"CROP ESTABLISHMENT TECHNIQUES IN RICE UNDER DIFFERENT ENVIRONMENTS IN HARYANA"

BY

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2000A14D

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Dedicated to Indian Farmers Who are Feeding the Entire Nation of more than 100 Crores Population, Particularly to the Small Farmers Who are Living Below Poverty Line and Taking One Time Meal

CERTIFICATE - I

This is to certify that this dissertation entitled **"Crop establishment techniques in rice under different environments in Haryana"**, submitted for the degree of **Doctor of Philosophy** in the subject of **Agronomy** of the Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Chinta Venkata Reddy,** Admn. No. **2000A14D** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

@	:	At the rate of
°C	:	Degree Celsius
C	:	Carbon
CD	:	Critical difference
cm	:	Centimetre
DAS	:	Days after sowing
DAT	:	Days after transplanting
et al.,	:	*et alli* (and others)
Fb	:	followed by
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram
HI	:	Harvest index
i.e.	:	id est (that is)
K	:	Potassium
kg	:	Kilogram
M	:	Metre
mm	:	Millimetre
N	:	Nitrogen
NS	:	Non-significant
P	:	Phosphorus
Rs	:	Rupees
SEm	:	Standard error mean
viz.	:	Namely

International Year of Rice - 2004

CHAPTER – I

INTRODUCTION

Developments in Indian agriculture in the past thirty years have been conducive to economic development and allowed production levels to match population growth with current grain stocks exceeding 70 million tonnes. The rice-wheat cropping system practiced on 10.5 million hectares in India is a strategic component of Indian Food Security. The population of India will stabilize around 1.5 billion by the year 2020. At that time, the annual demand for food grains will reach 343 million tonnes (Malik *et al.*, 2003). The country may have to import 14 million tonnes of food grain by 2010 and then imports may stabilize at the rate of 2% every year. To meet the domestic demand by 2010, India needs to increase rice yield by 32.7% and wheat yield by 35.1%. Second generation problems related to soil productivity and increased problems of pests and weeds are also likely to affect India's ability to meet the above production goals. Also, with globalization in agriculture and free market economies, the system profitability need to be focussed. Further, with dwindling per capita land availability (0.15 ha), which is expected to decrease in future and the country having more than 110 million farmers inhabiting 70 million villages and about 36% of the country population living below the poverty line are causes of concern, (Malik *et al.*, 2003).

Ladha *et al.* (2003) while discussing the sustainability of rice-wheat cropping system on the basis of long-term experiments stated that rice and wheat yield trends in the Indo-Gangetic Plain have remained either stagnant or have declined to some extent. With similar stagnation or decline in yield trends occurring in farmers' fields, the sustainability of this important cropping system is under threat. A declining trend raises serious concerns about the regional food security because a "population plateau" is yet to be realized and food grain production may not keep pace with it. However, the recent analysis suggest that the yield decline in long-term experiments are not wide spread and hence may be ignored, but the yield stagnation and large yield gap, both at the experimental stations and in farmers' fields are a cause of serious concern. Under present circumstances there is scope for improving crop productivity by suitable manipulation of crop management practices and the future research must focus on increasing the productivity of cultivars and enhance input use efficiency so as to fill the yield gap.

Rice (*Oryza sativa* L.) is the staple food for 65% of the total population in India (*www.fao/rice,* 2004). It has been number one food crop in India, assuring food security for rice eating population. It contributes 20-25% of agricultural GDP (Subbaiah and Balasubramanian, 2000).

In India, rice is being grown over an area of 43 million hectare with total production of 87 million tonnes amounting 41.8% of total food grain production (Singh, 2001). Presently, in Haryana the area, production and productivity of rice are around 1083 thousand hectare, 2583 thousand tonnes and 2385 kg ha^{-1}, respectively. But rice yield is either stagnant or declining in the irrigated ecosystems.

It has been estimated that nearly 57 and 31% of the total geographical land area is degraded in India and Haryana, respectively (Singh *et al.*, 2000) and it has resulted due to the traditional system of rice growing which is inefficient in terms of natural resource use.

In most of South Asia, common practice of establishing rice in the rice-wheat system is puddling.

Puddling helps in reducing water losses through percolation and controlling weeds in rice fields (Adachi, 1992; Singh *et al.*, 1995). But besides being costly, cumbersome and time consuming, it results in degradation of soil and other natural resources and subsequently poses difficulties in seedbed preparation for the succeeding wheat crop in rotation. In recent years, the migration of rural labour to the industrial sector, especially in India, has led to the non-availability of labour for transplanting at the appropriate time, resulting in a yield reduction. This method also results in drudgery particularly among women workers. It is therefore, imperative to look for alternative methods so as to overcome the associated problems encountered in transplanting after puddling (Budhar and Tamilselvan, 2001). To get rid of puddling or transplanting or both, efforts are required to explore the possibilities of other crop establishment techniques in rice like direct seeding under puddled or zero-till situations or transplanting under zero-till or unpuddled conditions.

Direct seeding offers advantages such as faster and easier planting, reduced labour and less drudgery, earlier crop maturity by 7-10 days, more efficient water use and higher tolerance to water deficit, less methane emission and often higher profit in areas with an assured water supply

(Balasubramanian and Hill, 2002). Thus, direct seeding is becoming an attractive and popular alternative to transplanting of rice. Asian rice farmers are shifting to direct seeding to reduce labour input, drudgery and cultivation cost (De Datta, 1986; De Datta and Flinn, 1986).

One possible sub-system of dry seeded rice could be zero-till rice. In this system, weeds are allowed to germinate and are then controlled with a non-selective herbicide like glyphosate. A zero-till drill is then used to seed rice. The weeds germinated with first showers/light irrigation, could be controlled with shallow ploughing (stale seed bed method) combined with mechanical/hand weeding or herbicide use after germination and growing of primed rice seed with zero-till machine in dry/moist soil or seeding broadcasting of pre-germinated rice seeds in wet or moist soil (Gupta *et al.*, 2002).

Baker *et al.* (1996) described various advantages of zero-tillage like 80% fuel conserved by conservation from tillage to non-tillage, time conservation, improvement in soil organic matter, preservation of soil structure, preservation of earthworms and other soil fauna, improved aeration and infiltration, prevention of erosion, soil moisture conservation, moderating soil temperature, reduced germination of weeds, more recreation and management time. He also indicated some disadvantages, as fields are not leveled, fertilizers are more difficult to incorporate, shift in dominant weed species and increased use of agricultural chemicals such as herbicides for controlling weeds.

The research efforts on varietal component of rice under different establishment techniques and under different environments needs proper attention. It is also important to study the crop environment in order to get optimum input efficiency and grain yield from crop. Weather influences plant growth, development and the incidence of insect-pest and disease and final grain yield (Yoshida and Parao, 1976). Keeping these points in view, the present investigation entitled "Crop establishment techniques in rice under different environments in Haryana" was planned with the following objectives"

1. To study the feasibility of different crop establishment techniques in rice.
2. To compare the growth, yield attributes and yield of rice under different crop establishment techniques in different environment.

CHAPTER - II

REVIEW OF LITERATURE

In this chapter, the literature pertaining to crop establishment techniques/resource conservation techniques adopted world wide have been reviewed under the following sub-heads:

2.1 Sustainability of rice-wheat cropping system (RWCS)

2.2 Transplanting and weed management

2.3 Direct seeding methods

2.4 Advantages of zero-tillage

2.5 Unpuddled sowing methods

2.6 Sowing under zero-till (ZT) system

2.7 Effect of method of rice establishment on soil properties

2.8 Water management under different establishment methods.

2.9 Suitability of varieties to different establishment methods

2.10 Mechanization and different methods of establishment

2.11 Effect of rice establishment techniques on following wheat crop

2.12 Climate change and rice yields

2.1 Sustainability of rice-wheat cropping system (RWCS)

Malik *et al.* (2000) while evaluating the past 30 years agricultural research accomplished under rice wheat cropping system (RWCS) have reported that by harnessing the technological breakthrough in modern varieties, their modified management and use of pesticides, the productivity and profitability of both rice and wheat in the system continued to increase over the period. However, a plateau seems to have appeared and now the productivity potential and profitability of rice-wheat system is fading to the extent that new sustainability agenda is needed to infuse stability in the system. Further they advocated the adoption of conservation tillage which can lead to safety and profitability of rice-wheat system in future by insuring improved productivity levels. Taking a serious note of the problem of herbicide resistance which is visible above ground, they pointed out that the zero-tillage technique has great potential for efficient utilization of natural resources below ground which have remained mismanaged for long. More, so the efficient managemeht of natural resources like water and organic matter through zero-tillage is another bright spot, which can be exploited by adopting such technologies.

Malik *et al.*, (2003) stated that with the consolidation of dominant RWCS position increased input use, especially in the high productivity zones of India, had led to second generation problems including herbicide resistance in the 1990s. Until the early 1990, *Phalaris minor* could be effectively controlled by isoproturon (a substituted urea compound). However, with continuous and indiscriminate use of this herbicide, led to resistance in the weed and was first reported from Haryana in 1993 (Malik and Singh, 1995).

Following this, the technology of wheat establishment involving no-tillage was tested to overcome the problem of resistance and control weeds in wheat. The technology showed positive results and good grain yield of wheat were realized. During previous 5 years, the yield advantages of no tillage have been maintained at permanent sites and the yield advantage was recorded during the this period (Malik *et al.*, 2002). A significant decrease in *Phalaris minor* populations was noted since the soil disturbance was least and the weed had no chance of being incorporated in the soil and then germinate.

Malik *et al.* (2002) highlighted the enhanced profitability, productivity and sustainability as key issues for the successes of zero-tillage technology. They further advocated that the environmental benefits of the technology will be premium for the society for long run. The burning of rice straw in rice-wheat cropping system is a cause of concern for environmentalist. Zero-tillage technology assumes that, in the end, management of loose straw is also connected to the environmental premium of technology. Sequestration of carbon, which is possible through this technology, will be a reliable guide to such environmental benefits. Zero-tillage in transplanted rice has been successfully tried at HAU again through collaborative efforts of Australian Centre of International Agricultural Research (ACIAR) and Rice Wheat Consortium (RWC). This will be a long-term objective for perfecting resource conservation technologies in both rice and wheat.

Harrington (2000), reported that rice-wheat in the Indo-Gangetic Plains may seem simple, but in reality they are enormously complex, with numerous productivity and sustainability problems, each embedded in a web of interactions. Rice-wheat system problems include late sowing, low water and nutrient use efficiency, ground water depletion (in some areas), salinity and sodicity and build up of problem weeds. Late sowing for example, reduces water and nutrient use efficiency, and restricted the time available within the rotation for break crops, thereby contributing to the build up of problem weeds and to soil fertility. Reduced and zero-tillage for rice and wheat improve timeliness of sowing and through these some system interactions would help farmers cope with multiple productivity and sustainability problems.

2.2 Transplanting and weed management

Transplanting of 3-5 week old seedlings into puddled fields is the most common and widely adopted practice to grow the rice crop in Indo-Gangetic Plains. Puddling is a traditional soil management operation used to reduce soil permeability to water and preserve the aquatic, anaerobic conditions suited for growth of wetland rice (Sanchez, 1973). It also helps in controling weeds, improve water and nutrient availability and facilitates transplanting of rice seedlings. Puddling benefits by reducing water percolation and controlling weeds (Adachi, 1992; Singh *et al.*, 1995).

However, repeated puddling destroys soil aggregates, breaks capillary pores, disperses fine clay particles, which settle in the bottom of the plough layer and this compacted layer restricts percolation of water and reduces recharge of groundwater aquifers and/or soil profile. Puddling may also influence the irrigation water requirement of succeeding crops. Poor growth of plants in puddled rice crop was observed by Padamaraju and Dev (1969).

According to Despsch and Moriya (1998) the results of exploiting agricultural systems without consideration of the consequences of soil degradation caused by soil preparation are evident in those regions where soil is cultivated intensively and continuously. Kandaswamy *et al.* (2001) estimated the labour and land preparation costs for rice production which accounted for 30-40% of total production cost. Repeated traditional tillage operations escalate the cost and reduce the farmers profits margin (Harrington *et al.*, 1993).

Sinha *et al.* (1998) reported that puddling results into degraded soil physical properties and formation of a plough-pan affecting root depth and there are concerns about environmental degradation and sustainability of resources in rice-wheat production system.

Tillage is an integral part of cropping system aimed at optimizing crop production by solving specific soil related ecological constraints to crop production and there are several specific reasons for soil tillage (Piggin *et al.*, 2000). Short-term reasons include optimization of soil temperature and moisture regimes, seed germination, seedling establishment, root proliferation and development, minimizing weed competition and energy input. Long-term reasons are maintenance of soil productivity and sustainable management of soil and water resources.

2.3 Direct seeding methods

Soil tillage and crop establishment are relatively labour intensive activities for rice in Asia. As economies in the region develop, labour is being drawn away from rice production resulting in late established crops causing revenue loss owing to delayed harvesting. Rising labour cost and need to bring improvement in rice production and productivity, have led to look for changes in crop establishment method (Pandey and Valasco, 2002).

Direct seeding offers advantages in faster and easier planting, reduced labour and less drudgery with earlier crop maturity by 7-10 days, more efficient water use and higher tolerance of water deficit, less methane emission and often higher profit in areas with an assured water supply, thus the area under direct seeded rice has been increasing as farmers in Asia seek higher productivity and profitability to offset increasing costs and scarcity of farm labour (Balasubramanian and Hill, 2002).

Direct seeding is becoming an attractive alternative to transplanting of rice. Asian rice farmers are shifting to direct seeding to reduce labour input, drudgery and cultivation cost (De Datta, 1986; De Datta and Flinn, 1986).

Bridgit and Potty (2002) reported that dry seeding of rice resulted in highest grain yield (6.5t ha^{-1}), followed by wet seeding (4.7t ha^{-1}) and transplanting (4.6t ha^{-1}). Since different methods of crop establishment had uniform management practices, a high yield in the dry-seeded crop will mean higher nutrient use efficiency than in other establishment methods. This can be explained on the basis of root characteristics, such as root number, average root length and maximum root length.

Budhar and Tamilselvan (2001) reported that direct seeding and throwing of seedlings under puddled conditions are viable alternatives to transplanting. Various stand establishment techniques –direct (wet) seeding by manual broadcasting or drum seeder or transplanting showed no significant difference in grain yield in two crop seasons. The pooled analysis of two seasons showed that the grain yield was highest in wet seeding by manual broadcasting (6.1 t ha^{-1}), closely followed by direct seeding using a drum seeder (5.3 t ha^{-1}) and traditional transplanting (5.3 t ha^{-1}).

Under dry direct seeded rice (D-DSR), the weeds are biggest biological constraint in all but water seeded rice since they emerge simultaneously with rice seedlings because of the absence of flooding in early stages. Generally, weeds such as grasses, sedges and broadleaf weeds are found in D-DSR fields. The dominant weeds in D-DSR fields were *Echinochloa crusgalli* and *Leptochloa chinensis* among grasses, *Cyperus difformis* and *Fimbristylis miliacea* among sedges and *Ammania baccifera, Eclipta prostrata* and *Sphenoclea zeylanica* in the broadleaf category.

Weed pressure is often two to three times higher in D-DSR than in transplanted crop. It has commonly been observed that dry direct seeding is subjected to relatively more weed pressure than wet direct seeding, probably because of differences in land preparation. Grassy weeds such as *E. crusgalli, E. colona* and weedy rice (*Oryza* spp.)

dominate the weed flora under continuous wet conditions. These weed species closely resemble the rice seedling and thus it is difficult to differentiate and remove such weeds in early growth stages. The weed species *Paspalum distichum* and *E. colona* may become dominant in rice grown under zero-tillage. The estimated yield losses from weeds on D-DSR reported in the literature range from 20% to 88% in India (DRR, 1996), 40% to 100% in South Korea (Park *et al.*, 1997) and 36% to 56% in Philippines (De Datta, 1986; Rao and Moody, 1994). Similar weed related yield losses have been reported to occur in other countries also. The weedy rice is a serious problem in temperate countries because the red pericarp spoils the appearance and market value of cultivated rice (Smith, 1981).

Singh *et al.* (2002a) studied the effects of crop establishment methods of rice and wheat in a five year field experiment. The rice establishment methods included the transplanting and direct seeding whereas tillage practices followed in wheat were zero and conventional tillage. Performance of transplanted and direct seeded rice was at par, but in the following season wheat yield was more in plots where rice was directly seeded. Puddling had adverse effect on the following wheat crop. Wheat yields sown with zero-tillage was simlar to the conventional tillage in 3 years.

2.4 Advantages of zero-tillage

Maurya (1986) reported a 50% higher basic infiltration rate in no-tilled plots (8.8 cm hr^{-1}) than tilled plots (4.4 cm hr^{-1}).

It is obvious that in zero-tillage system, the weeds that emerge before transplanting need to be controlled by applying non-selective herbicides like glyphosate or paraquat. Since soil is not disturbed under zero-tillage, the weed pressure remains comparatively less compared to system where frequent tillage operations are given prior to seeding/transplanting.

Tillage is considered a hazard, since it considerably destroys the soil organic matter and soil structure and accelerates the soil erosion and breaking the web of soil life itself (Papendick and Parr, 1997). Many studies have shown that with continuous no-tillage, soil organic matter increases, soil structure improves, soil erosion is controlled and in time, crop yields increased substantially from what was being realized under intensive tillage management (Cannell and Hawes, 1994; Papendick and Parr, 1997; Reeves, 1997). Kandaswamy *et al.* (2001)

found that in transplanted rice, the conservation tillage was as good as conventional tillage in terms of crop performance.

Hernanz *et al.* (1995) reported from Spain that substantial energy and production cost savings could be achieved through minimum and zero-tillage as compared to conventional tillage. The energy savings ranged from 7-11% for cereal crops, and production cost for minimum tillage were 13-24% less than for conventional tillage. For zero-tillage, these reductions ranged from 6-17%. Minimum and zero-tillage in cereal crops resulted in 18 and 20% higher energy productivity as compared to conventional tillage.

Aulakh and Gill (1987) observed low soil bulk density with zero-tillage and as bulk density increased, grain yield tended to decrease. Thanh (1993) also observed that no-tillage soil had higher volumetric water content, water holding capacity and water infiltration while decreased bulk density as compared to ploughed soil.

Piggin *et al.* (2002) stated that zero-till establishment technique is used widely for many crops around the world. There has been some work on rice, but it was mostly before the development of broad spectrum, non-residual herbicides and direct drill seeders. The technology has potential to allow savings in time, energy, water and labour during rice cropping. It is also important in the rice-wheat systems of the Indo-Gagnetic Plains, where farmers are becoming increasingly interested in zero-tillage in wheat and there are obvious benefits in extending the technology into rice.

Global warming may lead to change in the amount, distribution and intensity of rainfall/precipitation, with an overall increase in global humidity and precipitation (Lal, 2003). The projected climate change may also have a drastic impact on soil quality, growing season duration and biomass productivity.

An increase in atmospheric concentration of CO_2 is attributed to emission from fossil fuel combustion and land use change. The emissions from the land use change is due to depletion of soil organic carbon (SOC) pool (Lal, 2003). Technological options for SOC sequestration on agricultural soils include adoption of conservative tillage, use of manures and compost as per integrated nutrient management. The SOC sequestration is a cost effective strategy of mitigating the climate change during the first two to three decades of the 21st century while improving soil quality, biomass productivity and enhanced environment quality, the strategy of SOC sequestration also buys us time during which the non-carbon fuel alternatives can take effect (Lal, 2003).

2.5 Unpuddled sowing methods

Malik (2001) reported that transplanting in flat without puddled conditions (unpuddled) produced 88.6 q ha^{-1} then followed by transplanting in puddled condition produced 72.2 q ha^{-1}.

Kabaki *et al.* (2003) studied the yield of rice under different methods of cultivation. They reported that the no-tillage with row seeding produced, 2,513 kg ha^{-1} and no tillage with broadcasting produced 2,500 kg ha^{-1}; tillage with row seeding produced 2,550 kg ha^{-1} and tillage with broadcasting produced 2,581 kg ha^{-1}; transplanting produced 2,350 kg ha^{-1} indicating that tillage system gives higher yields followed no-tillage system.

Higuchi *et al.* (1997) conducted field studies to achieve improvement in productivity of rice and reduction in the retail cost of rice which is 5-20 times greater in Japan than in the USA, Australia, China and Thailand. According to them it was necessary to increase farm size and to make each stage of the rice production cycle more labour efficient. No-tillage direct seeding of rice was introduced and examined. Labour time was substantially reduced, as were the production costs. Rice plants grew nearly as well, as those on the cultivated seeding system. The number of weeds on the no-tillage area was much higher than on cultivated areas. Grain yields on the no-tillage system were slightly less than for ploughed areas.

Chungkon *et al.* (1996) realized higher seeding establishment with ridge sowing and irrigation immediately afterwards and heading date occurred 2-3 days earlier. They further added that soaked seed gave higher grain yields than unsoaked rice, and sowing into flat seedbeds gave higher yields than ridge or hill sowing.

In a two-location study Hobbs (2002) reported that the transplanting on puddled soils gave higher yield as compared to direct seeding on non-puddled soils (DSR).

2.6 Sowing under zero-till system

Tripathi *et al.* (1999) recorded comparable yield with zero and conventional tillage systems but zero-tillage saved more than 16% cost of cultivation. Campbell (1978) reported that crop production under minimum and zero-tillage has been increasing particularly in western Canada because conventional tillage systems have accelerated soil erosion problems and have depleted soil moisture and organic matter. These problems can be elevated by reducing or eliminating tillage (Lafond *et al.*, 1992).

Tiwari and Tomar (2002) reported that the average wheat grain yield in no-tillage plots was significantly higher (4166 kg ha^{-1}) than in conventional tillage (3426 kg ha^{-1}), deep till plots (3212 kg ha^{-1}), direct seeded rice (3868 kg ha^{-1}), lehi (3605 kg ha^{-1}) and transplanted rice (3331 kg ha^{-1}). Probably it was due to better physical environment in soils provided by no-tillage rice crop to the subsequent wheat crop.

DRR Annual Progress Report (2002) reported that at Karaikal (clayey soil), the grain yield from conservative tillage was significantly superior (6 t ha^{-1}) to other tillage practices tried. Next best treatment was conservative tillage followed by machete at 2.5 litre per hectare (5.2 t ha^{-1}) which was comparable to local tillage system as practiced by farmers followed by two hand weedings (4.8 t ha^{-1}). Similar trend of significant, increase in number of panicles m^{-2} and panicles weight with conservative tillage (521 and 4.04 g, respectively) was observed.

Abbassakiki *et al.* (1996) investigated the applicability of zero-tillage for irrigated rice cv. IR-46 as compared with conventional tillage and suggested that ZT will be more economical than CT, especially for small farmers.

Many terms such as direct-drill (DD), zero-till (ZT) or no-till (NT) have been used to describe crop establishment without cultivation. Studies in many countries have shown that many crops can be established on uncultivated soil. These suggested the primary function of ploughing is weed control, and showed that the omission of ploughing in weed-free situations does not result in a yield reduction (Christian and Ball, 1994; Vyn *et al.*, 1994).

Rasmussen (1999) reported that, one of the most striking effect of ploughless tillage is the increased density of soil just beneath the depth of tillage. More plant residues were left on or near the soil surface after ploughless tillage which led to lower evaporation. It also protected the soil against erosion. Nearly all species of earth-worms increased in number in ploughless tillage.

So *et al.* (2001) at International Rice Research Institute used tillage and seeding or transplanting methods, to classify rice farming systems and stated under zero-tillage or minimum tillage the seeding options will be broadcasting, dibbling and drill seeding and under transplanting options include manual transplanting of seedlings.

Tebrugge and During (1999) studied the impact of intensive soil tillage on several soil properties in a long term field experiment extending over 18 years. The experiments were based on comparative application of various tillage options. Tillage intensity of the systems was considered to decrease in the following sequence: conventional plough tillage (CT), reduced tillage (RT) and no-tillage (NT). In general, bulk density in the upper layer of NT soils was increased. Surface cover by crop residues and higher aggregate stability under NT protected soil fertility by avoiding surface sealing and erosion. Lateral losses of herbicides also reduced under NT conditions. Accumulation of organic matter and nutrients near the soil surface under NT and RT were favourable consequences of not inverting the soil and by maintaining a mulch layer on the surface.

2.7 Effect of different methods of sowing on soil properties

2.7.1 Effect of tillage on soil temperature

Various decisive factors like amount of soil cover, water content in various soil layers, thermal conductivity, volumetric heat conductivity and amount of heat that enters or leaves the soil surface determines the soil temperature. Tollner *et al.*, (1984) reported that temperature near the soil surface in no-till field was consistently 5 to 7°C lower than in the conventional till (CT) field. Doran and Smith (1987) also found moderate soil temperature when tillage intensity was reduced because crop residues from previous crop stay on the soil surface which reflect light and insulate the soil. Crop residues covered soil will generally be cooler during summer (Carefoot *et al.*, 1990) but will stay warmer during autumn and winter (Gauer *et al.*, 1982). Dao (1998) recorded 0.5 to 3.4°C higher daily average soil temperatures in the 0-20 cm depth under mouldboard (MB) ploughing than zero-tilled. Soil temperature in winter wheat crop recorded from 0-10 cm soil surface during February was higher (warming effect) under ZT compared to CT, whereas it was less to the extent of 0.5-1.0°C and 0.5-3.0°C and (cooling effect) during the months of March and April (Malik *et al.*, 2002).

2.7.2 Effect of tillage on soil moisture

The successful cultivation of crop depends mainly on efficiency of moisture conservation and its proper utilization by the crop. Shanholtz and Lillard (1969) reported that water use efficiency was increased from 57% on CT plot to 81% on no-tillage plots. Jones *et al.* (1986) indicated that the dead sod mulch provided by ZT systems was highly effective in reducing evaporation and run off from the soil surface. The mulch and standing stubble preserved under ZT reduce evaporation and may increase water retention, so soil moisture content is generally higher under ZT than under CT (Carefoot *et al.*, 1990).

2.7.3 Effect of tillage on soil organic matter dynamics

Ram Kanwar Malik *et al.* (2004) stated that long term no-till maintained at farmers field in Teek, Uchani and Nangla village in Haryana revealed an improvement in the NPK and organic matter status in soil. Due to less disturbance with ZT than with CT, plant residues and other soil amendments do not get mixed into the soil as much and further the surface layer is more cooler, less oxidative and more acidic (Blevins *et al.*, 1977; Doran, 1980). These conditions tend to cause the organic matter content to increase or decrease at a slower rate compared to CT. Utomo (1986) observed that soil organic matter content increased with time in ZT plots because of slower rate of organic matter decomposition and slower decomposition owing to cooler soil in ZT plots. Blevin *et al.*, (1983) earlier reported that organic matter content in 0 to 5cm soil layer under no-till (NT) was almost twice as those with CT. Other workers have also reported greater amounts of soil organic carbon in soils that have been under reduced or zero-tillage for long periods compared with soils under mouldboard plough tillage. Reduced tillage systems and direct drilling practices have been reported to maintain or increase organic carbon with concomitant increase in improved soil structure (Doran and Smith, 1987). However, it is difficult to detect changes in soils organic carbon and nitrogen in short-term following the implementation of new management practices.

Soil tillage systems such as conventional, reduced, deep and zero-tillage are considered important soil management practices. These practices may alter the soil physical environment and affect the plant and root growth thereby water and nutrient uptake and crop yields. The effect of tillage on moisture conservation depends upon soil type and climatic conditions (Prihar *et al.*, 1968), time of tillage (Willis and Bond, 1971), porosity and thickness of mulch created by tillage (Holmes *et al.*, 1960; Acharya and Prihar, 1969) and size of clods left at the surface after tillage (Chaudhary and Acharya, 1993).

2.8 Water management under different sowing methods

Timsina and Connor (2001) stated that rice grown with traditional practices in medium to heavy textured soils in the subtropics required around 1500 mm of water. This consists of 150-250 mm of water for land preparation, 500-1200 mm (5-12 mm per day for 100 days) during crop growth to meet evapo-transpiration needs, and unavoidable seepage (upto 600 mm) from the saturated root zone. Additionally, another 50 mm is required for growing rice seedlings to the transplanting stage (Guerra *et al.*, 1998).

In practice, however, the actual amount of water applied by farmers may greatly exceed the requirement, especially where rice is grown on light textured soils, as in the Indian and Pakistani Punjab where rice crops receive between 1300 and 1800 mm of irrigation (Bhatti and Kinje, 1992; Narang and Gill, 1994) in addition to mean seasonal rainfall of around 500 mm.

Subbulakshmi and Pandian (2002) found rice yields of 4988 kg, 4656 kg and 4988 kg with irrigation on disappearance of previously ponded water, rotational water supply and continuous submergence, respectively. They also studied various crop establishment techniques and reported that the broadcasting of seeds produced 4255 kg ha^{-1}, drum seeding 4574 kg ha^{-1}, throwing of seedling 5358 kg ha^{-1}, random transplanting 5164 kg ha^{-1} and line transplanting 5496 kg ha^{-1}.

Thabonithy *et al.* (1994) reported land preparation required about 18% of the total water requirement in transplanted (206 mm) and wet sown (219 mm) rice. Vertical percolation was highest with dry sowing (214.7 mm) and lowest with transplanting (93.9 mm). They further added that the total water reqûirement was 1154, 1105 and 1040 mm with transplanting, wet sowing and dry sowing, respectively. The water use efficiency in terms of grain yield per mm of water used was lower in transplanted than in wet or dry sown crops (3.07, 3.65 and 3.77 kg ha^{-1} mm^{-1}, respectively). However, the grain yield was not significantly different between treatments. Transplanting had the highest labour requirement (646 man hours ha^{-1}) and longer maturity than wet or dry sowing. The recommended dry sowing for rice establishment on heavy clay soils.

2.9 Varieties suitable for different methods of sowing

In surface or aerobic wet seeding, pregerminated rice seeds are sown on a well-puddled soil surface 1 to 2 days after puddling. Seedling establishment under anaerobic seeding is controlled by the interaction of environment and management factors (soil properties, temperature, water depth, planting depth and germination conditions), physiological characteristics (tolerance to submergence and anoxia, high elongation ability and/or resistance to soil stresses) and seed vigor (potential for rapid uniform emergence and development of normal seedlings). Varieties suitable for anaerobic seeding should have tolerance of anoxia conditions under submergence, rapid seedling growth and high elongation ability, high weed competitiveness and good seed vigour. Grain yields of several anoxia-tolerant cultivars (PSBRc4, PSBRc10, IR64, IR41996-50-2-1-3, IR 52341) were found to be same as those of high yielding semi-dwarf cultivars (Yamauchi *et al.*, 1995). IET994, IET9221, Vikas, Jalpriya, ADT36, ASD16, BR2655 varieties are used for anaerobic seeding.

Rao and Rao (1991) conducted experiment on varietal suitability to rainfed uplands and areas with limited irrigation, and reported 'Tulasi' variety suitable for direct seeding which is drought tolerant at both vegetative and reproductive phases, early maturing, photoperiod and temperature insensitive, resistant to blast, semi-dwarf and high yielding (up to 9 t ha^{-1}).

2.10 Mechanization and different methods of sowing

The wider availability of herbicides and innovative farm machinery have made it possible to reduce or omit soil tillage operations prior to seeding, particularly where the primary objective of tillage is weed control. Generally, a distinction is made between systems where tillage and seeding are combined into one operation (reduced or minimum tillage) and systems where seed is placed in the soil without any tillage (zero-tillage). The reduced tillage machinery in India, is extensively used for establishing cereals other than rice, such as wheat. However, experiences with rice are generally limited (Bakker *et al.*, 2002).

Sarkar and Moody (1983) mentioned that application of zero-tillage in ric% has led to many different results with regard to weeds. Often, perennial weeds become a problem over time, which cannot be effectively managed with out tillage.

A strategy for successful mechanization of farm production in developing countries was presented by Clarke (2000). He emphasized that rather than making policies that will stipulate by which means or how much agriculture will be mechanized, governments should strive to trains establish conditions that will ensure free and undistorted development of appropriate mechanization. This development will largely be based on good linkages among farmers, retailers, manufacturers and importers, where the government has a largely subsidiary role of facilitating these linkages and providing education and extension.

Mechanization can play an important role in alleviating constraints in dry direct seeding zero or reduced tillage systems for rice may reduce production costs by combining tillage and seeding operations, but require more sophisticated machinery that can handle field residues effectively. The development of new technology focus on providing cost-effective methods for land leveling, as reducing the unevenness in a direct seeded field can improve yields and increase water and fertilizer use efficiency.

Sharma *et al.* (2002) reported that transplanting by self-propelled transplanter resulted in significantly higher effective tillers per square meter (217.2 tillers m^{-2}) than direct sowing under dry (182.4 tillers m^{-2}) and wet (201.2 tillers m^{-2}) conditions. Manual transplanting and direct wet sowing by anaerobic seeder also proved superior to direct dry seeding. In comparison to manual transplanting, mechanical transplanting saved 93% time and 66% cost of transplanting. Likewise, anaerobic seeder saved 73% time and 24.5% cost than manual sowing.

