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# Development of a Double Caged (Active-Passive) Puddler

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ABSTRACT

Rice seedlings are usually transplanted in a puddled field. Tractor cage wheel, being used extensively for this purpose is poorly effective and causes excessive wear on the brakes. Animal drawn puddlers have low work rate. Because of higher rotary speed, rotary tiller tines wear very fast and consume excess power. A study was therefore undertaken to design and develop a double caged (active-passive) power operated puddler. A prototype power operated puddler of 400 mm width was designed and developed. It comprised two concentric cages. The inner cage was powered while the outer was dragged. The transmission system was developed for testing the performance of the puddler at different rotary speeds in the range of 41 to 181 rpm. Field experiments were conducted in order to evaluate performance of the developed puddler. The newly designed puddler unit was attached to a power tiller by replacing the conventional rotary tiller. The level of puddling was varied from single pass to three passes. The whole experiment was also conducted without dragged cage in the newly designed puddler. To compare the performance, a conventional power tiller operated rotary tiller was tested at available two rotary speeds. With increased rotary speed as well as number of passes puddling index of the developed puddler was found increasing. When the developed puddler was operated without dragged cage, the fuel consumption was found to be higher as compared to that with dragged cage. The developed puddler with dragged cage was found to be 14.5% and 30.5% fuel saving against power tiller operated rotary tiller, for 65.0 and 80.0 % puddling index, respectively.

## 1. Introduction

Rice is the major cereal crop of South East Asia as 2.7 billion people in Asia alone consume it as a staple food and 90 percent of the world's rice is produced and consumed in Asia. Rice is the staple food of more than half of the global population. Most of the consumers, who depend upon rice as food, live in less developed countries. There is need of at least 70% increase in supply by the year 2025 (*i.e.* 765 metric tons of rice) for meeting the growing demands (Sawarkar and Yumnam, 2015). In year 2014, paddy was grown in 163 million hectares area across the world in which India contributed 26.9 % (*i.e.* 43.9 million hectares). The rice production in this year was 741 million metric tons in which India's contribution was 21.19 % (*i.e.* 157 million metric tons). The average yield in the world was recorded as 4546 kg/ha which was 3576 kg/ha in India. The average yield of paddy in India was over 21 % less than the World's average (Anon., 2016). The improvement in the quality of land prepared for paddy cultivation and mechanization can increase the average yield of paddy. Paddy cultivation needs high energy input particularly for seedbed preparation and irrigation. Approximately 75 percent of water applied to rice crop is lost through deep percolation during submergence of fields (Swaminathan, 1972). In order to minimize the percolation losses, puddling is practiced.

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Basically, puddling is defined as the reduction in the apparent specific volume of soil by doing mechanical work on it (Badman and Rubin, 1948). In standing water, the soil is mixed with water thoroughly by mechanical action of secondary tillage tools. Puddling facilitates transplanting of rice and helps to reduce water loss through percolation and seepage. It also reduces leaching of nutrients beyond root zone, helps in controlling weeds and facilitates transplantation by providing soft and even soil surface (De Datta and Barker, 1978; Verma and Dewangan, 2006). The extent of reduction in percolation losses depends on the level of puddling. In a sandy loam soil, percolation rate decreases significantly with increase in puddling level from low to high (Aggarwal *et al.,* 1995). Effect of depth of puddling on percolation rate are contradictory (Bhadoria, 1986; Kar *et al.,* 1986, Singh *et al.,* 1993 and Sharma and Bhagat, 1993). Different tools and equipment are used in India for puddling, *viz.* (i) animal operated (a) indigenous plough; (b) harrow-cum puddler; (c) helical blade puddler; (d) conical rotary puddler; (e) rotary blade puddler; (ii) power tiller operated rotary puddler; (iii) tractor operated (a) disc harrow; (b) cultivator; (c) rotary tiller; and (iv) self-propelled hydro-tiller. In some parts of the country cage wheel of the tractor is the only means by which puddling is carried out.

