



Design, development and performance evaluation of manual planter for system of wheat intensification

H L KUSHWAHA¹, ANCHAL DASS², TAPAN KUMAR KHURA³, P K SAHOO⁴,
MUKESH KUMAR SINGH⁵ and INDRA MANI⁶

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 14 August 2018; Accepted: 19 November 2018

ABSTRACT

System of wheat intensification (SWI), a new planting method, has shown promising results. Manual planting in SWI is cumbersome, labored and time-consuming. Hence, a manually operated planter for SWI was designed and developed at ICAR-IARI, New Delhi, for precise planting of wheat (*Triticum aestivum* L.) seed. Field experiment was conducted to optimize design parameters i.e. plant spacing, number of seed/hill, treated/untreated and result was compared for conventional wheat cultivation with and without SWI management during winter season of 2015-16. The estimated labour requirements for manual planting under SWI method was 4–5 times more than the traditional drilling of wheat. The bulk density, true density, 1,000 seed weight, max. and min. dimensions and sphericity of the wheat seed were computed as 768 kg/m³, 1376 kg/m³, 39.9 g, 6.0 and 2.6 mm and 3.7, respectively. Based on these physical properties of wheat seed, a vertical cell type metering unit for single-row SWI planter was designed and fabricated. The metering unit of the planter was evaluated on a sticky belt at different speeds for distribution uniformity of seed per hill. It dropped 2-seeds per hill for 56% hills (points), 3 and 1 seeds per hill in 20% hills and missed-out seeds for 4–5% hills. The developed SWI planter was evaluated at IARI-Agronomy research field and its performance was compared with manual sowing and manual SWI planting. Number of hills germinated was found to be 22–24/m². The distribution of plant per hill was found 69% double, 23% single, 5% triple and 3% nil. Overall, germination of seed, plant growth and yield were significantly better (> 25% higher) in the plots sown by SWI planter compared to conventional wheat sowing.

Key words: Manual planter, Planter, Seed metering, System of wheat intensification

Wheat (*Triticum aestivum* L.) constitutes staple food for more than 35% of world population. In India, wheat being the principal food accounts for over 50% of calories intake of the people depicting the immense importance of wheat production in food security of the nation. India produced, an all-time record high of 98.4 million tonnes (mt) wheat from an area of 30.6 million hectares (mha) with an average productivity of 3.22 t/ha, in 2016-17 (Anonymous 2018). The productivity of wheat in India is still lower than the world average and also less than one-third of the best performing nation, New Zealand (10 t/ha), suggesting tremendous scope for improving wheat productivity and income of wheat growing farmers.

Undoubtedly, there has been unprecedented

improvement in wheat yields due to breeding as well as agronomic interventions with application of power machinery system, but there have not been any break through in wheat yield enhancement during last 2 decades. Despite all research and development efforts, the average productivity of wheat is hovering around 2–3 t/ha for last two decades. In pursuit of achieving high yields, indiscriminate/over use of resources like seed, water, fertilizers and other agro-chemicals, has made wheat cultivation not very economical on one hand and, deterioration and pollution of soil, water and the environment on the other. The prevalent conventional method of wheat cultivation requires a heavy amount of nutrients mostly applied through chemical fertilizers (120–150 kg N, 30–60 kg P₂O₅, 20–40 kg K₂O), and 100–125 kg of seed per ha. Both of these important inputs are often, either not available to farmers in time or farmers do not have the financial capacity to buy and use these costly inputs in adequate amounts. Apart from genetic improvement, a breakthrough in agronomic management provided with use of agricultural machines, has been utterly desired to break the yield barriers and enhance input use efficiency. Thus, inspired by the success of 'System of Rice

¹Senior Scientist (e mail: hlkushwaha@gmail.com), ²Principal Scientist (e mail: anchal_iari@rediffmail.com), Division of Agronomy, ³Senior Scientist (e mail: tapankhura@gmail.com), ⁴Principal Scientist (e mail: sahoopk1965@gmail.com), ⁵Scientist (e mail: muky12345@gmail.com), ⁶Principal Scientist & Head (e mail: maniindra99@gmail.com), Division of Agricultural Engineering.

Intensification' (SRI) in improving the rice productivity, SRI principles have been extended to wheat and the results have been encouraging in terms of yield enhancements and resource saving. The recently developed technology, System of Wheat Intensification (SWI), involves modifying the practices like seed rate, sowing of seeds at proper spacing, control of water in the main field, weeding/hoeing to ensure a higher ratio of tillers to mother seedling, increased number of effective tillers/hill, enhanced spike length and bolder grains and finally enhanced yield of wheat. A generalized SWI protocol includes, (1) seed treatment with a mixture of jaggery, cow urine, compost and hot water (2) seed rate 25 kg/ha, (3) sowing by dibbling of two sprouted seeds per hill at 20 × 20 cm, (4) use of *Trichoderma* treated (2.5 kg/ha) compost @ 2 t/ha + 68 kg DAP + 33 kg MOP before sowing, 68 kg /ha urea on 16th day; vermicompost @ 500 kg/ha + PSB culture @ 6.25 kg/ha on 20th day; 34 kg/ha urea + 34 kg/ha MOP on 36th day and vermicompost @ 500 kg/ha on 40th day, (5) application of six irrigations at 15, 25, 35, 60, 95 and 105 days after sowing (DAS), and (6) three weeding using cono-weeder at 20, 30 and 40 DAS. As SWI uses only 25 kg/ha of improved seed, it thus, saves 75–100 kg/ha costly and limited available seed depending upon the variety and environment where wheat is cultivated. A wider spacing between rows and plants (20 – 25 cm), and use of manure and organic seed treatment result into a higher yield (Khadka and Raut 2012). Suryawanshi *et al.* (2013) reported that SWI at 20 cm × 20 cm produced significantly higher grain yield compared to SWI at closer spacing. Adequate spacing between the plants and sowing of two seeds at one point facilitates desired moisture, aeration, nutrition and light to the crop roots. This helps faster and vigorous growth of plants. Bhargava *et al.* (2016) reported higher number of effective tillers/plant, grains/spike and 1000-grain weight under SWI compared to conventional cultivation method. In SWI number of tillers per plant is found 4–5 times more than conventional method as well as higher test weight were recorded, respectively (Dhar *et al.* 2014). Dhar *et al.* (2015) reported that SWI out performed conventional method of wheat cultivation with a 46% yield advantage under climatically stressful study year. It was also reported that there was better yield attributes, root traits and availability of N, P, and K in the soil after harvesting in SWI compared to conventional cultivation practices, pointing to sustaining soil fertility under the former method. Moreover, the larger yield gains compensated for the higher cost of cultivation involved in SWI method. System of Wheat Intensification has also been tested by some farmers working with the NGOs in central and northern parts of India. Several varieties of wheat, showed significant increases in grain and straw yields compared with the conventional broadcast and line sowing methods for crop establishment.

