

INVESTIGATIONS ON PUDDLED SOIL CHARACTERISTICS IN RELATION TO PERFORMANCE OF SELF- PROPELLED RICE TRANSPLANTER

Thesis

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By

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**DEDICATED TO
MILK
BELOVED PARENTS**

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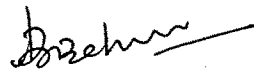
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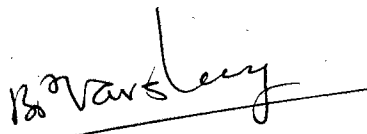
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CERTIFICATE

This is to certify that the thesis entitled "INVESTIGATIONS ON PUDDLED SOIL CHARACTERISTICS IN RELATION TO PERFORMANCE OF SELF-PROPELLED RICE TRANSPLANTER", submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY with major in FARM MACHINERY AND POWER ENGINEERING of the College of Post-Graduate Studies, G.B.Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by Mr. BIJOY KUMAR BEHERA, Id.No. 23953, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

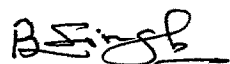
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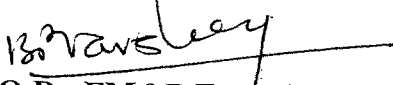
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Abbreviation and Notations

ANOVA	Analysis of variance
cc	Cubic centimeter
CD	Critical difference
cm	Centimeter
CV	Coefficient of variation
DAP	Days after puddling
DAT	Days after transplanting
d.b.	Dry weight basis
d.f.	Degree of freedom
F _{cal}	Calculated value of 'F'
Fig.	Figure
g	Gram
h	Hour
ha	Hectare
ha h ⁻¹	Hectare per hour
hp	Horse power
hrs	Hours
kg	Kilogram
kN	Kilo Newton
kPa	Kilo Pascal
kW	Kilo Watt
l	Litre
l/h	Litre/hour
m	Meter
m ²	Square meter
m.b.	Mould board
m.c.	moisture content
Mg	Megagram
ml	Millileter
m.s.	Mild steel
m.s.s.	Mean sum of square
N	Newton
Pa	Pascal
SEm	Standard error of mean
S.S.	Sum of square
%	Per cent
t	Tonnes

INTRODUCTION

1. INTRODUCTION

Rice is a major crop grown in more than 110 countries in the world with a total production of 527 million tonnes, out of which 78 per cent is contributed by major rice growing countries of Asia. India is the largest grower of rice in terms of area (42 million ha) in the world with an annual production of 82 million tonnes. However, it ranks second to China in terms of production (187 million tonnes) with an area of 31 million ha (**World Rice Statistics, 1994 and Survey of Indian Agriculture, 1999**).

About 50 per cent of the total irrigated area is under rice cultivation in India and hence, 50 per cent of irrigation water is used for rice crop whose water requirement is 10^7 l/ha (**Manian and Jivaraj, 1989**). Since, rice is the lowest productive crop per unit of water consumption amongst cereals, therefore, optimum water management and cultural practices need to be followed to ensure minimum losses of water. Approximately 75 per cent of water applied to rice crop is lost through deep percolation during submergence of field (**Swaminathan, 1972 and Agarwal *et al.*, 1980**). Hence, it is cultivated under puddled condition so as to minimize the percolation losses and to enhance the water and nutrient use efficiency of plant. Rice is also grown through direct seeding which is less costly in comparison to transplanting but weed infestation is a severe problem associated with this method (**Jaysuriya and Price, 1979**). Weeding in direct seeding requires 750-1250 man-hr per ha in comparison to 450 man-hr

for transplanted rice (Singh *et al.*, 1983). Besides that, loss of yield in unweeded direct seeding crop has been estimated to be 49 to 66 per cent whereas, it is only 13 per cent in case of transplanted rice (Bhatnagar and Sharma, 1975). In contrast transplanting using healthy and vigorous seedling gives a more uniform crop stand with higher yield (Khan and Gunkle, 1989).

Mostly in India and other developing countries of Asia, rice is transplanted manually which is labour intensive and requires 250-350 man-hr per hectare which is 25 per cent of the total labour requirement of this crop (Singh and Hussain, 1983). In addition to being labour intensive, manual transplanting involves a lot of drudgery reducing the human efficiency appreciably. In recent years, due to better employment opportunity in the cities and increase in the literacy status, there is often an acute shortage of labour at the time of rice transplanting. As a result, timely transplanting which is essential for maximizing crop yield is jeopardized. Manual transplanting also fails to meet the agronomical requirement like plant population per sq.-m and uniform row and hill spacing, thereby limiting the use of agricultural implements and hand tools for intercultural operations.

The above pitfalls of manual transplanting demand mechanization of rice transplanting. The first substitute of manual transplanting was a manual transplanter which required 70-80 man hrs per hectare, reducing the labour

requirement by 55 per cent (Singh and Hussain, 1983). But it has been observed that the use of manual transplanter is associated with human drudgery and low work capacity ranging from 0.01 to 0.015 ha hr⁻¹. Therefore, gradually the attention has shifted to develop either tractor/power tiller operated or self-propelled rice transplanters.

Manouverability of tractor, sinkage and tyre rut in puddled soil were the major stumbling blocks in the way of tractor operated transplanter as an alternative option to manual transplanter (Singh *et al.*, 1982). Power tiller operated transplanter was also associated with problems like sinkage and human drudgery as the operator has to control and steer the power tiller walking behind the machine and in between the transplanted rows without trampling the seedling (Annual Report, FIM, APAU, 1995). In order to mechanize rice transplanting, riding type self-propelled transplanter which can overcome aforesaid problem would be the best option and has a lot of potential. Hence, self-propelled transplanter are getting popular in major rice growing countries like China, Japan, Korea, Philippines etc. Since, India has almost 42 million hectare of area under rice and 50 per cent of that under wet-land condition, therefore, self-propelled rice transplanter could be an ideal replacement for manual transplanting and manual transplanter thereby providing timely operation as well as saving of money and human drudgery.

Like all other wetland agricultural machinery, self-propelled rice transplanter also has problems of poor traction, sinkage and steerability. Since, self-propelled rice transplanter works on puddled soil, it encounters a hard surface at plow pan and a soft puddled soil at the top where it must also have sufficient bearing capacity to prevent sinkage of the float. At the same time the plow pan must not be too deep to provide necessary thrust to propel the transplanter. Both traction and bearing capacity are dependent upon shear strength of the soil (Knight and Freitaz, 1962). Usually a transplanter would be immobilized either by failure in bearing or traction. Efficient working of a self-propelled rice transplanter requires a suitable puddled soil condition *vis-à-vis* optimum depth of puddling, degree of puddling and soil strength of puddled field. High degree of puddling severely affects the mobility of the transplanter and its performance. It takes longer sedimentation period when the transplanter could be operated.

Rice crop requires a good puddled field condition to create favourable physico-chemical and microbiological environment for normal growth of rice plant (Curfs and Moomaw, 1973; Singh *et al.*, 1977; Reddy and Hukkeri, 1979; Dayanand and Singh, 1980; Gupta and Jaggi, 1980; and De Datta, 1986). However, it has also been reported that excessive puddling is detrimental to subsequent crop in a wetland and dryland crop rotation (Bolton and De Datta, 1979; Sur *et al.*, 1981; Bajpai, 1994; Kar, 1995).

Studies, so far, on puddling equipment and self-propelled rice transplanter have been carried out in isolation to each other. Researchers working on self-propelled transplanter have not specified the suitable puddling equipment, degree of puddling and sedimentation period for efficient operation of transplanter (Mori, 1975; Khan *et al.*, 1979; Khan and Gunkel, 1988 and Mufti and Khan, 1995).

Therefore, in order to identify ideal puddled soil condition with respect to puddling equipment, its level of puddling and sedimentation period, for satisfactory performance of self-propelled rice transplanter as well as the rice crop, the present study was undertaken with the following objectives :

1. To study the effect of puddling on physical and dynamic properties of soil
2. To investigate the effect of seedling characteristics on transplanting performance in the laboratory
3. To evaluate the performance of self-propelled rice transplanter under different puddled conditions with regards to machine as well as crop parameters
4. To carry out a comparative study of self-propelled rice transplanter with manual transplanting and their economics

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Puddling is an important and widely accepted practice of wetland rice cultivation. It is considered to be antithesis of aggregation in agronomic practice (Beacher and Strickling, 1955). The term puddling has several meanings as per users. Technically, Bodman and Rubin (1948) defined puddling as the reduction in apparent specific volume of soil caused by mechanical manipulation under flooded condition. According to Dutta (1948), puddling is a process of churning the soil at high moisture content that leads to breaking of larger aggregates to smaller ones and their close resetting creates a muddy surface which is almost impermeable to water.

Self-propelled rice transplanter needs an ideal puddled condition in relation to depth as well as level of puddling, and soil strength at the time of transplanting. Puddled soil strength depends upon the type of puddling equipment used, level of puddling and sedimentation period.

Puddling brings about significant physico-chemical changes in soil. Depending upon the type of soil, puddling either proves to be advantageous or disadvantageous. The advantages of puddling are : (i) reduction of leaching losses leading to higher nutrient availability; (ii) reduction of weed infestation and (iii) ease of transplanting (Khan and Gunkel, 1989; Singh, 1983). The disadvantages of puddling are : (i) longer drying period to reach a workable moisture range for subsequent tillage operation after harvest of rice (Meelu *et al.*, 1979; Bolton and DeDatta, 1979; Sharma and De

Datta, 1986; Bajpai, 1994). On drying puddled soil becomes very hard and consumes a lot of energy for tillage and gives bigger clods if tilled at high moisture content (**Chaudhury, 1965**). Formation of hardpan causes shunting of root growth of subsequent upland crops resulting in loss of yield (**Nair, 1975; Singh, 1976; IRRI, 1979; Sur *et al.*, 1981; Singh *et al.*, 1995; Kar, 1995**).

Keeping these aspects in mind, the physical and dynamic properties of puddled soil, its effect on performance of transplanter and rice crop were reviewed under the following heads :

2.1 Puddlability of Soil

The term puddlability has been defined as susceptibility of soils to puddling, which is strongly influenced by the soil moisture and energy status of the solid phase (**Bodman and Rubin, 1948**). The puddlability, as quantified by **Beacher and Strickling (1955)** is the change in apparent specific volume of soil per unit of work.

McGeorge (1937) revealed that the degree of puddling has been related to moisture content and maximum state of puddling was affected at a moisture content closely approximating the moisture equivalent beyond which puddling decreases. **Singh *et al.* (1974)** observed that higher puddling index was indicator of better churning of soil leading to greater dispersion of soil in water. **Ghildyal (1978)** reported that high clay content facilitated

puddling. According to **De Datta (1981)** soils with more than 20 per cent clay particles are prone to puddling.

Tewari (1984) while evaluating rotary blade puddlers with different blade angles (0° , 15° , 30° and 45°) and blade width (5.0, 7.5 and 10.0 cm) found that 30° blade angle with 10 cm blade width produced highest puddling index of 45.27 per cent at three passes.

Sharma and De Datta (1985) proposed that degree of puddling depends on type of soil, tillage implement and intensity of puddling. Rotary implements generally are better for puddling than other types because their rotary motion continually changes the direction of shear stress and hence matches the weakest fracture plain within a clod.

Sharma *et al.* (1991) investigated the performance of different puddling equipment *viz.* rotary puddler; disc harrow; harrow cum puddler; country plough and observed that puddling index was highest in case of rotary blade puddler (two passes) because of better churning of soil. A screw shape is formed which has direct impact on churning quality of soil and water mixture. Disc harrow with three operation had almost the same puddling index obtained by rotary puddler.

Salokhe *et al.* (1993) reported that puddler speed and number of passes influence puddling index. They observed that at any given speed, puddling index increased with an increase in number of passes of rotavator.

However, increase in forward speed reduced the puddling index although not significantly.

2.2 Effect of Puddling on Physical Properties of Soil

It has been seen that texture and type of clay mineral, structure and organic matter content determine the effect of puddling on soil physical properties. Besides that, puddling equipment and level of puddling also influence the physical properties of soil.

2.2.1 Bulk density

Increase in bulk density from 0.54 to 1.48 Mgm^{-3} in a silty loam soil and from 0.61 to 1.91 Mgm^{-3} in a sandy loam soil was reported by **Bodman and Rubin, 1948**. **Dutta (1948)** also reported an increase of bulk density from 1.20 to 1.43 Mgm^{-3} in a silty loam soil. Similar observations were reported by **Pandya (1962)**, **Varade and Ghildyal (1967)** and **Kandaurov and Patrin (1974)**.

Ghildyal and Satyanarayan (1965) while studying the compaction effect on four soils (Sand, sandy loam, sandy clay loam and clay soil) reported that medium textured soils are more susceptible to compaction than sand and clay soil. Black soil required higher amount of moisture to obtain maximum bulk density. Similar observations were also made by **Varade and Ghildyal (1967)** on a lateritic sandy loam soil.

In a pot experiment on lateritic soil with two levels of puddling P_0 (0.113 watt-hr energy input) and P_1 (0.270 watt-hr energy input) and four

levels of water depth over the surface, **Naphade (1971)** observed that there was an increase of bulk density at higher energy as compared to lower energy input. In another pot study, **Naphade and Ghildyal (1971)** found that puddling decreased the apparent specific volume (reciprocal of bulk density) from 0.714 to 0.591 cm³ g⁻¹ resulting in an increase of bulk density of the same soil.

Patil and Ghildyal (1973) reported that puddling may cause an increase in bulk density of light soil and decrease the bulk density of heavy textured soil. Decrease of bulk density of silty clay loam and clay soil due to puddling was observed by **Sharma and De Datta (1985)** one day after puddling over non-puddled soil. But, the differences in bulk density narrowed down with time. **Sharma et al. (1988)** also reported a decrease of bulk density in clay and clay loam soil just after puddling.

Scheltema (1974) reported an increase in bulk density of puddled soil with time. Puddled soil bulk density increased on drying because of soil shrinkage. A puddled soil is very compact and hard on drying and develops broad and deep cracks, depending upon the nature and amount of clay (**Bajpai, 1994**). **Rath (1999)** also found that bulk density increased as moisture content of soil decreased with time (30 DAP to 60 DAP to harvest).

Tewari (1984) observed that bulk density of puddled soil increased with number of passes of rotary blade puddler. He obtained a maximum

bulk density of 1.552 Mgm^{-3} at 30 DAP with 30° blade angle and 75 mm blade width.

Manian and Jivaraj (1989) with different bullock drawn implements studied the quality of puddling and observed that bulk density of soil decreased immediately after puddling. They, however, did not observe bulk density at different stages of crop growth. **Salokhe *et al.* (1993)** observed similar trend of reduction in bulk density after puddling in Bangkok clay soil (Sand : 18%, Silt : 30%, Clay : 52%).

Rautaray *et al.* (1997) conducted a laboratory study of soil physical properties with varying levels of puddling and sedimentation period. It was reported by them that bulk density increased with puddling levels and sedimentation period. Bulk density with respect to depth increased at a particular sedimentation period. However, at higher level of puddling, the increase of bulk density with depth was very low due to slow settling of soil.

Dispersed soil settled with time (**Greenland, 1981**) and the bulk density may increase at lower moisture content. Flocculation of soil particles depends on soil texture. Settling is faster in sandy soils and in soils with 1:1 clay mineralogy (**Moormann and Breeman, 1978**).

2.2.2 Hydraulic conductivity

Animal, human and vehicular traffic add to the compaction, thereby creating an impervious layer known as hardpan over the years of continuous puddling (**Prihar *et al.*, 1985**). Hardpan in puddled soil has very low

hydraulic conductivity (Moorman and Breeman, 1978). Besides that, puddled soil itself reduces hydraulic conductivity due to destruction of transmission pores (Bodman and Rubin, 1948). Dispersion of finer particles increase the viscosity of fluid. Hence, water moves in at a very slow rate which inturn enhances the lodging of particles, thereby plugging the pore channels (Alva and Pattersen, 1979; Koenigs, 1963). As a result, hydraulic conductivity of hardpan is practically very low which is a desirable condition for ponding of water with minimum water losses. Closely packed parallel particles in puddled soil reduces saturated hydraulic conductivity and percolation loss by restricting water movement (Wikham and Singh, 1978; Gupta and Jaggi, 1979; Sharma and De Datta, 1988).

Bhole and Pandya (1965) found that hydraulic conductivity decreased as energy input to puddling increased. There was a negative correlation between energy input and hydraulic conductivity.

Naphade and Ghildyal (1971) reported that with decrease of apparent specific volume (ASV) from 0.714 to 0.591 cm³ g⁻¹, the hydraulic conductivity decreased from 1.92 mm hr⁻¹ to 0.19 mm hr⁻¹. Hydraulic conductivity has a positive correlation with ASV. Patel and Singh (1981) concluded that hydraulic conductivity decreased as bulk density increased.

Rane and Varade (1972) evaluated the performance of different bullock drawn puddlers with respect to hydraulic conductivity. A rotary blade puddler could reduce the hydraulic conductivity by 85 per cent over

control (no puddling). They further observed that hydraulic conductivity decrease with passage of time. Tewari (1984) reported 90 per cent reduction of hydraulic conductivity over non-puddled soil when puddling was done by a tractor drawn rotary puddler having three passes.

Prihar *et al.* (1975) compared conventional puddling by country plough with compaction and mechanical puddling by disc harrow, rotavator and rotary blade puddler in a sandy loam soil. From the standpoint of percolation losses, puddling with disc harrow, rotary puddler and rotavator were almost equal. Compaction did not show much promise as a substitute to puddling. But, Ghildyal and Satyanarayan (1969) suggested that compaction could be used as an alternative to puddling. They found that compaction significantly reduced hydraulic conductivity in sand, sandy loam, sandy clay loam and clay.

Tyagi *et al.* (1975) studied the effect of puddling by country plough, m.b. plough, disc harrow, power tiller with rotavator and tractor cage wheel on hydraulic conductivity in sandy loam soil. They observed that power tiller with rotavator produced maximum reduction of hydraulic conductivity (76 %) compared to other treatments. Agrawal *et al.* (1978) also found that power tiller with rotavator (two passes) reduced percolation losses significantly. It was further reported that tractor drawn rotary puddler was effective in single operation compared to two operations of disc harrow in terms of percolation loss and silt clay dispersion.

Sharma and De Datta (1985) compared hydraulic conductivity of non-puddled and puddled soil for clay and clay loam soil. In clay loam soil hydraulic conductivity decreased five fold (0.637 to 0.133 mm hr⁻¹) whereas, in clay soil hydraulic conductivity reduced non-significantly over non-puddled soil (0.10 to 0.08 mm hr⁻¹).

Increasing implement passes, thereby increasing the puddling intensity, reduces hydraulic conductivity and percolation losses. **Sharma *et al.* (1991)** found that percolation loss and infiltration rate reduced considerably when number of passes of rotary puddler and disc harrow were increased from one to two and two to three respectively. **Salokhe *et al.* (1993)** obtained a maximum of 76 per cent reduction in hydraulic conductivity over non-puddled soil when rotavator was used for three passes at 1 km hr⁻¹ forward speed of the tractor. Lowest reduction of hydraulic conductivity (19%) was obtained with one pass at 2 km hr⁻¹ forward speed.

Rath (1999) studied the effect of puddling by peg type and rotary puddler in comparison to spade puddling and found that hydraulic conductivity was statistically *at par* for peg type and rotary puddler but significantly higher in case of spade puddling for the years 1997 and 1998.

2.3 Effect of Puddling on Dynamic Properties of Soil

Awadhwai and Singh (1985) found that puddling considerably reduces the strength of soil. Strength of a soil is affected by its structure, void ratio, rate of shear, moisture content and thixotropy. The term

thixotropy is used to describe the phenomenon of increase in strength with time. Puddled soil exhibits thixotropic behaviour.

2.3.1 Cone index

Cone index is a measure of the strength over a depth profile of soil. Puddled soils are most likely cohesive soil unlike dry soils which are frictional – cohesive soils (Jaw and Lu, 1964; Salokhe and Gee Clough, 1988). Freitag (1968) obtained a very strong correlation between cohesion and cone index when friction angle was near zero (approximately 2 degree or less) which showed that whenever a strength measurement was needed in a wet, fine grained soil whose friction angle can be considered zero, the cone penetrometer could be used to measure soil strength with considerable accuracy. Konaka (1974) reported that penetrometer resistance test was used to show the dynamic properties of soil at variable depth and cone index could be representative of dynamic property of puddled soil collectively.

Singh *et al.* (1981), while studying the performance on a self-propelled rice transplanter on Bangkok clay soil with two levels of puddling (one plowing + one rotatilling + levelling (R_1) and one ploughing + two rotatilling + levelling (R_2), reported that the cone index value was 330 kPa for R_2 after 7-10 days of sedimentation period and 302 for R_1 after 2-5 days of sedimentation period indicating better puddling by twice rotatilling.

Salokhe and Gee Clough (1985) reported that cone index of a Bangkok clay was 1090 kPa when dry. After three days of flooding, the

cone index values reduced to 490 kPa and it further reduced to 180 kPa after puddling by a rotary cultivator.

Singh *et al.* (1985), while evaluating a manual drawn rice transplanter with three levels of puddling namely low level (two ploughing by m.b. plough + one operation by a rake harrow), medium level (in addition to low level puddling, six additional wet harrowing by a animal drawn vertical tyne rake harrow and high level (one dry cultivation about 10 cm deep using a rotary tiller and six wet harrowing by rake harrow drawn by a 4 kW power tiller), observed that at high level of puddling cone penetrometer resistance was significantly lower than that of other levels of puddling for all depths. They reported that cone index value of 243 kN m^{-2} represents soft soil condition while cone index value above 490 kN m^{-2} represents firm soil condition.

Kanoksak *et al.* (1988) observed that puddling by rotavator generated softer puddled bed than by rake harrow. The cone index values (0.0-31.5 cm) after 7 days of sedimentation period were 527.35 and 561 kPa for rotavator and rake harrow respectively. The cone penetrometer resistance at 0.0 and 7.0 cm for the corresponding treatments were 18 and 91 kPa and 15 and 157 kPa respectively. They reported that degree of puddling was higher in case of rotavator (86%) than in case of rake harrow (79%).

Khan and Gunkel (1989) investigated the effect of sedimentation period (2, 3, 4 and 5 days) in a silty loam soil on cone index at varying

penetration speed (2.1, 4.2 and 8.3 m/s). They found that cone index (0-5 cm) increased with sedimentation period for all penetration speed. But, higher the penetration speed, higher was the cone index. There was a high correlation between shear strength and cone index at all penetration speed. They further reported that cone index increased more rapidly between 2nd and 3rd day.

Salokhe *et al.* (1993) observed that per cent reduction in cone index increased as the number of passes of rotavator increased. The percentage reduction in cone index after puddling compared to before puddling were 82, 80 and 78 per cent after third pass at speed of 1.0, 1.5 and 2.0 km hr⁻¹ respectively. Number of passes had a significant effect on reduction of cone index while, the speed, at any given pass had no significant effect.

In a laboratory study with different puddling levels and sedimentation period, Rautaray *et al.* (1997) found that as the sedimentation period increased the shear strength of puddled soil increased for all depths. However, at higher level of puddling, the rate of increase of shear strength with depth was very low. For a particular depth, higher the level of puddling lower was the shear strength.

2.3.2 Sinkage resistance

Cone index represents the soil strength over a depth range collectively whereas sinkage resistance represents the bearing capacity of puddled soil. Since puddled soil exhibits thixotropic behaviour, sinkage

resistance increases over time. Higher the sinkage resistance, lower is the sinkage of the transplanter. Low bearing capacity of the rice soil creates traction and machinery immobilization problem, limiting the adoption of mechanization in rice producing Asian countries (Tanaka, 1984).

Bernstein (1913) reported that the pressure required to force a flat penetrating device into a homogeneous soil was approximated by a power law equation in the form of

$$P = KZ^n \quad \dots(2.1)$$

Where,

P = Penetration pressure, FL^{-2}

Z = Sinkage of penetrating device, L

K = Bernstein's modulus of deformation

n = Exponent of soil deformation

Similar pressure sinkage relationship was proposed by Pope (1969).

Bekker (1955) observed that the value of K is necessarily dependent upon the size of the penetrating device and proposed that K be expressed as :

$$K = K_c / b + K_\phi \quad \dots(2.2)$$

Where,

K_c = Cohesive modulus of soil deformation

K_ϕ = Frictional modulus of soil deformation

b = Smaller dimension of loading area

Contrary to this **Zuxun *et al.* (1990)** reported that pressure sinkage relationship of top layer soils of paddy field was dependent on area perimeter ratio rather than the size of the loading plate. The new model proposed by them is given below.

$$P = (K_1 + \alpha K_2) (Z/\alpha)^{\alpha\eta} \quad \dots(2.3)$$

Where,

P = Pressure, kg cm^{-2}

Z = Sinkage, cm

α = Area perimeter ratio

K_1 , K_2 and η are constants

Sargana (1983) studied the effect of deformation rate on Bangkok clay soil. During plate sinkage test, he observed that sinkage modulus increased with increasing penetration rate for both upper and lower layer. Later **Sargana *et al.* (1985)** reported that at lower depth of sinkage in puddled soil, the resistance was less but it increased at a faster rate with increase of sinkage. The penetration rate had a strong effect on resistance at higher sinkage than at lower sinkage. They concluded that in saturated puddled clay soil all properties, with the exception of internal friction angle, were strongly dependent on deformation rate. In such a soil it is essential that the deformation rate use in measuring soil properties should be close to that imposed by the vehicle on the soil.

In a study of performance evaluation of USG applicator, **Gangil (1993)** investigated the sinkage resistance of puddled soil created by peg type puddler and rotary puddler at different depths and sedimentation period. He reported that sinkage resistance increased with sedimentation period at upper layer (1-6 cm) and lower layer (11-16 cm) for both puddlers. Sinkage resistance was higher at a particular depth and sedimentation period for peg type puddler than rotary puddler. However, there was no significant difference of sinkage resistance at 48 hrs of sedimentation period for both the puddlers.

Garg *et al.* (1999) studied the effect of various contact pressure on sinkage of transplanter for silty clay loam (S_1) and sandy loam (S_2) soils at different sedimentation period. Sinkage was more at higher ground contact pressure in both the soils. For a particular contact pressure, the sinkage decreased with increase of sedimentation period. In case of silty clay loam soil, regaining of strength with increase in sedimentation period was relatively slow because of higher percentage of lighter clay particles taking more time to settle. However, in case of sandy loam soil, the soil gained strength at a faster rate and the sinkage at maximum contact pressure (24.44 g cm^{-2}) was less than 1 cm after 24 hours. They suggested that transplanting was not desirable at such a hard soil which might pose a problem for penetration of transplanting fingers. In silty clay loam soil, even after 72 hours of sedimentation period, the sinkage was always more than

2.0 cm at the highest contact pressure. The sinkage and contact pressure had a linear relationship.

2.4 Influence of Seeding Mat Parameters on Performance of Transplanter

In Japan, the transplanters using mat type seedlings have completely replaced transplanter using washed root seedling due to their better performance and lesser labour requirement (Hoshino, 1974; Hoshino, 1977). Number of seedlings transplanted per hill vary from country to country. While in Burma, 1 to 4 seedling are transplanted per hill, in Sri Lanka only one seedling is used (Paul, 1945). Usually, 5 to 7 seedlings are transplanted in Philippines. Results in India indicated that the number of fertile tillers is greater with 3-4 seedlings (Hedayetullah, 1977). Proper age of seedling for transplanting varies with management practices, growth period of variety and growing season. In case of high yielding varieties, the seedling should be transplanted at 4-5 leaf stage (Shastri, 1977).

Seedling above 25 cm height posed problems in working of self-propelled rice transplanter (Singh *et al.*, 1979). They also reported that wet nursery might slide too fast which would cause more number of seedlings per hill and thus would increase mat consumption. Uniformity of mat density was of paramount importance to them.

In a circular soil bin study for mechanical transplanting with four mat moisture contents, four seedling age and three transplanting speeds on two soils : sandy loam (S₁) and silty clay loam (S₂), **Garg *et al.* (1982)** observed that net power requirement increased with an increase in seedling age, planting speed and with a decrease in mat moisture content for both the soils S₁ and S₂. The effect of seedling age was predominant in soil S₂ than in soil S₁ at higher moisture content and higher planting speed. Mat consumption increased with an increase of moisture content and planting speed. Number of seedlings per hill also increased with an increase in seedling age, mat moisture content and transplanting speed for both the soils S₁ and S₂ except non-significant effect of seedling age on soil S₂.

Swain and Maity (1989) investigated the seedling mat parameters like seedling age and mat moisture content for two mat soils viz. pure sand and sandy loam soil. They reported that an increase in mat moisture content and seedling age increased the number of seedling per hill for both types of mats and the variation was significant with older seedling. Desired 3 to 4 seedlings per hill were obtained at 20 to 25 per cent moisture content with 25 to 30 days old seedling. Similar results were also reported by **Khan and Gunkel (1988)**. It was reported that increase of seedling age decreased the missing hill percentage. However, the findings of **Singh *et al.* (1985)** did not agree with it. They observed that with increase in seedling age, the

missing hill percentage increased because of the thicken stem and more roots in older seedling.

Mufti and Khan (1995) conducted a laboratory evaluation of Yanmar paddy transplanter and found that PTO gear setting had no effect on the missing percentage and number of seedlings per hill but it affected the hill spacing. Number of seedlings per hill was significantly affected by variety and age of seedling. They observed that missing hill percentage and seedlings per hill were dependent on the distribution and uniformity of seedling in a mat.

Hota (1997) found that mat rupture strength increased with seedling age. Fifteen days old seedling were difficult to be picked by transplanting fingers. He observed satisfactory performance of the manual transplanter with 25 days old seedling.

2.5 Effect of Puddling on Performance of Self-propelled Rice Transplanter

2.5.1 Effect of puddled soil condition on drag force

It has been realised that during soil-tool interaction, soil tool friction and soil adhesion contribute significantly to the total drag. The type and smoothness of the material affect, the adhesion property. The adhesive force between soil and other materials are due to moisture film. Adhesion acts as there is an increase in normal load under saturated condition. According to Nichols' classification (**Nichols, 1931**), the friction phase is found when the

soil is dry. As moisture is added adhesion begins and causes an increase in the apparent coefficient of friction. Total lubrication phase occurs when enough moisture is present to provide a free water surface to lubricate the soil-metal interface.

Rice transplanter, whose sizeable weight is supported by a float, tends to sink into soft puddled soil leading to an increase of drag force (Singh *et al.*, 1981). Soil accumulation ahead of the float also increases the drag force. Therefore, Shah (1980) suggested that floats should resemble snow skis. He found that a thin film of water reduced drag considerably but under dry condition the drag force increased more than five fold.

Gee Clough (1990) observed that the drag force of a turtle tiller under flooded condition was reduced by 61 per cent over non-flooded condition. But, in case of a boat tractor whose contact pressure was much higher than that of turtle tiller, the reduction of drag force was not significant because of squeezing out of water from the interface between metal float and soil, thus reducing the lubricating effect of water.

Alagusundaram *et al.* (1990) found that forward speed did not have much influence on drag force of deep placement fertilizer applicator for paddy crop. But, flooded and non-flooded condition had significant effect on drag force. They found that drag force was 94N in flooded condition compared to 170N in non-flooded condition. Float absorbed around 40 per cent and 60 per cent of drag force in flooded and no flooded conditions

respectively. Cage wheel absorbed around 20 and 15 per cent of drag force in the corresponding conditions.

Rahman (1992) observed that as moisture content of soil gradually increased leading to flooded condition, the drag force of an air cushion vehicle decreased considerably both in without and with air mode. The drag force was almost double at 46 per cent moisture content compared to flooded condition.

2.5.2 Mobility of transplanter

In case of self-propelled rice transplanter which operates on highly soft puddled soil, the traction is provided by cage wheel and floatation by float. The transplanter becomes immobile due to concurrent failure in bearing and traction. Traction failure can occur in a soil with adequate bearing strength also (**Knight and Freitag, 1962**). That situation arises when there is excessive float drag due to dry ground condition and the traction wheel can not provide sufficient thrust to propel the transplanter (**Singh *et al.*, 1981 and Gee Clough, 1985**).

In a wet soil, with hardpan at considerable depth, the utility of agricultural machines is limited due to their bogging because the traction wheel fails to touch the hardpan to produce necessary traction (**Awadwal and Singh, 1985**).

Singh and Garg (1976) observed that for adequate mobility of self-propelled transplanter, the depth of puddling should not be more than 10 cm.

The machine used to sink where the soil was too loose due to more depth of puddling. Similar observations were also made by **Singh and Garg (1979)** and **Singh *et al.* (1981)**.

Khan *et al.* (1979), from their experience of a study of Korean transplanter in Pakistan reported that depending upon the soil texture, the period of sedimentation period would differ from 1 to 10 days. Clayey soils required longer sedimentation period and that could be reduced if water was drained out after puddling.

While evaluating the performance of a self-propelled transplanter it was reported that maximum sinkage was observed in case of rotavator (two passes) and pulverising roller (two passes) at 15 cm depth of puddling for all sedimentation period of 24, 48 and 72 hrs. The ideal time for transplanting was 72 hrs after puddling whereas, in case of cultivator (two passes) at 15 cm depth of puddling, the ideal time of transplanting was at 48 hours after puddling. With other treatments, like cultivator (two passes), rotavator (one pass) and pulverising roller (two passes) at 10 cm depth of puddling, the ideal condition for transplanting was obtained after 48 hours (**Half Yearly Report, FIM, PAU, 1999**).

2.5.3 Transplanting performance

Puddling equipment and intensity of puddling alter the soil properties which in turn affect the transplanting performance in term of floating hill,

buried hill, row to row and hill to hill spacing (**Kanoksak *et al.*, 1988; Mufti *et al.*, 1995).**

Mori (1975) evaluated a self-propelled riding type transplanter in clay loam soil in Japan and found that hill to hill spacing was more than the preset value because of lesser wheel slip than the designed value. Wheel slip increased with deeper hardpan and increasing soil hardness. He further reported that with soft soil, transplanting depth increased resulting in a higher percentage of buried hill. Row to row spacing was also affected by softness of soil.

Singh and Garg (1976) observed that higher water level resulted in more floating hill percentage. According to them, water level should not be more than 5 cm. **Khan *et al.* (1979)** reported that 2 to 3 cm water level was permissible.

Singh and Garg (1979) designed, developed and evaluated a six row tractor drawn transplanter. They reported that due to flow of water behind the machine the seedlings were washed away and that was more pronounced when the tractor was operated at higher speed. In certain cases, the hill to hill spacing reduced due to slippage of tractor wheels and row to row spacing changed due to movement of soil through tractor wheels. **Singh *et al.* (1982)** modified the transplanter to ten rows but could not improve the performance because of poor manouverability of tractor, sinkage of

transplanter and rut formation in puddled soil. They finally concluded that tractor drawn transplanter may not be functionally and economically viable.

While studying a 12 row washed root type transplanter on Bangkok clay, Singh *et al.* (1981) found that, in soft soil condition (one ploughing + two rotary puddling + levelling with 2-5 days of sedimentation), buried, floating and missing hill percentage was considerably high due to flow of puddled soil around the transplanter and most affected were the two previously planted rows and 1-2 currently planted outer rows. But in standard soil condition (one ploughing + one rotary puddling + levelling with 7-10 days of sedimentation), the buried, floating and missing hill percentage were reduced to one-third of that in soft soil condition. They further reported that younger seedlings (22 days old) were more readily washed away by the water than older seedlings (28 and 34 days old). Older seedlings could be transplanted at higher water depth.

Singh *et al.* (1985) observed a higher percentage of floating hill in over puddled silty clay soil due to poor anchorage of seedling. Higher water level also increased the floating hill percentage irrespective of level of puddling because of loosening the pickers hold on the plants by washing the soil from the roots. But in loam soil, irrespective of water level (0-3, 3-6 cm), the floating hill percentage was higher than that in silty clay and silty loam soil because of the inability of pickers to hold a chunk of sandy soil from mat and higher cone index of soil at the time of transplanting. In silty

loam soil both floating hill and buried hill percentage were higher than that of silty clay soil. Poor performance of silty loam soil was due to stickyness of soil used in mat and overpuddled soil condition (low cone index). **Kanoksak *et al.* (1988)** also observed that at lower cone index of puddled soil buried and floating hill percentage increased.

In a laboratory study of sedimentation period effect of puddled soil on seedling withdrawal force, **Khan and Gunkel (1989)** reported that increasing of puddled soil strength due to aging increased seedling withdrawal force. The withdrawal force increased at a faster rate from 2 to 3 days of sedimentation period as compared to 3 to 4 and 4 to 5 days. Root area influenced the seedling withdrawal force significantly whereas water level and planting speed did not. Withdrawal force is an index of seedling anchorage and could be used as basis to decide a time gap between last puddling and transplanting by a mechanical transplanter.

Mufti and Khan (1995) evaluated the performance of Yanmar rice transplanter in silty loam and loam soil puddled by 4-6 passes of cultivator. They found that buried hills increased with small seedlings. Hill mortality rate was quite high. They suggested that at the time of transplanting the field should be level and hard enough to prevent movement of mud along with the float. **Garg *et al.* (1997)** in a study of manual transplanter observed that after 24 hours of sedimentation period, there was no flow of mud. But hill

mortality was quite high (average 12%) due to root and stem cutting by the transplanting fingers.

2.6 Effect of Puddling on Crop Performance

2.6.1 Root growth

Plant has to fully depend upon its root system to meet the water and nutrient requirement. The well developed extensive root system, therefore, is essential for overall growth. Root growth is strongly affected by the soil physical environment, more specifically the rhizospheric environment and crop management practices (Kar *et al.*, 1979; Katare and Upadhyaya, 1981). Soil strength which increases with increase of bulk density poses a serious hindrance to root growth (Taylor and Brar, 1991). Hasegawa *et al.* (1985) reported some green house and field data indicating a negative correlation between rice root growth and soil mechanical impedance. About 70 per cent of rice roots are in 0-5 cm, 93 per cent in 0-10 cm and 99 per cent in 0-25 cm layer (Sharma and De Datta, 1986).

Ghildyal and Satyanarayan (1969); Gupta and Kathvate (1972) observed a severe reduction in root density of rice plant with an increase in bulk density of lateritic sandy clay loam soil from 1.4 to 1.83 Mg m⁻³ because of compaction. It was also reported that most of the roots were restricted to 7 cm of soil and root weight decreased when bulk density increased beyond 1.63 Mg m⁻³.

Kar and Varade (1972) observed that with a density of less than 1.7 Mg m^{-3} in lateritic sandy loam soil, rice root growth and penetration were not related to soil strength, but above that density, the root growth and penetration were inversely related.

Kar *et al.* (1976) further investigated in controlled green house condition and evaluated the influence of mechanical impedance on root growth. They reported that root dry weight, volume and total number of rice roots significantly decreased when density increased from 1.2, 1.6 and 1.8 Mg m^{-3} to 1.4, 1.8 and 2.0 Mg m^{-3} in clay, loam and sandy loam soils, respectively. Similar results were reported by Merrigama *et al.* (1981).

Sharma *et al.* (1988) reported that root length density of rice was confined only within 10 to 15 cm layer. Puddling produced 44 per cent higher root length density than zero tillage and 33 per cent higher than minimum tillage in 15 cm soil layer in clay soil.

Mambani *et al.* (1990) observed that impedance greater than 0.75 MPa, significantly reduced root growth. Puddling increased soil moisture storage which minimized soil impedance during dry cycle more effectively than dry tillage. They further found that deep ploughing and deep puddling produced significantly higher root growth in comparison to conventional cultivation and puddling, no puddling and zero tillage by reducing the percolation losses and availability of nutrients to the growing roots.

Yao *et al.* (1992) found that root weight of manually transplanted rice was higher than that of mechanically transplanted rice at 7 days after transplanting (DAT). But, the proportion increased gradually and by the panicle initiation stage the root weights were similar. At maturity, roots of manually transplanted plants were markedly lighter than those of machine transplanted plants.

Rath (1999) revealed that peg type puddler produced higher root dry weight in comparison to rotary puddler. He cited the reason that higher bulk density in case of rotary blade puddler contributed towards lesser root dry weight.