The rate of work of a power operated tillage tool is higher than that of a dragged tool, hence power operated machines like rotary tillers and hydro-tiller have high work rates. The researches have also proved that quality of puddle also affected the water infiltration rate, hence improved puddling equipment may be promoted over conventional equipment for saving water (China, 2015). The hydro-tiller is meant for cultivation in flooded land where depth of water can be up to about 30 cm. Rotary tillers operate on water controlled conditions. Highest rate of puddling index and lowest percolation rate were observed when puddling was done by power tiller operated rotavator, as compared to traditional country plough, animal drawn rectangular blade and animal drawn disc harrow (Singh *et al.,* 1973; Kumar *et al.,* 2015). However, its operation requires high consumption of mechanical energy. Sometimes the churning of soil is more than adequate. By changing the design, it may be possible to obtain the required extent of puddling at an optimum consumption of mechanical energy. By limiting the speed of operation, the machine components will incur less wear with a consequent increase in their life. The investigation was carried out with the objective: to design and develop a power operated puddler prototype. The prototype was tested in the Experimental Farm (Sandy loam soil) of Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, West Bengal in year 2004-05 (Maheshwari, 2005).

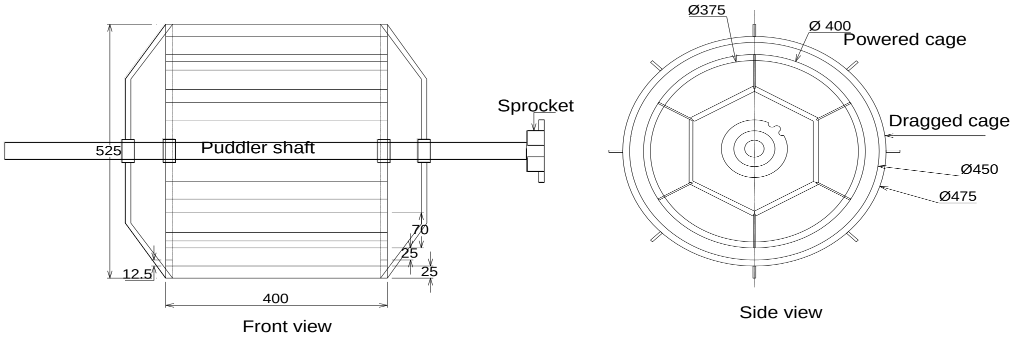
## 2. Design Considerations

The puddler was to be mounted on a power tiller for testing. Hence, some of the design dimensions were matched with the power tiller dimensions. The original tiller assembly was removed and different rotary speeds required for testing were obtained by adding an additional transmission unit between the driving and driven shafts of the tiller. The driven shaft was modified, two intermediate shafts were added and a set of six sprockets replaced the existing two.

## 3. Methodology

### *3.1 Design and development of prototype of puddler*

The prototype of puddler was having two cages as shown in Figure 1, The inner cage was powered while the outer cage was dragged. The outer cage was simply rolling on the ground and was helping in maintaining the depth of operation. Working width was kept 400 mm, outer diameter of powered cage at 400 mm and outer diameter of dragged cage at 525 mm. the central shaft had a minimum diameter of 32 mm. There were six blades fitted on the periphery of the inner cage. These were the working elements. Each blade was 400 mm long, 70 mm wide and made of mild steel sheet metal of three mm thickness.



Front view

Side view

(All dimensions are in mm)

**Figure 1.** Double caged (active –passive) puddler

All the blades were mounted on two rings, one at each end of the cage and made of mild steel round rod of 12.5 mm diameter. The outer cage had eight blades equally spaced on the drum of 525 mm diameter. A radial clearance of 25 mm was provided between the two cages. This spacing was kept to reduce the chances of jamming between the two cages during the field operation.

### *3.2 Design and development of power transmission unit*

Power transmission unit of the existing power tiller was modified in order to get different rotary speeds. The rotary driving unit of the power tiller can operate at two speeds. In the modified unit two more shafts were added and the driven shaft was replaced with a new one. There were six sprockets. For getting different speed ratios, different combinations sprockets were used (Table 1).