Higuchi *et al.* (1998) conducted research on mechanization of rice direct seeding in Japan and the U.S. and reported that to reduce labour requirements for rice production in Japan, a no-tillage direct sowing system was investigated in Tottori prefecture, Japan and Little rock, Arkansas, USA. The no-tillage system reduced labour time and production costs; effects on yield were not clear.

2.11 Effect of rice-establishment techniques on wheat

Sharma *et al.* (2003) narrated that, transplanting in puddled soils (wet tillage) is the most common method of crop establishment. Puddling, although a capital and energy intensive process, has survived for centuries since it provides certain advantages to the rice crop. It helps in land leveling, makes soil soft for transplanting, establishes reduced soil conditions that improve availability of soil nutrients, provides weed control and reduces percolation losses of water and nutrients.

Disadvantages of puddling in wheat crop, after rice includes: destruction of soil structure leading to higher bulk density, clod formation, decrease in the availability of soil nutrients.

Substitution of puddling with a less intensive tillage system or at least decreasing the frequency of puddling is one way of arresting yield decline in wheat grown in sequence with rice, since it is possible to avoid puddling in many soils without sacrificing rice yields (Lal, 1985). Coarse textured soils with loose single grain structure, fine-textured soils dominate in smectite clays, or soils with shallow water tables do not require puddling for growing rice.

Singh (2000), reported that, low light stress alone (65% NL) in general caused significant increase in the stature and foliage growth of rice plants, while decreased the biological and economic yield remarkably in all the rice cultivars. However, low light coupled with high temperature (38°C) and humidity (RH 94%) induced complete spikelet sterility, enhanced foliage growth and impaired the biological yield. Lower biological and economic yield recorded under low radiation was mainly due to significant reduction in the number of panicles per plant and grains per panicles.

Hong and Park (1992) conducted research on rice production costs, in which they collected data on labour savings and reductions in costs from 134 farms involved in the project. Average rice yield was 4267 kg ha^{-1} for the direct sowing method, 7% lower than for transplanting. Total labour input was 328 hours per hectare for direct sowing, 30% less than for transplanting. Net income per hactare was higher for direct sowing than for transplanting, as the transplanting and labour cost savings outweighed the yield loss and direct sowing costs.

2.12 Climate change and rice yields

As yields in some of the most productive regions are approaching a plateau or even declining, the likely effect of climate change on crop production adds to the already complex problem. Concern is widespread about the possible climate change caused by the increase in the concentration of greenhouse gases such as CO_2, CH_4, and N_2O in the atmosphere. To study the effects of climate change on yield, weather data along the transects of the Indo-Gangetic plain (IGP) were analyzed across several years (Pathak *et al.*, 2003). The significant decline in climatic potential rice yields at Ludhiana, Karnal, Delhi, and 24-Pargana was the result of a decrease in solar radiation, while at Ludhiana it was also partly the result of an increase in minimum temperature. The decrease in radiation and increase in minimum temperature influence rice yields through decreased photosynthesis, increased respiration, and a shortened vegetative and grain-filling period. (Yoshida and Parao, 1976; Penning de Vries, 1993; Horie *et al.*, 1995).

Hundal and Kaur (1996) also observed that increasing temperature and decreasing radiation levels were the reasons for a decline in simulated potential yields of rice and wheat at Ludhiana. It is widely perceived that, in all the major cities of India, increased aerosol concentrations have contributed to decreased solar radiation and consequently, increased minimum temperature (Hundal and Kaur, 1996;

Sinha *et al.*, 1998; Aggarwal *et al.*, 2000). Crop residue burning is widespread in the IGP (particularly in IGP Transects 2 and 3) and, while the CO_2 produced from burning is not considered to be a greenhouse gas contributor under these circumstances, other gases (e.g., N_2O and CH_4) are considered in greenhouse gas budgets and in turn can influence climate (Miura and Kanno, 1997; Kukla and Karl, 1993).

CHAPTER – III

MATERIAL AND METHODS

An investigation entitled, "Crop establishment techniques in rice under different environments in Haryana" was undertaken through two field experiments during *Kharif* (wet season) seasons of 2002 and 2003.

Experiment-I entitled, **"Effect of resource conservation technologies on growth and yield of rice under different environments"** was conducted at Research Farm, Regional Research Station (RRS) Uchani, Karnal of Chauhdary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana which is situated at 29°43' N latitude and 75°59'E longitude and at an altitude of 245 metres above mean sea level.

Experiment-II entitled, **"Performance of rice cultivars under different resource conservation techniques"** was conducted in the field of a farmer Sri Chithru Ram of village Dhons, district Kaithal, Haryana. The experimental site is situated at an elevation of 241 metres above mean sea level with a latitude of 29°48' N and longitude of 76°23' E in the subtropical zone. Dhons village is situated 38 km from international famous holy place "Jyothisar" (Near Kurukshetra), where God Lord Srikrishna delivered famous "Bhagawat Gita" message to Arjun under a Pepal tree.

The details of materials used and methods/ techniques adopted are described in this chapter.

3.1 Climate and weather

3.1.1 Experiment-I

Karnal has a semi-arid, sub tropical climate with severe cold conditions during the winter season. The maximum temperature reaches up to 45°C during summer, while minimum temperature falls to a level of 4°C. The average annual rainfall is 700-800 mm which is unevenly distributed throughout the year. About 80-90% of the total rainfall is received during monsoon months of July to September and few showers of cyclonic rains are received during December to January or in late spring.

3.1.2 Experiment-II

The climate of experimental site at village Dhons district Kaithal is semi arid sub-tropical. Normal annual rainfall ranges from 600 to 850 mm. About 80% of the annual precipitation falls between July to September i.e. during monsoon months. Winter rains add only 5-6% of the total annual rainfall and that too vary from year to year. The temperature in the region ranges from 4°C in the months of January to 44°C in May/June with hot winds blowing from West to East. The relative humidity is very high (83%) in July/August and as low as 52% in April/May. On the basis of climatic conditions, the cropping system is divided into main crop seasons i.e., *Kharif* (rainy or wet season) and *rabi* (winter season). The cultivation time for *Kharif* crops ranges from June to October and for *Rabi* crops from October to April. Rice-wheat is the main cropping sequence of this area.

3.2 Soil studies

3.2.1 Experiment-I

The soil of the experimental site was clay loam in texture and pH varied from 8.8 to 8.9. These soils give excellent response, especially to the application of nitrogen. Soil samples were taken before sowing and after harvest and the samples were analysed.

3.2.2 Experiment-II

Soil of the area are derived from Indo-Gangetic alluvium, which are very deep and clay loam in texture. Soil samples were taken before sowing and after harvest of the rice crop and the samples were analysed.

3.3 Cropping history of experimental sites

The cropping history of both experimental sites were same and is presented in Table 1. At both locations, rice was grown in *Kharif* and wheat in the *Rabi* season continuously from 1996-97 onwards. The experimental site at village Dhons had the history of continuous Rice-wheat for the last 10 years.

Table 1: Cropping history of experimental sites at Uchani and Dhons village

Year	Seasons	
	Kharif	**Rabi**
1996-97	Rice	Wheat
1997-98	Rice	Wheat
1998-99	Rice	Wheat
1999-00	Rice	Wheat
2000-01	Rice	Wheat

3.4 Technical programme

3.4.1 Experiment-I

"Effect of resource conservation technologies on growth and yield of rice under different environments".

Location : Regional Research Station, Uchani, Karnal

Treatments

Six crop establishment techniques/resource conservation techniques and methods of sowing/ transplanting

1. Puddled – transplant
2. Zero-till – Transplant
3. Zero-till – Broadcast (sprouted seed)
4. Puddled – Broadcast (sprouted seed)
5. Direct seeding with zero-till-drill under no-till.
6. Unpuddled (Dry field preparation fb irrigation) transplant

Dates of sowing

1. June 5^{th}
2. June 15^{th}
3. June 25^{th}

(Transplanting of one month old seedlings was done on July 5^{th}, July 15^{th}, July 25^{th} in the respective treatments during both years).

Treatment combinations

1. Puddled - Transplant – 5^{th} July
2. Puddled – Transplant – 15^{th} July
3. Puddled - Transplant – 25^{th} July

4. Zero-till - Transplant – 5^{th} July
5. Zero-till - Transplant – 15^{th} July
6. Zero-till - Transplant – 25^{th} July
7. Zero-till - Broadcast of sprouted seed – 5^{th} June
8. Zero-till - Broadcast of sprouted seed – 15^{th} June
9. Zero-till - Broadcast of sprouted seed – 25^{th} June
10. Puddled - Broadcast of sprouted seed – 5^{th} June
11. Puddled - Broadcast of sprouted seed – 15^{th} June
12. Puddled - Broadcast of sprouted seed – 25^{th} June
13. Direct seeding with zero-till-drill under no till – 5^{th} June
14. Direct seeding with zero-till-drill under no till – 15^{th} June
15. Direct seeding with zero-till-drill under no till – 25^{th} June
16. Unpuddled (Dry field preparation fb irrigation) – Transplant – 5^{th} July
17. Unpuddled (Dry field preparation fb irrigation) – Transplant – 15^{th} July
18. Unpuddled (Dry field preparation fb irrigation) – Transplant – 25^{th} July

Design : Randomized Block Design

Replications : Three

Total plots : 54

Gross Plot size: 8.25m × 8.25m

Net Plot size : 7.75m x 7.75m

Layout : Fig. 1.

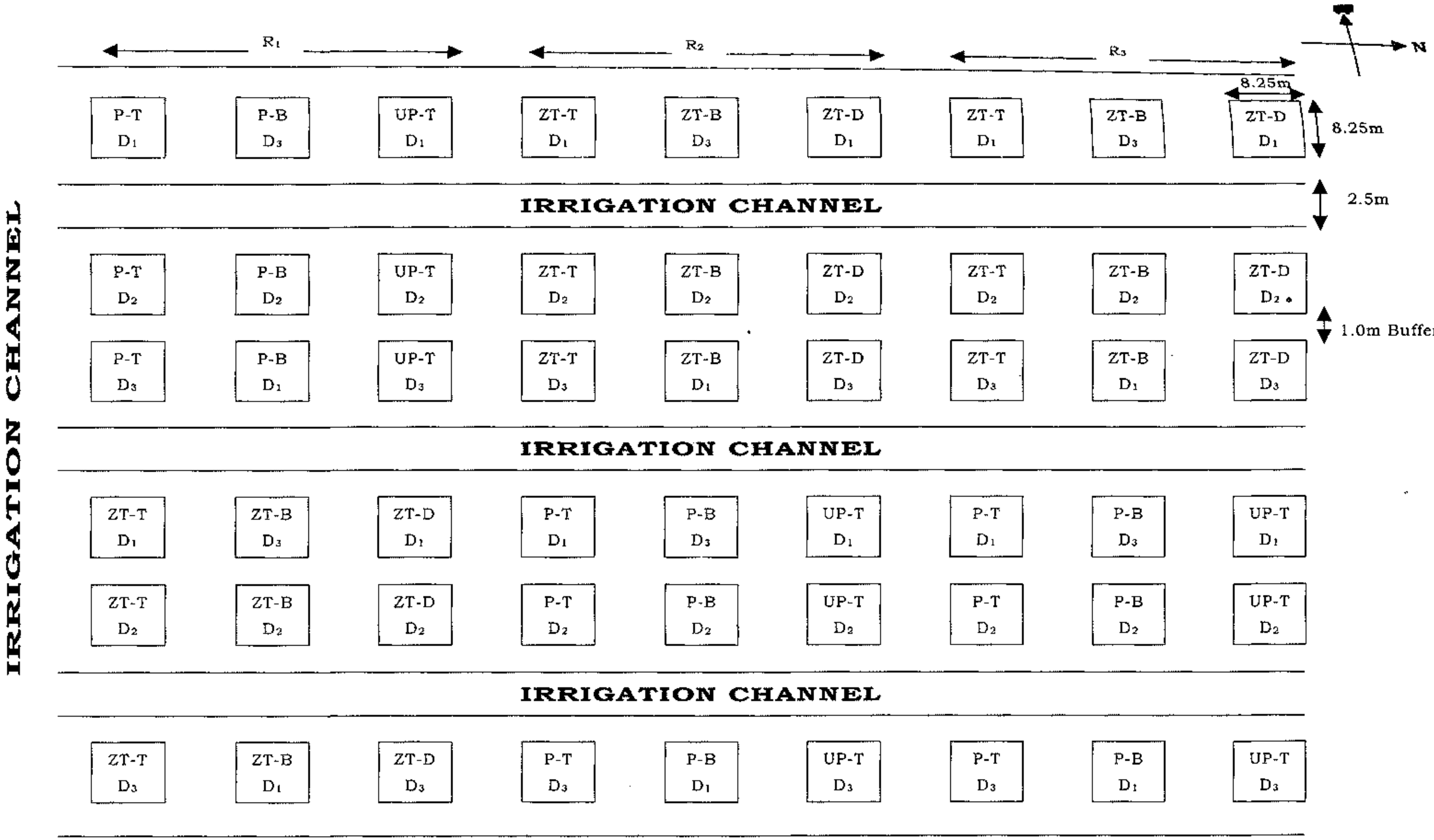

Fig. 1: Layout plan of Experiment-I

Details of abbreviations used in the experiment Layout

1. P-T : Puddled – transplant
2. ZT-T : Zero-till – Transplant
3. ZT-B : Zero-till – Broadcast (sprouted seed)
4. P-B : Puddled – Broadcast (sprouted seed)
5. ZT-D : Direct seeding with zero-till-drill under no-till.
6. UP-T : Unpuddled (Dry field preparation fb irrigation) transplant
7. D_1 : June 5th
8. D_2 : June 15th
9. D_3 : June 25th

3.4.2 Experiment-II

"Performance of rice cultivars under different resource conservation techniques".

Location: Farmer's field, village Dhons, district Kaithal, Haryana

Treatments

Four resource conservation techniques

1. Puddled – Transplant
2. Puddled – Broadcast (sprouted seed)
3. Zero-till – Transplant
4. Zero-till – Broadcast (sprouted seed)

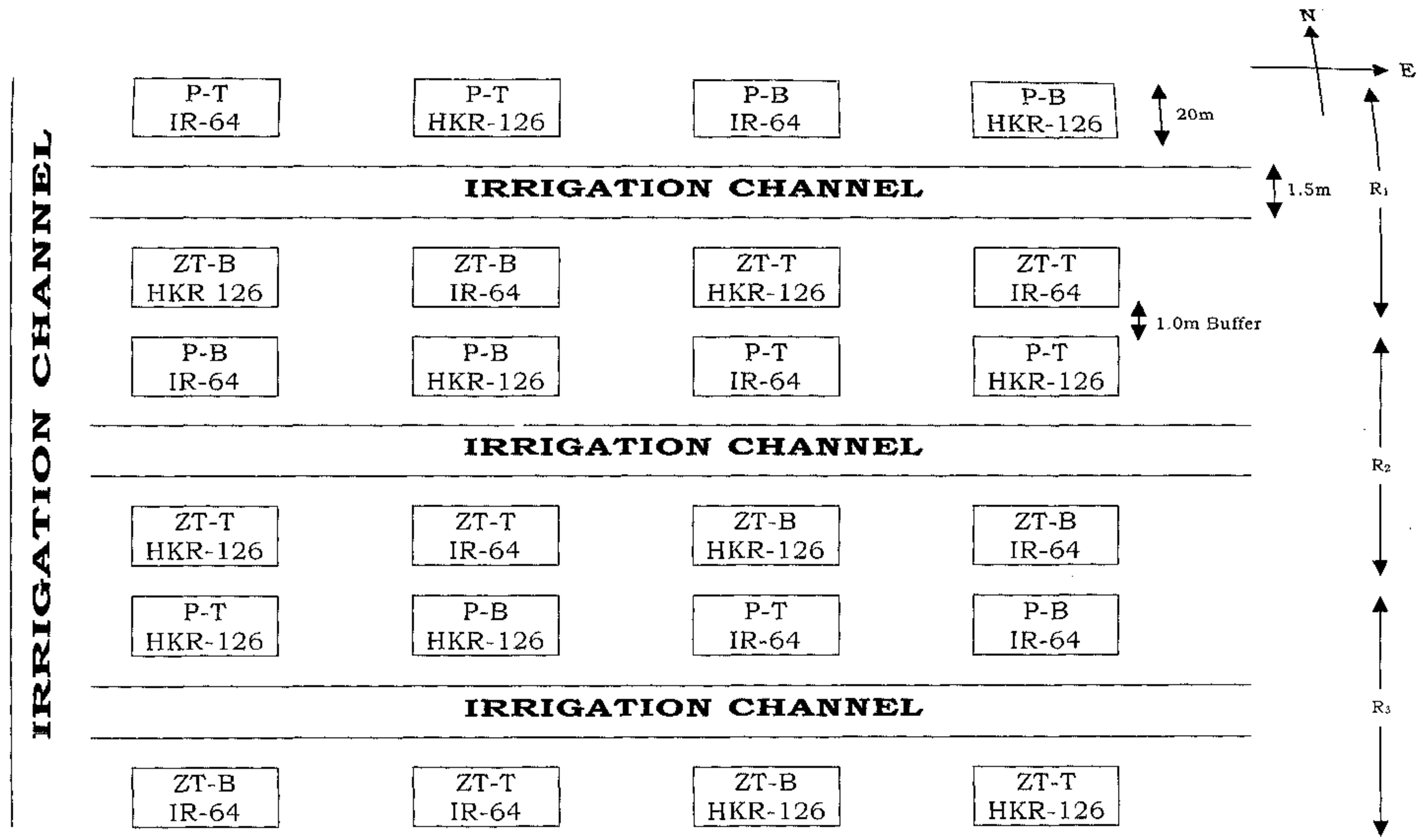

Fig. 2: Layout plan of Experiment-II

Two varieties

1. IR-64
2. HKR-126

Treatment combinations

1. Puddled – Transplant – IR-64
2. Puddled – Transplant – HKR-126
3. Puddled – Broadcast (sprouted seed) – IR-64
4. Puddled – Broadcast (sprouted seed) – HKR-126
5. Zero-till – Transplant -IR-64
6. Zero-till – Transplant –HKR-126
7. Zero-till – Broadcast (sprouted seed) – IR-64
8. Zero-till – Broadcast (sprouted seed) – HKR-126

Design : RBD

Replication : Three

Total plots : 24

Gross Plot size: 20 m x 33.3 m

Net Plot size : 19.5 m x 32.8m

Layout : Fig. 2.

Details of abbreviations used in the experiment layout

1. P-T : Puddled – Transplant
2. P-B : Puddled – Broadcast (sprouted seed)
3. ZT-T: Zero-till – Transplant
4. ZT-B: Zero-till – Broadcast

3.5 Spray of non-selective herbicide

At both the sites weeds which had emerged were controlled by spraying non-selective herbicides glyphosate (Roundup 41% SL @ 1.5% solution) 10 days before transplanting or broadcasting of sprouted seeds.

3.6 Nursery raising

8 kg per acre seed was treated with carbendazim @ 2g per kg of seed and kept for 24 hours. Then the seeds were soaked for 24 hours and the water was completely drained out. The soaked seeds were incubated in dark room for 36 hours to induce sprouting. The sprouted seeds were sown uniformly in the nursery.

At Site-I (Karnal), nursery sowings were done on June 5th, June 15th, June 25th in both years. At Site-II (Dhons village), nursery was sown on June 14th in both years. Other management practices for the nursery raising were followed as per the recommendations.

3.7 Field operations

3.7.1 Seed bed preparation

3.7.1.1 Zero-till-transplant plots

After wheat harvest, the fields were kept undisturbed, without subjecting to any preparatory tillage. To knock down already emerged weeds glyphosate (Roundup

41% SL @ 1.5% solution) was sprayed with knapsack sprayer fitted with flatfan nozzles (110° angle) using 500 litre water per hactare 10 days prior to transplanting or broadcasting of rice seed. The fields were flooded with water without puddling one day prior to transplanting.

3.7.1.2 Unpuddled-transplant plots

The fields were dry prepared by giving two harrowings in the month of May and June each followed by planking. Three harrowings followed by planking were given before flooding the field, one day prior to transplanting without subjecting to puddling.

3.7.1.3 Puddled-transplant plots

After harvest of wheat crop, fields were given two ploughing with disc harrow each followed by planking in the month of May and June 2002 and 2003. Then one day before transplanting of rice, fields were flooded with water and puddled by passage of three harrowing followed by planking.

3.7.2 Transplanting

30 days old seedlings were transplanted manually (one seedling per hill) on July 5th, July 15th and July 25th in both years under zero-till-transplant, unpuddled-transplant, puddled-transplant at Site-I. At Site-II (Dhons village), seedlings were transplanted on July 14th during both years.

3.7.2.1 Zero-till-broadcast plots

After wheat harvest, the plots were kept undisturbed without subjecting to any preparatory tillage. To control already emerged weeds glyphosate (Roundup 41% SL @ 1.5% solution) was sprayed with knapsack sprayer fitted with flat fan nozzle (110° angle) using 500 litre water per hactare 10 days prior to broadcasting of seeds. The fields were flooded with water without puddling one day prior to broadcasting.

3.7.2.2 Puddled – broadcast plots

Plots after harvesting of wheat crop, were given two ploughings with disc harrow each followed by planking in the month of May and June. Then one day before broadcasting of sprouted seeds, plots were flooded with water and puddled thrice with harrow each followed by planking.

3.7.2.3 Zero-till-drill sown plots

After wheat harvest, the plots were kept undisturbed without subjecting to any preparatory tillage. To (control already emerged weeds glyphosate (Roundup 41% SL @ 1.5%) was sprayed with knapsack sprayer using 500 litre water per hactare prior to drilling of seeds at row to row space equivalent to 17.5 cm.

3.8 Sowing of seeds in direct seeding plots

40 kg per hactare seed was used for sowing under direct sowing. The seeds were soaked in water for 24 hours and the water was completely drained. The soaked seeds were incubated in dark room for 24 hours to induce sprouting. The sprouted seeds were broadcasted uniformly on June 5th, June 15th and June 25th at Site-I and June 14th at Site-II during both the years.

3.9 Fertilizer application

Recommended dose of fertilizers was applied in soil. Full dose of phosphorus (60 kg ha^{-1}) and $ZnSO_4$ (25 kg ha^{-1}) was applied at the time of final preparatory tillage by broadcasting under all transplanting methods except under zero-till-transplant. Under zero-till-transplant, it was broadcasted just before flooding the field for transplanting. For broadcast plots fertilizer was applied one day prior to seeding. Nitrogen (150 kg ha^{-1}) was applied in three split doses i.e. 1/3rd at transplanting seeding, 1/3rd at 21 days after sowing (DAS)/days after transplanting (DAT) and remaining 1/3rd at 42 DAS/DAT.

3.10 Irrigation schedule

Plot wise frequent irrigations were given to maintain the 5 ± 2 cm level of standing water upto 15 days after transplanting/ seeding. After that irrigations were given as and when required to maintain the saturated conditions of soil. Irrigation was stopped 10 days before harvesting of the crop.

3.11 Harvesting and threshing

The crop was harvested at full physiological maturity. Border rows all round the experimental plots were harvested first, thereafter the net area separately. The grain weight was recorded at 14% moisture after threshing, cleaning and drying. The straw and grain weights were expressed in kg ha^{-1}.

3.12 Observations recorded and sampling procedures used (For both the experiments)

3.12.1 Crop observations

3.12.1.1 Plant Population (m^{-2})

The number of plants at three marked places from each plot were recorded at 30 and 60 DAS and 30 DAT by using 0.5 m x 0.5 m quadrate and expressed as number of plants per square metre.

3.12.1.2 Number of shoots (m^{-2})

Number of shoots were recorded at 60 and 90 DAS, and 30 and 60 DAT by using 0.5 m x 0.5 m quadrant from three places in each plot and expressed as number of shoots per metre.

3.12.2 Crop growth studies

3.12.2.1 Dry matter accumulation (g m^{-2})

Plants from the randomly selected places using 0.5 m x 0.5 m quadrant in each plot were cut close to the ground at 60 and 90, DAS and 30 and 60 DAT and at harvest to record dry matter accumulation. These samples were first dried in sun and then oven dried at 70°C till constant weight was achieved. After drying, the samples were weighed for recording dry weight and then dry weight was converted kg m^{-2}.

3.12.2.2 Plant height (cm)

The main shoots of 10 plants were tagged at random in each plot and height of the shoot was measured in centimetres at 60 and 90 DAS, and 30 and 60 DAT and at harvest. The height of each plant was measured from the base of the plant to the tip of the highest fully developed leaf before heading and up to tip of the panicle after heading.

3.12.2.3 Lead area index (LAI)

Leaf area was recorded from plant samples taken for dry matter studies. Leaf area was measured in square centimetres with the help of leaf area meter (L1 3000, LICOR Ltd., Nebraska, USA).

Leaf area index (LAI) was calculated by using the following formula:

$$LAI = \frac{\text{Total leaf area (cm}^2\text{)}}{\text{Land area occupied (cm}^2\text{)}}$$

3.12.3 Yield attributing character3 and yield

3.12.3.1 Number of effective tillers

The number of effective tillers were recorded at harvest by placing 0.5 m x 0.5 m quadrant at ten places in each plot and expressed as number of effective tillers per square metre.

3.12.3.2 Panicle length

Panicle length was measured in centimetres from ten effective tillers of tagged plants from each plot at harvest and averaged to get length of panicle.

3.12.3.3 Number of filled and unfilled grains per panicle

The numbers of filled and unfilled grains per ten panicles selected at random from each plot were counted and average number of grains per panicle were worked out.

3.13.3.4 1000-grain weight

One thousand filled grains from the produce of the net plots were counted and their weight was recorded in grams.

3.12.3.5 Grain yield

Produce of net plots was sun dried and threshed Grains thus obtained were winnowed, cleaned and weighed. The yield recorded in Kg per plot was standardized to 14% moisture and then weight was converted into kg ha^{-1}.

3.12.3.6 Straw yield

Dry weight of straw collected from net plot was recorded after sun drying for seven days and expressed in kg ha^{-1}.

3.12.3.7 Biological yield

Biological yield was computed by adding grain and straw yield together per plot and converted to kg ha^{-1}.

3.12.3.8 Harvest index

The Harvest Index (HI) was calculated by using the following formula:

$$HI = \frac{\text{Grain yield}}{\text{Grain yield + straw yield}} \times 100$$

3.13 Weather Parameters

The various daily weather parameters *viz.*, maximum temperature, minimum temperature, relative humidity (morning and evening), bright sunshine hours, rainfall were collected from CSSRI, Karnal, further daily data was utilized to compute weekly data.

The growing degree-days were calculated using daily maximum, minimum temperature and base temperature with the following equation.

$$\text{Growing degree days (GDD)} = \frac{\text{Maximum Temp.} + \text{Minimum Temp.}}{2} - (Tb)$$

Where, Tb is base temperature (10°C for rice)

3.14 Economics

The cost of cultivation and gross income (Rs. ha^{-1}) of various treatments were calculated on the basis of approved market rates for inputs and output. Net returns (Rs. ha^{-1}) were worked out by subtracting the total cost of cultivation of each treatment from the gross income of respective treatment. Benefit: cost ratio was also worked out.

3.15 Wheat yields

The yields of wheat shown after the harvest of rice crop were monitored during 2003-04 after experiment-I at RRS, Karnal and experiment II in farmers field at Dhons Village (Kaithal).

3.16 Statistical analysis

The data presented in thesis are the mean values. All the observations were statistically analyzed by using the statistical methods described by Panse and Sukhatme (1985). In order to see the significance of treatments' effect the data was subjected to statistical analysis by "analysis of variance" technique given by Fisher (1958). The significant treatment effect was judged with the help of 'F' test at 5% level of significance. To judge the significant difference between the means of two treatment effects, the critical difference (CD) was worked out by the following formulae:

$$C.D = \sqrt{2EMS/N} \times t_{5\%}$$

Where,

EMS = Error Mean Square

N = Number of replications of that factor for which CD is to be calculated.

$t_{5\%}$ = Table value of t at 5% level of significance at error degree of freedom.

CHAPTER - IV

EXPERIMENTAL RESULTS

METEOROLOGICAL PARAMETERS

4.1 Weather conditions prevailed during the crop season

The daily meteorological parameters prevailed during the *Kharif* 2002 and 2003 seasons were recorded. Using this data weekly meteorological standard weeks were computed for the two crops season shown in Table 2 and 3, Table 2 shows the mean weekly normal meteorological data. The meteorological parameters, which are plotted, are the maximum and minimum air temperature, morning and evening relative humidity, bright sunshine hours, rainfall and pan evaporation (Fig. 3-5).

4.1.1 Maximum temperature

During *Kharif* season 2002 mean weekly maximum air temperature gradually decreased from 36.3°C at emergence stage to a lowest value of 29.4°C during the 36^{th} week and afterward increasing trend was observed up to maturity stage shown in Fig. 3.

