}$ and $T_9$ were found equally good in terms of seed yield and stover yield, and therefore, these treatments were recommended for further investigation

**Fig. 3** A view of treatments after 65 days of sowing (DAS)

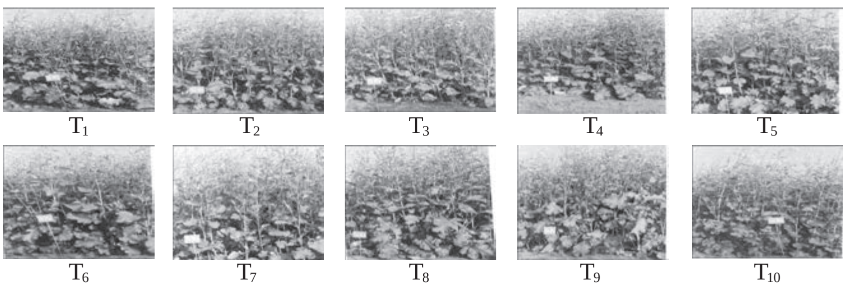


**Fig. 4** Root growth of mustard crop at harvest in different treatments under 'field pot experiment'

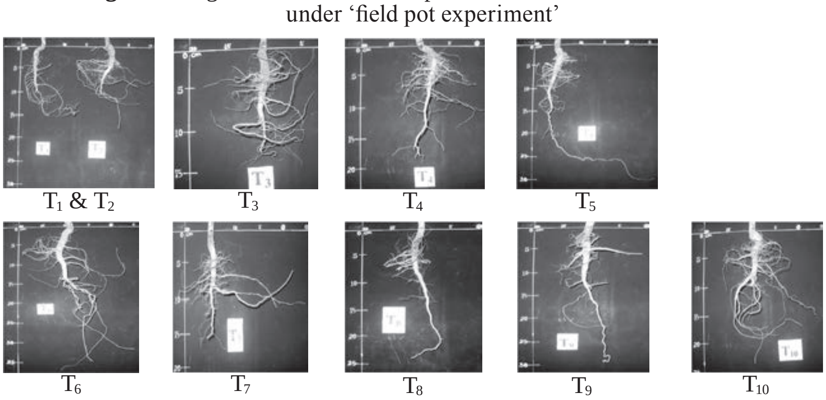


**Fig. 5** Subsoiler-cum-differential rate fertilizer applicator (Thakur *et al.*, 2008)

**Fig. 6** Developed subsoiler-cum-vermicompost and soil amendments applicator

**Table 4** Yield attributes of mustard crop affected by application of vermicompost and inorganic fertilizers at different depths

| Treatments | No. of Siliquae per plant | Seed yield, t/ha | Stover yield, t/ha | Harvest ndex, % | 1000 grain weight, g | Oil content, % | Oil yield, t/ha |
|---|---|---|---|---|---|---|---|
| $T_1$ | 263.80 | 1.779 | 6.404 | 21.74 | 4.11 | 41.30 | 0.735 |
| $T_2$ | 277.67 | 1.893 | 6.807 | 21.76 | 4.25 | 41.33 | 0.782 |
| $T_3$ | 264.07 | 1.799 | 5.796 | 23.69 | 4.57 | 41.80 | 0.752 |
| $T_4$ | 288.07 | 2.091 | 7.652 | 21.46 | 4.38 | 41.27 | 0.863 |
| $T_5$ | 368.20 | 2.185 | 7.945 | 21.57 | 4.67 | 41.03 | 0.896 |
| $T_6$ | 409.20 | 2.418 | 8.355 | 22.45 | 5.10 | 40.37 | 0.976 |
| $T_7$ | 269.07 | 1.884 | 5.966 | 24.00 | 4.45 | 41.27 | 0.777 |
| $T_8$ | 343.47 | 2.057 | 7.602 | 21.30 | 4.52 | 40.67 | 0.836 |
| $T_9$ | 384.53 | 2.112 | 7.756 | 21.40 | 5.22 | 41.50 | 0.880 |
| $T_{10}$ | 405.80 | 2.166 | 7.980 | 21.35 | 4.84 | 40.47 | 0.877 |
| Sem ± | 12.12 | 0.100 | 0.520 | 1.07 | 0.16 | 0.38 | 0.040 |
| CD at 5 % | 36.02 | 0.281 | 1.530 | NS | 0.47 | NS | 0.110 |

on a large experimental field in a mechanized system of crop production with a suitably designed machine for metering and placement of organic and inorganic fertilizers at different depths in above manner. In the present study, deep soil loosening and application of vermicompost in loosened subsoil zone showed considerable positive effects on improvement of soil properties and proved to be a superior combination to ameliorate compaction effects. Soil moisture content increased and bulk density decreased in the range of 0.84 to 1.80 percentage units and 6.92 to 12.99 %, respectively in treatments where vermicompost and fertilizers were placed in subsoil at various depths, while it increased the crop yield from 17.54 to 35.92 % over Control. The higher yield may be due to additional nutrient supplied through vermicompost and inorganic fertilizers at various depths in loosened soil as well as improvement in physical and biological properties of soil (Majumdar *et al*., 2002).

This in fact revealed the need for design and development of suitable machines for application of organic manures and inorganic fertilizers in above ratios at varying depths of placement. Already, a machine named as ‘Pant-ICAR subsoiler-cum-differntial rate fertilizer applicator’ has been developed and is being patented (Mandal, 2007 and Thakur *et al*., 2008). This machine (**Fig. 5**) can burst open the subsoil up to a depth of 500 mm and simultaneously places inorganic granular fertilizers in two different ratios and depths i.e. 80 % of fertilizers at 200-250 mm depths with two shallow leading winged tines and 20 % of fertilizers at 400-500 mm depths with the central subsoiling winged tine. It can also place equal amount of fertilizers at above two depths. After replacing the main subsoiling central tine with an additional tine, similar to leading tines, it becomes a chiseler-cum-fertilizer applicator and can place equal amount of fertilizers at the same depth of 200-250 mm. So, it is a versatile machine and is being used extensively for subsoiling and its fortification with nutrients. Also, based upon the findings of ‘field pot experiment’, another machine named as ‘Pant-ICAR subsoiler-cum-vermicompost and soil amendments applicator’ has been developed (**Fig. 6**). This machine places organic manures such as vermicompost, pressmud, FYM etc and inorganic fertilizers either separately or in their combination at depths up to 400 mm. It has also been evaluated for placement of soil amendments such as lime, gypsum, fly ash, rice husk, cement etc. into the subsoil at different depths up to 400 mm. This machine is also being patented.

## Conclusions

Deep placement of organic and inorganic fertilizers at different depths of 200 mm and 400 mm either 100 % inorganic or 50 % N through organic and remaining 50 % *N* through inorganic has shown significant increase in growth parameters as well as yield attributes and yield of mustard crop. The seed yield and oil yield were found higher by 35.92 and 32.79 % with that of conventional method of broadcasting and mixing of 100 % inorganic fertilizers in top 100 mm soil depth. It may be inferred from above results that degraded subsoils can be converted into productive land by incorporation of organic manures and amendments while subsoiling.

**Acknowledgments**

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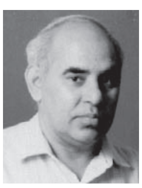
## News

# Congratulation!



### Prof. Gajendra Singh honoured with National Fellowship of Soil Conservation Society of India

Prof. Gajendra Singh has been awarded national fellowship of Soil Conservation Society of India for his vast experience and contribution in the field of management and natural resources through sustainable farm mechanisation. This honour was bestowed on him on the occasion of national conference on “Natural Resource Management for Food Security and Rural Livelihood” during 10-13 Feb 2015 at New Delhi.

*“ISAE E-Newsletter” February 2015*

# Optimization of an Industrial Type Prototype Shelf Dryer by Response Surface Methodology "A Case Study for Potato"

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## Abstract

By adopting the central-composite experiment design, the response surface methodology was used to optimize operating conditions of potato drying in the industrial prototype shelf dryer. The independent variables are thickness of potato slices (3.64, 5.0, 7.0, 9.0, and 10.36 mm), air temperature (43.18, 50, 60, 70 and 76.8 ºC) and air velocity (1.05, 1.6, 2.4, 3.2 and 3.74 m/s). The investigating responses are drying time, drying ratio and energy consumption. The analysis of variance (ANOVA) was performed to identify the significant parameters affecting the potato drying. Drying temperature of sliced potatoes is the most influential operating parameters that significantly control the drying time and ratio. Slice thickness is the most influential parameter that significantly controls energy consumption of potato.

***Key Words:*** Potato, shelf dryer, drying, optimization, response surface methodology.

## Introduction

Drying is one of the most important operations in the food and chemical industries. Drying is defined by Mujumdar (1997) as that unit operation which converts a liquid, solid or semi-solid feed material into a solid product of significantly lower moisture content. According to Lewicki and Jakubczyk (2004), drying assures microbial stability of the product and minimizes chemical and physical changes of the material during storage. Natural sun drying is practiced commonly in World and Turkey, but has some problems about the contamination by dirt and dust and infestation by insects, rodents and other animals. Because of the drying process should be undertaken in closed equipment, to improve the quality of the final products (Ertekin and Yaldiz, 2004). Potatoes are popular daily product that is prevalently consumed due to its nutritional value and sensory properties (Hassini *et al.*, 2002). Also potatoes are the fourth most important vegetable crop for human nutrition in the world. Potato is dried to moisture content of approximately 12 % (w.b) (Aghbashlo *et al.*, 2009). The dehydrated potato has a great importance in the foodstuff industry. Potatoes are manufactured as fried product, dried product and sterilized product that have a considerable commercial success in many countries (Hassini *et al.*, 2002).

Response surface methodology (RSM) is a collection of statistical and mathematical techniques that has been successfully used for developing, improving and optimizing processes (Raissi, 2009). RSM comprises a group of statistical techniques for empirical model building and model enterprise. By careful design and analysis of experiments, it seeks to relate a response, or output variable, to the levels of a number of predictors, or input variables, that affect it (Box and Draper, 2007). El-Aouar *et al.* (2006) reported that RMS presupposes the use of experimental design techniques to investigate and learn about the functional form of the process or system that involves one or more response variables that are influenced by various factors or independent variables. RSM has been reported to be an effective tool for optimizing a process when the independent variables have a combined effect on the desired response. The objective of RSM is to optimize this response and it has been extensively applied for drying of foods such as parboiled rice (Elbert *et al*., 2001), mushroom (Giri and Prasad, 2007), yam slice (Lin *et al*., 2007), potato (Eren and Kaymak-Ertekin, 2007), pear (Perez-Francisco *et al*., 2008), coroba (Corzo *et al*., 2008), hazelnut (Uysal *et al*., 2009), apple (Han *et al*., 2010), plum (Koocheki and Azarpazhooh, 2010). RSM is also an important tool in process and product improvement.

In this study, the aim is to investigate the effects of air temperature, velocity and slice thicknesses on the drying time, drying rate and energy consumption during drying of potato in industrial type prototype shelf dryer. Models were installed for air temperature, velocity and slice thicknesses with each one of these as a function of the process variables and to find the optimum operating conditions that maximize drying rate and minimize drying time and energy consumption for industrial type prototype shelf dryer.

**Table 1** Levels of variables

| Units Name | Variable | | Level | | | | |
|---|---|---|---|---|---|---|---|
| | | | −1.68 | −1 | 0 | 1 | 1.68 |
| Air Velocity (m/s) | $X_1$ | V | 1.05 | 1.6 | 2.4 | 3.2 | 3.74 |
| Air Temp. (ºC) | $X_2$ | T | 43.18 | 50 | 60 | 70 | 76.8 |
| Slice Thick. (mm) | $X_3$ | S | 3.64 | 5.0 | 7.0 | 9.0 | 10.36 |

## Material and Methods

Potato was obtained from a local market in Antalya, Turkey. Potatoes weighing between 70 and 80 g were selected and stored at 7 ºC before the experiments. Potatoes were removed from the refrigerator and equilibrated to room temperature before being cut into slices. The independent variables were thickness of potato slices (3.64, 5.0, 7.0, 9.0 and 10.36 mm), air temperature (43.18, 50, 60, 70 and 76.8 ºC) and air velocity (1.05, 1.6, 2.4, 3.2 and 3.74 m/s). The moisture content determination was done by drying the samples at 70 ºC until the weight became constant. Moisture content was determined as (Yagcioglu, 1999);

$$M = (W_w - W_d) / W_w \qquad (1)$$

where M is moisture content (w.b), $W_w$ is weight of fresh potato slices (g) and $W_d$ is weight of dried potato slices (g).

Drying rate was determined as a function of drying time for various slice thicknesses of potato samples as (Akpinar *et al*., 2003a).

$$dM/dt = (M_{t+dt} - M_t) / dt \qquad (2)$$

where dM/dt is drying rate (g water/g dry matter. h), $M_t$ is moisture content at t time (g water/g dry matter), $M_{t+dt}$ is moisture content at t + dt (g water/g dry matter), dt is time interval (h).

The following formula is used to determine energy consumption (Kocabıyık and Demirtürk, 2008);

$$E_C = E_T / W_r \qquad (3)$$

where $E_C$ is specific energy consumption (kWh/kg water), $E_T$ is total energy (MJ) and $W_r$ is the mass of the water which is removed from the sample (kg water).

The drying experiments were carried out using a prototype shelf dryer which could be regulated to any desired drying air temperature between 0 and 200 ºC-in the Department of Agricultural Machinery, Faculty of Agriculture, University of Akdeniz, Antalya, Turkey (**Fig. 1**). The dryer consisted of an airflow unit, fifteen heating element and a control unit (heating, air flow and lift, an electrical fan, two temperature measurement sensors, six trays and drying chamber). The products were spread in thin layers on trays. The desired drying air temperature was attained by electrical resistance heating and controlled by the heating control unit. The air passed from the heating unit and then to the drying chamber. Weighing of samples inside the drying chamber was done manually using an electronic balance with a capacity of 0 and 500 g with an accuracy of ± 0.001 g. The moisture content of the raw potato was between 79.01 and 83.05 % and dried to final moisture content of 10 % (w.b).

### Experimental Design

The variables chosen for convective drying experiments were air velocity (V), air temperature (T) and slice thickness (S). Variable levels were chosen with pre-drying experiments. Twenty experiments were performed according to a

**Fig. 1** Schematic view of prototype shelf dryer

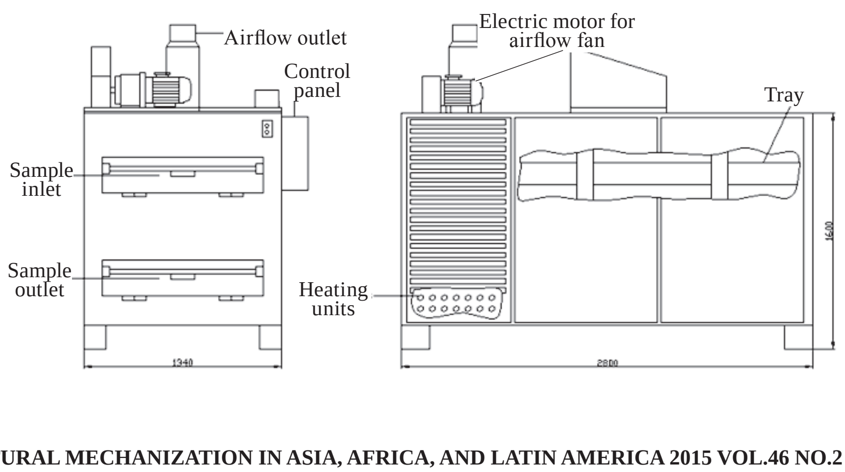


**Table 2** The experimental design and data for the response surface analysis

| Varible Levels (X) | | | Responses (Y) | | |
|---|---|---|---|---|---|
| V | T | S | Drying time, min | Drying rate, g water/g dry matter.h | Energy consumption, kWh/kg water |
| 1 | 1 | 1 | 390 | 11.00 | 5.44 |
| 1 | 1 | -1 | 190 | 22.15 | 2.68 |
| 1 | -1 | 1 | 530 | 8.10 | 9.51 |
| 1 | -1 | -1 | 620 | 7.02 | 10.48 |
| -1 | 1 | 1 | 560 | 7.80 | 7.31 |
| -1 | 1 | -1 | 300 | 13.88 | 4.93 |
| -1 | -1 | 1 | 590 | 7.17 | 6.64 |
| -1 | -1 | -1 | 490 | 8.79 | 5.38 |
| 1.68 | 0 | 0 | 580 | 7.42 | 3.84 |
| -1.68 | 0 | 0 | 410 | 10.68 | 3.67 |
| 0 | 1.68 | 0 | 150 | 28.22 | 6.67 |
| 0 | -1.68 | 0 | 670 | 6.39 | 4.10 |
| 0 | 0 | 1.68 | 570 | 7.47 | 5.31 |
| 0 | 0 | -1.68 | 270 | 15.41 | 5.22 |
| 0 | 0 | 0 | 480 | 9.11 | 5.55 |
| 0 | 0 | 0 | 480 | 8.98 | 5.55 |
| 0 | 0 | 0 | 540 | 7.78 | 6.30 |
| 0 | 0 | 0 | 540 | 8.11 | 6.30 |
| 0 | 0 | 0 | 510 | 8.58 | 6.22 |
| 0 | 0 | 0 | 570 | 7.07 | 6.21 |

**Table 3** Regression coefficients of the second-order polynomial model for the response variables (in coded units)

| Factors | Estimated coefficients | | |
|---|---|---|---|
| | DT | 1/DR | 1/E |
| Constant | 519.30 | 0.12169 | 0.16800 |
| V | 5.60 | 0.00128 | 0.00451 |
| T | -121.90 | -0.02832 | 0.01472 |
| S | 84.50 | 0.01922 | -0.02239 |
| $V^2$ | -4.20 | -0.00167 | 0.02646 |
| $T^2$ | -34.30 | -0.00810 | 0.00194 |
| $S^2$ | -30.70 | -0.00692 | -0.00059 |
| VT | -43.80 | -0.00957 | 0.04420 |
| VS | -8.70 | -0.00213 | -0.01226 |
| TS | 33.70 | 0.00715 | -0.02632 |
| $R^2$ | 0.902 | 0.880 | 0.575 |

**Table 4** ANOVA for different models

| Factors | P-values | | |
|---|---|---|---|
| | DT | 1/DR | 1/E |
| Constant | < 0.0001 | < 0.0001 | < 0.0001 |
| V | 0.748 | 0.773 | 0.773 |
| T | < 0.0001 | < 0.0001 | 0.356 |
| S | < 0.0001 | 0.001 | 0.172 |
| $V^2$ | 0.801 | 0.700 | 0.104 |
| $T^2$ | 0.062 | 0.082 | 0.898 |
| $S^2$ | 0.089 | 0.130 | 0.969 |
| VT | 0.074 | 0.120 | 0.050 |
| VS | 0.698 | 0.713 | 0.551 |
| TS | 0.155 | 0.233 | 0.215 |
| Lack-of-Fit | 0.054 | 0.163 | < 0.0001 |

second-order central composite rotatable design (CCRD) with five levels of each variable. **Table 1** gives the levels of variables in coded and actual units and **Table 2** indicates the combination of variable levels used in the CCRD. Experimental set for the dependent variables was randomized to minimize the effects of the unexplained. The center point in the design was repeated six times to calculate the reproducibility of the method (Giri and Prasad, 2007). The determination of the centre point for each independent variable was based on drying conditions. According to Yazgi and Degirmencioglu (2007), the response surface problem usually centers on an interest in some response Y, which is a function of k independent variables $\xi_1$, $\xi_2$, $\xi_3$ that is,

$Y = f(\xi_1, \xi_2, ........, \xi_k)$.................(4)

Response surface methodology was used to determine the relative contributions of $X_1$, $X_2$, and $X_3$ to various responses under study such as drying times (DT), drying rate (DR) and energy consumption (E) of dehydrated potato. The second order polynomial response surface model (**Eqn. 4**) was fitted to each of the response variables:

$$Y_k = b_{ko} + \sum_{i=1}^{3} b_{ki}X_i + \sum_{i=1}^{3} b_{kii}X_i^2 + \sum_{i \neq j=1}^{3} b_{kij}X_iX_j \quad (5)$$

where $b_{k0}$, $b_{ki}$, $b_{kii}$, and $b_{kij}$ are the constant, linear, quadratic, and cross-product regression coefficients, respectively, and *Xi* are the coded independent variables of $X_1$, $X_2$, and $X_3$ (Giri and Prasad, 2007; Perez-Francisco *et al.*, 2008; Myers *et al.*, 2009).