2.6.2 Crop growth and productivity

Puddling and subsequent flooding of rice field increase the growth and productivity of rice (**Kandaurov and Patrin, 1974; Overmuller and Mikkelson, 1974; Pande *et al.*, 1974; Bhan and Padwal, 1976**). Transplanted rice on puddled soil produced more yield than direct seeding rice because of reduction in leaching losses of nitrogen and efficient use of water (**Sakanoue and Mizuncema, 1962; Sanchez, 1973; De Datta and Kerim, 1974; Sharma and De Datta, 1985**). **Lal (1985)** reported that for soils with relatively high clay content, there are no obvious advantages in rice yield by puddling over no till method of seed bed preparation. But in medium textured soil, puddling increases grain yield over no till method (**Mambani *et al.*, 1990**).

Varade and Ghildyal (1967) found that dry matter and grain yield of rice were greater under moderate compaction (1.5 to 1.6 Mg m^{-3}) in lateritic sandy clay loam soil, but subsequent increase in bulk density decreased yield. **Ghildyal and Satyanarayan (1969)** showed that higher bulk density beyond 1.63 Mg m^{-3} not only affected yield adversely but also delayed the plant growth.

Sharma and De Datta (1985) observed that puddling significantly increased grains per panicle and plant height and subsequently yield for both clay and clay loam soil by lowering the soil strength at root zone. **Sharma *et al.* (1988)** in an experiment of different tillage methods (no tillage, minimum tillage, shallow puddling and deep puddling) on clay and clay loam soil reported that minimum tillage produced about 26 and 36 per cent higher grain yield than that with zero tillage in clay and clay loam soils respectively. The increase of yield in shallow and deep puddling over zero tillage was 33 and 28 per cent and 66 and 56 per cent for the above soils respectively. They attributed the increase in grain yield due to increase in plant height, panicle length and root length density and decrease in soil penetration resistance.

Sood and Acharya (1991) conducted an experiment on silty clay loam soil with deep ploughing and deep puddling (DP), shallow conventional cultivation and puddling (CP), conventional cultivation and non puddling (CN), compaction after conventional cultivation (CC) and zero

tillage without any preparatory tillage (ZT) as the tillage treatments and observed that CC showed significantly higher plant height and number of tillers per hill at all growth stages and higher dry matter accumulation at 30 DAT whereas DP produced higher panicle length and dry matter accumulation at panicles initiation stage. Treatments CN and ZT were *at par* but significantly lower than the treatment CP. There was no significant difference of yield between treatment CC and DP. However, yield in case of CP was significantly lower than that of CC and DP and higher than that of CN and ZT.

Sharma *et al.* (1991) evaluated four bullock drawn puddling equipment (rotary puddler, disc harrow, harrow-cum-puddler and desi plough) with varying number of passes and reported that rotary blade puddler with two puddling produced highest yield followed by disc harrow with three puddling, disc harrow with two puddling and rotary blade puddler with one puddling. Higher yield was attributed to lower percolation losses.

Rath (1999) observed that yield attributing characters and subsequently yield was significantly higher in case of peg type puddler and compaction after flooding compared to rotary puddler, spade puddling and no tillage in a silty-clay loam soil in the year 1997. But there was no significant difference of yield between peg type and rotary puddler in the year 1998. Low yield in case of rotary blade puddler was attributed to higher hill mortality and greater bulk density of soil leading to lesser root growth.

2.6.3 Transplanting methods on growth and productivity of rice

Manual transplanting most of the time fails to maintain a desired plant population. Moreover, line transplanting, where plant to plant and row to row distance are maintained, consumes more time resulting in a high cost of transplanting. Mechanical transplanting helps in maintaining optimum plant population besides saving time and cost.

Singh and Garg (1976) observed that plant population per sq.-m was higher in case of mechanical transplanting compared to that of random manual transplanting. The yield in mechanical transplanted plot was 17.51 per cent higher than that of random transplanting. However, line transplanting produced higher yield because of more number of hills per sq.-m.

Panda (1997) in a study of manual transplanter found that mechanical transplanting produced more effective tillers per hill and filled grains per panicle. Grain yield was significantly higher than that of manual transplanting. Similar observations were made by **Garg *et al.* (1997)**. They found 20.3 per cent higher tillers per hill and 3.41 per cent higher yield in case of machine transplanting compared to random manual transplanting.

2.7 Economics

Manual transplanting consumes around 250-350 man-hr per hectare **Singh *et al.* (1983)**. Uprooting of conventional nursery consumes a considerable time (180 man-hr) thereby increasing the man-hr requirement per hectare to 507 for random transplanting (**Hota, 1997**). It was further

reported that line transplanting consumed on an average 619 man-hr per ha. and a monetary gain of 38 and 14 per cent was obtained in mechanical transplanting by a four row manual transplanter over random and line transplanting respectively. **Garg *et al.* (1997)** reported a financial and labour saving of 45 and 60 per cent in machine transplanting (manually drawn) over manual transplanting.

Manian *et al.* (1987) found 628 man-hr requirement per hectare for manual transplanting. They observed a financial gain of 18.76 per cent in mechanical transplanting by IRRI four row manual transplanter over manual transplanting. A break even point of 3.12 ha per year was suggested. **Singh *et al.* (1983)** reported a break even point of 2 and 1 ha for double and single cropping seasons per year for an IRRI five row manual transplanter and obtained a 63 per cent financial gain over manual transplanting.

Mechanical transplanting by self-propelled transplanter reduces transplanting time considerably but transplanting cost per hectare increases due to its high initial cost which causes its annual fixed cost to shoot up. Transplanting cost could be reduced if hours of use per annum is increased.

Man-hr requirement per hectare of mechanical transplanting by Yanmar transplanter was 40 (**Mufti and Khan, 1995**). They observed that with an increase in area of coverage from 50 to 100 hectares per year the transplanting cost per hectare reduced from Rs. 1250.0 to 850.0 (Pakistan Rupees). They found the break-even point at 75 hectare of annual use.

From the foregoing review, the following conclusions could be drawn

1. Puddling brings about significant changes in physical and dynamic properties of soil
2. Higher depth of puddling and soft puddled soil increase sinkage of transplanter resulting in poor trafficability
3. Transplanter needs a well settled puddled soil surface to prevent flow of mud along with float to reduce buried & floating hill and hill mortality
4. Transplanting performance is affected by seedling density, mat moisture content and operating speed
5. Puddling is beneficial to rice crop but may be detrimental to subsequent crop

Studies so far on self-propelled rice transplanter have not specified puddling equipment, intensity of puddling and sedimentation period required for efficient operation of the transplanter. Therefore, a comprehensive study on effect of puddling on transplanter performance as well as its impact on rice crop needs to be carried out.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

Field experiments were conducted during Kharif season of years 1998 and 1999 to evaluate effect of puddled soil characteristics on performance of self-propelled rice transplanter and rice crop. Laboratory studies involving mat type seedling parameters and seedling withdrawal force in puddled soil were also conducted. The details of materials used, experimental procedure followed and measurement techniques adopted during the course of investigation are described in this chapter.

3.1 Experimental Site

The experiments were carried out in F₃ block of the Crop Research Centre of this university. It is situated at 29°N latitude, 72°29'E longitude and 243.8 m altitude and lies in a narrow belt to the south from the foot hills of the Shivalik range of Himalayas, known as *Tarai*, which contains wet moisture regime and high water table conditions for most part of the year.

3.2 Climate and Weather

The *Tarai* region enjoys a sub-humid, sub-tropical climate with hot and dry summers and severe cold winters. Generally, monsoon sets in the last week of June and continues upto September. Very often, a few showers are expected during winters and occasionally during summer months. The weather parameters like minimum temperature, relative humidity, rainfall and sunshine hours during the period of experimentation, as recorded at the

meteorological observatory of the Crop Research Centre are presented in Tables A.1 and A.2.

3.2.1 Kharif 1998

The weekly mean maximum and mean minimum temperature ranged from 25.8 to 41.8 °C and 8.7 to 27.7°C respectively. The total rainfall received during this season was 1502.00 mm distributed in 68 number of rainy days. The minimum and maximum sunshine hours per day varied from 1.6 (second week of August) to 10.6 (first week of June). The mean weekly maximum and minimum relative humidity ranged from 53.00 and 96.00 per cent and 18.00 and 88.00 per cent at 7.00 AM and 2.00 PM respectively.

3.2.2 Kharif 1999

The weekly mean maximum and mean minimum temperature ranged from 25.075 to 34.94°C and 8.85 to 27.04°C respectively. The total rainfall received during this season was 2518.96 mm distributed in 80 number of rainy days. The minimum and maximum sunshine hours per day varied from 3.07 (second week of September) to 9.92 (second week of October). The mean weekly maximum and minimum relative humidity ranged from 63.52 and 94.42 per cent and 31.14 and 81.57 per cent at 7.00 AM and 2.00 PM respectively.

3.3 Soil Characteristics

The soil of the experimental field was weak fine to fine medium granular structure, classified as mollisols (Despande *et al.*, 1971). Analysis of a composite soil sample, collected from the experimental field at several randomly selected spots upto a depth of 15 cm showed that it is silty clay loam in texture, slightly alkaline in soil reaction, rich in organic carbon, low in available nitrogen, rich in available phosphorous and potassium. The physico-chemical properties of the experimental field are given in Table 3.1.

3.4 Puddling Equipment

Three tractor drawn puddling equipment namely rotary puddler (R); peg type puddler (P) and nine tyne cultivator (C) were used for puddling the experimental field. The rotary blade puddler was developed at Department of FMandP Engg. of the university. Peg type puddler and cultivator were included in the experiment because of the reason that they are extensively used by local farmers as puddling equipment. The salient features of the puddling equipment are given in Table 3.2.

3.5 Self-propelled Rice Transplanter

A Chinese make self-propelled 8-row rice transplanter (Model : 2ZT-238-8), marketed by V.S.T. Agro Inputs, Bangalore, was used in the experiment (Plate 3.1). It has a fixed row to row spacing of 23.8 cm and variable plant to plant spacing of 10 and 12 cm with corresponding

Table 3.1 Initial physico-chemical properties of experimental soil

Properties	Value	Method used
Composition		
Sand, %	32.82	Bouyoucos hydrometer method (Bouyoucos, 1962)
Silt, %	42.00	
Clay, %	25.18	
Textural class	Silty clay loam	International system
Initial bulk density, Mg m⁻³		
i) 1998	1.42	Core sampler method (Black, 1971)
ii) 1999	1.44	
Saturated hydraulic conductivity, mm hr⁻¹		
i) 1998	0.830	Falling head, permeameter method (Rana & Varade, 1972)
ii) 1999	0.648	
Cone index of saturated soil, kPa		Cone penetrometer method
i) 1998	421.56	
ii) 1999	393.35	
Weed dry weight, g m⁻²		
i) 1998	22.5	Oven dry basis
ii) 1999	Weed free	
Electrical Conductivity (dSm⁻¹)	0.269	Conductivity bridge (Jackson, 1973)
pH (1:2.5 soil water suspension)	7.23	Beckam glass electrode pH meter (Jackson, 1967)
Organic carbon, %	1.23	Modified Walkley and Black method (Nelson & Sommers, 1982)
Total nitrogen, %	0.09345	Modified Kjeldahl Method (Bremner & Mulveney, 1982)
Available, kg N ha⁻¹	247.0	Alkaline KMnO ₄ method (Subbiah & Asija, 1956)
Available P, kg P ha⁻¹	110.9	Olsen's Method (Olsen <i>et al.</i> , 1994)
Available K, kg K ha⁻¹	252.0	Neutral normal ammonium acetate method (Knudsen, Peterson & Pratt, 1982)

Table 3.2 Specifications of the puddling equipment

Sl. No.	Particulars	Puddling equipment		
		Rotary	Peg type	Cultivator
1.	Type	Tractor drawn	Tractor drawn	Tractor drawn
2.	Overall dimensions			
	a) Length, cm	230	274	215
	b) Width, cm	85	42	85
	c) Height, cm (including top hitch)	115	75	110
3.	Working width, cm	220	240	220
4.	Soil working parts			
	a) Number	72 in 8 gangs	20	9
	b) Shape and size, cm	Rectangular (20x7.5x0.6)	Vertical (22x6)	Curved (35x7)
	c) Spacing, cm		12	25
5.	Scraper/leveller	Yes	Yes	No
6.	Weight, kg	255	120	180



(a) Front view



(b) Rear view

Plate 3.1 The self-propelled rice transplanter used in the experiment (a) Front view and (b) Rear view

Table 3.3 Technical specifications of self-propelled rice transplanter

Sl.No.	Item	Specifications
1.	Model	2ZT-238-8
2.	Dimension (L x W x H), cm	241 x 213.1 x 130
3.	Engine power, kW	2.4
4.	Fuel	Diesel
5.	Cooling system	Air cooled
6.	Weight, kg	320
7.	Walking mechanism	Single wheel driven
8.	Type of float	Fibre glass
9.	Working mechanism	Separate crank connecting rod transplanting mechanism
10.	Number of rows	8
11.	Row spacing, cm	23.8
12.	Hill to hill spacing, cm	10 and 12
13.	Frequency of transplanting, strokes min. ⁻¹	238
14.	Depth of transplanting	Adjustable with screw rod
15.	Traction wheel	
	a) Diameter, cm	70
	b) No. of lugs,	15
	c) Lug angle, degree	22 upward
16.	Frequency of strokes of fingers in one maximum displacement of tray, No.	14
17.	Max. depth of finger entering the mat, cm	1.7

maximum operating speed of 1.57 and 1.94 km hr⁻¹ respectively. The technical specifications of the transplanter are given in Table 3.3.

3.6 Field Experiment

3.6.1 Treatments

The field experiment during 1998 was conducted with three puddling equipment viz. rotary puddler, peg type puddler and 9 tyne cultivator and two levels of puddling (two and three passes) which accounted for six main plot treatments. Sedimentation period of 24, 48 and 72 hours of puddled soil were sub-plot treatments. On the basis of the findings of the year 1998, cultivator was dropped as a treatment and the experiment was conducted with peg type puddler with two levels of puddling (one and two passes) and rotary puddler with one pass as main plot treatments. Sedimentation period of 24, 36 and 48 hours were selected as sub-plot treatments. The details of the treatments and nomenclature used are given below :

1. Treatments (1998)

Sl.No.	Main Plot (Puddling equipment)	Symbols
1.	Rotary puddler two passes	R ₂
2.	Rotary puddler three passes	R ₃
3.	Peg type puddler two passes	P ₂
4.	Peg type puddler three passes	P ₃
5.	Cultivator two passes	C ₂
6.	Cultivator three passes	C ₃
	Subplot (Sedimentation period)	
7.	24 hours	S ₂₄
8.	48 hours	S ₄₈
9.	72 hours	S ₇₂

2. Treatments (1999)

SL.No.	Main Plot (Puddling equipment)	Symbols
1.	Peg type puddler two passes	P ₂
2.	Peg type puddler one pass	P ₁
3.	Rotary puddler one pass	R ₁
Subplot (Sedimentation period)		
4.	24 hours	S ₂₄
5.	36 hours	S ₃₆
6.	48 hours	S ₄₈

3.6.2 Experimental variables

Entire field experiment is segmented into different investigations. The independent and dependent variables along with statistical design are presented below. The experimental layout is given in Figures 3.1 and 3.2 for the years 1998 and 1999 respectively.

Investigation No. 1 : Studies on effect of puddling on physical properties of soil

A. Independent variable : Puddling equipment

B. Dependent variables :

1. Puddling index
2. Bulk density
3. Hydraulic conductivity

C. Statistical design : RBD with three replications

Investigation No. 2 : Studies on effect of puddling on dynamic properties of puddled soil

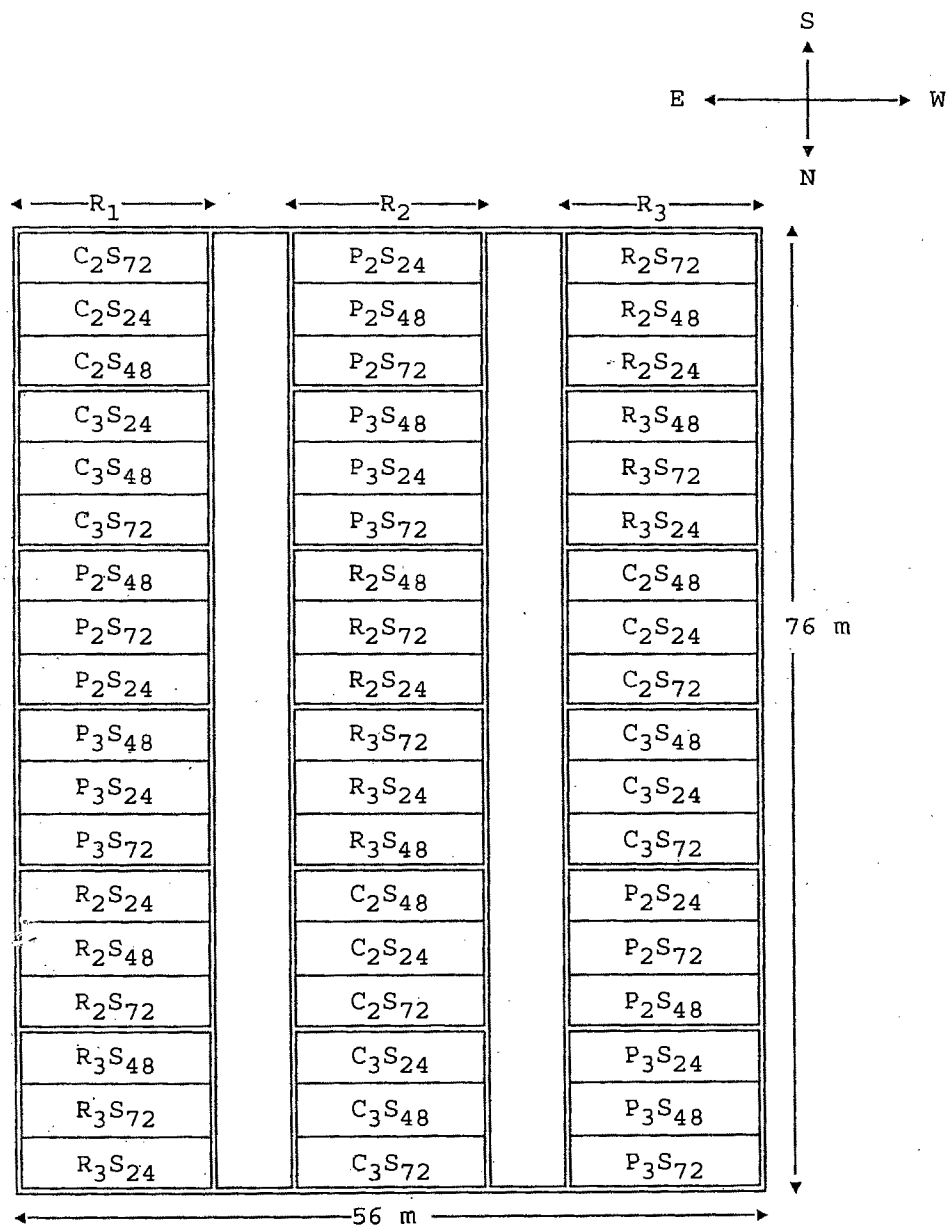
A. Independent variables:

1. Puddling equipment
2. Sedimentation period

B. Dependent variables :

1. Cone index
2. Sinkage resistance

C. Statistical design : Split plot with three replications

**Treatments:****Main Plot (Puddling Equipment)**

R₂ : Rotatry puddler two Passes
 R₃ : Rotatry puddler three Passes
 P₂ : Peg type puddler two Passes
 P₃ : Peg type puddler three Passes
 C₂ : Cultivator two Passes
 C₃ : Cultivator three Passes

Experimental Design:

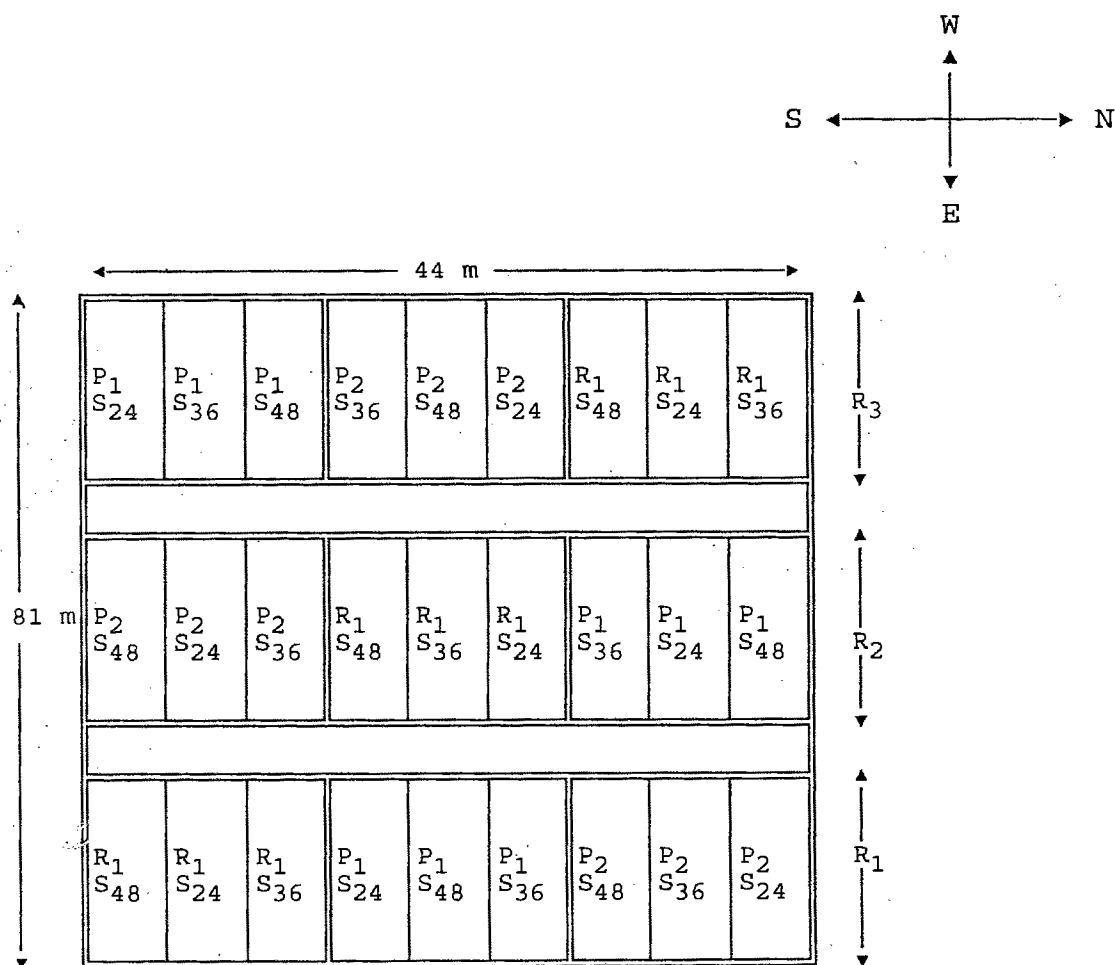
Split Plot

Replications : 3
 Main Plot Size : 15 m x 12 m
 Sub Plot Size : 15 m x 4 m
 Gross Plot Area : 4156 Sq. m.
 Net Plot Area : 3240 Sq. m.

Sub Plot (Sedimentation Period)

S₂₄ - 24 hrs
 S₄₈ - 48 hrs
 S₇₂ - 72 hrs

Fig. 3.1 Layout of field experiment (1998)



Treatments:

Main Plot (Puddling Equipment)

P₁ : Peg type puddler One Pass

P₂ : Peg type puddler two Passes

R₁ : Rotary puddler one Pass

Sub Plot (Sedimentation Period)

S₂₄ - 24 hrs Sedimentation

S₃₆ - 36 hrs Sedimentation

S₄₈ - 48 hrs Sedimentation

Experimental Design: Split Plot

Replications : 3

Main Plot Size : 25 m x 14 m

Sub Plot Size : 25 m x 4 m

Gross Plot Area : 3564 Sq. m.

Net Plot Area : 3150 Sq. m.

Fig. 3.2 Layout of field experiment (1999)

Investigation No. 3 : Studies on drag force of transplanter at different sedimentation period of puddled soil and water level.

A. Independent variables :

1. Sedimentation period : 24, 48 and 72 hours
2. Water level : <1, 1-2 and 2-4 cm

B. Dependent variable : Drag force

C. Statistical design : Two-factor CRD

Investigation No. 4 : Studies on effect of puddling on performance of self-propelled transplanter in rice crop

A. Independent variables:

1. Puddling equipment
2. Sedimentation period

B. Dependent variables :

1. Puddling parameters
 - i) Depth of puddling
 - ii) Depth of hardpan
2. Transplanter parameters
 - i) Sinkage of float and traction wheel
 - ii) Wheel slip
3. Transplanting parameters
 - i) Depth of transplanting
 - ii) Hill spacing
 - iii) Deviation in row spacing
 - iv) Buried and floating hills
 - v) Mechanical damage to seedling
 - vi) Hill mortality
 - vii) Hill population
 - viii) Missing hills
 - ix) Number of seedlings per hill
4. Crop performance
 - i) Root dry weight
 - ii) Yield attributes
 - a) Number of panicles per hill
 - b) Number of panicles per sq.-m

- c) Panicle length
- d) Grains per panicle
- e) Per cent unfilled grains per panicle
- f) Plant height
- iii) Yield
 - a) Grain yield
 - b) Straw yield
- iv) Harvest index

5. Statistical design : Split plot with three replications

Investigation No. 5 : Field performance evaluation of the transplanter in big plot and its comparison with manual transplanting

A. Independent variables:

- 1. Machine transplanting
- 2. Manual transplanting
 - i) Line transplanting
 - ii) Random transplanting

B. Dependent variables :

- i) Field capacity
- ii) Field efficiency
- iii) Fuel consumption
- iv) Crop performance
- v) Cost of mechanical and manual transplanting
- vi) Break even point in term of area covered by the transplanter
- vii) Payback period of the transplanter

3.6.3 Experimental procedures

3.6.3.1 Nursery raising

Mat type nursery was raised on a field adjacent to the experimental plot in order to minimize the transportation period of nursery. The field was harrowed twice by a tractor drawn offset harrow and levelled by planking. Polythene sheet of 50 to 60 gauge was spread over the levelled field. Iron



(a) Laying out of seedling mat



(b) Nursery bed after seedling emergence

Plate : 3.2 Nursery raising (a) Laying out of seedling mat and (b) Nursery bed after seedling emergence



frames of size 198.5 x 55 x 2.5 cm having eight compartments (50 x 22 x 2.5 cm) were placed on the polythene sheet. Thereafter, well pulverised soil was filled uniformly in all compartments and gently compacted upto a thickness of 2 cm. Water was sprinkled over it by a hand sprayer and was allowed to soak for sometime. Sprouted seeds (Variety : Govind) was spread uniformly over the mat at the rate of 100-110 g per mat. The seeds were covered with a thin layer of (2-4 mm) of soil. Thereafter frames were removed for further use in mat raising (Plate 3.2). To protect the seeds from bird damage the mats were covered by straw. Water was applied by a hand sprayer thrice in a day till there was complete emergence of seedling. After 4th day the straw was removed and water was applied by flooding so as to keep the mat soil wet throughout its growth period.

3.6.3.2 Field preparation and transplanting

After harvest of wheat one summer ploughing was done by a tractor drawn vertical disc plough in the experimental field. Subsequently, it was harrowed twice and was levelled by a scraper. Before puddling, water was flooded to about 10 cm for 24 hours. Puddling was done by different puddling equipment with a 47 hp (35 kW) Ford tractor model 3610. Transplanting was done by the Chinese make self-propelled transplanter (Plates 3.3 and 3.4) at different sedimentation period considered for the experiments. Hill to hill spacing was set at 12 cm for the experiment in the



Plate 3.3 Rice Transplanter in operation



Plate 3.4 A view of Transplanted rice field

year 1998. But in the subsequent year (1999), transplanting was done at 10 cm hill to hill spacing.

3.6.3.3 Fertilizer application and plant protection

Nitrogen, phosphorous and potassium were applied at the rate of 120, 60 and 40 kg per hectare. Half of nitrogen and full doses of phosphorous and potassium ~~are~~ were applied as basal dose after puddling. Zinc sulphate at the rate of 20 kg/ha was also applied in the plot. Remaining half dose of nitrogen was applied in two equal splits – first at tillering and second at panicle initiation stage. Organophosphatic insecticide, themate 10 G, was applied at the rate of 20 kg per hectare after 50 days of transplanting to control stem borer and leaf folder.

3.6.3.4 Water management

After transplanting 4-5 cm water was maintained. Thereafter, irrigation was applied at 7 days interval to all the treatments depending upon the rainfall.

3.6.3.5 Weed control

Two weedings were done manually at 30 and 60 days after transplanting.

3.6.3.6 Harvesting and threshing

Harvesting was done manually with the help of a sickle when grains were matured. One square meter area was harvested by using a 1mx1m iron

frame from each treatment and tied into bundles with proper tagging. Threshing was done by a powered plot thresher.

3.7 Seedling Characteristics

Seedling characteristics like density (number per sq.-cm), height (cm), leaf stage (number of leaves), root length (cm) and base thickness (cm) of the seedling were determined as per RNAM test code. Standard oven dry method was used to determine the moisture content of mat on dry basis. Since, it was difficult to maintain a particular mat moisture throughout an experiment, therefore, moisture ranges 10-15, 20-25 and 30-35 per cent were considered. Mat soil was collected at different times for a particular experiment for laboratory study to determine the mat moisture content. Wetting and drying period of seedling mat to obtain the above moisture ranges were fixed by preliminary study.

3.8 Laboratory Experiment

Two laboratory investigations were conducted in the year 1998 to study the influence of mat type seedling parameters on transplanting performance in terms of number of seedling per hill, missing hills and mechanically damaged hills (Plate 3.5) and the effect of puddling on seedling withdrawal force. Seedling withdrawal force in puddled soil was measured with sample collected from different treatments by using Instron Universal Testing Machine (Plate 3.6). The details about the experimental

variables and statistical design of the laboratory investigations are given below.

- Investigation No. 1** Studies on influence of seedling mat parameters on transplanting performance
- A. Independent variables:**
1. Age of seedling : 20, 25, 30 days
 2. Seed rate of mat : 70,90,110 g mat⁻¹
 3. Mat moisture content : 10-15, 20-25, 30-35 per cent
 4. Operating speed of transplanter : 1.38 and 1.88 km hr⁻¹
- B. Dependent variables :**
1. Number of seedling per hill
 2. Missing hills
 3. Mechanical damage to seedlings
- C. Statistical design :** Four factor CRD with two replications.
- Investigation No. 2 :** Studies on seedling withdrawal force at different sedimentation period and depth of transplanting
- A. Independent variables :**
1. Puddling equipment :
 - a) i) Rotary blade puddler
 - ii) Peg type puddler
 - iii) Cultivator
 - b) Level of puddling : Two and three passes
 2. Sedimentation period : 24, 48 and 72 hours
 3. Depth of transplanting 3, 5 and 7 cm
- B. Dependent variables :** Seedling withdrawal force
- C. Statistical Design :** Three factor CRD with two replications



Plate 3.5 Laboratory study of seedling parameters affecting transplanter performance



Plate 3.6 Measurement of seedling withdrawal force by using Instron Universal Testing Machine

3.9 Measurement Techniques

3.9.1 Depth of puddling

The effective depth of puddling was determined by penetrometer as suggested by **Taneja and Patnaik (1962)**. For this purpose, a 5x5 sq.-cm plate was attached to the base of the cone penetrometer by removing the cone. The dial gauge deflection was recorded by applying 9 kg load on the penetrometer. The penetrometer was pushed into puddled soil at a steady rate after puddling till the dial gauge deflection reached the deflection recorded earlier at 9 kg load and the corresponding depth was noted to represent the depth of puddling. Ten observations were taken for each treatment.

3.9.2 Puddling index

Soil water suspension samples were collected during last lap of puddling from different spots behind the puddling equipment with the help of 1.25 cm diameter steel pipe. Samples were taken from each treatment by closing the upper end of the pipe with thumb and collecting in a measuring cylinder till the volume reached 500 ml. The soil water suspensions were allowed to settle for 48 hours and the volume of soil settled was recorded. Puddling index was determined by the following relationship (**Baboo, 1976**)

$$\text{Puddling index (PI)} = (V_s/V) \times 100 \quad \dots(3.1)$$

Where,

V_s = Volume of soil

V = Total volume of the sample

3.9.3 Water level

In order to measure the water level in the puddled experimental plot a 5x5 cm steel plate was attached to a scale at the base. The steel scale was gently dipped into the water till it rests on the soil surface and water level was measured. Ten observations were recorded for each treatment.

3.9.4 Physical and dynamic properties

3.9.4.1 Bulk density (d.b.)

Soil samples for bulk density (d.b.) determination were collected with the help of a 10 cm diameter and 12 cm length core sampler. The core sampler was rammed into the soil by a hammer and dug out by a spade. Excess soil from the bottom of the core was trimmed. Standard oven dry method was followed to determine the moisture content of the soil sample and bulk density was calculated on dry basis using the following formula (Black, 1971) :

$$\text{Bulk density (Mg m}^{-3}\text{)} = \frac{\text{Dry weight of soil, Mg}}{\text{Total volume of soil, m}^3} \quad \dots(3.2)$$

Bulk density (d.b) was determined at two stages of crop growth (30 and 60 days after puddling).

3.9.4.2 Saturated hydraulic conductivity

Saturated hydraulic conductivity was determined using a falling head permeameter as suggested by Bhole (1963) and Rane and Varade (1972). The instrument consisted of a glass tube of 75 cm length and 1.25 cm

diameter. These were fixed to a depth of 10 cm from surface of the soil just after transplanting. The permeameters were filled with water upto a certain level, h_1 , which was kept constant for all treatments. Evaporation loss from the permeameters was checked by adding 3-4 drops of mobile oil. To prevent rain water entering the permeameter, the top was covered with a polythene sheet. Observations were recorded at 24 hours interval and the height of water column, h_2 , was noted. Saturated hydraulic conductivity was determined using the following formula (Bhole and Arya, 1964) :

$$K = (aL/At) 2.302 \log h_1/h_2 \quad \dots(3.3)$$

Where,

K = Saturated hydraulic conductivity, mm hr^{-1}

a = Cross-sectional area of the pipe, mm^2

L = Length of soil column, mm

A = Cross-sectional area of the soil column, mm^2

t = Elapsed time during which the head falls from h_1 to h_2 , hr

h_1 = Head of water column at the beginning, mm

h_2 = Head of water column after time 't', mm

Saturated hydraulic conductivity was measured at 30 and 60 days after puddling.

3.9.4.3 Cone index

To determine cone index, a cone penetrometer (model BL, 250 EC, Baker Mercer type C10, LC = 0.002 mm), having 2.618 cm diameter of cone

base with cone angle of 20° , was used. Cone penetrometer was calibrated with known weights and the relationship between applied load and dial gauge deflection was established (Fig. 3.3). Since, puddled soil was having low strength the cone penetrometer tends to sink without showing any deflection. That is why the weight of cone penetrometer (3485 g) per unit area of cone base was also taken into account while determining the cone penetrometer resistance (**Bhadoria, 1995**). The cone penetrometer resistance (CPR) per unit area (sq.-cm) was determined by the following relationship :

$$CPR, kg\ cm^{-2} = 0.648 + 0.025X \quad \dots(3.4)$$

Where,

X = dial gauge deflection, small divisions

The average cone penetrometer resistance over a depth range (0-15 cm) has been termed as cone index (**ASAE Standard, 313.2, 1995**). The calculated value of CPR and CI was multiplied by a constant factor 98.067 to get CPR and CI in kPa (**ASAE Standards, EP 285-7, 1995**).

Cone penetrometer readings at different depths were taken randomly from five different places in each treatment at an increment of 2.5 cm and converted into CPR by the above formula. Cone index values were determined by taking the average of CPR values at different depths (0-15 cm).

3.9.4.4 Sinkage resistance

To measure sinkage resistance of puddled soil plate sinkage method was adopted as proposed by **Gangil, 1993**. A mild steel plate of dimension 12 x 28.32 x 0.4 cm to simulate the size of the float (77 x 182 x 1 cm) in the length scale of 2.36 was used to develop a penetrometer device to measure sinkage resistance of puddled soil. The m.s. plate was fixed to a 1.25 cm diameter graduated rod at one end. The other end was connected to a dial gauge type proving ring used in cone penetrometer. The sinkage device (Plate 3.6) was calibrated with known weights to convert the dial gauge deflection into applied load (Fig. 3.4). Since, the weight of the instrument also applies a force on the puddled soil besides the applied force, therefore, weight per unit area of the penetrometer base (10.84 g cm^{-2}) was taken into account to determine the sinkage resistance. The penetrometer was slowly pushed into the puddled soil and the dial gauge deflection was recorded corresponding to the depth of penetration. The sinkage resistance at a particular depth was determined from the dial gauge deflection by the following formula :

$$M = 10.84 + 0.42 N \quad \dots(3.5)$$

Where,

M = Sinkage resistance, g cm^{-2}

N = Dial gauge deflection, small divisions

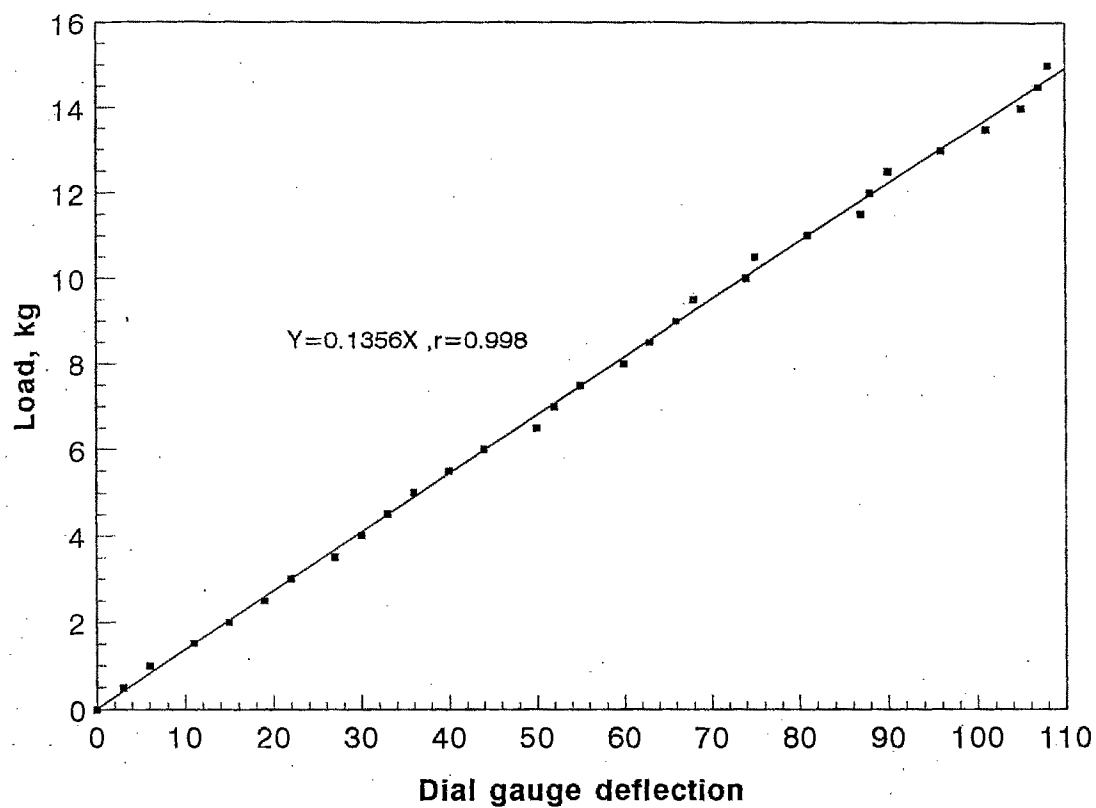


Fig 3.3 Calibration of cone penetrometer

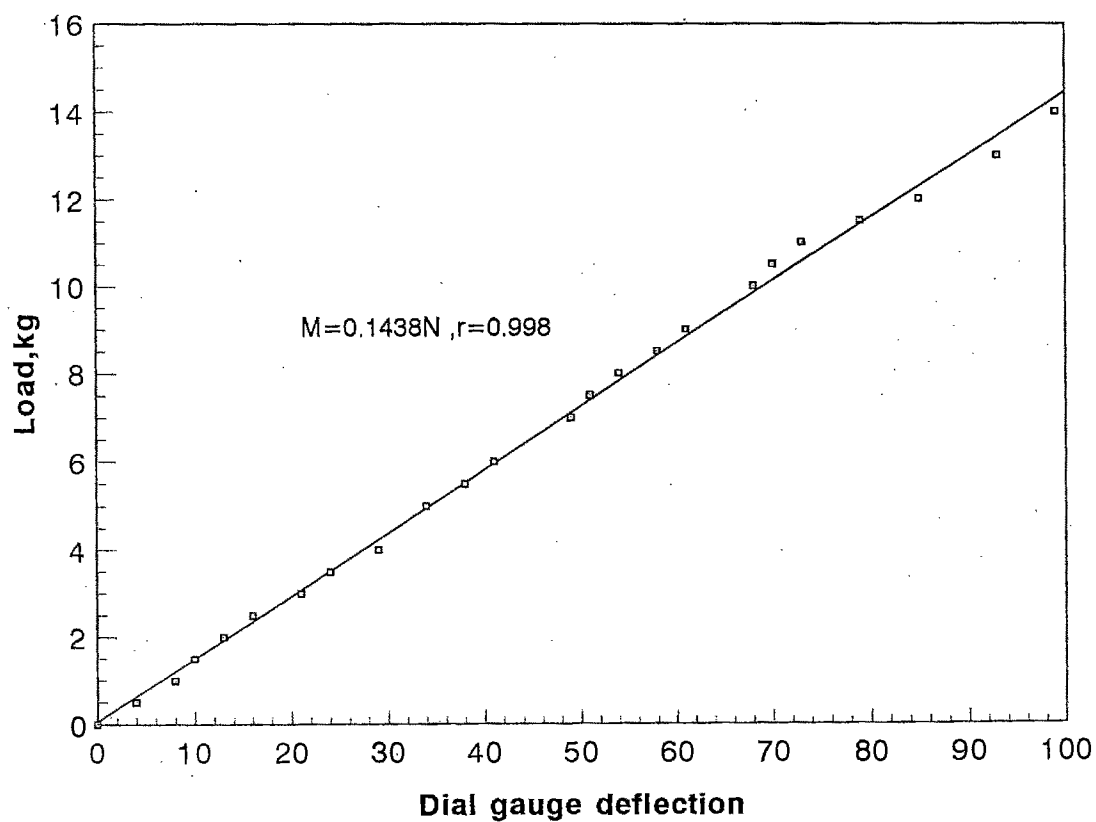


Fig 3.4 Calibration of penetrometer for sinkage resistance measurement



Plate 3.7 Penetrometer device to measure sinkage resistance of puddled soil

Sinkage resistance was measured in five randomly selected spots from each treatment upto a depth of 6 cm with an increment of 1 cm. The average of five observations was taken as representative sinkage resistance at a particular depth. Depth versus sinkage resistance relationship was established to predict the sinkage of float under different load conditions. The observed sinkage was compared with predicted sinkage.