Table 2: **Weekly metrological data during rice crop season 2002**

Standard week	Air temperature (°C)		Relative Humidity (%)		Bright sunshine hours (hrs.)	Pan evaporation (mm)	Rain fall (mm)
	Max.	Min.	Morning	Evening			
22	34.2	22.9	76	46	7.4	5.6	18
23	39.2	26.3	72	42	94	7.4	16.8
24	36.3	25.6	70	48	7.8	7.3	1.2
25	37.8	26.9	66	46	8.0	8.3	0.0
26	37.0	28.4	74	52	8.4	7.9	0.0
27	37.8	27.4	77	54	6.4	7.1	6.4
28	37.5	28.7	64	49	8.3	7.8	0.0
29	36.5	28.3	76	56	6.6	6.8	0.0
30	35.2	26.8	85	60	6.5	5.6	28.8
31	34.2	26.5	83	76	3.4	3.5	120.0
32	33.0	26.7	90	78	3.4	3.9	22.5
33	32.3	26.0	90	70	4.1	3.8	22.4
34	33.0	25.3	81	65	7.0	4.2	0.0
35	32.0	24.1	88	81	5.4	3.7	88.2
36	29.4	22.3	87	76	6.4	3.9	58.2
37	30.6	22.2	95	78	4.7	3.1	103.7
38	32.5	21.8	91	63	8.7	3.2	10.1
39	32.5	18.7	86	53	9.2	3.3	0.0
40	33.5	17.5	90	49	9.1	3.0	0.0
41	31.3	19.0	88	55	7.2	2.8	0.0
42	30.1	17.6	96	57	5.3	1.9	0.0
43	30.0	14.4	96	42	8.0	2.4	0.0
44	29.6	15.1	96	46	7.1	2.1	0.0
45	28.1	14.4	96	50	6.6	1.8	0.0

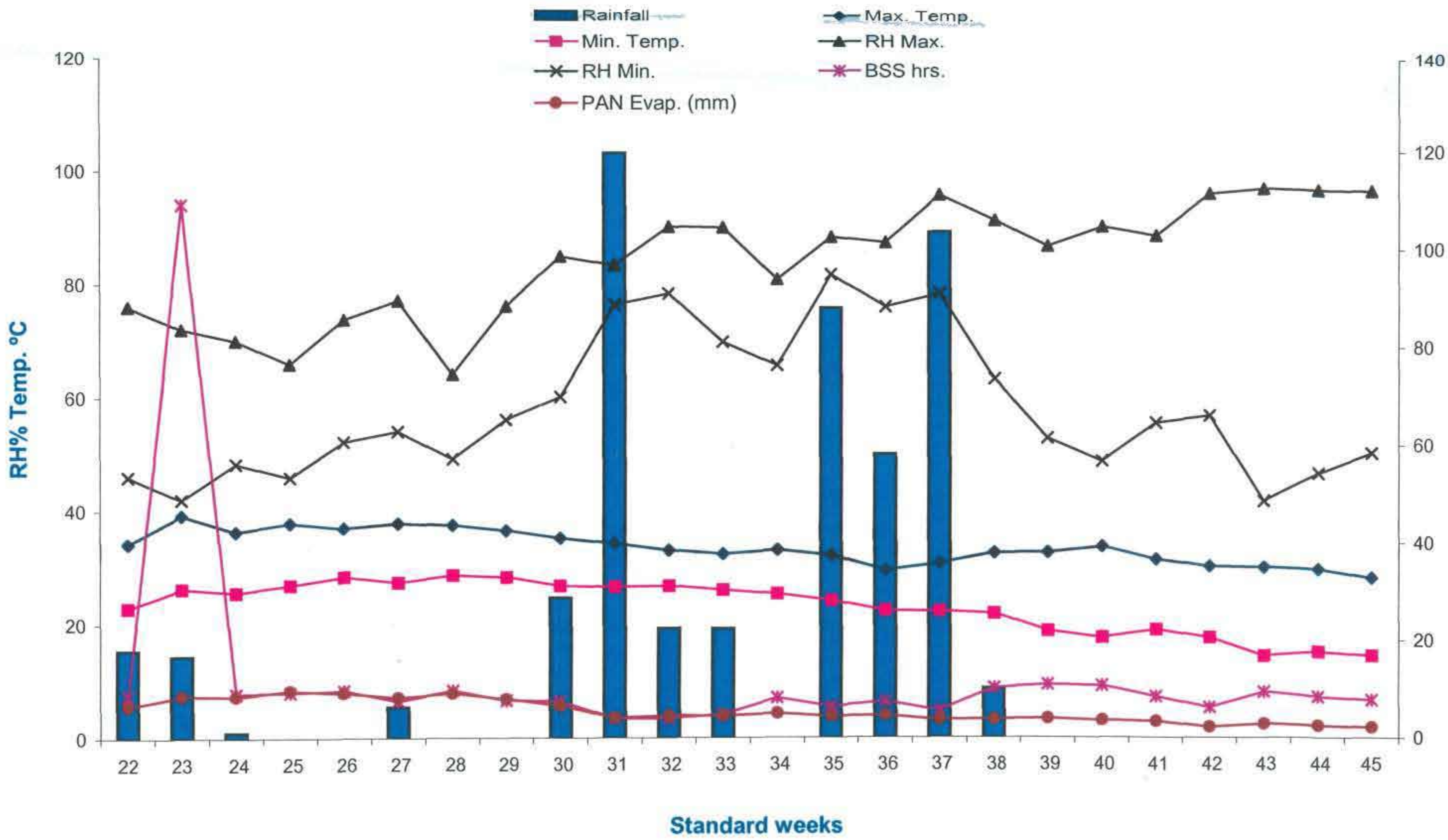

Fig. 3: Weekly meteorological data for *Kharif* crop season 2002

Table 3: Mean weekly metrological data during rice crop season 2003

Standard week	Air temperature (°C)		Relative Humidity (%)		Bright sunshine hours (hrs.)	Pan evaporation (mm)	Rain fall (mm)
	Max.	Min.	Morning	Evening			
22	43.4	25.4	40	18	10.9	10.7	0.0
23	40.3	28.0	62	40	4.6	8.8	0.0
24	41.5	27.0	55	38	7.5	9.2	10.0
25	33.9	25.9	84	58	6.4	5.5	11.8
26	35.6	25.9	84	55	6.7	5.8	16.8
27	34.3	26.2	86	61	7.0	5.6	6.8
28	31.0	24.6	95	79	5.0	3.4	84.6
29	32.4	26.3	89	73	6.2	3.2	46.2
30	34.0	26.7	85	68	8.5	4.2	5.9
31	31.6	25.2	92	75	4.6	3.0	53.0
32	33.9	25.3	89	69	5.8	4.1	32.4
33	33.0	25.6	89	72	5.7	3.2	8.8
34	33.6	25.6	90	70	8.8	4.4	16.8
35	33.1	25.9	92	74	6.3	2.8	66.6
36	31.2	24.6	93	77	5.5	2.7	9.4
37	31.5	24.4	96	77	4.5	2.4	12.4
38	33.7	24.4	95	65	7.4	3.3	0.0
39	31.9	19.6	93	53	8.8	3.5	0.0
40	32.7	16.6	94	42	9.3	3.3	0.0
41	33.0	15.3	91	29	8.2	3.3	0.0
42	32.1	15.5	94	32	8.1	2.8	0.0
43	30.4	15.3	96	43	7.8	2.2	0.0
44	30.2	14.3	93	41	8.0	2.1	0.0
45	30.0	12.4	88	31	7.8	2.2	0.0

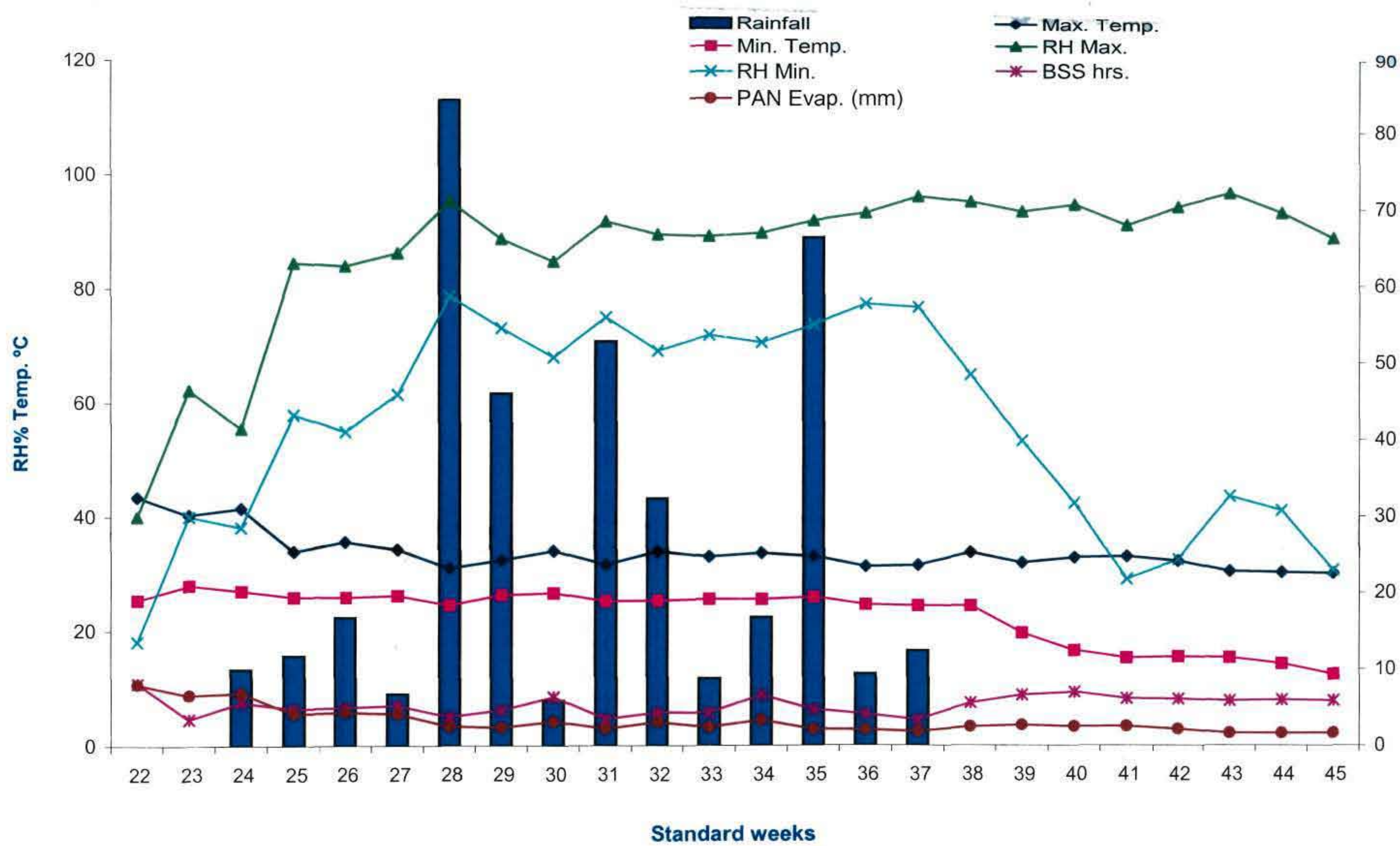

Fig. 4: Weekly meteorological data for *Kharif* crop season 2003

Table 4: **Weekly normal metrological data**

Standard week	Air temperature (°C)		Relative Humidity (%)		Bright sunshine hours (hrs.)	Pan evaporation (mm)	Rain fall (mm)
	Max.	Min.	Morning	Evening			
22	39.7	24.1	48	21	10.5	12.0	39.4
23	39.9	24.9	53	27	10.3	11.3	26.4
24	37.7	24.8	64	41	9.5	10.3	281.7
25	36.8	26.1	73	49	8.4	8.1	328.1
26	36.0	26.4	79	55	8.8	6.5	211.0
27	35.1	25.9	80	59	7.4	6.1	264.0
28	33.1	25.2	87	74	6.7	5.1	1018.9
29	32.3	25.8	90	73	6.5	4.3	989.4
30	32.5	26.0	88	73	6.5	4.5	599.3
31	32.1	25.7	88	74	5.8	4.3	592.6
32	32.1	25.5	90	76	6.1	3.8	512.3
33	32.7	25.2	88	69	8.1	4.5	488.1
34	32.8	25.2	87	68	9.6	4.3	419.6
35	33.0	24.7	86	65	9.4	4.3	329.2
36	32.6	24.1	87	64	9.2	4.2	330.0
37	32.6	23.2	89	61	9.3	4.3	166.2
38	32.6	22.0	88	57	9.5	4.1	44.6
39	33.4	21.2	86	51	9.8	4.0	46.6
40	32.6	18.9	87	49	9.9	4.0	84.6
41	32.3	18.2	87	45	9.7	3.6	45.4
42	32.3	16.7	87	39	10.2	3.3	0.0
43	30.8	15.3	87	40	9.3	3.1	23.9
44	29.7	13.9	89	41	9.2	2.8	70.8
45	28.8	12.8	89	39	9.7	2.7	0.0

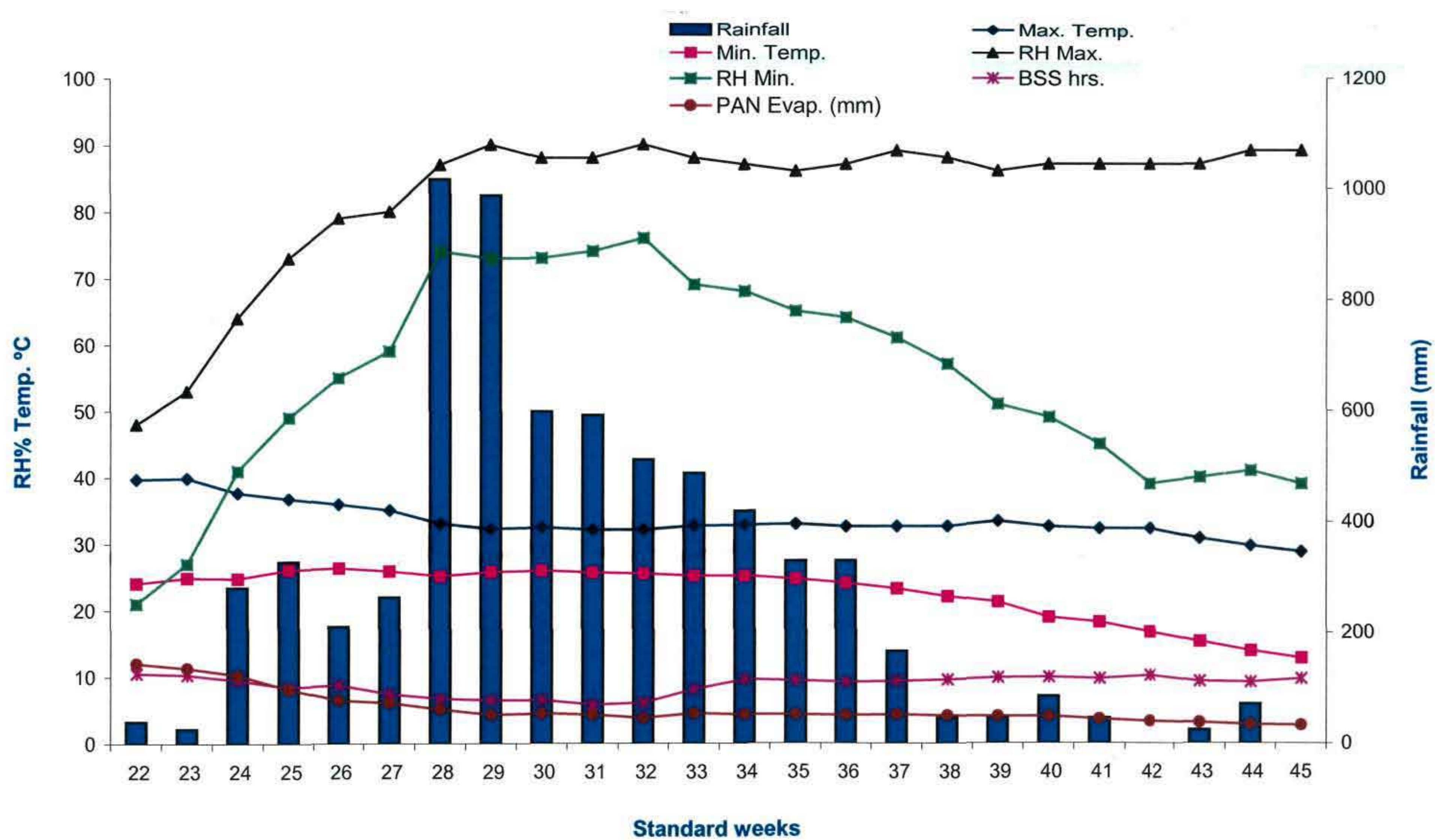

Fig. 5: Weekly normal meteorological data

During *Kharif* 2003 crop season the weekly mean maximum temperature varied from 43.4°C to 30.0°C shown in Fig. 4. Maximum temperature gradually decreased from the date of sowing to maturity.

4.1.2 Minimum temperature

The weekly mean minimum temperature varied from 28.7°C to 14.4°C during *Kharif* 2002 shown in the Fig. 3.

During 2003 *Kharif* season the values of weekly minimum temperature were ranged from 28.0°C to 12.4°C. the minimum weekly mean temperature values were gradually decreased from the date of sowing to maturity stage.

4.1.3 Relative humidity

The fluctuations in weekly morning and evening relative humidity values were observed during the two crop growth seasons. Weekly morning relative humidity ranges between the 96% (at week 42^{nd}, 43^{rd} and 44^{th}) and 69% (at week 28^{th}). During the 2003 crop season the morning weekly mean relative humidity values were ranged between 96% (at 37^{th} standard week) and 40% (at 22^{nd} standard Week).

The weekly evening relative humidity during 2002 was 42% (at 43^{rd} standard week) and 81% (at 35^{th} standard week). A comparison among the two years shown, 2002 crop season was shown by higher values of morning and evening relative humidity as compared to 2003 crop season.

4.1.4 Rainfall

During the *Kharif* season 2002 461.5 mm of rainfall was received which was spread over a 9 rainy days (rainy day $\geq$ 2.5 mm of rainfall), where as in 2003 a total 318.5 mm rainfall received over 14 rainy days. A comparison between the 2002 and 2003, good distribution of rainfall in 2003 crop season than 2002 crop season was observed.

4.1.5 Bright sunshine hours

Cloudy weather prevailed throughout the crop season in 2002. The 2003 crop season was slightly warmer when compared to 2002 crop season.

4.1.6 Pan evaporation

The atmospheric demand during the *Kharif* 2002 was lower when compared to 2003 *Kharif* season. This was due to less atmospheric demand; this may be due to more rainfall received during the year. In 2003 crop season the weekly mean pan evaporation values were lower than normal values. A comparison of both the years the 2002 crop season recorded higher pan evaporation values than 2003 crop season.

4.1.7 Relationship between accumulated heat units and different phenophases

Experiment-I

In order to know the growth response of rice cultivar to heat units, response functions were developed by using dry matter and accumulated heat units for different phenophases. The dry matter accumulation under different treatments followed the same trend with accumulated thermal time (Fig. 6-11). In puddled broadcast, zero-till-broadcast and zero-till direct seeding treatment consumed less accumulated heat units when compared with the puddled-transplant, zero-till-transplant and unpuddled-transplant. Unpuddled-transplant treatments in IR-64 consumed more heat units, whereas unpuddled-transplant treatment in IR-64 under varied environmental conditions consumed more heat units to reach maturity. June 5th sown crop consumed more accumulated heat units in *Kharif* 2003 crop seasons (Fig. 9) whereas, June 25th date of sown crop *Kharif* 2002 crop consumed less accumulated heat units (Fig. 8).

Experiment-II

The relationship between the various phenophases and accumulated heat units were depicted (Fig. 12-15). The accumulated heat units consumed in various phenophases in

Experiment-I

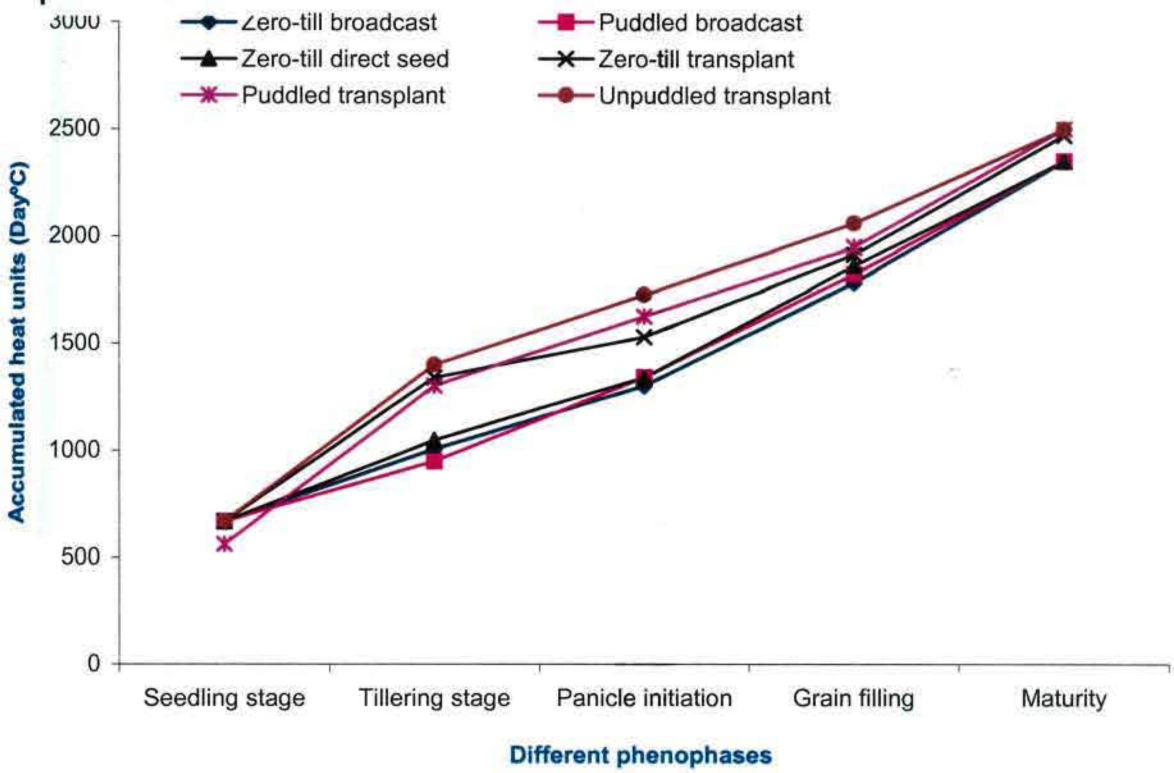

Fig. 6: Heat units consumed at different phenophases by rice crop (IR-64) sown on June 5 under different crop establishment techniques during 2002 *Kharif* crop season

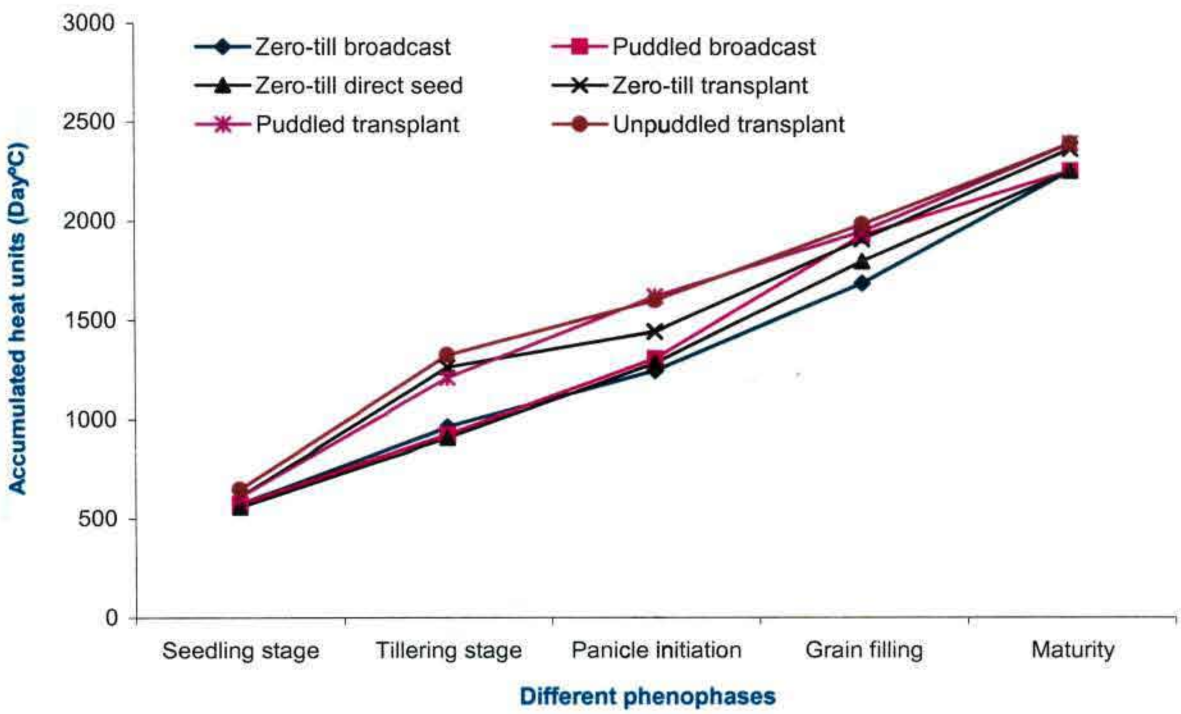

Fig. 7: Heat units consumed at different phenophases by rice crop (IR-64) sown on June 15 under different crop establishment techniques during 2002 *Kharif* crop season

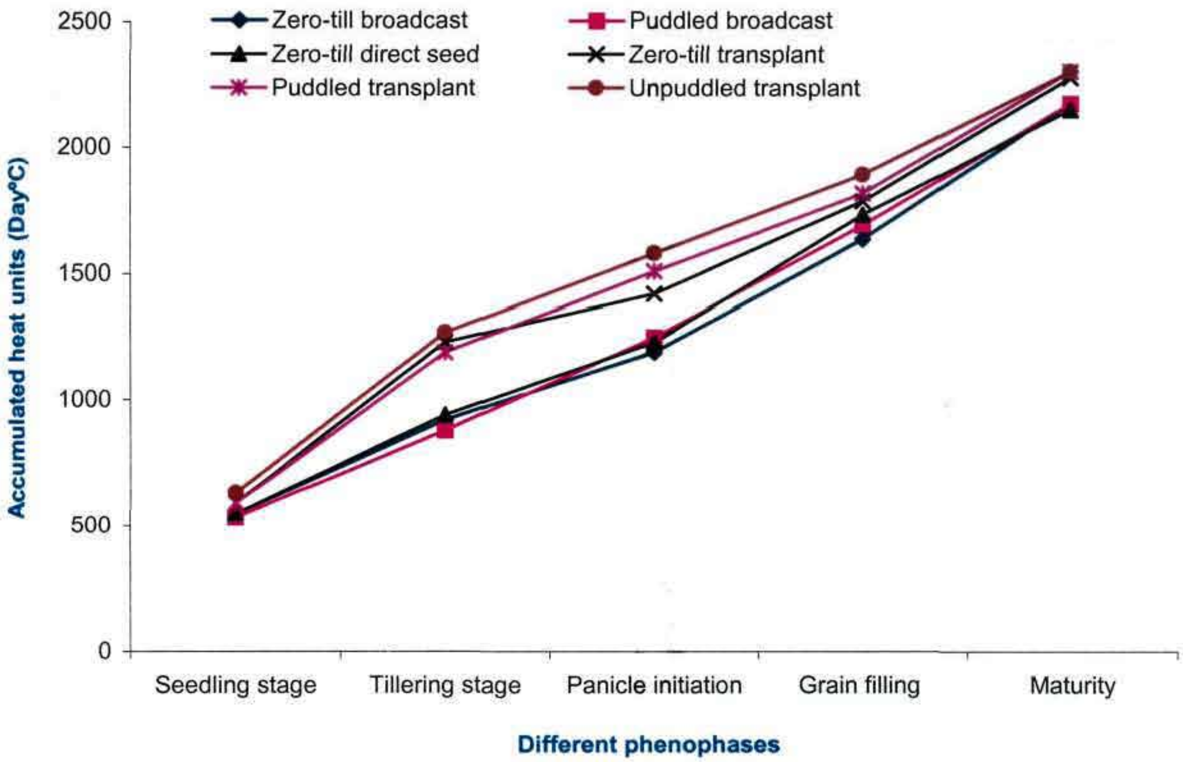

Fig. 8: Heat units consumed at different phenophases by Rice crop (IR-64) sown on June 25 under different crop establishment techniques during 2002 *Kharif* crop season

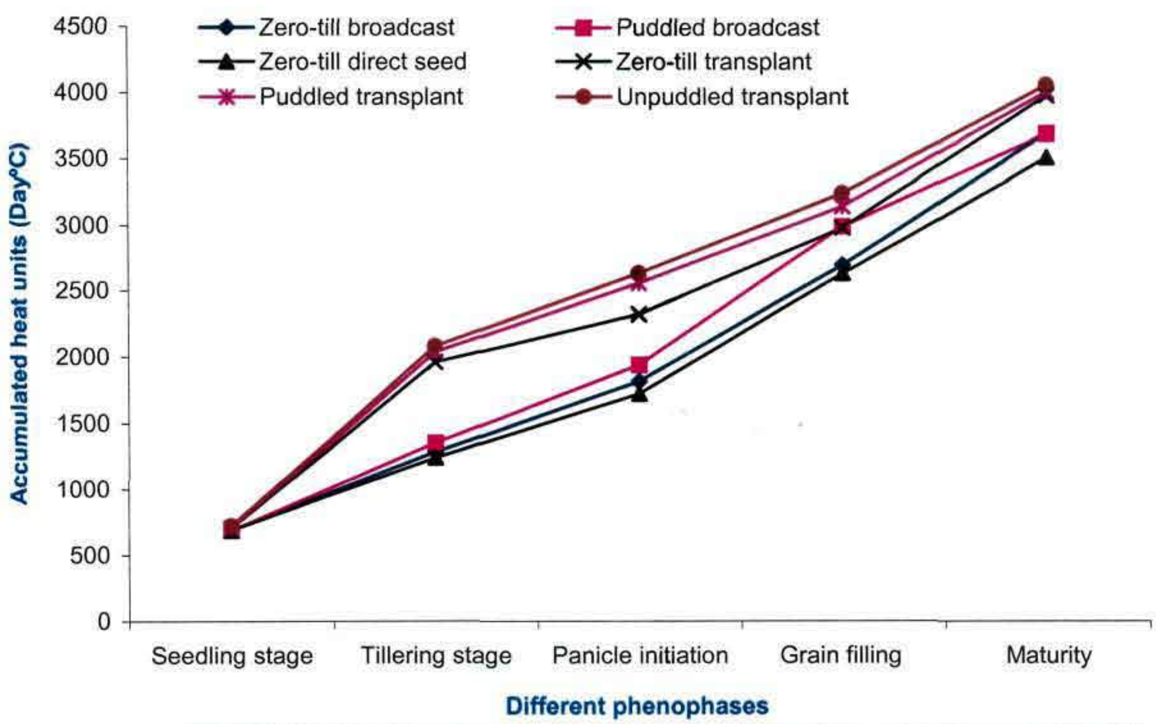

Fig. 9: Heat units consumed at different phenophases by rice crop (IR-64) sown on June 5 under different crop establishment techniques during 2003 *Kharif* crop season

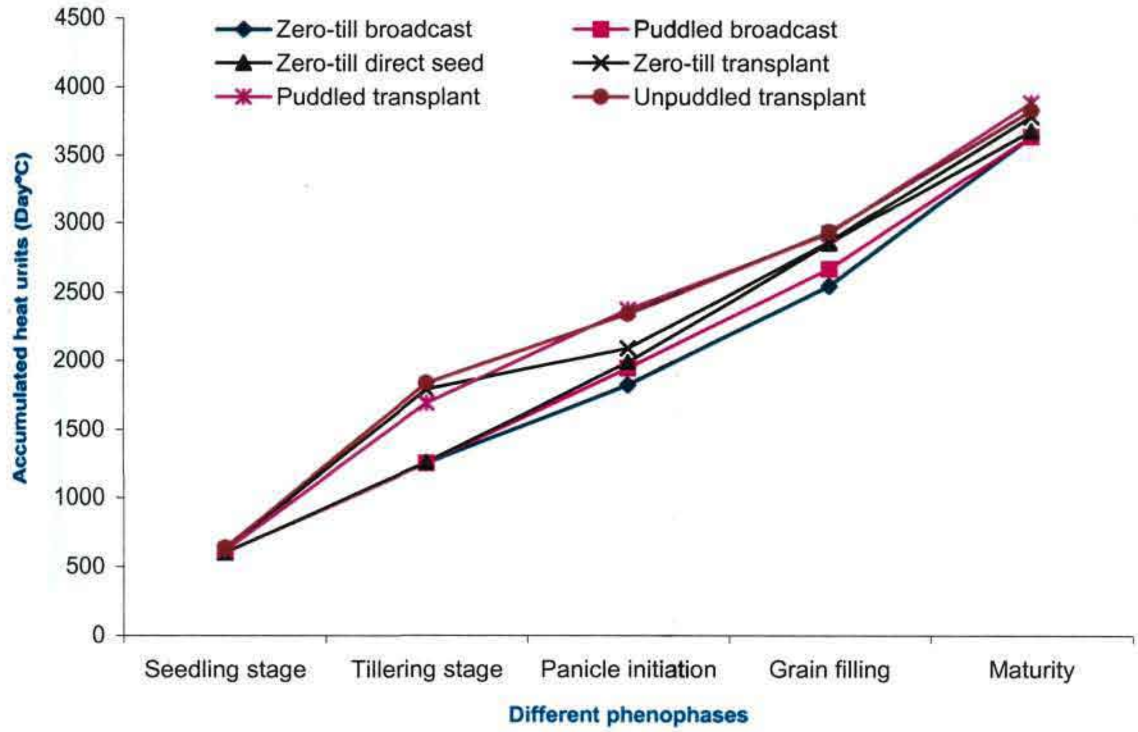

Fig. 10: Heat units consumed at different phenophases by rice crop (IR-64) sown on June 15 under different crop establishment techniques during 2003 *Kharif* crop season

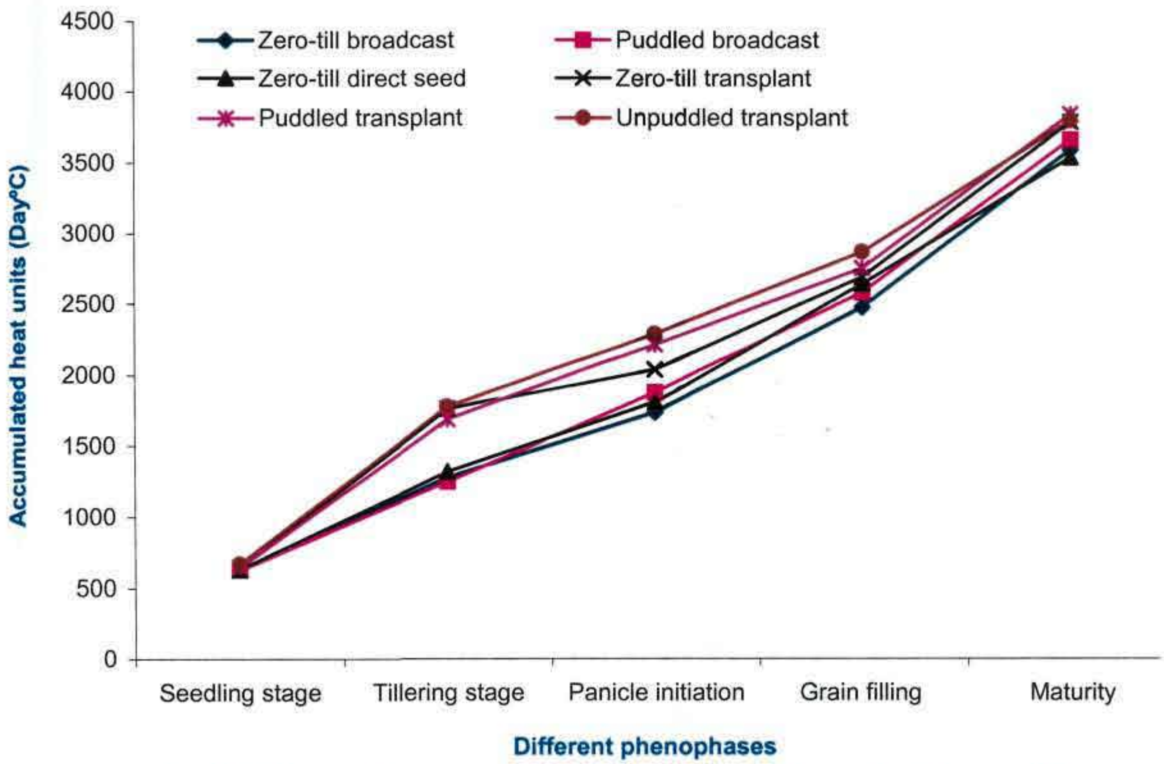

Fig. 11: Heat units consumed at different phenophases by rice crop (IR-64) sown on June 25 under different crop establishment techniques during 2003 *Kharif* crop season