### *3.3 Estimation of Power and Torque Requirements*

According to Gupta and Vishwanathan (1993) the torque required to operate a rotary machine was found to have the four components (Torque required to cut the soil slices, torque due to centrifugal force, soil-metal friction and soil-soil friction forces)
An estimation of these torques is given below:

**(a) Torque required to cut the soil slices :**

$$T_{is} = \sigma_s A\left(R_r - \frac{h}{3}\right)$$

Torque required for cutting the soil slice,

Where, $\sigma_s$ = shear strength of saturated soil = 800 N/m$^2$
$A_s$ =Area of shear failure = bh
b = width of soil slice cut = 0.4 m
h=depth of operation=0.07 m
$R_r$ = radius of rotation of active element = 0.2 m

Hence,

$$T_{is} = 800(0.40 \times 0.07)\left(0.20 - \frac{0.07}{3}\right) = 3.958\ Nm$$

**(b) Torque due to centrifugal forces**

Torque required for throwing the cut soil slices,

$$T_{cf} = F_{cf}\left(R_R - \frac{h}{3}\right)$$

Where, $F_{cf}$ = centrifugal force = $\frac{m_s U^2}{R_R}$

$m_s$ = mass of soil slice cut = $lhb\rho$

$l$ = tilling pitch = $\left(\frac{60 \times V_f}{nZ}\right)$

U = peripheral speed = $\frac{2\pi n R_R}{60}$

$V_f$ = forward speed = 1.5 km/h

$\rho$ = density of soil = 2500 kg/m$^3$

Z = number of blades which would cut identical path if $V_f$ = 0;

n = rotational speed of active element, rpm. (41 to 181 rpm)

**(c) Torque due to soil-metal friction**

Torque required for overcoming soil metal friction,

$$T_{smf} = \mu_k \times m_s \times g \times R_R$$

Where,

$\mu_k$ = coefficient of friction between soil-metal surface = 0.2

$g$ = gravitational acceleration = 9.81 m/s$^2$

**Table 1.** Different Sprocket combinations and rotary speeds of puddler shaft.

| Sl. No. | Low/ High gear | Number of teeth | | | | | | Speed of puddler shaft, rpm |
|---|---|---|---|---|---|---|---|---|
| | | Sprocket 1 | Sprocket 2 | Sprocket 3 | Sprocket 4 | Sprocket 5 | Sprocket 6 | |
| 1 | L* | 12 | 15 | 12 | 36 | 12 | 21 | 41 |
| 2 | L | 12 | 15 | 12 | 36 | 13 | 19 | 48 |
| 3 | H | 12 | 15 | 12 | 36 | 12 | 21 | 59 |
| 4 | H | 12 | 15 | 12 | 36 | 13 | 19 | 68 |
| 5 | L | 12 | 15 | 12 | 36 | 18 | 15 | 86 |
| 6 | L | 12 | 15 | 12 | 36 | 19 | 13 | 105 |
| 7 | H | 12 | 15 | 12 | 36 | 18 | 15 | 124 |
| 8 | H | 12 | 15 | 12 | 36 | 19 | 13 | 151 |
| 9 | H | 12 | 15 | 12 | 36 | 21 | 12 | 181 |

* (L= Low and H= High)

**(d) Torque due to soil-soil friction**

Torque required for overcoming soil-soil sliding friction

$$T_{smf} = \tau \times A_s \left( R_R - \frac{2h}{3} \right)$$

Where, $A_s$= area of sliding of cut soil slice = hl

$\tau$ = shearing stress in pure shear

$$= \eta_{ps} \times \left( \frac{U}{h} \right)^{nps} + \tau_y$$

$\tau_y$ = yield stress in pure shear = 200 N/m$^2$

$\eta_{ps}$ = coefficient of viscosity = 50 Pa-s

nps = exponent = 0.332

Based on the above mentioned calculations the total torque required and power requirement of the prototype puddler at different speeds were calculated. The design power and torque requirement were assumed as two times the theoretically calculated values. Hence, design was carried out for 50 Nm torque and 1000 W power requirement.

**Table 2.** Mass of soil slices lifted and torque required for throwing the cut soil slices.

| Rotor speed (n), rpm | Mass of soil slices lifted, kg | Torque due to centrifugal force, N-m | Torque due to soil-metal friction , N-m | Torque due to soil–soil friction , N-m |
|---|---|---|---|---|
| 41 | 7.114 | 4.020 | 2.791 | 2.748 |
| 49 | 5.952 | 4.804 | 2.336 | 2.351 |
| 59 | 4.944 | 5.785 | 1.940 | 1.999 |
| 71 | 4.108 | 6.962 | 1.612 | 1.703 |
| 86 | 3.391 | 8.432 | 1.331 | 1.443 |
| 105 | 2.778 | 10.295 | 1.090 | 1.217 |
| 124 | 2.352 | 12.158 | 0.923 | 1.056 |
| 151 | 1.932 | 14.806 | 0.758 | 0.894 |
| 181 | 1.611 | 17.747 | 0.632 | 0.767 |