3.9.4.5 Hardpan depth and its hardness

The hardpan depth and its hardness were determined with the help of the cone penetrometer used for determining cone index. The penetrometer was gradually pushed into the soil till there was no further penetration. The corresponding depth and dial gauge readings were recorded. The dial gauge reading was converted to cone penetrometer resistance (CPR) by using the Eq. (3.5). The depth represents the hardpan depth and the corresponding CPR represents the hardness. Ten observations were recorded randomly from each main plot treatment after puddling and the average of the observations was considered as representative value of hardpan depth and its resistance.

3.9.5 Measurement of transplanting parameters

3.9.5.1 Wheel slip

The transplanter was run on a grassy land and the distance covered by the traction wheel in 10 revolutions was measured. During field operation,

the distance covered in the aforesaid revolution was noted. Wheel slip was calculated by the following formula (Mehta *et al.*, 1995) :

$$\text{Wheel slip (\%)} = [(D_1 - D_2) / D_1] \times 100 \quad \dots(3.6)$$

Where,

D_1 = Distance travelled by traction wheel in 10 revolutions on a grassy land

D_2 = Distance travelled by the traction wheel in 10 revolution on puddled soil

3.9.5.2 Depth of transplanting

Just after transplanting, the seedling was uprooted holding it close to the soil surface. The distance from that point to the tip of the root was measured to determine the depth of transplanting. Twenty random observations were taken from each treatment and their mean was calculated to represent depth of transplanting.

3.9.5.3 Sinkage of float and traction wheel

Sinkage of float was measured by subtracting the preset depth of transplanting (3 cm) from the observed depth of transplanting of seedling. The depth of transplanting was set by adjusting the turning rod of the machine. Clockwise turning results in shallower depth and counter clockwise results in deeper depth. Distance between top of the tail piece to the tip of the transplanting finger at its lowest position is the set depth of transplanting. The traction wheel was graduated to measure its sinkage into puddled soil.

3.9.5.4 Buried and floating hill

Hills which are completely buried under soil after transplanting are called buried hill (Mori, 1975). Floating hills are those hills where all seedlings in a hill are either floating on the surface or just placed on the surface of the mud (Singh *et al.*, 1985).

Buried hills and floating hills were counted in a square meter area after transplanting. Five observations were taken for each treatment. Percentage floating and buried hill were calculated by the following formulae :

$$\text{Buried hill, \%} = \frac{\text{No. of buried hill per sq.-m}}{\text{Total no. of hill per sq.-m}} \times 100 \quad \dots(3.7)$$

$$\text{Floating hill, \%} = \frac{\text{No. of floating hill per sq.-m}}{\text{Total no. of hill per sq.-m}} \times 100 \quad \dots(3.8)$$

3.9.5.5 Hill mortality

One square-meter area was marked after transplanting and the number of hills transplanted were counted. After 15th day of transplanting, the number of hills surviving were counted. Hill mortality was determined by the following formula (Garg *et al.*, 1997) :

$$\text{Hill mortality, \%} = 1 - \frac{\text{No. of hills survived at 15 DAT per sq.-m}}{\text{Total no. of hill transplanted per sq.-m}} \times 100 \quad \dots(3.9)$$

3.9.5.6 Missing hill

Number of missing hills was counted along with total number of hills in a meter sq.-area. Percentage missing hill was calculated by using the following relationship :

$$\text{Missing hill, \%} = \frac{\text{No. of missing hills per sq.-m}}{\text{Total no. of hills per sq.-m}} \times 100 \quad \dots(3.10)$$

Five observations were taken at randomly selected spot in each.

3.9.5.7 Mechanical damage

Hills, with all seedlings damaged either by injury to stems or roots, are considered mechanically damaged hill (Singh *et al.*, 1985). Number of damaged hills was counted from a sq.-m area randomly selected and the damaged hill percentage was determined as follows :

$$\text{Mechanical damage, \%} = \frac{\text{No. of hills damaged per sq.-m}}{\text{Total no. of hills per sq.-m}} \times 100 \quad \dots(3.11)$$

Five observations were taken for each treatment

3.9.5.8 Hill spacing

Hill to hill spacing was measured by a steel scale of 30 cm length after transplanting. Twenty randomly selected observations were taken and the mean was determined to represent hill spacing.

3.9.5.9 Deviation in row spacing from the fixed spacing

The row spacing, after transplanting was measured and its deviation from the fixed row spacing was expressed in percentage. Twenty observations were taken for each treatment.

3.10 Drag Force

Drag force was measured by a hydraulic dynamometer of 1000 kg capacity with least count of 10 kg. The dynamometer was attached to the transplanter at one end by a chain and the other to the tractor drawbar by a rope. The height of the drawbar was adjusted so that the dynamometer and rope remained parallel to the ground. The tractor (35 kW, Mahindra 585) was used to pull the transplanter on a dry field in low second gear at a prefixed accelerator setting so as to maintain the operating speed of transplanter at about 1.5 km hr^{-1} . The drag force was measured at a steady deflection of the dynamometer.

3.11 Seedling Withdrawal Force

Seedling withdrawal force was measured in the puddled soil collected from the field with the help of 12 cm diameter and 15 cm length cylinder. The cylinder containing puddled soil was lifted out of the field by keeping a mild steel plate at the bottom. The plate was released over a tin container of 12 cm diameter and 15 cm length so that it poured into the container. The collected soil sample was kept in the laboratory for settlement. Preliminary studies on dimension of seedling cut by the transplanter finger revealed that

the base of the mat resembled a right circular cone. The dimension and weight of seedling was measured from 50 samples and the mean was taken as the representative dimension and weight of the seedling. Accordingly, a right circular cone, made of wood with base diameter 1.2 cm, top diameter 0.75 cm and height 2.0 cm, was made. A 2 mm metal rod was pierced into the wooden cone at the centre. The weight was kept 6.4 g as found by the mean weight of the seedlings. The artificial seedling was used for measuring the seedling withdrawal. The artificial seedling was fixed to the jaws of the Instron Universal Testing Machine (Plate 3.6) and inserted into puddled soil to different depths of 3.0, 5.0 and 7.0 cm at a penetration speed of 100 cm per minute. After two seconds, the seedling was pulled at a speed of 0.21 cm s^{-1} and the peak withdrawal force was read out on the computer screen (Khan and Gunkel, 1989).

3.12 Biometrics Observations

3.12.1 Root growth

After 60 days of transplanting, two plants from a particular row (4th row from the left) were randomly selected from each treatment and cut at the base. The root samples were taken with the help of a core sampler (10 cm diameter x 15 cm length). The core was rammed into the soil to a depth of 15 cm and later pulled out by excavating the soil around it. The collected samples were first dipped into a tank and then the root washing was done with the help of a foot sprayer on a wire mesh. Root dry weight

was determined after drying the washed roots in an oven at $60 \pm 5^\circ\text{C}$ for about 12 hours.

3.12.2 Number of panicles per sq.-m

Number of panicles per hill was counted from 10 hills in each sq.-m area, already marked for taking observations and converted into panicles per sq.-m by multiplying with the number of hills per sq.-m. Five observations were taken to each treatment.

3.12.3 Panicle length

Randomly selected 5 panicles from each marked sq.-m area were taken to measure the length of the panicles. Five observations were taken for each treatment.

3.12.4 Grains per panicle and unfilled grain

Grains are collected from 10 randomly selected panicles from earlier collected samples for panicle length determination. Filled and unfilled grains were separated. The filled grains were counted to determine the number of grains per panicle.

Unfilled grains were also counted and expressed in percentage by the following formula :

$$\text{Unfilled grain, \%} = \frac{\text{Number of unfilled grain}}{\text{Number of filled + Unfilled grain}} \times 100$$

...(3.12)

3.12.5 Plant height

Plant height was measured with the help of a meter scale from the base to the top of the plant. Twenty observations for each treatment were taken and the mean was determined to represent plant height. Plant height was recorded at the time of harvest.

3.12.6 Grain and straw yield

Grain and straw yield was determined from one sq.-m area. Ten observations were taken from each treatment. Thoroughly sundried harvested produce was weighed for total biological weight. A plot thresher was used for threshing the produce and grain yield was recorded. The moisture content of grain was determined by oven dry method and later yield was calculated at 14 per cent moisture content. By subtracting the grain yield from the biological yield, the straw yield was worked out for each treatment.

3.12.7 Harvest index

The harvest index was calculated by using the following relationship :

$$\text{Harvest index, \%} = \frac{\text{Grain yield, t/ha}}{\text{Biological yield, t/ha}} \times 100 \quad \dots(3.13)$$

3.13 Field Performance of Transplanter

The field performance of the transplanter in terms of effective field capacity, field efficiency, field machine index and fuel consumption, was evaluated in a plot of size 80x25 sq.-m with two replications.

3.13.1 Effective field capacity

It is the actual rate of coverage of area by a machine. Effective field capacity was determined by using the following relationship (Singh *et al.*, 1983) :

$$EFC = A / T \quad \dots(3.14)$$

Where,

EFC = Effective field capacity, ha hr⁻¹

A = Area covered, ha

T = Time taken, hr

Time 'T' includes time lost in turning, loading and adjustment of machine.

3.13.2 Field efficiency

Field efficiency was calculated by the formula given below.

$$\text{Field efficiency, \%} = \frac{\text{Effective field capacity, ha hr}^{-1}}{\text{Theoretical field capacity, ha hr}^{-1}} \times 100 \quad \dots(3.15)$$

3.13.3 Field machine index

It indicates the influence of field geometry on working capacity of a machine. Field machine index was worked out by the following formula (Renoll, 1970) :

$$FMI, \% = T_p / (T_p + T_d) \times 100 \quad \dots(3.16)$$

Where,

FMI = Field machine index;

T_p = Total productive time, min.;

T_t = Turning time loss, min.

3.13.4 Fuel consumption

Fuel consumption was determined by tank refilling method. Fuel tank of the engine was topped up just before starting the transplanting operation. After transplanting a certain area, the transplanter was kept on a level ground. Diesel was filled with the help of a measuring cylinder upto the same level. The quantity of diesel filled and time of transplanting were recorded to determine the fuel consumption per hr. Fuel consumption in liter per hectare was also calculated.

3.14 Economics

3.14.1 Cost of operation

Cost of operation of transplanter is normally calculated on hourly basis and subsequently converted into cost per hectare taking into account the field capacity. The details of the cost of operation have been presented in Table A.8.

3.14.2 Break even point

Break even point of the transplanter is expressed in term of area that should be transplanted by the transplanter annually so that the cost of

transplanting per hectare equals to that of manual transplanting. It was calculated from the following relationship (Manian *et al.*, 1987) :

$$\text{Breakeven point, ha} = \frac{\text{Annual fixed cost}}{\text{Cost of manual transplanting } h\bar{x}^{-1} - \text{Variable cost } h\bar{x}^{-1}} \quad \dots(3.17)$$

3.14.3 Payback period

Pay back period is the time needed to recoup the money invested at different levels of annual usage. The following formula was used to determine the payback period (Manian *et al.*, 1987) :

$$\text{Pay back period, years} = \frac{\text{Total investment}}{\text{Total annual cost of manual transplanting} - \text{Total annual cost of machine transplanting}} \quad \dots(3.18)$$

3.15 Statistical Analysis

The experimental data obtained were analysed statistically using analysis of variance (ANOVA) technique appropriate to different experimental designs followed during the investigations (Nigam and Gupta, 1979). The overall significance of treatment was tested by 'F' test. The treatments were compared pair-wise with the help of critical difference (CD) at 5 per cent level of probability wherever F-test was significant. Correlation studies (Panse and Sukhatme, 1985) were also performed to study the interrelationship between various parameters.

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Field experiment was conducted on silty clay loam soil in the year 1998 with three puddling equipment (Rotary puddler, peg type puddler and cultivator) and two levels of puddling (two and three passes) to study the effect of puddling on soil characteristics and performance of self-propelled rice transplanter under different sedimentation period. Effect of puddling on yield attributing characters and yield of rice was also studied. On the basis of the findings of the experiment in 1998, cultivator was dropped as a treatment and another experiment was carried out with peg type puddler (one and two passes) and rotary puddler (one pass) with a view to reduce the time gap between puddling and transplanting. Two laboratory studies *viz.* seedling characteristics affecting transplanting performance and seedling withdrawal force in puddled soil at various depth were also undertaken.

The results of the different experiments obtained during the course of investigations are presented and discussed in this chapter.

4.1 Effect of Puddling on Physical Properties of Soil

Physical properties like puddling index, bulk density (d.b.) and hydraulic conductivity were determined and discussed in this section.

4.1.1 Puddling index

The puddling index data under different treatments are shown in Table 4.1. It is evident from the table that puddling index increased

significantly with level of puddling, irrespective of puddling equipment. Increase of puddling index from 36.27 to 43.15, 27.93 to 38.33 and 15.20 to 26.33 per cent was observed for rotary puddler, peg type puddler and cultivator respectively when level of puddling increased from two to three passes in the year 1998. It was also clear from the data that puddling index was more in case of rotary puddler compared to that of others at each level of puddling. Maximum puddling index of 43.15 per cent was recorded in case of treatment R_3 which was significantly higher than that of other treatments. There was no significant difference of puddling index between treatments R_2 and P_3 and P_2 and C_3 respectively which shows that peg type puddler and cultivator require three passes each to obtain a similar state of puddling as that of R_2 and P_2 respectively. Treatment C_2 had the lowest puddling index of 15.20 per cent indicating poor quality of puddling.

In the second experiment during 1999, it was observed that puddling index of treatment P_2 (30.13%) was significantly higher than that of P_1 (19.40%) and R_1 (24.60%). Comparing the treatment P_2 between 1998 and 1999 experiments, it was found that puddling index was higher in 1999 compared to 1998.

Increase of puddling index due to increase in level of puddling is due to more soil manipulation by the implement which is in agreement with the results reported by Tewari (1989) and Salokhe *et al.* (1993). During puddling, soil undergoes two types of deformations : first, due to normal

stress which is associated with compression and second, because of tangential stress causing shear. Compression is most effective below upper plastic limit whereas shear effect dominates above it. Since, puddling is done under saturated condition of soil, it is shear stress which causes dispersion of soil particles in water. Rotary puddler due to rotary motion of its blades matches the weakest fracture plane of soil mass disintegrating it into fine particles (Sharma and De Datta, 1985). This is the reason for higher puddling index in case of rotary puddler. Besides that, the angular orientation of blade (30°) in rotary puddler creates a cycloid action of the blade on the soil thereby increases the churning of soil and water mixture which enhances the puddling index (Tewari, 1984). Low puddling index in case of peg type puddler and cultivator may be due to combing action of the soil working elements of the puddling equipment. Higher puddling index in case of peg type puddler compared to cultivator at a same puddling level may be because of close spacing of pegs. Puddling index for P_2 in the year 1999 was found more compared to that of 1998. It may be because of weed free and well prepared initial field condition.

4.1.2 Bulk density (d.b)

Bulk density of puddled soil was determined at 30 and 60 days after puddling (DAP) in both experiments. The details of the results are presented in Table 4.1. Percentage increase of bulk density over unpuddled soil was maximum for treatment R_3 (13.10) followed by R_2 (8.59), P_3 (7.75),

P₂ (5.56), C₃ (3.73) and C₂ (1.83) respectively at 30 DAP. It was observed that bulk density of puddled soil was higher compared to that of unpuddled soil for all the treatments. Increasing the puddling level from two passes to three passes, the bulk density increased significantly in case of rotary puddler and non-significantly for peg type puddler and cultivator. Comparing the treatments individually, it was found that treatment R₃ had maximum bulk density of 1.606 Mg m⁻³ which was significantly higher than that of other treatments, whereas, treatments R₂ (1.542 Mg m⁻³) & P₃ (1.530 Mg m⁻³) and P₂ (1.499 Mg m⁻³) & C₃ (1.474 Mg m⁻³) are statistically at par. Lowest bulk density of 1.446 Mg m⁻³ was obtained in case of treatment C₂.

At 60 DAP, an increase in bulk density over 30 DAP was observed for all treatments and it followed a trend similar to that of 30 DAP except for C₂ and C₃. At 30 DAP, bulk density for C₂ (1.446 Mg m⁻³) and C₃ (1.474 Mg m⁻³) was statistically *at par* but it differed significantly at 60 DAP with values of 1.458 and 1.498 Mg m⁻³.

During the year 1999, highest bulk density was recorded for treatment P₂ followed by treatments R₁ and P₁ both at 30 and 60 DAP. However, there was no significant difference of bulk density among treatments both at 30 and 60 DAP (Table 4.1).

The soil aggregates break into finer particles due to puddling and these remain suspended in water. Thereafter, flocculation of particles takes

place and there is a stratified settlement of soil particles leading to destruction of macropores which creates a dense soil. At higher level of puddling, the dispersion of particles in water is more which on settling reduces the porosity thereby resulting in a more compact soil. This might be the reason for increase in bulk density of soil after puddling and further increase of bulk density at higher level of puddling for all the treatments (Table 4.1). Similar observations were made by **Bodman and Rubin (1948)**; **Varade and Ghildyal (1967)**; **Kandaurov and Patrin (1974)**; **Tewari (1984)**; **Sharma and De Datta (1985)** and **Rath (1999)**. From the above observations, it could be concluded that higher the dispersion of soil particles in water, higher is the bulk density. It has also been noticed that though there is significant increase of puddling index with level of puddling (2 to 3), the bulk density increased significantly only in case of rotary puddler. This might be due to higher puddling index in case of rotary puddler and lower in case of peg type puddler and cultivator which may not be contributing towards the destruction of macropores as in case of rotary puddler.

Bulk density increased with respect to time. This might be due to shrinkage of soil at lower moisture content. Average moisture content of soil at 30 DAP was 28.30 and 28.70 per cent in the years 1998 and 1999 respectively whereas it was 21.50 and 23.35 per cent at 60 DAP for the

above years. The findings corroborate with the results reported by Scheltema (1974); Bajpai (1994) and Rath (1999).

4.1.3 Hydraulic conductivity

Hydraulic conductivity was measured by falling head permeameter under field condition at 30 and 60 DAP. Data on hydraulic conductivity are given in Table 4.1. Perusal of data revealed that irrespective of puddling equipment used, hydraulic conductivity of soil decreased after puddling and the decrease was more pronounced for treatment R₃ (76.99%) at 30 DAP for the year 1998. Increasing the puddling level from two to three passes decreased the hydraulic conductivity from 0.234 to 0.191, 0.312 to 0.239 and 0.547 to 0.370 mm hr⁻¹ for rotary puddler, peg type puddler and cultivator respectively. The decrease of hydraulic conductivity with increase of level of puddling was found significant in case of peg type puddler and cultivator and non-significant for rotary puddler. Maximum hydraulic conductivity of 0.547 mm hr⁻¹ was observed in case of treatment C₂ which was significantly higher than that of all other treatments. It was further noticed that hydraulic conductivity for treatments R₂, R₃ and P₃ are statistically *at par*, but these differed significantly from treatments P₂ and C₃ which were statistically *at par*.

At 60 DAP, hydraulic conductivity was almost equal to that of 30 DAP indicating stabilization of hydraulic conductivity. Similar observations were reported by Awadhwai and Singh (1985b).

In the second experiment (1999), minimum hydraulic conductivity of 0.257 mm hr^{-1} was found in case of P_2 which was significantly lower than that of P_1 (0.315 mm hr^{-1}) but statistically *at par* with R_1 (0.270 mm hr^{-1}). At 60 DAP, there was no appreciable variation in hydraulic conductivity over that of 30 DAP.

The hydraulic conductivity depends upon the amount and size of coarse pores (transmission pores) in the soil. Considerable reduction of hydraulic conductivity of puddled soil over unpuddled was observed in case of all treatments under the study. This might be due to clogging of pore space channels on settling of soil particles after puddling. Clogging of these channels reduce the water transmission pores which results in decreasing hydraulic conductivity. Similar results were reported by **Bhole and Pandya (1962)**; **Naphade and Ghildyal (1971)**; **Rane and Varade (1972)**; **Tyagi *et al.* (1974)**; **Sharma and DeDatta (1985)** and **Sharma *et al.* (1991)**. At higher level of puddling, viscosity of puddled soil increases. Hence, water moves in a very slow rate which in turn enhances lodgment of finer particles. Lodgment favours a more closely packed soil medium which reduces hydraulic conductivity considerably (**Alva and Petersen, 1979**). This might be the reason for lower hydraulic conductivity in case of treatment R_3 where there was maximum dispersion of soil particles in water.

An empirical relationship was established between bulk density and hydraulic conductivity from the values obtained from different treatments

Table 4.1 Effect of puddling by using different equipment on physical properties of soil

**1st Experiment
(1998)**

Initial bulk density, Mg m^{-3} : 1.42

Initial hydraulic conductivity, mm hr^{-1} : 0.830

**Average moisture content of soil, % : 28.30 (30 DAP);
21.50 (60 DAP)**

Treatments (Puddling equipment)	Puddling index, %	Bulk density, Mg m^{-3}		Hydraulic conduc- tivity, mm hr^{-1}	
		30 DAP	60 DAP	30 DAP	60 DAP
Rotary puddler two passes (R_2)	36.27	1.542 (8.59)*	1.561 (9.93)	0.234 (71.80)	0.229 (72.41)
Rotary puddling three passes (R_3)	43.15	1.606 (13.10)	1.636 (15.21)	0.191 (76.99)	0.206 (75.18)
Peg type puddler two passes (P_2)	27.93	1.499 (5.56)	1.520 (7.04)	0.312 (62.41)	0.303 (63.19)
Peg type puddler three passes (P_3)	38.33	1.530 (7.75)	1.548 (9.01)	0.239 (71.20)	0.238 (71.33)
Cultivator two passes (C_2)	15.20	1.446 (1.83)	1.458 (2.68)	0.547 (34.10)	0.551 (33.61)
Cultivator three passes (C_3)	26.33	1.474 (3.73)	1.498 (5.49)	0.370 (55.42)	0.364 (56.14)
SEm $\pm$	0.686	0.013	0.010	0.021	0.014
CD _(0.05)	2.150	0.040	0.032	0.067	0.043

**2nd Experiment
(1999)**

Initial bulk density, Mg m^{-3} : 1.44

Initial hydraulic conductivity, mm hr^{-1} : 0.648

**Average moisture content of soil % : 28.70(30 DAP);
23.35(60 DAP)**

Treatments (Puddling equipment)	Puddling index, %	Bulk density, Mg m^{-3}		Hydraulic conduc- tivity, mm hr^{-1}	
		30 DAP	60 DAP	30 DAP	60 DAP
Peg type puddler one pass(P_1)	19.40	1.472 (2.22)	1.487 (3.26)	0.315 (51.39)	0.325 (49.85)
Peg type puddler two passes(P_2)	30.13	1.507 (4.65)	1.519 (5.49)	0.257 (60.34)	0.258 (60.19)
Rotary puddler one pass(R_1)	24.60	1.492 (3.61)	1.504 (4.44)	0.270 (58.33)	0.263 (59.41)
SEm $\pm$	0.513	0.008	0.010	0.010	0.003
CD _(0.05)	2.00	NS	NS	0.040	0.013

* Values in the parenthesis are percentage change

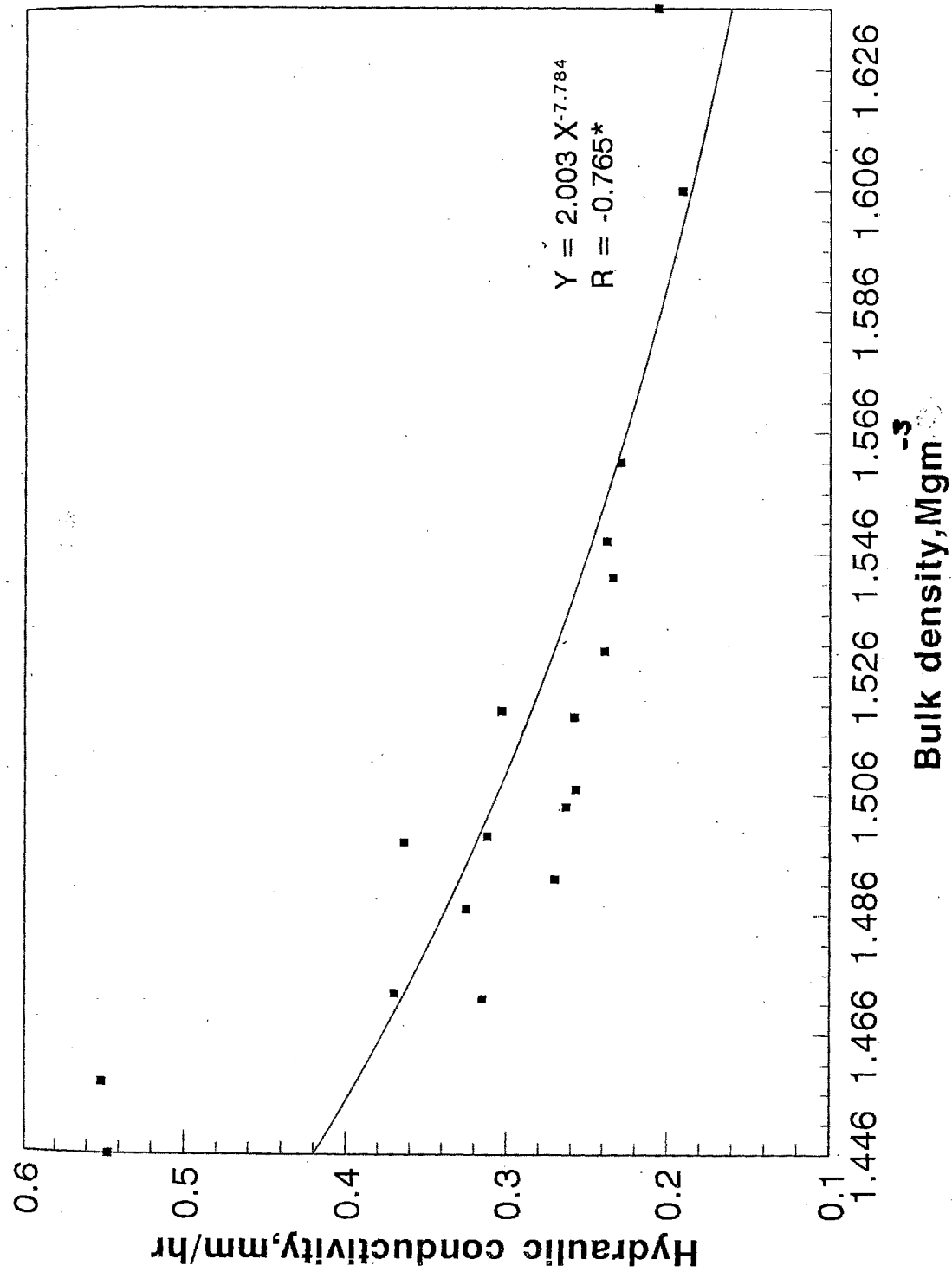


Fig. 4.1 Relationship between bulk density and hydraulic conductivity

(Fig. 4.1). It is clear from this figure that as bulk density increases hydraulic conductivity decreases but at higher bulk density the rate of decrease of hydraulic conductivity is low. This may be the reason due to which hydraulic conductivity of treatments R_2 , R_3 and P_3 were statistically *at par*. The correlation coefficient ($r=-0.765$) was found significant at 5 per cent level of significance.

4.2 Effect of Puddling on Dynamic Properties of Soil

4.2.1 Cone index

Cone penetrometer resistance (CPR) of puddled soil from 0 to 15 cm depth was measured at an increment of 2.5 cm in different levels of sedimentation period of 24, 48 and 72 hours and was presented in Tables A.3 and A.4. The average CPR of puddled soil for the depth range of 0-15 cm, termed as cone index, was shown in Table 4.2 and Figures 4.2 and 4.3. Cone index was measured to study the strength characteristics of puddled soil and its subsequent effect on transplanter performance.

It was observed that soil strength was reduced considerably after puddling to a depth of 10 cm for all treatments in both the experiments (Tables A.3 and A.4). As sedimentation period increased, the CPR increased at each depth and the increase was at a faster rate from 10 cm and onwards.

The data obtained on cone index at different sedimentation period revealed that it decreased after puddling and the decrease was more when

the level of puddling increased from 2 to 3 passes for all treatments (Figures 4.2 and 4.3). At a given level of puddling and sedimentation period lowest cone index was obtained in case of rotary puddler followed by peg type puddler and cultivator.

At 24 hrs of sedimentation period (S_{24}), maximum and minimum cone index were obtained in case of C_2 (248.82 kPa) and R_3 (109.34 kPa) respectively with a corresponding decrease of 40.97 and 74.06 per cent over that of saturated soil (unpuddled) in the first experiment. It was also noticed that at S_{24} , there was no significant difference of cone index between treatments R_2 & P_3 and P_2 & P_3 respectively. As sedimentation period increased, there was a significant increase in cone index for all treatments and similar trend as that of S_{24} was observed in case of S_{48} and S_{72} also. However, the increase of cone index was higher between 48 to 72 hrs of sedimentation for R_3 and between 24 to 48 hrs for C_2 , P_2 and C_3 respectively. But in case of R_2 and P_3 cone index increased uniformly for all sedimentation period. At S_{72} , cone index of C_2 was 410.41 kPa showing a firm soil condition whereas the cone index of R_3 was 241.35 kPa indicating a soft condition.

During the second experiment in the year 1999, it was observed that cone index of treatment P_2 was 211.78 kPa at S_{24} which was statistically *at par* with R_1 (234.39 kPa) but significantly lower than that of P_1 (254.85 kPa). Cone index increased with sedimentation period and behaved in a

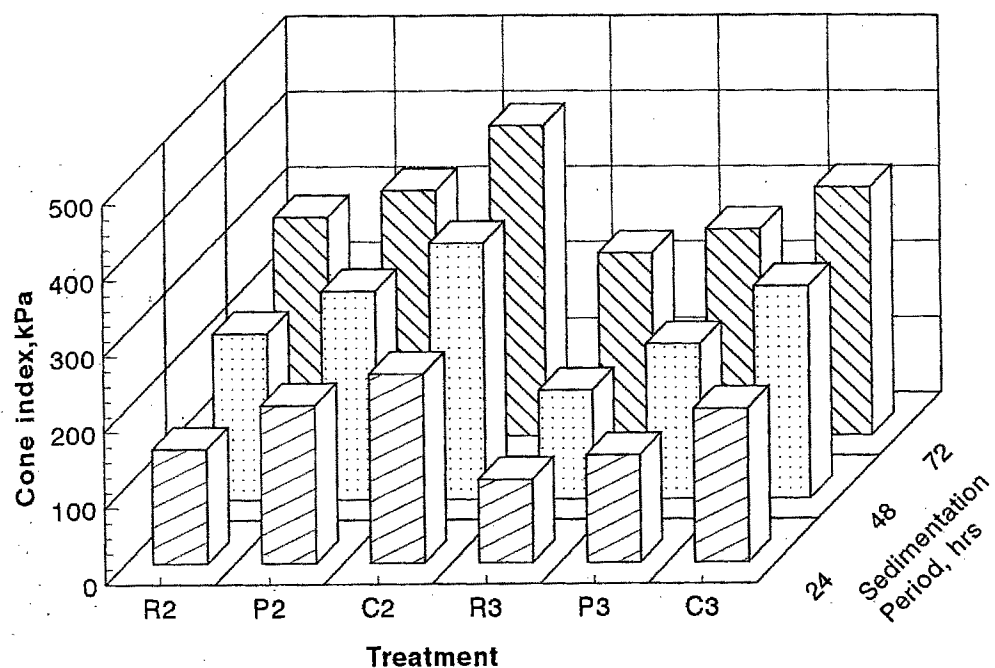


Fig. 4.2 Effect of puddling by using different equipment on cone index at three levels of sedimentation period (1998)

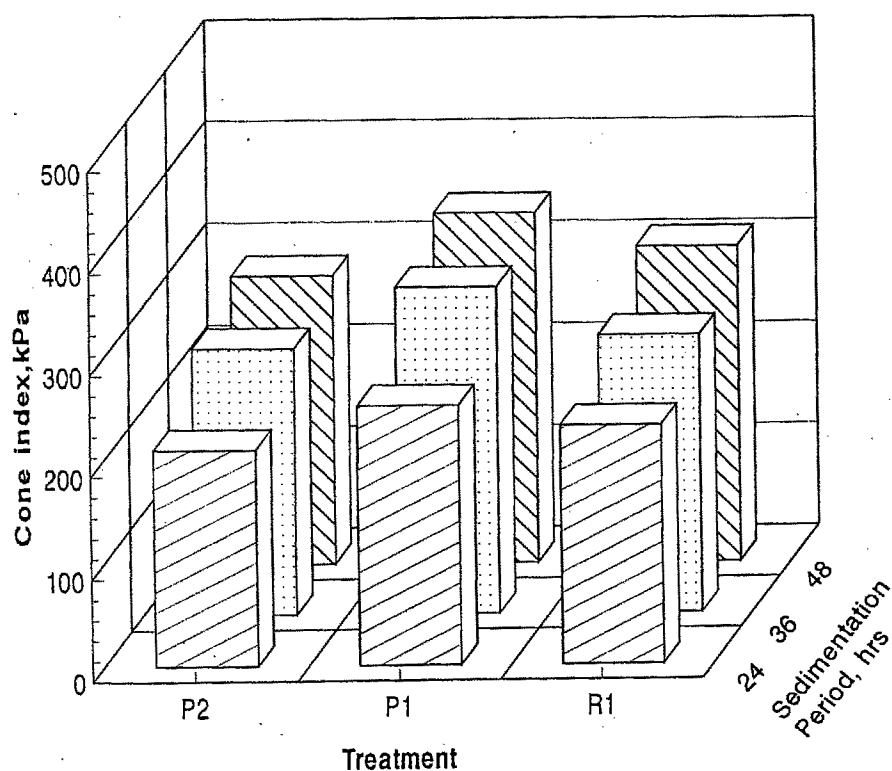


Fig. 4.3 Effect of puddling by using different equipment on cone index at three levels of sedimentation period (1999)

similar manner as that of S₂₄. However, the increase was more when sedimentation increased from 24 to 36 hours than 36 to 48 hrs.

The strength of soil is made up of two properties viz. (i) internal friction or resistance due to inter-locking of particles and (ii) cohesion or the resistance due to inter-particle forces which tends to hold the particles together in a soil mass. During the process of puddling, soil is thoroughly churned under flooded condition. Due to this, the internal friction becomes negligible and it depends solely on cohesion which is progressively reduced as puddling intensity is increased. Because of this, the cone index of puddled soil decreased considerably over that of saturated soil and it further decreased with level of puddling. These findings on cone index corroborate with that of **Salokhe *et al.* (1993)**. Decrease of cone index was comparatively higher in case of rotary puddler than peg type puddler and cultivator at a same level of puddling. This may be due to better puddling by rotary action of the blades whereas there was combing action in case of peg type puddler and cultivator which gives poor quality of puddling.

Increase of cone index with sedimentation period may be due to the fact that the dispersed soil particles settle with time and water level of field also recedes which results in a compact and firm medium they subsequently increases the strength of the soil. This phenomenon is called tixotropy (**Awadhwai and Singh, 1985**). Higher the level of puddling, slower will be the settlement of dispersed particles and hence, lower will be the cone index.

Table 4.2 Effect of puddling by using different equipment on cone index (0-15 cm) at three levels of sedimentation period

1st Experiment Initial cone index of saturated soil : 421.56 kPa
(1998)

Treatments (Puddling equipment)	Cone index, kPa			Mean
	Sedimentation period, hrs			
	24	48	72	
Rotary puddler two passes (R ₂)	150.27 (64.35)	219.55 (47.91)	289.96 (31.22)*	219.93
Rotary puddler three passes (R ₃)	109.34 (74.06)	143.66 (65.92)	241.35 (42.75)	164.78
Peg type puddler with two passes (P ₂)	207.56 (50.76)	275.20 (34.72)	324.76 (22.96)	269.17
Peg type puddler three passes (P ₃)	141.07 (66.54)	204.81 (51.42)	272.91 (35.26)	206.26
Cultivator with two passes (C ₂)	248.82 (40.97)	338.14 (19.79)	410.41 (2.64)	322.46
Cultivator with three passes (C ₃)	202.51 (51.96)	280.79 (33.39)	328.76 (22.00)	276.69
Mean	176.60	243.69	311.36	243.83
Factors	SEm±	CD _(0.05)		
Puddling equipment (a)	4.61	14.51		
Sedimentation period (b)	1.69	4.94		
Interaction (axb) 1.	4.14	12.10		
2.	5.71	17.54		

2nd Experiment Initial cone index of saturated soil : 393.35 kPa
(1999)

Treatments (Puddling equipment)	24	36	48	Mean
Peg type puddler one pass (P ₁)	254.85 (35.21)	320.39 (18.55)	342.48 (12.93)	305.91
Peg type puddler two passes (P ₂)	211.78 (46.16)	261.60 (33.49)	282.30 (28.23)	251.77
Rotary puddler one pass (R ₁)	234.39 (40.41)	272.74 (30.66)	308.95 (21.46)	274.89
Mean	233.69	287.62	311.24	277.52
Factors	SEm±	CD _(0.05)		
Puddling equipment (a)	7.00	27.38		
Sedimentation period (b)	2.70	8.31		
Interaction (axb) 1.	4.67	14.40		
2.	7.98	29.67		

Interaction (1) For comparing two sedimentation period for a same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period.

* Values in parenthesis shows percentage change in cone index over

This is the reason for low cone index in case of rotary puddler at higher sedimentation period compared to other puddling equipment. This observation is in agreement with **Khan and Gunkel (1989)**.

4.2.2 Sinkage resistance of puddled soil and its effect on float sinkage of transplanter

Sinkage resistance shows the load bearing capacity of puddled soil. Since, float sinkage of the transplanter takes place within the top layer of the puddled soil, therefore, sinkage resistance was measured from 1 to 6 cm depth with an increment of 1 cm at different sedimentation period and presented in Tables A.5 and A.6. Average values of sinkage resistance in the depth range of 1-6 cm have been determined to study the behaviour of the load bearing capacity of puddled soil (Table 4.3).