Experiment-II

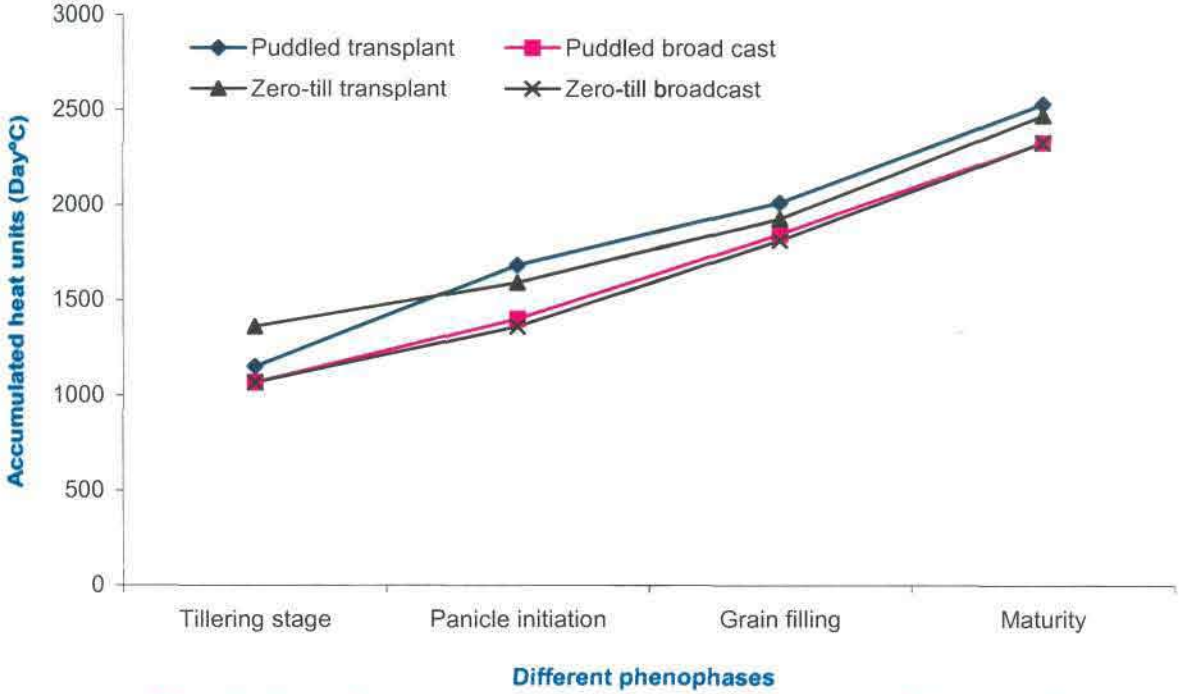

Fig. 12: Heat units consumed at different phenophases by Rice crop (IR-64) under different crop establishment techniques during the *Kharif* crop season 2002

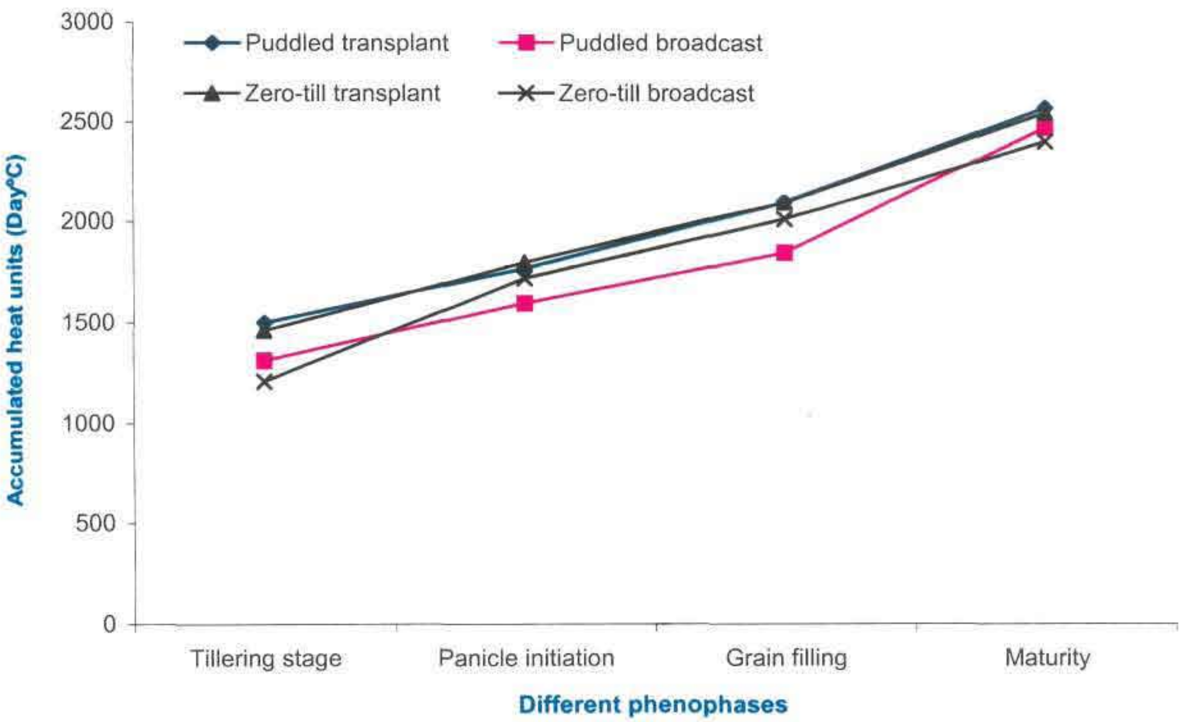

Fig. 13: Heat units consumed at different rice crop (HKR-126) under different crop establishment techniques during the *Kharif* crop season 2002

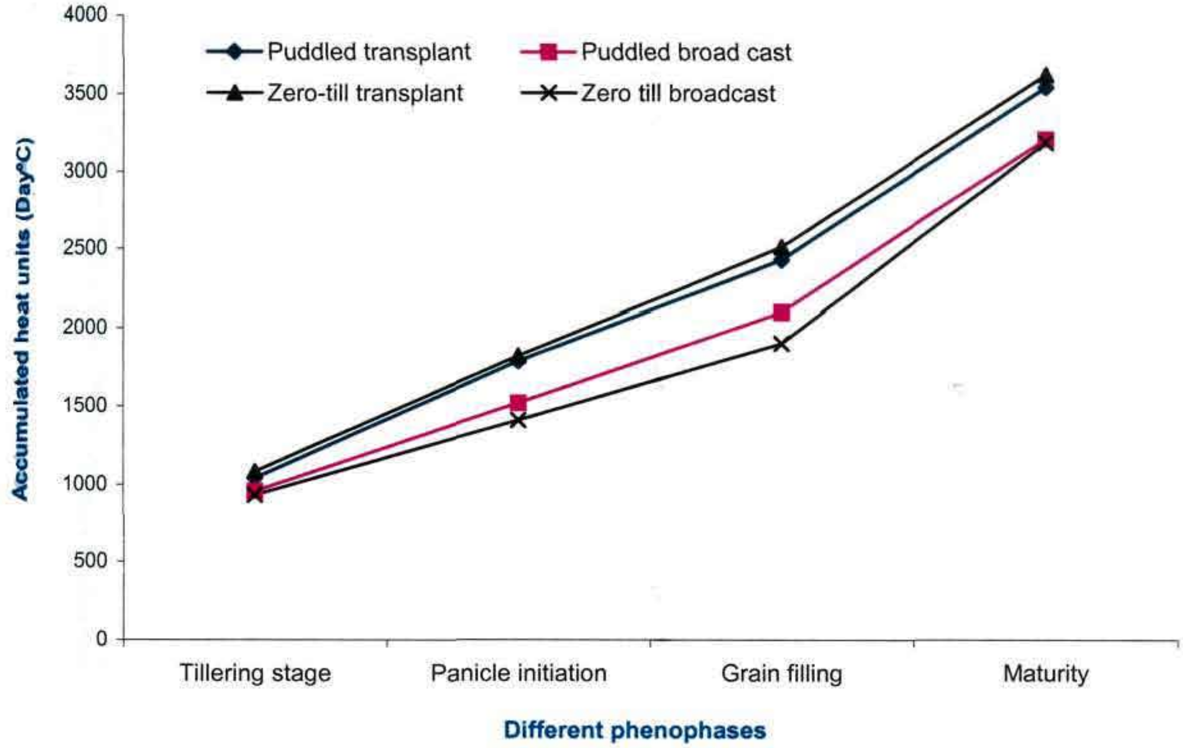

Fig. 14: Heat units consumed at different phenophases by rice crop (IR-64) under different crop establishment techniques during the *Kharif* crop season 2003

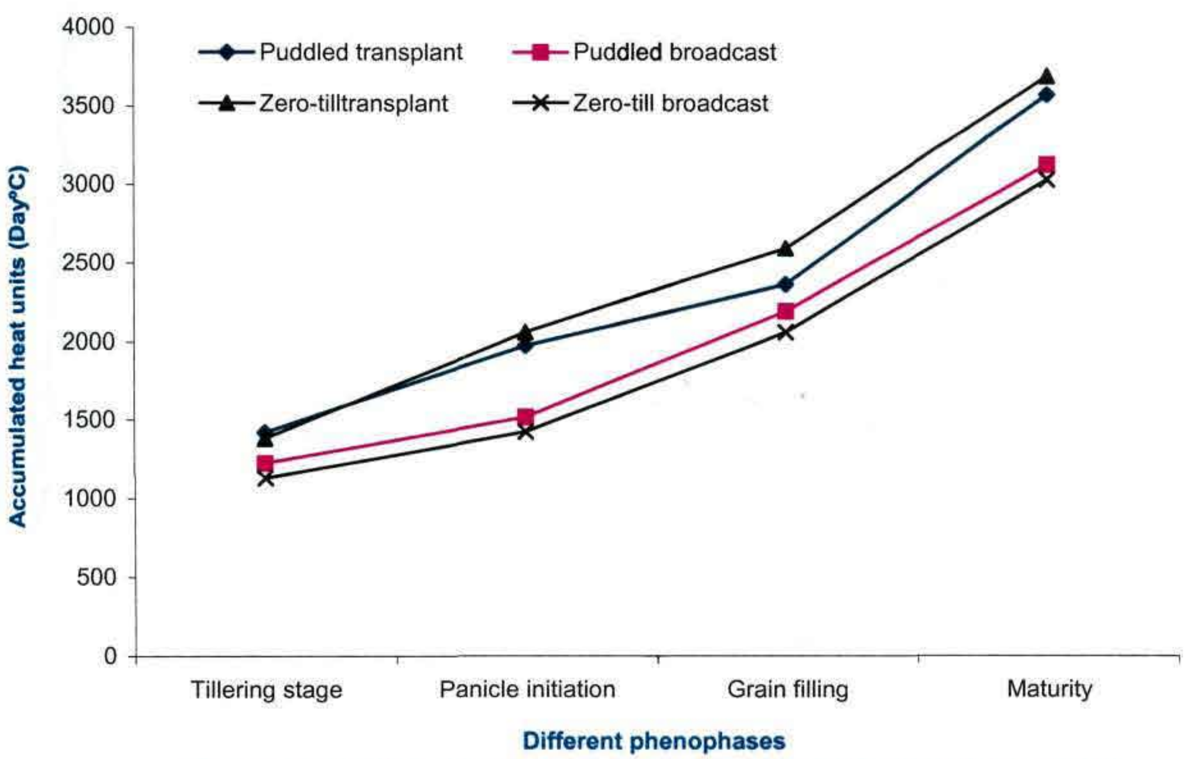

Fig. 15: Heat units consumed at different by rice crop (HKR-126) under different crop establishment techniques during the *Kharif* crop season 2003

IR-64 during 2002 and 2003 were higher in puddled-transplant, zero-till-transplant were higher than puddled-broadcast, zero-till-broadcast (Fig. 12 and 14).

Where as HKR-126, the puddled-transplant was consumed more accumulated heat units, whereas the zero-till-broadcast and puddled broadcast consumed less accumulated heat units (Fig. 13). It followed same trend in 2003 *Kharif* crops season (Fig. 15). When compared two varieties (IR-6 and HKR-126), HKR-126 consumed more Accumulated heat units to reach various phenophases in almost all treatments.

4.1.8 Relationship between dry matter accumulation and accumulated heat units

Experiment-I

Dry matter accumulation at harvest time showed direct relationship with accumulated heats during the crop growing seasons with respect to method of planting, similarly strong relationship were observed in different dates of transplant shown in Fig. 16-26.

Experiment-II

The relationship between the accumulated heat units and accumulated dry matter shown similar trend, which was shown in experiment-I. In 2003 *Kharif* crop

Experiment-I

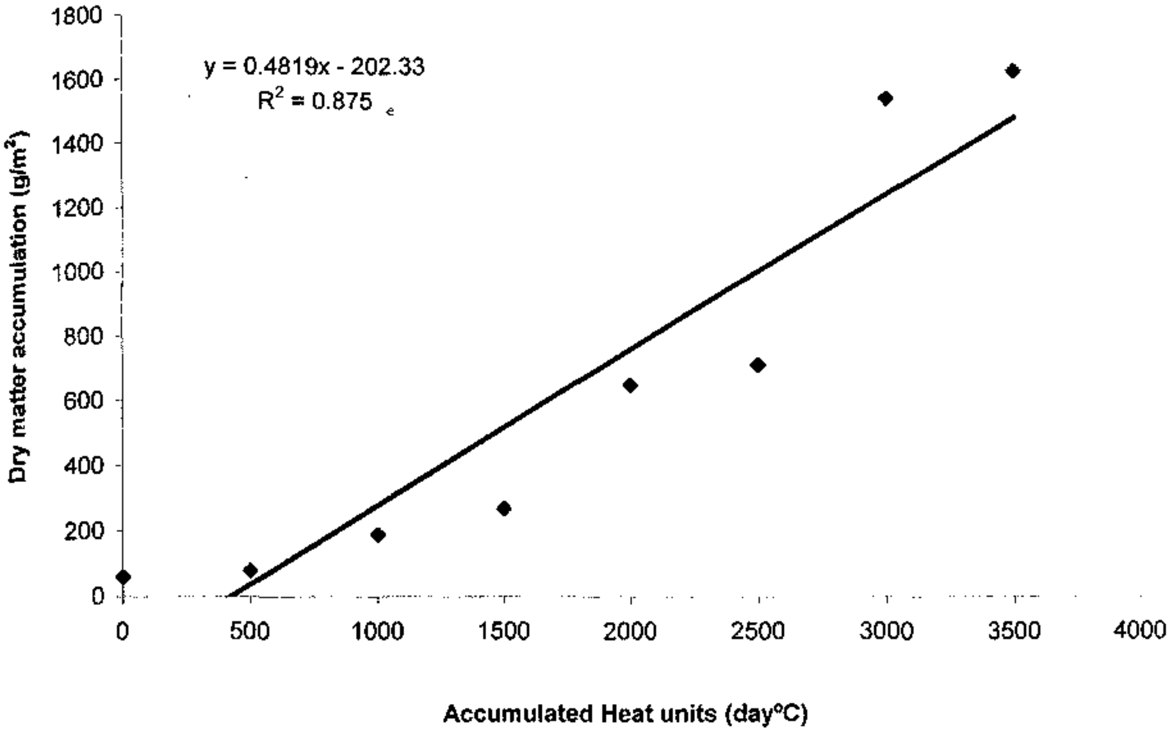

Fig. 16: Relationship between dry matter accumulation and accumulated heat units in zero-till broadcast

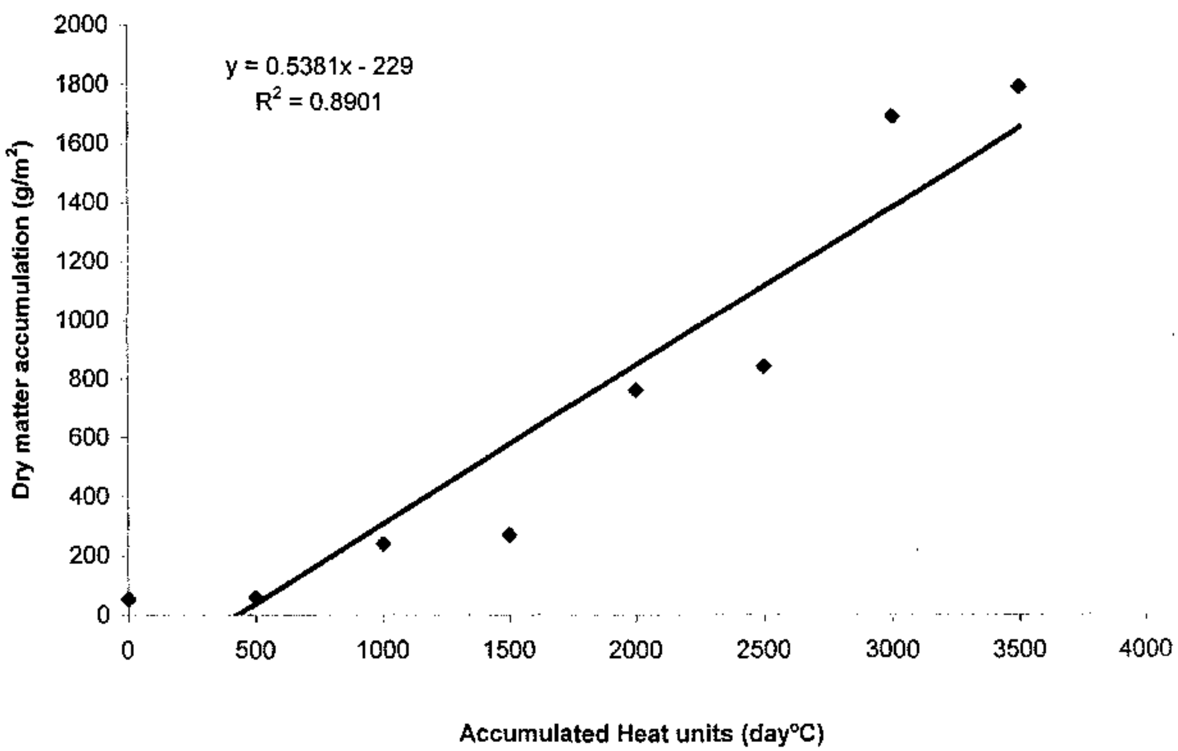

Fig. 17: Relationship between dry matter accumulation and accumulated heat units in puddled transplant

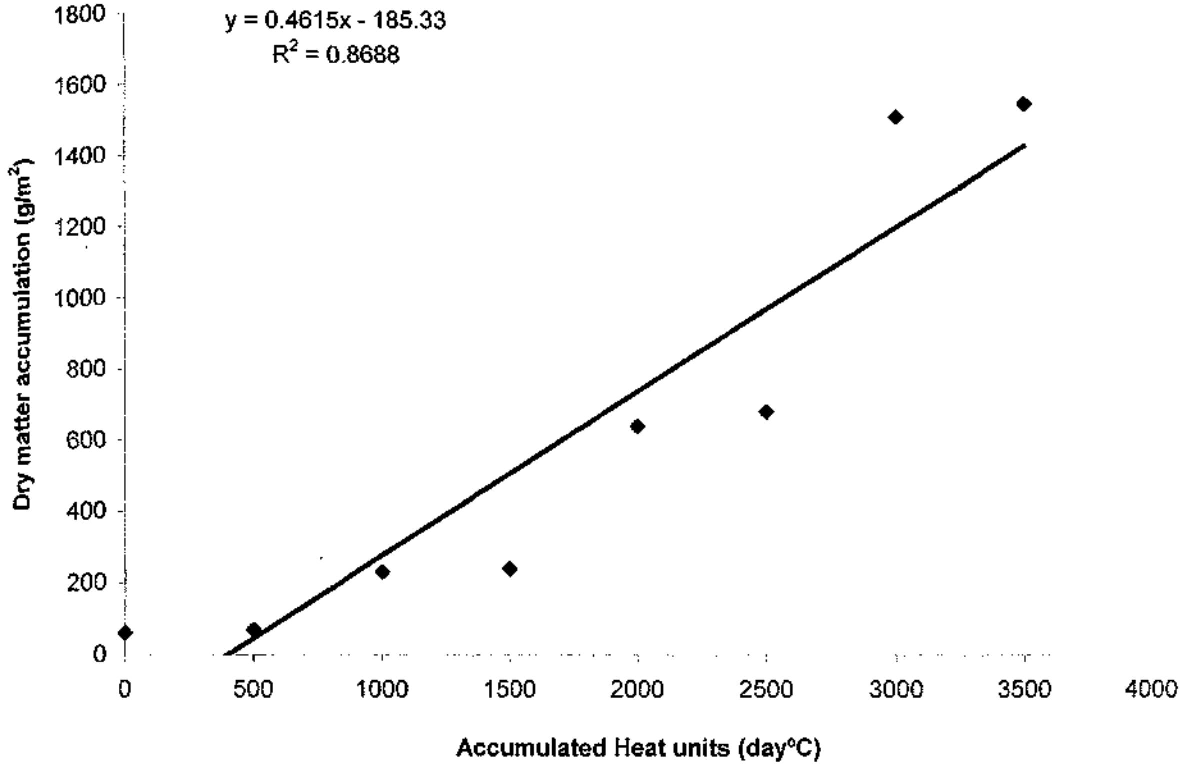

Fig. 18: Relationship between dry matter accumulation and accumulated heat units in zero-till drill direct seeding

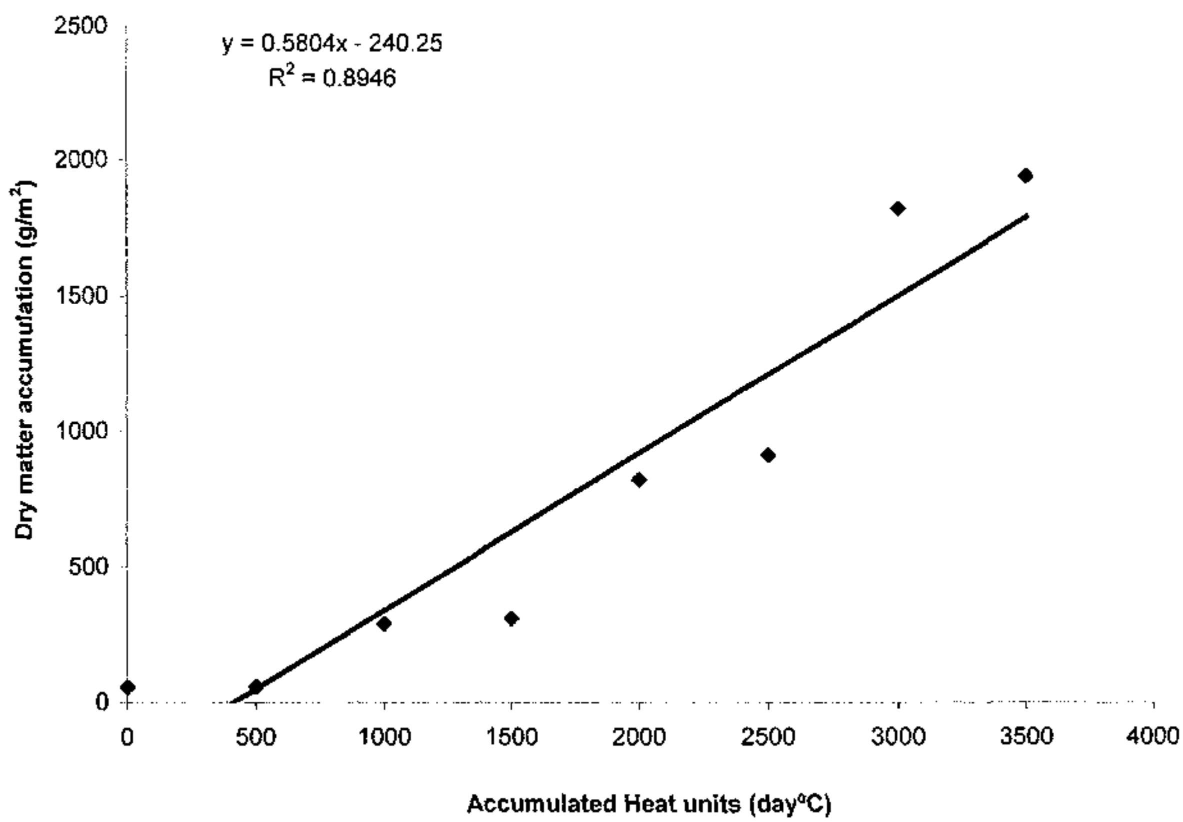

Fig. 19: Relationship between dry matter accumulation and accumulated heat units in zero till transplant

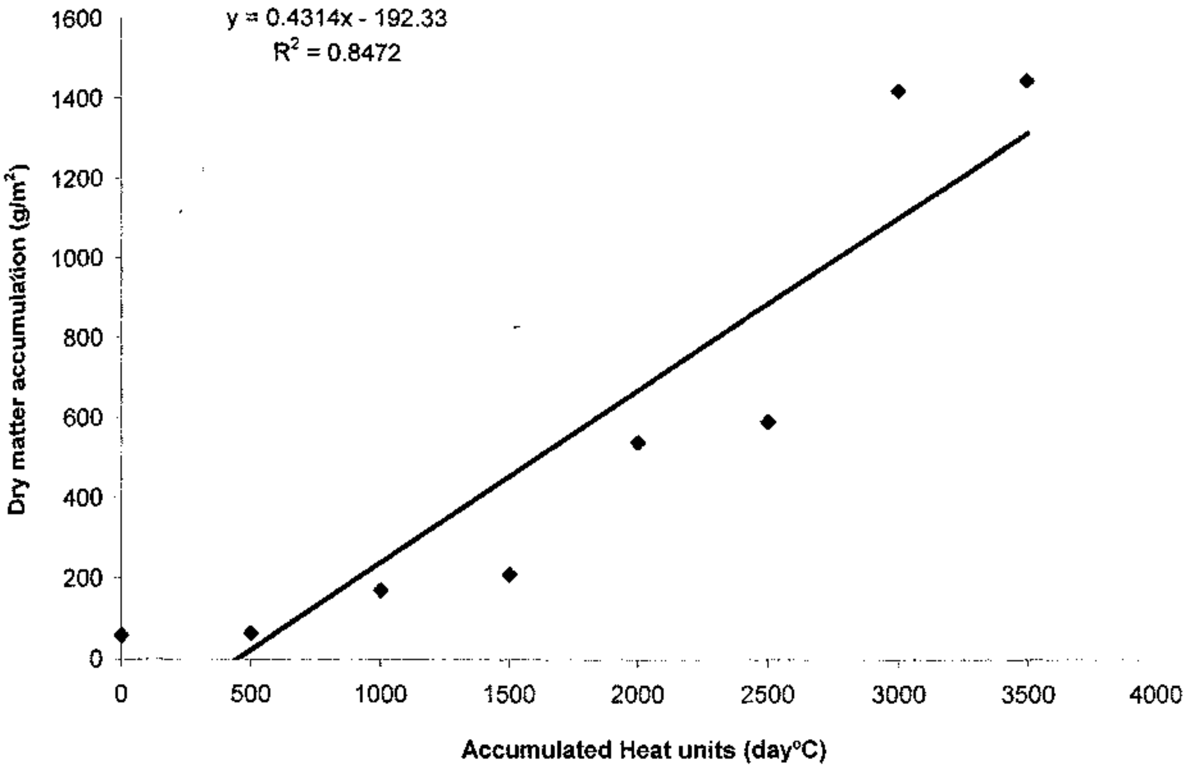

Fig. 20: Relationship between dry matter accumulation and accumulated heat units in puddled broadcast

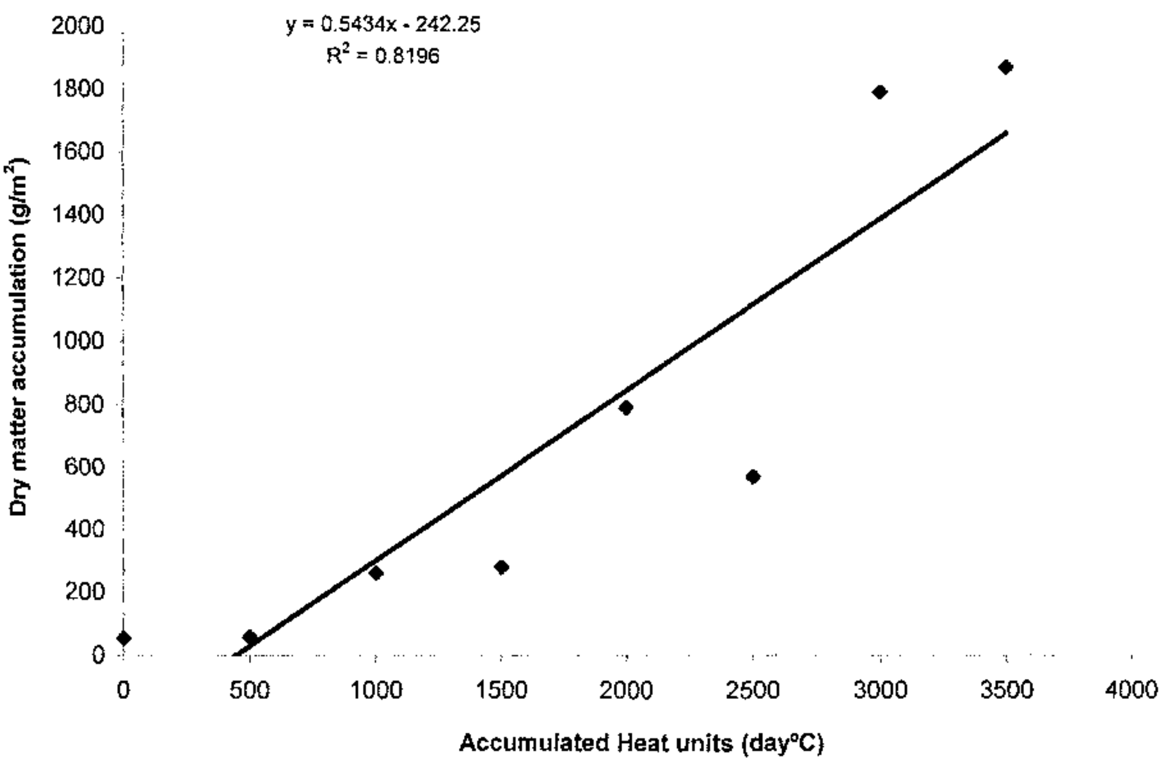

Fig. 21: Relationship between dry matter accumulation and accumulated heat units in unpuddled transplant

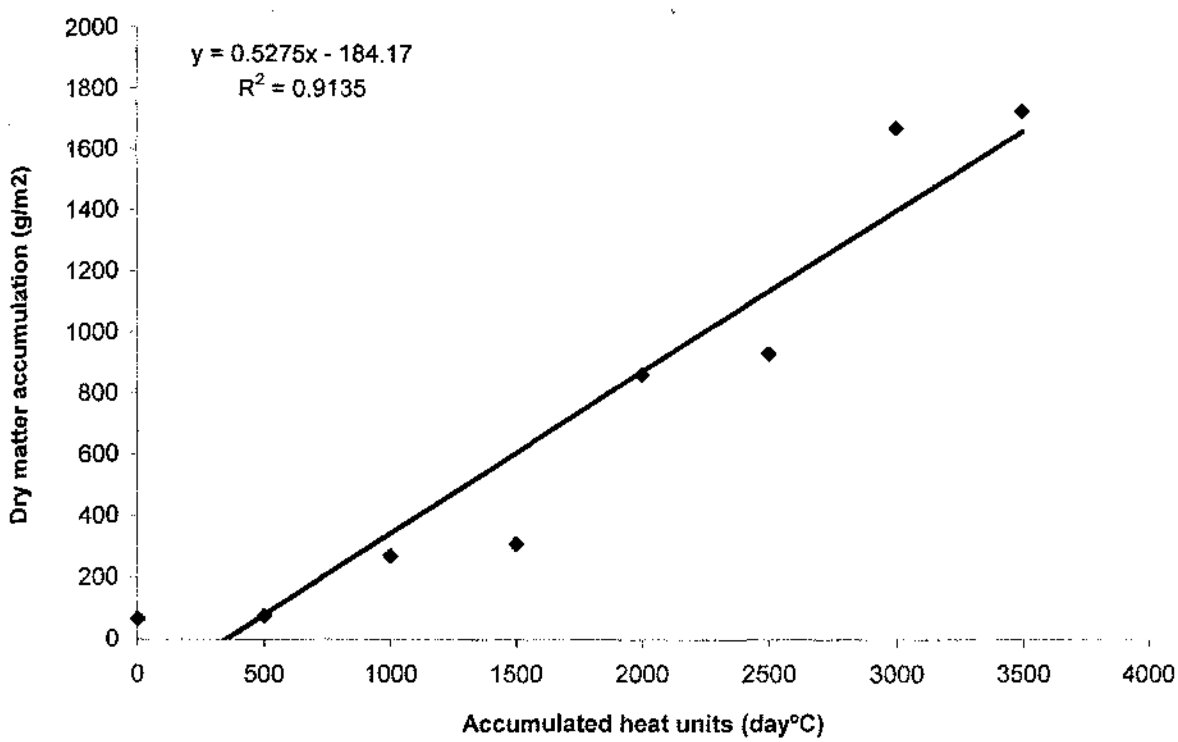

Fig. 22: Relationship between the dry matter accumulation and accumulated heat units of rice crop (IR64) for the first date of sowing (June 5)