Despite significant yield enhancement, SWI method is not getting favour with farmers mainly because the planting of 2-seeds/hill at specified plant spacing (20 × 20 cm) is a tedious, labour intensive and time consuming

operation due to non-availability of machinery. In India about 80% farmers are having less than 2 ha land and low purchase power. SWI method of planting has been adopted by small and marginal farmers. Development of single row manual SWI planter was taken up for targeting the small and marginal farmers. Keeping these in view, a study was undertaken to design and develop a single-row manually drawn SWI planter and to evaluate the SWI-planter in the field.

MATERIALS AND METHODS

While designing the SWI-planter components, specially the seed metering unit, the properties such as size, shape, sphericity, true density and angle of repose/friction of seed play important roles. Therefore, the range of shapes and sizes of wheat seed and their physical properties like grain length, width and thickness were determined. Based on these properties of wheat seed (var. HD 2967), shape and seed cell sizes on the seed metering unit to accommodate 2–3 seeds in each cells were designed. The physical properties of the seed were determined using the protocols suggested by (Sahoo and Srivastava, (2008) and Kushwaha *et al.* (2007).

The size of wheat seeds (var. HD 2967) was determined in terms of length (l), width (b) and thickness (t). Fifty seeds of variety were taken and dimensions l, b and t were measured at three major axes with the help digital vernier caliper having least count of 0.01 mm.

Size of each seed in terms of equivalent diameter (De) was also determined by using following formula:

$$De = (lbt)^{\frac{1}{3}} \quad (1)$$

Sphericity

The sphericity of seeds ϕ was calculated by using the following relationship (Mohsenin 1986):

$$\phi = \frac{(lbt)^{1/3}}{1} \quad (2)$$

The moisture content of the seed was determined by the oven dry method and 3 samples of seed were taken and kept in an oven at 105°C for 15 h after taking their initial weight. Thereafter, the samples were taken out, cooled in a desiccator and their dry weight was determined by using a digital balance. The moisture content was determined by the following relationship:

$$\text{Moisture content (db), \%} = \frac{W_1 - W_2}{W_2} \quad (3)$$

where, W_1 is the initial weight of the seeds in the sample (g) and, W_2 is the weight of the oven-dried seeds in sample (g).

The seeds were filled in a known volume cylinder without exerting additional pressure on seeds and its weight was measured on an electronic balance having least count of 0.01 g. The bulk density was calculated as weight of material per unit volume (g/cc).

The angle of repose of seeds was determined by angle

of repose apparatus, a cylinder (50 mm diameter and 60 mm height) was kept vertically on a wooden floor and filled with sample. Tapping during filling was done to obtain uniform packing and to minimize the wall effect. The cylinder was slowly raised above the floor so that whole material could slide and form heap. The height of heap (H) above the floor and the diameter of the heap (D) at its base were measured and angle of repose (θ) was determined using relationship as:

$$\text{Angle of repose } (\theta), \% = \tan^{-1} \frac{2H}{D} \quad (4)$$

Five samples, each comprising of 1,000-seeds were selected randomly and weighed in an electronic balance having least count of 0.01 g and the average value was computed.

The manual SWI planter was designed and fabricated in the Division of Agricultural Engineering (DAE), ICAR-Indian Agricultural Research Institute (IARI), New Delhi. The manual SWI planter consisted of main frame, metering unit with seed box, ground wheel with delivery unit, furrow opener, seed firming device (press wheels) and a handle. The conceptual design and drawing for the single row SWI planter was prepared with help of CAD software (Creo 5.0) and fabricated in the workshop of DAE, ICAR-IARI, New Delhi.

The main frame was made of mild steel (MS) 25 mm square section and of 2 mm thickness so that it should be rugged and light in weight. All the components, i.e. seed metering unit, ground wheel with delivery system, furrow opener and seed firming device (press wheels) were fitted on (Fig 1).

Metering unit was designed to accurately meter the desired quantity of seed(s) to be dropped in each hill. As per the recommendation in SWI method of planting, 2-seeds/hill should be planted. Thus, the metering cup was designed to accommodate 2–3 seeds and delivered to seed tube. The number of cups on the seed metering plate

was eight. The metering cup was designed on Pro-E and manufactured with 3D printing technology (Fig 2). The material used for 3D printing was poly lactic acid (PLA). The metering mechanism was evaluated on a sticky belt setup and performance parameters, such as hill to hill spacing, number of seeds/hill and missing percentage were recorded. A trapezoidal was designed to accommodate about 10 kg seed in one filling, its top opening 350 mm × 350 mm and base 140 mm × 50 mm with 250 mm height fabricated with 1.5mm mild steel sheet.