In the first experiment, it was observed that sinkage resistance decreased when puddling level increased for all the treatments. Minimum and maximum sinkage resistance of 17.67 and 37.20 g cm⁻² were found in case of treatments R₃ and C₂, respectively at 24 hrs of sedimentation (S₂₄). There was no significant difference of sinkage resistance between R₂ (20.56 g cm⁻²) and P₃ (19.16 g cm⁻²) and P₂ (32.91) and C₃ (30.79), respectively. However, the sinkage resistant in case of R₂, P₃ was significantly lower than that of P₂ and C₃. It is also clear from the table that sinkage resistance increases with sedimentation period. It was observed that the rate of increase was more from 48 to 72 hrs of sedimentation for

treatments R_2 , R_3 and P_3 whereas it was uniform in case of P_2 and C_3 for all sedimentation period. However, for C_2 the increase was at a faster rate between 24 to 48 hours.

In the second experiment, minimum sinkage resistance was obtained in case of P_2 (30.36 g cm^{-2}) at S_{24} which was significantly higher than that of P_1 (38.08 g cm^{-2}) but statistically *at par* with R_1 (32.51 g cm^{-2}). It followed a similar trend as that of the experiment carried out during 1998 but the rate of increase was faster between 24 to 36 hrs of sedimentation period for all the treatments. The interaction effect of puddling equipment and sedimentation period had significant effect on sinkage resistance for both the experiments.

The decrease of sinkage resistance with increase in level of puddling may be due to greater dispersion of lighter particles (silt and clay) taking more time to settle. The total silt plus clay fraction was estimated as 67.18 per cent in the soil of experimental field (Table 3.1). As the soil particles settle with time, the sinkage resistance increased. This is in agreement with Gangil (1993). Slower rate of increase of sinkage resistance from 24 to 48 hrs in case of R_2 , R_3 and P_3 may be attributed to slow settling of dispersed fine particles due to better puddling. Similar observations were reported for a silty-clay loam soil by Garg *et al.* (1999). Besides that, as mentioned in Chapter 4.1.3, there is an increase in viscosity of the puddled soil due to higher dispersion of soil particles in water which subsequently decreases the movement of water through it thereby preventing the soil to be

Table 4.3 Effect of puddling by using different equipment on sinkage resistance (1-6 cm) at three levels of sedimentation period

1st Experiment (1998)

Treatments (Puddling equipment)	Sinkage resistance, g cm ⁻²			Mean
	Sedimentation period, hrs			
	24	48	72	
Rotary puddler two passes (R ₂)	20.56	47.84	98.95	55.78
Rotary puddler three passes (R ₃)	17.67	29.36	81.45	42.82
Peg type puddler two passes (P ₂)	32.91	81.55	136.30	83.58
Peg type puddler three passes (P ₃)	19.16	40.70	99.35	53.07
Cultivator two passes (C ₂)	37.20	98.58	143.90	93.22
Cultivator three passes (C ₃)	30.79	74.18	123.59	76.30
Mean	26.43	62.03	113.93	67.46
Factors	SEm±	CD _(0.05)		
Puddling equipment (a)	0.551	1.740		
Sedimentation period (b)	0.268	0.780		
Interaction (axb) 1.	0.657	1.910		
2.	0.769	2.340		

2nd Experiment (1999)

Treatments (Puddling equipment)	Sinkage resistance, g cm ⁻²			Mean
	Sedimentation period, hrs			
	24	36	48	
Peg type puddler one pass (P ₁)	38.08	68.65	86.45	64.39
Peg type puddler two passes (P ₂)	30.36	57.23	73.86	53.81
Rotary puddler one pass (R ₁)	32.51	62.48	79.28	58.09
Mean	33.65	62.78	79.86	58.77
Factors	SEm±	CD _(0.05)		
Puddling equipment (a)	0.330	1.290		
Sedimentation period (b)	0.251	0.250		
Interaction (axb) 1.	0.435	1.339		
2.	0.485	1.679		

Interaction (1) For comparing two sedimentation period for same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period.

dried by sun ray. This might be contributing towards the softness of puddled soil leading to low sinkage resistance. In order to increase the sinkage resistance and to reduce the sedimentation period for transplanting, **Khan *et al.* (1979)** suggested that water should be removed after puddling and the soil be allowed to dry by sun. It was further recommended that water should be added before transplanting. However, irrigation water is costly as well as scarce and its scarcity is more severe during pre-monsoon transplanting. Therefore, the draining of puddled field and irrigating it again before transplanting may be a costly process and may not find acceptability amongst the farmers. Rather, it will be better to control the level of puddling and wait for suitable sedimentation period to carry out transplanting.

Relationships between depth of soil and sinkage resistance, measured under various treatments at three levels of sedimentation period, were established and are depicted in Figures 4.4 to 4.9. The best fit regression equations of the form $y = a + bx$ with 'x' as depth (cm) and 'y' as sinkage resistance (g cm^{-2}) have been developed. The correlation coefficients are significant at 1 per cent level of significance. It has been observed that the sinkage resistance increased with respect to depth which may be due to increase in geostatic pressure of soil with depth (**Gangil, 1993**). Similar results have been reported by **Garg *et al.* (1999)**. The empirical relationships established hold good for top layer of the puddled soil (1-6 cm) and may not

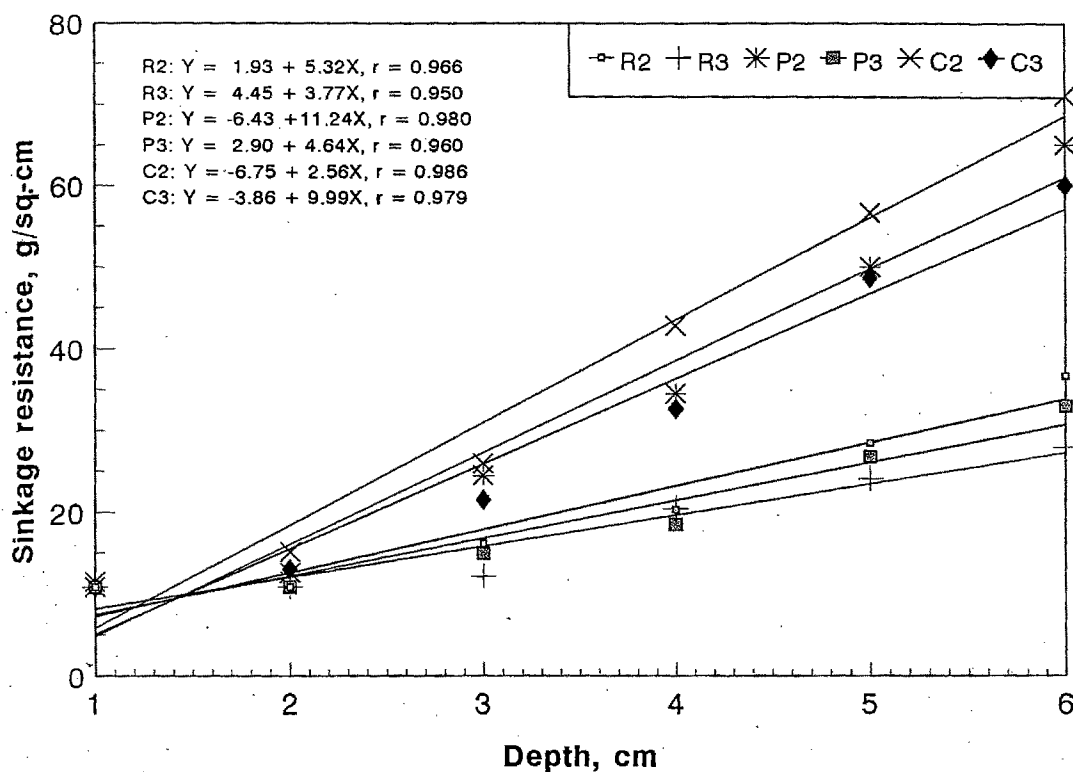


Fig. 4.4 Relationship between depth and sinkage resistance at 24 hrs of sedimentation period (1998)

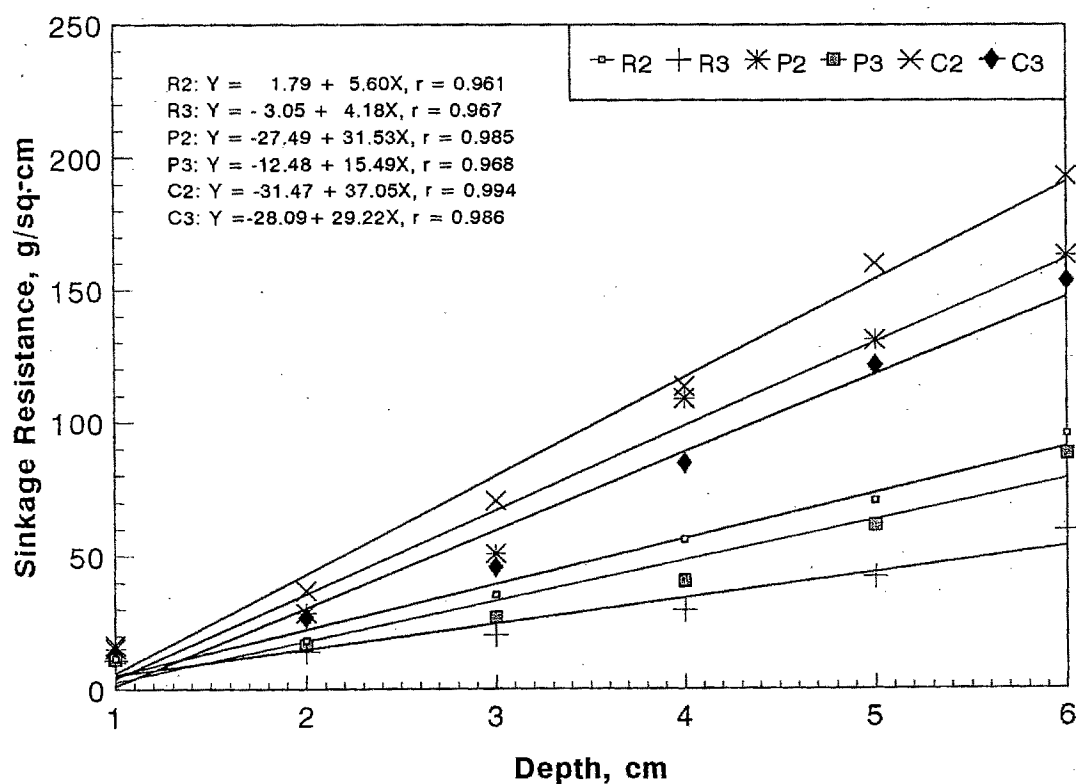


Fig. 4.5 Relationship between depth and sinkage resistance at 48 hrs of sedimentation period (1998)

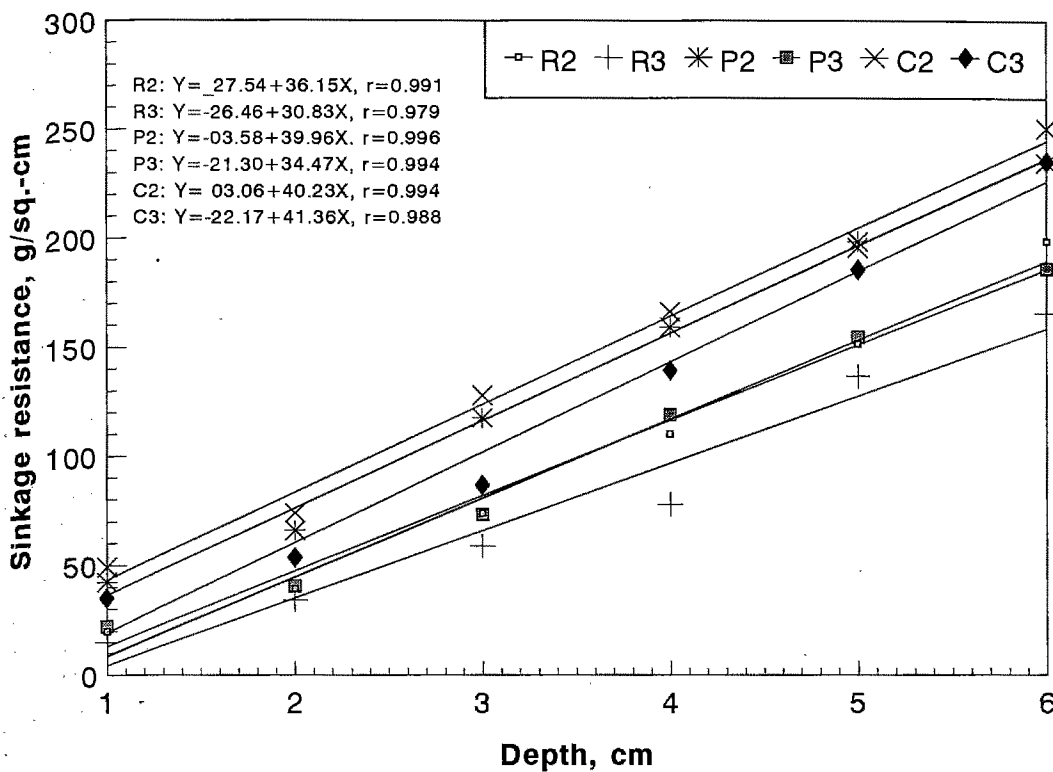


Fig. 4.6 Relationship between depth and sinkage resistance at 72 hrs of sedimentation period (1998)

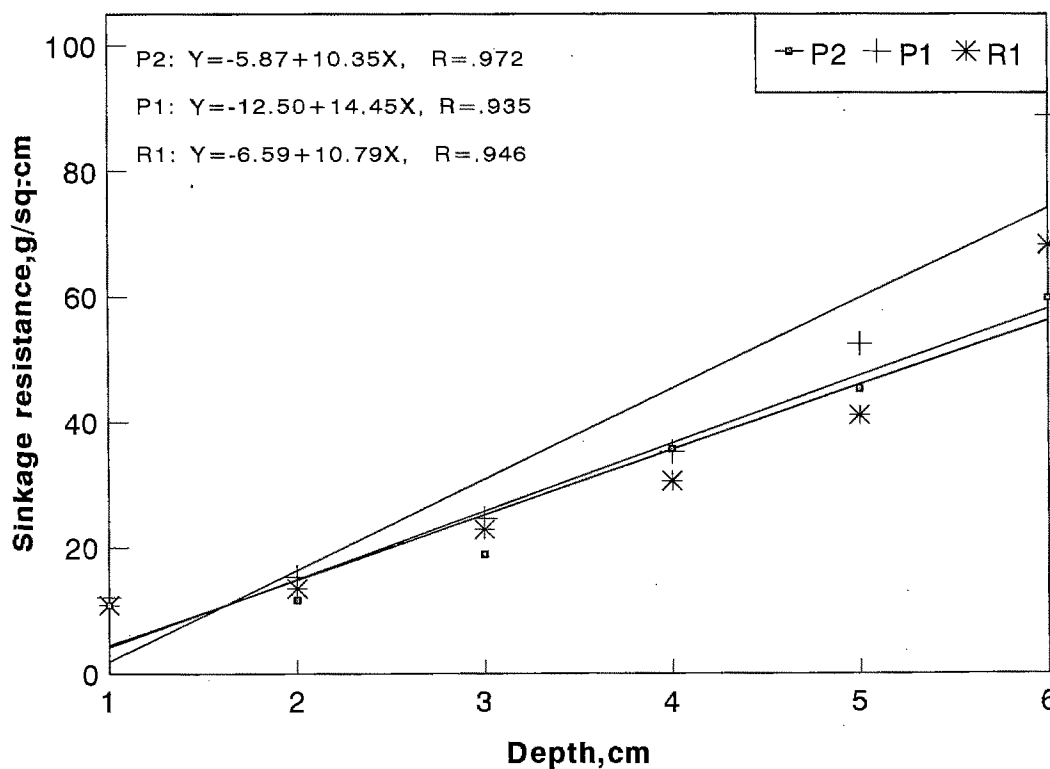


Fig. 4.7 Relationship between depth and sinkage resistance at 24 hours of sedimentation period (1999)

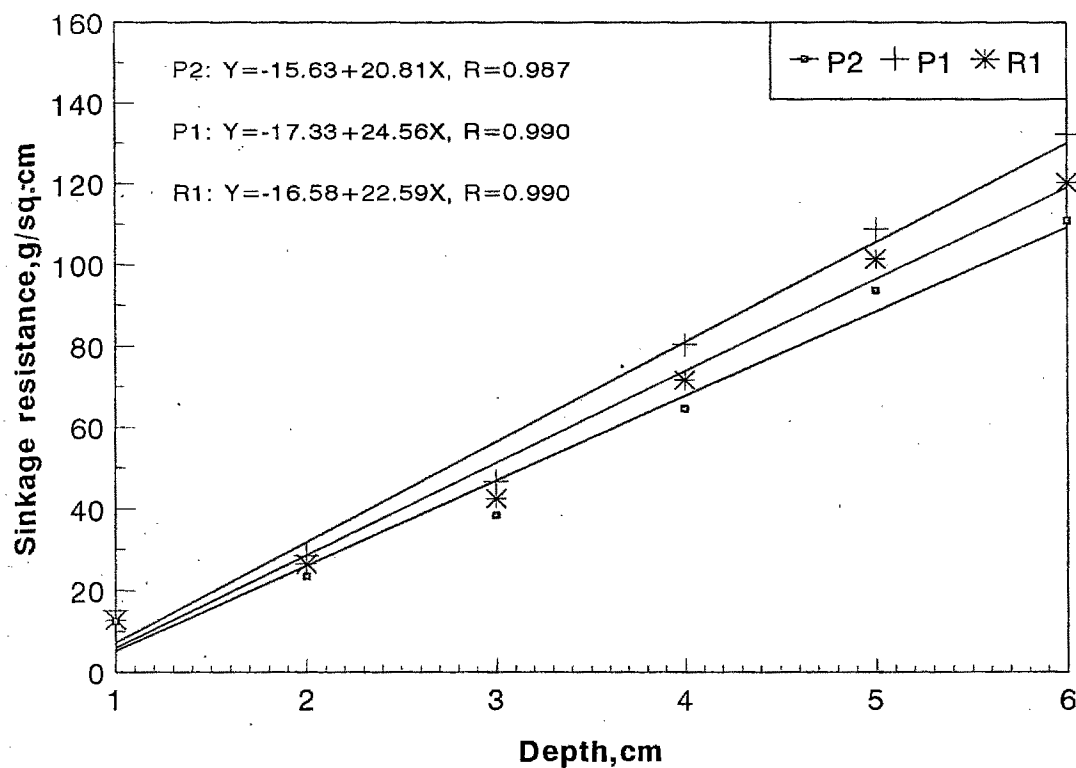


Fig. 4.8 Relationship between depth and sinkage resistance at 36 hours of sedimentation period (1999)

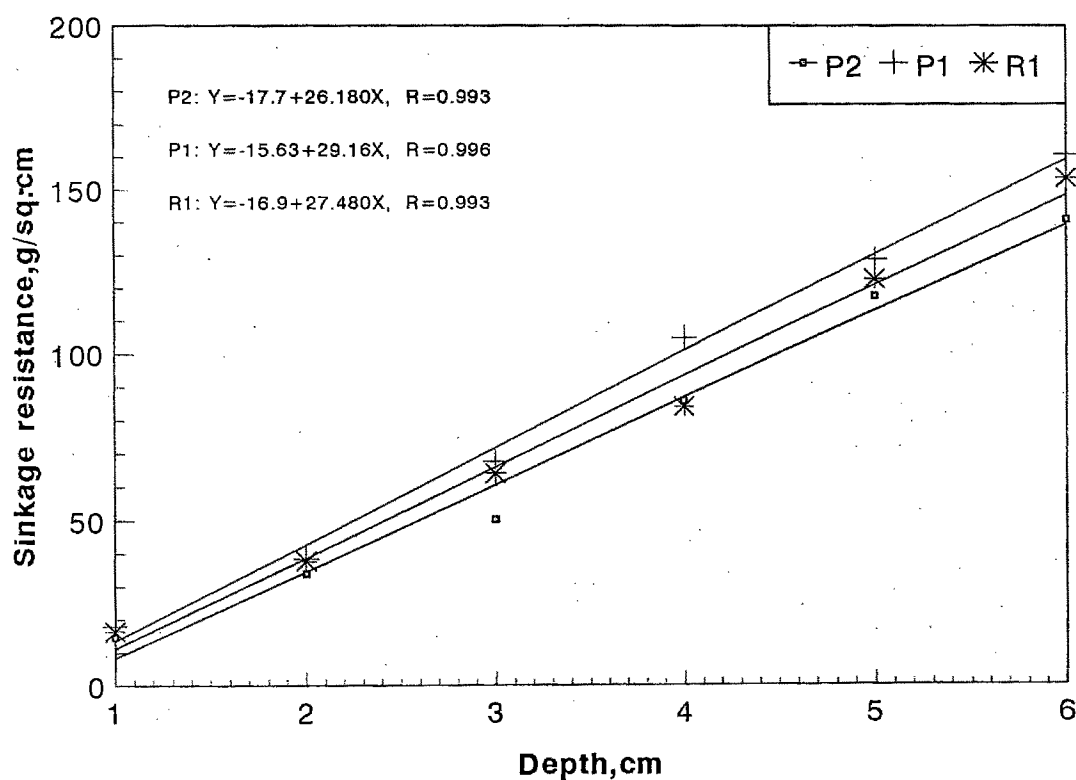


Fig. 4.9 Relationship between depth and sinkage resistance at 48 hours of sedimentation period (1999)

be true for deeper depth because, at higher depth, the soil resistance may increase exponentially as reported by Sargana *et al.* (1983).

Table 4.4 indicates that observed sinkage of float at contact pressure of 14.34 g cm^{-2} is appreciably higher at S_{24} compared to other sedimentation period in the first experiment. Maximum and minimum float sinkage of 3.15 and 1.98 cm were observed in case of treatments R_3 and C_2 , respectively at S_{24} which were significantly different from each other. Treatments R_2 (2.82 cm) & P_3 (2.90 cm) and P_2 (2.43 cm) & C_3 (2.30 cm) differed significantly but in between these are statistically similar. In general, as sedimentation period increased, float sinkage decreased significantly irrespective of puddling equipment and level of puddling. However, the decrease in float sinkage was found more in case of P_2 (49.38%), C_2 (46.70%) and C_3 (40.00%) when sedimentation period increased from 24 to 48 hours. At sedimentation period of 72 hours (S_{72}), the float sinkage decreased further for all treatments which was much below 1 cm for P_2 , C_2 and C_3 indicating firm soil condition whereas it was marginally below 1 cm for treatments R_2 (0.95 cm) and P_3 (0.98 cm).

Similar trend of declining float sinkage with sedimentation period was also observed in the second experiment (1999). Maximum float sinkage of 2.69 cm was obtained for P_2 at S_{24} which was significantly higher than that of P_1 (2.38 cm) but statistically *at par* with R_1 (2.58 cm) (Table 4.4). Float sinkage between P_1 and R_1 was observed to be non-significant. At S_{36} ,

float sinkage decreased and behaved identically to that of S_{24} but at 48 hours it was statistically *at par* with values of 1.19, 0.92 and 1.10 cm for treatments P_2 , P_1 and R_1 respectively.

More sinkage at S_{24} may be due to softness of puddled soil resulting in low sinkage resistance. With increase of sedimentation period, the soil gained strength which supported the weight of the float thereby reducing the sinkage.

The transplanter could be operated under three load conditions on the float (Table A.7). The load on the float per unit area (sq.-cm) has been termed as contact pressure of the float on puddled soil. In the present study, the transplanter was operated under condition-I with contact pressure 14.34 g cm^{-2} and sinkage was measured under field condition. With the help of regression equations of depth vs. sinkage resistance, the sinkage of the float was predicted and compared with the observed values (Table 4.4). Float sinkage was also predicted for other two load conditions having contact pressure 18.22 and 20.29 g cm^{-2} so that optimum condition for transplanting could be defined with respect to sinkage.

Comparing the predicted and observed float sinkage at 14.34 g cm^{-2} contact pressure, it was found that in some cases observed sinkages were higher than the predicted values while in others, it was lower (Table 4.4). The mean variation in observed and predicted float sinkage was 0.28 cm.

Test of goodness of fit ($\chi^2 = 1.737$) showed that the observed and predicted sinkages are *at par* at 1 per cent level of significance.

Predicted float sinkage at contact pressures of 18.2 and 20.29 g cm⁻² (conditions II and III) are also given in Tables 4.4. Predicted sinkage at contact pressure of 18.22 and 20.29 g cm⁻² was more than 3 cm for treatments R₂ (3.06 and 3.45 cm), R₃ (3.65 and 4.20 cm) and P₃ (3.30 & 3.74 cm) while it was in between 2 & 3 cm for treatments P₂ (2.19 & 2.37 cm), C₂ (1.99 & 2.15 cm) and C₃ (2.33 & 2.54 cm) at 24 hrs sedimentation period during first experiment. As usual, float sinkage increased with contact pressure and decreased with sedimentation period. At sedimentation period of 48 hrs (S₄₈), sinkage of float was within 2-3 cm for treatments R₂, R₃ and P₃ whereas it was in between 1 & 2 cm in case of P₂, C₂ and C₃ (Table 4.4).

Predicted sinkages further decreased at S₇₂ where it was much below 1 cm for P₂ and C₂ and about 1 cm for C₃ at contact pressures of 18.22 and 20.29 g cm⁻². However, it was 1.27 & 1.32, 1.17 & 1.20 and 1.45 & 1.52 cm for treatments R₂, P₃ and R₃ respectively.

In the second experiment, predicted sinkages were 2.33 & 2.53, 2.13 & 2.27 and 2.28 & 2.44 cm for treatments P₂, P₁ and R₁ respectively. Float sinkage decreased with sedimentation period and at S₄₈ it was between 1.0 & 1.5 cm for all treatments at contact pressures of 18.22 and 20.29 g cm⁻².

It was noticed that feeding of mat consumes a lot of time during transplanting operation hampering the field capacity. So, in order to minimize the feeding time, the transplanter should be operated with two separate loaders and additional mats on the float which gives a contact pressure of 20.29 g cm^{-2} (Table A.7). Garg *et al.* (1999) suggested that transplanting should not be done in too soft and hard soil. They further reported that float sinkage less than 1 cm signifies hard field condition which might pose problem in penetration of transplanting fingers into puddled soil. Assuming that float sinkage greater than 2 cm is indicative of soft soil, therefore, transplanting may be done at a float sinkage in between 1 to 2 cm.

In the present study, the float sinkage was found more than 2 cm at S_{24} for all the treatments. Whereas it was in between 1 to 2 cm in case of P_2 , C_2 , C_3 at S_{48} and for R_2 , R_3 and P_3 at S_{72} with a contact pressure of 20.29 g cm^{-2} . In the second experiment, float sinkage in between 1 to 2 cm was found both at S_{36} and S_{48} for all treatments.

If, float sinkage with respect to sedimentation period is considered as a yardstick for optimum time of transplanting after puddling, it may be said that treatments R_2 , R_3 and P_3 require 72 hrs of sedimentation whereas P_2 , C_2 and C_3 need 48 hrs to go for transplanting. In the second experiment, sedimentation period of 36 hrs may be suitable for transplanting for all treatments i.e. P_2 , P_1 and R_1 . However, these propositions would be

Table 4.4 Predicted and observed float sinkage at different contact pressures

1st Experiment (1998)

Treatments (Puddling equipment)	Sedimen- -tation period, hrs	Predicted float sinkage, cm			Observed sinkage, at 14.34 contact pressure , cm	Variation in observed and predicted values, cm
		Contact pressure, g cm ⁻²				
		14.34	18.22	20.29		
Rotary puddler (R ₂) two passes	S ₂₄	2.33	3.06	3.45	2.82	0.49
	S ₄₈	1.54	1.76	1.89	2.02	0.48
	S ₇₂	1.15	1.27	1.32	0.95	0.20
Rotary puddler three passes (R ₃)	S ₂₄	2.62	3.65	4.20	3.15	0.53
	S ₄₈	1.94	2.34	2.56	2.24	0.30
	S ₇₂	1.32	1.45	1.52	1.52	0.20
Peg type puddler two passes (P ₂)	S ₂₄	1.84	2.19	2.37	2.43	0.59
	S ₄₈	1.33	1.45	1.520	1.23	0.10
	S ₇₂	0.45	0.55	0.600	0.51	0.05
Peg type puddler three passes (P ₃)	S ₂₄	2.46	3.30	3.74	2.90	0.44
	S ₄₈	1.73	1.98	2.12	2.20	0.47
	S ₇₂	1.03	1.17	1.20	0.98	0.05
Cultivator two passes (C ₂)	S ₂₄	1.68	1.99	2.15	1.98	0.30
	S ₄₈	1.24	1.34	1.40	1.13	0.11
	S ₇₂	0.20	0.38	0.43	0.46	0.26
Cultivator three passes (C ₃)	S ₂₄	1.92	2.33	2.54	2.30	0.38
	S ₄₈	1.45	1.58	1.66	1.38	0.07
	S ₇₂	0.88	0.98	1.02	0.66	0.22

2nd Experiment (1999)

Treatments (Puddling equipment)	Sedimen- -tation period, hrs	Predicted float sinkage, cm			Observed sinkage, at 14.34 contact pressure , cm	Variation in observed and predicted values, cm
		Contact pressure, g cm ⁻²				
		14.34	18.22	20.29		
Peg type puddler one pass (P ₁)	S ₂₄	1.86	2.13	2.27	2.38	0.52
	S ₃₆	1.28	1.45	1.53	1.20	0.08
	S ₄₈	1.03	1.16	1.23	0.92	0.11
Peg type puddler two passes (P ₂)	S ₂₄	1.95	2.33	2.53	2.69	0.74
	S ₃₆	1.44	1.63	1.73	1.50	0.06
	S ₄₈	1.22	1.37	1.45	1.19	0.03
Rotary puddler one pass (R ₁)	S ₂₄	1.94	2.28	2.44	2.58	0.64
	S ₃₆	1.36	1.54	1.72	1.33	0.03
	S ₄₈	1.14	1.28	1.35	1.10	0.04

confirmed later in this chapter while taking into account the performance of the transplanter at different sedimentation period.

4.3 Effect of Seedling Characteristics and Operating Speed on Transplanter Performance Under Laboratory Condition

Effect of seedling age, density and mat moisture content were studied at two operating speeds 1.38 and 1.88 km hr⁻¹ on number of seedlings per hill, missing hill and mechanical damage to optimize the seedling parameter for efficient performance of transplanter. Three seedling age of 20, 25 and 30 days and three mat moisture content range of 10-15, 20-25 and 30-35 per cent were taken in the laboratory study.

The data on seedling characteristics are given in Table 4.5. Three seed rates of 70, 90 and 110 g eat⁻¹ were used in the experiment with mat area 50x22 sq.-cm. The corresponding densities were found to be 1.76, 2.17 and 2.65 seedlings per sq.-cm which were statistically significant with each other. Seedling height increased with age significantly but seedling density has no effect on seedling height. Similar observations were also made on root length and stem thickness (Table 4.5).

4.3.1 Seedling per hill

The data on number of seedlings per hill are presented in Table 4.6 and the analysis of variance in Table B.1.

Seedlings per hill varied between 1.43 to 2.20, 2.09 to 2.98 and 2.34 to 3.45 for densities 1.76, 2.17 and 2.65 per sq.-cm, respectively with the

Table 4.5 Seedling characteristics under different age and mat density

Age of seedling, days	Seed rate, g mat ⁻¹	Mat density, seedlings cm ⁻²	Seedling height, cm	Root length, cm	Stem thickness, mm
20	70	1.76	17.45	6.39	2.03
	90	2.17	17.39	6.31	2.03
	110	2.65	17.25	6.49	1.97
25	70	1.76	19.54	7.08	2.69
	90	2.17	20.60	7.29	2.63
	110	2.65	19.30	7.19	2.65
30	70	1.76	23.45	8.12	3.17
	90	2.17	23.32	7.99	3.28
	110	2.65	23.41	8.0	3.20

lowest being at 20 days old seedling, 10-15 per cent moisture content and 1.38 km hr⁻¹ operating speed and the highest being at 30 days old seedling, 30-35 per cent moisture content and 1.88 km hr⁻¹ operating speed.

It was observed that irrespective of age, mat moisture content and seedling density, seedlings per hill increased with operating speed. Operating speed had individual effect on number of seedlings per hill but its interaction with other parameters was found non-significant. However, the increase in number of seedlings per hill was more pronounced at higher age as well as moisture content.

Seedling density has significant effect on seedling per hill. Maximum seedling per hill was found at mat density of 2.65 followed by 2.17 and 1.76 per sq.-cm for any particular age and moisture content.

It was further noticed that with increase in mat moisture content, seedling per hill increased for each age and operating speed. At a seedling density of 1.67 per sq.-cm, the increase in seedling per hill was non-significant but the rate of increase was higher from 20-25 to 30-35 per cent moisture content contrary to a high rate of increase from 10-15 to 20-25 per cent for seedling densities of 2.17 and 2.65 per sq.-cm (Table 4.6). However, there was no significant increase of seedling per hill with respect to moisture content in case of mat density 2.17 per sq.-cm. But, for mat density of 2.65 per sq.-cm, the increase was significant between moisture content of 10-15 and 30-35 per cent whereas it was statistically *at par* between 20-25 and

30-35 per cent moisture content. Similar trend was observed for both the operating speeds.

In general the seedling per hill increased with age, however, with older seedling, the number of seedling per hill was found more at higher moisture content compared to lower moisture.

It was found that by increasing the operating speed, the transplanting speed also increased which resulted in greater impact force by the transplanting fingers on the mat. Besides that, vibration of the tray at higher speed tends to enhance the downward movement of the mats which contributes towards more consumption of seedlings. This may be the reason for higher number of seedling per hill when operating speed was increased which is in agreement with the results obtained by **Garg *et al.* (1982)**. At lower moisture content, seedling per hill was found minimum and increased with moisture content irrespective of age. The reason for less number of seedling at lower moisture content may be due to firmness of the mat in holding the seedlings. Whereas at higher moisture content, the roots are loosely held in the mat as a result of which more number of seedlings are pulled out. These observations tally with that made by **Singh *et al.* (1979)**; **Swain and Maity (1985)**. Seedlings per hill were found to increase with age as well as moisture content. It may be due to entanglement of roots which are loosely held at higher moisture. Similar observations were also

Table 4.6 Effect of seedling characteristics and operating speed on seedlings per hill

Age of seedling, days	Mat moisture content, %	Seedlings per hill					
		Operating speed, km hr ⁻¹					
		1.38			1.88		
		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)	Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)
		1.76 (70)	2.17 (90)	2.65 (110)	1.76 (70)	2.17 (90)	2.65 (110)
20	10-15	1.43	2.09	2.34	1.53	2.19	2.44
	20-25	1.52	2.29	2.67	1.67	2.43	2.80
	30-35	1.76	2.41	2.95	1.94	2.49	3.13
25	10-15	1.46	2.24	2.39	1.72	2.40	2.58
	20-25	1.60	2.46	2.76	1.86	2.59	2.96
	30-35	1.92	2.64	2.98	2.06	2.70	3.29
30	10-15	1.52	2.32	2.40	1.68	2.44	2.57
	20-25	1.63	2.60	2.65	1.94	2.66	2.95
	30-35	2.0	2.84	3.15	2.20	2.98	3.45

reported by Garg *et al.* (1982); Swain and Maity (1989) and Mufti and Khan (1995).

4.3.2 Missing hill

The data on missing hills with respect to seedling parameters are given in Table 4.6 and the analysis of variance in Table B.2. It is clear from the tables that seedling age, mat moisture content and operating speed had significant effect on percentage missing hill. However, their interaction was found non-significant.

When operating speed increased from 1.38 to 1.88 km hr⁻¹, the missing hills decreased marginally with few exception where there was increase in missing hills.

Density of seedling in the mat had significant effect on missing hills. It decreased as mat density increased from 1.76 to 2.17 and 2.17 to 2.65 seedlings per sq.-cm for all ages of seedling, mat moisture content and operating speeds. Variations of missing hill percentage for mat density of 1.76, 2.17 and 2.65 per sq.-cm were 8.59 to 14.85, 6.25 to 9.77 and 3.13 to 9.38 per cent respectively.

With increase of mat moisture content, missing hills decreased in most of the cases with few exceptions. Similar trend was observed for seedling age also. However, missing hills showed inconsistent behaviour.

Decrease of missing hill with increase of operating speed from 1.38 to 1.88 km hr⁻¹ may be due to faster mat sliding because of greater vibration

of seedling tray at higher operating speed. At lower speed, the mat might have struck to the seedling tray due to silty clay loam soil which is sticky in nature (Singh *et al.*, 1985). It has also been noticed that transplanting finger cut an area of approximately 0.9 sq.-cm. Since, existence of seedlings in each sq.-cm area are there, hence missing of hills should not be encountered theoretically. However, there were missing of hills which was primarily due to non-uniformity of seedling distribution in the mat. The non-uniformity may be greater at lower mat density leading to more missing hills. It was noticed that transplanting fingers did drop some portion of mat in their downward position, irrespective of whether there was seedling in it or not which indicates that hill missing was not due to transplanter. Non-uniformity of seedling in mat led to inconsistency in missing hills during the study. Mufti and Khan (1995) also had similar observations on missing hills. Hence, proper care should be taken to maintain optimum seedling uniformity along with density in the mat.

4.3.3 Mechanical damage

The data pertaining to mechanical damage to seedlings are given in Table 4.7 and the analysis of variance in Table B.3.

Mechanical damage to seedling varied between 0 to 6.63 per cent during the investigation. Lowest mechanical damage was found with 30 days old seedling at 1.38 km hr⁻¹ operating speed and the highest was in case of 20 days old seedling at 1.88 km hr⁻¹ speed.

Table 4.7 Effect of seedling characteristics and operating speed on missing hill

Age of seedling, days	Mat moisture content, %	Missing hill, %					
		Operating speed, km hr ⁻¹					
		1.38			1.88		
		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)	Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)		
		1.76 (70)	2.17 (90)	2.65 (110)	1.76 (70)	2.17 (90)	2.65 (110)
20	10-15	14.85	9.77	9.38	13.28	9.38	8.60
	20-25	10.94	8.03	7.63	11.33	7.82	7.43
	30-35	9.88	7.81	6.25	9.16	7.03	6.25
25	10-15	12.89	9.43	8.34	14.10	9.38	8.38
	20-25	10.42	7.25	6.25	12.50	6.25	7.82
	30-35	10.94	10.38	7.82	9.38	6.25	4.69
30	10-15	12.5	8.34	6.25	9.81	5.19	4.80
	20-25	12.5	9.38	5.47	8.25	4.60	3.13
	30-35	9.82	7.24	4.69	8.59	6.25	3.13

It was observed from the ANOVA (Table B.3) that mat moisture content and seedling density had no significant effect on mechanical damage to seedling whereas age and operating speed influenced it. So, for further analysis, mechanical damage at different mat density and moisture content were pooled together to represent it for the corresponding age and operating speed (Table 4.9).

It was observed that mechanical damage to seedling was maximum at lower age and higher operating speed. As operating speed increased from 1.38 to 1.88 km hr⁻¹ mechanical damage increased from 3.39 to 5.86, 2.57 to 4.05 and 1.63 to 2.59 per cent for 20, 25 and 30 days old seedling respectively. There was maximum increase of mechanical damage with respect to operating speed for 20 days seedling. With advancement of age the increase in mechanical damage narrowed down and it was found minimum (1.63%) at 1.38 km hr⁻¹ operating speed for 30 days old seedling.

Higher mechanical damage at 1.88 km hr⁻¹ operating speed may be due to more impact force exerted by the transplanting fingers on the seedling because of greater operating speed. At lower age, due to tenderness of seedlings, there has been more mechanical damage.