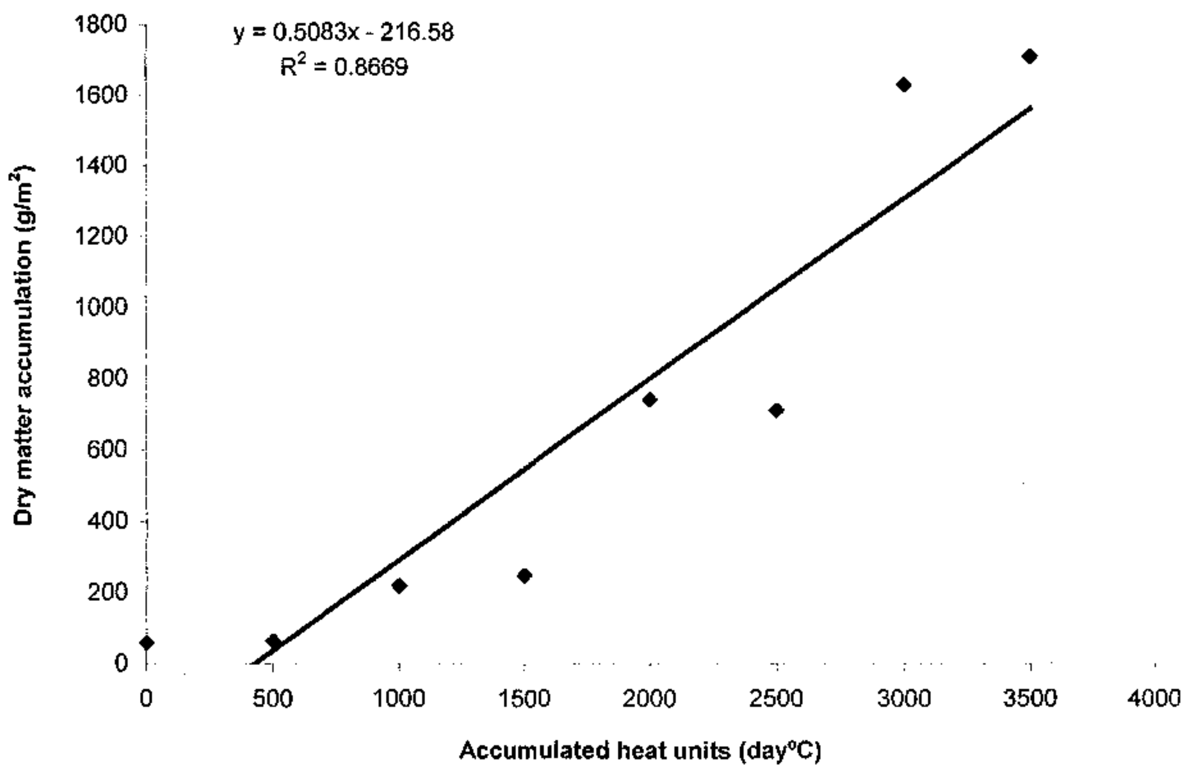

Fig. 23: Relationship between the dry matter accumulation and accumulated heat units of Rice crop (IR64) for the second date of sowing (June 15)

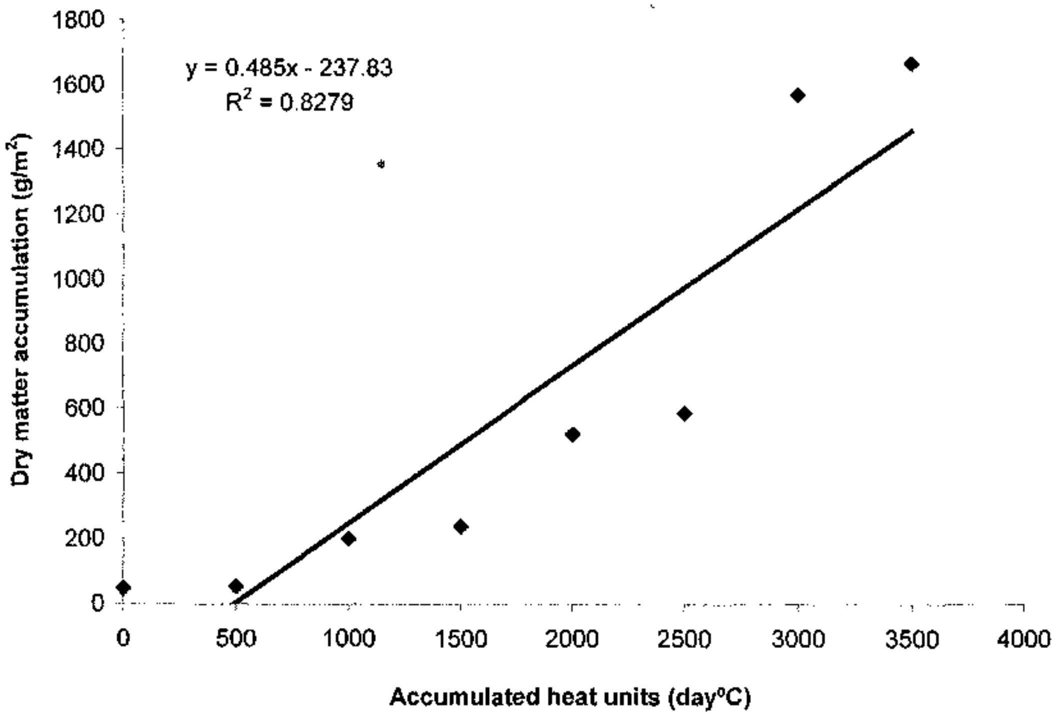

Fig. 24: Relationship between the dry matter accumulation and accumulated heat units of Rice crop (IR64) for third date of sowing (June 25)

Experiment-II

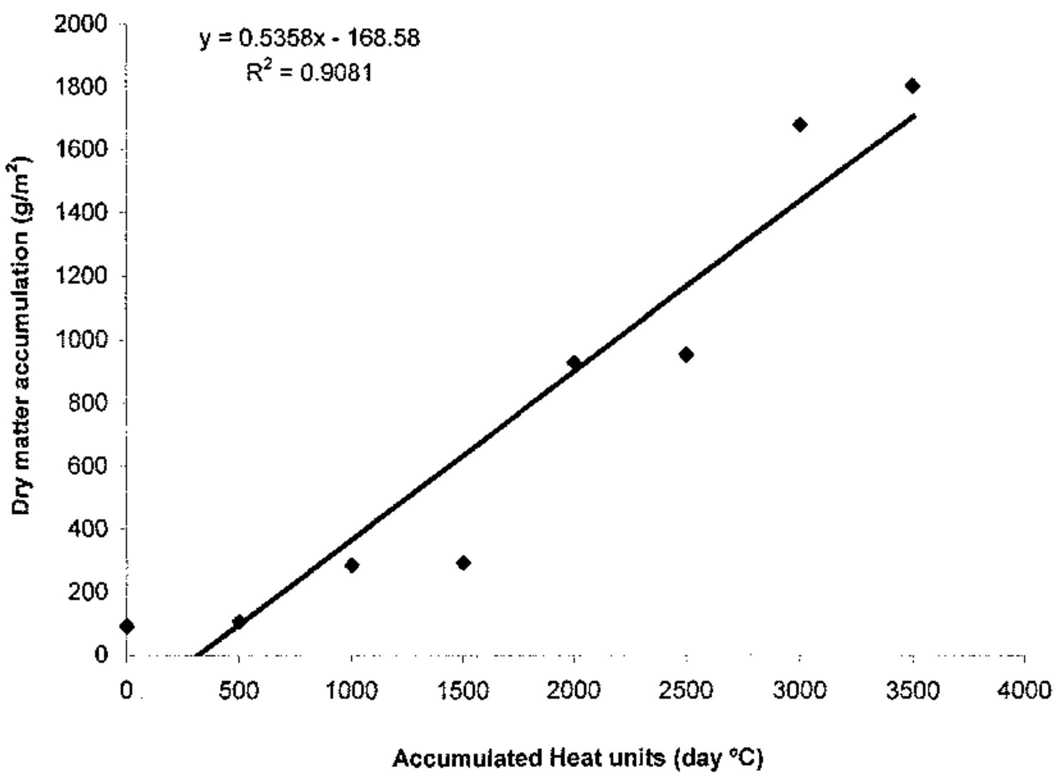

Fig. 25: Relationship between drymatter and accumulation heat units for the variety of IR-64

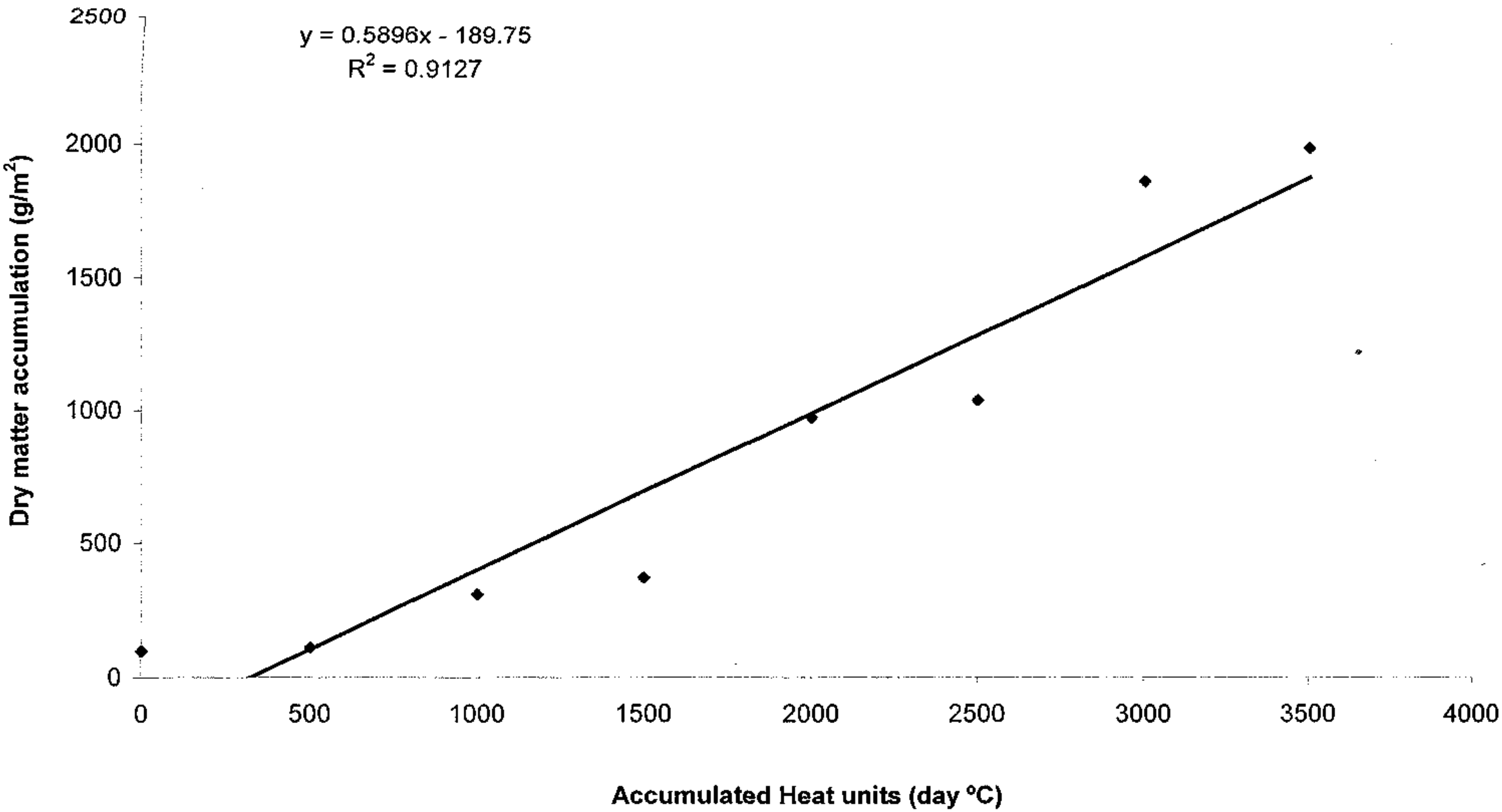

Fig. 26: Relationship between drymatter accumulation and heat units for the variety of HKR-126

season crop consumed more accumulated heat units in IR-64 (Fig. 25) and HKR-126 (Fig. 26), when compared to 2002 crop season.

The quadratic equations of the dry matter accumulated at the time of harvesting (g m^{-2}) and heat units were given below:

Experiment-I

Zero-till-broadcast	$y = 0.4819x - 202.33$	($R^2 = 0.875$)
Puddled broadcast	$y = 0.4314x - 192.33$	($R^2 = 0.8472$)
Zero-till drill direct seeding	$y = 0.4615x - 0.1853$	($R^2 = 0.8688$)
Zero-till-transplant	$y = 0.5804x - 240.25$	($R^2 = 0.8901$)
Puddled-transplant	$y = 0.5381x - 229.00$	($R^2 = 0.8904$)
Unpuddled-transplant	$y = 0.5434x - 242.25$	($R^2 = 0.8196$)
First date of sowing		
(D_1) June 5	$y = 0.5275x - 184.17$	($R^2 = 0.9135$)
Second date of sowing		
(D_2) June 15	$y = 0.5083x - 216.58$	($R^2 = 0.8669$)
Third date of sowing		
(D_3) June 25	$y = 0.4475x - 237.83$	($R^2 = 0.6465$)

Experiment-II

IR-64	$y = 0.5358x - 168.58$	($R^2 = 0.9081$)
HKR-126	$y = 0.5896x - 189.75$	($R^2 = 0.9127$)

4.2 Soil studies

Experiment-I

A perusal of data (Table 5) on soil properties of experiment I analyzed before and after crop harvest clearly shows that soils were alkaline in reaction with low organic carbon and available nitrogen content. The available phosphorus and potassium levels in soil were medium. The soil properties were not affected by crop establishment techniques in both the years. Also there was no marked change in these properties at the end of the study.

Experiment-II

The soil of experiment II as indicated by data (Table. 6) was slightly alkaline and low in soluble salts. The organic carbon and available nitrogen were low, whereas, available phosphorus and potassium content was medium. There was no significant change in pH, EC, OC and available nutrient status of soil after tv o years of experiment. None of the treatments were found to influence these properties in the course of study.

AGRONOMIC STUDIES

4.3 Result Experiment-I

4.3.1 Growth characteristics

4.3.1.1 Plant population (No. m^{-2})

The plant population of rice recorded at 30 DAS/at planting and 60 DAS/30 DAT (Table 7) was higher under direct

Table 5: Chemical properties of soil of Experiment-I before sowing and after harvest at RRS, Karnal

Method of sowing/ Properties	Method	Years	Initial status	Zero-till broadcast	Puddled-Broadcast	Zero-till drill	Zero-till-transplant	Puddled transplant	Unpuddled transplant
pH	1	2002	8.9	8.9	8.9	8.9	8.9	8.9	8.9
		2003	8.8	8.9	8.9	8.9	8.7	8.7	8.7
EC (dS m^{-1} at 25°C)	2	2002	0.32	0.32	0.32	0.32	0.31	0.32	0.32
		2003	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Organic carbon (%)	3	2002	0.35	0.36	0.35	0.36	0.36	0.35	0.36
		2003	0.37	0.38	0.36	0.38	0.38	0.37	0.38
Available N (kg ha^{-1})	4	2002	160	164	165	163	163	162	163
		2003	166	170	169	171	170	169	170
Available P (kg ha^{-1})	5	2002	18	21	19	21	21	19	21
		2003	21	24	22	24	24	21	24
Available K (kg ha^{-1})	6	2002	140	136	135	136	135	134	135
		2003	130	126	125	126	125	124	125
Zinc (ppm)	7	2002	3.3	3.3	3.2	3.3	3.2	3.1	3.2
		2003	3.0	3.0	2.9	3.0	2.9	2.8	2.9

Methods :
1. Class electrode pH meter method (Jackson, 1973)
2. Conductivity bridge method (Richards, 1954)
3. Walkley and Black's method (1934)
4. Alkaline permanganate method (Subbiah and Asija, 1956)
5. Olsen's method
6. Flame photometric method (Jackson, 1973)
7. Lindsay and Norvell (1978)

Table 6: Chemical properties of Experiment -II, before sowing and after harvest at Dhons village (Kaithal, Haryana)

Method of sowing/ Properties	Method	Years	Initial status	Puddled-transplant	Puddled-Broadcast	Zero-till-transplant	Zero-till broadcast
pH	1	2002	8.2	8.2	8.2	8.2	8.2
		2003	8.1	8.1	8.1	8.1	8.1
EC (dS m^{-1} at 25°C)	2	2002	0.32	0.32	0.32	0.32	0.32
		2003	0.31	0.31	0.31	0.31	0.31
Organic carbon (%)	3	2002	0.38	0.38	0.39	0.41	0.41
		2003	0.40	0.40	0.41	0.41	0.42
Available N (kg ha^{-1})	4	2002	165	163	163	165	165
		2003	166	168	169	167	168
Available P (kg ha^{-1})	5	2002	12	13	13	14	24
		2003	13	13	14	14	25
Available K (kg ha^{-1})	6	2002	271	268	268	266	266
		2003	268	268	268	264	265
Zinc (ppm)	7	2002	3.3	3.2	3.2	3.3	3.1
		2003	3.0	3.1	3.0	3.1	3.0

Method
1. Class electrode pH meter method (Jackson, 1973)
2. Conductivity bridge method (Richards, 1954)
3. Walkley and Black's method (1934)
4. Alkaline permanganate method (Subbiah and Asija, 1956)
5. Olsen's method
6. Flame photometric method (Jackson, 1973)
7. Lindsay and Norvell (1978)

Table 7: Effect of different crop establishment techniques and dates of sowing on plant population of rice crop at 30 DAS/planting and 60 DAS/30 DAT

Treatment	Plant Population (No. m^{-2})			
	30 DAS /planting		60 DAS/ 30DAT	
	2002	2003	2002	2003
Zero-till-Broadcast	55	58	50	52
Puddled Broadcast	50	53	46	47
Zero-till-drill-seeding	53	55	47	48
Zero-till Transplant	46	48	43	44
Puddled Transplant	43	44	41	42
Unpuddled Transplant	44	47	42	43
$SE_m \pm$	1.4	1.8	0.9	1.1
CD at 5%	4.2	5.2	2.8	3.4
June 5	53	55	49	50
June 15	49	49	44	45
June 25	44	46	41	42
$SE_m \pm$	1.0	1.2	0.6	0.8
CD at 5%	2.9	3.7	1.9	2.4

seeding compared to transplanting. The plant population at 60 DAS/30 DAT was little bit lower compared to what it was at 30 DAS/at transplanting.

Among methods of direct seeding (Table 7), the plant population was significantly higher under zero-till-broadcast than puddled-broadcast and zero-till-direct-seeding at 60 DAS during both the years. However, at 30 DAS, the plant population was at par among different methods of sowing except that it was statistically lower under puddled-broadcast in 2002.

Within different methods of transplanting (Table 7), the plant population at transplanting and 30 DAT was at par during both years.

Among different dates of sowing, the plant population recorded at 30 DAS/at planting and 60 DAS/30 DAT decreased significantly with the delay in sowing from 5^{th} to 25^{th} June in 2002 as well as 2003.

The interaction effect (Table 8) of crop establishment techniques and date of sowing was also significant. A significant decrease in plant population was recorded with delayed sowing transplanting upto June 25^{th} in

Table 8: Interaction effect of crop establishment techniques and dates of sowing on mean plant population (No. m^{-2}) of rice at 60 DAS /30 DAT during 2002

Crop establishment techniques	Dates of sowing			Mean
	June 5	June 15	June 25	
Zero-till – Broadcast	57.33	53.67	39.00	50
Puddled –Broadcast	48.67	46.33	43.00	46
Zero-till drill –seeding	52.33	44.67	44.00	47
Zero-till-transplant	46.00	42.00	41.00	43
Puddled-transplant	44.67	38.67	39.67	41
Unpuddled-Transplant	45.67	39.67	40.67	42
Mean	**49**	**44**	**41**	

	CD	SEm
Crop establishment techniques (A)	2.8	0.98
Dates of sowing (B)	1.9	0.69
A × B	4.89	1.70

case of direct seeding methods, however, in transplanting methods the reduction was not significant.

4.3.1.2 Number of shoots (No. m^{-2})

On an average the number of shoots/m^2 were higher under direct seeding compared to transplanting at 60 DAS/30 DAT and 90 DAS/60 DAT during both the years (Table 9).

Among methods of direct seeding, the number of shoots recorded at 60 and 90 DAS was slightly higher under zero-till-broadcast, however, it was at par with puddled-broadcast and zero-till-drill-seeding (Table 9).

Similarly, among three transplanting methods, number of shoot/m^2 at 30 and 60 DAT was slightly more under zero-till-transplant but it was at par with puddled-transplant and unpuddled-transplant.

The number of shoots/m^2 at 60 DAS/30 DAT and 90 DAS/60 DAT were significantly more under first date of sowing (5th June) compared to later two dates of sowing (15th and 25th June) during both years.

The interaction effect of crop establishment techniques and date of sowing on mean number of shots at 60 DAS/30 DAT (Table 10) shows that shoot number decreased with advancement of date of sowing under puddled

Table 9: Effect of different crop establishment techniques and dates of sowing on number of shoots of rice crop at 60 DAS/30 DAT, and 90 DAS/60 DAT

Treatment	Number of shoots (No. m^{-2})			
	60 DAS/ 30DAT		90 DAS/ 60DAT	
	2002	2003	2002	2003
Zero-till-Broadcast	363	374	300	314
Puddled Broadcast	361	370	296	311
Zero-till-drill-seeding	362	371	298	313
Zero-till Transplant	329	341	284	300
Puddled-Transplant	326	338	276	295
Unpuddled-Transplant	327	339	279	299
SE_m ±	3.4	4.0	4.4	4.4
CD at 5%	9.9	11.6	12.7	12.3
June 5	355	367	298	318
June 15	340	350	288	304
June 25	338	349	279	293
SE_m ±	2.4	2.8	3.1	3.1
CD at 5%	7.0	8.2	9.0	8.7

Table 10: Interaction effect of crop establishment techniques and dates of sowing on mean number of shoots (No. m^{-2}) of rice at 60 DAS /30 DAT during 2002

Crop establishment techniques	Dates of sowing			Mean
	June 5	June 15	June 25	
Zero-till – Broadcast	421.00	326.67	374.33	374
Puddled –Broadcast	388.00	369.33	353.00	370
Zero-till drill – seeding	363.00	383.00	367.00	371
Zero-till-transplant	356.67	341.33	325.00	341
Puddled-Transplant	343.67	334.00	336.33	338
Unpuddled-Transplant	331.33	345.67	340.00	339
Mean	367	350	349	

	CD	SE m
Crop establishment techniques (A)	11.6	4.0
Dates of sowing (B)	8.2	2.8
A×B	20.1	6.9

conditions, however, in zero-till-broadcast and zero-till-direct seeding higher number of shoots were obtained in late sown conditions.

4.3.1.3 Dry matter accumulation (g m^{-2})

On an average, the dry matter accumulation at 30 DAS/at planting was higher under broadcasting compared to transplanting during both years (Table 11).

The dry matter increased with the corresponding increase in the age of crop but the trend at 60 DAS/30 DAT, 90 DAS/ 60 DAT and at harvest was similar to what it was at 30 DAS/at planting.

The magnitude of increase was more between 30 to 60 DAS or from transplanting to 30 DAT. The data further revealed that zero-till-transplanting method consistently exhibited better growth of crop compared to all other methods. Even unpuddled-transplanted rice resulted into higher dry matter accumulation than puddled-transplant.

The dry matter accumulation recorded at different growth stages was by and large more under unpuddled-situation compared to puddled one.

Zero-till-broadcast among direct seeding methods and zero-till-transplant under transplanting methods produced higher dry matter compared to other methods.

Table 11: Effect of different crop establishment techniques and dates of sowing on dry matter accumulation at 30 DAS/at planting, 60 DAS/30 DAT, 90 DAS/60 DAT and harvest

Treatment	Dry matter (g m^{-2})							
	30 DAS/ at Planting		60 DAS/ 30 DAT		90 DAS/ 60 DAT		Harvest	
	2002	2003	2002	2003	2002	2003	2002	2003
Zero-till-Broadcast	60	78	190	270	650	710	1540	1630
Puddled-Broadcast	58	63	170	210	540	590	1420	1450
Zero-till-drill seeding	60	69	230	240	640	680	1510	1550
Zero-till-Transplant	55	58	290	310	820	910	1820	1940
Puddled-Transplant	54	58	240	270	760	840	1690	1790
Unpuddled-Transplant	53	57	260	280	790	870	1790	1870
$SE_m \pm$	0.9	1.5	13.8	14.3	59.5	50.2	82	94.0
CD at 5%	2.5	4.2	40	41	170	140	230	270
June 5	66	75	270	310	860	930	1670	1730
June 15	59	64	220	250	740	710	1630	1710
June 25	48	54	200	240	520	650	1570	1670
$SE_m \pm$	0.6	1.0	9.7	10.1	42.0	35.0	58	66.9
CD at 5%	1.8	3.0	28	29	120	100	N.S.	N.S.

The growth of rice continued to remain dependent upon sowing/transplanting time of rice. First date of sowing (5^{th} June)/transplanting exhibited significantly higher dry matter accumulation upto 90 DAS/60 DAT except it was at par with second date of sowing (June 15^{th})/transplanting. The dry matter accumulation of rice under 2^{nd} date of sowing (June 15)/transplanting was similar to 3^{rd} date of sowing (June 25)/transplanting at all growth stage except at 30 DAS/at planting during both years and at 90 DAS/60 DAT during 2002.

At harvest the difference in dry matter accumulation due to different dates of sowing/transplanting were non-significant and the trends were similar in 2002 and 2003.

4.3.1.4 Plant height (cm)

The plant height, in general was more under transplanting methods compared to direct seeding and it was also more under unpuddled conditions compared to puddled situation throughout the growth period and during both years (Table 12).

At 60 DAS/30 DAT, the plant height under zero-till-broadcast was more than other direct seeding methods but the differences were non-significant during both years. Similarly, zero-till-transplant being at par with unpuddled-

Table 12: Effect of different crop establishment techniques and dates of sowing on plant height 60 DAS/30 DAT, 90 DAS/60 DAT and harvest

Treatment	Plant height (cm)					
	60 DAS / 30DAT		90 DAS / 60 DAT		Harvest	
	2002	2003	2002	2003	2002	2003
Zero-till-Broadcast	64.9	69.6	94.8	97.8	102.0	104.3
Puddled-Broadcast	62.7	67.7	91.6	93.5	99.0	100.0
Zero-till drill seeding	64.6	67.7	93.8	95.9	100.0	101.1
Zero-till Tranplant	58.0	73.3	95.2	94.1	104.0	106.3
Puddled-Transplant	65.4	69.3	92.5	90.4	98.6	101.7
Unpuddled-Transplant	66.7	71.1	94.0	94.0	102.3	103.6
$SE_m \pm$	0.96	1.0	1.6	1.3	1.0	0.8
CD at 5%	2.9	3.1	NS	3.9	3.1	2.3
June 5	67.8	71.0	96.8	98.3	102.2	104.4
June 15	64.2	70.6	94.5	94.4	100.0	101.6
June 25	64.1	67.8	89.6	90.1	99.9	100.3
$SE_m \pm$	0.66	0.7	1.1	0.96	0.7	0.5
CD at 5%	2.0	2.2	3.4	2.7	NS	1.6

transplant produced longer plants compared to all crop establishment techniques during both years except that it was also at par with puddled-transplant during 2002.

At 90 DAS/60 DAT, the differences in terms of plant height among different crop establishment methods were non-significant during 2002. However, during 2003 zero-till-broadcast being at par with zero-till-drill seeding, zero-till-transplant and unpuddled-transplant produced longer plants compared to other methods.

At harvest, the maximum height was attained under zero-till-transplant during both years, however, it was at par with unpuddled-transplant and zero-till-broadcast in 2002 and zero-till-broadcast in 2003. The lowest height was recorded under puddled-transplant/puddled-broadcast during both the years of investigation.

Plant height was more under first date of sowing (5th June)/transplanting compared to subsequent sowings during both years and at all growth stages. At 60 DAS/30 DAT, the plant height under 25th June sowing/transplanting being at par with 15th June sowing/transplanting was significantly less than first date of sowing (5th June).

At 90 DAS/60 DAT, the plant height decreased significantly with the corresponding delay in sowing/

transplanting compared to 5th June during both years except that there was non-significant difference between 5th and 15th June sowing/transplanting during 2002.

All harvest, the plant height was more under first date of sowing/transplanting compared to subsequent sowings/transplantings and it was significantly more during 2003 but the differences were non-significant during 2002.

4.3.1.5 Leaf area index (LAI)

Among different crop establishment techniques, the leaf area index at 30 DAS/at planting was statistical similar during both years (Table 13), however, it was little bit more under direct seeding compared to transplanting methods. With the progress of crop growth, there was corresponding increase in the leaf area index upto 90 DAS/60 DAS and reduced significantly thereafter at harvest. The magnitude of increase was more under transplanting methods compared to direct seeding. The magnitude of increase in the leaf area index was also more from 30 DAS/at planting to 60 DAS/30 DAT compared to subsequent growth intervals.

At 60 DAS/30DAT, the leaf area index under zero-till-broadcast being superior to other direct seeding methods was at par with all transplanting methods during 2002 and 2003.

Table 13: Effect of different crop establishment techniques and dates of sowing on leaf area index (LAI) at 30 DAS/at planting, 60 DAS/30 DAT, 90 DAS/60 DAT and harvest

Treatment	Leaf area Index (LAI)							
	30 DAS/ at Planting		60 DAS/ 30 DAT		90 DAS/ 60 DAT		Harvest	
	2002	2003	2002	2003	2002	2003	2002	2003
Zero-till-Broadcast	0.480	0.540	3.60	3.63	5.10	5.25	0.423	0.565
Puddled-Broadcast	0.450	0.500	2.55	2.59	4.82	4.87	0.383	0.513
Zero-till-drill -seeding	0.461	.512	2.75	2.78	4.98	5.12	0.400	0.553
Zero-till-Transplant	0.371	0.452	3.72	3.76	5.65	5.68	0.648	0.720
Puddled-Transplant	0.350	0.448	3.65	3.69	5.33	5.36	0.590	0.690
Unpuddled-Transplant	0.360	0.450	3.68	3.71	5.39	5.42	0.642	0.713
$SE_m \pm$	0.04	0.03	0.1	0.08	0.09	0.09	0.04	0.06
CD at 5%	NS	NS	0.31	0.24	0.26	0.26	0.12	NS
June 5	0.701	0.673	3.53	3.66	5.41	5.55	0.706	0.802
June 15	0.329	0.472	3.31	3.27	5.19	5.20	0.499	0.618
June 25	0.215	0.285	3.13	3.14	5.02	5.09	0.354	0.474
$SE_m \pm$	0.03	0.02	0.07	0.06	0.06	0.06	0.03	0.04
CD at 5%	0.094	0.08	0.22	0.17	0.18	0.18	0.089	0.131

At 90 DAS/60 DAT, zero-till-transplant produced significantly higher leaf area index compared to puddled-broadcast and zero-till-drill seeding, however, it has at par with puddled-transplant during both years. Zero-till-transplant being at par with unpuddled-transplant produced significantly higher leaf area index compared to all crop establishment techniques. Puddled-broadcast was at par with zero-till-drill seeding, and puddled-transplant was at par with unpuddled-transplant during both years.

At harvest, the leaf area index was found to be reduced during 2002 as well as 2003. Direct seeding methods, however, were at par to each other. Leaf area index was also similar under transplanting methods and it was higher compared to direct seeding methods in 2002. The differences in respect of leaf area index at harvest among various crop establishment techniques were non-significant during 2003.

Leaf area index reduced with the delay in sowing/transplanting during both years. At 30 DAS/at planting, the leaf area index was significantly higher under first date of sowing (5th June)/transplanting compared to later sowings/transplanting during both years (Table 13).

At 60 DAS/30 DAT, the leaf area index under 5th June sowing/transplanting was significantly higher than subsequent dates of sowing (15th June and 25th June)/transplanting, however, it was at par between 15th June and 25th June sowings and transplantings during both years. Similar trend was observed at 90 DAS/60 DAT during both years. At harvest the leaf area index was significantly higher under first date of sowing (5th June) transplanting and it reduced significantly with the subsequent delay in sowing/transplanting during 2002 as well as 2003.

4.3.2 Yield attributes

4.3.2.1 Effective tillers (No. m^{-2})

In general, effective tillers were more under transplanting methods compared to direct seeding (Table 14).

Among direct seeding methods, zero-till-broadcast produced higher number of effective tillers/m^2 than puddled broadcast and zero-till-drill seeding, however, the differences were non-significant during both years.