The ground wheel provided drive to metering mechanism and other side was the part of seed delivery unit. The ground wheel consisted of design values as 50 cm diameter, 5 cm width and consisted of 16 lugs. It was made of MS flat of 50×5 mm. The lugs of the ground wheel got drive from the ground and transmitted to the seed metering plate. Another side of the ground wheel was covered with the MS sheet that provided support to seed delivery way. Eight spiral vanes were fitted between two plates which were designed to guide seed for dropping in the furrow at fixed intervals (Fig 3). Spiraled vanes were provided for radial movement of seeds to the furrow opener and maintained the desired plant to plant spacing.

Wide “inverted T” type furrow opener was provided in the planter to open narrow furrow to place seeds properly (Fig. 4). It was designed in a way such that made a well-defined slit in the seed bed where seed was placed at a desired depth. This component of the planter was made of MS flat (40×10 mm).

Press wheel was designed to cover the seed and compact soil around the seed for better seed-soil contact. It consisted of two wheels of 200 mm diameter and 30 mm width and made of MS Flat. Two wheels were assembled at an angle 150° and created a gap of 20 mm just behind the furrow. Both these wheel compact soil from both sides whereas the gap kept the seed vertically open to germinate. The press wheel assembly also controlled the seeding depth along with ground wheel (Fig 5).

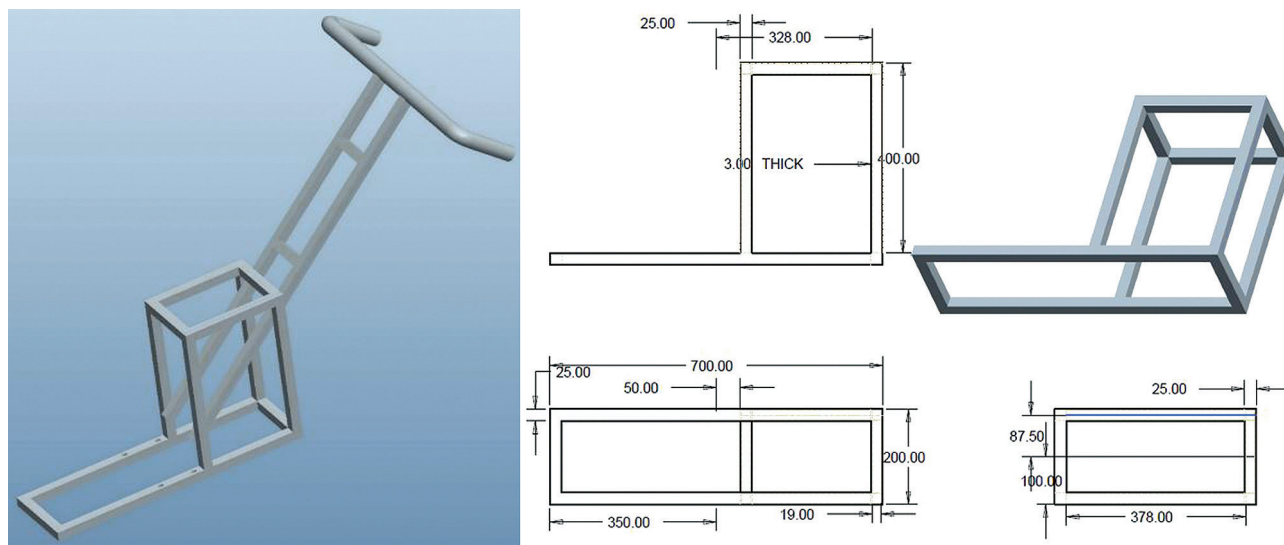


Fig 1 Main frame of Manual SWI Planter.

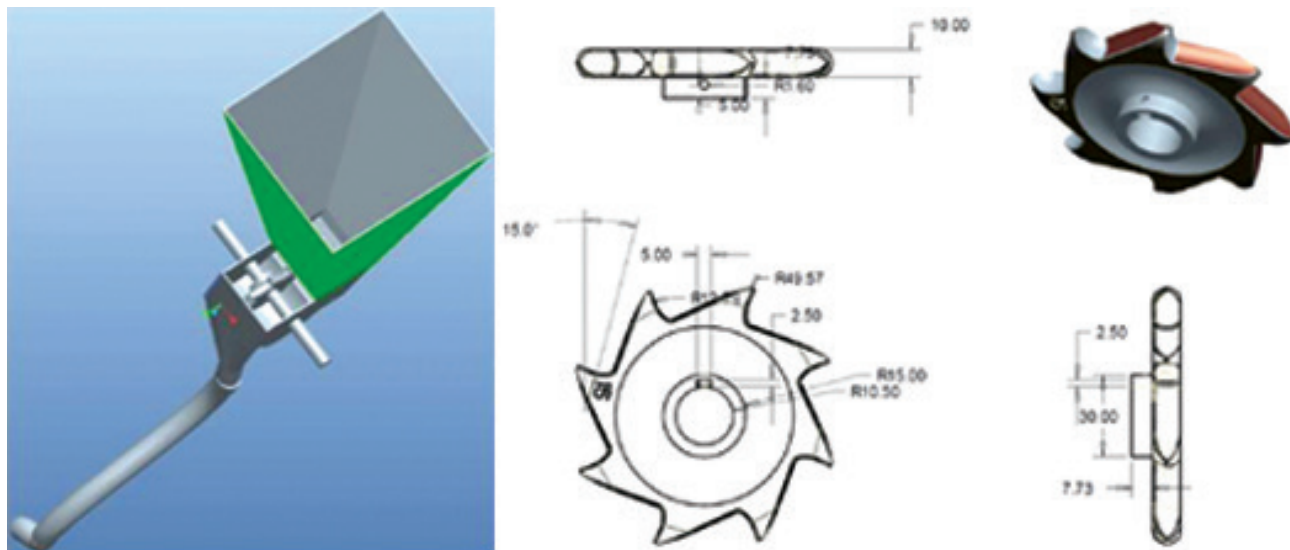


Fig 2 Metering unit with box and metering roller.