From this investigation, it is felt that 110 g mat⁻¹ seed rate giving seedling density of 2.65 per sq.-cm may be used to obtain 2-3 seedlings per hill as agronomical requirement and also to minimize missing hills. Since, there was no significant difference of number of seedlings per hill and

Table 4.8 Effect of seedling characteristics and operating speed on mechanical damage to seedling

Age of seedling, days	Mat moisture content, %	Mechanical damage, %					
		1.38			1.88		
		Operating speed, km hr ⁻¹					
		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)		Seedling density, No. cm ⁻² (Seed rate, g mat ⁻¹)	
		1.76 (70)	2.17 (90)	2.65 (110)	1.76 (70)	2.17 (90)	2.65 (110)
20	10-15	3.13	3.13	3.52	5.87	6.25	5.47
	20-25	3.51	3.51	3.52	5.47	5.87	5.10
	30-35	3.52	2.74	3.91	6.24	6.63	5.87
25	10-15	3.13	3.13	2.74	5.10	5.47	3.91
	20-25	2.35	2.74	2.06	4.22	3.13	4.00
	30-35	2.06	3.63	1.25	3.50	4.00	3.13
30	10-15	2.33	0.0	2.34	3.13	1.63	2.63
	20-25	2.34	2.35	1.57	3.13	3.52	2.13
	30-35	1.40	0.78	1.57	2.74	2.65	1.75

Table 4.9 Effect of age and operating speed on mechanical damage to seedlings

Seedling age, days	Mechanical damage, %	
	Operating speed, km hr ⁻¹	
	1.38	1.88
	3.39	5.86
20		
25	2.57	4.05
30	1.63	2.59

missing hill between 20-25 and 30-35 per cent moisture content, therefore, 20-25 per cent moisture content may be used so as to avoid more consumption of mat at higher moisture content. At low operating speed, mechanical damage is less but this advantage is offset by reduction in the field capacity. So, in order to increase the field capacity and to reduce mechanical damage, 30 days old seedling could be used.

4.4 Performance of Transplanter under Different Puddled Soil Condition

The performance of the transplanter with respect to drag force, seedling withdrawal force, mobility of transplanter, depth of transplanting, traction wheel slip, hill spacing, deviation in row spacing, buried and floating hill, mechanical damage to seedling, hill mortality, missing hill and hill population were studied under different puddled field condition and the performance results are presented and discussed in this section.

The seedling characteristics in respect of age, height, leaf stage, seedling density, root length, and stem thickness are shown in Table 4.10. The operating speeds of the transplanter were kept at 1.49 and 1.38 km hr⁻¹ for the first and second experiment respectively.

4.4.1 Effect of sedimentation period and water level on drag force of the transplanter

Drag force of the transplanter was measured under puddled condition with respect to three sedimentation period 24, 48 and 72 hours and three water levels <1, 1-2 and 2-4 cm. Puddling of the field was done by peg type

Table 4.10 Seedling characteristics and operating speed of transplanter during 1998 and 1999

Sl.No.	Item	Year	
		1998	1999
1	Age, days	23.00	25.00
2	Average height, cm	17.00 (1.10)	16.02 (2.90)*
3	Leaf stage	2.89 (0.17)	2.70 (0.07)
4	Seedling density, No. cm ⁻²	2.73 (0.342)	2.43 (0.28)
5	Root length, cm	6.79 (0.85)	7.41 (1.27)
6	Stem thickness, mm	2.15 (0.30)	2.32 (0.39)
7	Operating speed, km/hr	1.49 (0.05)	1.38 (0.08)

* Values in parenthesis show the standard deviation

puddler with two passes. The hardpan depth and its hardness were found to be 20 cm and 990.37 kPa respectively. The cone index values obtained at S_{24} , S_{48} and S_{72} sedimentation were 220.28, 270.26 and 351.00 kPa respectively. The data pertaining to drag force are presented in Table 4.11 and the relationships of drag force with respect to sedimentation period and water level are shown in Fig. 4.10.

It is evident from the table that both sedimentation period and water levels influence the drag force significantly.

The drag force decreased as the water level increased for all sedimentation period and the decrease was found to be more pronounced at S_{72} i.e., 30.96 and 69.14 per cent when water level increased from <1 to 1-2 cm and 1-2 to 2-4 cm, respectively. The decrease of drag force at water level 1-2 and 2-4 cm over that of <1 cm were 13.06 & 26.50 and 11.06 & 34.47 per cent for sedimentation period S_{24} and S_{48} , respectively.

At water level <1 cm, maximum drag force of 2.81 kN was recorded at S_{72} which was significantly higher than that obtained at S_{24} and S_{48} . The drag force marginally and non-significantly decreased from 2.45 to 2.35 kN when sedimentation period increased from S_{24} to S_{48} . With water level 1-2 cm, the drag force was obtained as 2.13 kN at S_{24} . Drag force showed a declining trend with sedimentation period. However, it did not differ significantly at S_{48} and S_{72} . Similar trend was also observed at water level 2-4 cm. But, the decrease of drag force at S_{48} and S_{72} over that of S_{24} were

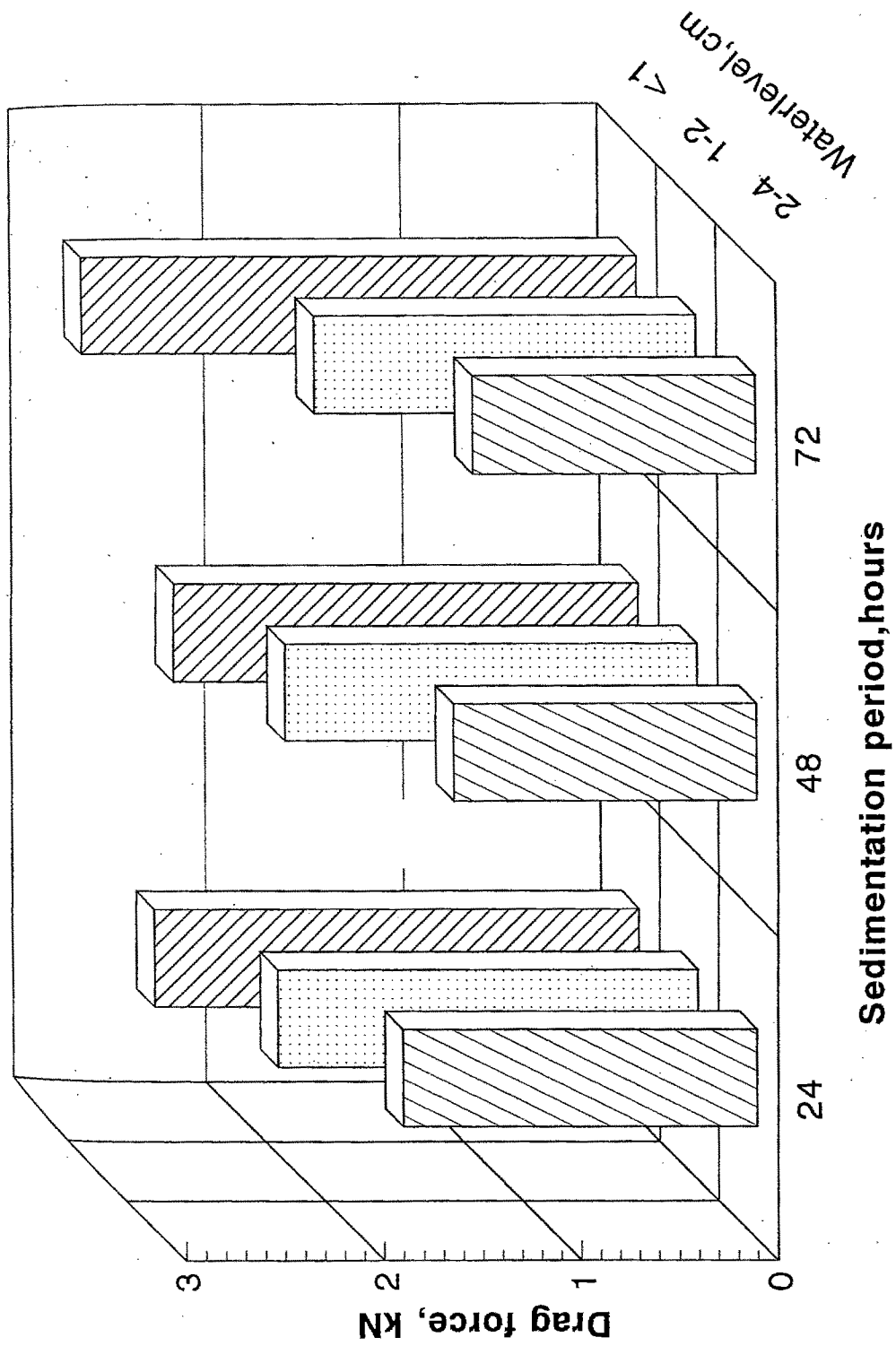


Fig. 4.10 Effect of sedimentation period and water level on drag force

Table 4.11 Effect of sedimentation period and water levels on drag force of the transplanter

Sedimentation period, hours	Drag force, kN			Mean
	Water level, cm			
	<1	1-2	2-4	
24	2.45	2.13	1.80	2.13
48	2.35	2.09	1.54	1.99
72	2.81	1.94	1.44	2.06
Mean	2.54	2.05	1.59	2.06
Factors	SEm±	CD _(0.05)		
Sedimentation period (a)	0.030	0.089		
Water level (b)	0.030	0.889		
Interaction (axb)	0.052	0.154		

14.44 and 20.00 compared to 1.86 and 8.92 per cent in case of water level 1-2 cm.

Drag force of the transplanter is comprised of (a) the adhesive force of puddled soil with float; (b) resistance due to float sinkage; and (c) rolling resistance of the traction wheel. It was observed that drag force decreased as the water level increased. This may be due to better floatation of the float leading to low sinkage and lesser adhesion because of adequate lubrication between float and puddled soil. Similar results were reported by **Shah (1980)**; **Alagusundaram *et al.* (1990)** and **Rahman (1992)**. At S_{24} , even if the sinkage of the float was more, the drag force was observed to be comparatively lower with 2-4 cm water level. This may be due to flowable state of soil which imparts lower resistance on the float. Besides that, there was no accumulation of soil ahead of the float because of upward bend at the front of the float. Increase of drag force at S_{72} with <1 cm water level may be because of more adhesion between float and puddled soil and greater rolling resistance of traction wheel. Adhesive force might have increased because of squeezing out of water by float pressure at the interface between float and soil leading into reduction of the lubricating effect of water. The present findings are in accordance with **Singh *et al.* (1981)**; **Gee Ghosh (1985)** and **Gee Clough *et al.* (1990)**. **Singh *et al.* (1981)** also noticed that dry field condition increases the drag force so rapidly that it leads to bogging of the transplanter.

4.4.2 Seedling withdrawal force

Seedling withdrawal force was measured by using Instron Universal Testing Machine at 3, 5, 7 cm depth of transplanting in the laboratory. This study was carried along with the field experiment of the year 1998 with a view to identify optimum period of transplanting after puddling. Data pertaining to seedling withdrawal force are presented in Table 4.12.

It was observed that seedling withdrawal force increased with depth of transplanting for all puddling equipment and sedimentation period. Lowest withdrawal force of 0.93 N was found in case of R_3 at 3 cm depth and it went upto 1.53 and 2.48 N when sedimentation period was increased to 48 and 72 hours, respectively, thereby registering an increase of 64.52 and 62.09 per cent. At 5 and 7 cm depth, the seedling withdrawal force increased with sedimentation period and the corresponding increase were 55.55 & 82.86 and 28.51 & 63.90 per cent respectively which indicated faster rate of rise between S_{48} to S_{72} for R_3 . The variation in withdrawal force was found significant at 5 per cent level. Similar trend was also noticed with treatments R_2 and P_3 except a non-significant rise in withdrawal force at 3 cm depth between S_{24} and S_{48} .

Comparing the treatments P_2 , C_2 and C_3 , the lowest seedling withdrawal force of 1.62 N was obtained in case of C_3 at 3 cm depth of transplanting at S_{24} . Thereafter, it increased with sedimentation period between S_{24} to S_{48} at a rate of 41.18, 45.59 and 37.04 per cent for P_2 , C_2 and

C₃ respectively. Increase of seedling withdrawal force from S₄₈ to S₇₂ was found to be at slower rate for P₂ (5.38%) and C₃ (5.41%) whereas it decreased between the same sedimentation period. The variation in withdrawal force was significant between S₂₄ and S₄₈ and non-significant between S₄₈ and S₇₂ for treatments P₂ and C₃. But it was significant in case of C₂ between all sedimentation period. At 5 and 7 cm depth of transplanting, increase of withdrawal force between S₂₄ to S₄₈ and decrease of the same between S₄₈ to S₇₂ were noticed for C₂ and C₃ except P₂ where there was a marginal increase (6.59%) between S₄₈ to S₇₂.

Seedling withdrawal force is said to be an index of seedling anchorage in the puddled soil (**Khan and Gunkel, 1989**). Increase in seedling withdrawal force with depth may be due to more frictional resistance between seedling and soil. At S₂₄, puddled soil remains in a flowable state carrying very little gripping strength. This may be the reason for comparatively low withdrawal force at S₂₄. As sedimentation period increased proper settling of soil particles takes place and the soil could offer more resistance to the seedling drawn after transplanting thereby increases the withdrawal force. Rate of increase of seedling withdrawal force was higher between S₄₈ to S₇₂ for R₂, R₃ and P₃ and between S₂₄ to S₄₈ in case of P₂, C₂ and C₃ because of more gain in the soil strength between those sedimentation period. This is in agreement with **Khan and Gunkel (1989)**.

Table 4.12 Effect of puddling by using different equipment on seedling withdrawal force at three sedimentation period and depth (3, 5 & 7 cm)

Treatments (Puddling equipment)	Sedimentation period, hrs	Seedling withdrawal force, N		
		Depth, cm		
		3	5	7
Rotary puddler two passes (R ₂)	24	1.25	1.51	2.42
	48	1.60	2.40	3.45
	72	3.01	4.41	5.90
Rotary puddler three passes (R ₃)	24	0.9	1.35	2.35
	48	1.53	2.10	3.02
	72	2.48	3.84	3.95
Peg type puddler two passes (P ₂)	24	1.87	2.7	3.65
	48	2.64	4.40	5.54
	72	2.79	4.69	4.94
Peg type puddler two passes (P ₃)	24	1.36	1.76	2.34
	48	1.98	2.56	3.59
	72	3.16	4.56	5.88
Cultivator two passes (C ₂)	24	2.06	2.79	4.35
	48	3.08	3.89	5.24
	72	2.15	2.42	3.05
Cultivator three passes (C ₃)	24	1.62	1.91	3.48
	48	2.22	4.01	5.85
	72	2.34	3.67	4.91

Factors	A	B	C	AxB	BxC	AxC	AxBxC
SEM±	0.182	0.057	0.057	0.142	0.142	0.100	0.245
CD (0.05)	0.232	0.164	0.104	0.401	0.401	0.284	0.695
Factors	A	Puddling equipment					
	B	Sedimentation period					
	C	Depth of transplanting					

Puddled soil behaves as visco-elastic mass (Awadhwal and Singh, 1985(b)). When subjected to stress, it undergoes an instantaneous elastic response followed by a delayed elastic strain combined with viscous flow. On removal of the stress, the instantaneous elastic strain recovers immediately and the delayed elastic strain recovers over a period of time whereas viscous flow remains (Gupta and Pandya, 1966). Khan and Gunkle (1989) described the behaviour of puddled soil under two responses : first, the deformation due to application of stress and second relaxation after its withdrawal. The relaxation depends on the water level and the strength of soil. When the puddled soil after aging gained strength, it may be in a state which, when subjected to a stress, may deform with very little relaxation. This might be the reason for decrease of seedling withdrawal force at S_{72} in case of P_2 , C_2 and C_3 for all depths of transplanting. At that point of time, the soil may behave as plastic mass without any viscous behaviour.

Since, seedling withdrawal force is considered as an index of seedling anchorage therefore, higher the withdrawal force lesser will be the buried and floating hills. From that standpoint, it is felt that transplanting could be done after 72 hours of sedimentation of puddled soil in treatments R_2 , R_3 and P_3 whereas it could be done at 48 hours of sedimentation period in case of P_2 , C_2 and C_3 respectively.

4.4.3 Mobility of transplanter

Mobility of the transplanter depends upon the depth of puddling, hardpan depth and sinkage of float (Singh and Garg, 1976). In order to study the mobility of the transplanter these parameters were studied and discussed in this section. The data regarding depth of puddling, hardpan depth and its hardness are given in Table 4.13. There was no appreciable variations in traction wheel sinkage under different sedimentation period, hence these were pooled together to represent the average sinkage in each main plot treatment (Table 4.13).

In the first experiment (1998), maximum depth of puddling (14.36 cm) was obtained in case of treatment R_3 which was significantly higher than that of other treatments. Lowest puddling depth (10.72 cm) was recorded for C_2 . There was no significant difference in depth of puddling between treatments C_2 & P_2 and treatments R_2 , P_3 & C_3 respectively. It was observed that, irrespective of puddling equipment, depth of puddling increased significantly with puddling level (2 to 3). However, with peg type puddler and cultivator at same level of puddling the depth of puddling was found less compared to rotary puddler. The hardpan depth varied within 19-22 cm with their corresponding hardness of 1022-1123 kPa, respectively. There was no significant difference in hardpan and its hardness. Traction wheel sinkage was observed within the range of 22.50 to 24.50 cm.

In the second experiment it was noticed that depth of puddling was significantly higher in case of P_2 (10.93 cm) and R_1 (10.09 cm) than that of P_1 (8.91 cm). Depth of puddling for P_2 and R_1 were statistically *at par*. Hardpan depth and its hardness varied between 19.50 to 20.67 cm and 1033 to 1074 kPa, respectively which were statistically similar. The traction wheel sinkage varied from 21 to 22 cm. During both the experiments, mobility problem of transplanter was not encountered.

Higher depth of puddling in case of rotary puddler compared to peg type puddler and cultivator may be due to its more weight and rotary action of blade which resulted in cutting of soil and its mixing with water. Increase in depth of puddling at more number of passes may be due to progressive increase in softness of the puddled soil with each operation thereby resulting in greater penetration of ground working parts of the puddlers. Similar observations were made by **Taneja and Patnaik (1962)**.

It was noticed that immobility of the transplanter would take place when the traction wheel fails to generate necessary thrust to propel it either because of failure due to insufficient wheel traction or poor soil bearing capacity. Bearing failure results due to excessive float drag whereas traction failure takes place when the traction wheel moves in a soil with low strength resulting wheel spinning without developing sufficient traction for the movement of equipment. The sinkage of the float was not to that extent which may warrant a bearing failure (Table 4.4). Since, the traction wheel

Table 4.13 Effect of puddling by using different equipment on depth of puddling, hardpan & its hardness and traction wheel sinkage of transplanter

1st Experiment (1998)

Treatments (Puddling equipment)	Depth of puddling, cm	Hardpan depth, cm	Hardness of hardpan, kPa	Traction wheel sinkage, cm
Rotary puddler two passes (R ₂)	12.23	21.92	1082.01	23.16
Rotary puddler three passes (R ₃)	14.36	22.47	1123.14	24.50
Peg type puddler two passes (P ₂)	11.14	20.17	1115.12	22.86
Peg type puddler three passes (P ₃)	12.79	22.0	1097.88	24.19
Cultivator two passes (C ₂)	10.72	19.08	1022.44	22.50
Cultivator three passes (C ₃)	12.14	20.5	1030.69	23.62
SEm±	0.373	1.190	115.05	0.795
CD _(0.5)	1.175	NS	NS	NS

2nd Experiment (1999)

Treatments (Puddling equipment)	Depth of puddling, cm	Hardpan depth, cm	Hardness of hardpan, kPa	Traction wheel sinkage, cm
Peg type puddler one pass (P ₁)	8.91	19.50	1033.49	21.46
Peg type puddler two passes (P ₂)	10.93	20.67	1074.24	22.53
Rotary puddler one pass (R ₁)	10.09	20.00	1070.16	21.92
SEm±	0.256	0.860	30.00	1.104
CD _(0.5)	1.000	NS	NS	NS

touched the hardpan under both experiments (Table 4.13), it could produce necessary traction, hence, there was no traction failure. This was the reason for encountering no mobility problem. From this, it could be inferred that upto 15 cm depth of puddling, mobility will not be a problem for the transplanter.

4.4.4 Depth of transplanting

The data obtained on depth of transplanting under different puddled conditions are presented in Tables 4.14 and 4.15

In the first year experiment, it was observed that increasing the puddling level from two to three passes, depth of transplanting increased significantly from 5.82 to 6.15, 5.43 to 5.90 and 4.98 to 5.30 cm for rotary puddler, peg type puddler and cultivator respectively at 24 hours of sedimentation period. Maximum depth of transplanting 6.15 cm was found in case of R_3 whereas the minimum was 4.98 cm for C_2 . Treatments R_2 & P_3 and P_2 & C_3 varied significantly. However, in between these they were statistically *at par*. Depth of transplanting decreased significantly with increase in sedimentation period and followed a similar trend at S_{48} and S_{72} as that of S_{24} .

In the second experiment during 1999, maximum depth of transplanting was recorded as 5.69 cm in case of P_2 at S_{24} which was statistically *at par* with R_1 (5.58 cm) but significantly higher than P_1 (5.38 cm). Similar to the first year experiment, depth of transplanting was found

to decrease with sedimentation period. However, at S_{48} , there was no significant difference in depth of transplanting among treatments.

It was noticed that depth of transplanting depends upon the float sinkage. Higher the float sinkage, more was the depth of transplanting. In the present study, the depth of transplanting was set at 3 cm. But it was found considerably high at 24 hours sedimentation. This may be due to more sinkage of the float at this stage because of softer puddled soil resulting out of inadequate settling of soil particles. With increase in sedimentation period, puddled soil gained strength thereby reduces the float sinkage which in turn results in lesser depth of transplanting. More depth of transplanting in case of R_2 , R_3 and P_3 compared to P_2 , C_2 and C_3 may be due to better puddling and slow settling of particles. Higher depth of transplanting under the soft puddled condition was also reported by Mori (1975).

4.4.5 Traction wheel slip

The data on traction wheel slip have been given in Tables 4.14 & 4.15 which indicates an increase of 2.55 to 13.59 per cent in the first year experiment with the lowest and highest for treatment R_3 at S_{24} and C_2 at S_{72} sedimentation level respectively. At 24 hours, the traction wheel slip was within the range of 2.55 to 4.28 per cent for treatments R_2 , R_3 , P_2 , P_3 and C_3 which were statistically *at par* whereas, C_2 was statistically higher than that of R_2 , R_3 and P_3 and *at par* with P_2 and C_3 . In general, it was observed that traction wheel slip increased significantly with sedimentation period and the

increase was found to be more pronounced at S_{72} in case of treatments P_2 , C_2 and C_3 with values of 12.59, 13.59 and 12.79 per cent, respectively which were statistically similar but significantly higher than treatments R_2 (7.58%), R_3 (5.22%) and P_3 (7.03%).

During the field experiment of 1999, minimum traction wheel slip of 2.13 per cent was recorded in case of P_2 followed by R_1 (3.96%) and P_1 (4.94%) at S_{24} . Thereafter, traction wheel slip increased with sedimentation period, however, the increase was non-significant. At S_{48} , it was 6.51, 7.63 and 8.92 per cent in case of treatments P_2 , R_1 and P_1 , respectively. The interaction effect of puddling equipment and sedimentation period on traction wheel slip was also found non-significant.

Traction wheel slip depends upon the drag force of the transplanter. That is, higher the drag force, more will be the slip. It means at a very high drag force, the slip will be so high that the traction wheel starts spinning and the transplanter becomes immobile. Low traction wheel slip at S_{24} may be due to less drag force because of better lubrication at the interface of float and puddled soil. At this level of sedimentation, the water level in the field for all treatments was more than 2 cm which enhanced the process of lubrication. As sedimentation period increased, soil becomes harder and water level gradually recedes which increases the drag force and subsequently the wheel slip. Greater wheel slip for treatment P_2 , C_2 and C_3 at S_{72} may be due to more drag force because of higher soil-float adhesion.

Adhesive force increases when there is inadequate lubrication between float and soil surface. Average water level of the field at S_{72} for treatments P_2 , C_2 and C_3 were only 0.58, 0.35 and 0.61 cm which might have been squeezed out due to float contact pressure leading to increase in adhesion between float and soil. Some dry patches due to unlevelled field condition might have also contributed to more adhesion. Comparatively lower wheel slip at S_{72} for treatments R_2 , R_3 and P_3 may be due to higher water level (1-2 cm) in the field leading to lower adhesion and less drag force. This has been confirmed with the investigation results on drag force presented in Art 4.4.1. Mori (1975) also reported an increase of wheel slip at hard soil surface.

4.4.6 Hill spacing

Hill spacing measured under different treatments are illustrated in Tables 4.14 and 4.15. The hill spacing was preset at 12 and 10 cm during first and second year experiment respectively.

The hill spacing was found more than the preset value of 12 cm at 24 hrs sedimentation period in the first experiment. Maximum and minimum hill spacing of 12.60 and 12.10 cm were obtained in case of R_3 and C_2 , respectively. However, there was no significant difference in hill spacing among treatments. It decreased with increase in sedimentation period significantly for treatments P_2 , P_3 , C_2 & C_3 and non-significantly for treatments R_2 & R_3 when sedimentation period increased from 24 to 48 hours. At S_{48} , the hill spacing was less than 12 cm for treatments P_2 , C_2

and C_3 with values of 11.88, 11.62 and 11.94 cm respectively which were statistically *at par* whereas it was found more than 12 cm for treatments R_2 (12.18 cm), R_3 (12.46 cm) and P_3 (12.36 cm). As sedimentation period increased to 72 hours, the hill spacing decreased considerably for treatments P_2 , C_2 and C_3 which were found to be 5.42, 7.5 and 5.42 per cent less than the preset spacing. But, it was closely equal to 12 cm for treatments R_2 and P_3 and higher than that for R_3 (12.29 cm). Hill spacing was statistically *at par* for treatments P_2 , C_2 , & C_3 and R_2 , R_3 & P_3 respectively.

During the second experiment (1999), hill spacing was observed more than the prefixed spacing of 10 cm for all the treatments at S_{24} and thereafter, it decreased with increase in sedimentation period. However, it was more than the preset spacing at S_{48} . The interaction effect of puddling equipment and sedimentation period on hill spacing was found non-significant.

Hill spacing depends on the traction wheel slip. Higher hill spacing at S_{24} may be due to low wheel slip than the designed slip for the transplanter. As sedimentation period increased the wheel slip increased resulting in a decrease in hill spacing. Similar observations were made by Mori (1975).

4.4.7 Deviation in row spacing

The data on deviation in row spacing are presented in Tables 4.14 and 4.15. The above tables reveal that deviation in row spacing from the preset

Table 4.14 Effect of puddling by using different equipment on depth of transplanting, traction wheel slip, hill spacing and deviation in row spacing (1998)

Treatments (Puddling equipment)	Depth of transplanting, cm			Traction wheel slip, %			Hill spacing, cm			Deviation in row spacing, %			Mean
	Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs			
	24	48	72	24	48	72	24	48	72	24	48	72	
Rotary puddler two passes (R ₂)	5.82	5.02	3.95	2.58	4.43	7.58	12.50	12.18	12.02	7.28	3.99	3.51	4.93
Rotary puddler three passes (R ₃)	6.15	5.24	4.50	2.55	4.00	5.22	12.59	12.46	12.29	8.56	4.90	3.25	5.57
Peg type puddler two passes (P ₂)	5.43	4.23	3.51	3.72	7.16	12.59	12.26	11.88	11.35	6.77	2.19	2.00	3.65
Peg type puddler three passes (P ₃)	5.90	5.20	3.89	2.72	4.46	7.03	12.54	12.36	12.04	8.82	4.36	2.74	5.30
Cultivator two passes (C ₂)	4.98	4.06	3.46	4.28	9.46	13.59	12.11	11.62	11.10	4.11	2.74	1.99	2.95
Cultivator with three passes (C ₃)	5.30	4.38	3.66	3.48	6.58	12.79	12.23	11.91	11.35	5.14	1.89	1.57	2.87
Mean	5.59	4.69	3.84	3.22	6.02	9.8	12.37	12.07	11.69	6.78	3.34	2.51	4.21
Factors			SEM±			SEM±			SEM±			SEM±	CD _(0.05)
Puddling equipment(a)			0.0524			0.430			0.197			0.194	0.610
Sedimentation			0.0252			0.148			0.321			0.132	0.387
period (b)			0.044			0.363			0.078			0.325	0.949
Interaction (axb) 1.													
2.			0.051			0.523			0.207			0.329	0.986

Interaction (1) For comparing two sedimentation period for same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

Table 4.15 Effect of puddling by using different equipment on depth of transplanting, traction wheel slip, hill spacing and deviation in row spacing (1999)

Treatments (Puddling equipment)	Depth of transplanting, cm			Traction wheel slip, %			Hill spacing, cm			Deviation in row spacing, %			Mean	
	Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs				
	24	36	48	Mean	24	36	48	Mean	24	36	48			
Peg type puddler one pass (P ₁)	5.38	4.20	3.92	4.50	4.94	6.02	8.92	10.45	10.36	10.09	5.54	3.67	2.81	4.00
Peg type puddler two passes (P ₂)	5.69	4.50	4.19	4.79	2.13	4.0	6.51	10.94	10.49	10.32	5.81	4.43	3.64	4.63
Rotary puddler one pass (R ₁)	5.58	4.33	4.10	4.77	3.96	5.91	7.63	10.57	10.56	10.32	5.47	2.45	2.64	3.52
Mean	5.65	4.34	4.07	4.69	3.68	5.31	7.69	10.65	10.47	10.24	5.61	3.52	3.03	4.05
Factors			SEM±	CD _(0.05)		SEM±	SEM±		SEM±	CD _(0.05)			SEM±	CD _(0.05)
Puddling equipment(a)			0.487	0.191		0.324	0.324		0.11	NS			0.158	0.610
Sedimentation period (b)			0.483	0.149		0.343	0.343		0.106	0.327			0.169	0.520
Interaction (axb)														
1.			0.080	0.258		0.183	0.183		0.595	NS			0.52	NS
2.			0.084	0.282		0.175	0.175		0.583	NS			0.484	NS

Interaction (1) For comparing two sedimentation period for same puddling equipment
Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

spacing was significantly higher at 24 hours of sedimentation period (S_{24}) compared to S_{48} and S_{72} for the first experiment (1998). Treatments R_3 (8.56%) & P_3 (8.82%) and R_2 (7.28%) & P_2 (6.77%) were statistically *at par*. Treatment C_2 had the lowest (4.11%) deviation in row spacing. In general, it decreased with increase in sedimentation period. However, at S_{48} there was no significant difference in the deviation of row spacing between treatments R_2 , R_3 & P_3 and P_2 , C_2 & C_3 respectively. Similar trend was also observed at S_{72} with a further decrease in deviation of row spacing.

In the second experiment, deviation in row spacing was found between 5.46 to 5.81 per cent at S_{24} . It decreased with sedimentation period and the variation was 2.64 to 3.64 per cent at S_{48} . However, the interaction effect of puddling equipment and sedimentation period was non-significant.

Higher deviation in row spacing from the theoretical preset value at S_{24} may be due to movement of puddled soil along with the float which disturbs the row spacing. More variation in case of R_2 , R_3 and P_3 compared to P_2 , C_2 and C_3 may be because of inadequate settling of soil particles leading to more sinkage of float which displaces more mud. With increase in sedimentation period, puddled soil settles and its flow is reduced which in turn reduces the deviation in row spacing. This corroborates with the findings of Mori (1975).

4.4.8 Buried and floating hill

Buried and floating hills, observed after transplanting and expressed in percentage are given in Table 4.16 and 4.17 for the first and second year experiment respectively.

4.4.8.1 Buried hills

During first year experiment buried hills were observed to be conspicuously high at 24 hours of sedimentation period for all treatments. Maximum (11.09%) and minimum (4.44%) buried hills were obtained for treatments R_3 and C_2 respectively at 24 hours sedimentation period (Table 4.16). Treatments R_2 (9.98%) & R_3 (11.09%) and R_2 (9.98%) & P_3 (9.71%) were statistically *at par*. However, treatments R_2 , R_3 and P_3 differed significantly from all other treatments i.e. P_2 , C_2 and C_3 . Buried hill in case of C_3 (6.18%) was significantly higher than that of treatments P_2 (5.10%) and C_2 (4.44%) where both were statistically similar.

Increasing the puddling level from 2 to 3 passes buried hill increased significantly in case of peg type puddler and cultivator and non-significantly in case of rotary puddler.

In general it was noticed that as sedimentation period increased, buried hill decreased for all treatments. At S_{48} sedimentation period, buried hill in case of R_3 was still high (7.51%) which was statistically *at par* with P_3 but significantly higher than rest of the treatments. Buried hill for treatments P_2 (2.20%), C_2 (1.30%) and C_3 (2.31%) were found statistically

similar. At S_{72} , there was no buried hill for treatments P_2 , C_2 and C_3 . However, with treatment R_3 , it was 3.59 per cent which was significantly higher than that of all other treatments including R_2 and P_3 where it was found to be 1.00 and 1.35 per cent respectively.

In second experiment during 1999, maximum buried hill was obtained in case of P_2 (5.87%) at S_{24} followed by P_1 (3.33%) and R_1 (3.27%) which were statistically *at par* but significantly lower than that of P_2 (Table 4.17). Thereafter, buried hill decreased with sedimentation period and at S_{36} , there was no significant difference among all treatments. At S_{48} , it was 1.32 per cent for P_2 whereas it was only 0.53 and nil for treatments P_1 and R_1 respectively.

4.4.8.2 Floating hill

Like buried hill, the floating hill percentage was also found high at S_{24} during first experiment. It was observed that increasing the puddling level from 2 to 3, floating hill increased significantly for all treatments. Floating hill varied between 4.00 to 9.56 per cent at S_{24} sedimentation with the lowest and highest being in case of C_2 and R_3 , respectively. There was no significant difference in floating hill among treatments R_2 & P_3 and P_2 , C_2 & C_3 respectively. However, in between these differed significantly (Table 4.16). Floating hill percentage declined with increase in sedimentation period from S_{24} to S_{48} and followed a similar trend as that of S_{24} . It further decreased at S_{72} except in case of C_2 where there was an

increase of floating hill from 1.28 to 3.00 per cent. In case of C_3 , there was no floating hill but treatment R_3 still had a floating hills of 2.70 per cent which was statistically higher than that of R_2 (1.31%) and P_3 (2.26%).

During the second experiment in the year 1999, highest floating hill of 4.05 per cent was obtained in case of P_2 at S_{24} (Table 4.17). In this experiment also, floating hill decreased with increase in sedimentation period for all treatments. However, the interaction effect of puddling equipment and sedimentation period was found non-significant which indicates that there was no statistical difference of floating hill under different treatments with respect to sedimentation period.

Higher percentage of buried and floating hills at S_{24} may be due to poor anchorage of seedling in soft soil and movement of puddled mass along with the float due to its higher sinkage (Table 4.4). Puddled soil because of inadequate settling remains in a flowable state where the strength of the soil (cone index) is very low resulting in poor gripping capacity of seedlings which was also evident from the results of seedling withdrawal force (Table 4.12). Due to more float sinkage, the depth of transplanting increased which might have also contributed towards the buried hill. Besides above reasons, high water level at low sedimentation created a wave action thereby washing away the seedlings which in turn might have increased the floating hill. It was observed that due to flow of mud and water at least two rows of the previously transplanted pass were normally affected.

As sedimentation period increases, soil gains strength and the flow of soil along with the float reduces. This is the reason for reduction in buried and floating hills with increase in sedimentation period. At higher sedimentation period, the seedling withdrawal force was more which gives a better anchorage to seedlings. These findings are in agreement with Mori (1975); Singh and Garg (1976); Singh *et al.* (1981); Singh *et al.* (1985); Kanoksak *et al.* (1988) and Khan and Gunkel (1988). Increase of floating hill in case of C₂ at S₇₂ compared to S₄₈ may be due to hard soil (Cone index : 410.41 kPa) where there was problem of penetration of transplanting finger into the soil. This situation arised where there was a patch without water due to unlevelled field condition. The floating hills in this case were the hills which had not been transplanted into the soil because of hard surface and lied on the field with their roots exposed.

There existed a linear relationship between cone index and buried & floating hill which showed a good negative correlation ($r=-0.914$) between them. The correlation coefficient was significant at 1 per cent level of significance.

4.4.9 Mechanical damage

Data on mechanical damage to seedling are presented in Tables 4.16 and 4.17 for the first and second experiment respectively.

Mechanical damage to seedling varied between 0 to 2.31 per cent for the first experiment. Higher mechanical damage was observed for treatments

R_2 (1.54%), P_2 (1.95%), P_3 (1.33%), C_2 (2.31%) and C_3 (2.00%) at S_{72} whereas it was comparatively less at other sedimentation period. The average mechanical damage was 0.96 per cent with standard deviation of 0.73. The higher standard deviation signifies the inconsistency in the mechanical damage values.

During the second experiment (1999), mechanical damage to seedling was comparatively less than that observed in the first experiment. The average mechanical damage was found as 0.26 per cent with standard deviation of 0.44 which shows inconsistency in the data of mechanical damage. Maximum mechanical damage of 1.40 per cent was found in case of treatment R_1 at S_{48} .

Mechanical damage to seedlings mainly depends upon the transplanting speed. Higher mechanical damage in the first experiment compared to the second may be due to greater operating speed (Table 4.10). More mechanical damage to seedlings at S_{72} in the first experiment may be due to transplanting in relatively harder soil where it offers more resistance to the penetrating seedlings which enhances the process of seedling damage.

4.4.10 Hill mortality

Results on hill mortality are presented in Tables 4.16 and 4.17 for the first and second experiments respectively.

In the first experiment, maximum mortality (17.38%) was obtained with treatment R_3 at S_{24} followed by R_2 (16.24%) and P_3 (15.62%).

Increasing the puddling level from 2 to 3 passes, mortality increased significantly in case of peg type puddler and cultivator whereas the increase was non-significant for rotary puddler. Mortality in case of treatments P_2 (9.46%), C_2 (7.78%) and C_3 (9.94%) were statistically *at par*. Mortality decreased significantly for all treatments when sedimentation period increased from S_{24} to S_{48} but the decrease was more pronounced in case of treatments P_2 (3.94%), C_2 (2.49%) and C_3 (3.13%) than that of R_2 (11.06%), R_3 (13.56%) and P_3 (9.71%). It further decreased at S_{72} varying from 2.42 to 4.93 per cent with exception in case of C_2 where there was an increase in mortality from 2.49 to 4.50 per cent when sedimentation period increased from 48 to 72 hours. However, there was no significant difference in mortality among treatments.

During the second experiment, highest hill mortality of 8.28 per cent was recorded in case of treatment P_2 at S_{24} which was significantly higher than R_1 (5.37%) and P_1 (4.88%). Similar to the first experiment, mortality decreased with increase in sedimentation period significantly. At S_{36} , mortality was 4.23 per cent for P_2 followed by P_1 (1.97%) and R_1 (1.77%). There was no hill mortality in case of P_1 at S_{48} whereas a marginal increase in hill mortality from 1.77 to 2.78 per cent was observed for treatment R_1 .