The coding of independent variables into *Xi* is expressed by the following **Eqn**;

$X_i = (\xi_1 - \xi^*) / d_s$.......................(6)

where $\xi_i$ is the actual value in original units $\xi^*$ is the mean value (centre point) and $d_s$ is the step value (Yazgi and Degirmencioglu, 2007).

## Results and Discussion

The experimental data of various responses during convective drying of potato are presented in **Table 2**. The estimated regression coefficients of the quadratic polynomial models (**Eqn. 5**) for various responses are given in **Table 3**.

Analysis of variance indicated that the models are highly significant at $P < 0.05$ for all the responses. The lack of fit did not result in a significant P-value in case of drying time and drying rate indicating that the models are sufficiently accurate for predicting these responses. However, for energy consumption, the lack of fit was significant, indicating that a high proportion of the variability was not explained by the data. Therefore, the models for drying time and drying rate were not adequate (**Table 4**).

**Drying Time**

The drying time of potato slices

varied between 150 and 670 min. Some researchers determined drying time of potatoes for different dryers. This drying time was between 460 and 740 min, 200 and 450 min (Akpinar *et al.*, 2003b; Iciek and Krysiak, 2009) for convective dryer, 50 and 108 min for low-pressure superheated steam drying (Kingcam *et al.*, 2008) and 90 and 105 min for fluidized bed dryer (Bakal *et al.*, 2011). Different drying time occurs due to the use of samples with different drying techniques or dryers. The regression equation describing the effect of the process variables on drying time of potato slices in terms of actual levels of the variables are given in **Table 3**.

$$DT = 519.3 + 5.6V - 121.9T + 84.5S - 4.2V^2 - 34.3T^2 - 30.7S^2 - 43.8VT - 8.7VS + 33.7TS \quad (7)$$

It can be observed from ANOVA test that air temperature and slice thickness were the significant variables for regression equation describing the drying time at $P < 0.05$. The effect of air velocity for regression equation of the drying time was not significant. Air temperature (T) was the main factor affecting drying time, as revealed by corresponding regression coefficient and P value.

The negative effect of air temperature and positive linear effect of slice thickness suggested that lower drying time are observed when high air temperature level is combined with low value of slice thickness during convective drying of potato (**Figs. 2** and **3**). Increase in of drying air temperature reduces the drying time required to reach any given level of moisture rate since the heat transfer increases. Similar results were obtained by different authors on drying various vegetables (Troncoso and Pedreschi, 2007; Lee and Hsieh, 2008; Aghbashlo *et al.*, 2010; Taheri-Garavand *et al.*, 2011). Thin sliced products dried faster for the reduced distance the moisture itinerary and increased surface area submitted for the given volume of the product. This finding is consistent with results in the literature (Ertekin and Yaldiz, 2004; Sacilik and Elicin, 2005; Heybeli and Ertekin, 2008; Kaya *et al.*, 2009; Doymaz and Gol, 2011).

### Drying Rate

The drying rate of potato slices

**Fig. 2** Effect of air temperature and slice thickness on drying time (air velocity 2.4 m/s)

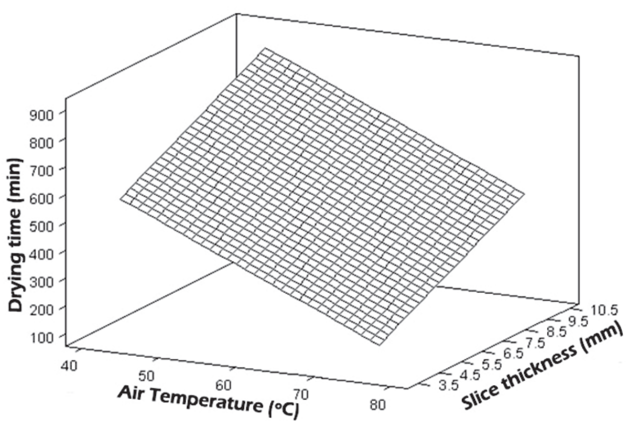



**Fig. 3** Effect of air temperature and velocity on drying time (slice thickness 7 mm)

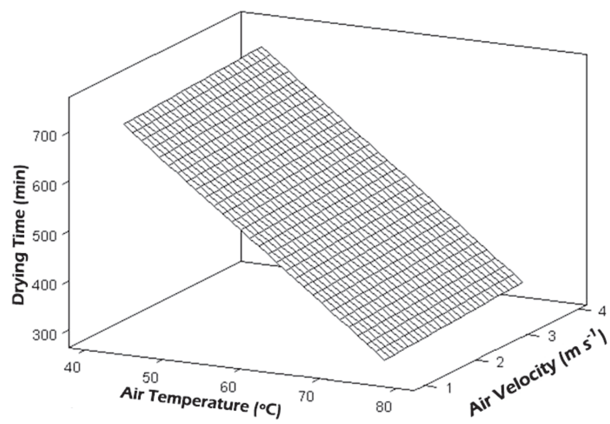



**Fig. 4** Effect of slice thickness and air temperature on drying rate (air velocity 2.4 m/s)

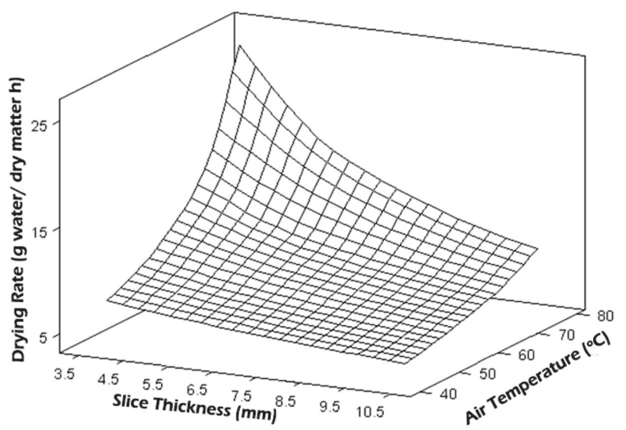
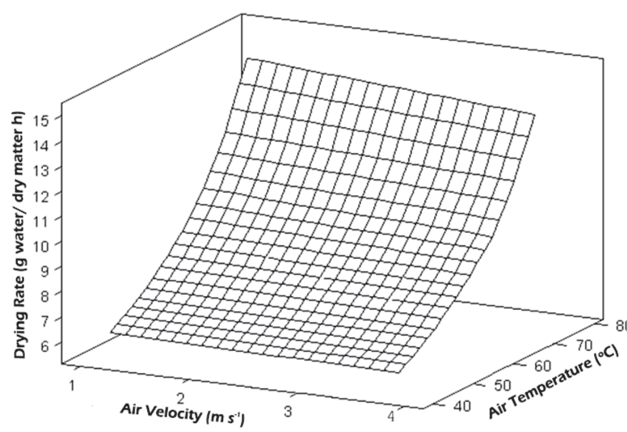



**Fig. 5** Effect of air velocity and temperature on drying rate (slice thickness 7 mm)



varied between 6.39 and 28.22 gwater/g.dry matter.h. Lin *et al.* (2005) in far-infrared radiation on the freeze-drying the drying rate were found 0.4344, 0.6633 and 1.259 g/h for 10, 17.5 and 25 mm of sweet potato cube, respectively. Yadollahinia *et al.* (2009) determined that a high initial drying rate was observed following by a gradual decrease as the slices approached the dried state and very close drying rates were also identified. The following relationship was developed for drying rate with the actual levels of process variables:

$$DR^{-1} = 0.12169 + 0.00128V - 0.02832T + 0.01922S - 0.00167V^2 - 0.0081T^2 - 0.00692S^2 - 0.00957VT - 0.00213VS + 0.00715TS \quad (8)$$

While air temperature and slice thickness were significant variables for regression equation describing the drying rate ($P < 0.05$), the effect of air velocity for regression equation describing the drying rate was not significant. Air temperature was the main factor affecting drying rate, as revealed by corresponding regression coefficient and *P* value.

The negative effect of slice thickness and positive effect of air temperature suggested that higher drying rate was observed when high air temperature is combined with low value of slice thickness during convective drying of potato (**Figs. 4** and **5**). In other words, the drying rate increased with the increase in drying air temperature and decrease in slice thickness. The main factor affecting the drying rate of the previous researchers' reports indicated that drying air temperature was significant factor by Akpinar *et al.* (2003b) for potato, Kaymak-Ertekin (2002) for red pepper, Sacilik and Elicin (2005) and Heybeli and Ertekin (2007) for apple, Chinenye (2009) for cocoa bean, Kulshreshtha *et al.* (2009) for mushroom, Zielinska and Markowski (2010) for carrots.

In case of all the treatments, the drying rate decreased continuously throughout the drying period. The constant rate period was not observed in any of the experimental runs for the entire duration. The drying of potato slices took place in the falling rate period. Similar type of observation was reported by Chirife and Cachero (1970) and Singh *et al.* (2006) for tapioca roots and potato, respectively, where in two falling rate period but no constant rate period were observed. The absence of a constant drying rate period is not unexpected.

## Energy Consumption

The energy consumption of convective dryer for drying of potato slices varied between 2.68 and 10.48 kWh/kg of water. Aghbashlo *et al.* (2008) found the energy consumption to vary between 3.75 and 24.04 kW.

The following relationship was developed for energy consumption with the actual levels of process variables:

$$E^{-1} = 0.1680 + 0.00451V + 0.01472T - 0.02239S + 0.02646V^2 + 0.00194T^2 - 0.00059S^2 + 0.04426VT - 0.02632TS \quad (9)$$

Constant of the model is only one significant factor on regression equation describing the energy consumption at $P < 0.05$ (**Table 4**). Air velocity, air temperature and slice thickness are not significant variables for regression equation of the energy consumption. Slice thickness (S) was the main factor affecting energy consumption as revealed by corresponding regression coefficient and *P* value.

The positive effect of slice thickness and the negative effect of air velocity and air temperature suggest that higher energy consumption are generally observed when high level slice thickness is combined with lower value of air velocity or air temperature during convective drying of potato (**Figs. 6** and **7**). The finding is consistent with results in the literature. The energy consumption decreased with increasing drying air temperature (Alibas, 2006; Sharma and Prasad, 2006). Reduction in drying time was observed with the increasing drying air tem-

**Fig. 6** Effect of air temperature and slice thickness on energy consumption (air velocity 2.4 m/s)

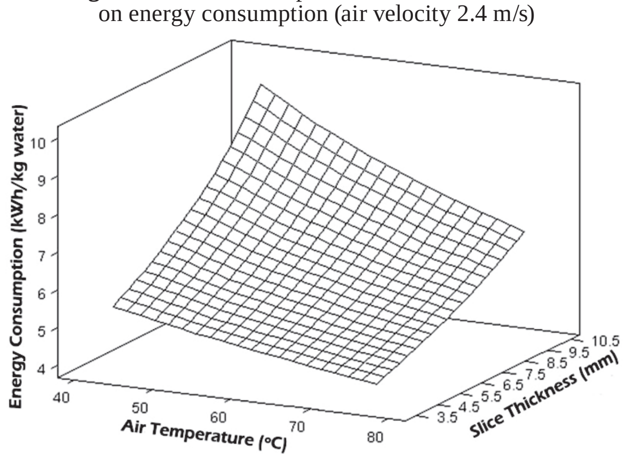



**Fig. 7** Effect of air velocity and slice thickness on energy consumption (air temperature 60 ºC)

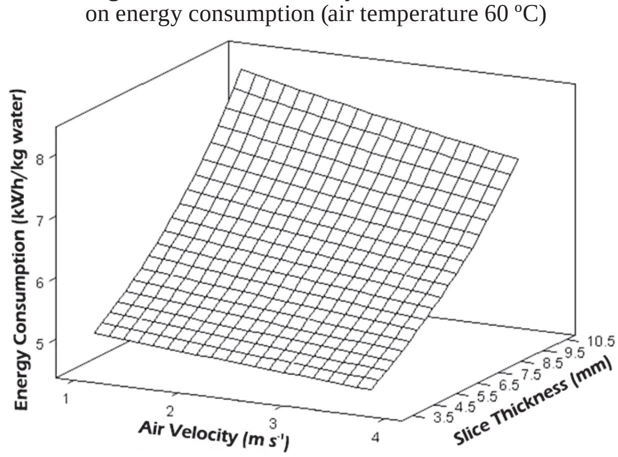


**Table 5** Solution for optimum conditions

| Air velocity (m/s) | Air Temperature (ºC) | Slice thickness (mm) | Drying time (min) | Drying rate (g water/g dry matter. h) | Energy consumption (kWh/kg water) | Desirability |
|---|---|---|---|---|---|---|
| 2.40 | 61.150 | 6.99 | 502.73 | 9.01 | 5.9 | 0.916 |

**Table 6** Comparison of experimental with predicted values

| Response | Predicted value | Actual value ± SD | Standard error | Mean difference | Sig. (2 tailed) |
|---|---|---|---|---|---|
| Drying time (min) | 502.73 | 510.0 ± 30.0 | 13.42 | 7.27 | 0.617 |
| Drying Rate (g water/ g dry matter. h) | 9.01 | 8.51 ± 0.56 | 0.25 | -0.49 | 0.12 |
| Energy consumption (kWh/kg water) | 5.9 | 6.02 ± 0.37 | 0.15 | 0.12 | 0.45 |

perature. As a result of reduction in drying time energy consumption was reduced.

Low slice thickness and high air temperature and air velocity was needed to decrease energy consumption. According to Erbay and Icier (2008) higher temperature increase the heat losses significantly due to the insufficient isolation of some driers. Our findings of air temperature conflict with Erbay and Icier (2008), Dincer and Sahin (2004), Akpinar (2004), Akpinar *et al*. (2005) and Colak and Hepbasli (2007) because in this study the higher air temperature were needed for lower energy consumption. The reason for this result was probably the sufficient isolation of the drier used. The effect of air velocity and temperature on energy consumption was lower than the effect of slice thickness. The increase in air velocity and temperature caused the decrease in energy consumption. Therefore, high temperature drying was needed for low energy consumption.

**Optimization of Convective Drying for Potato and Experimental Validation**

The desired goals for each factor and response (target values of air velocity, temperature and slice thickness for maximum drying rate and minimum drying time and energy consumption) were chosen (for equal weight of 1) and the program was run for the optimum conditions and the obtained solutions are presented in **Table 5**. The table indicates the optimum conditions of independent variables and also the predicted values of the responses. Composite desirability of solution was 0.916.

Drying experiments were performed using the derived optimum drying conditions and drying time, drying rate and energy consumption for convective potato drying were determined. The experimental values (mean of 3 measurements) as well as the predicted values of various attributes are presented in **Table 6**. One sample t-test was conducted using the statistical software SPSS to compare the mean actual values of the responses with the predicted values. No significant differences between the actual and predicted values were found.

## Conclusions

While the air temperature in an industrial type shelf dryer had a most pronounced effect on drying time and rate of potato slices, slice thickness had most pronounced effect on energy consumption. Drying time reduced with increasing temperature with reducing size, the drying rate increased with the increase in drying air temperature and decrease in slice thickness. Higher energy consumptions are generally observed when high level slice thickness is combined with lower value of air velocity or air temperature during convective drying of potato.

The optimum condition was found to be 2.40 m/s air velocity, 61.15 ºC air temperature and 6.99 mm potato slice thickness. The experimental response values were found in close proximity to the predicted values from fitted models. The effect of convective drying parameters on drying time, rate and energy consumption can be effectively analyzed and optimization of the process can be done using RSM, with a minimum number of experiments. The optimum drying conditions with the process can be scaled for the variables.

**Acknowledgement**

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■■

## News

# Congratulation!

**Prof. Linus Opara received CIGR awards in 2014**

Prof. Linus Opara (Co-operating Editor of AMA) received CIGR award for his contribution for spreading CIGR mission and goals into African.

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# Effect of Long-Term Conservation Tillage on Soil Physical Properties and Soil Health under Rice-Wheat Cropping System in Sub Tropical India



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## Abstract

Tillage influence soil aggregation, microbial activity in the soil and enhance the oxidation of soil organic carbon (SOC). A long term study was carried out to investigate the impact of conservation tillage on soil aggregates, SOC and microbial biomass carbon (MBC) in rice (Oryza sativa)-wheat (Triticum aestivum) cropping system at experimental station of Varanasi, Uttar Pradesh under the aegis of All India Co-ordinated Research Project (AICRP) of Integrated Farming Systems (IFS) during 2003-10. The four rice crop establishment techniques i.e., direct seeding in zero tilled soil ($P_1$), wet seeding of sprouted rice seed with drum seeder in puddled condition ($P_2$), manual transplanting in puddled soil ($P_3$) and mechanical transplanting in puddled soil ($P_4$) served as horizontal treatments while four tillage practices in wheat (i.e. $T_1$- rotavator till drill, $T_2$- conventional sowing, $T_3$- strip till drilling, $T_4$- Zero till drilling) served as vertical treatments in strip plot design with three replications. Total water stable aggregates (WSA)(> 0.053 mm) in the soil at surface 0-15 cm depth, ranged between 69.92 and 88.78 % in rice crop, while in winter crop it varied between 74.62 and 83.57 %. According to mean weight diameter (MWD) different treatments in regard to crop establishment technique of rice could be ranked in the order $P_1 > P_4 > P_2 > P_3$ and $T_4 > T_3 > T_1 > T_2$ in wheat strip regarding tillage practices. However, the MWD decreased drastically in lower soil depth. The SOC ranged from 4.06 to 5.67 g $kg^{-1}$ in soil samples from rice plots and from 4.32 to 5.24 g $kg^{-1}$ in different tillage treatments in wheat at surface 0-15 cm layer. SOC contents in direct seeding in zero tilled rice strip (5.67 g $kg^{-1}$) and zero till drill in wheat strip (5.24 g $kg^{-1}$) were significantly higher than other treatments in all soil depth. The MBC of direct drilling zero tilled (441 μg $g^{-1}$) in rice strip and zero till drill in wheat strip (395 μg $g^{-1}$) had the highest values while the manually transplanted-puddled (383 μg $g^{-1}$) rice and conventional wheat sowing had the lowest values (334 μg $g^{-1}$) at all the depths. The differences were significant in at P < 0.01 for both SOC and MBC and ranked in order of $P_1 > P_2 > P_4 > P_3$ of rice crop strip and $T_4 > T_3 > T_1 > T_2$ in wheat crop strip under 0-15 cm soil depth. The decrease in SOC an average all treatments was about 51 and 89 percent from layer 0-15 to 15-30 and 30-45 cm, respectively. The interaction effects of P at same level of T and T at same level of P treatments on MWD, SOC and MBC were significant ($P < 0.01$) in 0-15 and 15- 30 cm soil depth.