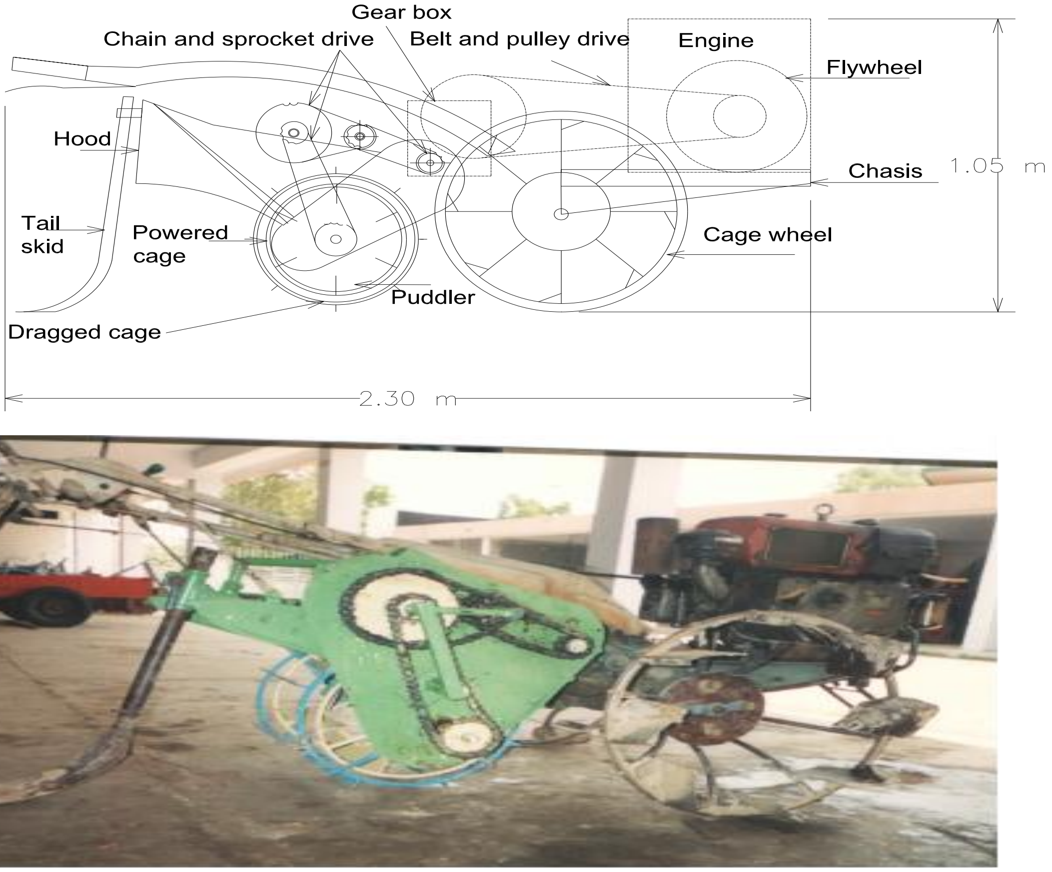


**Figure 2.** (a and b) Experimental puddler attached with power tiller (side view)

### *3.4 Measurement of fuel consumption*

An auxiliary fuel tank and burette were used for measurement of fuel consumption of the power tiller during operation of the puddler. It had a least count of 0.1 cm$^3$.