Relationships between buried hill, floating & mechanically damaged hill and mortality were established and shown in Figures 4.11 to 4.14. From the above figures, it was noticed that mortality in most of cases were

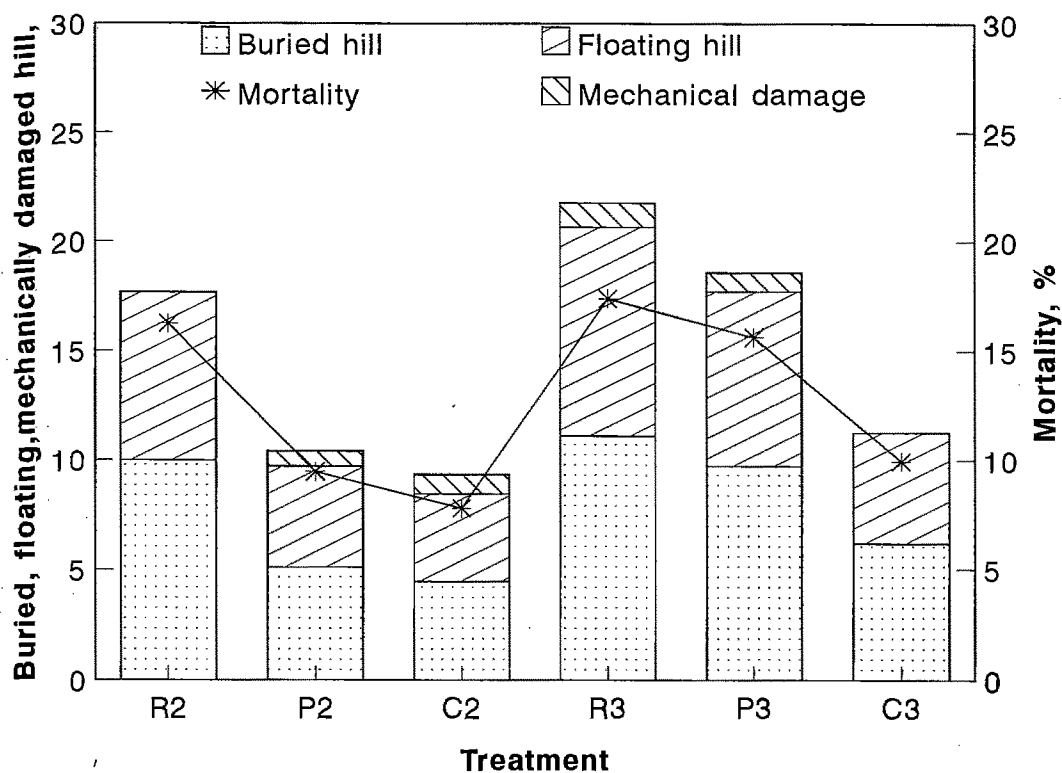


Fig. 4.11 Effect of puddling on buried & floating & mechanically damaged hill and mortality at 24 hours of sedimentation period (1998)

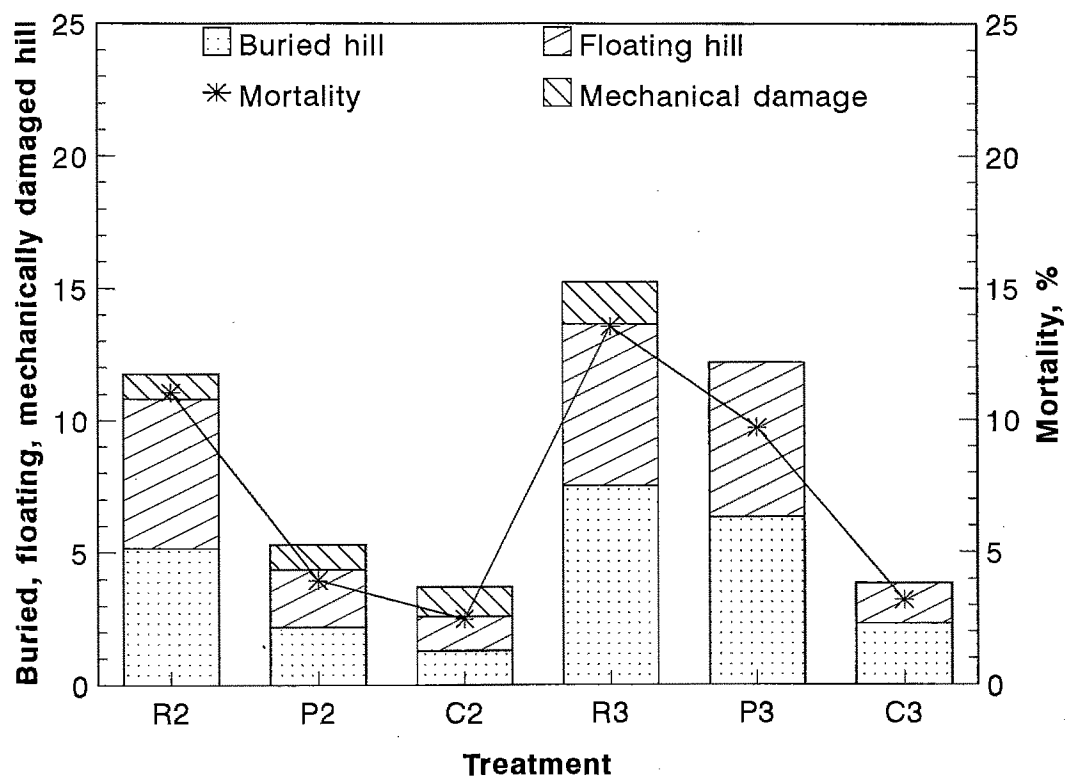


Fig. 4.12 Effect of puddling on buried, floating & mechanically damaged hill and mortality at 48 hours of sedimentation period (1998)

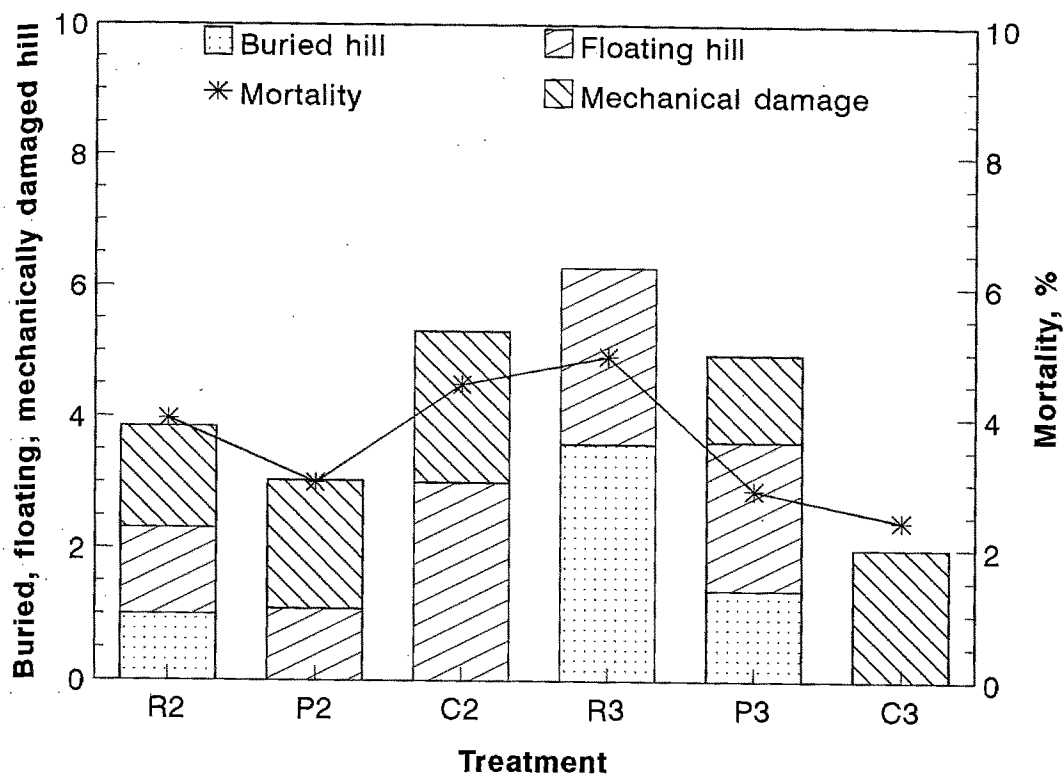


Fig. 4.13 Effect of puddling on buried, floating & mechanically damaged hill and mortality at 72 hours of sedimentation period (1998)

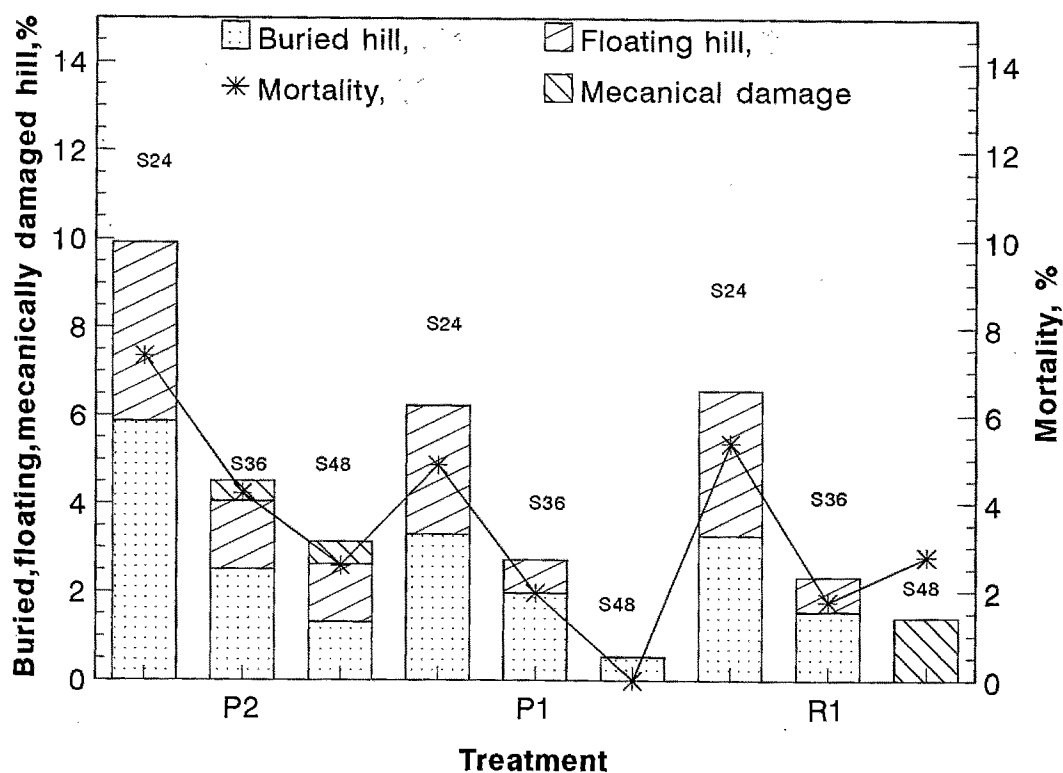


Fig. 4.14 Effect of puddling on buried, floating & mechanically damaged hill and mortality at 24, 36 and 48 hrs of sedimentation period (1999)

Table 4.16 Effect of puddling by using different equipment on buried and floating hill, mechanical damage to seedling and hill mortality at three levels of sedimentation period (1998)

Treatments (Puddling equipment)	Buried hill, %			Floating hill, %			Mechanical damage, %			Hill mortality, %		
	Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs		
	24	48	72	24	48	72	24	48	72	24	48	72
Rotary puddler two passes (R ₂)	9.98	5.17	1.00	7.68	5.64	1.31	0.0	0.94	1.54	16.24	11.06	3.97
Rotary puddler three passes (R ₃)	11.09	7.51	3.59	9.56	6.14	2.69	1.10	1.60	0.0	17.38	13.56	4.93
Peg type puddler two passes (P ₂)	5.10	2.20	0.0	4.60	2.17	1.08	0.70	0.95	1.95	9.46	3.94	3.00
Peg type puddler three passes (P ₃)	9.71	6.32	1.35	8.00	5.87	2.26	0.86	0.0	1.33	15.62	9.71	2.89
Cultivator two passes (C ₂)	4.44	1.30	0.0	4.0	1.28	3.00	0.89	1.12	2.31	7.78	2.49	4.50
Cultivator three passes (C ₃)	6.18	2.31	0.0	5.07	1.51	0.00	0.00	0.00	2.00	9.94	3.13	2.42
Mean	7.75	4.14	0.99	6.49	3.77	1.72	0.59	0.77	1.52	12.74	7.32	3.62
Factors			SEm±			SEm±						SEm±
Puddling equipment (a)			0.20			0.239						0.712
Sedimentation period (b)			0.21			0.161						0.267
Interaction (a x b)			0.510			0.278						0.660
1.			0.462			0.330						0.890
2.												
Interaction (1)			CD _(0.05)			CD _(0.05)						CD _(0.05)
Interaction (2)			0.64			0.753						2.24
			0.61			0.331						0.78
			1.49			0.811						1.91
			1.37			1.00						2.73

Interaction (1) For comparing two sedimentation period for same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

Table 4.17 Effect of puddling by using different equipment on buried and floating hill, mechanical damage to seedling and hill mortality at three levels of sedimentation period (1999)

Treatments (Puddling equipment)	Buried hill, %			Mean	Floating hill, %			Mean	Mechanical damage, %			Mean	Hill mortality, %			Mean
	Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs			
	24	36	48		24	36	48		24	36	48		24	36	48	
Peg type puddler one pass (P ₁)	3.33	1.97	0.53	1.94	2.93	0.75	0.00	1.23	0.0	0.0	0.00	0.00	4.88	1.97	0.0	2.28
Peg type puddler two passes (P ₂)	5.87	2.50	1.32	3.19	4.05	1.55	1.30	2.30	0.0	0.46	0.51	0.32	8.28	4.23	2.59	5.03
Rotary puddler one pass (R ₁)	3.27	1.55	0.0	1.59	3.30	0.78	0.00	1.37	0.0	0.0	1.40	0.47	5.37	1.77	2.78	3.31
Mean	4.10	2.00	0.62	2.24	3.42	1.03	0.43	1.63	0.0	0.15	0.64	0.26	6.18	2.66	1.79	3.54
Factors			SEm±	CD _(0.05)			SEm±	CD _(0.05)							SEm±	CD _(0.05)
Puddling equipment(a)			0.144	0.562			0.040	0.157							0.306	1.197
Sedimentation period (b)			0.170	0.523			0.097	0.30							0.219	0.676
Interaction (a x b)			0.294	0.910			0.169	NS							0.380	1.170
1.			0.280	0.923			0.144	NS							0.436	1.521
2.																

Interaction (1) For comparing two sedimentation period for same puddling equipment
Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

less than total buried, floating and mechanically damaged hills with few exception where mortality was higher. It may be due to survival of some of the floating hills. It was observed that mortality decreased with increase in sedimentation period. A linear relationship between cone index and mortality was found with a good negative correlation ($r=-0.884$) which was significant at 1 per cent level of significance.

Decrease of mortality with increase of sedimentation period may be due to reduction of buried and floating hill which generally contribute towards hill mortality.

4.4.11 Missing Hill

Data regarding missing hill are presented in Tables 4.18 and 4.19 for both the experiments of years 1998 and 1999.

It was noticed that missing hills varied between 3.35 to 12.08 per cent for all the treatments in the first experiment with an average of 7.04 per cent and standard deviation of 2.64. Higher standard deviation indicates the inconsistency in missing hills. During second experiment, missing hill varied between 5.83 to 11.81 per cent with an average of 8.96 per cent with standard deviation of 1.23.

Missing hill mostly depends upon the seedling density and its uniformity in the mat (Mufti and Khan, 1995). Higher missing of hills in the present study was due to non-uniformity of seedling distribution in the mat. Besides that, silty clay loam soil of the seedling mat being sticky in

nature may have caused problem in sliding of mat on the tray resulting in more missing of hills. Similar observations were made by **Singh *et al.* (1985)**. More hill missing in the second experiment compared to the first may be due to lower seedling density (Table 4.10). Missing hill was found more than the allowable limit of 5 per cent (**Mori, 1975**). Hence, it needs to be careful to maintain proper density of seedling as well as its uniformity in the mat.

4.4.12 Seedling per hill

Data on number of seedlings per hill are given in Tables 4.18 and 4.19.

Seedling per hill varied between 2.44 to 3.60 and 2.51 to 2.94 in the first and second experiments respectively. The corresponding mean values of seedling per hill were 2.95 and 2.70 respectively with standard deviation of 0.30 and 0.13 respectively. From this, it was found that the agronomical requirement of 2-3 seedlings per hill was met in the study. More seedling per hill in the first experiment may be due to higher seedling density (2.73) per sq.-cm compared to 2.43 per sq.-cm in the second experiment (Table 4.10).

4.4.13 Hill population

Data on number of hills per sq.-m, expressed as hill population, are presented in Tables 4.18 and 4.19.

In the first experiment, it was observed that with increase of sedimentation period hill population increased in most of the treatments with

exception of P_2 at S_{72} where it was 28.93 compared to 29.13 at S_{48} . Comparing the treatments at S_{24} , it was noticed that increasing the puddling level from 2 to 3, hill population decreased only in case of peg type puddler (27.5 to 24.0) whereas for rotary puddler there was a marginal increase from 24.00 to 25.30. Hill population in case of R_2 , R_3 and P_3 are statistically *at par* but significantly lower than that of treatments P_2 , C_2 and C_3 which were statistically similar. At S_{48} , hill population increased significantly for treatments P_2 , P_3 , C_2 and C_3 contrary to a non-significant increase in R_2 (24.00 to 25.20) and a marginal decrease in case of R_3 (25.30 to 25.20). When sedimentation period increased from 48 to 72 hours, hill population further increased in case of R_2 (28.5%), R_3 (28.20), C_2 (31.50) and P_3 (28.70) but there was a marginal decrease in case of P_2 (28.9). From the above results, it was noticed that the hill population behaved inconsistently.

In the second experiment, it was found that hill population increased with sedimentation period. However, there was no significant effect of puddling equipment and sedimentation period on hill population. Lowest hill population was obtained in case of P_2 (31.80) compared to that of P_1 (32.47) and R_1 (32.20) at S_{24} (Table 4.19).

In general, hill population depends upon mortality, hill spacing and finally on missing hills. Increase of hill population with respect to sedimentation period may be due to reduction in mortality (Table 4.16 and 4.17) and hill spacing (Table 4.14 and 4.15). At higher sedimentation period,

Table 4.18 Number of seedlings per hill, missing hill, hill population and water level under various treatments (1998)

Treatments (Puddling equipment)	Seedling per hill			Missing hill, %			Hill population per sq.-m			Water level, cm			Mean	
	Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs				
	24	48	72	24	48	72	24	48	72	24	48	72		
Rotary puddler two passes (R ₂)	2.36	2.44	2.82	10.59	11.12	5.12	24.0	25.20	28.47	25.89	4.0	2.62	1.30	2.64
Rotary puddler three passes (R ₃)	3.05	3.11	3.00	4.17	9.95	6.60	25.33	25.20	28.20	26.24	4.83	3.99	1.56	3.46
Peg type puddler two passes (P ₂)	2.84	2.89	2.78	5.00	6.09	12.08	27.47	29.13	28.93	28.51	2.39	1.14	0.58	1.37
Peg type puddler three passes (P ₃)	2.67	3.25	3.45	7.46	7.64	9.40	23.80	26.67	28.67	26.38	3.67	2.39	1.23	2.43
Cultivator two passes (C ₂)	3.07	3.60	2.80	6.19	7.70	3.63	27.67	29.67	31.53	29.62	1.84	0.88	0.35	1.02
Cultivator three passes (C ₃)	3.17	3.15	2.82	5.49	3.35	5.20	27.20	31.00	31.53	29.91	1.84	1.08	0.61	1.18
Mean	2.86	3.07	2.95	6.48	7.64	7.00	25.91	27.81	29.56	27.75	3.10	2.02	0.94	2.02

Table 4.19 Number of seedlings per hill, missing hill, hill population and water level under various treatments (1999)

Treatments (Puddling equipment)	Seedling per hill			Mean	Missing hill, %			Mean	Hill population per sq.-m			Mean	Water level, cm			Mean
	Sedimentation period, hrs				Sedimentation period, hrs	Sedimentation period, hrs			Sedimentation period, hrs	Sedimentation period, hrs			Sedimentation period, hrs			
	24	36	48			24	36			48	24			36	48	
Peg type puddler one pass (P ₁)	2.94	2.51	2.67	2.71	11.21	9.24	7.13	9.19	32.47	34.93	36.80	34.73	2.06	1.69	1.23	1.66
Peg type puddler two passes (P ₂)	2.76	2.50	2.69	2.65	5.83	8.00	9.03	7.62	31.80	33.13	34.27	33.10	2.85	2.12	1.50	2.16
Rotary puddler one pass (R ₁)	2.77	2.75	2.75	2.76	11.65	11.81	6.81	10.09	32.20	33.73	35.53	33.82	2.91	2.35	1.63	2.30
Mean	2.82	2.59	2.70	2.70	9.56	9.68	7.66	8.97	32.16	33.93	35.53	33.88	2.61	2.05	1.45	2.04

traction wheel slip was found to increase leading to a decrease of hill spacing which in turn increased the hill population. More hill population for R_3 at S_{24} compared to that of R_2 and P_3 inspite of higher hill mortality may be due to less missing hills in case of R_3 (4.17%) than that of R_2 (10.59%) and P_3 (7.46%). Decrease of hill population in case of P_3 at S_{72} may again be due to more missing hills (12.08%). Similar reasons may be attributed to non-significant variation in hill population among treatments P_2 , P_1 and R_1 at S_{24} and S_{36} (second experiment), even if hill mortality in case of P_2 (8.28 & 4.23%) was significantly higher compared to that of P_1 (4.88 & 1.97%) and R_1 (5.37 & 1.77%).

As missing hill showed lack of consistency in the data, the hill population failed to follow a particular trend although hill mortality and spacing decreased with increase in sedimentation period. However, missing hill being controllable and a function of seedling mat uniformity and density, hill population depends upon mortality and hill spacing which in turn depend on the puddled condition. So, in order to have an optimum plant population, the mortality of hill resulting due to buried, floating and mechanically damaged hills should be controlled.

4.5 Crop Performance Under Different Puddled Soil Condition

Crop performance in term of root growth, yield attributing characters and yield are presented and discussed in this section.

4.5.1 Root growth

Data pertaining to root growth, expressed in term of dry weight, are shown in Table 4.20.

It was observed from the above table that the interaction of puddling equipment and sedimentation period on root dry weight was non-significant both in the first as well as second experiment. Puddling equipment had significant effect on root dry weight in the first and second experiment. Therefore, the main factor (puddling equipment) means were compared for further analysis.

In the first experiment, maximum root dry weight was obtained in case of treatment P₃ (3.66 g) closely followed by R₂ (3.56 g) and P₂ (3.45 g) with non-significant difference among these. Root dry weight in treatments R₃ (3.13 g), C₂ (2.95 g) and C₃ (2.92 g) were statistically similar but lesser than that of treatments P₂, P₃ and R₂.

It was also observed that, increasing puddling level from 2 to 3, root dry weight increased for peg type puddler, decreased in case of rotary puddler and remained almost constant for cultivator.

In the second experiment, highest root dry weight was recorded in case of P₂ (4.60 g) which was statistically superior to P₁ (4.17 g) and R₁ (4.27 g). Root dry weight was observed higher in second experiment compared to the first for all the treatments.

Table 4.20 Effect of puddling by using different equipment on root dry weight at three levels of sedimentation period

1st Experiment (1998)

Treatments (Puddling equipment)	Root dry weight, g			Mean
	Sedimentation period, hrs			
	24	48	72	
Rotary puddler two passes (R ₂)	3.48	3.59	3.62	3.56
Rotary puddler thrice passes (R ₃)	3.12	3.08	3.20	3.13
Peg type puddler into passes (P ₂)	3.40	3.49	3.47	3.45
Peg type puddler three passes (P ₃)	3.50	3.71	3.78	3.66
Cultivator for passes (C ₂)	2.84	3.01	2.99	2.95
Cultivator three passes (C ₃)	3.0	2.93	2.84	2.92
Mean	3.22	3.30	3.32	3.28
Factors	SEm±	CD _{0.05}		
Puddling equipment (a)	0.079	0.250		
Sedimentation period (b)	0.055	NS		
Interaction (axb) 1.	0.135	NS		
2.	0.136	NS		

2nd Experiment (1999)

Treatments (Puddling equipment)	Root dry weight, g			Mean
	Sedimentation period, hrs			
	24	36	48	
Peg type puddler to passes (P ₂)	4.21	4.59	5.00	4.60
Peg type puddler on pass (P ₁)	3.78	4.21	4.51	4.17
Rotary puddler (R ₁)	4.17	4.23	4.41	4.27
Mean	4.06	4.34	4.64	4.35
Factors	SEm±	CD _(0.05)		
Puddling equipment (a)	0.081	0.316		
Sedimentation period (b)	0.090	0.278		
Interaction (axb) 1.	0.156	NS		
2.	0.151	NS		

Interaction (1) For comparing two sedimentation period for same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

The major factors which influence root growth are : (i) Soil moisture, (ii) aeration; (iii) nutrient availability and (iv) mechanical impedance. Comparatively less root dry weight in case of C₂ and C₃ may be due to poor nutrient availability because of higher leaching losses resulting out of more hydraulic conductivity of puddled soil. Similar observations were made by **Rath (1999)**. Less root dry weight in case of R₃ where the hydraulic conductivity was minimum may be due to greater bulk density (1.61-1.64 Mg m⁻³) which might have restricted the root growth. High bulk density reduces the porosity of soil considerably which in turn increases the mechanical impedance of soil leading to restriction in root growth. **Ghildyal and Satyanarayan (1969)** reported a decrease in root dry weight when bulk density increased which was later confirmed by **Gupta and Kathvarte (1972)** and **Katare and Upadhyay (1980)**. **Kar *et al.* (1976)** observed that at low as well as high bulk densities root dry weight decreased for a loam soil.

Higher root dry weight for all treatments in the second experiment compared to the first may be due to early transplanting which facilitated a better crop growth.

4.5.2 Yield attributes

Yield attributes like number of panicles per hill as well as per sq.-m, panicle length, grains per panicle, unfilled grain and plant height are presented and discussed in this section.

4.5.2.1 Panicles per hill

The data on number of panicles per hill are given in Tables 4.21(a) and 4.22(a) for first and second experiments respectively.

Maximum panicles per hill (11.12) was recorded in case P_3 which was significantly higher than that of all other treatments. Treatments R_2 (10.43), R_3 (10.07) and P_2 (9.98) were found statistically *at par* but significantly higher than C_2 (8.68) and C_3 (8.73). In the second experiment, maximum panicles per hill was obtained in case of P_2 (11.03) which was statistically similar to R_1 (10.75) but higher than P_1 (10.11). However, number of panicles per hill for treatments R_1 and P_1 were statistically *at par*.

The effect of puddling equipment and sedimentation period was found non-significant on number of panicles per hill in both the experiments.

4.5.2.2 Number of panicles per square meter

The data pertaining to number of panicles per sq.-m are presented in Tables 4.21(a) and 4.22(a) for both the experiments.

Panicles per sq.-m increased with sedimentation period for all the treatments in both the experiments. However, the effect of puddling equipment and sedimentation period was found non-significant.

Comparing the main factor means (Puddling equipment) in the first experiment, it was found that treatment P_3 had maximum number of panicles per sq.-m (294) which was statistically *at par* with P_2 (284) and R_2 (270) but superior to treatments R_3 (263), C_2 (257) and C_3 (261) respectively.

In the second experiment, maximum panicles per sq.-m was obtained in case of P_2 (365) followed by R_1 (364) and P_1 (353). However, there was no significant difference of panicles per sq.-m among the treatments.

More number of panicles per sq.-m was observed in the second experiment compared to the first experiment. This was due to greater number of hills/sq.-m because of lesser hill to hill spacing and less mortality. The lower mortality was due to reduced puddling level for all the treatments resulting in less buried and floating hill percentage.

4.5.2.3 Panicle length

The data, recorded on panicle length at the time of harvest, are shown in Tables 4.21(a) and 4.22(a).

In the first experiment panicle length varied between 27.38 to 24.86 cm with the highest in case of P_3 at S_{72} and lowest for C_2 at S_{24} . Sedimentation period as well as interaction between puddling equipment and sedimentation had no significant effect on panicle length. Comparing the main factor means, it was observed that there was maximum panicle length in case of P_3 (24.58 cm) closely followed by R_2 (24.34 cm) and P_2 (24.12) which were statistically *at par*. Minimum panicle length of 22.74 cm was recorded in case of treatment C_2 which was statistically inferior to R_3 (23.60 cm) and C_3 (23.45 cm). However, treatments R_3 and C_3 were statistically similar but differed significantly from P_2 , P_3 and R_2 . In the second

experiment panicle length varied between 23.70 to 23.93 cm. However the variation was found non-significant.

4.5.2.4 Grains per panicles

Table 4.21(b) and 4.22(b) show that in the first experiment, grains per panicle increased with increase in sedimentation period for all treatments but the variation was found not significant. Comparison of main factor (puddling equipment) revealed that treatment P_3 had highest grains per panicle (90) which was statistically *at par* with R_2 (87) and P_2 (87) but significantly higher than that of R_3 (83), C_2 (77) and C_3 (82). However, treatments R_3 and C_3 are statistically similar but superior to C_2 which had the minimum number of grains per panicle (77).

In the second experiment, only the main factors had significant effect on grains per panicle whereas the interaction was found non-significant. Maximum grains per panicle were observed in case of P_2 (116) followed by R_1 (112) and P_1 (107). Treatments P_2 and R_1 were statistically *at par* but differed significantly from P_1 . Grains per panicles in the second experiment were higher than that of the first experiment.

4.5.2.5 Unfilled grains per panicle

Data pertaining to unfilled grain per panicle are given in Tables 4.21(b) and 4.22(b).

The above tables reveal that the variation in unfilled grains per panicle was non-significant with respect to puddling equipment (main

factor) and sedimentation period (sub-factor) in both the experiments of years 1998 and 1999. However, maximum unfilled grain per panicle was recorded in case of C₂ (32.50%) whereas the lowest was for R₃ (28.50%) which was statistically lower than that of C₂. The rest of the treatments were found to be statistically *at par*. In the second experiment, the unfilled grains varied between 14.50 to 15.80 per cent where the variation was non-significant.

4.5.2.6 Plant height

Plant height, recorded at the time of harvest is presented in Tables 4.21(b) and 4.22(b).

Effect of puddling equipment and sedimentation period on plant height was found non-significant for both the experiments. The variation in plant height was observed between 89.00 to 91.86 cm with the lowest and highest being in case of C₂ and P₃ respectively in the first experiment whereas it was between 92.92 to 93.14 cm in the second experiment. Plant height was comparatively greater in the second experiment than the first year investigation.

4.5.3 Grain and straw yield

Data recorded on grain and straw yield are presented through Tables 4.23 and 4.24 and the effect of puddling and sedimentation period on grain yield are depicted in Figures 4.15 and 4.16.

Table 4.21(a) Effect of puddling by using different equipment on yield attributes of rice crop at three levels of sedimentation period (1998)

Treatments (Puddling equipment)	Number of panicles per hill			Mean	Number of panicles per sq.-m			Mean	Panicle length, cm			Mean
	Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs			
	24	48	72		24	48	72		24	48	72	
Rotary puddler two passes (R ₂)	10.47	10.72	10.12	10.44	251.28	270.14	287.45	262.62	24.26	24.00	24.79	24.35
Rotary puddler three passes (R ₃)	9.99	9.98	10.05	10.00	252.79	251.50	283.41	262.57	23.26	23.26	23.66	23.59
Peg type puddler two passes (P ₂)	10.08	9.63	10.22	9.98	276.90	280.52	295.66	284.36	24.16	24.06	24.15	24.12
Peg type puddler three passes (P ₃)	10.89	11.17	11.30	11.12	259.18	297.79	323.97	293.64	24.28	24.60	24.86	24.58
Cultivator two passes (C ₂)	8.78	8.49	8.76	8.68	242.85	251.81	276.20	256.95	22.38	23.10	22.73	22.74
Cultivator three passes (C ₃)	8.61	9.09	8.50	8.73	234.19	281.79	268.00	261.33	23.42	23.42	23.54	23.46
Mean	9.80	9.85	9.82	9.32	252.87	272.26	289.12	271.42	23.63	23.81	23.94	23.75
Factors			SEm±	CD _(0.05)			SEm±	CD _(0.05)			SEm±	CD _(0.05)
Puddling equipment (a)			0.146	0.461			7.234	22.79			0.227	0.716
Sedimentation period (b)			0.126	NS			3.753	10.96			0.11	NS
Interaction (axb)				NS			9.19	NS			0.26	NS
1.				NS			10.42	NS			0.32	NS
2.												

Interaction (1) For comparing two sedimentation period at same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

Table 4.21(b) Effect of puddling by using different equipment on yield attributes of rice crop at three levels of sedimentation (1998)

Treatments (Puddling equipment)	Number of grains per panicle			Mean	Unfilled grain, %			Mean	Plant height, cm			Mean
	Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs			
	24	48	72		24	48	72		24	48	72	
Rotary puddler two passes (R ₂)	84.40	85.00	92.20	87.20	29.64	30.48	30.53	30.22	90.63	90.16	91.44	90.74
Rotary puddler three passes (R ₃)	80.70	84.00	85.50	83.40	28.27	27.77	29.45	28.49	91.86	90.35	90.37	90.86
Peg type puddler two passes (P ₂)	85.50	86.40	88.75	86.88	30.45	28.85	29.80	29.70	91.37	90.80	90.06	90.74
Peg type puddler three passes (P ₃)	88.50	90.45	91.70	90.22	29.33	30.16	28.42	29.30	90.41	92.89	92.27	91.86
Cultivator two passes (C ₂)	75.00	78.50	78.00	77.17	32.88	30.40	34.20	32.49	89.71	88.88	88.44	89.00
Cultivator three passes (C ₃)	80.50	81.35	82.58	81.48	31.62	29.70	30.00	30.45	89.44	90.36	89.38	89.72
Mean	82.43	84.28	86.45	84.39	30.37	29.57	30.40	30.11	90.57	90.57	90.33	90.49
Factors			SEm±	CD _(0.05)			SEm±	CD _(0.05)			SEm±	CD _(0.05)
Puddling equipment (a)			1.169	3.682			0.724	2.280			0.385	NS
Sedimentation period (b)			0.689	2.012			0.460	NS			0.300	NS
Interaction (axb)												
1.			1.680	NS			1.120	NS			0.735	NS
2.			1.810	NS			1.170	NS			0.778	NS

Table 4.22(a) Effect of puddling by using different equipment on yield attributes of rice crop at three levels of sedimentation period (1999)

Treatments (Puddling equipment)	Number of panicles per hill			Mean	Number of panicles per sq.-m			Mean	Panicle length, cm			Mean
	Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs			
	24	36	48		24	36	48		24	36	48	
Peg type puddler one pass (P ₁)	9.78	10.44	10.10	10.11	323.73	364.67	371.31	353.24	23.68	23.80	23.93	23.80
Peg type puddler two passes (P ₂)	10.75	11.00	11.31	11.04	341.85	366.08	387.59	365.17	23.84	23.83	24.15	23.93
Rotary puddler one pass (R ₁)	10.68	10.66	10.93	10.76	343.90	359.56	388.34	363.93	23.79	23.37	23.96	23.70
Mean	10.40	10.72	10.78	10.63	336.49	363.44	382.41	360.78	23.77	23.67	24.01	23.82
Factors				CD _(0.05)			SEm±	CD _(0.05)			SEm±	CD _(0.05)
Puddling equipment (a)			SEm±	0.680			7.204	NS			0.470	NS
Sedimentation period (b)			0.213	NS			6.722	20.71			0.247	NS
Interaction (a x b)			0.368	NS			11.64	NS			0.429	NS
1.			0.347	NS			11.92	NS			0.586	NS
2.												

Interaction (1) For comparing two sedimentation period at same puddling equipment
Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

Table 4.22(b) Effect of puddling by using different equipment on yield attributes of rice at three levels of sedimentation period (1999)

Treatments (Puddling equipment)	Grains per panicle			Mean	Unfilled grain, %			Mean	Plant height, cm			Mean
	Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs			
	24	36	48		24	36	48		24	36	48	
Peg type puddler one pass (P ₁)	107.13	105.30	108.13	106.86	15.55	15.80	16.00	15.78	91.47	93.49	94.46	93.14
Peg type puddler two passes (P ₂)	114.70	113.10	118.93	115.57	11.91	15.85	15.79	14.52	90.39	92.30	96.07	92.92
Rotary puddler one pass (R ₁)	114.02	107.53	115.73	112.43	15.45	14.27	16.30	15.34	92.59	91.64	94.83	93.02
Mean	111.95	108.63	114.27	111.62	14.31	15.31	16.03	15.21	91.48	92.48	95.12	93.03
Factors												
Puddling equipment (a)				CD _(0.05) 4.24			SEm± 0.324	CD _(0.05) NS			SEm± 0.805	CD _(0.05) NS
Sedimentation period (b)				7.31			0.789	NS			0.687	2.115
Interaction (a x b)												
1.			4.11	NS			1.364	NS			1.189	NS
2.			3.53	NS			1.162	NS			1.261	NS

Interaction (1) For comparing two sedimentation period at same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

4.5.3.1 Grain yield

In the first experiment (1998), it was observed that grain yield increased with sedimentation period for all the treatments (Fig. 4.15). However, the increase was found significant only in case of treatments R₂, P₃ and C₃ between sedimentation period S₄₈ to S₇₂, S₂₄ to S₄₈ and S₂₄ to S₄₈ respectively. The percentage increase in grain yield for the corresponding treatments were 10.38, 14.53 and 10.36, respectively. Comparison of the grain yield at various levels of sedimentation period revealed that at S₂₄, treatment C₂ had lowest yield (2.73 t/ha) compared to rest of the treatments which were statistically *at par*. At S₄₈, grain yield demonstrated similar behaviour with the exception of treatment P₃ where it was significantly higher (3.69 t/ha) than that of other treatments. Rest of the treatments were statistically similar except C₂ in which grain yield was lower than all other treatments. At 72 hours of sedimentation, maximum grain yield of 3.99 t/ha was obtained in case of P₃ which was significantly higher than rest of the treatments. Lowest grain yield of 3.098 t/ha was recorded in case of C₂ which was statistically *at par* with treatments C₃ (3.32 t/ha) and R₃ (3.35 t/ha). However, grain yield in case of R₂ (3.68 t/ha) and P₂ (3.457 t/ha) were statistically non-significant whereas R₂ was statistically superior to R₃, C₂ and C₃. Grain yield in case of treatment P₂ was significantly higher than that of C₂ but equivalent to R₃ and C₃ statistically.

Comparing the main factor (Puddling equipment) means, it was observed that P_3 had the highest yield of 3.63 t/ha followed by R_2 (3.40 t/ha), P_2 (3.37 t/ha), C_3 (3.25 t/ha), R_3 (3.20 t/ha) and C_2 (2.931 t/ha). Treatment P_3 was statistically superior to all other treatments whereas treatment P_2 , R_2 and C_3 are statistically *at par*.

During the second experiment, only sedimentation period effect was observed significant on grain yield. Maximum grain yield of 5.33 t/ha was obtained in case of P_2 at S_{48} followed by R_1 (5.17 t/ha). However, maximum grain yield of 5.08 t/ha in case of treatment P_1 was recorded at S_{36} . It was observed that even with low level of puddling the grain yield was remarkably higher than that obtained in the first experiment.

Grain yield is affected by physico-chemical status of soil and optimum plant population taking into account others parameters constant for all treatments. Increase in grain yield with respect to sedimentation period may be because of better plant population due to less mortality. Poor performance of treatment C_2 may be due to less nutrient availability because of higher leaching losses resulting due to greater hydraulic conductivity. Similar observations were made by Tyagi *et al.* (1975); Sharma and De Datta (1986); Sharma *et al.* (1988) and Rath (1999). Although the puddling quality was good in case of R_3 , its performance in term of yield was found poor. This may be due to low plant population because of higher mortality because of more buried and floating hills. Another reason for poor

yield may be higher bulk density. Reduction in yield as a result of higher bulk density was also reported by Ghildyal and Satyanarayan (1969); Gupta and Jaggi (1979) and Sharma *et al.* (1988). The soil physical properties obtained after puddling were almost similar for treatments P₃ and R₂ but P₃ contributed more grain yield than R₂ which might be due to more number of panicles per sq.-m (Table 4.21). In comparison to C₂ grain yield in case of C₃ was significantly higher. This may be due to less leaching losses because of comparatively lower hydraulic conductivity (Table 4.1).

Low grain yield in the first experiment compared to the second might be due to late transplanting, stem borer infestation and higher percentage of unfilled grains. The hill population was higher in the second experiment because of less mortality and hill spacing. In the second experiment (1999) the hill spacing was set at 10 cm whereas it was 12 cm during the first experiment. The transplanting during the first experiment (1998) was carried out in the last week of July whereas it was performed in the first week of the same month in the second experiment (1999). Although themet @20 kg per hectare was applied to control the stem borer, however, they migrated from the nearby field. There was a heavy rainfall of 283.5 mm in the third week of October i.e. before harvesting which might have facilitated the attack of gandhibug resulting in an increase of unfilled grain to the tune of 28-34 per cent in the first experiment while it was only 12-16 per cent in the second experiment [Tables 4.21(b) and 4.22(b)].