***Key Words:*** Zero tillage; Conservation tillage; Crop establishment method; Rice- wheat cropping system


## Introduction

Rice (Oryza sativa)-wheat (Triticum aestivum) cropping system is the major cropping system in South Asia occupies about 13.5 million hectares (Mha) in the Indo-Gangetic Plains (IGP) in India, Pakistan, Bangladesh and Nepal and another 10 Mha in China (Sharma and Bhushan, 2001). The productivity of this system is declining and its sustainability is of utmost importance for ensuring regional food security.

The puddling of rice fields is one of the most common practices in India that consumes time, water, energy and results in subsurface compaction, which is not conducive to the succeeding wheat crop (Bajpai and Tripathi, 2000; Bhattacharyya *et al*., 2009). The newer approach is now focuses on conservation agriculture in which 'no' or 'zero' tillage is propagated as it is characterized by higher soil organic carbon (SOC) sequestration (Dick *et al*., 1991), better aggregation (Lal *et al*., 1994) and improved pore size distribution (Bhattacharyya *et al*., 2006). Conservation tillage practices, such as no tillage, can increase soil aggregation and improve microbial biomass and activities (Minoshima *et al*., 2007; Zibilske and Bradford, 2007; Wright *et al*., 2008).

Agricultural land management practices are one of the most significant anthropogenic activities that change the soil characteristics, including physical, chemical and biological properties and process. The microbial biomass can be altered by the different agricultural resource conservation practices (Liebig *et al*., 2006; Yao *et al*., 2006; Elfstrand *et al*., 2007; Frey *et al*., 2007; Govaerts *et al*., 2008; Lauber *et al*., 2008). However, improved knowledge of how tillage management regulates the interaction between soil aggregates and microbial community structure and function may help to understand better the mechanisms that lead to increase SOC sequestration and improving fertility in agricultural ecosystems. Conservation tillage is widely adopted to improve sustainability of agricultural ecosystems and reduce input cost and saves natural resources. However, differences in soil structure and function often develop as a result of application of conventional tillage or reduced tillage regimes. Previous studies have shown that microbial biomass is higher in soils under no till plot compared to conventional tillage practices (Alvear *et al*., 2005; Bausenwein *et al*., 2008; Spedding *et al*., 2004).

Microbial biomass provides an indicator of SOC degradation since it has a turnover time of less than one year. It responds rapidly to changes in conditions and management that alter SOC levels. Tillage affects both soil microbial biomass carbon and mineralizable carbon because it allows fast breakdown of SOC. Tillage reduces aggregation (Jastrow, 1996) and results in decline of SOC (Sainju *et al*., 2006; Bossuyt *et al*., 2002). Tillage breaks down aggregates and alters aggregate size distribution, typically by decreasing the proportion of macroaggregates in soil (Wright *et al*., 2008). Grandy and Robertson (2006) observed that years of soil regeneration can be lost after a single conventional tillage (CT) event, hence, no tillage (NT) is an option that can be used to reduce the adverse effects of CT.

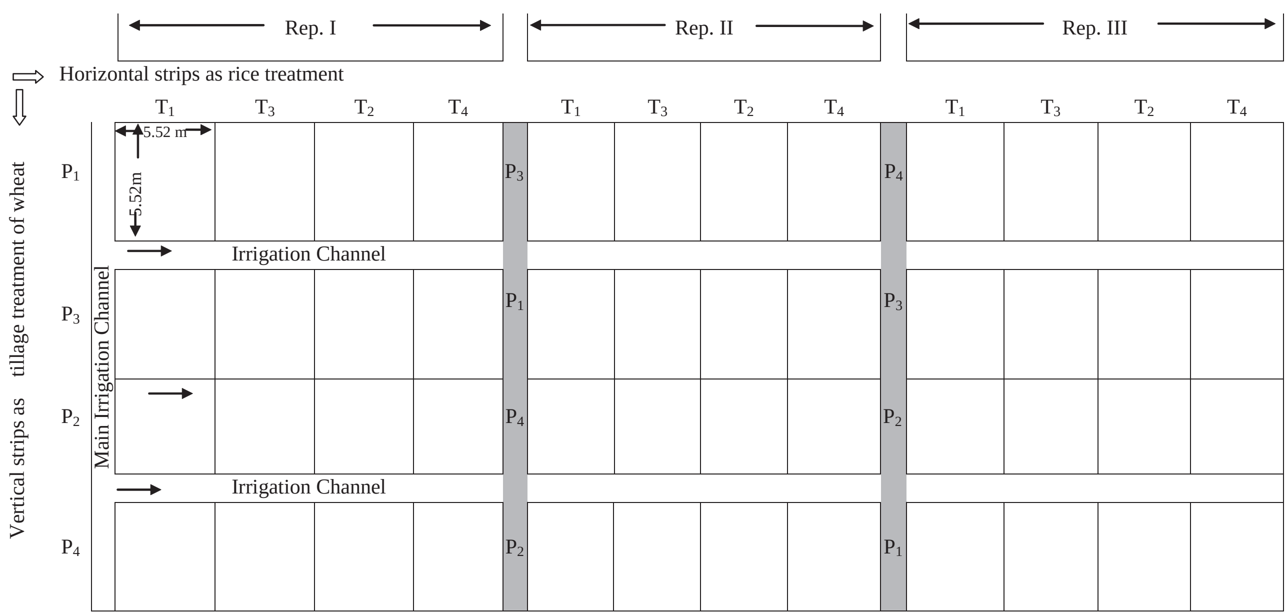
The objectives of this study were to determine the impact of different resource conservation technologies consisting establishment techniques of rice and different tillage practices of wheat on SOC, MBC and soil aggregation in rice-wheat cropping system.

## Material and methods

### Experimental Site

A field experiment was conducted for 7 years (2003-04 to 2009-10) at the research farm of Banaras Hindu University, Varanasi (25º18´N and 80030 E, 128.93 m above sea mean level), Uttar Pradesh, on a sandy

**Fig. 1** Layout of the permanent experimental plots



loam soil (Typic Haplaquept) under the aegis of All India Co-ordinated Research Project on Integrated Farming System (AICRP IFS). The soil (0-15 cm deep) of the experimental site had a pH of 7.9, EC of 0.22 dS $m^{-1}$, bulk density of 1.34 Mg $m^{-3}$, SOC of 4.0 g $kg^{-1}$, available N of 185.2 kg $ha^{-1}$, $NaHCO_3$ extractable P of 12.1 kg $ha^{-1}$ and 1N ammonium acetate extractable K of 212.0 kg $ha^{-1}$. As per the mean of 50 years, (1960-2010) the annual rainfall of the area remains around 1081 mm.

### Experimental Design and Treatments

The trials consisted of four rice planting treatments in the rainy season and four tillage practices in winter wheat. The four rice crop establishment techniques in rainy season were $P_1$: direct drilling rice in zero tilled plot, $P_2$: sprouted rice seeded with drum seeder –wet seeded rice, $P_3$: manual transplanting in puddled plot, $P_4$: mechanical transplanting in puddled plot and four tillage practices in wheat during winter season were $T_1$: rotavator till drilling, $T_2$: conventional tilled sowing, $T_3$: strip till drilling, $T_4$: zero till drilling. They were placed in strips using strip plot design (Gomez and Gomez, 1984) and replicated three times. In this design, the rice crop establishment treatments were in strip plot of 5.5 × 22.1 m size horizontally within each replication. In winter season, sowing of wheat under varying tillage options, the same size strips were assigned randomly and arranged vertically or perpendicular to rice crop establishment plots within each replication to understand the interaction effect in a measured area of 5.5 × 5.5 m (**Fig. 1**).

### Crop Management

The sowing of rice (cultivar PHB-71) in direct drilling under zero tilled plots before onset of monsoon ($P_1$), in nursery to get seedlings for manual transplanting ($P_3$) and mechanical transplanting by self propelled transplanter ($P_4$) and sprouted seeds (24 hour soaked) used in drum seeder ($P_2$) were performed on same day. The seed rate for rice in planting treatments was 70 kg $ha^{-1}$ for direct seeding, 35 kg $ha^{-1}$ sprouted seeds through drum seeder in wet field, while, 30 and 20 kg $ha^{-1}$ seeds were used for growing of seedling for manual and self propelled transplanter, respectively. Direct seeding of rice in dry bed was performed under no till conditions of field through zero till drill while for transplanting (both through manual and mechanical transplanter) and drum seeder in puddled field consisted of one cultivator, two puddling and one planking. Twenty one days old seedlings were used for manual and mechanical transplanting. The seedlings were raised on mat type nursery and these seedlings were used for transplanting through self propelled rice transplanter. All direct seeded plots received frequent irrigation to keep the soil wet. After harvesting of rice, a pre sowing irrigation was given to the all plots to ensure optimum moisture in the soil at sowing. The wheat was sown by different methods immediately after harvest of rice. The rotavator till drilling ($T_1$) was done after one pass of rotavator. However, in conventional sowing of wheat ($T_2$), one cultivator, two harrows followed by one planking were performed before sowing of wheat. Under zero till drilling of wheat ($T_4$), sowing was done directly without land preparation in standing rice stubbles of about 20 cm height (about 2 Mg $ha^{-1}$) which was left in field as a mulch and for strip till drilling of wheat, sowing ($T_3$) was done directly using strip till drill in single pass where about 7.5 cm strip was tilled through PTO operated rotary blade in front of tynes before sowing.

The fertilizer dose for both crops i.e. rice and wheat were 120: 60: 60 kg N: P: K $ha^{-1}$. Full dose of P through single super phosphate and K through muriate of potash were applied at the time of land preparation in tilled plots, before seeding in the zero tilled plots. Nitrogen was applied in three splits, ½ at field preparation, ½ in two equal splits at the active tillering and at the panicle initiation stages of crops (rice and wheat) growth. The experimental plots were kept weed free in rice crop in zero till drill after application of glyphosate (N-(phosphonomethyl)-glycine) at the rate 1.5 kg $ha^{-1}$ active ingredient as post emergence non selective herbicide followed by two hand weedings at 20 and 40 DAS (day after sowing) and in drum seeded rice, pendimethalin (N-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine) 30 EC at the rate of 1.25 kg $ha^{-1}$ and manually and mechanically transplanted, butachlor (N-(butoxymethyl)-2-chloro-N (2,6-diethylphenyl) acetamide) 50 EC at the rate of 2 kg $ha^{-1}$ active ingredient after 5 days after transplanting followed by one hand weeding 30 days after transplanting. Wheat (cultivar HUW-234) was sown during the second week of November in all the years. Sulfosulfuron 1-(4,6-dimethoxypyrimidin-2-yl)-3-[(2-ethanesulfonylimidazo 1,2-a]pyridine) sulfonyl] urea at rate 30 g active ingredient $ha^{-1}$ was applied 30 days after sowing in all plots to control weeds in wheat. Full dose of P and K were applied at the time of sowing, and N was applied in two equal splits at the time of sowing and grown root initiation stages. Both rice and wheat crop were irrigated according to the irrigation schedules in the different treatments.

### Soil Sampling and Analysis

Undisturbed soil cores (15 cm long and 7.6 cm diameter) in triplicates were obtained from 0-15, 15-30, 30-45 and 45-60 cm soil layers after the harvest of wheat in 2010 from each plot randomly. Composite samples were prepared after mixing different cores of each depth. Samples were air-dried and each sample was divided in two parts. One part was used for chemical analysis while the other was used for determination of aggregate size distribution (Yoder, 1936) and mean weight diameter (MWD). SOC was estimated using the $K_2Cr_2O_7$ wet-digestion method (Walkey and Black, 1934).

Soil MBC was analyzed by the fumigation extraction method (Anderson and Ingram, 1993; Vance *et al*., 1987). For MBC each sample was further sub-divided into two equivalent portions, one was fumigated for 24 h with ethanol free chloroform and other was the unfumigated control. Both fumigated and unfumigated soils were shaken for 30 min with 0.5 M $K_2SO_4$ (1 : 4 soil : extraction ratio) and centrifuged and filtered through a membrane filter with 0.45 µm pores. The MBC in the soil extracts was determined originally by wet digestion with $K_2Cr_2O_7$ followed by back- titration with ferrous ammonium sulphate and was calculated as difference in extractable C before and after fumigation using a KC value 0.45 (Wu *et al*., 1990).

Soil water stable aggregates (WSA) > 0.053 were determined by wet sieving procedure (Cambardella and Elliot, 1993). Approximately 100 g of air dried soil were taken for aggregate (diameter 5-8 mm) analysis. Soil samples were immersed in water on a nest of sieves (4.76, 2.0, 1.0, 0.50, 0.25, 0.11 and 0.053 mm) for 10 min before start of wet sieving action. The sieve nest was then clamped and secured to the drum. The assembly was oscillated up-down by a pulley arrangement for 30 min at a frequency of 30-35 cycles min-1 with a stroke length of 4 cm in salt free water inside the drum. The WSA retained on the sieves were then backwashed into pre-weighed containers, oven-dried at 50 ºC for 2-3 days, and weighed. The weight of oven dried soil of each size was expressed as percentage of the total weight. The mean weight diameter (MWD, mm) was calculated using the following relationship (van Bavel, 1949):

$$MWD = (\sum^{n}_{i=1} wixi) / W$$

Where, $w_i$ is the weight of soil of the $i^{th}$ size fraction $x_i$ is the average diameter of that size class and W is the total weight of aggregates of all the size classes (n).

Geometric mean diameter (GMD, mm) was calculated as follows.

$$GMD = exp\ [\sum_{i=1}^{n} (Wi \times In\ (Xi)]$$

Where $W_i$ is the mean proportion of aggregates fraction *i* and $X_i$ is the mean diameter of aggregate fraction *i* (Kremper and Chepil 1965).

Statistical analysis was carried out using the methods suggested by Gomez and Gomez (1984). All parameters were analysed as a strip plot model (rice crop as horizontal and wheat crop as vertical factor). Tillage treatments for each crop establishment means were separated using least significant difference (LSD) at P < 0.01. The correlation matrix was developed among SOC, MBC, WSA and MWD. Regression equations were developed between SOC, MBC with WSA and MWD.

## Results and Discussion

**Effect of Tillage and Crop Establishment on Aggregate Size Distribution, Mean Weight Diameter (Mwd) and Geometric Mean Diameter (Gmd)**

The total soil water stable aggregate (WSA) > 0.053 mm, at 0-15 cm depth, ranged between 69.92 and 88.78 % which ranked in order $P_1 > P_2 > P_4 > P_3$ in different rice strip as well as in wheat strip, ranged between 74.62 and 83.57 % that ranked in order $T_4 > T_3 > T_1 > T_2$ and both

**Table 1** Effect of tillage and planting management on aggregate size distribution (%) of soil at (0-15) cm soil depth in rice-wheat cropping system

| Treatment | Total WSA | > 4.76 mm | 1.0-2.0 mm | 0.5-1 mm | 0.25-0.5 mm | < 0.25 mm | Macro aggregate | > 0.11 mm | < 0.053 mm | Micro aggregate |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_1$ | 88.78 | 8.80 | 8.41 | 10.74 | 12.31 | 14.48 | 51.07 | 17.97 | 19.74 | 37.71 |
| $P_2$ | 81.88 | 4.97 | 5.85 | 9.00 | 9.71 | 12.26 | 39.52 | 18.99 | 23.37 | 42.36 |
| $P_3$ | 69.92 | 4.69 | 5.53 | 4.67 | 4.84 | 8.04 | 21.13 | 22.64 | 26.15 | 48.79 |
| $P_4$ | 73.36 | 5.96 | 5.65 | 12.53 | 6.57 | 10.27 | 27.79 | 20.92 | 24.66 | 45.57 |
| LSD (P = 0.05) | 3.06 | 0.33 | 0.23 | 0.06 | 0.44 | 0.60 | 1.67 | 1.55 | 0.50 | 1.68 |
| LSD (P = 0.01) | 4.63 | 0.49 | 0.35 | 0.09 | 0.67 | 0.91 | 2.53 | 2.35 | 0.76 | 2.55 |
| $T_1$ | 76.51 | 5.39 | 6.69 | 7.81 | 7.62 | 10.72 | 32.23 | 20.48 | 23.80 | 44.28 |
| $T_2$ | 74.62 | 3.07 | 5.80 | 9.13 | 6.97 | 9.96 | 29.82 | 20.51 | 24.29 | 44.80 |
| $T_3$ | 79.24 | 6.95 | 6.31 | 8.72 | 8.81 | 11.60 | 35.52 | 20.32 | 23.40 | 43.73 |
| $T_4$ | 83.57 | 9.01 | 6.64 | 11.27 | 10.04 | 12.77 | 41.94 | 19.20 | 22.42 | 41.62 |
| LSD (P = 0.05) | 1.11 | 0.08 | 0.37 | 0.05 | 0.27 | 0.41 | 0.98 | 0.50 | 0.46 | 0.32 |
| LSD (P = 0.01) | 1.68 | 0.12 | 0.56 | 0.08 | 0.41 | 0.62 | 1.49 | 0.76 | 0.70 | 0.49 |

**Horizontal strip for rice crop:** $\mathbf{P_1}$- Direct drilling in zero tilled plot, $\mathbf{P_2}$- Seeding sprouted rice with drum-puddled plot, $\mathbf{P_3}$- Manual transplanting–puddled plot, $\mathbf{P_4}$- Mechanical transplanting–puddled plot. **Vertical strip for wheat crop:** $\mathbf{T_1}$- Rotavator till drilling, $\mathbf{T_2}$- Conventional tilled sowing, $\mathbf{T_3}$- Strip till drilling, $\mathbf{T_4}$- Zero till drilling.
**LSD**- Least Significant Difference at (P < 0.05 and P < 0.01)

strip treatments had significant values ($P < 0.01$). The treatment $T_4$ was significantly ($P < 0.01$) higher than other treatments (i.e. $T_1$, $T_2$ and $T_3$) which were significantly ($P < 0.05$) at par. However, $T_1$ and $T_3$ were statistically ($P < 0.05$) at par but higher than $T_2$. In lower depth (15-30 cm), the total WSA had similar trend but lower aggregate value. Among the different treatments (**Table 1**), in rice strip, the proportion of micro-aggregates (42.36, 48.80, 45.57 %) was greater as compared to macro-aggregates (39.53, 21.13, 27.79 %) in $P_2$, $P_3$ and $P_4$, respectively, however, $P_1$ had smaller proportion of micro-aggregates (37.71 %) than macro-aggregates (51.07 %) under surface (0-15 cm) depth. In wheat strip, higher proportion of micro-aggregates was observed which ranked in the order of $T_2 > T_3 > T_1$ than macro-aggregates. Among the macro-aggregates (0.25-4.76 mm), it ranked in order $P_1 > P_2 > P_4 > P_3$ in rice strip, whereas, in wheat crop, it ranked in order $T_4 > T_3 > T_1 > T_2$ and both had significant (at $P < 0.01$) differences each other and vice versa in micro-aggregates. The reason may be because of intensity of mechanical manipulation of soil through tillage had given higher proportion of micro-aggregates. Whereas, in 15-30 cm soil depth (**Table 2**), irre-