### *3.5 Experiment 1: To determine the effect of puddler shaft speed and number of passes on the puddling index (PI) of the soil operated by the prototype puddler (having the outer cage).*

The puddler was mounted on the power tiller as shown in Figure 2 and 3. The field was prepared beforehand with a cultivator. Water level was maintained at about 5 cm. Plots were randomly distributed. Each plot was of (5×2.5) m size. During the puddling operation fuel consumption was noted down. Fuel consumed during straight runs was only used. Fuel consumed during turning and during idle travel was not considered. Fuel consumed for puddling was calculated as follows: Fuel consumed for puddling = Fuel consumed with puddler working - Fuel consumed without puddler working. After the first pass soil samples were collected for determination of puddling index. Puddling Index (PI) was calculated as follows (Anon., 1985):

$$PI = \frac{\text{Volume of settled soil after 48 hours from sampling}}{\text{Volume of soil sample}} \times 100$$

The depth of operation was measured at different places and the average was found out. Puddling was carried out for the second and third passes also. Puddling index and fuel consumption was determined in all cases. The rotor speed was changed by changing the sprockets.

### *3.6 Experiment 2: To determine the effect of puddler shaft speed and number of passes on the puddling index (PI) of the prototype puddler without the outer cage.*

The procedure for experiment 1 was repeated after removing the outer cage of the puddler.

### *3.7 Experiment 3: To determine the effect of puddler shaft speed and number of passes on the puddling index (PI) of power tiller operated rotavator.*

The power tiller was fitted with the original rotavator tines. Only two speeds were available. Puddling was carried out at these speeds. Puddling index and fuel consumption were determined.

**Figure 3.** Experimental puddler attached with power tiller (rear view)

**Figure 4.** Experimental puddler in field operation

**Figure 5.** Field condition before and after puddling

## 4. Results and Discussion

The puddling index and fuel consumption values (ml/m$^3$ soil puddled) were analysed statistically. It was found that the rotary speed , number of passes and their interaction had significant effects on the puddling index (PI). ANOVA of puddling index of developed power operated puddler with and without dragged cage is shown in Table 3. The rotary speed, number of passes and the interaction of rotary speed × number of passes were all significant at 1 percent level of significance in both cases. Figure 6 shows the variation of puddling index with rotary speed for different number of passes. Higher puddling index values were obtained at higher rotary speeds. Puddling index was also higher as number of passes increases. ANOVA of fuel consumption per unit volume of puddle (FC) is shown in Table 4. The rotary speed, number of passes and the interaction of rotary speed × number of passes were found significant at 1 percent level of significance in both cases Figure 7 shows the variation of fuel consumption with rotary speed for different number of passes. Higher fuel consumption values were obtained at higher rotary speeds. Fuel consumption was found increasing as the number of passes increases. Thus higher value of puddling index was found associated with higher fuel consumption.

**Table 3.** ANOVA of puddling index of prototype puddler.

| **Source of variation** | **Degree of freedom** | **Power operated puddler with dragged cage** | | | **Power operated puddler without dragged cage** | | |
|---|---|---|---|---|---|---|---|
| | | **SS** | **MS** | ***F* value** | **SS** | **MS** | ***F* value** |
| Rotary speed (R) | 8 | 1734.7 | 216.8 | 107.3** | 1993.8 | 249.2 | 281.78** |
| Number of Passes (P) | 2 | 7471.0 | 3735.5 | 1847.7** | 6849.7 | 3424.9 | 3872.17** |
| Interaction (RP) | 16 | 112.4 | 7.0 | 3.5** | 105.3 | 6.6 | 7.44** |
| Error | 54 | 109.2 | 2.0 | | 47.8 | 0.9 | |
| Total | 81 | 9427.3 | 3961.3 | | 8996.6 | 111.069 | |