A CAD design of the SWI planter was prepared which had components like main frame, traction wheel, furrow opener, seed hopper, seed metering unit, seed covering and compaction unit, seed delivery unit and handle (Fig. 6). As the planter moved forward, the seed delivery unit along with ground wheel started rotating. The ground wheel rotation provided drive to the seed metering plate. The seed metering unit, consisting of eight cups, delivered seed to seed tube in every one-eighth of its rotation. The seed tube transferred the seed to the seed delivery unit. The seed delivery unit also consisted of eight spiral vanes such that delivered seed(s) from the tube transferred to the furrow through spiral vanes. The spiral vanes maintained the seed spacing in the furrow. The press wheels of the planter pressed soil from both sides around the seeds for better soil-seed contact.

The manual SWI planter is operated by two persons.

One person pulls the equipment from the front and another one guides it (Tiwari *et al.* 2010). The subjects for the ergonomic study were selected randomly. However, age, gender, medical and physical fitness, occupation and willingness for the subjects were also considered. Five subjects were selected who had body dimensions within 5th percentile and 95th percentile limits. The selected subjects were from same age group with mean age of 32 years. The field experiments were conducted on SWI planter by using different subjects. Different levels of independent and dependent parameters were recorded as shown in Table 1.

Before starting the experiment, subject was given sufficient rest so that resting heart rate could be achieved. The experiments were carried out for 1 hour and after every 15 minute, subjects were asked for subjective observation of body part discomfort. The same procedure was followed for each experiment (Fig 7). After completion of the

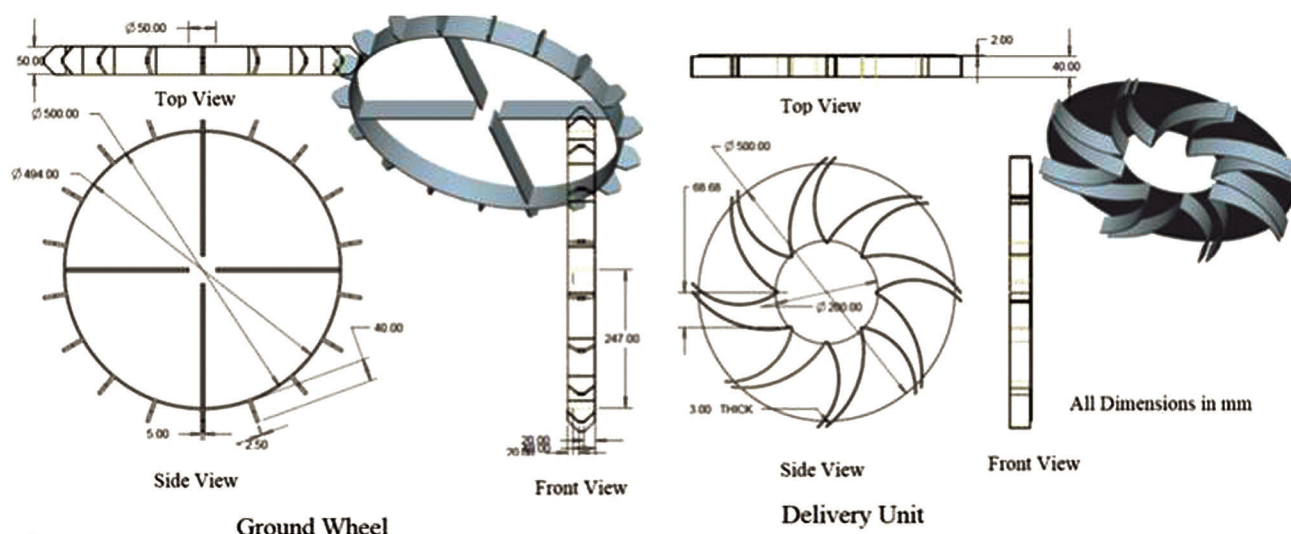


Fig 3 Ground wheel with delivery unit



Fig 7 Measurement of body part discomfort score (BPDS)

using treated seed (MSWIT); sowing with SWI planter using non-treated seed (MSWINT); manual sowing with SWI management using treated seed (MLSWIT); manual sowing with SWI management using non-treated seed (MLSWINT); recommended sowing with SWI management using treated seed (RPSWIT); recommended sowing with No-SWI management non-treated (RPNo-SWI); check row with SWI management using treated seed (CRSWIT); check row with SWI management using non-treated seed (CRSWIINT). In check row planting, plant and row spacing of 20 cm was maintained by manually removing all plants in between these hills at 20 days after sowing (DAS). The experiment was conducted in a randomized block design. In recommended conventional method of sowing, seed was planted at a row spacing of 22.5 cm, while in SWI planting a row and hill spacing of 20 cm was maintained. As per treatment, seeds were planted at each hill in SWI and gaps were filled within 15 DAS. The size of each experimental unit was 1.8×10 m. Wheat variety HD 2967 was used in this study.