Within transplanting methods, zero-till-transplant resulted into significant higher number of effective tillers than puddled-transplant and unpuddled-transplant during 2002 and puddled-transplant during 2003. Effective tillers under puddled-transplant and unpuddled-transplant were

Table 14: Effect of different crop establishment techniques and dates of sowing on yield attributes

Treatment	Effective tiller (No. m^2)		Panicle length (cm)		Filled grains (No./panicle)		Unfilled grains (No./panicle)		1000 grain weight (g)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Zero-till Broadcast	260	272	24.8	25.3	114	123	18	16	25.76	25.91
Puddled Broadcast	255	264	24.2	25.2	110	116	20	19	24.42	24.83
Zero-till drill seeding	257	266	24.4	24.5	112	121	19	19	25.33	25.71
Zero-till Transplant	280	296	25.9	26.2	134	147	16	14	26.79	28.10
Puddled Transplant	268	277	25.2	25.5	129	142	20	18	26.18	27.21
Unpuddled Transplant	274	285	25.4	25.7	131	144	19	17	26.24	27.43
$SE_m \pm$	3.7	4.3	0.3	0.4	2.4	3.2	1.5	1.2	0.3	0.3
CD at 5%	10.65	12.47	1.13	NS	7.09	9.20	NS	NS	0.96	1.09
June 5	272	278	25.8	26.3	129	144	16	15	26.03	27.95
June 15	268	276	24.6	25.0	122	131	18	16	25.77	26.29
June 25	256	275	24.5	24.9	114	122	21	20	25.56	25.35
$SE_m \pm$	2.6	3.0	0.2	0.2	1.7	2.2	1.1	0.8	0.2	0.2
CD at 5%	7.53	NS	0.80	0.82	5.01	6.50	3.10	2.50	NS	0.77

at par during both years, and unpuddled-transplant (285 m^{-2}) was at par with zero-till-transplant (296 m^{-2}) during second year of experimentation.

Among all crop establishment techniques, zero-till-transplant was superior during both years except that it was at par with unpuddled-transplant during 2003. zero-till-broadcast (260 m^{-2}) and puddled-transplanted (268 m^{-2}) during 2002 and zero-till-broadcast (272 m^{-2}), zero-till-drill seeding (266 m^{-2}) and puddled-transplant (277 m^{-2}) during 2002 also produced effective tillers at par with each other.

Among different dates of sowing, the effective tillers produced at first date (5th June) and second date (15th June) being at par with each other produced significantly more number of effective tillters compared to last date (25th June) of sowing (256 m^{-2}) in 2002. The effective tillers were higher under first date of sowing during 2003 also but the differences among different dates of sowing were non-significant.

4.3.2.2 Panicle length (cm)

Panicle length, in general, was more under transplanting situation compared to direct seeding (Table 14).

Within direct-seeding-methods, the panicle length was similar, however, zero-till-broadcast produced longer panicles than puddled-broadcast and zero-till-drill-seeding in 2002.

Similarly among transplanting methods, zero-till-transplant (25.9 cm) produced longer panicles than puddled-transplant (25.2 cm) and unpuddled-transplant (25.4 cm) during 2002. Zero-till-broadcast was also at par with all transplanting methods in this respect and puddled condition both under direct seeding as well transplanting resulted into shorter panicles. The trend was similar during 2003, however, the differences among different crop establishment techniques were non-significant.

Panicle length during both years was significantly more under first date of sowing (5th June/transplanting) compared to other two later dates of sowing (15th and 25th June)/transplanting which were at par to each other.

4.3.2.3 Filled grain/panicle (Number)

The number of filled grains/panicle were significantly less under methods of direct seeding compared to each of the transplanting methods (Table 14)

Within direct seeding methods, zero-till-broadcast produced more number of filled grains/panicle, however, it was at par with puddled-broadcast and zero-till-drill-seeding during 2002 and 2003.

Similarly, among transplanting methods, zero-till-transplant produced more filled grains/panicle but it was at par with puddled-transplant as well as unpuddled-transplant during both years.

Date of sowing/transplanting had a significant effect in terms of producing filled grains/panicle. Earliest date of sowing (15th June)/Transplanting produced significantly more field grains/panicle than other two later dates of sowing/transplanting during both years. However, second date of sowing (15th June)/transplanting turned out to be superior to third/last date of sowing (25th June)/ transplanting in this respect during 2002 as well as 2003.

4.3.2.4 Unfilled Grain/Panicle (Number)

In general, unfilled grains/panicle were more under direct seeding than transplanting methods during 2003 and more or equal in 2002 however, the differences among different crop establishment methods were non-significant during both years (Table 14).

Puddling favoured to produce more unfilled grains/panicle both under direct seeding as well as transplanting and it was closely followed by unpuddled-condition. Zero-till-situation both under broadcast seeding and transplanting resulted into less number of unfilled grain/panicle. Zero-till-transplant among all crop establishment techniques was found to produce less number of unfilled grains/panicle, however, the differences were non-significant during both years.

Among different dates of sowing/ transplanting, the lowest number of unfilled grains/panicle were produced under first date of sowing (5^{th} June)/ transplanting which was at par with second date of sowing (15^{th} June)/ transplanting during both the years. The unfilled grains/panicle produced by 15^{th} June sown rice were at par with 25^{th} June sown rice in 2002 but significantly less during 2003.

4.3.2.5 1000-grain weight (g)

The test weight (1000-grain weight) produced by rice under direct seeding methods was less than what was produced under transplanting methods during both years (Table 14).

During 2002, puddled-broadcast (24.42 g) being at par with zero-till-drill-seeding (25.33 g) was inferior to zero-till-broadcast (25.76 g). Zero-till-broadcast was also at par with puddled-transplant (26.24 g) and unpuddled-transplant in respect of 1000-grain weight, however, it was inferior to zero-till-transplant (26.79 g).

The differences among various transplanting methods were also non-significant during 2002. In second year also the trend was similar except that there was no significant difference among direct seeding methods as well as among transplanting methods but each transplanting method was superior to each direct seeding methods.

The influence of dates of sowing/transplanting was visible in terms of 1000-grain weight of rice during both years, however, it was more clear during 2003 (Table 14). Early sowing (5^{th} June)/transplanting resulted into higher test weight or bold grains during both years. However, the differences were non-significant during 2002. Grains produced by rice sown on 5^{th} June/transplanting were significantly bolder than the rice sown on 15^{th} June/transplanting and similarly the 1000-grain weight produced by rice sown on 15^{th} June/transplanting was significantly higher than that sown on 25^{th} June/transplanting during 2003 (Table 14).

4.3.3 Yields and Harvest Index

4.3.3.1 Grain yield (kg ha^{-1})

Grain yield of rice under transplanting methods was more than direct seeding methods and it was also more under unpuddled situation compared to puddled one during both years (Table 15 & Fig. 27). Zero-till-broadcast among direct seeding methods and zero-till-transplant among

Table 15: Effect of different crop establishment techniques and dates of sowing on yield and Harvest Index

Treatment	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Biological yield (kg ha^{-1})		Harvest Index (%)	
	2002	**2003**	**2002**	**2003**	**2002**	**2003**	**2002**	**2003**
Zero-till-Broadcast	5183	5408	6994	7280	12177	12708	42.60	42.60
Paddled-Broadcast	5117	5367	6907	7245	12024	12612	42.60	42.60
Zero-till-drill- seeding	5150	5392	6950	7281	12100	12673	42.60	42.60
Zero-till-Transplant	6100	6358	7314	7626	13414	13984	45.46	45.46
Puddled-Transplant	5924	6208	7408	7450	13032	13659	45.46	45.46
Unpuddled-Transplant	6009	6283	7212	7538	13222	13821	45.46	45.46
$SE_m \pm$	142	145	184	183	326	329	0.02	0.02
CD at 5%	409	419	NS	NS	940	947	0.075	0.075
June 5	5789	6035	7339	7660	13128	13695	44.03	44.03
June 15	5574	5810	7076	7374	12650	13183	44.03	44.03
June 25	5380	5664	6827	7187	12206	12850	44.03	44.03
$SE_m \pm$	100	103	130	129	231	232	0.01	0.01
CD at 5%	289	296	376	374	665	670	NS	NS

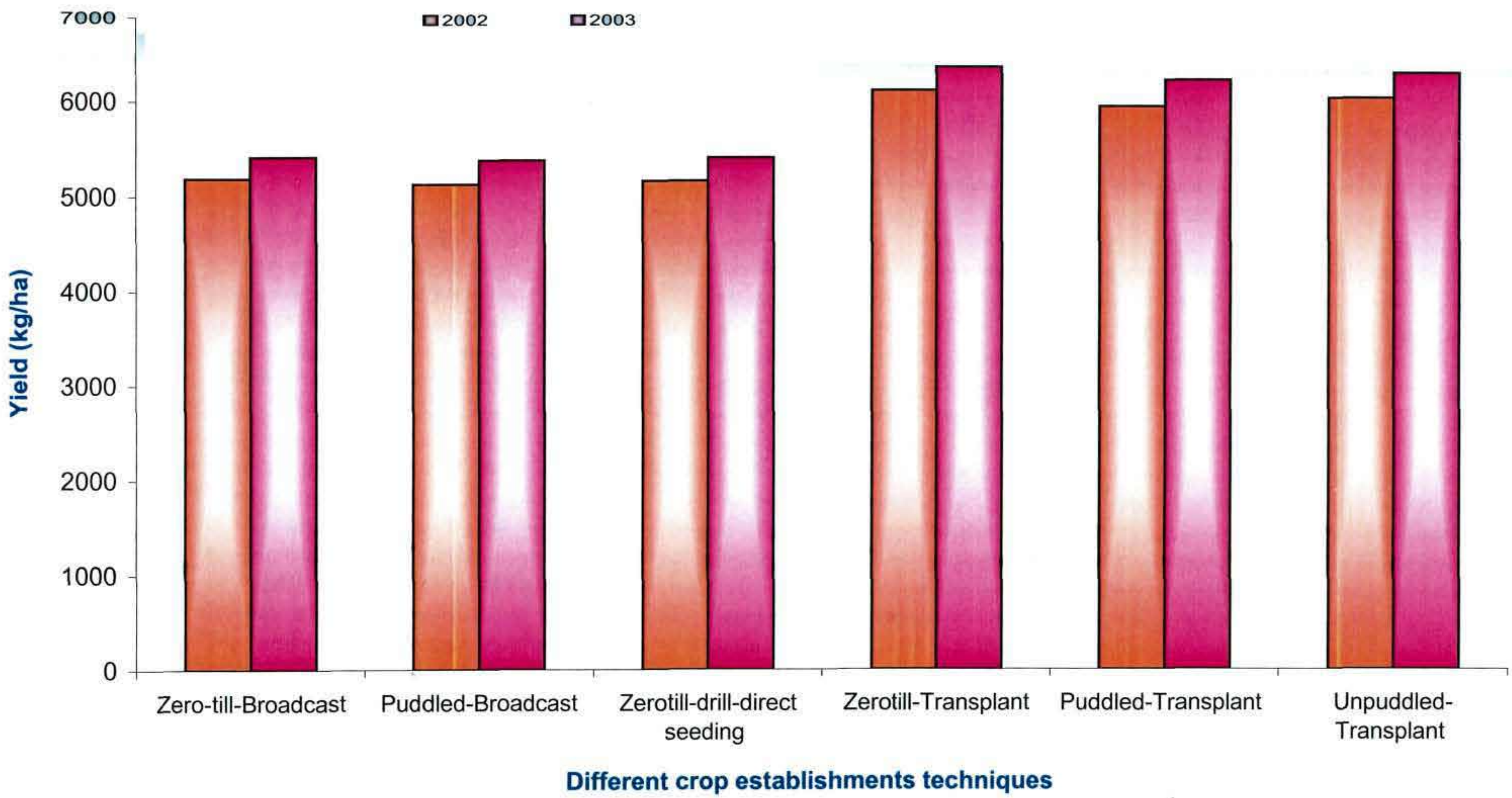

Fig. 27: Effect of different crop establishment techniques on grain yield of rice

transplanting methods produced higher yields during both year, however, the differences among various methods when compared under each category were non-significant. Zero-till-transplant produced maximum grain yield during both years and it was closely followed by unpuddled-transplant and then puddled-transplant in the sequence. It was also at par with zero-till-broadcast only during 2003.

Among different dates of sowing/transplanting, the maximum grain was produced under first date of sowing (5th June)/transplanting, however it was statistically at par with second date of sowing (15th June)/transplanting during both years (Table 15 & Fig. 28).

Grain yield was minimum under last date of sowing (25th June)/transplanting, however, it was at par with 15th June sowing /transplanting. Compared to first of sowing, the reduction in grain yield at 2nd and 3rd dates of sowing was 3.7-7.1 % and 3.7-6.1 %, during 2002 and 2003, respectively.

Variable effect (Table 16 & Fig. 29) of date of sowing was observed on rice yield under different crop establishment techniques showing interaction effect. Delayed sowing transplanting caused yield reduction under all the crop establishment methods. However, maximum and significant

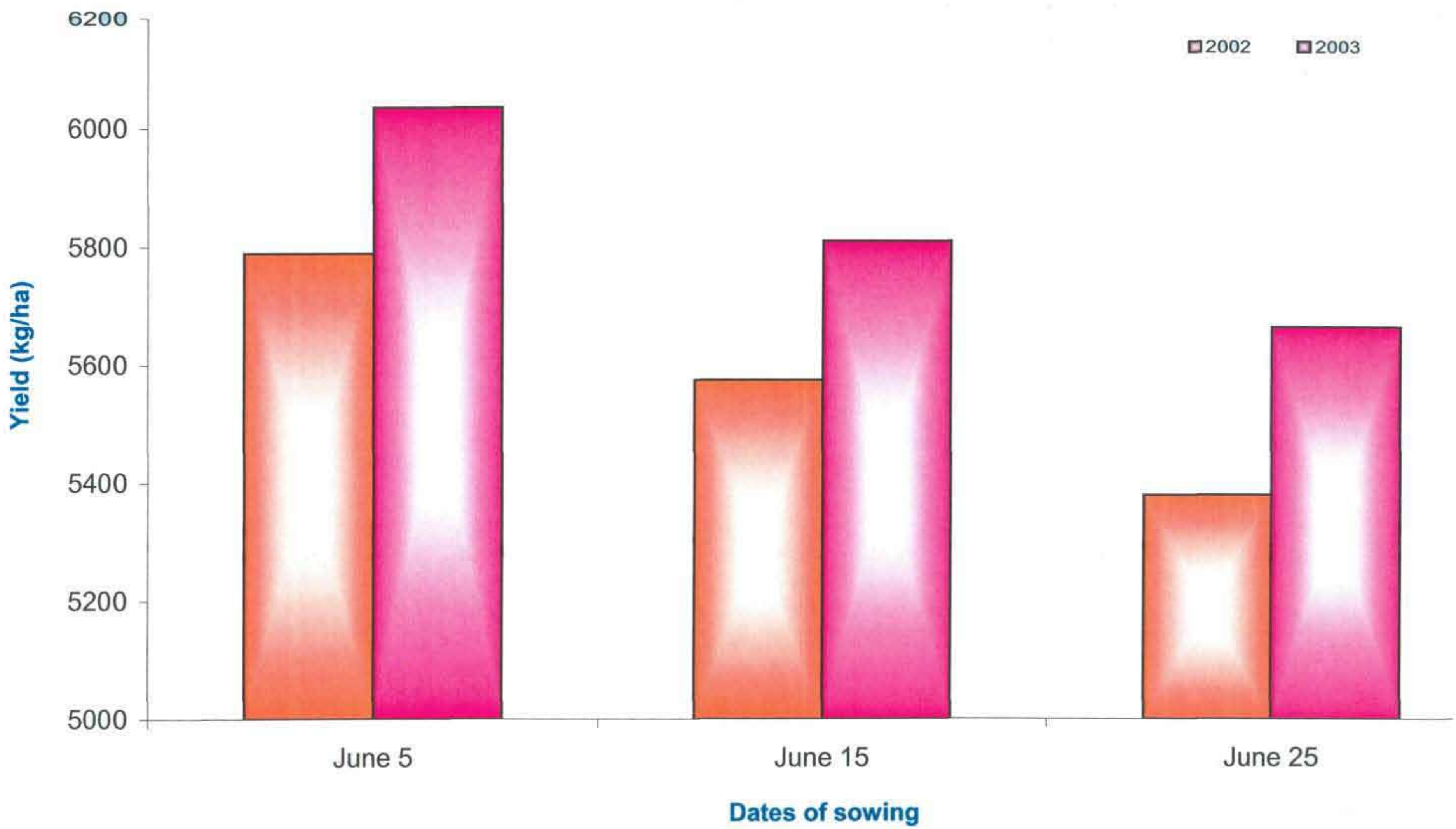

Fig. 28: Effect of different date of sowing on grain yield of rice

Table 16: Interaction effects of Crop establishment techniques and dates of sowing on mean grain yield (kg ha^{-1}) during 2002

Crop establishment techniques	Dates of sowing			Mean
	June 5	June 15	June 25	
Zero-till –Broadcast	5278.0	5204.7	5068	5183.5
Puddled–Broadcast	5273.0	5206.3	4873.0	5117.4
Zero-till-drill–seeding	5283.3	5183.3	4983.3	5150
Zero-till-transplant	6503.0	5980.0	5816.7	6100.0
Puddled-Transplant	6188.3	5885.0	5698.3	5923.9
Unpuddled-Transplant	6205.0	5985.0	5838.3	6009.4
Mean	5788.5	5574.0	5379.6	

	CD	SEm
Crop establishment techniques (A)	409	142
Dates of sowing (B)	289	100
A×B	N.S.	246

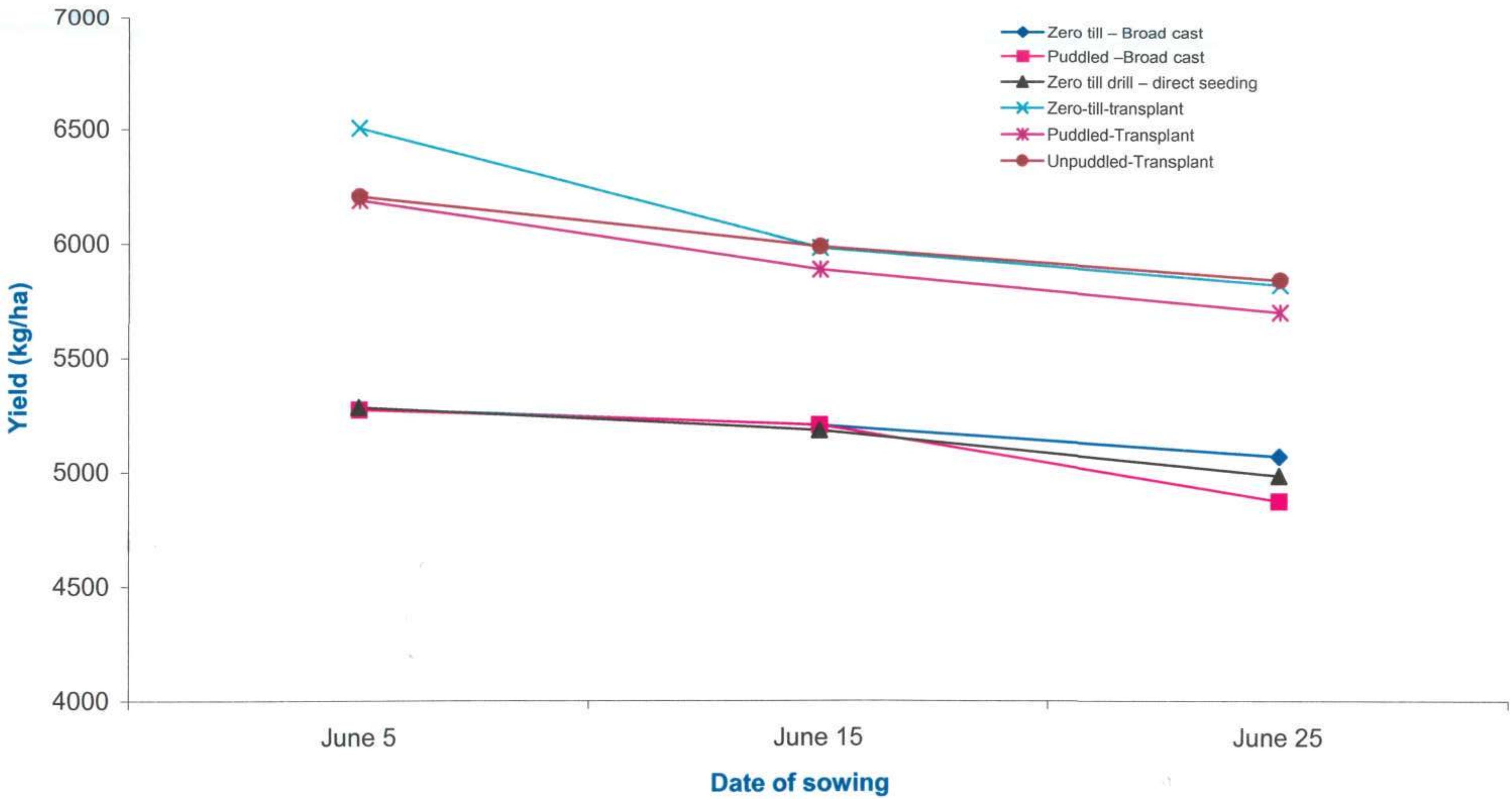

Fig. 29: Interaction effect of crop establishment techniques and dates of sowing on grain yield of rice during 2002

yield reduction due to delayed sowing upto June 25 as compared to June 5 was observed in zero-till transplanting (10.55%). A reduction of 7.58% and 7.9% was recorded in zero-till-broadcast and puddled-transplant methods. Crop yield was least affected by delayed sowing under zero-till-direct seeding where a reduction of only 3.97% was observed under delayed sowing.

4.3.3.2 Straw yield (kg ha^{-1})

On an average, the straw yield produced under direct seeding and transplanting methods was similar during 2002 as well as 2003 (Table 15). The maximum straw yield was produced under zero-till-transplant and it was significantly more than all other treatments during 2002 but at par with zero-till-broadcast during 2003. Straw yield under puddled conditions was less than unpuddled situation both under direct seeding as well as transplanting in 2002 and 2003.

Among different dates of sowing/transplanting, the straw yield was maximum under 5th June of sowing/transplanting and it reduced with subsequent delay in sowing/transplanting, however, the differences were non-significant during both years (Table 15).

4.3.3.3 Biological Yield (kg ha^{-1})

Biological yield of rice, in general, was more under transplanting methods compared to direct seeding during both years (Table 15). It was also more under unpuddled conditions compared to puddled one both under direct seeding as well as transplanting methods. Among direct seeding methods, zero-till-broadcast produced maximum biological yield. Whereas, under transplanting methods, zero-till-transplant followed by unpuddled-transplant method into highest biological yield of rice. Zero-till-transplant also proved superior to all other crop establishment methods in producing biological yield during both years.

Biological yield of rice was significantly higher under 5th June sowing/transplanting during both years and it decreased significantly with subsequent delay in sowing transplanting (Table 15).

4.3.3.4 Harvest index (HI)

Harvest index was more under transplanted rice compared to direct seeded rice in both years (Table 15). Among direct seeding methods, there was non-significant difference in terms of harvest index during both years. Harvest index was also similar under transplanting methods during both years.

Harvest index was not significantly influenced by various dates of sowing/transplanting during both years.

4.3.4 Economic studies

The data pertaining to economics of rice cultivation as influenced by different treatments comprising crop establishment techniques and different dates of sowing are presented in Table 17.

A perusal of the data indicates that the highest gross return of Rs. 36080 and 37576 per hectare were obtained in zero-till-transplant with a benefit: cost of 1.52 and 1.58 during 2002 and 2003, respectively. This treatment was followed by zero-till-broadcast (1.39 and 1.47 during 2002 and 2003, respectively), zero-till-drill seeding (1.38 and 1.44), unpuddled-transplant (1.35 and 1.39). Among all the treatments puddled broadcast methods was found to be least profitable with a benefit: cost of 1.25 and 1.32 during 2002 and 2003, respectively.

Dates of sowing also influenced the net returns. June 5th sowing was found to be most profitable with benefit: cost of 1.42 and 1.48 during 2002 and 2003, respectively. Delayed sowing reduced the returns.

4.3.5 Wheat Yield (kg ha^{-1})

To study the effect of various establishment techniques of rice on the following wheat crop, wheat was sown

Table 17: Economics of rice cultivation as influenced by different crop establishment techniques and dates of sowing

Treatment	Total cost of cultivation (Rs. ha^{-1})		Gross return (Rs. ha^{-1})		Net return (Rs. ha^{-1})		Benefit : Cost ratio	
	2002	2003	2002	2003	2002	2002	2003	2003
Crop establishment techniques								
Zero-till-Broadcast	21704	21738	30380	32066	8676	10327	1.39	1.47
Puddled-Broadcast	24419	24456	30568	32344	6148	7888	1.25	1.32
Zero-till--seeding	22150	22175	30765	31975	8615	9800	1.38	1.44
Zero-till transplant	23667	23697	36080	37576	12413	13878	1.52	1.58
Puddled-transplant	26358	26392	35057	36706	8698	10313	1.32	1.39
Unpuddled-transplant	26181	26213	35554	37141	9373	10927	1.35	1.41
Dates of sowing								
June 5	24105	24134	34272	35703	10167	11569	1.42	1.48
June 15	24079	24113	33029	34654	8949	10541	1.37	1.43
June 25	24056	24090	31901	33547	7845	9457	1.32	1.39

Table 18: Effect of rice establishment techniques of rice on wheat yield (*Rabi* 2003-04)

Crop establishment techniques in rice (*Kharif* 2003)	**Grain yield (kg ha^{-1})**
Zero-till-Broadcast	5330
Puddled-Broadcast	4920
Zero-till-drill-seedling	5320
Zero-till-Transplant	5270
Puddled-Transplant	4895
Unpuddled-transplant	5360
$SE_m \pm$	142
CD at 5%	NS

by zero-till-drill and the yields were monitored after experiment-I (Table 18).

Higher yield of wheat (5360 Kg ha^{-1}) was obtained after unpuddled-transplant rice followed by zero-till-broadcast (5330 Kg ha^{-1}), zero-till-drill seeding (5320 Kg ha^{-1}). Lowest yield was recorded in puddled-transplant (4895 Kg ha^{-1}) followed by puddled-broadcast (4920 kg ha^{-1}).

4.4 Result Experiment-II

4.4.1 Growth Characteristics

4.4.1.1 Plant population (No. m^{-2})

Averaging over different crop establishment techniques, the population of rice plants recorded at 30 DAS/at planting and 60 DAS/30DAT was statistically at par between two rice cultivars IR-64 and HKR-126 during 2002 as well as 2003 (Table 19).

Among different crop establishment techniques averaged over two rice cultivars, the plant population at 30DAS/at planting under puddled-transplant (38 and 40 m^{-2}) being at par with zero-till-transplant (40 and 42m^{-2}) was significantly less than puddled-broadcast (57 and 60 m^{-2}) and zero-till-broadcast (56 and 59 m^{-2}). Puddled-broadcast and zero-till-broadcast were at par during 2002 and 2003. Similar trend was found at 60 DAS/30DAT during both the

Table 19: Effect of different crop establishment techniques and rice cultivars on plant population at 30 DAS/at planting and 60 DAS/30 DAT

Treatments	Plant Population (No. m^{-2})			
	30 DAS/At planting		60 DAS/30DAT	
	2002	2003	2002	2003
Variety				
IR-64	49	52	44	45
HKR-126	53	54	45	49
SE_m ±	1.6	1.4	1.3	1.7
CD at 5%	NS	NS	NS	NS
Crop establishment techniques				
Puddled-Transplant	38	40	34	36
Puddled-Broadcast	57	60	50	52
Zero-till-Transplant	40	42	36	38
Zero-till-Broadcast	56	59	48	51
SE_m ±	2.3	2.0	2.0	2.3
CD at 5%	7	6	6	7

years except that the plant population was reduced to the extent of 4 plants/m^2 under transplanting methods and 7-8 plants/m^2 under direct broadcasting methods.

4.4.1.2 Number of shoots/m^2

Rice cultivars IR-64 and HKR-126 when averaged over deferent crop-establishment techniques, produced statistically similar number of shoots at 30 DAS/at planting as well as at 60DAS/30DAT during both years (Table 20). The number of shoots of two varieties ranged from 387-392 m^{-2} at 30 DAS/at planting and 332-336 m^{-2} at 60 DAS/30DAT.

Among different crop establishment techniques averaged over two rice cultivars, the number of shoots recorded at 30DAS/at planting under puddled-transplant (365 an 368 m^{-2}) being at par with zero-till-transplant (369 and 371 m^{-2}) were significantly less than puddled-broadcast (405 and 407 m^{-2}) and zero-till-broadcast (414 and 416 m^{-2}) which were at par to each other during 2002 and 2003. Similar trend was found at 60 DAS/30 DAT during both years except that the number of shoots at this stage reduced to the extent of 45 m^{-2} and 65 m^{-2} under transplanting and broadcasting methods, respectively.

Table 20: Effect of different crop establishment techniques and rice cultivars on number of shoots at 60 DAS/30 DAT and 90 DAS/60 DAT

Treatments	Number of shoots (No. m^{-2})			
	60DAS/30DAT		90DAS/60DAT	
	2002	2003	2002	2003
Variety				
IR-64	387	390	332	335
HKR-126	389	392	333	336
SE_m ±	3.9	3.9	3.9	3.9
CD at 5%	NS	NS	NS	NS
Crop establishment techniques				
Puddled-Transplant	365	368	320	323
Puddled-Broadcast	405	407	341	342
Zero-till-Transplant	369	371	324	327
Zero-till-Broadcast	414	416	347	349
SE_m ±	5.6	5.6	5.5	5.5
CD at 5%	17	17	16	17

4.4.1.3 Dry matter accumulation (g m^{-2})

When averaged over crop establishment techniques, the dry matter accumulation by two rice varieties IR-64 and HKR-126 was non-significant at 30DAS/at planting and at harvest during 2002 as well as 2003 (Table 21). The dry matter accumulation by both varieties increased with the corresponding increase in the age of crop and the trend of this increase was similar in both varieties and during the both years of experimentation.

At 60 DAS/30DAT and 90DAS/60DAT, the dry matter accumulation in HKR-126 was more than IR-64 during both years but the differences were significantly during 2003. The magnitude of increase in the dry matter accumulation was more from 60DAS/30DAS to 90DAS/60DAT in the both varieties and during both years.

Among different crop establishment techniques averaged over two rice varieties, the dry matter accumulation at 30 DAS/at transplanting was significantly more under broadcasting methods compared to transplanting methods during both years (Table 21). However, puddled-transplant was at par with zero-till- transplant and puddled-broadcast was at par with zero-till-broadcast in this respect during both years. At 60 DAS/30DAT during 2002, the dry matter

Table 21: Effect of different crop establishment techniques and rice cultivars on drymatter accumulation at 30 DAS/at planting, 60 DAS, 30 DAT, 90 DAS/60 DAT and at harvest.

Treatments	Drymatter accumulation (g m^{-2})							
	30 DAS/At planting		60 DAS/30DAT		90 DAS/60DAT		Harvest	
	2002	2003	2002	2003	2002	2003	2002	2003
Variety								
IR-64	92	107	287	295	930	956	1680	1806
HKR-126	96	111	306	368	973	1038	1860	1984
$SE_m \pm$	1.7	2.6	13.0	18.9	22.1	23.9	76.1	75.0
CD at 5%	NS	NS	NS	57	NS	72	NS	NS
Crop establishment techniques								
Puddled-Transplant	89	95	312	342	972	1033	1968	2075
Puddled-Broadcast	98	122	266	312	884	894	1580	1710
Zero-till-Transplant	86	90	355	369	1020	1080	2003	2106
Zero-till-Broadcast	104	132	254	304	930	980	1551	1690
$SE_m \pm$	2.4	3.6	18.0	26.7	31.1	33.7	107	107
CD at 5%	7.2	11.0	55.8	NS	NS	102	320	320

accumulation under puddled-transplant (312g m^{-2}) being at par with zero-till-transplant (355 g m^{-2}) was superior to puddled-broadcast (266g m^{-2}) and zero-till-broadcast (254 g m^{-2}), and puddled-broadcast was at par with zero-till-broadcast. The trend was similar at harvest during both the years. There was no significant variation in respect of dry matter accumulation among different crop establishment techniques at 60DAS/30DAT in 2003 and 90 DAS/60 DAT during 2002. The dry matter accumulation at 90 DAS/60DAT during 2003 was higher under zero-till-transplant however, it was at par with puddled-transplant and zero-till-broadcast but superior to puddled-broadcast (Table 21). In general the magnitude of dry matter accumulation at 60DAS/30 DAT up to harvest was as follows: zero-till-transplant > puddled-transplant > puddled-broadcast > zero-till-broadcast except that zero-till-broadcast produced non significantly more dry matter than puddled-broadcast at 90DAS/60 DAS during 2002 and 2003.

4.4.1.4 Plant height (cm)

When averaged over different crop establishment techniques, the plant height attained by HKR-126 was more than IR-64 at each growth stage, however, the differences were non-significant at 60 DAS/30DAT during both years, and at harvest during 2002 (Table 22). The plant height attained by HKR-126 was significantly more at 90 DAS/60 DAT during both years, and also at harvest during 2003.