** = significant at 1% level

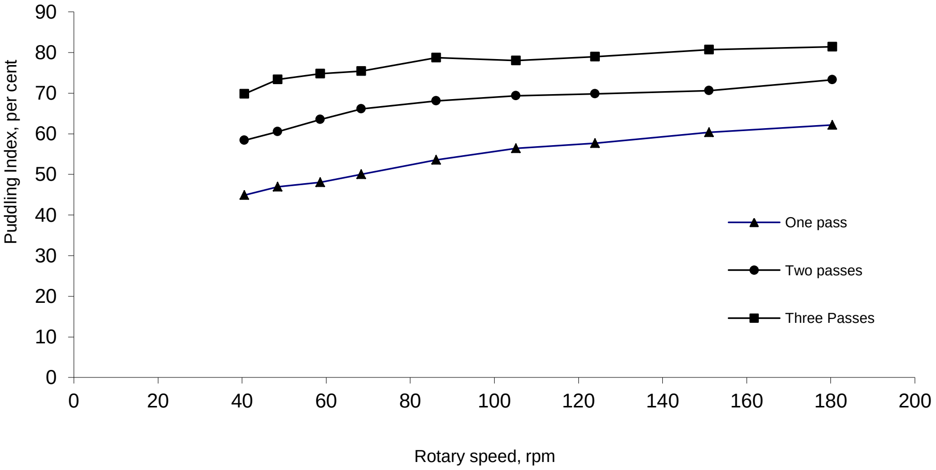


**Figure 6 (a).** Variation of puddling index of soil operated by prototype puddler (having dragged cage).

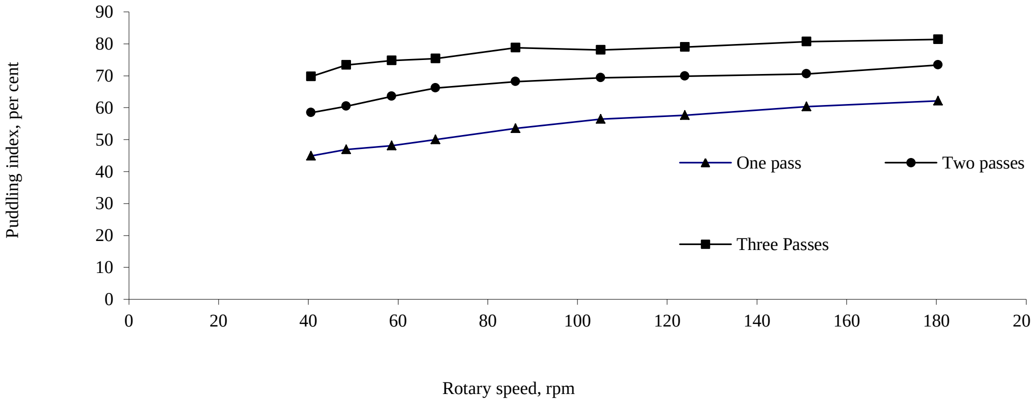


**Figure 6(b).** Variation of puddling index of soil operated by prototype puddler without dragged cage.

**Table 4.** ANOVA of fuel consumption per unit volume of soil of prototype puddler.

| **Source of variation** | **Degree of freedom** | **Power operated puddler with dragged cage** | | | **Power operated puddler without dragged cage** | | |
|---|---|---|---|---|---|---|---|
| | | **SS** | **MS** | ***F* value** | **SS** | **MS** | ***F* value** |
| Rotary speed (R) | 8 | 750.98 | 93.87 | 638.78** | 686.45 | 85.80 | 1260.48** |
| Number of Passes (P) | 2 | 11790.92 | 5895.46 | 40117.00** | 16201.03 | 8100.51 | 118995.89** |
| Interaction (RP) | 16 | 106.94 | 6.68 | 45.48** | 108.29 | 6.76 | 99.42** |
| Error | 54 | 7.93 | 0.14 | | 3.67 | 0.06 | |
| Total | 81 | 12656.78 | 158.21 | | 16999.45 | 220.98 | |