To separate out healthy and viable seeds from the shriveled and unviable ones all seeds were put in a 20% salt water solution, the seeds which floated on the surface of water were removed and the healthy and bold seeds that settled at the bottom of the container were retained. For

seed treatment, a mixture of 10 litres warm water (60°C), 2 kg well-decomposed vermicompost, 3 litres of cow urine, and 2 kg of jaggery (unrefined sugar) was prepared in an earthen pot. After mixing these ingredients properly, 5 kg seeds were dipped in the mixture in successive lots and left for 8 hours. The next step was to separate the seeds from the mixture by filtration and washing with clean water. Treated seeds were kept in shade for 12 hours, during which time the seeds fully sprouted (Dhar *et al.* 2014).

RESULTS AND DISCUSSION

The values of physical properties of wheat seed were determined for designing the SWI planter as shown in Table 2. The bulk density of the seeds was 768 kg/m^3 , true density 1376 kg/m^3 , 1000-seed weight 39.9 g. The dimensions (length $\times$ width $\times$ thickness) of the seed were $6.0 \times 3.7 \times 2.6$ mm with sphericity of 3.67 mm. By considering the wheat seeds physical parameters, seed metering mechanism was developed using 3D printing of poly-lactic acid (PLA) material. The distribution uniformity of seeds/hill during evaluation of seed metering unit on sticky belt was observed as 2 seeds/hill for 56% hills, 3 seeds/hill and 1 seed/hill for 20% hills each and 4–5% missing hills.

Using the physical properties (Table 2) of wheat seeds, design and drawing for single row SWI planter was prepared with help of CAD and fabricated accordingly. The major features of the developed SWI-planter include: manually powered-single row planter; depth variation up to 5 cm for seed placement; seed to seed spacing 20 cm; seed metering for 2–3 seeds/hill; proper seed covering with adequate compaction and machine weight was matched with human power.

The average speed of the manual SWI was observed as 1.76 kmh^{-1} . Two manual labourers required for operating the implement. The field capacity and field efficiency of the manual SWI planter was 0.035 hah^{-1} and 76%, respectively. Average pull force required to operate the implement was found as 45 kgf. The average depth of placement of seed in the furrow was 50 mm.

Ergonomic evaluations

The manual SWI planter was operated with two



Fig 8 Manual SWI Planter under field trial

Table 2 Physical properties of wheat seed at 11.8 db moisture content used for SWI

Parameter	Value
Length (mm)	6.0 ± 0.26
Width (mm)	3.7 ± 0.18
Thickness (mm)	2.60 ± 0.01
Sphericity (mm)	3.67 ± 0.22
Angle of friction (M.S. sheet), Degree	21.5 ± 2.08
Bulk density (g/cc)	0.768 ± 0.11
True density (g/cc)	1.376 ± 0.20
1000-seed weight (g)	39.9 ± 1.13

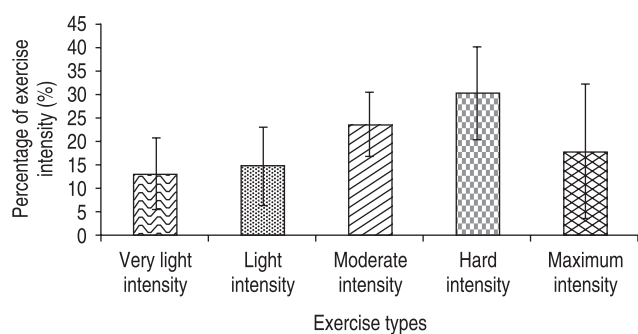


Fig 9 Exposure of exercise intensity during operating manual planter.

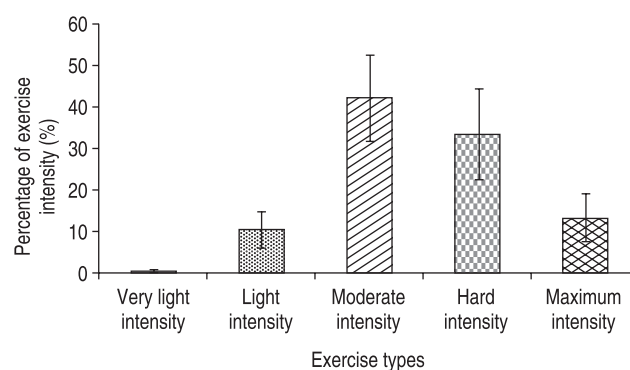


Fig 10 Exposure of exercise intensity during guiding manual planter.