The plant height among different crop establishment techniques averaged over two rice cultivars was more under zero-till-transplant, which was statistically equal to puddled-transplant at 60DAS/30DAT, 90DAS/60DAT and also at harvest during both years. Plant height under broadcast seeding i.e. puddled-broadcast as well as zero-till-broadcast being at par with each other was significantly less than transplanting situation at all growth stages and during both years except that plant height under puddled-transplant and puddled-broadcast was also at par at 90DAS/60DAT and at harvest (Table 22). The magnitude of increase in the plant height was more from 60 DAS/30 DAT to 90 DAS/60DAT compared to from 90DAS/60 DAT to harvest, however, the trend of increase under transplanting and broadcasting methods was almost similar.

4.4.1.5 Leaf area index (LAI)

Leaf area index of both rice cultivars averaged over different crop establishment techniques, increased with the corresponding increase in the age of crop from 30DAS/at planting to 90 DAS/60 DAT and reduced significantly at

Table 22: Effect of different crop establishment techniques and rice cultivars on plant height at 60 DAS/30 DAT, 90 DAS/60 DAT and harvest

Treatments	Plant height (cm)					
	60 DAS/30DAT		90 DAS/60DAT		Harvest	
	2002	2003	2002	2003	2002	2003
Variety						
IR-64	67.0	65.8	86.0	88.1	99.0	100.6
HKR-126	67.9	66.3	90.8	92.1	100.7	102.0
$SE_m \pm$	1.0	8.0	0.98	0.98	0.76	0.47
CD at 5%	NS	NS	2.9	2.9	NS	1.4
Crop establishment techniques						
Puddled-Transplant	70.8	68.6	90.4	92.5	101.4	102.6
Puddled-Broadcast	65.2	63.7	87.2	88.9	99.5	100.5
Zero-till-Transplant	71.4	69.3	91.9	93.5	103.6	104.8
Zero-till-Broadcast	62.5	62.8	84.0	85.7	95.1	97.4
$SE_m \pm$	1.4	1.43	1.39	1.39	1.07	0.67
CD at 5%	4.5	3.4	4.2	4.2	3.2	2.2

harvest during both years. In general, the leaf area index was more in HKR-126 compared to IR-64 at all the growth stages and during both the years except that the difference were non-significant at 30 DAS/at transplanting in 2003, at 60DAS/30DAT in 2002 and at 90DAS/60 DAT in 2002 as well as 2003 (Table 23). The magnitude of increase in leaf area index in case of both varieties and different crop establishment technique was more from 30DAT/at transplanting to 60DAS/30DAT followed by from 60 DAS/30DAT to 90DAS/60DAT and then it was reduced from 90 DAS/60DAT to harvest during both the year of study.

Among different crop establishment techniques averaged over rice cultivars, the leaf area index under both transplanting methods, i.e. puddled-transplant and zero-till-transplant was significantly less than both of the broadcasting methods (puddled-broadcast and zero-till-broadcast), however, under each category they were at par to each other at 30DAS/at planting during both years.

At 60DAS/30DAT and 90DAS/60DAT, the leaf area index under zero-till-transplant being at par with puddled-transplant was significantly higher than both puddled-broadcast and zero-till-broadcast, which were also at par to each other during both years except that LAI under puddled-

Table 23: Effect of different crop establishment techniques and rice cultivars on leaf area index (LAI) at 30 DAS/at planting, 60 DAS/30 DAT, 90 DAT/60 DAT and at harvest

Treatments	Leaf area index (LAI)							
	30 DAS/At planting		60 DAS/30DAT		90 DAS/60DAT		Harvest	
	2002	2003	2002	2003	2002	2003	2002	2003
Variety								
IR-64	0.299	0.455	3.141	3.185	5.125	5.089	0.492	0.495
HKR-126	0.492	0.468	3.288	3.441	4.905	5.136	0.647	0.681
SE_m ±	0.01	0.02	0.06	0.03	0.15	0.17	0.04	0.04
CD at 5%	0.046	NS	NS	0.10	NS	NS	0.145	0.140
Crop establishment techniques								
Puddled-Transplant	0.364	0.421	3.962	3.942	5.531	5.684	0.621	0.625
Puddled-Broadcast	0.433	0.510	2.621	2.783	4.609	4.692	0.532	0.542
Zero-till-Transplant	0.315	0.355	3.892	3.984	5.651	5.771	0.631	0.695
Zero-till-Broadcast	0.470	0.560	2.483	2.544	4.270	4.304	0.495	0.498
SE_m ±	0.02	0.03	0.09	0.04	0.22	0.24	0.06	0.06
CD at 5%	0.065	0.095	0.294	0.14	0.68	0.73	NS	NS

broadcast (2.783) was significantly more than zero-till-broadcast at 60DAS/30DAT during 2003. There was no significant difference among various crop establishment techniques in respect of leaf area index at harvest during 2002 as well as 2003.

Interaction effect of crop establishment methods and varieties (Table 24) was also observed on LAI. In case of IR-64 variety highest LAI 4.009 was observed under puddled-transplant and it decreased to 3.76 in zero-till transplant. But in HKR-126 zero-till transplant method increased LAI of crop to 4.207 from 3.875 recorded under puddled-transplant condition.

4.4.2 Yield attributes

4.4.2.1 Effective tillers (No. m^{-2})

Averaging different crop establishment techniques, the number of effective tillers produced by HKR-126 was significantly more than IR-64 during 2002 as well as 2003 (Table 25).

Among different crop establishment techniques, zero-till-transplant (effective tillers 295 m^{-2} in 2002 and 307 m^{-2}) in 2003 being at par with puddled-transplant (291 m^{-2} in 2002 and 306 m^{-2} in 2003) produced significantly less number of effective tillers compared to puddled-broadcast

Table 24: Interaction effect between cultivars and crop establishment technique on mean leaf area index (LAI) at 60 DAS/30 DAT during 2003

Crop establishment technique	Cultivars		Mean
	IR-64	HKR-126	
Paddled-Transplant	4.009	3.875	3.942
Paddled-Broadcast	2.649	2.916	2.783
Zero-till-Transplant	3.760	4.207	3.984
Zero-till-Broadcast	2.320	2.767	2.544
Mean	3.185	3.441	

	CD	SE(m)
Cultivars (A)	0.10	0.03
Crop establishment technique (B)	0.14	0.04
A x B	0.20	0.06

Table 25: Effect of different crop establishment techniques and rice cultivars on yield attributes

Treatment	Effective tillers (No. m^2)		Panicle length (cm)		Filled grain/panicle (NO.)		Unfilled grain/panicle (NO.)		1000 grain weight (g)	
	2002	2003	2002	2003	2002	2002	2003	2003	2002	2003
Variety										
IR-64	304	316	26.2	27.7	117	23.95	27.0	123	23.95	27.0
HKR-126	316	328	25.3	27.7	127	25.23	28.3	172	25.23	28.3
$SE_m \pm$	3.7	3.7	0.23	0.23	3.3	3.6	0.8	1.16	0.40	0.43
CD at 5%	11.3	11.2	0.7	NS	NS	1.2	NS	10.9	1.2	NS
Crop establishment techniques										
Puddled-Transplant	291	306	26.3	29.5	133	25.0	28.6	159	25.0	28.6
Puddled-Broadcast (sprouted seed)	329	341	25.2	26.4	109	24.3	26.7	140	24.3	26.7
Zero-till-Transplant	295	307	25.9	28.4	138	26.0	28.8	161	26.0	28.8
Zero-till-Broadcast (sprouted seed)	325	334	25.9	26.6	108	23.3	26.5	130	23.3	26.5
$SE_m \pm$	5.2	5.2	0.32	0.33	4.7	5.1	1.13	1.64	0.57	0.61
CD at 5%	16.0	15.9	NS	1.0	14.5	1.7	1.8	15.4	1.7	1.8

(329 and 341 m^{-2}) and zero-till-broadcast (325 and 334/m^{-2}). Puddled-broadcast and zero-till-broadcast were at par with each other in this respect during both years.

4.4.2.2 Panicle length (cm)

Averaging different rice cultivars over crop establishment techniques, rice cultivar IR-64 produced longer panicles compared to HKR-126 during 2002, but the differences were non-significant during 2003 (Table 25).

Among different crop establishment techniques averaged over rice cultivars, Puddled-transplant being at par with zero-till-transplant produced panicles significantly longer than puddled-broadcast as well as zero-till-broadcast during 2003. However, the differences in this respect among various crop establishment techniques were non-significant during 2002. The difference was also non-significant between panicle length produced under puddled-broadcast and zero-till-broadcast in 2003.

4.4.2.3 Filled grains/panicle (No.)

Filled grains/panicle produced by HKR-126 were more than IR-64 during both years, however, the difference were significant only in 2003 (Table 25).

Among different crop establishment technique, the number of filled grains/panicle was significantly higher under zero-till-transplant (138 and 161/panicle), which was statistically at par with puddled-transplant (133 and 159/panicle) during both years. puddled-broadcast produced number of filled grain/panicle (109 in 2002 and 140 in 2003) statistically at par with zero-till-broadcast (108 in 2002 and 103 in 2003).

4.4.2.4 Unifilled grain/panicle (No.)

Averaging varieties over different crop establishment techniques, HKR-126 produced more unfilled grains/panicle (21/panicle) than IR-64 (15/panicle) during 2003 (Table 25), however, the differences were non-significant during 2002.

Among different crop establishment techniques, the number of unifilled grains/panicle were significantly higher under puddled-transplant (16/panicle), which was at par with zero-till-broadcast (15/panicle) during 2002. The number of unfilled grains under puddled-broadcast (11/panicle) being at par with zero-till-transplant (10/panicle) were less than other two crop-establisment-techniques in 2002. During 2003, the trend was little bit different and puddled-transplant resulted into significantly higher number of unfilled grains (24/panicle) than rest of the three crop establishment techniques which were, however, at par to each other (Table 25).

4.4.2.5 1000-grain weight (g)

Rice variety HRR-126 resulted into significantly more 1000-grain weight (25.2g) compared to IR-64 (23.9g) during 2002 (Table 25). However, the differences between these two varieties were non-significant in this respect during 2003.

Among different crop establishment techniques, zero-till-transplant produced 1000-grain weight (26 g) statistically similar to puddled-transplant (25 g) and puddled-braodcast (24.3g) during 2002, however it was superior to zero-till-broadcast (23.3 g). During 2003, zero-till-transplant and puddled-transplant being at par with each other produced 1000-grain weight significantly more than puddled-broadcast and zero-till-broadcast. However, 1000-grain weight during 2003 was at par between two methods under broadcasting.

4.4.3 Yields and Harvest Index

4.4.3.1 Grain yield (kg ha^{-1})

Between two rice cultivars, HKR-126 yielded significantly higher than IR-64 during 2002 as well as 2003 (Table 26). The increase in grain yield under HKR-126 compared

Table 26: Effect of different crop establishment techniques and rice cultivars on yield.

Treatments	Yield				Yield			
	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Biological yield (q ha^{-1})		Harvest index (%)	
Variety								
IR-64	5595	5905	67.2	76.7	123.1	135.8	45.45	43.48
HKR-126	6053	6412	72.8	76.9	133.5	141.0	45.45	45.46
$SE_m \pm$	449	46.4	0.6	1.8	1.2	3.7	0.07	0.005
CD at 5%	277	268	4.1	NS	7.5	NS	NS	0.032
Crop establishment techniques								
Puddled-Transplant	6335	6720	76.0	83.8	139.4	151.0	45.45	44.47
Puddled-Broadcast	5335	5605	64.2	69.9	117.4	126.0	45.45	44.47
Zero-till-Transplant	6365	6745	76.4	84.1	140.0	151.6	45.45	44.47
Zero-till-Broadcast	5262	5565	63.5	69.4	116.5	125.0	45.44	44.47
$SE_m \pm$	111	94.7	1.2	1.1	2.3	2.1	0.03	0.002
CD at 5%	343	291	4.0	3.7	7.2	65	NS	NS

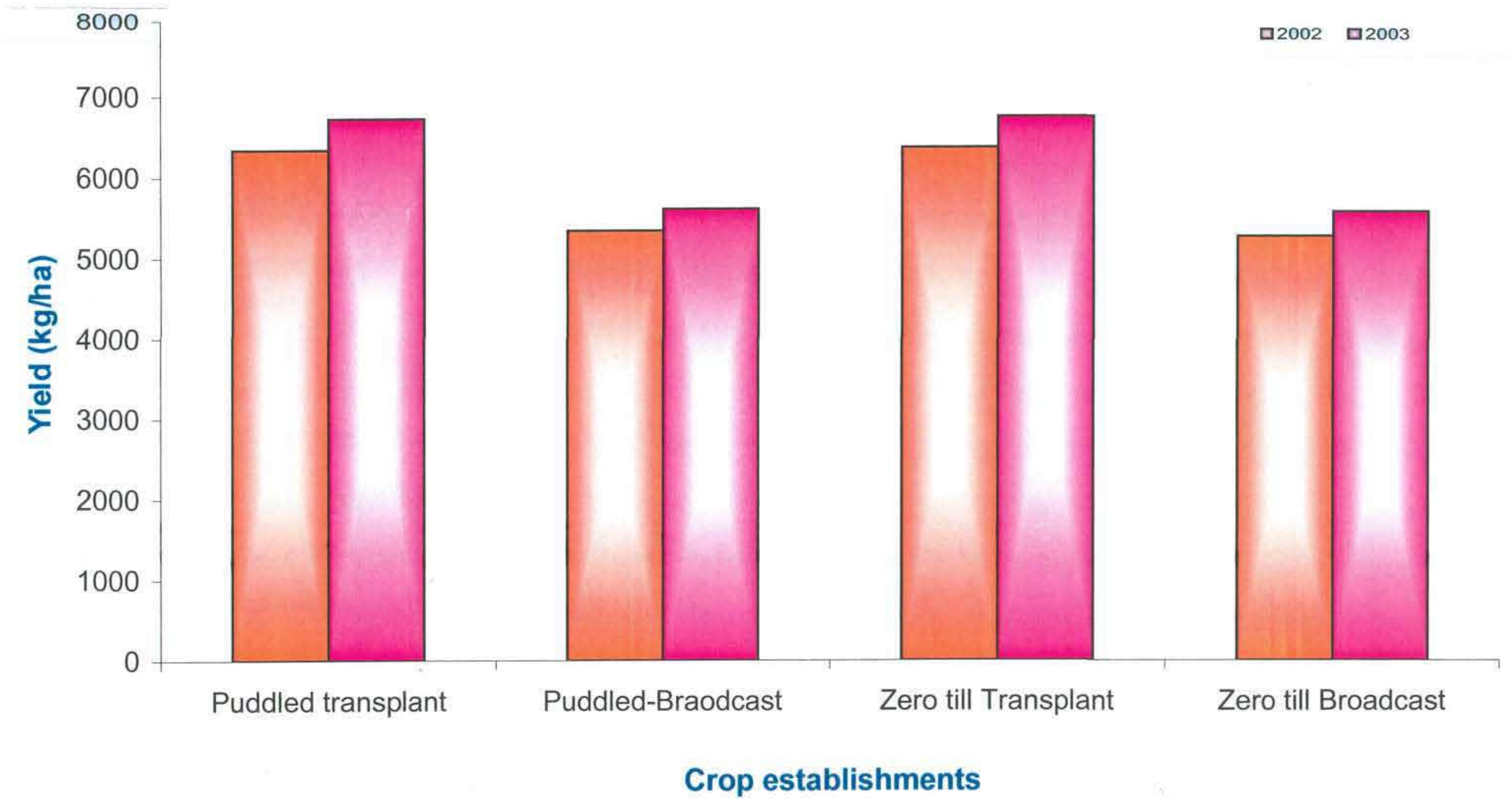

Fig. 30: Effect of different crop establishment techniques on grain yield

to IR-64 was 8.2 and 8.6 per cent during 2002 and 2003, respectively.

Among different crop establishment techniques, (Table 26 and Fig. 30) the grain yields of rice under zero-till-transplant (6395 kg ha^{-1} in 2002 and 6745 kg ha^{-1} in 2003) and puddled-transplant (6335 kg ha^{-1}. in 2002 and 6720 kg ha^{-1} in 2003) being at par with each other were significantly more than both puddled-broadcast (5335 kg ha^{-1} in 2002 and 5605 kg ha^{-1} in 2003) as well as zero-till-broadcast (5262 kg ha^{-1} in 2002 and 5565 kg ha^{-1} in 2003). However, puddled-broadcast and zero-till-broadcast produced statistically similar grain yields during both years.

4.4.3.2 Straw yield (q ha^{-1})

The trend of straw yield of rice under two rice varieties and four crop establishment techniques was similar to that of grain yield during both years of present investigation. Straw yield produced by HKR-126 was more than IR-64 during both years, however the differences were significant only in 2002 (Table 26)

Among different crop establishment techniques zero-till-transplant and puddled-transplant being at par with each other produced straw yield significantly more than puddled-broadcast as well zero-till-broadcast during both years. Straw yield under two broadcasting methods, was at par during 2002 as well as 2003.

4.4.3.3 Biological yield (t ha^{-1})

Biological yield is merely a summation of grain yield and straw yield. HKR-126 resulted into higher biological yield compared to IR-64 during both years (Table 26), however, the difference were significant only during 2002.

Among different crop establishment techniques zero-till-transplant and puddled-transplant being at par with each other produced significantly higher biological yield compared to both puddled-broadcast and zero-till-broadcast during 2002 as well as 2003.

4.4.3.4 Harvest Index (HI)

When averaged over crop establishment techniques, HKR-126 resulted into significantly higher harvest index (HI) compared to IR-64 during 2003 (Table 26). However, the difference between two varieties was non-significant in this respect during 2002.

Among different crop establishment techniques, the HI was statistically similar during 2002 as well as 2003. In general, the harvest index was higher during first year compared to second year (Table 26).

4.4.3.5 Wheat yield (kg ha^{-1})

To study the effect of various establishment techniques of rice on the following wheat crop, wheat was sown by zero-till-drill and the yields were monitored after experiment II (Table 27).

Higher yield of wheat (5260 kg ha^{-1}) was obtained after zero-till-broadcast rice followed by zero-till-transplant rice followed by zero-till-transplant (5150 kg ha^{-1}). Lowest yield was recorded in puddled-transplant rice (4900 kg ha^{-1}) followed by puddled-broadcast (5070 kg ha^{-1}).

Table 27: Effect of rice establishment technique of rice on wheat yield (Rabi 2003-04) at Farmers field (Village Dhons)

Treatments	Wheat-yields in Rabi 2003-04
	Grain yield (kg ha^{-1})
IR 64	——
HKR 126	——
CD	
Puddled-Transplant	4900
Puddled-broadcast	5073
Zero-till-Transplant	5150
Zero-till-broadcast	5260
CD	NS

Experiment II at Farmers field (Village Dhons, Kaithal Distt.)

Rice Plots (under zero-tillage) at Prithala area.

QRT (ICAR) team members visiting the experiment I at
Regional Research Station, Uchani, Karnal.

CHAPTER – V

DISCUSSION

An investigation entitled, "Crop establishment techniques in rice under different environments in Haryana" comprising two separate field experiments (Experiment I at Regional Research Station, Uchani, Karnal & Experiment II at farmer's field) were conducted in the *Kharif* season of 2002 and 2003. The results of these experiments presented in previous chapter, are discussed here in this chapter.

5.1 METEOROLOGICAL STUDIES

5.1.1 Weather conditions prevailed during the crop season

The daily meteorological parameters prevailed during the *Kharif* 2002 and 2003 seasons were recorded. Using this data weekly meteorological standard weeks were computed for the two seasons. The meteorological parameters, which were plotted, are the maximum and minimum air temperature, morning and evening relative humidity, bright sunshine hours, rainfall and pan evaporation.

5.1.1 Maximum temperature

During *Kharif* season 2002 mean weekly maximum air temperature gradually decreases from 36.3°C at emergence stage to a lowest value of 29.4°C during the 36th week and afterward increasing trend was observed up to maturity stage. The weekly mean temperature during 2002 were closely followed the normal values except 36th week where these were slightly below normal values shown in the table 4 (Fig. 5).

During *Kharif* 2003 crop season the weekly mean maximum temperature varied from 43.4°C to 30.0°C. weekly mean maximum temperatures during 2003 were slightly above normal values upto 31st standard week later on mean maximum temperature values are slightly below the normal values from 32nd to 39th standard weeks, whereas in later stages the mean maximum temperature values were close to the normal values.

A comparison among two years shown that mean maximum temperature prevailed from emergence to maturity were close to the normal values in 2002, where as in 2003 the maximum temperature values were slightly higher than the normal at emergence and maturity stages.

5.1.1.2 Minimum temperature

The weekly mean minimum temperature varied from 28.7°C to 14.4°C during *Kharif* 2002, that the overall weekly values were slightly higher than the normal values from 24th to 35th standard weeks, whereas during to 40th standard weeks the minimum temperature values are lower than normal value and again increases upto maturity stage.

During 2003 *Kharif* season the values of weekly minimum temperature were ranged from 28.0°C to 12.4°C. the minimum weekly mean temperature values gradually decreased from the date of sowing to maturity stage. The weekly mean minimum temperature during the 2003 crop season was slightly higher than normal values.

5.1.1.3 Relative humidity

The fluctuations in weekly morning and evening relative humidity values were observed during both the crop seasons. Weekly morning relative humidity ranges between 96% (at week 42nd, 43rd and 44th) and 69% (at week 28th). The weekly mean morning relative humidity values were close to the normal up to 41st standard week. During the 2003 crop season the morning weekly mean relative humidity values were ranged between 96% (at 37th standard week) and 40% (at 22nd standard week). At early stages of crop growth the morning relative humidity values were slightly lower than normal but later stages it was higher than normal values.

The weekly evening relative humidity during 2002 was 42% (at 43rd standard week) and 81% (at 35th standard week). Later stages of the crop growth the weekly mean evening relative humidity values are higher than normal values. However in second year of experiment the whole crop season experienced higher values of evening relative humidity than normal values and the values were ranged between 18% (at 22nd standard week) to 77% (at 36th and 37th standard weeks). A comparison among the two years 2002 crop season higher values of morning and evening relative humidity as compared to 2003 crop season.

5.1.1.4 Rainfall

During the *Kharif* season 2002, 461.5 mm of rainfall received and spreaded over a 9 rainy days (rainy day $\geq$ 2.5 mm of rainfall), where as in 2003 a total 318.5 mm rainfall received over 14 rainy days. A comparison between the 2002 and 2003 shown, a good distribution of rainfall in 2003 crop season than 2002 crop season was observed.

5.1.1.5 Bright sunshine hours

The bright sunshine hours during the both crop seasons were below normal values. Cloudy weather prevailed throughout the crop season in 2002, where as in second crop season (2003) the Bright sunshine hours were below the normal values. The 2003 crop season was slightly warmer when compared to 2002 crop season.

5.1.1.6 Pan evaporation

The weekly mean pan evaporation values in the *Kharif* 2002 were lower when compared to normal values. This was due to less atmospheric demand and more rainfall received during that year. In 2003 crop of season the weekly mean pan evaporation values were lower than normal values. A comparison of both the years the 2002 crop season recorded higher pan evaporation values than 2003 crop season.

5.1.2 Relationship between accumulated heat units and different phenophases

Experiment-I

The dry matter accumulation under different treatments followed the same trend with accumulated thermal time. In different plant establishment techniques unpuddled-transplant technique consumed more number of accumulated heat units, due to plant taken more thermal time in early growth stages. Whereas zero-till-broadcast establishment technique consumed less amount of accumulated heat units in both the years. Under different dates of sowing unpuddled-transplant, puddled-transplant and zero-till-transplant establishment techniques consumed more accumulated heat units when compare to zero-till-broadcast, zero-till direct seeding and puddled broadcast. In zero-till-broadcast and zero-till direct seeding and puddled broadcast establishment techniques consumed less accumulated heat units may be due to crop did't exposed to transplant shock and those came to early maturity.

Experiment-II

In puddled-transplant establishment technique consumed more accumulated heat units in both varieties (IR-64 and HKR-126). Zero-till-broadcast establishment technique consumed lowest accumulated heat units in IR-64 and HKR-126. In both the years HKR-126 consumer more accumulated heat units might be due to more heat units required to complete its vegetative growth stage.

5.1.3 Relationship between dry matter accumulation and heat units

Experiment-I

Dry matter accumulation at harvest time shown direct relationship with accumulated heats during the crop growing seasons with respect to method of establishment techniques. *Kharif* crop season (2003) crop consumed more accumulated heat units due to this reason crops dry matter accumulation was also high.

Among the three dates of sowing (June 5, June 15 and June 25) the June 5th sown crop accumulated dry matter was higher than June 15 and June 25 in both the years. This might be due to higher temperature prevailed during first date of sowing.

Experiment-II

The dry matter accumulation in relation to accumulated heat units was more in 2003 *Kharif* crop season due to availability of more accumulated heat units for IR-64 and HKR-126, whereas in 2002 *Kharif* season the availability of accumulated heat units were low.

5.2 AGRONOMIC STUDIES

The crop establishment in rice-wheat cropping system is at the centre of all crop management practices that may effect natural resource conservation of cropping system as a whole. In Haryana, rice-wheat is practiced in a relatively homogenous ecological regions with some variation in soil types and irrigation practices. This cropping system is highly input use intensive. The transplanting of rice is highly labour intensive. Rice is transplanted into puddled soils followed by continued sub-mergence. Puddling reduces infiltration of water but also destroys the soil structure (Hobbs, 2002). There is heavy reliance on groundwater and therefore, the rice is threatened by unsustainable ground water use due to inappropriate management practices. Number of tubewells have grown exponentially and pump irrigation dominates the gravity irrigation in the area. In the field, the upper limit for water productivity, well managed, disease free water limited to cereals crops is 20 kg ha^{-1} mm^{-1}. In rice, the productivity of water is more important than the yield of the crop. Recent analysis of three key cereals including rice, wheat and maize, have shown doubts as to whether yield potential will continue to be realized or not. The yield of non-hybrid varieties of rice have shown little gain in the last 30 years (Peng *et al.*, 2000). These arguments indicate that management issues which can reduce the use of external inputs can decrease the cost of cultivation and improve profitability of farmers.

In order to produce more at less cost, it is necessary to conserve the natural resources base by avoiding frequent tillage operations in favour of zero-tillage. The success of zero-tillage wheat has shown that this technology provides higher yield at less cost and also saves the use of fuel, and wear and tear of tractor (Mailk *et al.*, 2002). The present study was conducted to compare different crop establishment techniques in rice to explore the possibilities of avoiding puddling and/or transplanting. The results have been discussed under the following headings:

5.2.1 Direct seeded rice vs. transplanted rice

Direct seeding is becoming an attractive alternative to transplanting. The adoption of direct seeded rice has taken place in South East Asia mainly because of labour shortage. Asian rice farmers are shifting to direct seeding to reduce labour input, drudgery and cultivation cost (De Datta, 1986; De Datta and Flinn, 1986). The irrigation water productivity of direct seeding method of rice was estimated as 0.41 kg m^{-3} and corresponding values for transplanting method was 0.34 kg m^{-3} (Waqar *et al.*, 2004). The present investigation describes the growth and yield pattern of rice under different crop establishment methods. Studies were conducted at two sites, one at Regional Research Station, Karnal with six crop establishment techniques including zero-till-broadcast, puddled-broadcast, zero-till-drill direct seeding, zero-till-transplant, puddled-transplant and unpuddled-transplant each under three dates of sowing *viz.* June 5th, June 15th and June 25th. In all there were 18 treatment combinations. The other experiment at farmers field in the village Dhons (Kaithal, Haryana) had four crop establishment techniques and two varieties with eight treatment combinations.

At farmers field direct seeded rice both under puddled and zero-tillage situation had more population and number of shoots per unit area, however, the growth of rice in terms of plant height (Table 22) dry matter accumulation (Table 21) leaf area index (Table 23) remained less than that of transplanted rice either under puddled condition or unpuddled condition.

Direct seeding treatments had significantly more tiller production at harvest which did significantly decrease the panicle length in 2002 and number of filled grains per panicle during both years. These treatments also significantly affected the 1000-grain weight along with above two parameters (Table 25). During both years, the grain yield of paddy ranged between 5295 kg ha^{-1} to 5605 kg ha^{-1} under direct seeded method compared to 6335 kg ha^{-1} and 6745 kg ha^{-1} under transplanting methods. The lower yields recorded under direct seeded rice were dependent on early plant vigour and yield attributing characters which were not favourably affected by direct seeding compared to transplanting of rice.

At RRS, Karnal, the crop was established by direct seeding or transplanting on June 5, June 15 and June 25. The average paddy yield of transplant methods (6147 kg ha^{-1}) irrespective of tillage method was more than overall average of direct seeding methods (5270 kg ha^{-1}). These results did indicate that the growth of rice continued to stay better under transplanted situation. The work done at IRRI or elsewhere have shown similar yields under both direct seeded or transplanted situation. At places where the yield were similar or more, the use of aerobic rice varieties might have made a difference in the performance of two systems. The climatic conditions under present study might be more favourable for transplanted rice than for direct seeded rice.

The estimate of water use during 2003 have shown that number of irrigation applied at farmers' field were similar in both direct seeded and transplanted rice but the amount of water used was more in direct seeded rice than in transplanted rice (Appendix). The yield obtained in the present investigation and the amount of water used do not match the work done in Pakistan, where the water productivity under direct seeded was more than under transplanted rice. The yield gap between direct seeded rice and transplanted rice is still significant. The studies need to be continued by sowing rice just like that of wheat, so that the excess water used during early period can be saved by avoiding irrigation for more time during the early stages.

The agronomy of transplanted rice has been very well established but for direct seeded rice the agronomy with respect to seed rate, varieties and nutrient scheduling have to be perfected before taking this practice for large scale validation. Under ideal situation with assured irrigation the early growth advantage of transplanted rice was maintained throughout the season, therefore the transplanted rice yields were better than yields of direct seeded rice.

Transplanting and direct seeding were considered as a distinct identity for the purpose of discussion. The leaf area index which is measure of leafiness has shown that at harvest the leafiness in transplanted rice was more than the direct seeded rice. Although direct seeded rice led to produce similar or more number of shoots (305 m^{-2}) compared to transplanted method (298 m^{-2}) but it did not lead to production of more leafiness (Table 13) and also dry weight per unit area. The yield attributing characters given in Table 14 support the yield data that direct seeding of rice is not superior over transplanting of rice. On an average, in direct seeding methods where the seeding was done on June 5th resulted in 16% lower yield compared to the average of all transplanting methods. Although the plant population in direct seeded method (48 m^{-2}) remained more than the transplanted rice (43 m^{-2}) but that could not be translated into improved productivity of paddy. The plant population, however, was not affected by different tillage techniques in the situation where seeding was done on June 25th or the transplanting was done on July 25th. Direct seeding of rice at other places has been found to be successful. Based on the results of 13 On Farm Trials conducted at different locations in different districts of Uttaranchal and Uttar Pradesh stated that there were not much differences in grain yields due to transplanting or direct seeding (Singh *et al.*, 2002). In the eastern section of Indo-Gangetic Plain and to some extent in the *Tarai* areas of UP, the rainfall is received earlier than Haryana conditions. Since there is no shortage of water even in the month of June due to rains and also due to availability of irrigation water, the potential of direct seeded rice specially when seeded in the first week of June may be more in such situations like that of *Tarai* belt of UP than in Haryana conditions. In places like Bihar rains are also received in the first week of June, but the intensity of rain is not so high so as to facilitate puddling. In those situations rice can be seeded directly with or without tillage. In those situations the yield may remain same or more than the transplanted rice because the transplanting in rice is invariably delayed. Bridgit and Potty (2002) reported that in Kerala dry seeding of rice resulted in highest grain yield (6.5 t ha^{-1}), followed by wet seeding (4.7 t ha^{-1}) and transplanting (4.6 t ha^{-1}). Kandaswamy *et al.* (2001) also reported that transplanted rice under conservation tillage performed as good as under conventional tillage. The delay in the transplanting under situations of Bihar is also due to the fact that farmers start raising the nursery after the onset of rains in the end of June or beginning of July. Although, the demand for direct seeding may grow in future, but in present state of agronomic practices, the yield potential could not be exploited as has been realised in case of transplanted rice. Among agronomic practices, weed management, irrigation scheduling and seed rate have not been perfected.

Regarding water requirement exact figures can not be made available in the present study but direct seeded rice (DSR) matured 10-15 days earlier than the transplanted rice

(TR) but it may still of little more water than transplanted rice. Such studies need to be conducted at farmers' field.

The rising labour cost, increased availability of herbicides for direct seeded rice and demand for diversification, will be the driving force for the adoption of direct seeded rice. Due to shortage of labour or its increased cost farmers may have to resort to direct seeded rice in future. The unpuddled direct seeded rice both under zero-tillage or reduced tillage would require intensive research efforts, starting from developing of varieties for aerobic rice to whole range of new agronomic practices. The direct seeding technology, as an alternative to the transplanting method of rice establishment, however, could not be established in the farmers' field study.

5.2.2 Transplanted rice

In all, the crop establishment techniques seed to seed cycle was kept same. For example for direct seeded methods, the sowing was done on 5^{th}, 15^{th} and 25^{th} June while the nursery sowing for transplanting methods was also done on 5^{th}, 15^{th} and 25^{th} June and transplanting was done on 5^{th}, 15^{th} and July 25^{th}, respectively.