** = significant at 1% level

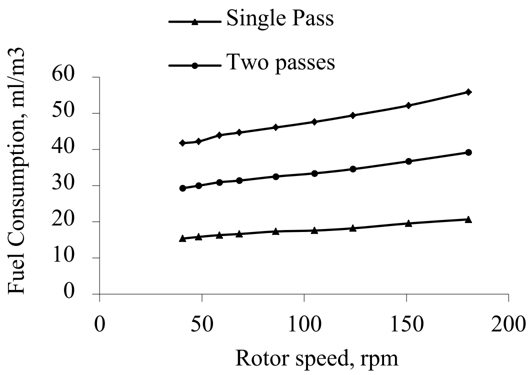


**Figure 7(a).** Variation of fuel consumption of prototype puddler (having dragged cage).

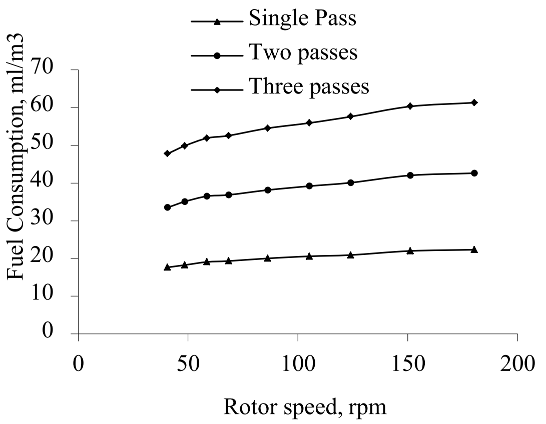


**Figure 7(b).** Variation of fuel consumption of prototype puddler without dragged cage.

An increase in puddling index was obtained as the number of passes increased from one pass to two and from two to three. However, the fuel consumption was also increased as the number of passes increased. The ratios of change in puddling index / change in fuel consumption are presented in Figure 8. The ratio was found decreasing generally with the number of pass and decreasing with the rotary speed. Hence, if the required amount of puddling is obtained with one number of pass at the proper rotary speed it would be the most economic choice.

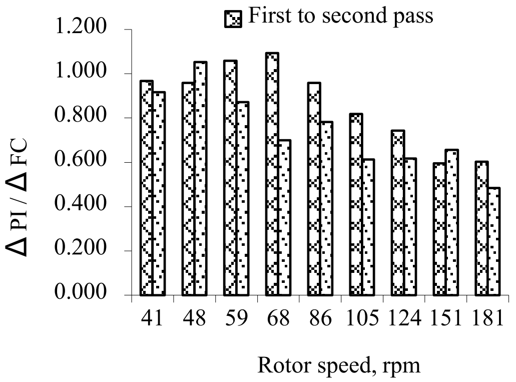


**Figure 8(a).** Variation of $\Delta PI / \Delta FC$ of prototype puddler (having dragged cage).

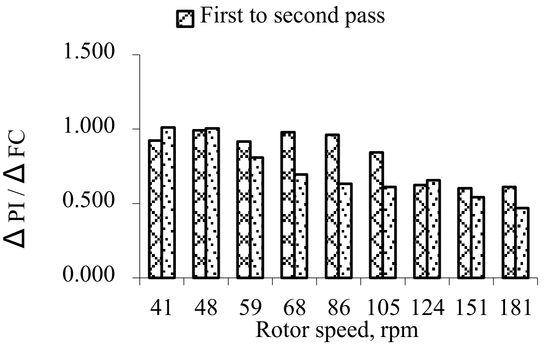


**Figure 8(b).** Variation of $\Delta PI / \Delta FC$ of prototype puddler without dragged cage.

Empirical equations were fitted to the PI and FC values as follows:

a) For power operated puddler with dragged cage:

$PI = 27.57 + 14.35\ p + 0.152r + 0.0274\ pr\ (R^2 = 0.96)$

$FC = 2.52 + 11.82\ p + 0.005\ r + 0.307\ pr\ (R^2 = 0.99)$

b) For power operated puddler without dragged cage:

$PI = 28.32 + 13.80\ p + 0.156\ r + 0.02686\ pr\ (R^2 = 0.96)$

$FC = 2.84 + 14.36\ p + 0.002\ r + 0.031\ pr\ (R^2 = 0.99)$

Where PI = puddling index, percent;
FC = fuel consumption, ml/m3 soil;
p = number of passes (1, 2, 3 *etc.*); and
r = rotor speed, rpm

**Table 5.** Puddling index and fuel consumption of power tiller operated rotary tiller.

| Sl. No | Rotary speed (R), rpm | Puddling index, | | | Fuel consumption, ml/m$^3$ | | |
|---|---|---|---|---|---|---|---|
| | | One pass | Two passes | Three passes | One pass | Two passes | Three passes |
| 1 | 211 | 44.7 | 64.3 | 80.9 | 17.61 | 33.88 | 48.73 |
| 2 | 315 | 46.7 | 67.2 | 84.5 | 17.72 | 33.95 | 48.96 |