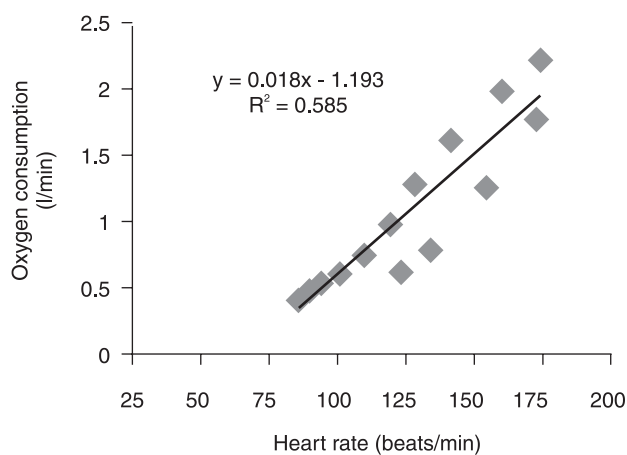
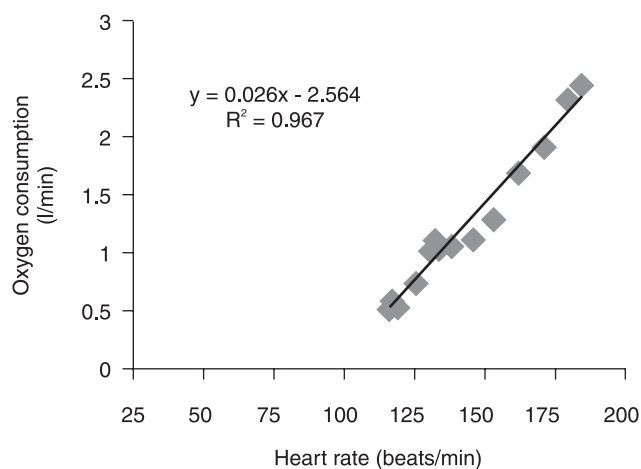
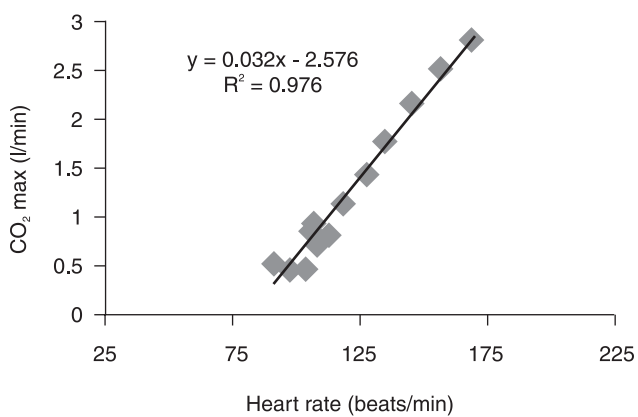
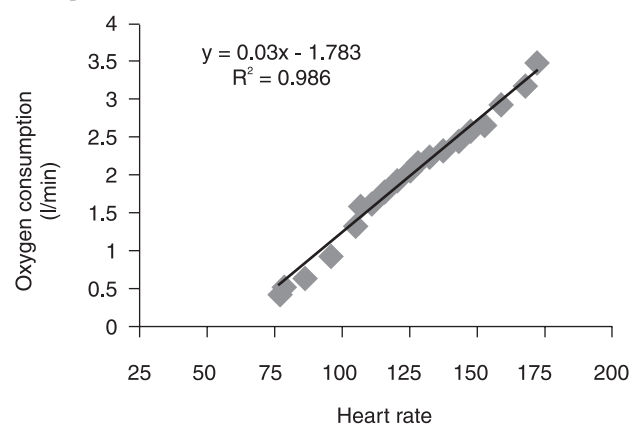
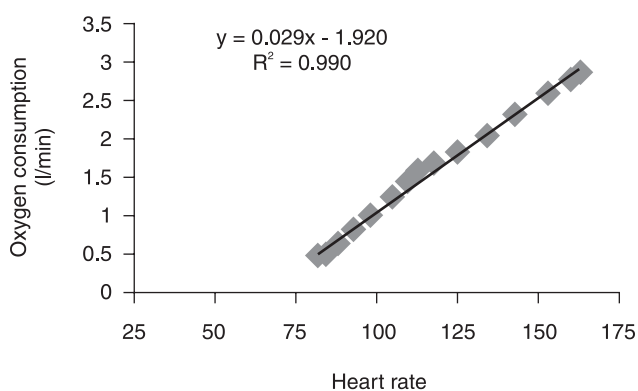


Fig 11 Calibration parameters for subjects.

subjects (human labour). The average heart rate and average maximum heart rate of the operators pulling the planter was as 136.8 bpm and 170.4b pm, respectively. The operators were in very light intensity, light intensity, moderate intensity, hard intensity and maximum intensity for 13.0,14.8, 23.8, 30.4 and 18% of the total experimental period (Fig 9).

The average heart rate and average maximum heart rate of subjects who guided the planter and maintained the depth of planting of the seed was observed as 128.6 bpm and 163.0 bpm, respectively. Operators were exposed moderate to hard intensity work for 76 %of experimental period and 13.6 % of time in maximum intensity of work (Fig 10).

The selected five subjects were calibrated as explained above. The calibration charts of subjects are represented in Fig 11. The relationship between the heart rate and oxygen consumption of the all subjects were found linear but defer with subject as reported by Rodalh (1989), Sanders and McCormick (1993), Bridger (1995) and Kroemer and Grandjean (2000).

The average energy expenditure of the operator and guide were observed as 46.52 kJ/min and 23.49 kJ/min respectively (Fig 12).

The body part discomfort score (Fig 13) was the highest in the wrist region of the operator and guide, with the values of 8.2. The majority of discomfort experienced by the operators and guides in shoulder, elbow, lower back, thigh and knee was observed as 3.6&3.8, 7.6&6.6, 5.8&4.8, 4.6&2.0 and 4.2 &2.4, respectively.

Wheat crop performance

The germination of seed was 22–24/m². With SWI planter sowing, the distribution of seeds per hill was 69% double seed, 23% single seed, 5% triple seed and 3% no seed(s) hill. Overall, germination of seed and grain yield were significantly better in machine sown plots compared to conventional or manually sown SWI/ non-SWI plots. Final yield in machine sown SWI (7.26 t/ha) was more than recommended sowing with No-SWI management non-treated (RPNo-SWI) planting of wheat by 22.3% (Fig 14). The increase in grain yield due to SWI mainly stemmed from significant improvement in the harvest index (about 45% in SWI and about 40% in RPNo-SWI sown wheat). Straw yield (8.8 t/ha) was 2% higher in RPNo-SWI. In northern India, yield improvement ranging from 35–67% due to SWI methods have been reported (Adhikari *et al.* 2017).The higher overall germination of seed,