With puddling, one of the many issues which have been widely debated is the possible deterioration in the soil health. But under different rice cultures, retention of water to decrease percolation and weed management have been key component for adoption of puddled rice. The success of transplanting without any tillage operation or puddling was studied in the two environments with the detailed experiment at RRS, Karnal and another experiment with limited number of treatments at farmer's field. Field experiments conducted at RRS, Karnal and in village Dhons showed that the zero-tillage transplanted paddy had approximately same yield potential as the best existing practice of puddled-transplanting. An overall analysis of data in present study suggested similar yield potential of zero-till-transplanted rice to that of transplanted rice. The study does indicate that puddling may not be necessary for obtaining acceptable yield levels. This is evident from statistically similar yield level (average of 2002 & 2003) under treatments where transplanting was done without any tillage operation (6229 kg ha^{-1}) or with normal tillage but without puddling (6146 kg ha^{-1}) and under puddled situation (6066 kg ha^{-1}).

The transplanting with multiple cultivation and puddling did not bring about any significant gain in the yield of transplanted rice. The extent of tillage operation under unpuddled conditions were less than the puddling. The yield obtained under this treatment indicate that there could be distinct possibility for raising rice without puddling. The analysis of growth and yield attributes has shown that even preparatory cultivation may not be needed for realising higher yields in transplanted rice (Table 15).

The extensive use of puddling is likely to lead to disturbance of soil structure. There could be a need for change for double zero-tillage (ZT) in both rice and wheat. Since farmers are now faced with potential increase in cost of cultivation, introduction of such practices will help farmers not only economically but also to change their mindset in favour of unpuddled or zero-tilled rice.

Further in view of various soil properties, zero-till-transplanting rice has a scope but it has to be thoroughly evaluated at farmers' fields under situations comprising different soil types. Thanh (1993) observed that no-tillage soil had higher volumetric water content, water holding capacity and water infiltration while decreased bulk density as compared to ploughed soil. Hence higher grain yield under zero-till-transplant could be possible due to these reasons, which might have not only favoured quick establishment and better initial growth of the crop but also better efficacy of herbicides. Piggin *et al.* (2000) also reported that zero-tillage has potential to reduce costs and increase sustainability of irrigated rice culture, while maintaining the yield.

It is something like pandemonium in respect of change from transplanted rice (TR) to Direct Seeded Rice (DSR). The system can't be fueled by expectations. We are now fairly placed with respect to ideas that the rice can be successfully grown without puddling and zero-tillage transplanted rice is a distinct possibility. At the back of zero-tillage transplanted rice perhaps may inhibit its acceptance is the amount of water used for zero-till transplanted rice compared to puddled-transplanted rice. In the present investigation, the amount of water needed under this practices, was more than transplanting. There are certain issues which need to be put into practice which include the possibility of introducing paddy transplanter for zero-till transplanted rice (ZTTR). Farmers may be ready to accept this but still the question of the amount of water used need to be answered.

5.2.3 Weed Management

Current weed management practices available for rice are in favour of transplanted rice but not in favour of direct seeded rice. The practice of using herbicides in transplanted rice has been universally accepted but such herbicides are not effective for direct seeded rice. Lot of research has been done on evolving herbicides for direct seeded rice in South-East Asia and other countries but not much work has been done in India. The knowledge of basic biology and ecology of weeds in direct seeded or transplanted rice is essential for development of suitable weed management practices.

Moreover, herbicides recommended for transplanted rice are selective only for transplanted situation but not for direct seeded situations. There is a possibility of crop injury from the use of herbicides recommended for transplanted rice. Although some new herbicides are available for direct seeded rice but their potential has still not been adequately studied. In the absence of an acceptable chemical weed control strategy, the success of direct seeded rice is full of uncertainties.

Some of herbicides have been found successful in direct seeded rice. Singh and Malik (1995) evaluated XDE-537 (cyhalofop-butyl) against barnyard grass in direct seeded rice. Sangawan *et al.* (1996) evaluated cyhalofop butyl and other herbicides for the control of barnyard grass (*Echinochloa colonum* L.) in direct seeded rice. Singh *et al.*

(1995) evaluated KIH-2023 as a post-emergence graminicide for direct-seeded upland rice.

5.2.4 Varieties

The traditional technique of transplanting rice were combined with cultivar choice and other management practices. In the present study IR-64 and HKR-126 varieties were used under favour field trial. These varieties were evolved under anaerobic conditions. The performance of HKR-126 was better than IR-64 under all tillage options. The growth period of two varieties is different with HKR-126 taking approximately 132 days for maturity compared to 126 days for IR-64. For appropriate comparison, it is important to compare the varieties of same duration, hence it needs further studies. Introduction of direct seeded rice specially under unpuddled conditions would require tailoring of varieties for direct seeded under aerobic conditions.

5.2.5 Effects of Crop establishment techniques on yield of wheat

Experiment-I RRS, Uchani, (Karnal)

Research efforts during past have followed a commodity approach. In most studies, the reporting has always been on individual crop rather than a system approach. In the system approach, the yield should be evaluated on the basis of combined yield of both crops. The agronomic practices followed in one crop are likely to have their impact on the succeeding crop. In the present study the yield estimates of succeeding wheat crop indicate that puddling in rice has the tendency to adversely affect the yield of wheat. The yield of wheat following the treatment of zero-tillage in transplanting rice was 4.1q ha^{-1} more than the yield of wheat following the treatment of puddling. Although the monitoring was done only in 2003, but data do indicate that tillage options in rice may lead to variable cause and effect on the growth and yield of succeeding crop of wheat and vice-versa. Some work done on direct seeded in the *Tarai* belt does indicate that yield of wheat in more after direct seeded rice (Singh *et al.*, 2002). Hobbs *et al.* (1994) reported that puddling of soil alters physico-chemical properties of soil, which has adverse effect on the following wheat crop in rotation.

Experiment-II

Higher yield of wheat (5260 kg ha^{-1}) was obtained after zero-till-broadcast rice followed by zero-till-transplant rice followed by zero-till-transplant (5150 kg ha^{-1}). Lowest yield was recorded in puddled-transplant rice (4900 kg ha^{-1}) followed by puddled-broadcast (5070 kg ha^{-1}).

CHAPTER – VI

SUMMARY AND CONCLUSION

Two years field study was conducted at Regional Research Station, Karnal with six tillage options including zero-till-broadcasting, puddled-broadcast, zero-till-drill seeding, zero-till-transplant, puddled-transplant and unpuddled-transplant. The field studies were also conducted at village-Dhons (Kaithal) with two rice varieties under four tillage options comprising puddled-transplant, puddled-broadcast, zero-till-transplant and zero-till-broadcast. The summery of research results has been given as under.

Experiment-I: "Effect of resource conservation technologies on growth and yield of rice under different environments"

Growth and yield studies

1. The plant population per square metre remained significantly more in direct seeded rice compared to transplanted rice during both years.
2. The direct seeding or transplanting of rice on June 5th had significantly more number of plants per unit

area when compared to late seeding/transplanting of June 15th or June 25th.

3. The number of shoots per square metre at 90 DAS/60 DAT tended to remain higher in direct seeded method compared to transplanting.

4. When averaged over transplanting and direct seeding methods, dry matter of paddy at harvest was significantly more due to transplanting compared to direct seeding. At harvest, zero-till-transplant produced more dry weight of rice compared to puddled-transplanting.

5. The early June sowing/transplanting proved superior in respect of dry matter accumulation by the crop at different stages.

6. The plant height of paddy at harvest was significantly more under zero-till-transplanting compared to puddled-transplanting. Similarly earliest transplanting or direct seeding (June 5) had maximum plant height compared to other treatments.

7. The leaf area index (LAI) under zero-till-transplanting remained better than other treatments both at 90 DAS/60 DAT and at harvest. When averaged over direct seeding or transplanting methods,

transplanting of rice had more leaf area index than direct seeded of rice.

8. Transplanting of rice without tillage had significantly more number of effective tillers compared to puddled-transplant. When averaged over tillage methods, direct seeding of rice did not exhibit any positive impact on the effective tillers compared transplanted rice.

9. The number of effective tillers were more when direct seeding/transplanting was done on June 5^{th} compared to June 15^{th} or June 25^{th}. Such effects were more clear in 2002 but not in 2003.

10. The panicle length remained more when rice was raised by transplanting method compared to direct seeded rice. Within transplanting methods, the difference were, however, non-significant in both years.

11. The number of filled grains were significantly different between direct seeding methods and transplanting method. But the differences among transplanting methods remained non-significant.

12. Number of filled grains were maximum when seeding/transplanting done on June 5^{th}. The effect of

tillage methods remained non-significant in respect of unfilled grains per panicle.

13. Transplanting of rice produced heavier grain compared to direct seeding methods. The trend remained similar in both years.

Meteorological studies

14. The meteorological parameters was observed during the *Kharif* 2003 crop season was warmer than 2002 *Kharif* crop season.

15. Among the crop establishment techniques unpuddled-transplant technique has consumed more accumulated heat units, whereas lowest accumulated heat units were consumed by zero-till-broadcast establishment technique.

Economics

16. Highest gross return, & benefit: cost ration obtained by zero-till-transplant during both years 2002 and 2003 followed by zero-till-broadcast, zero-till-drill seeding and unpuddled-transplant. Among all the treatment puddled broadcast method was found to be least profitable.

Wheat yields

17. Wheat yields monitored during *Rabi* 2003-04 shows that higher yields were obtained in wheat sown after unpuddled-transplant rice followed by zero-till-broadcast and zero-till-drill seeding. Lowest of wheat yield was obtained after puddled rice.

Experiment-II: Performance of rice cultivars under different resource conservation techniques

Growth and yield studies

1. Broadcast methods were found superior to transplanting methods in Plant population at 60 DAS /30 DAT during 2002 and 2003 was higher under broadcast compared to transplanting. Variety HKR-126 retained higher population stand compared to IR-64.

2. Zero-till-broadcast followed by puddled broadcast recorded higher number of shoots per m^2 compared to zero-till-transplant and puddled-transplant treatments at 90 DAS/60DAT. HKR-126 and IR-64 varieties were found to be at par with respect to number of shoots per square metre.

3. Zero-till-broadcast at 30 DAS, zero-till-transplant at 90 DAS/60 DAT, and harvest were found superior to

other treatments. Dry matter accumulation was more in variety HKR-126 at all the crop growth stages.

4. Plant growth in terms of height was more under transplanting compared to the broadcasting. Rice variety HKR-126 attained significantly more height only at 90 DAS/60 DAT.

5. Maximum LAI was found at 90 DAS/60 DAT. Zero-till-transplant followed by puddled-transplant were superior to other methods of sowing in this respect. Variety HKR-126 statistically had more LAI at harvest only.

6. Transplanting treatment had less tillers than broadcast but had more panicle length, number of filled grains per panicle and 1000-grain weight and consequently higher grain and straw yield HKR-126 was found slightly superior to IR-64 in these respects.

7. Zero-till-transplant followed by puddled-transplant recorded greater biological yield and were statistically superior to puddled-broadcast and zero-till-broadcast methods. Varieties did not vary significantly in respect of biological yield except during the year 2002.

8. Wheat yields monitored during Rabi 2003-04 shows that higher yield obtained in wheat sown after zero-till-broadcast rice followed by zero-till-transplant rice. Lowest wheat yield was obtained after puddled-transplant rice.

Meteorological studies

9. The HKR-126 consumed more number of accumulated heat units, when compare to IR-64. Among the crop establishment techniques puddled broadcast techniques consumed more number of accumulated heat units whereas lowest accumulated heat units were consumed by rice crop under zero-till-broadcast technique.

Conclusion

Two years field studies were conducted at Chaudhary Charan Singh Haryana Agricultural University's Regional Research Station, Uchani (Karnal) and at farmers field at village Dhons (Kaithal) with a major objective of exploring the opportunities of resource conservation techniques in rice. The results show that in order to increase system productivity zero-till-transplanting or unpuddled-transplanting can be an alternative proposition in place of puddled-transplant. Compared with traditional method of puddled-transplanting, direct seeding of rice did not exhibit any advantage. Both options i.e. zero-tillage and direct seeding of rice need further studies at farmers' field.

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APPENDIX-IA

Data related to irrigation schedule to various crop establishment technique treatments of rice crop in farmers field at village, Dhons during Kharif 2002

Treatment 1 Crop establishment **Puddled-transplant**

Irrigation details

Irrigation No.	Date	Source	Time (HR:Min)
1	14-Jul-2002	Tubewell	10.30
2	15-Jul-2002	Tubewell	2.30
3	16-Jul-2002	Tubewell	4.10
4	17-Jul-2002	Tubewell	4.30
5	18-Jul-2002	Tubewell	3.30
	19-Jul-2002		
6	20-Jul-2002	Tubewell	4.40
7	21-Jul-2002	Tubewell	4.20
8	22-Jul-2002	Tubewell	3.30
	23-Jul-2002		
9	24-Jul-2002	Tubewell	3.30
10	25-Jul-2002	Tubewell	4.10
	26-Jul-2002		
11	27-Jul-2002	Tubewell	3.30
12	28-Jul-2002	Tubewell	3.50
	29-Jul-2002		
13	30-Jul-2002	Tubewell	3.30
	31-Jul-2002		
14	1-Aug-2002	Tubewell	3.45
	2-Aug-2002		
15	3-Aug-2002	Tubewell	2.30
16	4-Aug-2002	Tubewell	3.30
	5-Aug-2002		
17	6-Aug-2002	Tubewell	4.00
	7-Aug-2002		
18	8-Aug-2002	Tubewell	3.30
	9-Aug-2002		
19	10-Aug-2002	Tubewell	4.00
	11-Aug-2002		
20	12-Aug-2002	Tubewell	3.30
	13-Aug-2002		
	14-Aug-2002		
21	15-Aug-2002	Tubewell	4.0
	16-Aug-2002		
22	17-Aug-2002	Tubewell	3.30
23	18-Aug-2002	Tubewell	4.15
	19-Aug-2002		
24	20-Aug-2002	Tubewell	3.30
	21-Aug-2002		
	22-Aug-2002		
25	23-Aug-2002	Tubewell	4.15
	24-Aug-2002		
26	25-Aug-2002	Tubewell	4.30
	26-Aug-2002		
	27-Aug-2002		
	28-Aug-2002		
27	29-Aug-2002	Tubewell	4.45
	30-Aug-2002		
	31-Aug-2002		
	1-Sep-2002		
	2-Sep-2002		
	3-Sep-2002		
28	4-Sep-2002	Tubewell	4.00
	5-Sep-2002		
	6-Sep-2002		
	7-Sep-2002		
29	8-Sep-2002	Tubewell	4.30
	9-Sep-2002		
	10-Sep-2002		
	11-Sep-2002		
	12-Sep-2002		
	13-Sep-2002		
	14-Sep-2002		
	15-Sep-2002		
	16-Sep-2002		
	17-Sep-2002		
	18-Sep-2002		
	19-Sep-2002		
	20-Sep-2002		
	21-Sep-2002		
30	22-Sep-2002	Tubewell	5.15
	23-Sep-2002		
	24-Sep-2002		
	25-Sep-2002		
	26-Sep-2002		
31	27-Sep-2002	Tubewell	4.30
	28-Sep-2002		
	29-Sep-2002		
32	30-Sep-2002	Tubewell	5.30
	1-Oct-2002		
	2-Oct-2002		
	3-Oct-2002		
33	4-Oct-2002	Tubewell	6.00
	5-Oct-2002		
	6-Oct-2002		
34	7-Oct-2002	Tubewell	5.15
	8-Oct-2002		
	9-Oct-2002		
35	10-Oct-2002	Tubewell	6.30
	11-Oct-2002		
	12-Oct-2002		
	13-Oct-2002		
36	14-Oct-2002	Tubewell	7.30
	15-Oct-2002		
	16-Oct-2002		
37	17-Oct-2002	Tubewell	8.00
	18-Oct-2002		
	19-Oct-2002		
	20-Oct-2002		

APPENDIX-IB

Treatment 2
Crop establishment : **Puddled-broadcast**

Irrigation details

Irrigation No.	Date	Source	Time (HR:Min)
1	14-Jun-2002	Tubewell	8.40
	15-Jun-2002		
2	16-Jun-2002	Tubewell	7.20
	17-Jun-2002		
3	18-Jun-2002	Tubewell	6.15
	19-Jun-2002		
	20-Jun-2002		
4	21-Jun-2002	Tubewell	5.30
	22-Jun-2002		
	23-Jun-2002		
5	24-Jun-2002	Tubewell	6.10
	25-Jun-2002		
	26-Jun-2002		
	27-Jun-2002		
6	28-Jun-2002	Tubewell	6.30
	29-Jun-2002		
	30-Jun-2002		
7	1-Jul-2002	Tubewell	6.10
	2-Jul-2002		
8	3-Jul-2002	Tubewell	8.15
	4-Jul-2002		
	5-Jul-2002		
	6-Jul-2002		
	7-Jul-2002		
9	8-Jul-2002	Tubewell	6.30
	9-Jul-2002		
	10-Jul-2002		
10	11-Jul-2002	Tubewell	6.10
	12-Jul-2002		
11	13-Jul-2002	Tubewell	4.40
12	14-Jul-2002	Tubewell	2.30
13	15-Jul-2002	Tubewell	3.10
14	16-Jul-2002	Tubewell	2.10
15	17-Jul-2002	Tubewell	2.30
16	18-Jul-2002	Tubewell	3.20
	19-Jul-2002		
17	20-Jul-2002	Tubewell	4.30
18	21-Jul-2002	Tubewell	3.20
	22-Jul-2002		
	23-Jul-2002		
	24-Jul-2002		
19	25-Jul-2002	Tubewell	4.30
	26-Jul-2002		
20	27-Jul-2002	Tubewell	3.30
21	28-Jul-2002	Tubewell	4.10
	29-Jul-2002		
	30-Jul-2002		
22	31-Jul-2002	Tubewell	5.30
	1-Aug-2002		
	2-Aug-2002		
	3-Aug-2002		
	4-Aug-2002		
23	5-Aug-2002	Tubewell	5.20
	6-Aug-2002		
	7-Aug-2002		
	8-Aug-2002		
24	9-Aug-2002	Tubewell	4.30
	10-Aug-2002		
	11-Aug-2002		
25	12-Aug-2002	Tubewell	5.00
	13-Aug-2002		
	14-Aug-2002		
26	15-Aug-2002	Tubewell	4.30
	16-Aug-2002		
27	17-Aug-2002	Tubewell	5.15
	18-Aug-2002		

Irrigation No.	Date	Source	Time (HR:Min)
	19-Aug-2002		
28	20-Aug-2002	Tubewell	4.30
	21-Aug-2002		
	22-Aug-2002		
29	23-Aug-2002	Tubewell	5.30
	24-Aug-2002		
	25-Aug-2002		
	26-Aug-2002		
30	27-Aug-2002	Tubewell	5.45
	28-Aug-2002		
	29-Aug-2002		
	30-Aug-2002		
	31-Aug-2002		
	1-Sep-2002		
	2-Sep-2002		
	3-Sep-2002		
31	4-Sep-2002	Tubewell	6.00
	5-Sep-2002		
	6-Sep-2002		
32	7-Sep-2002	Tubewell	5.30
	8-Sep-2002		
	9-Sep-2002		
	10-Sep-2002		
	11-Sep-2002		
	12-Sep-2002		
	13-Sep-2002		
	14-Sep-2002		
	15-Sep-2002		
	16-Sep-2002		
	17-Sep-2002		
	18-Sep-2002		
	19-Sep-2002		
	20-Sep-2002		
	21-Sep-2002		
	22-Sep-2002		
	23-Sep-2002		
33	24-Sep-2002	Tubewell	6.15
	25-Sep-2002		
	26-Sep-2002		
	27-Sep-2002		
	28-Sep-2002		
	29-Sep-2002		
	30-Sep-2002		
	1-Oct-2002		
34	2-Oct-2002	Tubewell	8.30
	3-Oct-2002		
	4-Oct-2002		
	5-Oct-2002		
	6-Oct-2002		
	7-Oct-2002		
35	8-Oct-2002	Tubewell	7.30
	9-Oct-2002		
	10-Oct-2002		
	11-Oct-2002		
36	12-Oct-2002	Tubewell	8.00
	13-Oct-2002		
	14-Oct-2002		
	15-Oct-2002		
	16-Oct-2002		
37	17-Oct-2002	Tubewell	8.30
	18-Oct-2002		
	19-Oct-2002		
	20-Oct-2002		

APPENDIX-IC

Treatment 3 Crop establishment : **Zero-till-transplant**

Irrigation details

Irrigation No.	Date	Source	Time (HR:Min)
1	12-Jul-2002	Tubewell	8.40
	13-Jul-2002		
2	14-Jul-2002	Tubewell	3.30
3	15-Jul-2002	Tubewell	4.20
4	16-Jul-2002	Tubewell	4.30
5	17-Jul-2002	Tubewell	6.00
6	18-Jul-2002	Tubewell	8.00
	19-Jul-2002		
7	20-Jul-2002	Tubewell	5.00
8	21-Jul-2002	Tubewell	4.30
9	22-Jul-2002	Tubewell	5.10
	23-Jul-2002		
10	24-Jul-2002	Tubewell	5.00
11	25-Jul-2002	Tubewell	5.10
	26-Jul-2002		
12	27-Jul-2002	Tubewell	4.50
13	28-Jul-2002	Tubewell	6.0
	29-Jul-2002		
	30-Jul-2002		
14	31-Jul-2002	Tubewell	5.30
15	1-Aug-2002	Tubewell	5.30
	2-Aug-2002		
	3-Aug-2002		
	4-Aug-2002		
16	5-Aug-2002	Tubewell	7.30
	6-Aug-2002		
17	7-Aug-2002	Tubewell	5.30
	8-Aug-2002		
18	9-Aug-2002	Tubewell	5.15
	10-Aug-2002		
19	11-Aug-2002	Tubewell	5.00
	12-Aug-2002		
	13-Aug-2002		
	14-Aug-2002		
20	15-Aug-2002	Tubewell	5.15
	16-Aug-2002		
	17-Aug-2002		
21	18-Aug-2002	Tubewell	5.05
	19-Aug-2002		
	20-Aug-2002		
	21-Aug-2002		
	22-Aug-2002		
	23-Aug-2002		
22	24-Aug-2002	Tubewell	5.30
	25-Aug-2002		
	26-Aug-2002		
23	27-Aug-2002	Tubewell	6.15
	28-Aug-2002		
	29-Aug-2002		
	30-Aug-2002		
24	31-Aug-2002	Tubewell	5.30
	1-Sep-2002		
	2-Sep-2002		

Irrigation No.	Date	Source	Time (HR:Min)
	3-Sep-2002		
	4-Sep-2002		
25	5-Sep-2002	Tubewell	5.45
	6-Sep-2002		
	7-Sep-2002		
26	8-Sep-2002	Tubewell	5.30
	9-Sep-2002		
	10-Sep-2002		
	11-Sep-2002		
	12-Sep-2002		
	13-Sep-2002		
	14-Sep-2002		
	15-Sep-2002		
	16-Sep-2002		
	17-Sep-2002		
	18-Sep-2002		
	19-Sep-2002		
	20-Sep-2002		
	21-Sep-2002		
	22-Sep-2002		
	23-Sep-2002		
27	24-Sep-2002	Tubewell	5.45
	25-Sep-2002		
	26-Sep-2002		
	27-Sep-2002		
	28-Sep-2002		
	29-Sep-2002		
28	30-Sep-2002	Tubewell	9.30
	1-Oct-2002		
	2-Oct-2002		
	3-Oct-2002		
	4-Oct-2002		
	5-Oct-2002		
29	6-Oct-2002	Tubewell	8.30
	7-Oct-2002		
	8-Oct-2002		
	9-Oct-2002		
30	10-Oct-2002	Tubewell	8.00
	11-Oct-2002		
	12-Oct-2002		
	13-Oct-2002		
31	14-Oct-2002	Tubewell	9.00
	15-Oct-2002		
	16-Oct-2002		
32	17-Oct-2002	Tubewell	8.30
	18-Oct-2002		
	19-Oct-2002		
	20-Oct-2002		

APPENDIX-ID

Treatment 4 Crop establishment : zero to broadcast

Irrigation details

Irrigation No.	Date	Source	Time (HR:Min)
1	14-Jun-2002	Tubewell	8.10
	15-Jun-2002		
2	16-Jun-2002	Tubewell	6.15
	17-Jun-2002		
3	18-Jun-2002	Tubewell	5.45
	19-Jun-2002		
	20-Jun-2002		
4	21-Jun-2002	Tubewell	5.25
	22-Jun-2002		
5	23-Jun-2002	Tubewell	5.10
	24-Jun-2002		
	25-Jun-2002		
6	26-Jun-2002	Tubewell	6.30
	27-Jun-2002		
	28-Jun-2002		
	29-Jun-2002		
	30-Jun-2002		
	1-Jul-2002		
7	2-Jul-2002	Tubewell	6.10
	3-Jul-2002		
	4-Jul-2002		
	5-Jul-2002		
	6-Jul-2002		
8	7-Jul-2002	Tubewell	5.20
	8-Jul-2002		
	9-Jul-2002		
	10-Jul-2002		
	11-Jul-2002		
	12-Jul-2002		
	13-Jul-2002		
9	14-Jul-2002	Tubewell	8.30
	15-Jul-2002		
10	16-Jul-2002	Tubewell	6.20
	17-Jul-2002		
11	18-Jul-2002	Tubewell	7.00
	19-Jul-2002		
	20-Jul-2002		
	21-Jul-2002		
12	22-Jul-2002	Tubewell	6.30
	23-Jul-2002		
	24-Jul-2002		
13	25-Jul-2002	Tubewell	6.40
	26-Jul-2002		
	27-Jul-2002		
14	28-Jul-2002	Tubewell	6.30
	29-Jul-2002		
15	30-Jul-2002	Tubewell	5.30
	31-Jul-2002		
16	1-Aug-2002	Tubewell	5.20
	2-Aug-2002		
	3-Aug-2002		
	4-Aug-2002		
	5-Aug-2002		
17	6-Aug-2002	Tubewell	5.30
	7-Aug-2002		
	8-Aug-2002		
	9-Aug-2002		
18	10-Aug-2002	Tubewell	5.15
	11-Aug-2002		
	12-Aug-2002		
	13-Aug-2002		
	14-Aug-2002		
19	15-Aug-2002	Tubewell	5.30
	16-Aug-2002		
	17-Aug-2002		
	18-Aug-2002		

Irrigation No.	Date	Source	Time (HR:Min)
20	19-Aug-2002	Tubewell	5.00
	20-Aug-2002		
	21-Aug-2002		
	22-Aug-2002		
21	23-Aug-2002	Tubewell	5.15
	24-Aug-2002		
	25-Aug-2002		
	26-Aug-2002		
	27-Aug-2002		
	28-Aug-2002		
22	29-Aug-2002	Tubewell	5.30
	30-Aug-2002		
	31-Aug-2002		
	1-Sep-2002		
	2-Sep-2002		
	3-Sep-2002		
23	4-Sep-2002	Tubewell	5.30
	5-Sep-2002		
	6-Sep-2002		
24	7-Sep-2002	Tubewell	5.30
	8-Sep-2002		
	9-Sep-2002		
	10-Sep-2002		
	11-Sep-2002		
	12-Sep-2002		
	13-Sep-2002		
	14-Sep-2002		
	15-Sep-2002		
	16-Sep-2002		
	17-Sep-2002		
	18-Sep-2002		
	19-Sep-2002		
	20-Sep-2002		
	21-Sep-2002		
	22-Sep-2002		
	23-Sep-2002		
25	24-Sep-2002	Tubewell	5.15
	25-Sep-2002		
	26-Sep-2002		
	27-Sep-2002		
	28-Sep-2002		
	29-Sep-2002		
	30-Sep-2002		
	1-Oct-2002		
26	2-Oct-2002	Tubewell	8.15
	3-Oct-2002		
	4-Oct-2002		
	5-Oct-2002		
27	6-Oct-2002	Tubewell	7.30
	7-Oct-2002		
	8-Oct-2002		
28	9-Oct-2002	Tubewell	8.30
	10-Oct-2002		
	11-Oct-2002		
	12-Oct-2002		
	13-Oct-2002		
29	14-Oct-2002	Tubewell	9.00
	15-Oct-2002		
	16-Oct-2002		
30	17-Oct-2002	Tubewell	8.30
	18-Oct-2002		
	19-Oct-2002		
	20-Oct-2002		

Annexure II: **Cost of cultivation of Paddy (Rs. Per acre) during 2002 and 2003 of experiment I at Regional Research Station, Uchani, Karnal**

Operation	Detail	Rate (Rs.)	Zero till-Broadcast	Puddled-Broadcast	Zero-till sowing	Zero-till-transplant	Puddled-transplant	Unpuddled-transplant
1. Preparatory tillage								
Disc harrow	3	175	—	525	—	—	525	525
Planking	2	70	—	140	—	—	140	140
2. Presowing irrigation	1	200	200	200	200	200	200	200
3. Puddling cultivator	2	300	—	600	—	—	600	—
Disc narrow	3	175	—	-	—	—	—	525
Planking	2	70	—	140	—	—	140	140
4. Nursery raising (including labour, seed, seed treatment etc.,)	—	—	—	—	—	500	500	500
5. Broadcasting/zero-till drill sowing	—	—	212	212	387	—	—	—
6. Transplanting	—	—	—	—	—	450	450	450
7. Herbicide	—	—	390	390	390	390	390	390
8. Bund making one labour	1	80	80	80	80	80	80	80
9. Fertilizer DAP (24 kg P_2O_5)	—	16.10	386	386	386	386	386	386
Urea (51 kg/acre)	—	10.50	536	536	536	536	536	536
(9 kg through DAP)								
10. Fertilizer application	1	80	80	80	80	80	80	80
11. Hand weeding	—	—	640	320	640	640	320	320
12. Irrigations	20	165	3300	3300	3300	3300	3300	3300
13. Plant Protection	—	—	600	600	600	600	600	600
14. Harvesting/Threshing/winnowing	—	—	900	900	900	900	900	900
15. Rent	—	—	712	712	712	712	712	712
16. Miscellaneous	—	—	400	400	400	400	400	400
Grant total (cost per acre)	—	—	8436	9521	8611	9174	10259	10184
Cost per hectare	—	—	21090	23802	21528	22938	25648	25460

ABSTRACT

Title of Thesis	:	**Crop establishment techniques in rice under different environments in Haryana**
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Admission No.	:	2000A14D
Title of Degree	:	Doctor of Philosophy
Name and Address of Major Advisor	:	**Dr. R.K. Malik** Professor (Weed Science) & Head Agronomy, Dean, Post-Graduate Studies CCS Haryana Agricultural University, Hisar-125004, INDIA
Degree Awarding University	:	CCS Haryana Agricultural University, Hisar-125004 (Haryana) India.
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Key words: Rice, zero-till, puddling, Broadcasting, Unpuddled, Variety.

To study the effect of resource conservation techniques on the growth and yield of paddy a field investigation entitled, "Crop establishment techniques in rice under different environments in Haryana" was conducted during *Kharif* seasons of 2002 and 2003. Crop establishment methods experiment at RRS, Uchani (Karnal) comprised of zero-till-broadcast, puddled-broadcast, zero-till-drill seeding, zero-till-transplant, puddled-transplant and unpuddled-transplant under three times of seeding/transplanting. Similarly, an experiment was also conducted at farmer's field with two rice cultivars (HKR126 and IR64) under four crop establishment techniques including puddled-transplant, puddled-broadcast, zero-till-transplant and zero-till-broadcast. Based on these studies, it was realized that the plant population was more in direct seeded rice but the leaf area index remained more in transplanted rice. Irrespective of tillage options, the growth of paddy at farmers field also indicated that the leaf area index and dry matter production at harvest remained more under transplanted rice. The differences between three methods of transplanting at Regional Research Station, Karnal and two

methods of transplanting at farmers field were marginal with a mean yield advantage of 2.72 and 0.42% due to zero tillage-transplanting compared to conventional transplanting. The grain yield of HKR-126 and of IR-64 were 6158, 5824 kg ha^{-1} in zero till transplant and puddled transplant, respectively. Wheat yield after different treatments under rice were also monitored in subsequent rabi season of 2003-04 in both the experiments at RRS, Uchani (Karnal) and at farmer's field. Two distinct tillage systems, in respect of direct seeding or transplanting had a variable effect on yield of wheat. Wheat yields were lower in the plots of puddled rice than the unpuddled rice. Irrespective of tillage systems, transplanting of rice proved superior over direct seeding of rice. As far as system productivity is concerned, tillage system irrespective of method of seeding had significant impact on the yield of both rice and wheat. When taken together, zero-till-transplanting and unpuddled transplanting method are suggested as priorities for further research to increase the productivity of rice-wheat cropping system as a whole. The research on the different soil types, improved water and nutrient management will be needed before making final recommendations for acceptance by farmers.

In Experiment-I, among the crop establishment techniques, unpuddled transplant technique consumed more accumulated heat units. In experiment-II among the different crop establishment techniques puddled broadcast technique consumed more accumulated heat units. Variety HKR-126 consumed more number of accumulated heat units than IR-64.

Highest gross return and benefit:cost ratio was obtained by zero-till-transplant and puddled broadcast found to be [1] ast-profitable during both years.

MAJOR ADVISOR

16/10/04

SIGNATURE OF STUDENT

HEAD OF THE DEPARTMENT