**Table 2** Effect of tillage and planting management on aggregate size distribution (%) of soil at (15-30) cm soil depth in rice-wheat cropping system

| Treatment | Total WSA | > 4.76 mm | 1.0-2.0 mm | 0.5-1 mm | 0.25-0.5 mm | < 0.25 mm | Macro aggregate | > 0.11 mm | < 0.053 mm | Micro aggregate |
|---|---|---|---|---|---|---|---|---|---|---|
| $P_1$ | 72.62 | 1.05 | 1.27 | 3.51 | 6.42 | 13.33 | 25.57 | 18.68 | 28.37 | 47.05 |
| $P_2$ | 69.62 | 0.68 | 2.03 | 4.27 | 6.21 | 13.55 | 26.74 | 20.09 | 22.79 | 42.88 |
| $P_3$ | 47.48 | 0.65 | 1.14 | 2.58 | 2.16 | 10.16 | 16.69 | 9.51 | 21.28 | 30.79 |
| $P_4$ | 59.88 | 0.92 | 1.73 | 3.96 | 3.23 | 11.14 | 20.98 | 14.30 | 24.60 | 38.90 |
| LSD (P = 0.05) | 3.13 | NS | 0.77 | 0.44 | 1.52 | 4.71 | 3.20 | 0.01 | 0.84 | 0.84 |
| LSD (P = 0.01) | 4.74 | NS | 1.17 | 0.67 | 2.30 | 7.13 | 4.85 | 0.01 | 1.27 | 1.27 |
| $T_1$ | 62.94 | 0.71 | 2.26 | 3.74 | 4.33 | 10.86 | 21.89 | 17.07 | 23.98 | 41.05 |
| $T_2$ | 56.64 | 1.01 | 0.99 | 3.11 | 3.14 | 10.21 | 18.46 | 14.81 | 23.37 | 38.18 |
| $T_3$ | 61.16 | 0.59 | 1.58 | 3.85 | 5.39 | 13.20 | 24.61 | 12.58 | 23.97 | 36.55 |
| $T_4$ | 68.85 | 0.98 | 1.35 | 3.63 | 5.15 | 13.92 | 25.02 | 18.11 | 25.72 | 43.84 |
| LSD (P = 0.05) | 2.11 | NS | 0.53 | 0.44 | 0.73 | 2.53 | 1.76 | 0.01 | 0.87 | 0.86 |
| LSD (P = 0.01) | 3.19 | NS | 0.81 | 0.67 | 1.11 | 3.83 | 2.66 | 0.01 | 1.31 | 1.31 |

**Horizontal strip for rice crop: $P_1$**- Direct drilling in zero tilled plot, **$P_2$**- Seeding sprouted rice with drum-puddled plot, **$P_3$**- Manual transplanting–puddled plot, **$P_4$**- Mechanical transplanting–puddled plot. **Vertical strip for wheat crop: $T_1$**- Rotavator till drilling, **$T_2$**- Conventional tilled sowing, **$T_3$**- Strip till drilling, **$T_4$**- Zero till drilling.
**LSD**- Least Significant Difference at ($P < 0.05$ and $P < 0.01$), **WSA:** Water Stable Aggregate

**Table 3** Effect of tillage and planting management on MWD (mm) of total soil aggregate in different soil depth under rice wheat cropping system

| Soil depth (cm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (0-15) | | | | | | (15-30) | | | | |
| P/T | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean |
| $P_1$ | 0.48 | 0.42 | 0.47 | 0.58 | 0.49 | 0.15 | 0.12 | 0.17 | 0.16 | 0.15 |
| $P_2$ | 0.30 | 0.29 | 0.34 | 0.52 | 0.36 | 0.18 | 0.12 | 0.14 | 0.17 | 0.15 |
| $P_3$ | 0.18 | 0.17 | 0.20 | 0.21 | 0.19 | 0.12 | 0.09 | 0.10 | 0.19 | 0.12 |
| $P_4$ | 0.24 | 0.22 | 0.25 | 0.28 | 0.25 | 0.12 | 0.15 | 0.12 | 0.13 | 0.13 |
| Mean | 0.30 | 0.28 | 0.32 | 0.40 | 0.32 | 0.14 | 0.12 | 0.13 | 0.16 | 0.14 |
| LSD of P (horizontal strip) | | | | (P = 0.05) | 0.018 | | | | | NS |
| | | | | (P = 0.01) | 0.027 | | | | | NS |
| LSD of T (vertical strip) | | | | (P = 0.05) | 0.009 | | | | | NS |
| | | | | (P = 0.01) | 0.014 | | | | | NS |
| LSD of P at same level of T | | | | (P = 0.05) | 0.033 | | | | | NS |
| | | | | (P = 0.01) | 0.048 | | | | | NS |
| LSD of T at same level of P | | | | (P = 0.05) | 0.022 | | | | | NS |
| | | | | (P = 0.01) | 0.029 | | | | | NS |

**Horizontal strip for rice crop: $P_1$**- Direct drilling in zero tilled plot, **$P_2$**- Seeding sprouted rice with drum-puddled plot, **$P_3$**- Manual transplanting–puddled plot, **$P_4$**- Mechanical transplanting –puddled plot. **Vertical strip for wheat crop: $T_1$**- Rotavator till drilling, **$T_2$**- Conventional tilled sowing, **$T_3$**- Strip till drilling, **$T_4$**- Zero till drilling.
**LSD**- Least Significant Difference at ($P < 0.05$ and $P < 0.01$), **MWD**- Wet mean weight diameter.

spective of treatments in both strip, the proportion of micro-aggregates (0.25-4.76 mm) was greater as compared to macro-aggregates (0.053-0.11mm). In micro-aggregates, < 0 .053 mm fraction constituted significantly (P = 0.01) higher portion in $P_1$ than $P_2$, $P_3$ and $P_4$ as well $T_4$ as compared to $T_1$, $T_2$, $T_3$ in treatments of rice and wheat strip, respectively.

The highest MWD values were observed in $P_1$ (0.49 mm) and lowest in $P_3$ (0.19 mm) in rice strips while in wheat strip, the highest were in $T_4$ (0.40 mm) and lowest in $T_2$ (0.28 mm) in 0-15 cm soil layer (**Table 3**). The MWD values, however, drastically decreased from 0-15 to 15-30 cm soil depth, which varied from 0.12 to 0.15 mm in rice strip and 0.12 to 0.16 mm in wheat strip (Table 3). They ranked in the order of $P_1 > P_2 > P_4 > P_3$ in rice strip and $T_4 > T_3 > T_1 > T_2$ in wheat strip in 0-15 cm soil depth.

Significantly higher GMD was observed in $P_3$ (0.29) followed by $P_4$ (0.21), $P_2$ (0.19) and $P_1$ (0.15) in rice strip, however, in wheat strip, highest GMD was in $T_2$ (0.25) followed by $T_3$ (0.22), $T_1$ (0.19) and $T_4$ (0.17) under 0-15 cm soil depth (**Table 4**). The GMD values increased from 0-15 to 15-30 cm soil depth. At 15-30 cm depth, it was significantly (P < 0.01) higher in $P_3$ (0.48) than others treatments as $P_4$ (0.32), $P_2$ (0.19) and $P_1$ (0.19) in rice strip, and wheat strip, significantly greater GMD was in $T_2$ (0.37) as compared to $T_1$ (0.32), $T_3$ (0.27) and $T_4$ (0.23). Like SOC and MBC concentration, the interaction effects of P on MWD at same level of T and T at same level of P treatments were significant (at P < 0.01) at 0-15 cm soil depth, however, it was non- significant at soil depth layer (15- 30 cm). Whereas, GMD had shown significant (at P < 0.01) interaction effect at both level (i.e. effect of P at same level of T and T at same level of P treatments) and soil depths (i.e. 0-15 and 15-30 cm).

The effect of tillage practices in wheat strips and crop establishment methods in rice crop strips on soil structural properties deserved to be discussed in terms of tillage induced differences in: (i) SOC concentration and (ii) MBC. Higher SOC and MBC concentration in surface soil layer (0-15 cm) in "no till system" in both the crops may lead to greater aggregate stability (Lal *et al.*, 1994; Bhattacharyya *et al.*, 2008). The decreased aggregate size with reduced or conventional tillage either crop or both crops could be attributed to mechanical disruption of macro aggregates. That disruption may have exposed soil organic matter previously protected against oxidation (Pin-heiro *et al.*, 2004).

The higher amount of WSA in zero tillage plots can be ascribed to regular addition of organic matter through additional root biomass added to soil resulting in greater C availability and enhanced microbial activity, which helped in binding of aggregates. Puget *et al.* (1995) also reported reduction in the amount of WSA as a result of tillage. In this study, drum seeded ($P_2$), manual transplanting ($P_3$) and mechanical rice transplanting ($P_4$) fields were puddled in the standing water after wet tilling before transplanting and it was again cultivated in friable moisture level for wheat cultivation every year. This could have resulted in breaking down of macro-aggregates to smaller size aggregates. Further as opposed to milder wetting and sieving techniques, slaking

**Table 4** Effect of tillage and planting management on GMD of total soil aggregate in different soil depth under rice wheat cropping system

| | Soil depth (cm) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (0-15) | | | | | (15-30) | | | | |
| P/T | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean |
| $P_1$ | 0.13 | 0.20 | 0.16 | 0.11 | 0.15 | 0.20 | 0.26 | 0.11 | 0.18 | 0.19 |
| $P_2$ | 0.19 | 0.25 | 0.22 | 0.10 | 0.19 | 0.20 | 0.26 | 0.18 | 0.13 | 0.19 |
| $P_3$ | 0.24 | 0.31 | 0.32 | 0.28 | 0.29 | 0.49 | 0.67 | 0.40 | 0.37 | 0.48 |
| $P_4$ | 0.19 | 0.26 | 0.20 | 0.19 | 0.21 | 0.38 | 0.28 | 0.39 | 0.23 | 0.32 |
| Mean | 0.19 | 0.25 | 0.22 | 0.17 | 0.21 | 0.32 | 0.37 | 0.27 | 0.23 | 0.30 |
| LSD of P (horizontal strip) | | | | (P = 0.05) | 0.031 | | | | | 0.024 |
| | | | | (P = 0.01) | 0.048 | | | | | 0.037 |
| LSD of T (vertical strip) | | | | (P = 0.05) | 0.032 | | | | | 0.023 |
| | | | | (P = 0.01) | 0.049 | | | | | 0.035 |
| LSD of P at same level of T | | | | (P = 0.05) | 0.071 | | | | | 0.053 |
| | | | | (P = 0.01) | 0.036 | | | | | 0.031 |
| LSD of T at same level of P | | | | (P = 0.05) | 0.072 | | | | | 0.052 |
| | | | | (P = 0.01) | 0.033 | | | | | 0.024 |

**Horizontal strip for rice crop:** $P_1$**-** Direct drilling in zero tilled plot, $P_2$**-** Seeding sprouted rice with drum-puddled plot, $P_3$**-** Manual transplanting–puddled plot, $P_4$**-** Mechanical transplanting–puddled plot. **Vertical strip for wheat crop:** $T_1$**-** Rotavator till drilling, $T_2$**-** Conventional tilled sowing, $T_3$**-** Strip till drilling, $T_4$**-** Zero till drilling.
**LSD-** Least Significant Difference at (P < 0.05 and P < 0.01), **GMD-** Geometric mean diameter

destroys the relatively less stable macro aggregates leaving behind only more stable micro-aggregates. Occurrence of relatively lower proportion of micro aggregates in no tilled or less tilled plots was observed only due to less mechanical destruction of macro aggregates.

The greater sensitivity of soil aggregate to tillage effects is not surprising since analysis of components (Lupwayi *et al.*, 2001). The primary effect of tillage results in physically disturbance of soil structure. Higher tillage usually disrupts soil aggregates and lowers SOC and MBC (Jiang and Xie, 2009; Jiang *et al.*, 2011). The specific effect however depends largely on the disturbance that occurs at the spatial scale to which the microorganisms are most sensitive (Young and Ritz, 2000). Studies in Texas (Unger, 1982; Nuttall *et al.*, 1986) showed that tillage decreased aggregate stability. The results of these studies showed that tillage affected C availability to the microbial biomass by disrupting soil structure and exposing protected organic material. This may be responsible for lower MWD recorded tillage plots. Soil organic matter stabilizes soil aggregates by acting as a binding material (Tisdall and Oades, 1982) and their hydrophobic properties reduce the destructive internal hydration (Chenu *et al.*, 2000). In conventional agricultural systems, the soil aggregates are unstable and do not resist repeated wetting-drying cycles (Park and Smucker, 2005).

The crop rotation of maize and wheat on a sandy loam soil with minimum tillage and surface retention has been found to improve mean weight diameter aggregates and water retention and decreased soil bulk density (Ghuman and Sur, 2001). In tropical soils, an increase in soil aggregation has been found under no tillage practices (Six *et al.*, 2002). The importance of micro aggregates to stabilize soil organic matter has been emphasised (Helfruch *et al.*, 2008). Most of soil organic matter could be sequestered as a mineral associated fraction (Jastrow, 1996; Zotaralli *et al.*, 2007). Long-term minimum tillage enhanced the physical protection of organic carbon and nitrogen in Haplic Luvisols (Jacob *et al.*, 2009).

In this study, it was found that water stable aggregates responded to the tillage systems. In rice cropping, puddling could result in the destruction of soil aggregates (Sharma and De Dutta, 1985). A puddle soil consists of a solid-liquid system in which individual clay particles or clusters are oriented in parallel rows and are surrounded by capillary pores saturated with water (Sharma and De Dutta, 1985). Sand and clay particles and some aggregates are parts of soil matrix. However, the degree of aggregation destruction due to puddling irrigation or water logging is difficult to quantify because drying is necessary to measure aggregation. In the present study, the soil aggregates during the rice growing seasons were quantified only after crop harvest from the dry soil.

In tropical and sub tropical conditions, soil aggregation has been found to increase during the early years of no tillage adoption (Six *et*

**Table 5** Effect of tillage and planting management on organic carbon (g kg$^{-1}$) at different soil depth in rice wheat cropping system

| | Soil depth (cm) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (0-15) | | | | | (15-30) | | | | | (30-45) | | | | | (45-60) | | | | |
| /T | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean |
| $PP_1$ | 5.66 | 4.83 | 5.76 | 6.44 | 5.67 | 3.93 | 2.96 | 4.22 | 4.68 | 3.95 | 2.49 | 2.44 | 3.51 | 3.71 | 3.04 | 1.46 | 1.37 | 1.61 | 1.76 | 1.55 |
| $P_2$ | 4.54 | 4.44 | 4.93 | 5.71 | 4.90 | 3.65 | 3.60 | 3.72 | 4.22 | 3.80 | 2.49 | 2.34 | 2.63 | 3.66 | 2.78 | 1.17 | 1.12 | 1.32 | 1.61 | 1.30 |
| $P_3$ | 3.89 | 4.04 | 4.09 | 4.22 | 4.06 | 2.29 | 2.24 | 2.44 | 2.57 | 2.38 | 2.01 | 2.00 | 2.11 | 2.12 | 2.06 | 1.00 | 1.00 | 1.01 | 1.02 | 1.01 |
| $P_4$ | 4.24 | 3.95 | 4.54 | 4.59 | 4.33 | 2.75 | 2.13 | 2.46 | 2.60 | 2.48 | 2.15 | 2.13 | 2.18 | 2.20 | 2.16 | 1.05 | 1.03 | 1.06 | 1.19 | 1.08 |
| Mean | 4.58 | 4.32 | 4.83 | 5.24 | 4.74 | 3.16 | 2.73 | 3.21 | 3.52 | 3.15 | 2.28 | 2.23 | 2.61 | 2.92 | 2.51 | 1.17 | 1.13 | 1.25 | 1.40 | 1.24 |
| LSD of P (horizontal strip) | | (P = 0.05) | | | 0.33 | | | | | 0.15 | | | | | 0.07 | | | | | 0.17 |
| | | (P = 0.01) | | | 0.49 | | | | | 0.23 | | | | | 0.11 | | | | | 0.26 |
| LSD of T (vertical strip) | | (P = 0.05) | | | 0.12 | | | | | 0.18 | | | | | 0.15 | | | | | 0.04 |
| | | (P = 0.01) | | | 0.19 | | | | | 0.28 | | | | | 0.23 | | | | | 0.06 |
| LSD of P at same level of T | | (P = 0.05) | | | 0.70 | | | | | 0.33 | | | | | 0.21 | | | | | 0.31 |
| | | (P = 0.01) | | | 1.04 | | | | | 0.47 | | | | | 0.30 | | | | | 0.45 |
| LSD of T at same level of P | | (P = 0.05) | | | 0.63 | | | | | 0.38 | | | | | 0.31 | | | | | 0.10 |
| | | (P = 0.01) | | | 0.85 | | | | | 0.51 | | | | | 0.41 | | | | | 0.14 |

**Horizontal strip for rice crop:** $\mathbf{P_1}$- Direct drilling in zero tilled plot, $\mathbf{P_2}$- Seeding sprouted rice with drum-puddled plot, $\mathbf{P_3}$- Manual transplanting–puddled plot, $\mathbf{P_4}$- Mechanical transplanting–puddled plot. **Vertical strip for wheat crop:** $\mathbf{T_1}$- Rotavator till drilling, $\mathbf{T_2}$- Conventional tilled sowing, $\mathbf{T_3}$- Strip till drilling, $\mathbf{T_4}$- Zero till drilling.
**LSD**- Least Significant Difference at ($P < 0.05$ and $P < 0.01$)

*al*., 2002). Conventional tillage leads to increased soil disruption and increased decomposition of soils organic matter due to exposure of soil to wet and dry cycles (Beare *et al*., 1994 a, b) changes in soil conditions due to ploughing (Camberdella and Elliot, 1993) and disruption of the microbial community (Holland and Coleman, 1987) Madari *et al*. (2005) reported that no tillage along with residue covers improved aggregate stability, aggregate size classes and total organic carbon in soil aggregates. In this study, about seven years of zero, tillage improved soil micro aggregates in surface layer (0-15 cm) of soil. In minimum tillage systems new aggregates were formed due to incorporation of crop residues in the soil and storage of excess organic matter in biochemically degraded fraction especially in the surface soil (Jacobs *et al*., 2009a).

**Effect of Tillage and Crop Establishment on Soil Organic Carbon (SOC)**

The SOC ranged from 4.06 to 5.67, 2.38 to 3.95, 2.06 to 3.04, 1.01 to 1.55 g $kg^{-1}$ in rice strip and from 4.32 to 5.24, 3.15 to 3.52, 2.23 to 2.92 and 1.13 to 1.40 g $kg^{-1}$ in different tillage treatment in wheat strip in 0-15, 15-30, 30-45 and 45-60 cm soil layers, respectively (**Table 5**). The SOC ranked in order $P_1 > P_2 > P_4 > P_3$ which had significant ($P < 0.01$) differences in rice crop establishment treatment in all soil depths. However, in the different tillage treatments in wheat crop, the SOC content had significant ($P < 0.01$) differences and ranked in order $T_4 > T_3 > T_1 > T_2$ under 0-15 cm soil depth. The highest SOC of treatment $P_1$ (5.67 g $kg^{-1}$) in rice strip and $T_4$ (5.24 g $kg^{-1}$) in wheat strip was observed, however, the lowest values were 4.06 g $kg^{-1}$ in $P_3$ and 4.32 g $kg^{-1}$ in $T_2$ in 0-15 cm soil depth. Similar trends were noticed in all other soil layer. However, when it was compared in each strip to see overall effect, it was observed highest in $P_1T_4$ (6.4 g $kg^{-1}$) and lowest in $P_3T_1$ (3.89) and $P_4T_2$ (3.95 g $kg^{-1}$). The increase of SOC was observed 65.6 and 59.4 % with $P_1T_4$ over $P_3T_1$ and $P_3T_2$, respectively, It was because of treatment $P_1T_4$ in both the crops was grown in no till conditions from 2003 to 2010 (7 years). The interactions of P at same level of T and T at same level of P were significant at $P < 0.001$ at all soil depth. Treatment $T_4$ had shown significantly (at $P < 0.01$) highest and lowest in $T_2$ of SOC at same level of $P_1$, $P_2$, $P_3$ and $P_4$. It was due to no tilled condition maintained in both crop seasons. However, treatment $P_1$ had significantly (at $P < 0.01$) highest but lowest value was in $P_3$ at same level of $T_1$, $T_2$, $T_3$ and $T_4$.