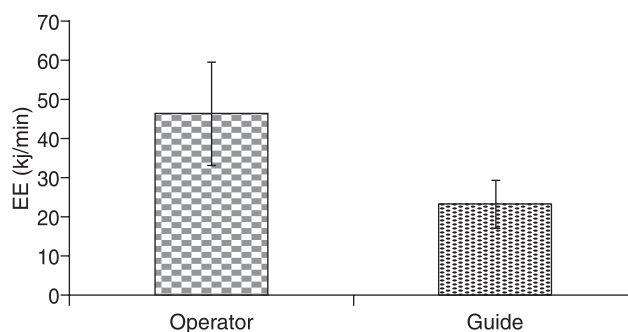


Fig 12 Comparison of energy expenditure of operator and guide .

plant growth and grain yield were significantly better in machine sown plots compared to conventional or manually sown SWI/ non-SWI plots. Moreover, inducement of growth of larger, vigorous and more efficiently-functioning root systems and increasing and supporting more beneficial life in the soil, which can buffer the effects of drought, storm damage, extreme temperatures, pests and diseases, leading to much higher yields, is feasible on large as well as small farms (Adhikari *et al.* 2017).

Conclusion

The seed metering unit and seed box for single-row SWI planter was designed based on wheat seed properties. The developed metering unit was evaluated in laboratory and seed distribution was found as 56% two seed/hill, 20% seeds/hill 3 & 1 seed and 4–5 % missing. Field performance of the SWI planter was compared with manual planting.

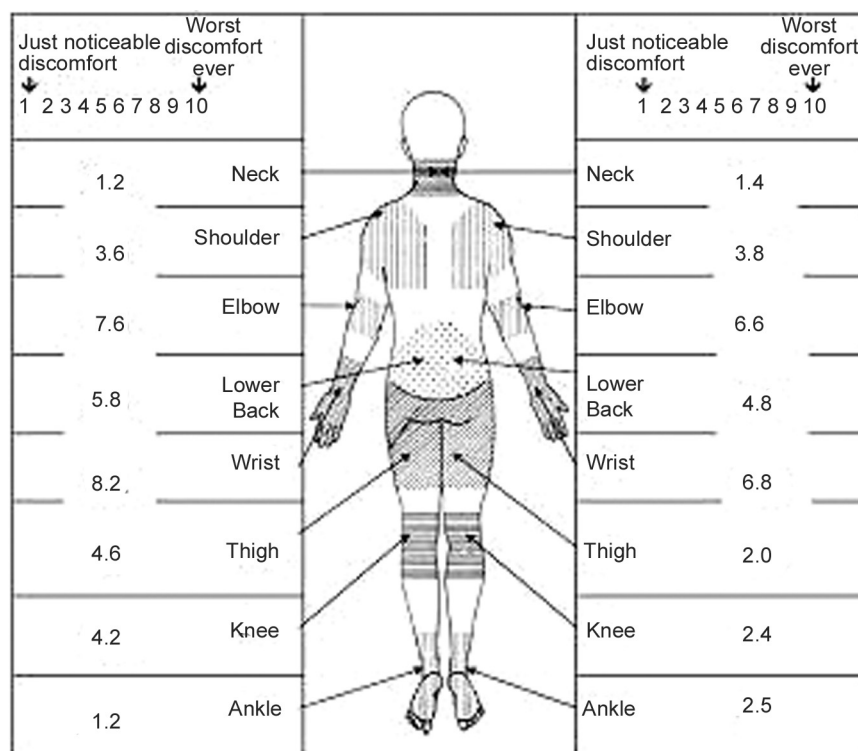


Fig 13 Body part discomfort score.

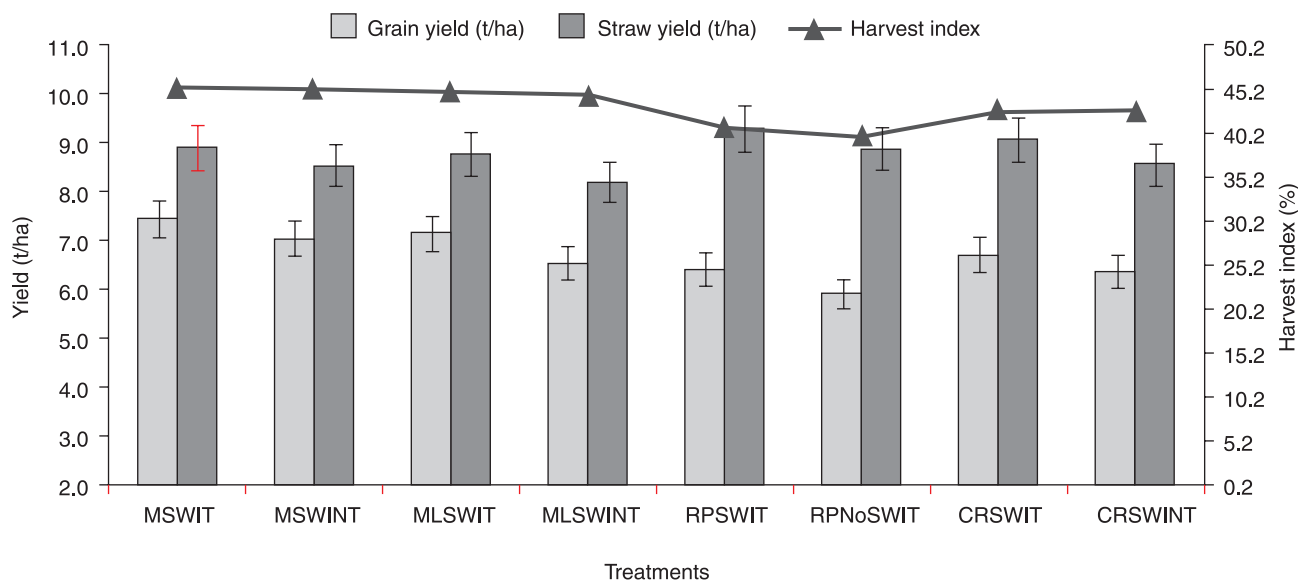


Fig 14 Yield and harvest index of wheat under SWI (machine sown, manually sown) and non-SWI treatments.