A puddling index of 65 percent can be obtained at a rotor speed of 42.3 rpm with 2 passes and 80 per cent can be obtained at a rotary speed of 114.8 rpm with 2 passes of prototype puddler (having dragged cage). Corresponding fuel consumption values were 28.99 and 33.85 ml/m$^3$ respectively. A puddling index of 49.5 percent was achieved in one pass at 42.3 rpm. The fuel consumption was 15.86 ml/m$^3$. The improvement in puddling index from 49.5 to 65.0 percent was obtained with an additional fuel consumption of 13.13 ml/m$^3$ from 1st pass to 2nd pass and from 65.0 to 80.5 percent was obtained with fuel consumption of 13.13 ml/m$^3$ from 2nd to 3rd pass. Hence, it must be emphasized that if satisfactory puddling could be achieved in one pass itself then fuel consumption will be the minimum. When the outer cage was removed the same puddling quality as stated earlier (*i.e.* PI 65 percent and 80 percent) can be attained at rotor speed 43.3 rpm with 2 passes and 114.8 rpm with 2 passes respectively. Corresponding fuel consumption values were 34.33 and 38.91 ml/m$^3$ respectively. The power tiller operated rotavator was operated in the same soil conditions. It was operated at the two speeds available with the commercial model for one, two and three passes. The puddling index and fuel consumption values are given in Table 5. Fuel consumption was estimated to be 33.86 and 48.73 ml/m$^3$ respectively for 65 and 80 per cent puddling index. These were approximately 16.8 and 44.0 per cent higher than that required for the prototype puddler (having dragged cage).

## 5. Conclusion

An increase in puddling index was observed as the number of passes increased from one pass to two and from two to three. However, the fuel consumption was also increased as the number of passes increased. The puddler with dragged cage can result in a puddling index of 65 percent for the tested soil when operated at 42.3 rpm with two passes. It consumes 14.5 percent less energy compared to the rotary tiller, which is generally operated at 211 rpm.

## 6. References

Aggarwal GC, Sidhu AS, Sekhon NK, Sandhu KS, and HS Sur (1995). Puddling and N management effects on crop response in a rice-wheat cropping system. *Soil & Tillage Research* 36(3-4): 129-139

Anonymous. Indian standard. Test code for puddler, IS: 11531-1985

Anonymous, Agricultural statistics at a glance 2016, http://agricoop.nic.in, accessed on Nov 11, 2017 at 14:50 hours.

Bhadoria PBS (1986). Effect of compaction and tillage on the yield and percolation losses of rice in laterictic sandy loam soil. *J. Agron. Crop Sci.,* 156: 45-49

Bodman GB, and J Rubin (1948). Soil puddling. Soil Sci. *Soc. Amer. Proc.,* 13(1): 27-37

Chhina RS (2015). Comparative performance of different puddling equipments. International *J Agric Eng* 8(2): 210-214

De Datta SK, and R Barker (1978). Land preparation of rice soils. In: Soils and rice. Int Rice Inst, Loss Bonos, Philippines, pp. 623-48

Gupta CP, and R Vishvanathan (1993). Power requirement of a rotary tiller in saturated soil. Transactions of the *ASAE* 36(4):1009-1012

Kar S, Samui RP, Prasad J, Gupta CP, and TK Subramanyam (1986). Compaction and tillage depth combinations for water management and rice production in low retentive permeable soils. *Soil & Tillage Research*, 6 (3): 211-222

Kumar A, Mandal S, Singh RK, and MB Tamhankar (2015). Comparative performance of puddlers in low lands of hilly areas. *Indian J Hill Farming* 28(1): 63-68

Maheshwari RK (2005). Unpublished M.Tech Thesis, Agricultural and Food Engineering Department, IIT Kharagpur, India.

Sawarkar A, and S Yumnam (2015). Breeding for Earliness in Rice. *Popular Kheti*, 3(4): 142-146

Sharma PK, and RM Bhagat (1993). Puddling and compaction effects on water permeability of texturally different soils. *J. Indian Soc. Soil Sci.,* 41: 1-6

Singh AK, Srivastava LK, Jaggi IK, and RO Das (1993). Water percolation dynamics as influenced by submergence level and depth of puddling in rice. *J. Indian Soc. Soil Sci.,* 41: 213-217

Singh KN, Singh B, and B Singh (1973). Performance studies on various puddling equipment. *J. Agric. Engg.,* 10: 14-16

Swaminathan MS (1972). Scientific management and use of water. *Indian Farming*, 22(2): 5-7

Verma AK, and Dewangan ML (2006). Efficiency and energy use in puddling of lowland rice grown on Vertisols in Central India. *Soil & Tillage Research* 90 (1-2): 100–107