The decrease in SOC an average all treatments was about 51 and 89 percent from layer 0-15 to 15-30 and 30-45 cm, respectively. However, very low SOC content (1.0 g $kg^{-1}$) was observed in 45 -60 cm soil depth. Edwards *et al*. (1992) had reported that conservation tillage increased the SOC about 56 % as compared to conventional tillage over a 10 year period. Increase in organic carbon content with reduced and no tillage treatment has been reported previously by others, al-

**Table 6** Effect of tillage and planting management on MB-C (µg $g^{-1}$ soil) in different soil depth under rice wheat cropping system

| Soil depth (cm) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (0-15) | | | | | (15-30) | | | | | (30-45) | | | | | (45-60) | | | | |
| /T | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean | $T_1$ | $T_2$ | $T_3$ | $T_4$ | Mean |
| $PP_1$ | 420 | 419 | 438 | 489 | 441 | 377 | 368 | 401 | 452 | 399 | 313 | 305 | 343 | 386 | 337 | 248 | 240 | 260 | 307 | 263 |
| $P_2$ | 367 | 363 | 397 | 441 | 392 | 343 | 327 | 352 | 409 | 358 | 287 | 275 | 298 | 354 | 304 | 202 | 180 | 217 | 270 | 217 |
| $P_3$ | 282 | 260 | 291 | 299 | 283 | 233 | 209 | 242 | 247 | 232 | 145 | 125 | 164 | 175 | 152 | 68 | 47 | 86 | 100 | 75 |
| $P_4$ | 307 | 296 | 318 | 351 | 318 | 276 | 252 | 296 | 300 | 281 | 196 | 189 | 219 | 234 | 210 | 128 | 118 | 139 | 165 | 138 |
| Mean | 344 | 334 | 361 | 395 | 359 | 307 | 289 | 323 | 352 | 318 | 236 | 224 | 256 | 287 | 251 | 162 | 146 | 175 | 211 | 173 |
| LSD of P (horizontal strip) | | | (P = 0.05) | | 11.7 | | | | | 3.3 | | | | | 5.1 | | | | | 6.0 |
| | | | (P = 0.01) | | 17.7 | | | | | 5.0 | | | | | 7.7 | | | | | 9.2 |
| LSD of T (vertical strip) | | | (P = 0.05) | | 3.8 | | | | | 1.8 | | | | | 3.4 | | | | | 5.9 |
| | | | (P = 0.01) | | 5.8 | | | | | 2.7 | | | | | 5.1 | | | | | 9.0 |
| LSD of P at same level of T | | | (P = 0.05) | | 23.1 | | | | | 6.8 | | | | | 9.8 | | | | | 13.3 |
| | | | (P = 0.01) | | 33.0 | | | | | 9.7 | | | | | 14.1 | | | | | 18.7 |
| LSD of T at same level of P | | | (P = 0.05) | | 14.3 | | | | | 5.1 | | | | | 7.4 | | | | | 13.1 |
| | | | (P = 0.01) | | 19.5 | | | | | 7.0 | | | | | 10.0 | | | | | 17.7 |

**Horizontal strip for rice crop:** $\mathbf{P_1}$- Direct drilling in zero tilled plot, $\mathbf{P_2}$- Seeding sprouted rice with drum-puddled plot, $\mathbf{P_3}$- Manual transplanting–puddled plot, $\mathbf{P_4}$- Mechanical transplanting–puddled plot. **Vertical strip for wheat crop:** $\mathbf{T_1}$- Rotavator till drilling, $\mathbf{T_2}$- Conventional tilled sowing, $\mathbf{T_3}$- Strip till drilling, $\mathbf{T_4}$- Zero till drilling.
**LSD**- Least Significant Difference at ($P < 0.05$ and $P < 0.01$)

though the results varied with soil type, crops, kind of management, and climate. Other studies have also indicated a higher organic carbon content under RT and NT practices compared to CT practices (Hooland, 2004). Many of the soil quality parameters (Bhattacharyya *et al.*, 2008) are generally related to soil organic matter content and its quality (Gregorich *et al.*, 1994), therefore it is of prime importance to increase or preserve the soil organic matter content for the physical, chemical and biological quality of soil (Bradford and Peterson, 2000). No tilled and reduced tillage could promote soil C storage due to a proportionate increase in both bacterial and fungal biomass (Van Groenigen *et al.*, 2010). According to Bell *et al.* (2003), soil management to increase SOC is due to less mixing and aeration of residues and the promotion and stabilization of aggregates especially in the surface soil layer. These data strengthen the statement that tillage has much more importance in SOC preservation than stubble management. In undisturbed soil in treatment $P_1T_4$ in both crop seasons (i.e. rice in rainy season and wheat in winter season) where plant residue of about 2 Mg $ha^{-1}$ was left on the soil surface and not incorporated into the soil by tillage, the slow surface residue decomposition could provide additional organic N & C (Drinkwater *et al.*, 1998) to promote the growth of microorganisms that produce adhesive agents for the stabilization of the aggregates (Beare *et al.*, 1994). It has been reported that the conservation tillage systems increase the storage of soil organic matter and the stability of macro aggregates compared to conventional tillage in various types of soils and climatic regions (Paustian *et al.*, 2000; Six *et al.*, 2000; Kushwaha *et al.*, 2001; Jacobs *et al.*, 2009b). The zero tillage in rice -wheat systems has been found to be increase soil carbon, crop yield and nitrogen uptake (Neelam and Gupta, 2009). During tillage, soil aggregates are broken, increasing oxygen supply and surface area exposure of organic material, this promotes the decomposition of organic matter. In the addition to serving as a storage compartment for nutrients, soil also contributes to improving soil physical characteristics. In upland soils, SOM improves soil structures and trafficability, but the degree of improvement again depends on particle size distribution. Sandy soils with low SOM contents lack substantial structure and are prone to severe erosion. Adding crop residues or manure will increase microbial activity, which in some studies has led to the build up of SOM and the formation of macro and micro aggregates (Angers *et al.*, 1993; Sparling *et al.*, 1992). Differences in aggregate stability also depend on the sources of the organic materials (Tisdall, 1991). On the other end of the particle spectrum heavy clay soils are often characterised by poor structure and aeration, but they can be improved through the addition of organic amendments. Therefore, the positive effect of SOM on soil structure will be more pronounced for a clay soil than for a silty soil.

**Effect of Tillage and Crop Establishment on Soil Microbial Biomass Carbon (Mbc)**

The MBC ranged from 283 to 441 μg $g^{-1}$ in 0-15 cm, 232 to 399 μg $g^{-1}$ in the 15-30 cm and decreased with depth (i.e. 75 to 263 μg $g^{-1}$ in 45 to 60 cm) in rice strip plot (**Table 6**). While in wheat strip, it ranged from 289 to 352 μg $g^{-1}$ in 15-30 cm soil layer and 224 to 287 μg $g^{-1}$ in 30-45 cm layer in wheat strip. MBC decreased with depth in wheat strip ranging from 146 to 211 μg $g^{-1}$ in 45-60 cm depth. Significantly ($P < 0.01$) higher MBC was observed under treatment $P_1$ (441 μg $g^{-1}$) in rice strip and $T_4$ (395 μg $g^{-1}$) in wheat strip than other treatments and lowest was in $P_3$ (283 μg $g^{-1}$) and $T_2$ (334 μg $g^{-1}$) at 0-15 cm soil depth. Significant differences (at $P < 0.01$) in MBC were recorded in order $P_1 > P_2 > P_4 > P_3$ of rice crop strip and $T_4 > T_3 > T_1 > T_2$ in wheat crop strip under 0-15 cm soil depth. Similar trend were also observed in the other soil layer. MBC in all treatments decreased by 13 and 43 % from 0-15 to 15-30 and 30-45 cm soil depth, however, very low MBC content (75 μg $g^{-1}$) was observed in 45-60 cm soil depth. The strip of zero till drill in both crops had significantly (at $P < 0.01$) higher MBC contents. It was observed that an average MBC was about 8, 14, 13 and 19 % of the SOC in 0-15, 15-30, 30-45 and 45-60 cm soil layer, respectively.

The interaction of P at same level of T and T at same level of P were significant at ($P < 0.01$). It was observed highest in $P_1T_4$ (489 μg $g^{-1}$) and lowest in $P_3T_2$ (260 μg $g^{-1}$). Significantly highest MBC in $T_4$ and lowest in $T_2$ were observed at same level of $P_1$, $P_2$, $P_3$ and $P_4$. It was due to no tilled condition maintained in both crop seasons. However, treatment $P_1$ had significant at $P < 0.01$ highest and was lowest value in $P_3$ at same level of $T_1$, $T_2$, $T_3$ and $T_4$.

It has been widely reported that microbial biomass can be altered through tillage practices and is higher in soils under no tillage than conventional tillage (Feng *et al.*, 2003; Nyamadzawo *et al.*, 2009; Ganzalez-Chavez *et al.*, 2010). This study also confirms these findings. Soil microbial biomass was significantly greater in minimum/ no tillage treatments in both crops. Higher biomass under no tillage could be attributed to higher SOC under no tilled (Jiang *et al.*, 2011) and it was due to deposition and accumulation of residues in surface soil. Whereas, soil microbial biomass change associated with aggregates was different than the response for whole. Therefore, it was likely that tillage decreased soil microbial biomass mainly by decreasing the proportion in the whole soil. Soil microbial biomass carbon (MBC) was mainly concentrated within macro-aggregates and tillage initiated a shift from macro-aggregates to micro-aggregates and individual practices (Jiang *et al*., 2011). It was likely that tillage decreased soil MBC mainly by decreasing the proportion of soil macro-aggregates in the whole soil. Microbial biomass can be altered through tillage practices and is greater in soils under no tilled plot (Mullen *et al*., 1998). As observed for SOC, MBC decreased with soil depth. The enrichment of MBC in no tilled plot was generally related with SOC and WSA (Garcia- Gil *et al*., 2000), and these parameters were positively correlated with MBC (Madejon *et al*., 2007). In all treatments MBC decreased with the depth probably due to decrease of SOC which may have affected microbial growth.

**Relationships Among SOC, MBC with Total WSA and MWD**

Linear correlation coefficients between various properties measured in this study are shown **Table 7**. Soil organic carbon (SOC), microbial biomass carbon (MBC), water soluble aggregate (WSA) and mean weight diameter (MWD) were significantly (at $P < 0.01$) correlated with each other. Correlation matrix developed among SOC, MBC, WSA and MWD. The increase of SOC was positively and significantly ($P < 0.01$) correlated with MBC, WSA and MWD. Regression equation between SOC and total WSA ($y = 10.7x + 28.1$), SOC and MWD ($y = 0.11x - 0.19$) suggests a strong relationship which explained 95 % and 85 % variability respectively (**Fig. 2a**). Similarly, regression equation between MBC and total (WSA ($y = 0.18x + 10.7$), MBC and MWD ($y = 0.002x - 0.29$) also suggests strong relationship among MBC and soil aggregation which explained 77 and 52 % variability respectively (**Fig. 2b**). The similar results were also sown by Wang *et al.* (2011) and Madejon *et al*. (2007). The MBC was also positively and significantly ($P < 0.01$) correlated with WSA and MWD.

**Table 7** Correlation matrix for SOC, MB-C, WSA and MWD

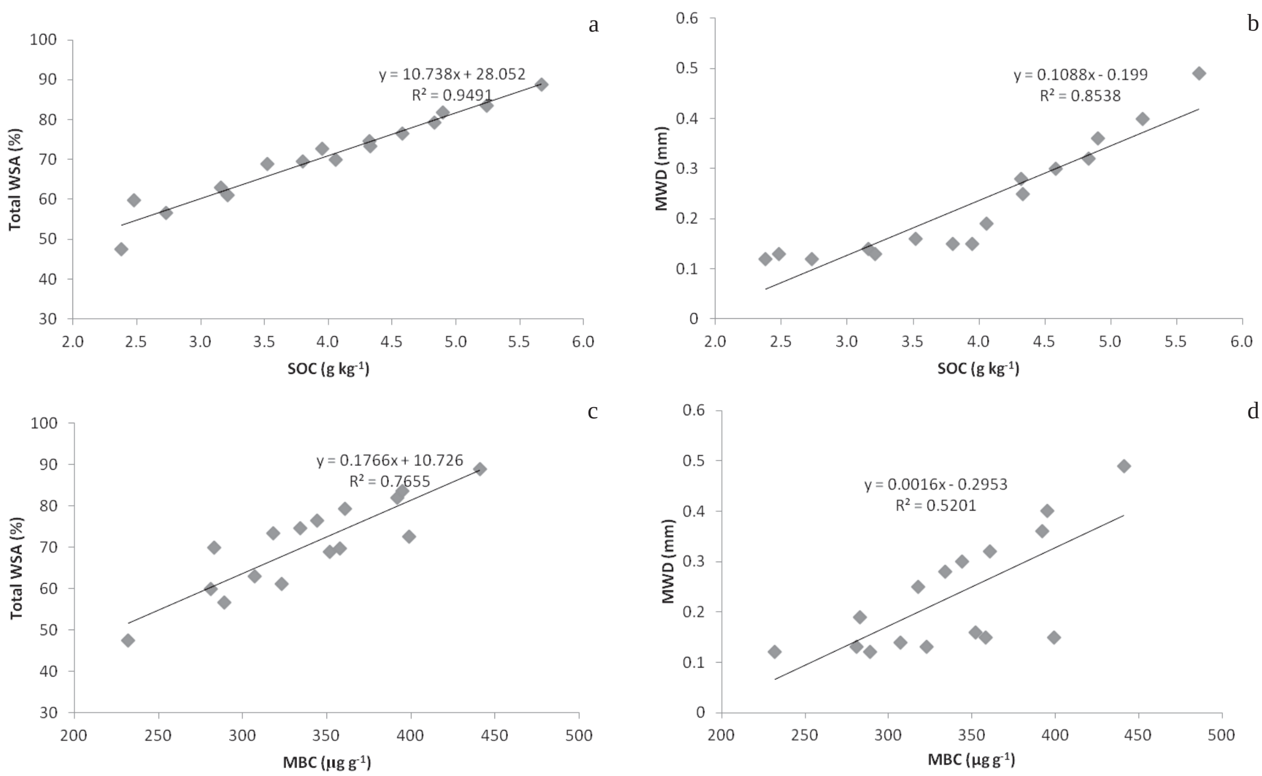
| Parameters | SOC | MB-C | WSA | MWD |
|---|---|---|---|---|
| SOC | 1 | | | |
| MB-C | 0.947** | 1 | | |
| WSA | 0.874** | 0.963** | 1 | |
| MWD | 0.671** | 0.625** | 0.638** | 1 |

SOC: Soil organic carbon; MB-C: Microbial biomass carbon; WSA: Water soluble aggregate; MWD: Mean weight diameter
**Significant at ($P$=0.01)

## Conclusions

It was concluded that direct drilling in zero tilled rice strip and

**Fig. 2** Relationship between a: SOC with Total WSA, MWD and b: MBC with Total WSA, MWD



wheat sown in zero tilled strip had significantly higher SOC and MBC contents while it was lowest in conventionally sown wheat and manually transplanted rice in puddled field. However, the completely no till plots in both crops (i.e., $P_1T_4$) had shown the highest value of SOC and MBC and lowest was in conventional tilled plot in both seasons (i.e., $P_3T_2$). The total soil water stable aggregate content (WSA)> 0.053 mm and MWD (mm) had also shown similar trend like SOC and MBC. It may be recommended that in view of soil health (i.e., SOC and MBC) long term zero tilled /minimum tilled plot had shown higher value as compared to conventional tilled plot.

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# Design and Experimental Evaluation of a Shearing Type Macadamia Nut Cracking Machine



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## Abstract

A new type of shearing type macadamia nut cracker was designed and manufactured, and its performance and cracking efficiency were evaluated through cracking tests. Results of tests showed that the cracking rate for nuts of various grades was up to 85% and effective kernel rate reached 80%.



***Key Words***: shearing; macadamia nut; cracking


## Introduction

Macadamia nut is a new kind of nut in China with an annual yield of about 10 million tons. The kernel of macadamia is a food with high nutrition and it can also be used to extract the precious macadamia oil or as raw material in food processing industry. The comprehensive utilization of macadamia nut shells and kernels has begun in some countries (Braga *et al*., 1999; Liu *et al*., 1999), and Chinese researchers are also working on macadamia comprehensive utilization.

South China Research Institute of Agricultural Products Processing developed a macadamia shell sawing machine in 1998 and Guangxi Autonomous Region Research Institute of Tropical Crops developed a plate type macadamia nut racking machine and a chain type macadamia nut racking machine but none of the machines have been sold in the market. Until now macadamia nut cracking operation is still conducted by hand, by striking nuts manually with a hammer. The operation is labor-consuming, low efficient, tending to cause finger injury and with serious kernel breakage. The lagging of nut cracking technology has restricted the large-scale production of macadamia nuts.

## Materials and Methods

### Construction and Working Principle of the Macadamia Cracker

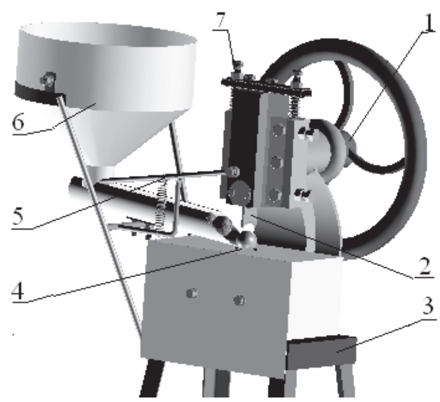
***Main Construction***

The designed shearing type macadamia nut cracker consisted of a feeding funnel, a nut dropping chute, a cutter, a rotation mechanism and a framework, which is shown in **Fig. 1**.

***Working Process***

Through the feeding funnel, a macadamia nut were dropped into the slightly inclined nut dropping chute and reached nut positioning unit. The rotating wheel drove the slide block to move downward through the rotation mechanism. As the cutter moved downwards with the slide block, sheared and cracked the nut. While the slide block moved downwards, one end of the lever type stirring mechanism moved down with the bear frame as the fulcrum, causing the lever end that is at the exit of the feeding funnel to move upwards, preventing the blocking of the feeding funnel with nuts. The lever returned with the tension force of a return spring when the slide block moved upwards. The cutting depth of the cutter into nuts

**Fig. 1** Construction of the shearing type macadamia nut cracker




1. Rotation mechanism, 2. Cutter, 3. Framework, 4. Nut positioning unit, 5. Lever type stirring mechanism, 6. Feeding funnel, 7. Caging device

could be set by adjusting the installation height of the hilt and stop bolt through a chucking. The coarse adjustment of the chucking could be made by adjusting the install position of the slide block.