Number of germinated hills was found to be 22–24 per m². The distribution of plants per hill was found as 69% double, 23% single, 5% triple and 3% nil. The field capacity and field efficiency of the manual SWI planter was 0.035ha h⁻¹ and 76% respectively. Overall, yield was significantly (>25 % higher) better in machine-planted plots compared to conventional wheat sowing or manually sown SWI. Therefore, under small land holding condition, the developed SWI planter will make feasible more acreage planting of wheat and help adoption and spread of SWI technology ultimately leading to higher farm productivity and resource (particularly, seed) saving.

REFERENCES

- Adhikari P, Araya H, Aruna G, Balamatti A, Banerjee S, Baskaran P, Barah B C, Behera D, Berhe T, Boruah P, Dhar S, Edwards S, Fulford M, Gujja M, Ibrahim H, Kabir H, Kassam A, Khadka R B, Koma Y S, Natarajan U S, Perez R, Sen D, Sharif A, Singh G, Styger E, Thakur A K, Tiwari A, Uphoff N and Verma A. 2017. System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: experience with diverse crops in varying agroecologies. *International Journal of Agricultural Sustainability*.
- Anonymous. 1971. Ergonomics guide to assessment of metabolic and cardiac costs of physical work. *American Industrial Hygiene Association Journal* **32**: 562–4.
- Anonymous. 2018. Annual Report on agriculture. Department of Agriculture and Cooperation, Ministry of Agriculture and Farmers Welfare, Govt. of India. <http://agricoop.nic.in/sites/default/files/Krishi%20AR%202017-18-1%20for%20web.pdf>.
- Bhargava C, Deshmukh G, Sawarkar S D, Alawa S L and Ahirwar J. 2016. Wheat intensification in comparison with convention method of wheat line sowing to increase wheat yield. *Plant Archives* **16**(2): 801–4.
- Bridger R. 1995. *Introduction to Ergonomics*, Second Edition. McGraw-Hill, New York.
- Corlett E N and Bishop R P. 1976. A technique for assessing postural discomfort. *Ergonomics* **19**(2): 175–82.
- Dhar S, Barah B C and Vyas A K. 2014. Evaluation of System of Wheat Intensification (SWI) as compared to other methods of wheat cultivation in north western plain zone of India. (In): Selected seminar papers. International Workshop on “Recent Changes in Rice Production and Rural Livelihoods: New insights on System of Rice Intensification as a socio-technical Movement in India. Organized by National Consortium on SRI (NCS) and WAGENINGEN at NASC Complex, New Delhi, pp 1–13.
- Dhar S, Barah B C, Vyas A K and Uphoff N T. 2015. Comparing System of Wheat Intensification (SWI) with standard recommended practices in the north-western plain zone of India. *Archives of Agronomy and Soil Science* **62**(7): 994–1006.
- Khadka R B and Raut P. 2012. System of Wheat Intensification (SWI): a new concept on low-input technology for increasing wheat yield in marginal land. Kathmandu: Paper for European Union Food Facility Project & Forum for Awareness and Youth Activity, Nepal.
- Kroemer K H E and Grandjean E. 2000. *Fitting the Task to the Human*, Fifth Ed. A textbook of occupational ergonomics, Taylor & Francis Ltd, UK.
- Kushwaha H L, Srivastava A P and Singh H. 2007. Physical properties of okra seed. *Journal of Agricultural Engineering* **44**(1): 88–91.
- Mohsenin N N. 1986. *Physical properties of plant and animal materials*. Golden and Breach Science Publishers, New York, pp 51–8.
- Rodahl K. 1989. The Physiology of work, pp 51–79. Taylor and Francis, London.
- Sahoo P K and Srivastava A P. 2008. Seed pattern characteristics of different metering systems for soaked okra seed. *Journal of Agricultural Engineering* **45**(1): 1–6.
- Sanders M S and McCormick E J. 1993. Human Factors in Engineering and Design, 7th Edition. McGraw-Hill Education.
- Singh, S P, Gite L P, Majumder J and Agarwal N. 2008. Aerobic capacity of Indian farm women using sub-maximal exercise technique on treadmill. *Agricultural Engineering International: the CIGR e-journal*. MES 08 001. Vol. X.
- Smolander J, Ajoiviita M, Juuti T, Nummela A and Rusko H 2011.

- Estimating oxygen consumption from heart rate and heart rate variability without individual calibration. *Clinical Physiology and Functional Imaging* **31**: 266–71.
- Smolander J, Juuti T, Kinnunen M L, Laine K, Louhevaara V, Männikkö K and Rusko H. 2008. A new heart rate variability based method for the estimation of oxygen consumption without individual laboratory calibration: Application example on postal workers. *Applied Ergonomics* **39**(3): 325–31.
- Suryawanshi P K, Patel J B and Kumbhar N M. 2013. Yield and economics of wheat (*Triticum aestivum* L.) influence by SWI techniques with varying nitrogen levels. *International Journal of Agricultural Sciences* **9**(1): 305–8.
- Tiwari P S, Gite L P, Majumder J, Pharade SC and Singh V V. 2010. Push/pull strength of agricultural workers in central India. *International Journal of Industrial Ergonomics* **40**: 1–7.
- Varghese M A, Saha, P N and Atreya N. 1994. Aerobic capacity of urban women homemakers in Bombay. *Ergonomics* **38**(9): 1877–83.