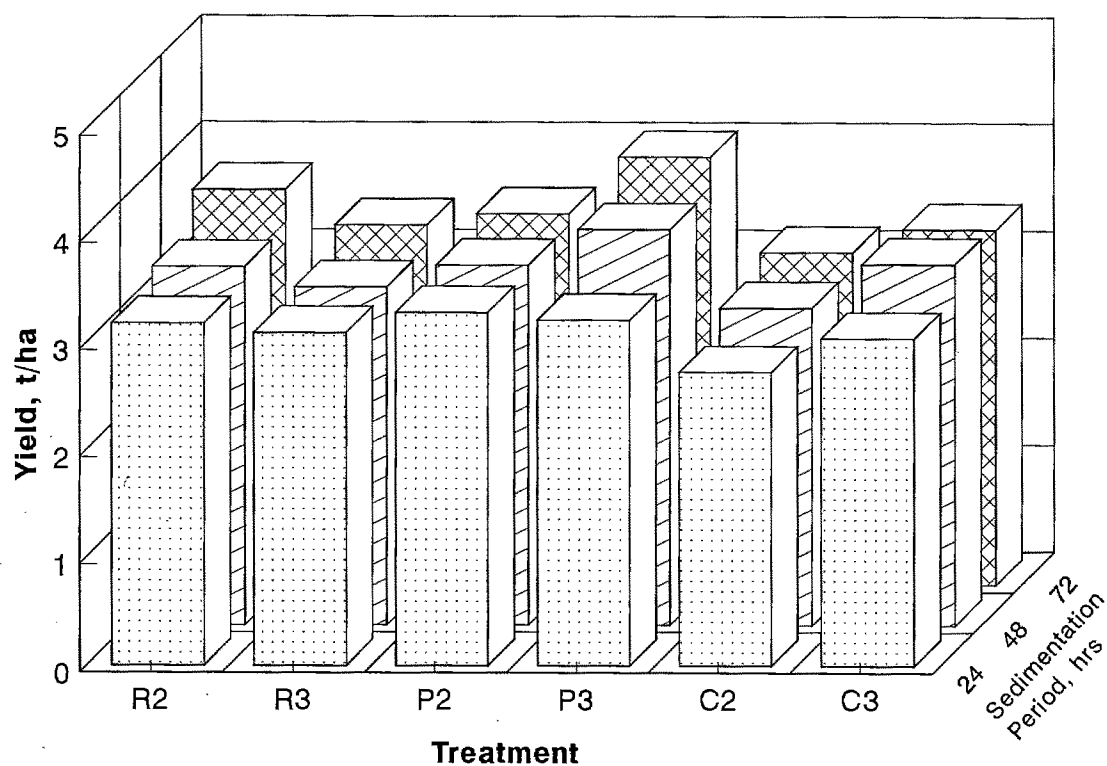


Fig. 4.15 Effect of puddling by using different equipment on yield at three levels of sedimentation period (1998)

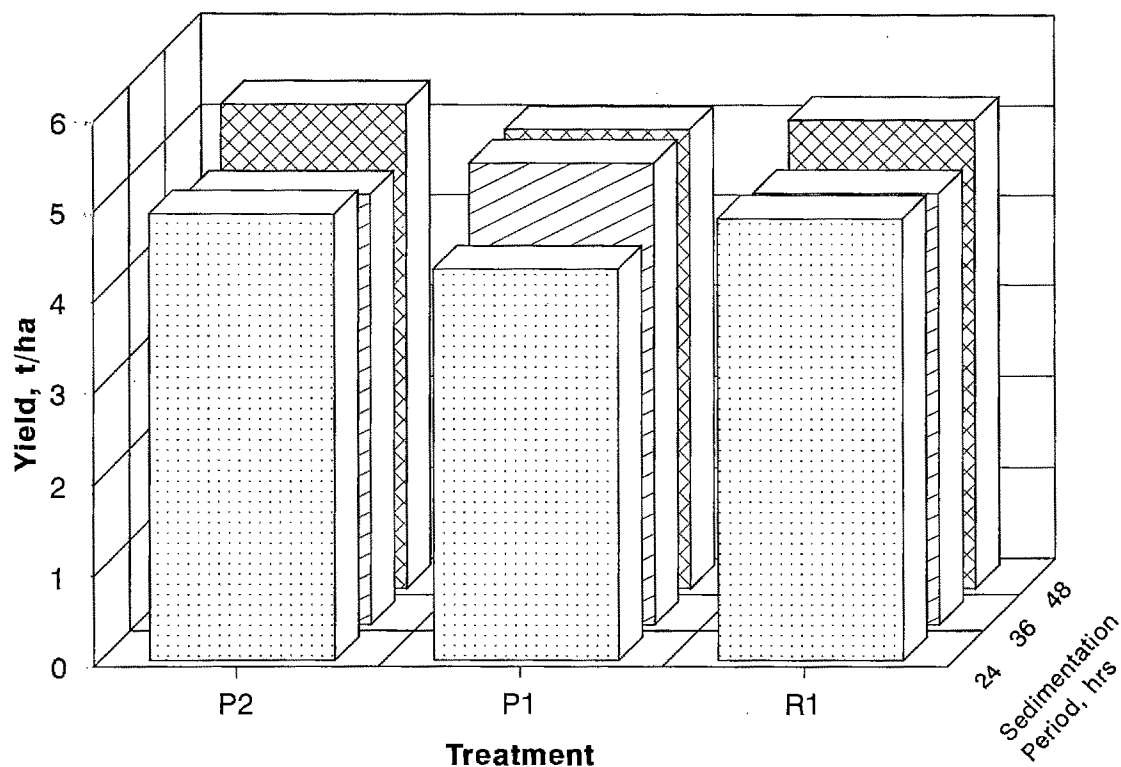


Fig. 4.16 Effect of puddling by using different equipment on yield at three levels of sedimentation period (1999)

The yield was found higher, even if the puddling level was reduced in the second experiment. Well prepared and weed free initial field condition might have improved the quality of puddling in term of bulk density and hydraulic conductivity (Table 4.1) giving a better root and crop growth and ultimately higher yield.

4.5.3.2 Straw yield

Data obtained on straw yield are given in Tables 4.23 and 4.24.

In the first experiment, maximum and minimum straw yield of 7.15 and 6.00 t/ha were observed in case of C₃ at S₄₈ and C₂ at S₂₄ respectively. There was no significant difference in straw yield among treatments at S₂₄. In treatment C₃, highest straw yield of 7.15 t/ha was obtained at S₄₈ which was statistically superior to rest of the treatments. Straw yield in case of treatments P₃ (6.66 t/ha), C₂ (6.58 t/ha) and P₂ (6.56 t/ha) were statistically *at par* but significantly higher than R₂ (6.2 t/ha) and R₃ (6.11 t/ha) which were statistically similar. At 72 hours of sedimentation, maximum straw yield was recorded in case of P₃ (7.13 t/ha). Comparing the main factor (puddling equipment) means, it was observed that treatment R₃ (6.23 t/ha) had the lowest straw yield compared to rest of the treatments which were statistically *at par* (Table 4.23).

In the second experiment, straw yield was non-significant within the treatments and varied between 7.20 to 7.92 t/ha with the lowest and highest being in case of P₁ at S₂₄ and R₁ at S₄₈ respectively.

4.5.3.3 Harvest index

Harvest index is defined as the ratio of grain yield to total biological yield. Data obtained on harvest index have been recorded in Tables 4.23 and 4.24.

In the first experiment, harvest index varied from 30.96 to 35.84 per cent. Minimum harvest index at S_{24} was observed in case of C_2 (31.33%) which was statistically inferior to rest of the treatments. After 48 hours of sedimentation (S_{48}), treatment C_2 had still minimum harvest index (30.96%) whereas treatments P_3 (35.75%) and R_2 (34.97%) were significantly higher than that of P_2 (33.81%) and R_3 (34.01). However, in between these are statistically *at par*. At S_{72} , treatment P_3 had the maximum harvest index of 35.84 per cent which was significantly higher than the rest of the treatments whereas treatments R_2 (34.14%), R_3 (34.35%) and P_2 (34.41%) were statistically *at par* but superior to C_2 (31.49%) and C_3 (32.73%). Comparing the main factor (puddling equipment) means, it was found that treatment P_3 had maximum harvest index (35.16%) which was statistically similar with R_2 (34.54%) and significantly higher than rest of treatments. The minimum harvest index of 31.26 per cent was obtained in case of treatment C_2 .

During the second experiment, comparatively greater harvest index than that of first experiment was observed for all treatments where it varied from 37.75 to 41.64 per cent while minimum being in case of P_1 at S_{24} and

Table 4.23 Effect of puddling by using different equipment on grain yield, straw yield and harvest index (1998)

Treatments (Puddling equipment)	Grain yield, t ha ⁻¹			Straw yield, t ha ⁻¹			Harvest index, %		
	Sedimentation period, hrs			Sedimentation period, hrs			Sedimentation period, hrs		
	24	48	72	24	48	72	24	48	72
Rotary puddler two passes (R ₂)	3.18	3.33	3.68	6.05	6.20	7.03	34.50	34.97	34.14
Rotary puddler three passes (R ₃)	3.10	3.15	3.35	6.18	6.11	6.41	33.39	34.01	34.35
Peg type puddler two passes (P ₂)	3.29	3.35	3.46	6.27	6.56	6.52	34.43	33.81	34.41
Peg type puddler three passes (P ₃)	3.22	3.69	3.99	6.28	6.66	7.14	33.89	35.75	35.84
Cultivator two passes (C ₂)	2.74	2.96	3.10	5.99	6.59	6.74	31.33	30.97	31.49
Cultivator three passes (C ₃)	3.05	3.37	3.32	6.18	7.16	6.89	33.40	32.34	32.46
Mean	3.10	3.31	3.48	6.16	6.55	6.79	33.49	33.64	33.78
Factors			SEm±			SEm±			SEm±
Puddling equipment (a)			0.050			0.0947			0.233
Sedimentation period (b)			0.037			0.0507			0.163
Interaction (a x b)									
1.			0.091			0.124			0.400
2.			0.090			0.139			0.402
			CD _(0.05)			CD _(0.05)			CD _(0.05)
			0.158			0.298			0.737
			0.109			0.148			NS
			0.267			0.363			1.168
			0.269			0.420			1.204

Interaction (1) For comparing two sedimentation period at same puddling equipment
Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

Table 4.24 Effect of puddling by using different equipment on grain yield, straw yield and harvest index (1999)

Treatments (Puddling equipment)	Grain yield, t ha ⁻¹			Mean	Straw yield, t ha ⁻¹			Mean	Harvest index, %			Mean
	Sedimentation period, hrs				Sedimentation period, hrs				Sedimentation period, hrs			
	24	36	48		24	36	48		24	36	48	
Peg type puddler one pass (P ₁)	4.31	5.08	5.06	4.82	7.20	7.82	7.79	7.60	37.75	39.41	39.38	38.85
Peg type puddler two passes (P ₂)	4.92	4.73	5.33	4.99	7.58	7.24	7.51	7.44	39.63	39.67	41.64	40.32
Rotary puddler one pass (R ₁)	4.87	4.75	5.17	4.93	7.88	7.65	7.92	7.82	38.16	38.30	39.49	38.65
Factors			SEm±	CD _(0.05)			SEm±	CD _(0.05)			SEm±	CD _(0.05)
Mean	4.70	4.86	5.19	4.91	7.55	7.57	7.74	7.62	38.52	39.13	40.17	39.27
Puddling equipment (a)			0.173	NS			0.338	NS			0.890	NS
Sedimentation period (b)			0.101	0.311			0.138	NS			0.348	1.072
Interaction (a x b)												
1.			0.175	NS			0.239	NS			0.603	NS
2.			0.224	NS			0.390	NS			0.102	NS

Interaction (1) For comparing two sedimentation period at same puddling equipment

Interaction (2) For comparing two puddling equipment at same or different levels of sedimentation period

maximum in case of P_2 at S_{48} . However, there was no significant difference in harvest index among treatments.

4.6 Field Evaluation of the Transplanter and its Economics

The performance evaluation of the transplanter was carried out in a plot of size 80x25 sq.-m and the results are presented in Table 4.25. The transplanter was operated after 48 hours of sedimentation period by using peg type puddler with two passes.

4.6.1 Field performance

The field capacity of self-propelled rice transplanter was found to be 0.15 ha hr^{-1} with field efficiency of 58.32 per cent at an average operating speed of 1.34 km hr^{-1} . The turning time loss was estimated as 6.10 per cent indicating good maneuverability of the equipment and ideal field size. Since, the length of the field was 80 m compared to its width of 25 m, therefore, the number of turnings reduced which was amply demonstrated by a high field machine index of 90.53 per cent. Seedling mat feeding and their adjustment consumed 25.35 per cent of total time of operation even if 3 persons (two loaders and one feeder) were employed into service. The occasional clogging of transplanting fingers with seedling was also observed because of buckling of mat at the base of tray. The fuel consumption per hour was measured as 0.40 l which amounted to a fuel consumption of 2.70 l ha^{-1} . There was no major problems encountered during the operation of the transplanter.

Table 4.25 Field evaluation of self-propelled transplanter

Sl.No.	Parameters	Values
1	Average operating speed, km hr ⁻¹	1.34
2	Average turning time, s	20.50
3	Width of operation, cm	196.00
4	Field capacity, ha/hr	0.15
5	Field efficiency, %	58.32
7	Per cent distribution of operating time	
i)	Turning time	6.10
ii)	Mat feeding and adjustment	25.35
iii)	Transplanting time	60.23
iv)	Others (Replacement of transplanting fingers, engine shut down etc.)	8.32
8	Field machine index, %	90.53
9	Fuel consumption, l/hr	0.40
10	Seedling mat requirement, number/ha (mat size : 50 x 22 cm)	390.00

4.6.2 Crop performance under different transplanting methods

Crop performance of machine transplanting was compared with that of manual method. Manual transplanting was done in two ways i.e. (i) line and (ii) random transplanting. The data on crop performance are presented in Table 4.26.

It was observed that manual line transplanting had maximum hill population of 38 per sq.-m whereas it was minimum in random transplanting (28 sq.-m). In case of transplanting by self-propelled transplanter, the average hill population was observed to be 33 per sq.-m. The average number of seedlings per hill were found to be 2.70, 3.0 and 3.20 in case of machine, manual line and random transplanting respectively. Number of panicles per hill were maximum in case of transplanter followed by manual row and random transplanting. Highest yield of 5.62 t/ha was recorded in case of machine compared to 5.54 and 4.57 t/ha in line and random transplanting respectively which were 1.41 and 17.48 per cent less than that of the transplanter. Low yield in random transplanting may be due to poor hill population leading to lesser panicles per sq.-m. Although, the hill population was highest in case of manual line transplanting than that of machine, the yield was comparatively less. The advantage of more hill population might have been offset by comparatively lesser number of panicles per hill and subsequently less panicles per sq.-cm (Table 4.26). More number of panicles per hill were observed due to earlier establishment

Table 4.26 Crop performance under different transplanting methods (Variety : Govind)

Sl. No.	Parameters	Machine transplanting	Manual transplanting	
			Line	Random
1	No. of hills per sq.-m	33.00	38.00	28.00
2	Seedling per hill	2.70	3.00	3.20
3	No. of panicles per hill	9.97	7.80	8.53
4	No. of panicles per sq.-m	329	296	239
5	Grains per panicle	116	123	115
6	Panicle length, cm	24.40	25.34	24.58
7	Per cent unfilled grain per panicle	15.00	20.95	15.63
8	Plant height, cm	95.56	98.00	100.47
9	Yield, t ha ⁻¹			
i)	Grain	5.62	5.54	4.57
ii)	Straw	7.17	7.34	6.83
10	Harvest index, %	43.93	43.00	40.00

of rice plants on the field in case of machine transplanting in comparison to manual method. In fact, plants remained live (green) due to existence of soil with roots which resulted in their earlier establishment and ultimately led to more panicles per sq.-m. However, there was not appreciable difference in yield between machine and manual line transplanting.

4.6.3 Economics

The cost of transplanting by different methods have been determined and presented in Tables A.8 and A.9 and Fig. 4.17.

The cost of operation of the transplanter per hour were found as Rs. 109.30 and Rs. 82.56 for one season (300 hours use) and two seasons (500 hours use) per year respectively (Table A.8). Taking into account the field capacity of the machine, the cost of transplanting amounted to Rs. 1491.50 and Rs. 1313.00 per ha, respectively for the above mentioned annual usage. The cost of transplanting also includes the cost of nursery raising, its management, uprooting, headland manual transplanting and gap filling (Table A.8). The cost of manual line and random transplanting were estimated as Rs. 2988.00 and Rs. 2563.00 per ha respectively (Fig. 4.17) which gives a monetary benefit of Rs. 1497.00 and Rs. 1072.00 per ha in case of transplanting with its 300 hours of use over that of line and random transplanting in one season. The corresponding benefits, if the transplanter is used for two seasons (500 hours) in a year, are Rs. 1675.00 and Rs. 1250.00 per ha respectively.

4.6.4 Break even point

The transplanter because of heavy initial investment, accrued a high annual fixed cost (Table 4.27) which is gradually reduced as the area of coverage per year increases (Table 4.27). The minimum area (ha), the transplanter should cover so that its cost of transplanting per ha equals to that of manual transplanting, is termed as break even point. The break even point was determined to be 10.32 and 13.21 ha with respect to manual line and random transplanting respectively (Fig. 4.18).

4.6.5 Payback period

The payback period which indicates the return of the investment, depends upon the annual use in term of area of coverage (Fig. 4.19). It was found that the pay back period would be 10.45 years when the annual use of the transplanter is 15 ha. For an use of 60 ha in a year, the payback period will only be one year. It is inferred that the area of coverage should be as much as possible to make the transplanter economically viable. It should be put into custom hiring service if farmer does not have adequate area for transplanting.

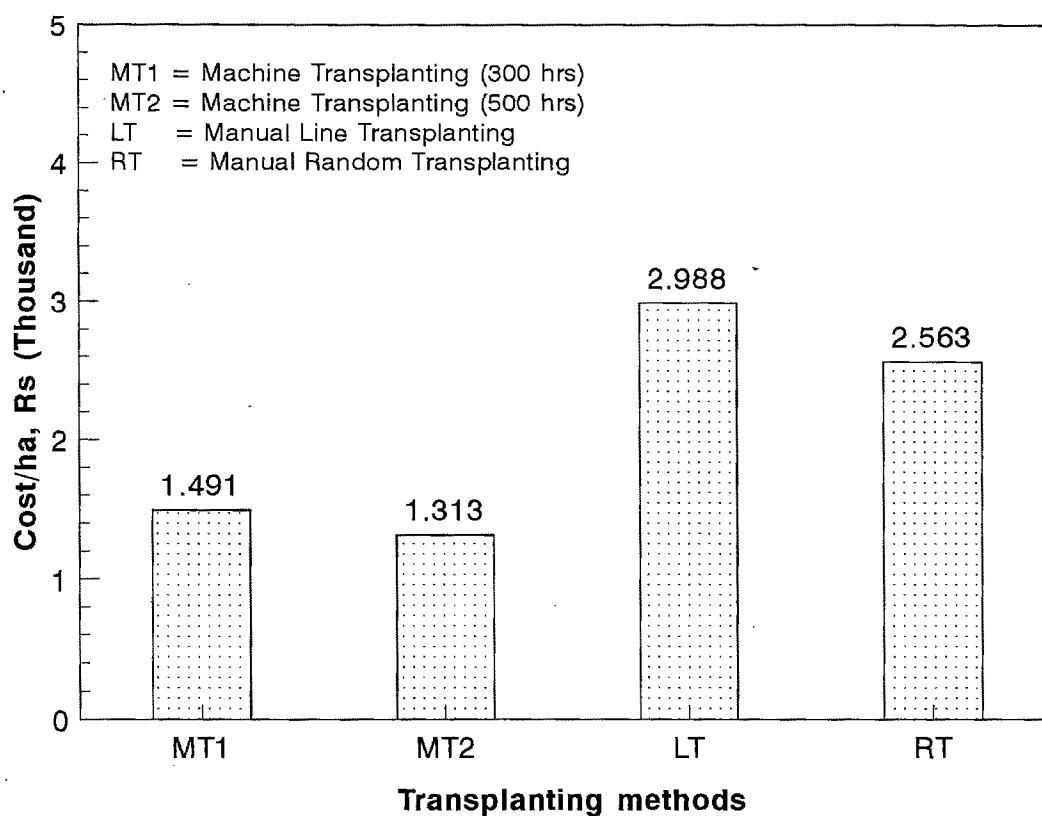


Fig 4.17 Comparative cost of transplanting under different methods

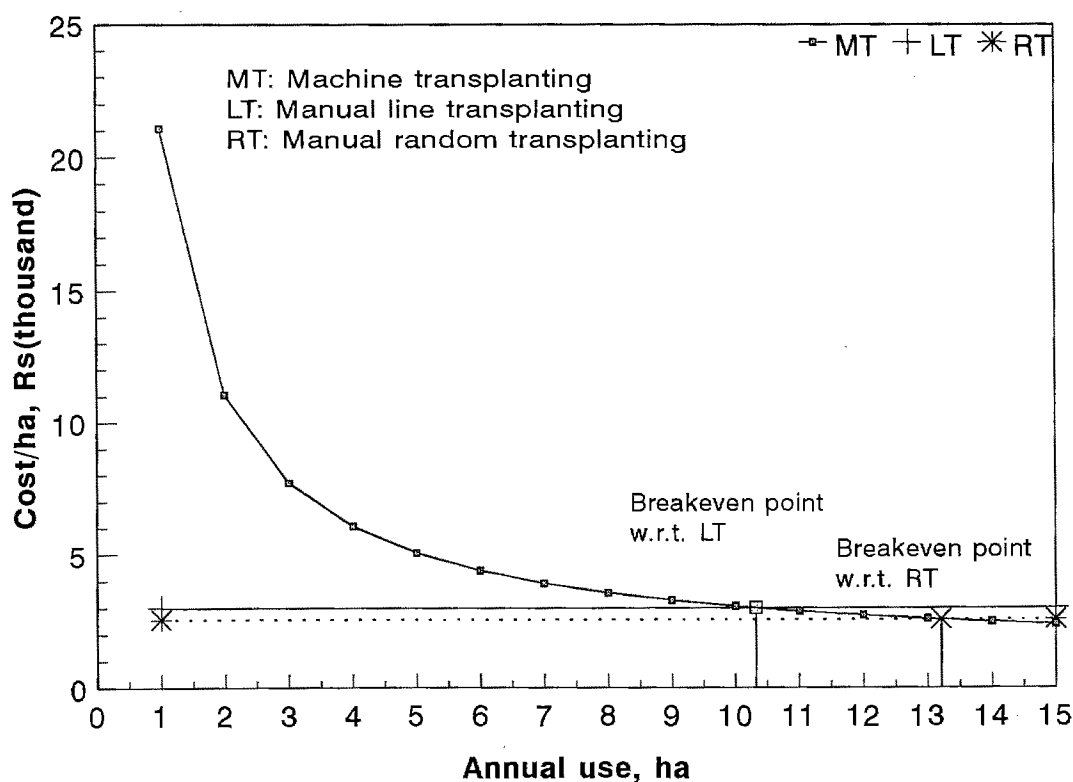


Fig 4.18 Effect of annual usage on cost of transplanting per hectare of the transplanter and its breakeven point

Table 4.27 Cost of transplating (Rs./ha) of the transplanter based on annual area and cost of manual transplanting

Sl. No.	Annual area covered by transplanter, ha yr ⁻¹	Annual fixed cost, Rs ha ⁻¹	Variable cost,* Rs ha ⁻¹	Total cost, Rs ha ⁻¹	Cost of manual transplanting, Rs ha ⁻¹	
					Line	Random
1	1	20022	1047	21069	2988	2563
2	2	10011	1047	11058	2988	2563
3	3	6674	1047	7721	2988	2563
4	4	5006	1047	6053	2988	2563
5	5	4005	1047	5052	2988	2563
6	6	3337	1047	4384	2988	2563
7	7	2860	1047	3907	2988	2563
8	8	2503	1047	3550	2988	2563
9	9	2225	1047	3272	2988	2563
10	10	2002	1047	3049	2988	2563
11	11	1820	1047	2867	2988	2563
12	12	1669	1047	2716	2988	2563
13	13	1540	1047	2587	2988	2563
14	14	1430	1047	2477	2988	2563
15	15	1335	1047	2382	2988	2563

* Variable cost per hectare includes machine variable cost, cost of nursery raising, uprooting, gap filling and cost of polythene.

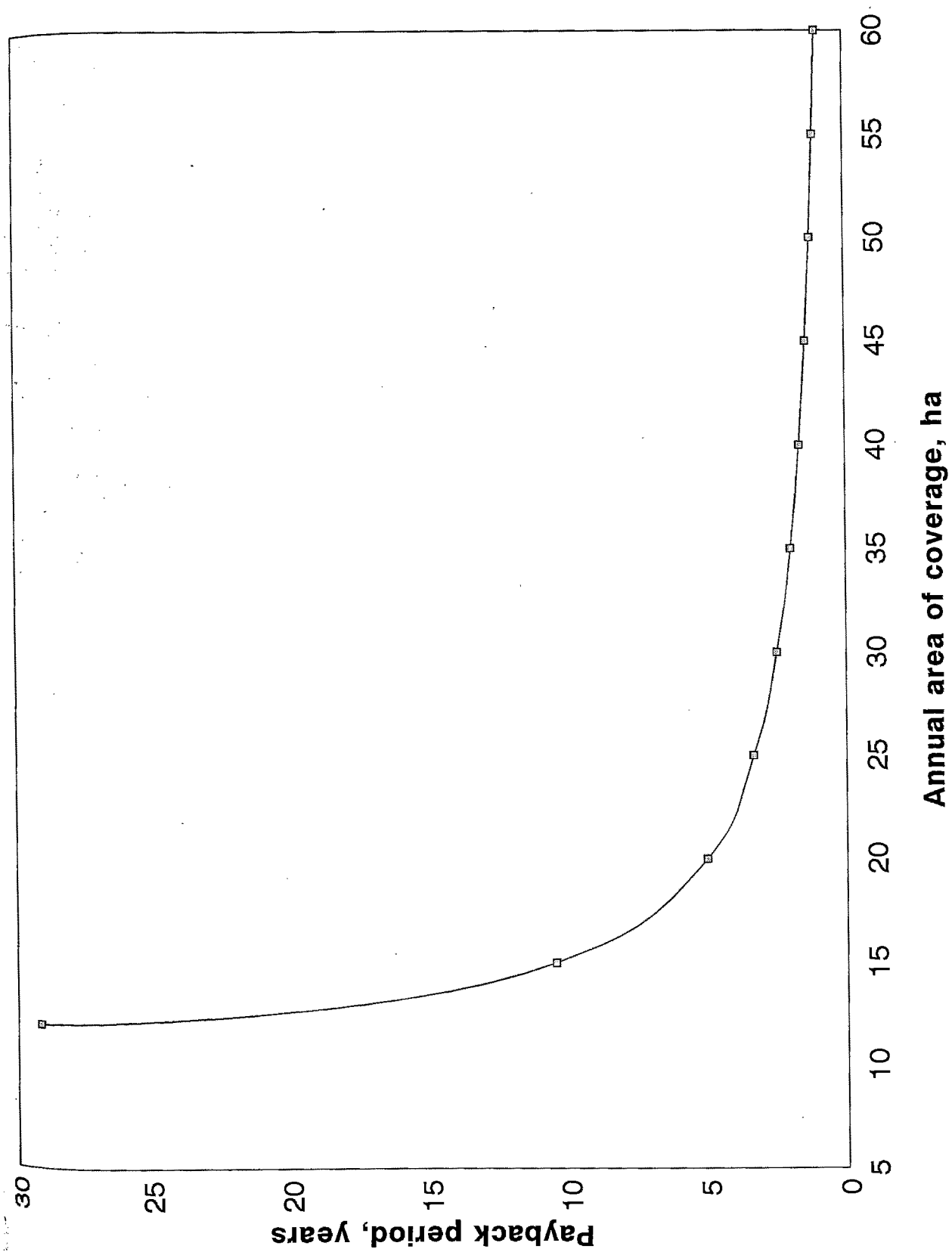


Fig. 4.19 Effect of annual use on payback period of transplanter

Table 4.28 Payback period of the transplanter with respect to annual use

Sl. No.	Area trans-planted, ha yr. ⁻¹	Fixed cost, Rs. yr. ⁻¹	Total variable cost, Rs. yr. ⁻¹	Total cost of transplanting, Rs. yr. ⁻¹	Cost of manual line transplanting, Rs. yr. ⁻¹	Benefits, Rs. yr. ⁻¹	Payback period, yrs.*
1	2	3	4	5	6	7=6-5	8
1	12	20022	12564	32586	35856	3270	29.00
2	15	20022	15705	35727	44820	9093	10.45
3	20	20022	20940	40962	59760	18798	5.00
4	25	20022	26175	46197	74700	28503	3.33
5	30	20022	31410	51432	89640	38208	2.49
6	35	20022	36645	56667	104580	47913	1.98
7	40	20022	41880	61902	119520	57618	1.65
8	45	20022	47115	67137	134460	67323	1.41
9	50	20022	52350	72372	149400	77028	1.23
10	55	20022	57585	77607	164340	86733	1.10
11	60	20022	62820	82842	179280	96438	1.00

* Pay back period = Initial investment/benefits

SUMMARY AND CONCLUSIONS

5. SUMMARY AND CONCLUSIONS

Rice transplanting by self-propelled rice transplanter could provide timeliness in operation, saving in cost and minimizing human drudgery. However, it needs an ideal puddled soil condition for its satisfactory performance in respect of depth and degree of puddling and soil strength. Puddling creates a favourable physico-chemical and microbiological environment for crop growth. However, excess puddling leads to the requirement of longer sedimentation period for the satisfactory operation of self propelled rice transplanter. Hence, it was felt that a comprehensive study in respect of effect of puddled soil characteristics on performance of self-propelled rice transplanter as well as its impact on rice crop need to be investigated. Keeping these aspects in mind, an experiment was carried out with three puddling equipment (Rotary puddler, Peg type puddler and Cultivator) and two levels of puddling (two and three passes) under three sedimentation period 24, 48 and 72 hours. On the basis of the findings of the aforesaid study second experiment was conducted in a well prepared and weed free field with peg type puddler (one and two passes) and rotary puddler (one pass) with a view to reduce sedimentation period. Two laboratory studies, first effect of seedling characteristics on transplanter performance and second seedling withdrawal force in puddled soil were also undertaken. The performance of the transplanter in terms of field capacity,

field efficiency and fuel consumption was taken up in the field and the crop performance was compared with that of manual transplanting. Economics of transplanter in comparison to manual transplanting was also worked out.

Based on the experimental results, the following inferences have been drawn :

1. The puddling index was found to increase with level of puddling. The maximum puddling index of 43.15 per cent was recorded in case of R_3 followed by P_3 (38.33%), R_2 (36.27%), P_2 (27.93%), C_3 (26.33%) and C_2 (15.20%) in the first experiment whereas maximum puddling index of 30.13 per cent was observed for P_2 treatment.

Bulk density also increased with puddling level. Maximum and minimum bulk density of 1.606 and 1.446 Mg m^{-3} were found in case of R_3 and C_2 in the first experiment at 30 DAP whereas it varied non-significantly from 1.472 to 1.507 Mg m^{-3} in the second experiment.

Hydraulic conductivity decreased after puddling over that of saturated soil in all treatments. In the first experiment, minimum hydraulic conductivity of 0.191 mm hr^{-1} was obtained in case of R_3 which was statistically *at par* with R_2 (0.234 mm hr^{-1}) and P_3 (0.239 mm hr^{-1}) at 30 DAP. In the second experiment, hydraulic conductivity varied between 0.257 to 0.315 mm hr^{-1} at 30 DAP.

2. Cone index (0-15 cm depth) decreased after puddling over that of saturated soil, but the reduction was more in case of rotary puddler

compared to other puddling equipment. At S_{24} , cone index decreased from 150.27 to 109.34, 207.56 to 141.07 and 248.82 to 202.51 kPa when puddling level increased from 2 to 3 passes in case of rotary puddler, peg type puddler and cultivator respectively. Cone index increased with sedimentation period and the increase was faster between 24 to 48 hours for treatments P_2 , C_2 and C_3 and between 48 to 72 hours for R_2 , R_3 and P_3 . In the second experiment, minimum cone index was recorded for P_2 (211.78 kPa) at 24 hours of sedimentation.

3. In the first experiment, maximum and minimum sinkage resistance at S_{24} were found to be 19.16 and 37.20 g cm⁻² in case of treatment R_3 and C_2 , respectively. Sinkage resistance increased significantly with sedimentation period but the increase was found faster between 24 to 48 hours in case of treatments P_2 , C_2 and C_3 and between 48 to 72 hours for R_2 , R_3 and P_3 . In the second experiment, rate of increase was observed higher between 24 to 36 hours of sedimentation period.

4. Considering float sinkage between 1-2 cm as the ideal condition for transplanting, it was seen that the predicted sinkage at contact pressure of 20.29 g cm⁻² was found within 1-2 cm for treatments P_2 , C_2 and C_3 after 48 hours of sedimentation whereas it was so after 72 hours for R_2 , R_3 and P_3 . In the second experiment the similar condition was found after 36 hours.

5. In the laboratory study, it was observed that number of seedlings per hill increased with increase in operating speed and age of seedling. Density

of mat significantly affected the number of seedlings per hill. With increase in mat moisture content, the seedlings per hill increased but the increase was found non-significant between 20-25 and 30-35 per cent moisture range. The optimum 2-3 seedlings per hill was met with mat density of 2.65 seedlings per sq.-cm at 20-25 per cent moisture.

Missing hill percentage varied between 8.59 to 14.85, 6.25 to 7.97 and 3.13 to 9.38 per cent for seedling density of 1.76, 2.17 and 2.65 per sq.-cm which were obtained at seed rate of 70, 90 and 110 g per mat (mat size : 50 x 22 sq.-cm). It was observed that hill missing was due to non-uniformity in seedling distribution in the mat.

Mechanical damage to seedling varied between 0.00 to 6.63 per cent. Seedling age and operating speed had significant effect on mechanical damage.

6. Drag force of the transplanter decreased as the water level increased for all treatments as well as sedimentation period. It was more pronounced at 72 hours of sedimentation with a decrease of 30.96 and 69.14 per cent when water level increased from <1 to 1-2 cm and 1-2 to 2-4 cm range respectively. Minimum and maximum drag force of 1.44 kN and 2.81 kN were observed at <1 and 2-4 cm water level at 72 hours of sedimentation.

7. Seedling withdrawal force is an index of seedling anchorage in the puddled soil. At lower sedimentation period (S_{24}), the seedling withdrawal force was conspicuously low with minimum value of 0.93 N in case of R_3 at

3 cm depth of transplanting. Seedling withdrawal force increased at a faster rate between 48 to 72 hours in case of treatments R_2 , R_3 and P_3 and similar phenomenon was observed between 24 to 48 hours in case of P_2 , C_2 and C_3 .

8. Depth of transplanting increased with increase in level of puddling and was higher in case of rotary puddler compared to others at a given level of puddling. Depth of puddling varied between 10.72-14.36 cm and 8.91-10.93 cm in the first and second experiment respectively. The traction wheel touched the hardpan and provided necessary thrust to propel the transplanter. At the same time, sinkage of the float was also not so high to create a bearing failure. Hence, mobility problem of the transplanter was not encountered during experimentation.

9. Increase of traction wheel slip with respect to sedimentation period was observed for all treatments. Traction wheel slip was found to vary between 2.55 to 13.59 and 2.13 to 8.92 per cent in the first and second experiment respectively.

10. Hill spacing was observed more than the preset spacing for all treatments in both the experiments at S_{24} . It decreased with sedimentation period and was less than the preset spacing in case of P_2 (11.88 cm), C_2 (11.62 cm) and C_3 (11.98 cm) at S_{48} with a further decrease at S_{72} . Hill spacing in the second experiment was observed always above the preset spacing with variation between 10.09 to 10.94 cm for all sedimentation period.

11. Deviation in row spacing from the fixed spacing of 23.80 cm provided in the machine was found to be 4.11 to 8.82 and 5.46 to 5.81 per cent at S_{24} in the first and second experiment respectively. It decreased with increase in sedimentation period.

12. Buried and floating hill percentage varied between 4.49 to 11.09 and 4.00 to 9.56 per cent at S_{24} in the first experiment and decreased with increase of sedimentation period. However, it was found less in treatments P_2 , C_2 and C_3 at S_{48} indicating faster settling of soil particles. At S_{72} , buried and floating hill was considerably low for all the treatments except C_2 where there was an increase from 1.28 to 3.00 per cent. In the second experiment, buried and floating hill was lower compared to first experiment due to reduced level of puddling.

13. Hill mortality was considerably high at 24 hours of sedimentation period for R_3 (17.38%), R_2 (16.24%) and P_3 (15.26%) compared to P_2 (9.46%), C_2 (7.78%) and C_3 (9.94%). Mortality decreased with sedimentation period but the decrease was more pronounced in case of P_2 , C_2 and C_3 at S_{48} . In the second experiment, mortality was maximum in case of P_2 (8.27%) followed by R_1 (5.37%) and P_1 (4.88%) at S_{24} and further decreased with increase in sedimentation period.

14. Hill population increased with sedimentation period due to reduction in mortality and hill spacing. But in some cases, it showed inconsistent behaviour because of greater variations in missing hills. However, missing

hills being controllable, hill population is dependent upon the size mortality which in turn depends upon puddled soil condition.

15. Crop yield increased with sedimentation period for both the experiments but the increase was significant with an increase of 10.38, 14.53 and 10.36 per cent only in case of R_2 , P_3 and C_3 between sedimentation period of S_{48} to S_{72} , S_{24} to S_{48} and S_{24} to S_{48} , respectively in the first experiment. Comparing the main factor (puddling equipment) means, it was observed that P_3 contributed maximum grain yield of 3.63 t ha^{-1} whereas it was minimum with C_2 (2.93 t ha^{-1}). In the second experiment grain yield varied non-significantly between 4.82 to 4.99 t ha^{-1} . Grain yield was appreciably higher in the second experiment even if the level of puddling was reduced.

16. The field capacity, field efficiency and fuel consumption of the transplanter were found to be 0.15 ha hr^{-1} , 58.32 per cent and 0.40 l hr^{-1} , respectively. It was noticed that mat feeding consumed 25.35 per cent of total operating time.

17. Hill population per sq.-m was found to be maximum (38) in manual line transplanting whereas number of panicles per sq.-m (329) was maximum in case of the transplanter. Highest grain yield of 5.62 t ha^{-1} was recorded in case of machine transplanting compared to 5.54 and 4.47 t ha^{-1} in manual row and random transplanting which was 1.41 and 17.48 per cent less than that of the transplanter.

18. Cost of transplanting per ha for self-propelled transplanter was estimated to be Rs. 1491.50 and Rs. 1313.00 for one season (300 hours) and two seasons (500 hours) of use in a year compared to Rs. 2988.00 and Rs. 2563.00 for manual line and random transplanting.

19. The transplanter break even point in term of annual area of coverage was 10.31 and 13.21 ha in comparison to manual line and random transplanting. Payback period of the self-propelled transplanter decreased with annual area of coverage and it was found to be 10.45 years and 1 year if annual area of coverage is 15 and 60 ha respectively.

Based on above results, the following conclusions are drawn :

1. The performance of the rotary puddler in terms of puddling index and hydraulic conductivity was better compared to peg type puddler and cultivator.
2. Rotary puddler with two as well as three passes and peg type puddler with three passes required 72 hours of sedimentation period for satisfactory performance of the transplanter whereas peg type puddler with two passes and cultivator with two and three passes required 48 hours of sedimentation. Reducing the puddling level further to one pass in a well prepared weed free initial field condition, the transplanter may be operated after 24 to 36 hours of sedimentation in case of rotary and peg type puddler. Since, there was no significant difference in grain yield with reduced level of puddling,

therefore, rotary and peg type puddler may be used with one pass so as to minimize sedimentation period.

3. Seedling mat density of 2.65 per sq.-cm obtained with seed rate of 110 g mat⁻¹ (mat size : 50 x 22 sq-cm) was found most suitable with mat moisture content of 20-25 per cent to obtain the agronomical requirement of 2-3 seedling per hill with minimum missing of hills. In order to minimize mechanical damage to seedling, 30 days old seedlings were found better.

4. The field capacity of the transplanter was 0.15 ha hr⁻¹ with a field efficiency of 58.32 per cent. Transplanting by self-propelled rice transplanter gave a monetary benefit of Rs. 1497.00 and Rs. 1072.00 per ha in comparison to manual line and random transplanting respectively.

Since, the study has been confined only to silty clay loam soil, therefore, it is suggested to have further investigations in light soil (sandy loam) to identify the puddling equipment, level of puddling and its sedimentation period required for satisfactory performance of the transplanter.