## Design and Analysis of Main Components

### *Rotation Mechanism*

The rotation mechanism mainly consisted of a rotating wheel, a rotating shaft, a sliding chute, a caging device, and a cutter positioning hole (**Fig. 2**). Its function was to transfer the manual rotating force exerted upon the rotating wheel into an impact and shearing force to crack the shell and obtain the kernel.

### Lever Type Stirring Mechanism

The main components of the lever type stirring mechanism were poking finger, return spring, bearing rod, and connect collar. The main function of this mechanism was to help the nut drop into the chute and prevent the blocking of the chute by nut accumulation and ensure single-row layout of nuts in the chute. As shown in **Fig. 3**, when the rotation mechanism rotated, the cutter moved with downward movement of the sliding block. One end of the lever type stirring mechanism moved downwards with the sliding block, fixed to it by a connect collar, and the other end moved upwards in the feeding funnel with 2 as fulcrum. The movement of the sliding block could be considered as an instantaneous impact process, so was the movement of the other end of the poking finger in the feeding funnel. It could smooth the funnel with the movement of the rotation mechanism and without extra manual operation.

### *Nut Positioning Unit*

Nut positioning unit (**Fig. 4**) consisted of a positioning ring, a supporting sleeve, a fixed plate, and a bolt. Positioning ring was made by punch forming a ring form stainless gasket of a specific diameter to make it form a concave angle, then welding it to the cylindrical supporting sleeve and fixing them to the fixed plate with the bolt, located directly below the blade edge by adjusting in installation. The concave angle helped nuts center, mainly functioning as fixing nuts, supporting them against the impact force of the cutter and ensuring successful nut cracking.

### *Cutter*

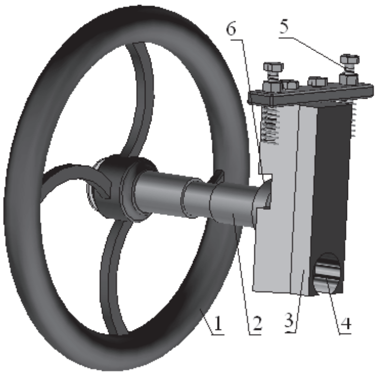
The main components of the cutter (**Fig. 4**) were a crescent cutter head and a cutter hilt. Cutter head was made with 40 Cr steel treated with thermal refining and partial quenching, while cutter hilt was made of Q235A and was cylindrical. The crescent cutter head was inserted into one end of the hilt and fixed by dot welding at the outer contact surface. The cutter was tightly fixed in the cutter positioning hole (as shown in **Fig. 2**) with a wedge.

Shearing with crescent head cutter could fix the nuts with crescent cutter head and rapidly cut open the shells with instantaneous impact force, which was especially efficient in cracking dried nuts.

## Prototype of Cutting Type Macadamia Nut Racker

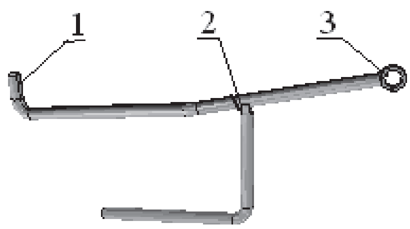
**Fig. 6** shows completed prototype.

**Fig. 2** Rotation mechanism



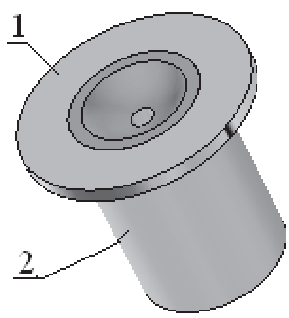

1. Rotating wheel, 2. Rotating shaft,
3. Sliding block, 4. Cutter positioning hole,
5. Caging device, 6. Sliding chute

**Fig. 3** Lever type stirring mechanism



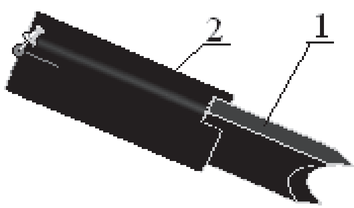

1. Stirring finger, 2. Supporting rod,
3. Connect collar

**Fig. 4** Nut positioning unit




1. Positioning ring,
2. Supporting sleeve

**Fig. 5** Cutter




1. Crescent cutter head,
2. Cutter hilt

**Table 1** Test results

| | | | | | |
|---|---|---|---|---|---|
| whole kernels | 64 | 60 | 52 | 40 | 30 |
| more than half kernels | 13 | 12 | 14 | 17 | 15 |
| Half kernels | 8 | 10 | 12 | 15 | 17 |
| big kernel pieces | 8 | 10 | 11 | 15 | 21 |
| Small kernel pieces | 7 | 8 | 11 | 13 | 17 |

**Table 2** Variance analysis

| Source of variation | Sum of squares | Level of freedom | Mean squares | F value | Pr > F |
|---|---|---|---|---|---|
| Grade of kernels | 1.51 | 3 | 0.50 | 48.94 | < 0.0001 |
| Grade of nuts | 0.10 | 4 | 0.02 | 2.27 | 0.1217 |
| Error | 0.12 | 12 | 0.01 | | |
| Total | 1.73 | 19 | | | |

R-Square=0.9286

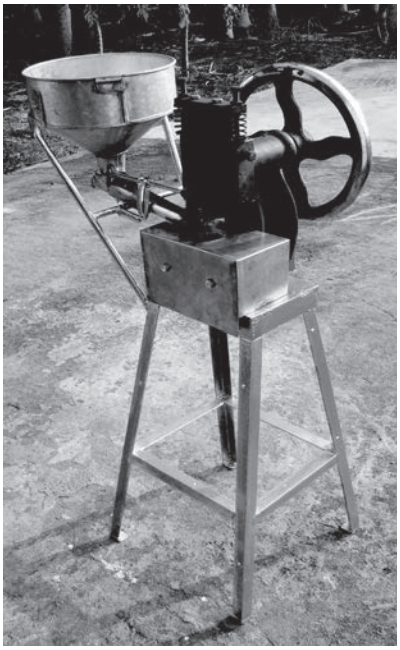
## Results and Discussion

With the designed and manufactured prototype, shearing tests were conducted on the selected samples. The test results are shown in **Table 1**.

The logarithmic transformation was applied to the data in **Table 1** and analysis was made with statistical software SAS8.1. The results of analysis are shown in **Table 2**.

It is indicated in **Table 2** that there was a significant difference between nut grades and cracking efficiency, with a 0.1217 probability in significance test. The results of multiple comparison showed that the higher the nut grades, the more percentages of whole kernels, more than half kernels and half kernels. The prototype was stable in performance and achieved a higher whole kernel rate than manual nut cracking.

**Fig. 6** Prototype of the small scale macadamia nut cracker



## Conclusions

- A new working principle for macadamia nut crackers was proposed, that is, to crack nuts by shearing instead of pressing and rubbing.
- Designs and analyses were made on rotation mechanism, nut positioning unit, lever type stirring mechanism, cutter and the whole machine.
- Replacing the manual pressing force with shearing force could greatly increase processing efficiency and decrease working intensity. The machine was easy to operate. Nuts of various sizes could be cracked by adjusting the installation position of the cutter. The obtained kernels satisfied production requirements. The results of experimental tests on the shearing and cracking performance of the prototype showed that the cracking rate for nuts of different grades could reach 85% and effective kernel obtaining rate was up to 80 %.
- Further studies should be done on comparison and analysis of cracking efficiency at various moisture contents and drying time to provide theoretical basis for the improvement of the prototype.

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# Development and Evaluation of Open Top Biomass Gasifier for thermal Application

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## Abstract

Based on energy consumption pattern and cooking methodology adopted in the community cooking system, an open top gasifier for thermal application was developed and evaluated to determine its performance and thermal efficiency. The study revealed that traditional cooking systems utilize biomass as a main source of fuel with average thermal efficiency of 14.14 percent which revealed the inefficient utilization of biomass. The average thermal efficiency (21.86 percent) of open top gasifier was found to be higher than traditional cooking system indicates the greater conversion of fuel in to heat. The laboratory testing of open top gasifier revealed the saving of about 22 percent of fuel wood (Acacia nilotica) over the traditional cooking system with clean environment.

***Key Words:*** Biomass, Community Cooking, Gasifier, thermal efficiency

## Introduction

Thermal gasification of biomass is one of the established and proven processes for harnessing the biomass energy. Biomass is one of the most promising sources of energy. In India, a total of about 62-310 Mt of biomass is produced annually (Sudha *et al.*, 2003). Biomass has great potential in various fields such as cooking, heating, and drying of fruits, vegetables and electricity generation. Cooking fuel use patterns in India revealed that in the rural households, firewood and dung accounted for about 80 percent of the total expenditure on cooking fuels. As per estimates, about 249.78 Mt of surplus biomass was available in India from all sources including agro-processing residues, grassland, forests, roadside, agro forestry and degraded habitats. Their availability is likely to increase to about 384.51 Mt by 2015 (Panwar *et al.*, 2009). Despite rapid urbanization, 84 % of rural households rely on biomass as their primary cooking fuel (National Sample Survey, 2004-2005). The traditional stove called "chulhah" is most commonly used for cooking in India. Though it is primarily designed for burning fuel wood, the same has been adapted to burn crop residue and dung cakes. The main problems associated with these cooking devices are their inability to vent smoke out of kitchen which causes significant levels of indoor air pollution. The use of traditional fuels may have serious consequences for human health (Larson and Jin, 1999; Joon *et al.*, 2009).

Gasifier is the device used to produce combustible producer gas through gasification process, which is further used for combustion to provide heat energy. Biomass gasifier technology offers high thermal efficiency, good process controllability, economic viability and environmental acceptability while using agro and forestry residues available in rural areas and biomass based industries (Patel *et al.*, 2006). The static bed (or "open core") gasifier is a simple reactor technology available principally for small-scale or remote applications requiring fuel gas for heat or power. The reactor top can be left open for refueling (Tiangco *et al.*, 1996). Biomass based open core down draft gasifier system performs constantly well in industries for thermal application which means of energy conservation.

## Material and Methods

The present study was focus on development of open top gasifier based community cooking system based on the performance evaluation of traditional biomass cooking system available at Boys Hostel of CAET, DBSKKV, Dapoli. The area is located at 17º 45´ N latitude and 73º 26´ E longitude and at an altitude of 256 m above mean sea level.

The development of open top gasifier based cooking system was carried out based on the performance evaluation of traditional cooking system. The capacity of a proposed gasifier should meet the heat energy required to cook the meals per batch. The physical parameters of traditional cooking system, food habit and quantity, fuel type and its consumption rate, time required for cooking were considered while developing the gasifier based cooking system (Belonio, 2005).

The following parameters were considered while developing the gasifier base community cooking system.

***Energy needed, (kcal h$^{-1}$):***

The amount of energy required for cooking the average quantity of food per batch was considered as the energy output of gasifier system. It was computed as

$$Qn = [(Mf \times Es) + (Mu \times Eu)] / T \quad (1)$$

***Energy input, (kg h$^{-1}$):***

The amount of energy needed in terms of fuel to be fed into the gasifier computed as

$$FCR = Qn / (HVf \times \acute{\eta}g) \quad (2)$$

***Reactor diameter, (m):***

The size of the reactor in terms of the diameter of the cross section of the cylinder computed as

$$D = (1.27FCR / SGR)^{0.5} \quad (3)$$

***Height of reactor, (m):***

The total distance from the top and the bottom end of the reactor computed as

$$H = (SGR \times T) / p_{rh} \quad (4)$$

Where,

*D*: Diameter of reactor, m
*Es*: Specific energy, kcal kg$^{-1}$
*Eu*: Specific energy of utensil, kcal kg$^{-1}$
*FCR*: Fuel consumption rate, kg h$^{-1}$
*H*: Length of the reactor, m
*HVf*: Heat value of fuel, kcal kg$^{-1}$
*Mf*: Mass of food, kg
*Mu*: Mass of utensil, kg
*Qn*: Energy needed, kcal h$^{-1}$
*SGR*: Specific gasification rate of fuel, kg m$^{-2}$ h$^{-1}$
*T*: Cooking time, h
*ήg*: Gasifier stove efficiency, %
*ρrh*: Fuel density, kg m$^{-3}$

The gasifier was fabricated using locally available material. The schematic view of open top gasifier is shown in **Fig. 1**. The pictorial view of developed gasifier is shown in **Fig. 2**. The technical specifications of open top gasifier are shown in **Table 1**.

**Fig. 1** Three dimensional and schematic representation of open top gasifier

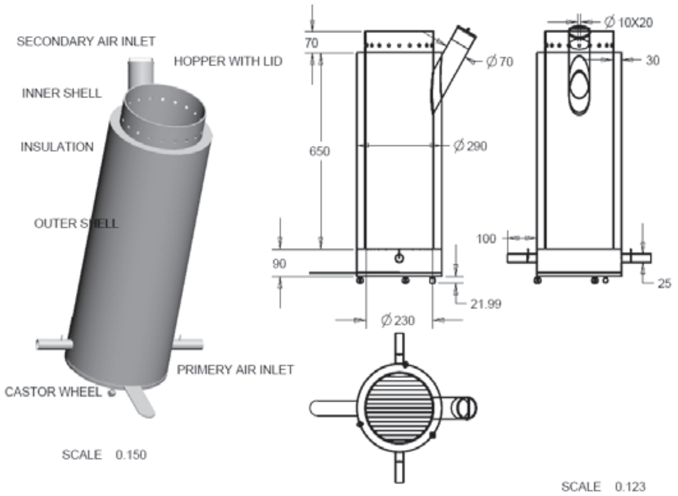



**Fig. 2** Development of open top gasifier for community cooking

**Table 1** Technical specification of open top gasifier

| Particulars | Specifi-cations |
|---|---|
| Gasifier reactor inner diameter, m | 0.23 |
| Gasifier reactor outer diameter, m | 0.29 |
| Gasifier reactor height, m | 0.65 |
| Diameter of burner, m | 0.23 |
| Height of burner, m | 0.07 |
| No. of secondary air vents | 20 |
| Height of ash chamber, m | 0.09 |
| Diameter of ash chamber, m | 0.29 |
| Area of grate, m$^2$ | 0.041 |
| Height of grate from bottom, m | 0.09 |
| Adjustable primary air vent, m$^2$ | 0.004 |
| Caster wheel | 0.3 |

**Table 2** Food habit and quantity of food material per batch

| Item | Avg. Quantity, kg |
|---|---|
| Rice | 6 |
| Pulses | 2 |
| Vegetable | 7 |
| Cereal | 1.5 |
| Water | 29.3 |
| Energy needed, kcal per batch | 3,400.01 |

## Result and Discussion

**Performance of Traditional Community Cooking System**

The traditional cooking system (65 meals/batch) consists of double pot type Chula with metal chimney. The dimensions of Chula were 45, 32 and 18 cm of length, breadth and depth, respectively. The chimney was placed at a height of 170 cm from base and with opening of 225 and 115 cm of length and breadth, respectively. The Chula was made up of bricks and cement as constructing material. The utensils used for cooking was made up of aluminium. The dimensions of utensils were 40 and 45 cm of diameter and 22 and 25 cm depth, for pot 1 and pot 2, respectively.

The type and the average food quantity used by the system were shown in **Table 2**. The average time required by the food to get cooked per batch was 3 h and the average energy required for the food cooking based on specific energy was found to be 3,400 kcal per batch. The operational parameters of traditional cooking system were summarized in **Table 3**.

It was observed that, the traditional biomass based community cooking system consumed 15 kg babul (Acacia nilotica) per batch to meet the cooking requirement of 65 meals per batch. The average time consumed for cooking by system was found to be 3 h with the average fuel consumption rate of 5 kg $h^{-1}$. The average energy input from the biomass, babul (Acacia nilotica) for cooking was found to be 48,360 kcal per batch. The thermal efficiency of the community biomass cooking system was found to be 14.14 % on the basis of water boiling test (WBT).

The result of thermal efficiency of traditional cooking system revealed that the huge amount of energy wastage which showed the scope for biomass saving with clean environment by replacing it by gasifier, based community-cooking system.

Based on the energy requirement, type of fuel available, size of utensil etc. an open top gasifier operating on natural draft of air was developed and fabricated.

**Performance Evaluation of Open Top Gasifier Based Community-Cooking System**

The open top gasifier was evaluated to determine the various operational parameters for thermal application. The thermal profile of the gasifier reactor at different height from grate and flame temperature was evaluated. The analysis of the feedstock for the gasification was studied for the proximate analysis and calorific value estimation.

**Properties of Feedstock**

The air dried biomass of babul (Acacia nilotica) cut into convenient size, i.e. 4-5 cm diameter and 5-7 cm long was used as feed stock for testing the gasifier system. Physical and thermal properties of feedstock influenced the operation of the thermal system to a great extent that are mentioned in **Table 4**.

The proximate analysis of the biomass babul (Accacia nilotica) revealed that it was suitable of the fuel for gasification. It was observed that the moisture content of the fuel under the acceptable limit (below 15 %) to ensure free flow and good quality gas production. Also the data indicated that the higher amount of volatile matter, the lower amount of the ash content in the fuel, the average higher heating value was found to be 3,224.2 kcal $kg^{-1}$ that revealed the suitability of the fuel for gasification.

**Testing of Open Top Gasifier**

The laboratory test of open top gasifier was carried out to determe its performance. Parameters related to the gasifier namely; temperature at predetermined locations, consumption of feedstock and temperature of the flame produced and other operating parameters with thermal efficiency were recorded. The performance of the open top gasifier was analyzed under the following parameters:

**Operational Characteristics**

The performance test runs of the gasifier were carried out by loading the gasifier reactor with rated loadings capacity. The results obtained from the series of test runs for open

**Table 3** Operational characteristics of traditional cooking system (per batch)

| Particular | Avg. value |
|---|---|
| Type of fuel | Babul (Acacia nilotica) |
| Fuel consumption, kg | 15 |
| Time required for cooking, h | 03 |
| Fuel consumption rate, kg $h^{-1}$ | 05 |
| Alternate fuel used | LPG |
| Alternate fuel consumption LPG, kg | 02 |
| Energy input from biomass, kcal | 48,360 |
| Energy input from LPG, kcal $m^{-3}$ | 25,000 |
| Total energy input, kcal | 61,360 |
| Operating days per year, Nos. | 330 |
| Thermal efficiency, % | 14.14 |

**Table 4** Proximate analysis and calorific value of wood fuel, Babul (Acacia nilotica)

| Property | Value |
|---|---|
| Moisture content, % | 11.33 |
| Volatile matter, % | 67.56 |
| Ash content, % | 2.1 |
| Fixed carbon, % | 19.01 |
| Higher heating value, kcal $kg^{-1}$ | 3,224.2 |
| Bulk density, kg $m^{-3}$ | 259 |

top gasifire in laboratory are shown in **Table 5**.

The operational characteristics showed that the average start-up time of open top gasifier was 5 min that depends on the amount of fuel (kerosene) used for ignition of biomass (Acacia nilotica) (charge). The average fuel used for ignition was 12 ml. The average operating time of fully loaded open top gasifier was found to be 1.58 h with average total operating time was 1.67 h, with the average total fuel consumed during the test 6.67 kg.