LITERATURE CITED

LITERATURE CITED

- Agarwal, M.C.; Singh, R.; Batra, M.L. and Agarwal, R.P. 1978. Evaluation of different implements for puddling of rice soils. *IL RISO*. 27(4) : 301-305.
- Anonymous. 1994. World Rice Statistics. IRRI, Manila 1099, Philippines.
- Anonymous. 1995. Annual Report, AICRP on FIM. APAU, Rajendranagar, Hyderabad.
- Anonymous. 1999(a). Half-yearly report AICRP on FIM, PAU, Ludhiana.
- Anonymous. 1999(b). Survey of Indian Agriculture.
- Alagusundaram, K.R.; Gee Clough, D. and Jayas, D.S. 1990. Drag force analysis of deep placement fertilizer applicator for rice. *AMA*. 21(2) : 21-26.
- Alva, A.K. and Peterson, L. 1979. Soil physical properties in relation to rice yield and water consumption under flooded and unflooded condition. *Plant Soil*. 52 : 353-363.
- ASAE Standard, 42nd ed. 1995. Terminology for soil engaging components for conservation tillage planters, drills and seeders, S₄₇₇ Dec. 93, pp. 312-317.
- ASAE Standard, 42th ed. 1995. ASAE Engineering Practice, ASAE EP 285.7, use of SI Units. St. Joseph, Michigan. pp. 30-37.
- Awadhwai, N.K. and Singh, C.P. 1985a. Dynamic behaviour of wet soil and tillage and traction in wet land. *AMA*. 16(2) : 11-20.
- Awadhwai, N.K. and Singh, C.P. 1985b. Characterization of puddled soil. *J. Agric. Engg., ISAE*. 22(1) : 9-14.
- Baboo, Bangali. 1976. Effect of lug angle of cage wheel on traction and puddling performance of dual wheels. Thesis, M.Tech. GBPUAT, Pantnagar. 98 p.

- Bajpai, R.K. 1994.** Effect of tillage methods and fertility levels on soil physical properties, crop growth and productivity in rice-wheat cropping system. Thesis, Ph.D. GBPUAT, Pantnagar.
- Beacher, B.P. and Strickling, E. 1955.** Effect of puddling on water stability and bulk density of aggregates of certain Maryland soils. *Soil Sci.* 80 : 363-373.
- Bekker, M.G. 1955.** A system of physical and geometrical soil values for the determination of vehicle performance and soil trafficability. Proc. Inter. Service Symp., Inst. of Tech. & Duke Univ., Office of Ord. Res., Durham, NC.
- Bernstein, R. 1913.** Problems of experimental mechanics of plough. Der Motorwagen No. 16.
- Bhadoria, P.B.S. 1995.** Measurement of soil physical properties. Lecture notes. In : IRRI Training Programme on Engineering for Rice Agriculture, held at IIT, Kharagpur from 6 Nov. to 15 Dec.
- Bhan, S. and Padwal, V.D. 1976.** Effect of soil and water management practices on yield and water use of direct seeded rice under light textured alluvium of Uttar Pradesh. *Indian J. Agric. Sci.* 46 : 503-506.
- Bhatnagar, D.K. and Sharma, S.N. 1975.** Comparative study of different methods of seeding on the yield of rice with and without weeding. *Indian J. Agronomy.* 20(1) : 58-59.
- Bhole, N.G. 1963.** Measurement of quality of puddle. Thesis, M.Tech. IIT, Kharagpur, India.
- Bhole, N.G. and Arya, A.C. 1964.** Measurement of quality of puddle. *J. ISAE.* 1(1) : 27-30.
- Bhole, N.G. and Pandya, A.C. 1965.** Puddling of soil. *The Harvester.* (J. Agril. Engg. Soc.), IIT, Kharagpur. 7 : 11-17.
- Black, C.A. 1971.** Methods of soil analysis – Part 2. *Am. Soc. Agron. Inc.* Publisher, Madison, Wisconsin, USA.
- Bodman, G.B. and Rubin, J. 1948.** Soil puddling. *Soil Sci. Soc. Am. Proc.* 13 : 27-37.

Bolton, F.R. and De Datta, S.K. 1979. Dry soil mulching in tropical rice. *Soil Sci. Plant Nutr.* (Tokyo). 25 : 173-181.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analyses of soils. *Agron. J.* 54 : 464-465.

Bremner, J.M. and Mulveney, C.S. 1982. Nitrogen-Total. In : Page, A.L.; Miller, R.H. and Kineey, D.R. (eds.). Methods of soil analysis – Part II. *Am. Soc. Agron. Inc. Soil Sci. Soc. Am. Inc.* Madison, Wisconsin, USA. pp. 595-624.

Chaudhary, T.N. 1965. Effect of different tillage methods on soil structure. Thesis, DIIT, IIT, Kharagpur.

Curfs, H.P.F. and Moomaw, J.C. 1973. Tillage investigations of irrigated and dryland soils in West Africa. Proc. 6th Int. Conf. on Soil Tillage, Wageningen, Netherlands.

Dayanand and Singh, A.K. 1980. Puddled rice proves better. *Seeds Farms.* 6(5) : 35.

De Datta, S.K. and Kerim, M.S.A.A. 1974. Water and nitrogen economy in rainfed rice as affected by puddling. *Soil Sci. Soc. Am. Proc.* 38(3) : 515-518.

Deshpande, S.B.; Fahrenbacher, J.B. and Ray, B.W. 1971. Mollisols of Tarai region of Uttar Pradesh, Northern India. II. Genesis and Classification. *Geoderma.* 6 : 195-201.

Dutta, A.K. 1948. Puddling and their treatments in relation to soil structure and crop growth. *J. Am. Soc. Agron.* 40 : 324-330.

Freitag, D.R. 1968. Penetration test for soil measurements. *Trans. ASAE.* pp. 750-753.

Frenkel, H.; Goertzen, J.O. and Rhoades, J.D. 1978. Effects of type and content, exchangeable sodium percentage and electrolyte concentration on clay dispersion and soil hydraulic conductivity. *Soil Sci. Soc. Am. J.* 42 : 32-39.

Gangil, S. 1993. Design, development and performance evaluation of urea super granule applicator. Thesis, M.Tech. GBPUAT, Pantnagar.

- Garg *et al.* 1999. Effect of ground contact pressure and soil settlement period on paddy transplanter sinkage. Personal Communication, PAU, Ludhiana.
- Garg, I.K.; Sharma, V.K. and Mahal, J.S. 1997. Development and field evaluation of manually-operated, six-row paddy transplanter. *AMA*. 28(4) : 21-28.
- Garg, I.K.; Singh, C.P. and Sharma, V.K. 1982. Influence of selected seedling mat parameters and planting speed on performance of rice transplanter. *AMA, Spring*. pp. 27-33.
- Gee-Clough, D. 1985. The special problem of wetland traction and flotation. *J. Agric. Engg. Res.* 32 : 279-288.
- Gee-Clough, D.; Palaniappan, S. and Gavino, R.B. 1990. Field performance tests of turtle tiller and boat tractor. *AMA*. 21(3) : 9-12.
- Ghildyal, B.P. 1978. Effect of compaction and puddling on soil physical properties and rice growth. *In* : IRRI. *Soil and Rice*. pp. 317-336.
- Ghildyal, B.P. and Satyanarayana, T. 1965. Effect of compaction on physical properties of four different soils in India. *J. Indian Soc. Soil Sci.* 13 : 149-155.
- Greenland, D.J. 1981. Recent progress in studies on soil structure and its relation to properties and management of paddy soils. pp. 42-58. *In* : Proceedings Symposium. Paddy Soil Nanjing, China. 19-24 Oct. 1980. Science Press, Beijing, China.
- Gupta, C.P. and Pandya, A.C. 1966. Rheological behaviour of soil under static loading. *Trans. ASAE*. 9(5) : 718-724.
- Gupta, J.P. and Kathavate, Y.V. 1972. Effect of soil compaction and different water regimes on oxygen diffusion, nutrient uptake, growth and yield of rice. *IL RISO*. 21(3) : 191-200.
- Gupta, R.K. and Jaggi, I.K. 1979. Soil physical conditions and paddy yield as influenced by depth of puddling. *J. Agron. Crop Sci.* 148 : 329-336.

- Hasegawa, S.; Thangaraj, M. and Toole, J.C. 1985. Root behaviour : fields and laboratory studies for rice and non-rice crops. *In : Soil Physics and Rice*. IRRI, Los Banos, Philippines. pp. 383-395.
- Hedayetullah, S. 1977. A study on the effect of cultural factor in transplanted paddy on the behaviour of some plant characteristics influencing the yield. *Indian J. Agric. Sci.* 17 : 69-80.
- Hoshino, S. 1974. Recent advances on rice transplanters. *JARQ.* 8(4) : 209-213.
- Hoshino, S. 1977. New developments in transplanting rice. *JARQ.* 11:1-16.
- Hota, B.K. 1997. Performance evaluation and modification for four row mat type manually operated rice transplanter. Thesis, M.Tech. OUAT, Bhubaneswar.
- IRRI (International Rice Research Institute). 1979. Annual Report for 1978. Los Banos, Philippines. 548 p.
- Jackson, M.L. 1967 and 1973. Soil Chemical Analysis. Prentice Hall Pvt. Ltd., India.
- Jana, R.K. and Ghildyal, B.P. 1971. Effect of solar energy and moisture tension on the nitrogen response of upland rice. Vol. IP. 487-497. *In* : Kanwar, J.S.; Datta, N.P.; Banis, S.S.; Bhumbla, D.R. and Biswas, T.D. (eds.). Proc. of Intl. Symp. on Soil Fertility. *Indian Soc. Soil Sci.*, IARI, New Delhi.
- Jaw, C.J. and Lu, P.K. 1964. The mechanical properties of paddy field soil in relation to moisture content. *Acta Pedol.* 12 : 132-142.
- Jayasuriya, S. and Price, E.C. 1979. Economic evaluation of dry seeded rice : some thought on risk aspect. Paper Presented at Agric. Econ. Cropping System Seminar, IRRI, Philippines.
- Kandaurov, N. and Patrin, P. 1974. Minimum tillage for rice; *Zemledelie*. No. 9 : 24-26.
- Kanoksak, E.; Munthumkarn, V.; Goto, N.O.Y. and Yamauchi, T. 1988. Performance of self-propelled riding type rice transplanter. *Kasetsat J. (Nat. Sci. Suppl.)*. 22 : 79-87.

- Kar, S. 1995. Puddling and soil physical properties. Lecture note presented in Engineering for Rice Agriculture Training held from 6 Nov. to 15 Dec., 1995 at IIT, Kharagpur, India conducted by IRRI, Los Banos, Laguna, Philippines.
- Kar, S. and Varade, S.B. 1972. Influence of mechanical impedance on rice seedling root growth. *Agron. J.* 64(1) : 80-81.
- Kar, S.; Varade, S.B. and Ghildyal, B.P. 1979. Pore size distribution and root growth relation of rice in artificial synthesized soil. *Soil Sci.* 128 : 364-368.
- Katare, R.A. and Upadhyay, U.C. 1981. Root studies on paddy under different planting methods and irrigation levels. *Indian J. Agron.* 26: 240-242.
- Khan, A.; Sakur, Abdul; Chaudhary, A.D. and Chaudhary, F.M. 1979. Modification and testing of Korean paddy transplanter in Pakistan. *AMA*, Winter : 79-85.
- Khan, A.S. and Gunkel, W.W. 1988. Mechanical transplanting of rice in Pakistan. *AMA*. 19(1) : 21-34.
- Khan, A.S. and Gunkel, W.W. 1989. Puddled soil and rice seedling characteristics affecting rice seedling withdrawal force. *Trans. ASAE*. 32(1) : 41-49.
- Knight, S.J. and Freitag, D.R. 1962. Measurement of soil trafficability characteristics. *Trans. ASAE*. 5 : 121-124.
- Knudsen, D.; Peterson, G.A. and Pratt, P.G. 1982. Lithium, sodium and potassium. In : Page, A.L.; Miller, R.H. and Keeney, D.R. (eds.). Methods of soil analysis- Part II. *Am. Soc. Agron. Inc. Soil Sci. Soc. Am. Inc.*, Madison, Wisconsin, USA. pp. 225-246.
- Koenigs, F.F.R. 1963. The puddling of clay soils. *Netherland J. Agric. Sci.* 11(2) : 145-156.
- Konaka, T. 1974. Similitude studies of soil dynamic properties in puddling field. *JARQ*. 8(1) : 37-39.

- Kumar, V.; Mahajan, K.T.; Ghildyal, B.P. and Varade, S.B. 1971. Growth response of rice to submergence, soil aeration and soil strength. *Indian J. Agric. Sci.* 41(6) : 527-534.
- Lal, R. 1985. Tillage in lowland rice based cropping systems. *In* : Soil Physics and rice, IRRI, Los Banos, Philippines. pp. 283-307.
- Mambani, B.; De Datta, S.K. and Redulla, C.A. 1989. Soil physical behaviour and crop response to tillage in lowland rice soil of varying clay content. *Plant Soil.* 126(2) : 227-235.
- Manian, R.; Natrajanmoorthy, K.; Chinnanchetty, G. and Kumar, V.J.F. 1987. Evaluation of IRRI transplanter in clay loam soil. *J. Agric. Engg.* 24(2) : 127-137.
- Manian, R. and Jivaraj, P. 1989. Puddled characteristics of soil with selected implements. *AMA.* 20(1) : 21-24 & 26.
- McGeorge, W.T. 1937. Studies on soil structure : Some physical characteristics of puddled soils. *Arizona Agril. Expt. Stn. Tech. Bull.* 67.
- Meelu, O.P.; Devi, V.; Sharma, R.N.; Jalota, S.K. and Sandhu, B.S. 1979. Influence of paddy and corn in different rotations on wheat yield, nutrient removal and soil properties. *Plant Soil.* 51(1) : 51-57.
- Mehta, M.L.; Verma, S.R.; Mishra, S.K. and Sharma, V.K. 1995. Testing and evaluation of agricultural machinery. NATIC, Ludhiana, India. p. 253.
- Moormann, F.R. and Breeman, Van N. 1978. Soil forming processes in aquatic rice lands. pp. 83-106. *In* : Rice : Soil, water, land. IRRI, Los Banos, Laguna, Philippines.
- Mori, Y. 1975. Performance of rice transplanters as evaluated by national test. *JARQ.* 9(3) : 152-155.
- Mufti, A.I. and Khan, A.S. 1995. Performance evaluation of Yanmar paddy transplanter in Pakistan. *AMA.* 26(1) : 31-36&40.
- Nair, P.K.R. 1971. Studies on multiple cropping with rice under different soil management system. Thesis, Ph.D. GBPUAT, Pantnagar.

- Naphade, J.D. and Ghildyal, B.P. 1971.** Effect of puddling on physical properties of rice soils. *Indian J. Agric. Sci.* 41(12) : 1065-1067.
- Nelson, D.W. and Sommers, L.E. 1982.** Methods of soil analysis. Part II. *Am. Soc. Agron., Inc. Soil Sci. Soc. Am., Inc. Madison, Wisconsin, USA.* pp. 539-577.
- Nichols, M.L. 1931.** Dynamic properties of soils-II. Soil and metal friction. *Agric. Engg.* 12 : 321-324.
- Nigam, A.K. and Gupta, V.K. 1979.** Handbook on analysis of agricultural experiments, edn. 1, 307 pp. *Indian Agric. Stats. Res. Inst., N. Delhi.*
- Overmuller, A.J. and Mikkelsen, I.S. 1974.** Effect of water management on the growth and nutrient uptake of rice. *Agron. J.* 66 : 627-632.
- Pande, H.K.; Mitra, B.N. and Rao, K.V.P. 1974.** Measures for reducing water loss in the lowland rice field under acid laterite. *Oryza.* 11(2) : 45-52.
- Pandya, A.C. 1962.** Puddling of soil for paddy cultivation. *The Agril. Engg.* 8 : 16.
- Panse, V.G. and Sukhatme, P.V. 1985.** Statistical methods for agricultural workers. India Offset Press, A-1 Mayapuri, New Delhi. Published by ICAR, New Delhi. pp. 97-128.
- Patil, B.A. and Ghildyal, B.P. 1973.** Effect of soil manipulation on nitrogen fertilization of rice crop. *Fert. News.* 18(12) : 51-52.
- Paul, W.R.C. 1945.** Paddy cultivation, Ceylon Govt. Press, Ceylon.
- Prihar, S.S.; Ghildyal, B.P.; Painuli, D.K. and Sur, H.S. 1985.** Physical properties of mineral soils affecting rice based cropping systems. *In : Soil Physics and Rice.* pp. 57-70, IRRI, Los Banos, Philippines.
- Rahman, H. 1992.** Air cushion vehicle model for wetland paddy field. *AMA.* 23(4) : 28-32.
- Rane, D.B. and Varade, S.B. 1972.** Hydraulic conductivity as an index for evaluating the performance of different puddlers. *J. Agric. Engg.* 9(1) : 11-16.

- Rath, B.S. 1999.** Studies on methods of wheat sowing at various levels of puddling in rice under rice-wheat cropping system. Thesis, Ph.D. GBPUAT, Pantnagar.
- Rautaray, S.K.; Watts, C.W. and Dexter, A.R. 1997.** Puddling effect on soil physical parameters. *AMA*. 28(3) : 37-40.
- Reddy, S.R. and Hukkeri, S.B. 1979.** Soil, water and weed management for direct-seeded rice grown on irrigated soils in North-Western India. *Indian J. Agric.Sci.* 49 : 427-433.
- Renoll, E.S. 1970.** A method for predicting field-machinery efficiency and capacity. *Trans ASAE*. 13 : 448-449.
- Sakanoue, Y. and Mizunuma, Y. 1962.** Effect of harrowing upon the behaviour of nitrogen in well drained paddy field with gravel layer. *J. Sci. Soil Manure, Japan*. 33 : 386-390.
- Salokhe, V.M. and Gee-Clough, D. 1988.** Working with Bangkok Clay Soil – Some experineces. *AMA*. 19(2) : 33-41.
- Salokhe, V.M.; Miah, H.M. and Hoki, M. 1993.** Puddling effect on some physical properties of Bangkok clay soil. *Agril. Engg. J.* 2(1-2):59-71.
- Sanchez, P.A. 1973.** Puddling of tropical rice soils I. Growth and nutritional aspect. *Soil Sci.* 115(2) : 149-158.
- Sargana, M.A. 1983.** Deformation-rate effects on soil parameters for terramechanics. Thesis, M. Engg. (No. AE-83-12), AIT, Bangkok.
- Sargana, M.A.; Gee-Clough, D. and Gupta, C.P. 1985.** A dynamic equation for the pressure sinkage relationship in saturated clay soils. *J. Terramechanics*. 22(2) : 111-120.
- Scheltema, W. 1974.** Puddling against dry ploughing for lowland rice culture in Surinam Agril. Res. Rep. 823, Centre for Agril. Publishing and Documentation, Wageningen, Netherland. 241 p.
- Shah, N.G. 1980.** Study of float devices for wetland machinery. Thesis, M.Engg. (No. AE-80-20). AIT, Bangkok.
- Sharma, D.N.; Jain, M.L. and Prerri, S.C.L. 1991.** Field performance evaluation of bullock-drawn puddler. *AMA*. 22(1) : 29-33.

- Sharma, P.K. and De Datta, S.K. 1985. Puddling influence on soil, rice development and yield. *Soil Sci. Soc. Am. J.* 49 : 1451-1457.
- Sharma, P.K. and De Datta, S.K. 1986. Physical properties and processes of puddled rice soils. *Adv. Soil Sci.* 5 : 139-178.
- Sharma, P.K.; De Datta, S.K. and Redula, C.A. 1988. Tillage effects on soil physical properties and wetland rice yield. *Agron. J.* 80(1) : 34-39.
- Shastry, S.V.S. 1977. Research note, All India Coordinated Rice Research Project. International Rice Commission Newsletter. 26(2) : 11.
- Singh, A.; Gee Clough, D. and Singh, G. 1981. Field performance and evaluation of a paddy transplanter. *AMA*. Spring : 23-30.
- Singh, C.P. and Garg, I.K. 1976. Field evaluation of a Japanese paddy transplanter. *J. Agric. Engg.* 13(1) : 15-18.
- Singh, C.P. and Garg, I.K. 1979. Design, development and field evaluation of a tractor mounted paddy transplanter. *J. Agric. Engg.* 16(2):59-66.
- Singh, C.P. ; Garg, I.K.; Sharma, V.K. and Panesar, B.S. 1982. Design, development and evaluation of a 10-row tractor mounted paddy transplanter. *J. Agric. Engg.* 19(3) : 81-89.
- Singh, G. and Hussain, U.K. 1983. Modification and testing of a manual rice transplanter. *AMA*. 14(2) : 25-30.
- Singh, G.; Sharma, T.R. and Bockhop, C.W. 1985. Field performance evaluation of a manual rice transplanter. *J. Agric. Engg. Res.* 32 : 259-268.
- Singh, M.P.; Pandey, K.P. and Ojha, T.P. 1974. Field performance test with rigid power tillers wheels. *The Harvester.* 16 : 22-25.
- Singh, N.T.; Josan, A.S. and Gupta, J.P. 1977. Complementary effect of soil puddling, submergence and organic matter on rice production. *Agron. J.* 69 : 882-884.
- Singh, R.D.; Singh, B. and Singh, K.N. 1983. Evaluation of IRRI, Pantnagar bullock drawn six-row paddy seeder. *AMA*. 14(3) : 15-20.

- Sood, M.C. and Acharya, C.L. 1991. Effect of tillage methods on root, plant growth and nutrient uptake by wetland rice on acidic Alfisol, *Ann. Agric. Res.* 12(4) : 344-351.
- Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for estimation of available N in soil. *Curr. Sci.* 25 : 259-260.
- Sur, H.S.; Prihar, S.S. and Jalota, S.K. 1981. Effect of rice-wheat and maize-wheat rotation on water transmission and wheat root development in a sandy loam soil of Punjab, India. *Soil Till. Res.* 1(4) : 361-371.
- Swain, S. and Maity, S.P. 1989. Influence of seedling mat parameters on performance of manually operated rice transplanter. *J. Agric. Engg., ISAE.* 26(2) : 173-181.
- Swaminathan, M.S. 1972. Scientific management and use of water. *Indian Farming.* 22(2) : 5-7.
- Tanaka, T. 1984. Operation in paddy fields : State-of-the-art-report. *J. Terramechanics.* 21(2) : 153-179.
- Taneja, M.L. and Patnaik, S. A technique for determining the degree and depth of soil puddle. *Rice Newsletter.* Jan.-March. pp. 27-28.
- Taylor, H.M. and Brar, G.S. 1991. Effect of soil compaction on root development. *Soil Till Res.* 19 : 111-119.
- Tewari, G. 1984. Development and performance evaluation of tractor drawn rotary blade type puddlers. Thesis, M.Tech. GBPUAT, Pantnagar.
- Tyagi, N.K.; Acharya, N. and Mohanty, P.C. 1975. Effect of puddling implements on percolation losses and water use efficiency in rice fields. *Indian J. Agric. Sci.* 45(3) : 132-135.
- Varade, S.B. and Ghildyal, B.P. 1967. Mechanical impedance and growth of paddy in artificially compacted lateritic sandy loam soil. *J. Indian Soc. Soil Sci.* 15 : 157-162.
- Wikham, T.H. and Singh, V.P. 1978. Water movement through wet soils. In : Soil and Rice, IRRI, Los Banos, Laguna, Philippines. pp. 337-360.
- Yao, Y.M.; Wang, J.P.; Zhao, J.L.; Zhu, X.L. and Zhu, Y.L. 1992. A study of the characteristics of machine transplanted rice seedling. *Jiangsu Agric. Sci.* 1 : 15-17.

APPENDICES

Table A.1 Standard meteorological weeks' average weather data during experimentation June to November, 1998 at Crop Research Centre, Pantnagar

Standard week	Date	Temperature(°C)		Rainfall, mm	Number of rainy days	Number of bright sunshine hours	Relative humidity (%)	
		Min	Max				Min (1400 hr)	Max (0700 hr)
23	04-10 June	24.9	41.8	00.0	0	10.6	18	53
24	11-17	24.5	36.6	70.2	2	6.5	41	67
25	18-24	27.7	36.7	00.0	0	10.4	52	75
26	25-1	27.0	34.5	53.0	3	6.8	59	83
27	02-08 July	25.8	31.8	109.0	6	3.8	77	91
28	09-15	25.6	32.6	132.2	5	7.2	70	86
29	16-22	25.5	31.4	37.6	6	2.8	76	94
30	23-29	26.1	33.8	22.2	3	6.9	66	92
31	30-5A	26.1	32.1	14.2	3	6.1	73	88
32	06-12 Aug.	26.1	31.8	48.8	7	3.75	77	93
33	13-19	24.7	29.5	273.2	7	1.6	86	96
34	20-26	24.6	29.0	221.0	6	2.3	88	94
35	27-2	25.1	32.5	18.6	2	5.5	76	94
36	03-09 Sept.	24.5	33.2	11.4	2	7.9	63	89
37	10-16	24.6	32.1	10.2	3	3.3	63	88
38	17-23	24.7	31.6	16.4	3	5.9	68	85
39	24-30	23.4	30.4	164.2	3	5.7	77	89
40	01-07 Oct.	22.4	31.0	08.8	1	7.6	69	89
41	08-14	20.2	32.8	00.0	0	10.0	53	77
42	15-21	20.1	27.5	283.4	4	3.7	72	91
43	22-28	18.2	30.5	00.0	0	9.1	54	90
44	29-04	14.6	29.2	00.0	0	10.0	49	89
45	05-11 Nov.	15.2	27.3	07.6	2	7.1	58	87
46	12-18	13.3	27.6	00.0	0	9.5	49	91
47	19-25	12.0	27.3	00.0	0	7.1	52	92
48	26-2	8.7	25.8	00.0	0	9.5	47	96

Table A.2 Standard meteorological weeks' average weather data during experimentation June to November, 1999 at Crop Research Centre, Pantnagar

Standard week	Date	Temperature(°C)		Rainfall (mm)	Number of rainy days	Number of bright sunshine hours	Relative humidity (%)	
		Min	Max				Min (1400 hrs)	Max (0700 hrs)
23	04-10 June	22.85	35.23	69.10	4.0	9.84	30.29	63.57
24	11-17	26.00	33.44	559.00	5.00	7.00	64.57	84.43
25	18-24	26.97	34.94	359.00	4.00	9.91	54.71	81.71
26	25-1	25.50	33.96	99.20	4.00	5.37	73.42	89.14
27	02-08 July	24.75	32.53	45.0	5.00	4.65	78.16	78.66
28	09-15	27.04	31.28	49.0	6.00	6.7	75.0	75.10
29	16-22	25.61	31.72	137.76	1.00	4.62	72.14	85.85
30	23-29	24.84	31.81	234.14	7	3.35	75.42	92.7
31	30-5A	26.0	31.71	75.39	5	6.23	70.85	88.28
32	06-12 Aug.	25.12	31.54	110.77	7.00	3.17	75.71	92.85
33	13-19	25.30	31.95	13.58	3.00	5.57	69.14	91.42
34	20-26	25.22	31.71	82.95	3.60	3.68	71.14	93.71
35	27-2	24.58	31.47	138	2.0	5.82	67.28	92.42
36	03-09 Sept.	24.47	30.35	108.98	6.0	3.07	81.57	93.42
37	10-16	23.91	30.10	71.19	7.00	3.84	80.28	94.42
38	17-23	24.01	31.22	166.00	5.0	6.0	71.71	93.28
39	24-30	23.32	30.21	101.15	2.00	6.28	76.42	93.42
40	01-07 Oct.	21.92	29.22	90.75	4.00	5.72	74.85	91.00
41	08-14	16.70	30.78	0.0	0.0	9.92	72.57	82.85
42	15-21	17.10	30.45	0.0	0.0	8.38	73.30	86.00
43	22-28	16.24	30.59	0.0	0.0	9.38	57.4	85.43
44	29-04	14.92	30.59	0.0	0.0	9.68	37.0	88.28
45	05-11 Nov.	11.82	29.07	0.0	0.0	9.68	34.5	88.00
46	12-18	8.85	27.62	0.0	0.0	9.68	34.5	88.0
47	19-25	9.38	26.24	6.0	0.0	8.50	31.14	89.71
48	26-2	9.10	25.075	0.0	0.0	6.67	39.75	92.50

Table A.3 Effect of puddling by different equipment on cone penetrometer resistance of puddled soil at various depth and sedimentation period (1998)

Treatments	Cone penetrometer resistance, kPa							Cone index, kPa	
	Depth, cm								
	0.0	2.5	5.0	7.5	10.0	12.5	15.0		
R ₂	S ₂₄	63.55	63.55	63.55	63.55	137.09	270.49	390.1	150.27
	S ₄₈	63.55	63.55	87.57	134.16	284.3	380.03	523.48	219.55
	S ₇₂	63.55	83.16	93.95	157.20	416.09	501.91	713.90	289.96
R ₃	S ₂₄	63.55	63.55	63.55	63.55	85.51	156.61	269.09	109.34
	S ₄₈	63.55	63.55	63.55	107.68	121.89	200.75	384.65	143.66
	S ₇₂	63.55	92.97	117.49	142.00	288.55	406.74	578.16	241.35
P ₂	S ₂₄	63.55	63.55	63.55	87.17	221.55	341.04	612.55	207.56
	S ₄₈	63.55	93.95	108.17	179.85	296.75	519.55	664.55	275.20
	S ₇₂	63.55	113.56	136.61	241.05	455.84	558.19	710.54	324.76
P ₃	S ₂₄	63.55	63.55	63.55	75.80	115.71	235.36	370.00	141.07
	S ₄₈	63.55	63.55	79.89	112.58	255.56	365.92	492.59	204.81
	S ₇₂	63.55	97.87	112.58	151.37	409.55	483.30	594.85	272.91
C ₂	S ₂₄	63.55	63.55	116.00	149.36	236.86	479.26	633.16	248.82
	S ₄₈	63.55	110.12	132.26	277.35	440.09	583.35	710.24	338.14
	S ₇₂	63.55	137.10	183.19	348.92	571.95	709.05	864.74	410.41
C ₃	S ₂₄	63.55	63.55	63.55	88.85	243.47	306.55	588.55	202.67
	S ₄₈	63.55	83.37	102.77	187.97	394.35	437.96	696.27	280.79
	S ₇₂	63.55	100.32	124.84	250.84	450.99	559.35	751.55	328.76

Table A.4 Effect of puddling by different equipment on cone penetrometer resistance at various depths and sedimentation period (1999)

Treatments	Cone penetrometer resistance, kPa							Cone index, kPa
	Depth, cm							
	0.0	2.5	5.0	7.5	10.0	12.5	15.0	
P ₁ S ₂₄ S ₃₆ S ₄₈	63.55	87.57	99.39	142.49	286.39	463.88	640.66	254.85
	63.55	101.55	128.63	202.80	400.94	567.61	777.69	320.39
	63.53	116.20	141.07	234.10	425.80	615.88	800.76	342.48
P ₂ S ₂₄ S ₃₆ S ₄₈	63.55	63.55	75.81	106.70	191.78	376.10	605.00	211.78
	63.55	88.06	97.87	150.64	266.26	457.88	706.97	261.16
	63.55	92.97	115.03	182.71	295.10	480.95	745.79	282.30
R ₁ S ₂₄ S ₃₆ S ₄₈	63.55	63.55	75.00	89.29	183.14	438.59	727.42	234.39
	63.55	98.36	112.0	133.18	270.42	520.89	770.76	272.74
	63.55	106.45	130.82	206.60	315.82	546.11	793.30	308.95

Table A.5 Effect of puddling by using different equipment on sinkage resistance of puddled soil at various depths and three levels of sedimentation period (1998)

Depth, cm	Sinkage resistance, g cm ⁻²					
	Treatments					
	R ₂	R ₃	P ₂	P ₃	C ₂	C ₃
A. 24 hours of sedimentation period						
1	10.84	10.84	10.84	10.84	11.51	10.84
2	10.84	10.84	12.60	10.84	15.10	13.00
3	16.20	12.15	24.50	14.91	26.00	21.52
4	20.30	20.46	34.50	18.51	42.80	32.60
5	28.48	24.10	50.00	26.81	56.70	48.70
6	36.70	27.97	65.10	33.04	71.10	60.10
Mean	20.56	32.91	37.20	17.67	19.16	31.13
B. 48 hours of sedimentation period						
1	11.54	10.84	15.30	11.26	16.50	13.40
2	18.23	13.91	28.50	16.43	35.91	26.72
3	35.27	20.36	50.79	26.81	70.70	45.76
4	56.05	29.60	108.80	40.40	113.40	84.50
5	70.62	42.00	130.90	61.41	159.80	121.40
6	95.35	59.60	163.00	87.92	193.00	153.40
Mean	47.84	81.55	98.55	29.36	40.70	74.18
C. 72 hours of sedimentation period						
1	20.00	15.00	42.30	22.20	49.26	35.00
2	39.50	34.30	66.10	40.70	74.10	53.80
3	74.00	59.00	117.60	73.50	128.00	86.83
4	110.30	78.10	159.10	119.00	166.20	139.40
5	151.50	136.80	198.20	154.71	195.47	185.50
6	198.60	165.50	234.53	186.00	250.40	235.00
Mean	98.98	99.35	136.30	99.35	143.90	123.59

Table A.6 Effect of puddling on sinkage resistance of puddled soil at various depths and three levels of sedimentation period (1999)

Depth, cm	Sinkage resistance, g cm ⁻²		
	Treatment		
	P ₂	P ₁	R ₁
A. 24 hours of sedimentation period			
1	10.84	12.1	10.84
2	11.67	15.29	13.51
3	18.94	24.62	22.88
4	35.64	35.20	30.53
5	45.22	52.39	40.98
6	59.82	88.90	68.32
Mean	30.36	38.08	32.51
B. 36 hours of sedimentation period			
1	12.52	15.17	12.85
2	23.44	28.56	26.49
3	38.39	46.65	42.45
4	64.51	80.45	71.57
5	93.58	108.84	101.29
6	110.93	132.20	120.29
Mean	57.23	68.65	62.48
C. 48 hours of sedimentation period			
1	14.73	18.24	16.52
2	33.96	38.44	37.80
3	50.44	67.70	61.21
4	85.74	104.86	84.10
5	117.50	128.64	122.64
6	140.79	160.85	153.39
Mean	73.86	86.45	79.28

Table A.7 Weight distribution and float contact pressure of transplanter under different operating conditions

1.	Total float area, sq.-cm ²	15475.00
2.	Total weight of the transplanter including operator, kg (Assuming average weight of operator as 60 kg)	380.00
3.	Weight transferred to float, kg (Assuming 50% of total weight)	190.00
4.A	Condition I (Operator and seedling only)	
i)	Weight of mats @4.00 kg/mat for eight mats, kg	32.00
ii)	Total weight on float	190+32 = 222
iii)	Contact pressure of float, g cm ⁻²	14.34
B.	Condition II (With operator, two loaders and seedling)	
i)	Weight of loaders @60.00 kg per loader, kg	120
ii)	Weight of loaders transferred to float (assuming 50%)	60 kg
iii)	Total weight on the float, kg	190+32+60 = 282
iv)	Contact pressure of float, g cm ⁻²	18.22
C.	Condition III (with operator, two loaders and mats on tray as well as on float)	
i)	Weight of loaders , kg	60
ii)	Weight of total 16 mats @4 kg mat ⁻¹	64
iii)	Total weight on the float, kg	190+60+64 = 314
iv)	Contact pressure, q cm ⁻¹	20.29

Table A.8 Cost of operation of self-propelled rice transplanter

1. Assumptions	
i) Purchase price, Rs.	95,000.00
ii) Life span, years	10
iii) Annual use, hours	
a) One season	300
b) Two seasons	500
2. Fixed cost	
i) Total investment cost	
a) Cost of transplanter, Rs.	95,000.00
b) Cost of steel frame for nursery raising 4 frames @200.00/frame	800.00
Total initial cost, Rs.	95,800.00
ii) Depreciation cost	
Assuming 10% salvage value, Rs.	$(95,800.00 - 9580.00) / 10 = 8622.00$
iii) Interest @18% per annum, Rs.	$[(95800+9580)/2] \times 18 / 100 = 9484.00$
iv) Insurance and shelter @2% of the transplanter cost, Rs.	1916.00
Total annual fixed cost, Rs.	2022.00
i) Fixed cost, Rs./hr	
a) One season (300 hrs/annum)	66.74
b) Two seasons (500 hrs/annum)	40.00
3. Variable cost per hour	
i) Labour cost for 4 labours @Rs. 6.25/hr	25.00
ii) Fuel (Diesel) cost @Rs. 15.50/l (Fuel consumption : 0.40 l/hr)	6.20
iii) Lubrication cost, Rs. (30% of the fuel cost)	1.86

- iv) Repair and maintenance cost, Rs. (5% of initial cost per 500 hrs of annual use) 9.50
- Total variable cost, Rs./hr 42.56**
4. Total cost of operation, Rs./hr
- a) One season (300 hours) 109.30
- b) Two seasons (500 hours) 82.56
5. Cost of transplanting per hectare
- i) Cost of polythene for 20 m length @ Rs. 10/m length, Rs. 200.00
- ii) Nursery bed preparation, management and uprooting (70.00 man-hour per hectare @Rs. 6.25 / hr), Rs. 437.50
- iii) Gap filling and headland transplanting for 20 man-hr hr⁻¹ @6.25/hr, Rs. 125.00
- iv) Operating cost of transplanter @6.67 hrs per ha, Rs.
- a) One season (300 hrs/annum) 729.00
- b) Two seasons (500 hrs/annum) 550.70
6. Total cost of transplanting, Rs. ha⁻¹
- i) One season 1491.50
- ii) Two seasons 1313.20

Table A.9 Cost of manual transplanting

Sl. No.	Activities	Man-hr requirement	Cost, Rs.
1.	Nursery raising and management per hectare	50	313
2.	Nursery uprooting per hectare	100	625
3.	Transplanting per hectare		
i)	Line	328	2050
ii)	Random	260	1625
4.	Total cost of transplanting, Rs ha ⁻¹		
i)	Line	-	2988
ii)	Random	-	2563

Table B.1 ANOVA for seedlings per hill for the laboratory experiment

Source	d.f.	S.S.	M.S.	Fcal	SEM	CD
Age of seedlings (i)	2	0.86	0.41	11.74	0.031	0.500
Mat density (j)	2	20.89	9.95	285.17	0.031	0.500
Moisture content (k)	2	4.62	2.20	63.09	0.031	0.500
Operating speed (l)	1	0.82	0.75	21.50	0.025	0.452
Interaction of ij	4	0.12	0.030	0.876	0.054	ns
Interaction of ik	4	0.14	0.034	0.976	0.054	ns
Interaction of il	2	0.0312	0.015	0.426	0.044	ns
Interaction of jk	4	0.38	0.093	2.681	0.054	0.658
Interaction of jl	2	0.028	0.014	0.393	0.044	ns
Interaction of kl	2	0.002	0.001	0.032	0.044	ns
Interaction of ijk	8	0.017	0.002	0.059	0.093	ns
Interaction of ijl	4	0.012	0.003	0.084	0.076	ns
Interaction of ikl	4	0.015	0.004	0.106	0.076	ns
Interaction of jkl	4	0.020	0.005	0.139	0.076	ns
Interaction of ikl	8	0.018	0.002	0.064	0.132	ns
Error	54	1.883	0.035	-	-	-
Total	107	29.874	0.279			

Table B.2 ANOVA for missing hill for the laboratory experiment

Source	d.f.	S.S.	M.S.	Fcal	SEm	CD
Age of seedlings (i)	2	82.02	39.06	6.58	0.406	1.806
Mat density (j)	2	431.09	205.28	34.61	0.406	1.806
Moisture content (k)	2	29.97	42.84	7.22	0.406	1.806
Operating speed (l)	1	35.51	32.28	5.44	0.331	1.632
Interaction of ij	4	10.84	2.64	0.44	0.703	ns
Interaction of ik	4	14.90	3.63	0.61	0.703	ns
Interaction of il	2	24.12	11.49	1.93	0.574	ns
Interaction of jk	4	15.69	3.83	0.64	0.703	ns
Interaction of jl	2	4.26	2.03	0.34	0.574	ns
Interaction of kl	2	2.40	1.14	0.19	8.574	ns
Interaction of ijk	8	6.40	0.79	0.13	1.218	ns
Interaction of ij l	4	6.15	1.50	0.25	0.994	ns
Interaction of ikl	4	34.87	8.50	1.43	0.994	ns
Interaction of jkl	4	2.51	0.61	0.10	0.994	ns
Interaction of ijkl	8	2.91	0.36	6.06	1.722	ns
Error	54	320.32	5.92	-	-	-
Total	107	108.98				

Vita

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