As per above results shown in **Table 5**, the average specific gasification rate was 96.25 kg m-2h$^{-1}$. Based on fuel consumption and height of reactor, the average combustion zone rate was 0.4 m h$^{-1}$ with average thermal efficiency 21.86 % in laboratory test. The average input in terms of heat energy, average power input, and average power output is shown in **Table 5**. The final product of combustion i.e. ash produced was 2.76 %.

**Table 5** Operational characteristics of open top gasifier (Laboratory test)

| Parameters | Value |
|---|---|
| Start-up time, min | 5.0 |
| Operating time, h | 1.58 |
| Total operating time, h | 1.67 |
| Total fuel consumed, kg | 6.67 |
| Fuel consumption rate, kg h$^{-1}$ | 3.99 |
| Ignition fuel kerosene, ml | 12.0 |
| Specific gasification rate, kg m$^{-2}$ h$^{-1}$ | 96.25 |
| Combustion zone velocity, m h$^{-1}$ | 0.40 |
| Heat energy input, kcal | 21,475 |
| Thermal efficiency, % | 21.86 |
| Power input, kW | 15.42 |
| Power output, kW | 3.34 |
| Ash produced, % | 2.76 |

**Fig. 3** Thermal profile test of open top gasifier


### Thermal Efficiency by Water Boiling Test:

The water boiling test of open top gasifier was carried out to evaluate the thermal performance of open top gasifier. The average thermal efficiency was 21.86 %. The higher thermal efficiency of open top gasifier than the traditional biomass cooking system (14.4 %) revealed the scope for fuel saving.

### Thermal Profile of Open Top Gasifier:

The thermal profile includes the thermal profile of combustion zone and the flame temperature.

### Thermal Profile of Combustion Zone:

**Fig. 3** shows the zones for temperature measurement at different height from the grate of gasifier reactor and flame temperature with respect to operating time of the reactor.

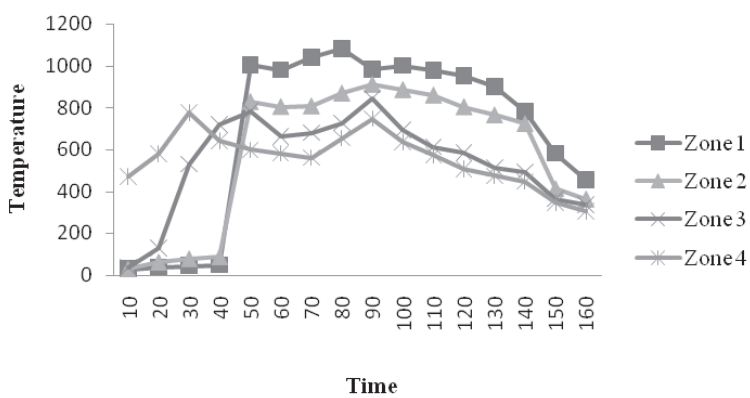
The thermal profile of gasifier was taken at pre-defined locations at the average fuel combustion rate of 4 kg h$^{-1}$ are shown in **Fig. 4**. The temperature was measured at every 10 min interval from the ignition of gasifier up to the end of the process. The gasifier is of open top, the wood was lit-up from the top. Hence the hot bed moves from top to bottom up to the grate in to the reactor.

During initial starting phase, the temperature was higher at the Zone-4 and decreased up to the ambient at Zone-1. After 50 minutes, the condition changed and higher temperature was observed at Zone-1 and lower temperature at Zone-4.

In the Zone-4, a gradual rise in temperature from 400ºC to 800 ºC was observed during initial 30 minutes of operation. The gradual decrease in temperature up to 560 ºC was observed in Zone-4 till 80 minutes of operation. The gradual decrease in temperature from upper zone during the operation of gasifier indicated the movement of char towards the grate.

In Zone-3, a gradual rise in temperature from 50 ºC to 800 ºC was observed during initial 50 minutes of operation. It showed that the hot bed was moved from Zone-4 to Zone-3. The maximum temperature reached in the Zone-3 was 884 ºC. The gradual decrease in temperature up to 550 ºC was observed in 80 minutes of interval. The gradual de-

**Fig. 4** Thermal profile of open top gasifier at different locations



crease in temperature from Zone-3 during the operation of gasifier indicated the movement of char towards the grate.

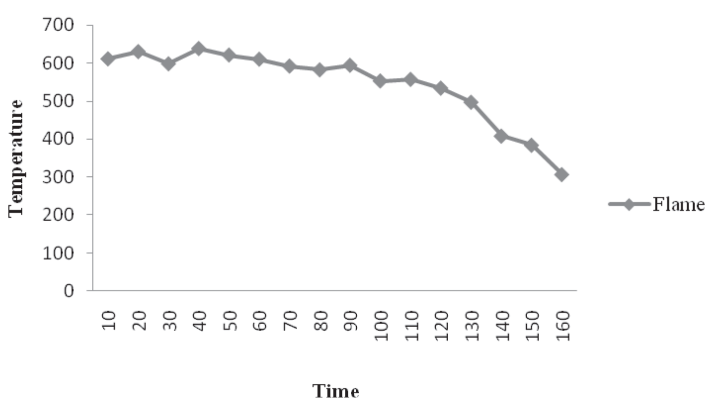
The temperature observed at Zone-1 and Zone-2 was in the range of 30 ºC to 80 ºC for first 40 minutes of operation. The sudden change of temperature was observed at Zone-1 and Zone-2 at 40 to 50 min period of time due to the movement of hot charge bed from Zone-3 to Zone-2. It was observed that the temperature increased above 800 ºC at Zone-2 and near to 1000 ºC at Zone-1. The temperature in Zone-2 remained in the range of 700 ºC to 900 ºC up to 140 minutes of operation and after that gradually decreased till the end of process. The temperature in Zone-1 remained in the range of 800 ºC to 1100 ºC up to 140 minutes then decreased gradually till the end of process.

**Flame Temperature of Open Top Gasifier:**

The flame temperature profile of open top gasifier is shown in **Fig. 5**. It was observed that the maximum temperature attained by the flame was 638 ºC that indicated an adequate amount of heat was produced for cooking.

The fabrication cost of gasifier was considered as fixed cost of the cooking system. The fabrication cost of open top gasifier involves material cost and fabrication cost. The material cost was Rs. 2,430/- (≈ $ 40.50). Fabrication cost involves welding rods; electricity and labor charges were Rs. 1,100/-(≈ $ 18.30). The total cost of manufacturing was Rs. 3530/-(≈$58.80).

**Fig. 5** Flame temperature profile open top gasifier Cost of open top gasifier:




## Conclusions

This study could establish that the thermo-chemical conversion of biomass through gasification was one of the promising routes among the renewable energy options for future energy. The average thermal efficiency using standard water boiling test of open top gasifier was found to be 21.86 %. By using babul wood (Acacia nilotica) with dimension 4 to 5 cm thick and 5 to 7 cm long as feed stock for gasification provided a greater conversion of fuel into heat than traditional cooking system with saving of about 22 % of fuel wood (Acacia nilotica) over the traditional cooking system.

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# Mechanized Mulching Practices with Plastic Filmand Wheat Straw in Dryland Wheat Planting

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## Abstract

In order to investigation into the effects of mulching practices on sustainable dryland uses, the study was carried out over a three year period in a comparative experiment on three farming practices, the wheat straw mulching practice, the plastic film mulching practice and the conventional farming practice., The study examined soil water, nutrients, organic matter and residues, and wheat yields and economic efficiencies against the different practices. The plastic film mulching practice could perform better in soil moisture conservation in a short term but decreased its effects of soil water and nutrient conservation year by year afterwards. The wheat straw mulching practice could increase soil organic matter and then improve soil water storage capacity and fertility, thus helpful for dryland farming to form a cycle of sustainable development.

***Key Words:*** mechanization; plastic film; mulching; wheat straw; soil water and nutrient; dryland farming; sustainable development

## Introduction

High attention is given to adoptions of mulching practices for soil moisture conservation in order to deal with water shortage and fully utilize limited rainwater in dryland farming region. Mulching practices can significantly modify farmland tillage modes and soil water movements, prevent soil water from vertical evaporation and disorderly flows, make soil water laterally move beneath mulched plastic film, increase water movement resistance, and reduce useless water losses., Thus mulching is capable of effectively retaining and conserving soil moisture to create favorable soil water conditions for early crop growth and promoting crops to consume soil water at late growth stages, improving use efficiency of limited rainwater, and remarkably increasing crop yield (Zhou L. M. *et al*., 2009; Guo Zhongsheng *et al*., 2010; Wang Hongli et al., 2011). However, plastic film mulching can remarkably reduce soil water and in particular, the water content in 80-120 cm soil to approach the soil wilting coefficient, thereby causing year to year soil water fluctuations and creating the risk of deep soil desiccation, so that they can increase crop yield in one year but result in decreased crop yield next year, This is, not helpful for sustainable farmland exploitation. Furthermore, mulching is time consuming, toilsome, difficult to apply, causes severe plastic film pollution and uneasy seedling emergences in following cropp (Wang Hongli *et al*., 2011).

It is certain that mulching is capable of conserving soil moisture, a crucial problem in dryland farming (Li Like, 2002). But from the angle of long-term sustainable development of dryland farming, what mulching materials should be chosen need to be studied. Current mulching practices include the double-ridged plastic film mulching practice, sand mulching practice, straw mulching practice, wheat straw mulching practice, and straw and plastic film combined mulching practice (Wang Hongli *et al*., 2011; Du Guoping, 2013; Mai Zizhen *et al*., 2007). The double-ridged plastic film mulching practice is capable of improving soil condition in 0-200 cm soil before the jointing stage of corn, promoting deep soil water exploitation by corn and significantly increasing corn yield and consumption. The sand mulching practice is capable of improving soil water condition in 0-200 cm soil before the jointing stage, increasing crop water consumption and yield to some extent but does not perform as well as the double-ridged plastic film mulching practice. Where the double-ridged plastic film mulching practice is adopted in two consecutive years, the soil water consumption depth and intensity increase so that in 80-120 cm soil the water content decreased to 7.89 %, comparable to the wilting coefficient, i.e., a dry soil layer forms. As a result, the double-ridged plastic film mulching practice increases the risk of deep soil desiccation although it is capable of increasing crop yields (Wang Hongli *et al*., 2011). Where the straw mulching practice was adopted, it is capable of breaking original plowpan and then thickening topsoil as well as decreasing soil compactness, increasing soil porosity, soil field water holding capacity, and organic matter, nitrogen, potassium and phosphorous contents (Du Guoping, 2013). The straw and plastic film combined mulching practice is capable of inhibiting soil water evaporation, increasing soil water storage and maintaining and stabilizing soil temperature (Mai Zizhen *et al*., 2007).

Because of its vast area and deep and thick soil, the loess plateau of China possesses rich and abundant soil resources for agricultural development. In the loess plateau, underground water is deep underground, incapable of directly involving in the soil-plant-atmosphere cycle and thus farmland water resources are composed of only rainwater and soil water (Wang Xuechun *et al*., 2009). But in the plateau, the rainfall is low and the climate is dry. The study was intended to investigate soil water, organic matter and nutrient dynamics of drylands, economic efficiency of dryland farming as well as effects of mulching practices and materials on sustainable development of dryland farming in the loess plateau on the condition that wheat straw mulching and plastic film mulching were practiced.

## Materials and Methods

**Experiment Sites**

The experiment sites were located in eight counties of Shaanxi, Yaoxian, Chengcheng, Baishui, Yongshou, Binxian, Xunyi and Chunhua. Representing 1,000 km$^2$, these sites distribute within 35º- 45º40´ N., stands at 900-1300 m above sea level and has an annual rainfall ranging within 560-580 mm. in the sites, the soils were loessal soil and the slope gradients were below 5º; and the main crops were wheat and the wheat variety was Jinmai 6.

**Mulching Materials and Practices**

With the conventional farming practice as their control, Two mulching practices for soil moisture conservation, plastic film mulching and wheat straw mulching practices, were comparatively experimented in three years (**Fig. 1**). **Fig. 1a** presents the plastic film mulching practice (Li Like, 1994), one mulching practice commonly adopted in China in the recent years, which has a coverage of 46 %. Figure 1b presents the wheat straw mulching practice, the priority mulching practice of the study, which has coverage of 100 %. The soil water content was 14.1 % before mulching.

**Soil Parameters and their Measurements**

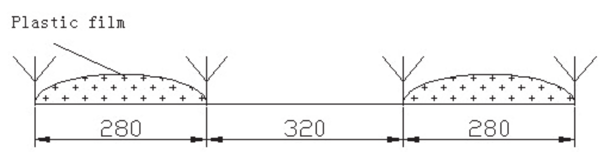
Soil Water measurement: 50 sampling points were chosen in the above mentioned sites with the purpose of highly accurate statistical analysis and soil samples were taken in 0-100 cm soil beneath the mulched plastic film and wheat straw every 20 cm at these points with cutting ring; and the sampling was done once in each week during the experiment period and the soil water contents of the samples were averaged as the soil water content in the individual years in question.

Soil organic matter measurement: soil organic matters include various plant and animal residues as well as microbes and their different organic products and are capable of not only providing crops with various essential nutrients but also playing a decisive role in soil structure formation and physical and chemical property improvement.

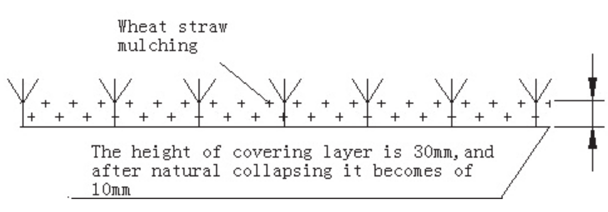
The study adopted the Potassium dichromate oxidation and colorimetry to determine organic matter. The steps for the measurement were as follows: concentrated sulfuric acid was added into potassium dichromate solution to produce the heat of dilution and as a result potassium dichromate oxidized organic matter carbon so that $Cr_6$ + was reduced to $Cr_3$ +; Next $Cr_3$ + was determined by colorimetry with the standard colors prepared with glucose and the organic matter contents were calculated depending on the result thus obtained (Xie Xixiang, 2005).

Mulching Material residue mea-

**Fig. 1** the two different mulching practices




a) Plastic film mulching practice




b) Wheat straw mulching practice

surement and their effect examination: the mulching materials were removed and then whether there existed seedling absences occurred and how the straws decomposed were examined; and the plastic film residual was calculated at the same time.

### Indicators and Their Calculations of Economic Efficiency Assessment

Economic indicators of agricultural technique assessment should be reasonable, i.e., they do not only can really indicate actual technique-triggered economic return but also are feasible and useful ones whose true data can be collected. Relying on the above principle, the study chose and adopted the following indicators of economic efficiency assessment:

***Total Yield Increment***

The indictor was defined as the increment of the yield of one crop for which a new technique was adopted compared with the yield of the crop for which the conventional techniques instead of the new technique were adopted. The formula by which the study calculated the total yield increment was as follows:

$Yw = (Ye - Yc) \times A_1$ ................. (1)

*Yw*: the total yield increment of wheat;

*Ye*: the yield of wheat for which the plastic film mulching practice or the wheat straw mulching practice was adopted;

*Yc*: the yield of wheat for which the conventional practice was adopted;

$A_1$: the accumulative area of wheat.

***Net Income Increment***

The formula to calculate the net income increment was as follows:

$Yn = Yw \times Pw - (Ce - Cc) \times A_1$ (2)

*Yn*: the net income increment;

*Pw*: the price of wheat;

*Ce*: the cost to adopt the plastic film mulching practice or the wheat straw mulching practice;

*Cc*: the cost to adopt the conventional practice;

***Average Annual Net Income Increment***

The average annual net income increment was calculated by the following formula:

$Ia = In / N$ ................................. (3)

*Ia*: average annual net income increment;

*In*: the net income increment;

*N*: the number of experiment years.

***Investment Yield Increment***

The investment yield increment was defined as the ratio of the net investment yield increment of a new technique put into use to the research, development and promotion cost of the technique. The investment yield increment was calculated by the formula:

$Yr = In / [Cr + Cp + (Ca' - Cc') \times A$ .................................................(4)

*Yr*: the research-investment yield increment;

*Cr*: research cost;

*Cp*: promotion cost;

*Ca'*: cost per unit area to adopt the plastic film mulching practice or the wheat straw mulching practice;

*Cc'*: the cost per unit area to adopt the conventional practices;

*A*: the planting area (Liu Xiaofeng, 2012) .

**Fig. 2** Soil woter contents between the two different mulching practices

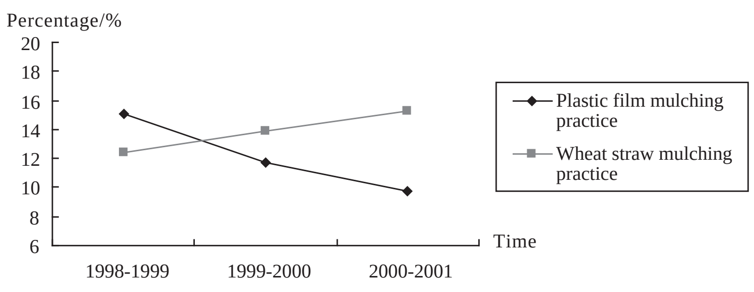
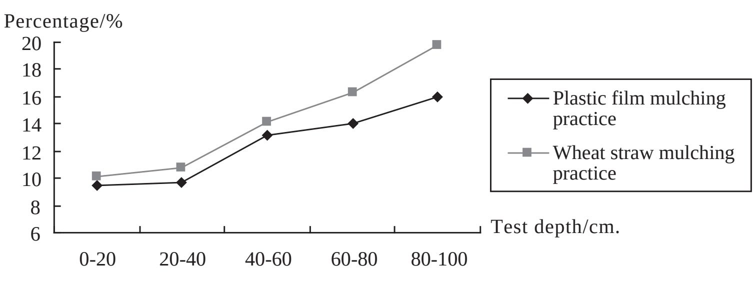



**Fig. 3** Soil woter contents in the different soil layers and mulching practices




## Results and Discussion

### Soil Water Contents

The average soil water contents measured in each year between 1998 and 2000 are shown in **Fig. 2**. The average annual rainfalls were separately 570 mm, 581 mm and 566 mm in the three years. **Fig. 2** shows that the soil water contents completely differed between the two mulching materials.

In the first experiment year, the soil water contents were higher where the plastic film mulching practice was adopted than where the wheat straw mulching practice and the conventional practice were adopted. Where the plastic film mulching practice was adopted, the soil water contents were evidently lower in the second experiment year than in the first experiment year although the rainfall was slightly higher in the second experiment year than in the first year, and tended to continue on decreasing and was lower in the third experiment year than those where the wheat straw mulching practice was adopted. It follows that

**Table 1** soil residuals of the mulching materials with the different mulching practices adopted

| Experiment Year | Plastic film mulching practice | Wheat straw mulching practice |
|---|---|---|
| 1998-1999 | – | – |
| 1999-2000 | There were seedling absences of wheat occurring, visible un-rotten straw dug out, residual plastic film found in 3 % of seedling absent locations | Wheat did not get affected at the seedling stage |
| 2000-2001 | There were seedling absences of wheat occurring, visible un-rotten straw dug out, residual plastic film found in 6 % of seedling absent locations | Wheat did not get affected at the seedling stage |

plastic film mulching indeed took air tightening effect, blocking soil water from evaporation, and took greenhouse effect, increasing soil temperature, so that the soil temperatures increasingly differ between mulched and un-mulched belts and hence soil water could not escape from mulched belts but easily diffused into un-mulched belts and then evaporated from them. Where the plastic film mulching practice was adopted, it increased soil temperature, promoted the crop to grow quickly and increased soil water evaporation, so that it increased soil water consumption.

The measured water contents in the different soil layers are presented in **Fig. 3**.

It can be seen from **Fig. 3** that the greenhouse effects brought about in the consecutive experiment years caused deep soil water to move upward, hence resulting in deep soil drying. Where the wheat straw mulching practice was adopted, there were no greenhouse effects brought about, although there was no plastic film taking insulating effect. In the meantime, the straw mulching practice continuously improved soil structure and increased soil water storage capacity. Although at the beginning the soil water contents were lower where the straw mulching practice was adopted than where the plastic film mulching practice was adopted, the year to year adoption of the wheat straw mulching practice gradually increased soil water year by year. Paradoxically, the soil water contents were higher with the wheat straw mulching practice than with the plastic film mulching practice after the practices were applied in the consecutive years. Because of the above mentioned reasons, this abnormality was an inevitable tendency in dryland region without access to irrigation, as reported in relevant literatures (Li Yuannong *et al.*, 2001).

**Fig. 4** Soil organic matter contents between the two different mulching practices

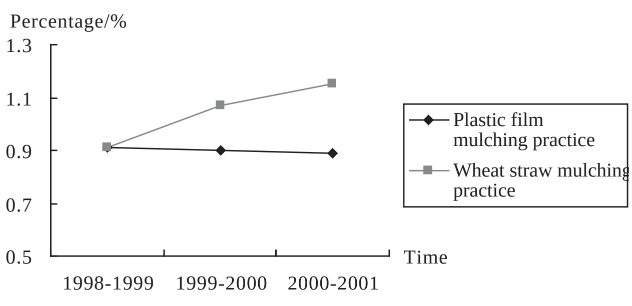
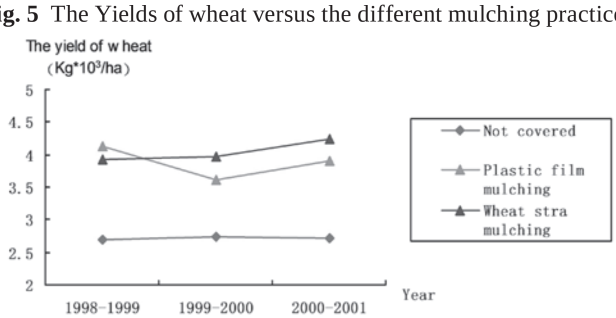



**Fig. 5** The Yields of wheat versus the different mulching practices




## Soil Organic Matter Contents

The soil organic matter contents are presented in **Fig. 4**. The soil organic matter contents increased year by year where the wheat straw mulching practice was applied compare to where the plastic film mulching practice was applied and this was helpful to improve soil fertility.

## Soil residuals of the Mulching Materials

Soil residuals and their impacts of the mulching materials on seedling emergences are shown in **Table 1**. It can be seen from **Table 1** that plastic film residuals were very difficult to completely remove where the plastic film mulching practice was applied and the residuals accumulated more and more as the practice was applied for more and more years, so that the residuals exerted more and more influence on seedling emergence, thus causing more and more severe seedling absences, which was an important problem of pollution not to be ignored. Where the wheat straw mulching practice was adopted, humus formed but no pollutants remained, which was helpful to improve soil fertility.

## Wheat yield

The Yields of wheat versus the different mulching practices are presented in **Fig. 5**. It can be seen from the figure that in the experiment year when the plastic film machining practice was adopted, the yield of wheat increased greatly (Wang Yong *et al*., 1999) and its increment was as high as about 100 kg per mu. However, under the same water and fertilization conditions as in the first experiment year, the yield of wheat did not increase much in the second experiment year and presented a negative increase in the third experiment year. The reason for this result was that in the first experiment year, because it took greenhouse effect, the plastic film mulching practice promoted wheat to grow too much, hence resulting in the crop consuming too much soil water and nutrients and at the same time, different soil organic matter contents affected soil capacities to take up rainwater. Therefore, the plastic film mulching practice was capable of effectively bringing soil fertility into full play but incapable of maintaining and improving soil fertility for future production.

**Fig. 6** The average economic efficiencies in three experiment years versus the different mulching practices

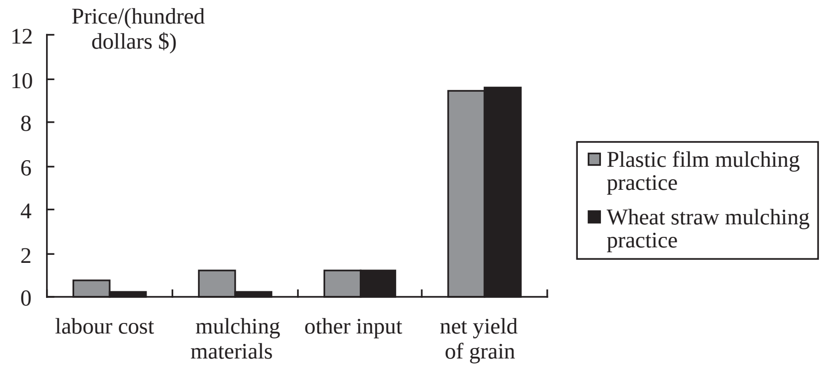
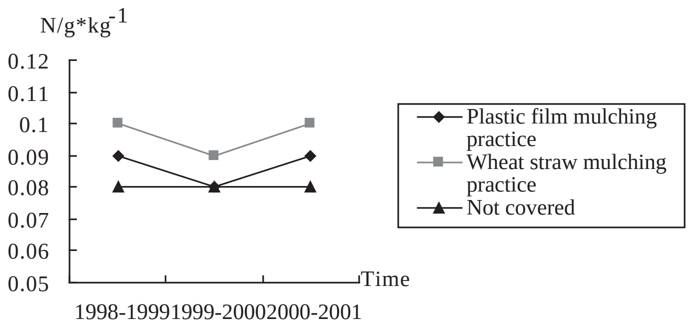
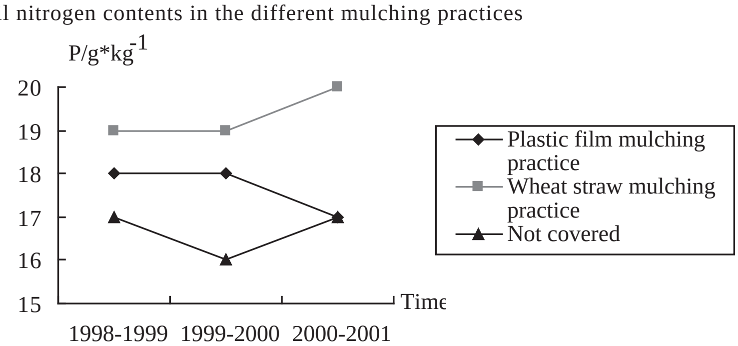


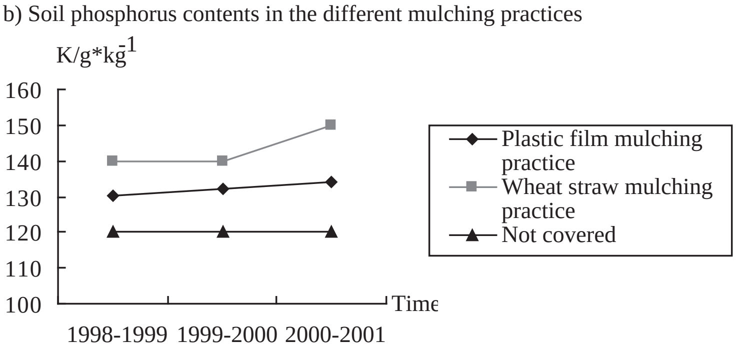

**Fig. 7** Measured soil nitrogen, phosphorus and potassium contents against the different mulching practices




a) Soil nitrogen contents in the different mulching practices




b) Soil phosphorus contents in the different mulching practices




c) Soil potassium contents in the different mulching practices

## Economic Efficiencies

**Fig. 6** presents the average economic efficiencies in the three experiment years when the mulching practices.

It can be seen from the **Fig. 6** that the different mulching practices had different input/output ratios. Where the plastic film mulching practice was adopted, its input/output ratio (yield increment/investment ratio) was 1 : 3 and where the wheat straw mulching practice was adopted, its input/output ratio was 1 : 5.6. In the two cases, the other inputs, i.e., ones excluding the mulching materials, such as fertilizers, seeds, pesticides and tillage services, were the same. It is too costly to adopt the plastic film mulching practice because plastic film was an expensive one-time input and this had been the biggest barrier to the adoption of the practice in the recent years.

## Soil Nutrients

Measured soil nitrogen, potassium and phosphorus contents against the different mulching practices are presented in **Fig. 7**. It can be seen from the figure that the soil fertility appeared the highest with the wheat straw mulching practice, moderate with the plastic film mulching practice and the lowest with the conventional practice. And the soil fertility increased more with the wheat straw mulching practice than with the plastic film mulching practice. It follows that the wheat straw mulching practice took better effect in maintaining and improving dryland soil fertility.

## Conclusions

The plastic film mulching practice evidently increased the yield of wheat at the beginning and decreased the effect year by year later, and that resulted in soil water storing capacity declining and plastic film-caused pollution evidently increasing at the same time. The wheat straw mulching practice could not only avoid plastic film caused pollution but also fully exploit wheat straw rather than it was burnt to cause environmental pollution.

The wheat straw mulching practice did not increased the yield of wheat more than the plastic film mulching practice at the beginning, but tended to increasingly do so year by year later. Meanwhile, the wheat straw mulching practice was able to optimize soil structure, promote microbes to multiply, and increase soil organic matter, thus improving agricultural production stamina and dryland use sustainability.

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# ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

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**Optimization of Wear Rate of Agricultural Grade Boron Steel Using Response Surface Regression: Dushyant Singh**, Central Institute of Agricultural Engineering, ICAR, Nabi-bagh, Bhopal-462038, INDIA; **K. P. Saha**, same; **Manoj Kumar**, same; **C. G. Joshy**, Central Institute of Fisheries Technology, ICAR, Cochin-682029, INDIA, **D. P. Mondal**, Advance Material and Processes Research Institute, CSIR, Bhopal-462 026, INDIA.

Second order response surface regression model was developed to predict the wear rate of boron steel influenced by three factors namelyapplied load, hardness and peening intensity. In the developed model, the influencing factors like applied load, peening intensity, second degree polynomial of peening intensity and interactions of applied load with both of hardness and peening intensity were having significant effect on wear rate of boron steel. The interaction between load and hardness, load and peening intensity were found to have significant effect on wear rate. But the interaction between hardness and peening intensity produced a non-significant effect on wear rate. Based on the Tukey's HSD test and grouping of the levels of different factors, the minimum wear rate of boron steel was observed at an applied load of 75N, hardness at 446 Hv in inter-critically annealed boron steel subjected to shot peening at an intensity of 0.17 Almen "A".

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**Physical Properties of Castor (Ricinus Communis L.) Seed in Relation to Soaking Hours: Ajit Singh**, Research Associate, Department of Horticulture, College of Agriculture, CCS Haryana Agricultural University, Hisar-125004, Haryana, INDIA. er.ajitsangwan@rediffmil.com; **Vijaya Rani**, Assistant Professor, Department of Farm Machinery & Power Engineering, College of Agricultural Engineering and Technology, same. vizayarani@yahoo.com; **Anil Kumar**, same. anil_saroha@rediffmail.com; **S. Mukesh**, Assistant Agricultural Engineer, same. miukeshjainhisar@rediffmail.com

Knowledge of physical properties of the castor seed determined as a function of soaking hours (moisture content) can be used in designing of sowing and processing equipment. The physical properties of the castor seed were determined for a range of soaking hours from unsoaked seed to seed soaked for 12 hours, for which the moisture range of seed varied from 5.9 % to 32.8 % dry basis. The length, width, thickness, surface area, arithmetic and geometric mean diameter of castor seed after 12 hours of soaking increased by 5.40, 2.75, 2.95, 3.64, 3.93 and 5.88 %, respectively over unsoaked seed. The sphericity decreased from 70.84 to 69.68 % and roundness increased from 57.16 to 61.52 % with the increased moisture content. One hundred seed weight, single seed volume and bulk density increased from 28.60 to 37.99 g, 320.02 to 380.02 $mm^3$ and 517.08 to 620.08 kg $m^{-3}$ as soaking hours increased to 12 hours over unsoaked seed. True density and porosity increased for first 6 hrs of soaking from 896.03 kg $m^{-3}$ to 1010.39 kg $m^{-3}$ and 42.12 to 43.55 % over unsoaked seed and then the values decreased to 1001.55 kg $m^{-3}$ and 37.96 % respectively when the hours of soaking further increased to 12 hours. The angle of repose and coefficient of static friction increased from 31 to 41 degrees and 0.32 to 0.62 with increased moisture content. Regression equations that could be used to adequately express the relationship between the physical properties as mentioned and soaking hours were established.

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# Books

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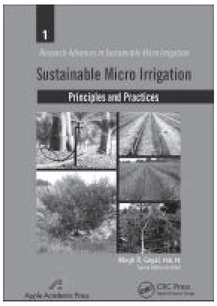


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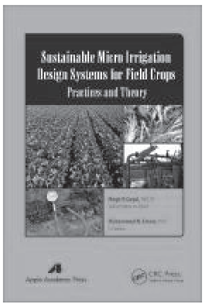


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This new book, Sustainable Micro Irrigation Design Systems for Field Crops: Practices and Theory, is planned to bring together the best research for efficient micro irrigation methods for field crops from around the world.

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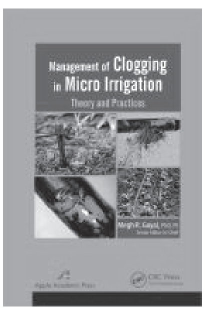
- an historical review
- a review of the current status and potential applications of micro irrigation
- basic principles and applications
- research results for vegetable/row/tree crops
- research results on simulation of micro irrigation and wetting patterns
- a discussion on the development of software for micro irrigation design
- information geared specifically for micro irrigation for small farms and marginal farmers
- design charts for micro irrigation methods in arid, humid, semiarid, and tropical climates
- methods and techniques that can be easily applied to other locations that are not covered here

## Management of Clogging in Micro Irrigation

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Micro irrigation, also known as trickle irrigation or drip irrigation or localized irrigation or high frequency or pressurized irrigation, is an irrigation method that saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. Clogging is a menace in the success of drip irrigation system, and the situation is more complex under subsurface drip irrigation. Irrigation planners and engineers have found a variety of innovative methods to help to minimize clogging.

This valuable resource will address this critical problem, covering

- the mechanics and maintenance of micro irrigation systems to prevent clogging
- emitter clogging
- how chemigation, such as acidification and chloration, can be used to help prevent clogging
- flushing and filtration systems on the performance of micro irrigation systems
- how to evaluate the uniformity coefficients
- how to evaluate micro irrigation systems in connection with municipal wastewater
- how to minimize clogging when using municipal wastewater
- the special problem of clogging in subsurface drip irrigation

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# EVENT CALENDAR

◆ **ICAFUS 2015**
—XIII International Conference on Agriculture, Food and Urbanizing Society—
*May 14-15, 2015*, Amsterdam, NETHERLANDS
https://www.waset.org/conference/2015/05/amsterdam/ICAFUS

◆ **FRUTIC ITALY 2015 International Conference**
*May 19-22, 2015*, Milan, ITALY
http://www.aidic.it/frutic/main.html

◆ **XXXVI CIOSTA CIGR V Conference 2015**
—Environmently Friendly Agriculture And Forestry For Future Generations—
*May 26−28, 2015,* Saint−Petersburg, RUSSIA
CIOSTA− Commission Internationale del' Organization Scientifique du Travail en Agriculture was founded in 1950 and has organized many conferences, seminars, workshops and other meetings on the optimization of bio−production management and work, system engineering and innovative technologies. The theme of the Conference 2015 is "Environmentally Friendly Agriculture and Forestry for Future Generations" and is now calling for papers.
info@ciosta2015.org.

◆ **GRAPAS International 2015**
*June 9-11, 2015,* Cologne, GERMANY
http://www.victam.com

◆ **2nd International Controlled Traffic Farming Conference Location to be confirmed**
*June 14-16, 2015,* CZECH REPUBLIC
http://www.controlledtrafficfarming.com/Home/Default.aspx

◆ **New Frontiers of Biosystems and Agricultural Engineering for Feeding the Planet**
*June 22-23, 2015,* Naples, ITALY
durso@unina.it

◆ **10th ECPA Meeting**
—European Conference on Precision Agriculture Conference theme: Precision agriculture for efficient resources management under changing global conditions—
*July 12-16, 2015,* ISRAEL
http://www.ecpa2015.com/#!call-for-papers/c1cyg

◆ **GreenSys 2015**
*July 19-23, 2015*, Evora, PORTUGAL
http://www.greensys2015.uevora.pt

◆ **ASABE 2015 Annual International Meeting**
*July 26-29, 2015*, New Orleans Louisianna, USA
http://www.asabe.org/meetings-events.aspx

◆ **AgTech Summit**
*July 2015*, Salinas Valley, California USA
www.thecalifornian.com/...ag-tech-summit-salinas

◆ **IMATEX E.A 2015**
—International Modern Agricultural Technologies Exhibition East Africa 2015—
*August 6-8, 2015*, Nairobi, KENYA
www.inagritech-exhibition.net/why-should-visit

◆ **The 3rd INAgriTech 2015**
—The 3rd Indonesia International Agricultural Equipment, Technology & Machinery Exhibition 2015—
*August 6-8, 2015*, Jakarta, INDONESIA
www.inagritech-exhibition.net/why-should-visit

◆ **Construction, Technology and Environment in Farm Animal Husbandry**
*September 8-10, 2015*, Friesing-Weihenstephan, GERMANY
http://www.btu-tagung.de/

◆ **HAICTA 2015**
—7th International Conference on Information and Communication Technologies in Agriculture, Food and Environment—
*September 17-20, 2015*, Kavala, GREECE
http://2015.haicta.gr/

◆ **AgroWorld Kazakhstan**
—Central Asia's International Agricultural Exhibition—
*November 4-6, 2015, Almaty,* KAZAKHSTAN
http://agroworld.kz/en/

◆ **Land.Technik AgEng 2015**
*November 6-7, 2015,* Hannover, GERMANY
www.vdi.de/landtechnik-ageng

◆ **4th CIGR International**
—AgEng Conference 2016− Robotics, Environment and Food Safety—
*June 26-29, 2016,* Aarhus, DENMARK
http://conferences.au.dk/cigr-2016/

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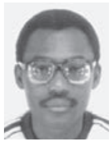
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**AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA**

(Vol.44, No.2, Spring, 2013-)

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**Vol.45, No.2, Spring 2014**



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**Vol.45, No.3, Summer 2014**



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**Vol.45, No.4, Autumn 2014**



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**Vol.46, No.1, Winter 2015**



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The Editorial Staff of the AMA requests of articles for publication to observe the following editorial policy and guidelines in order to improve communication and to facilitate the editorial process:

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Priority in the selection of article for publication is given to those that –

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h. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
i. Indicate by footnotes or legends any abbreviations or symbols used in tables or figures.
j. Convert national currencies in US dollars and use the later consistently.
k. Round off numbers, if possible, to one or two decimal units, e.g., 45.5 kg/ha instead of 45.4762 kg/ha.
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