COMPETITIVE ABILITY AND ALLELOPATHIC POTENTIAL OF RICE CULTIVARS AGAINST WEEDS

Thesis

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By

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CERTIFICATE

This is to certify that the thesis entitled **"COMPETITIVE ABILITY AND ALLELOPATHIC POTENTIAL OF RICE CULTIVARS AGAINST WEEDS"** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** with major in **PLANT PHYSIOLOGY** and minor in **MOLECULAR BIOLOGY AND BIOTECHNOLOGY** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona-fide* research carried out by **Ms. PRATIBHA SINGH, Id. No. 32927**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

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C E R T I F I C A T E

We, the undersigned, members of the Advisory Committee of **Ms. Pratibha Singh, Id. No. 32927**, a candidate for the degree of **Doctor of Philosophy** with major in **Plant Physiology** and minor in **Molecular Biology and Biotechnology**, agree that the thesis entitled **“COMPETITIVE ABILITY AND ALLELOPATHIC POTENTIAL OF RICE CULTIVARS AGAINST WEEDS”** may be submitted in partial fulfilment of the requirements for the degree.

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ABBREVIATIONS

µg	Microgram
A	Area
CGR	Crop growth rate
cm	Centimeter
cm^2	Centimeter square
CRC	Crop Research Centre
CRD	Complete randomized design
CWCI	Crop weed competitive index
d	Days
DAT	Days after transplanting
DMP	Dry matter production
dw	Dry weight
fw	Fresh weight
g	Gram
h	Hour
HPLC	High pressure liquid chromatography
L	Liter
LAI	Leaf area index
LAR	Leaf area ratio
LWR	Leaf weight ratio
m	Meter
m^2	Meter square
mg	Milligram
min	Minute
ml	milliliter
NAR	Net assimilation rate
pH	Hydrogen ion concentration
ppm	Per Particle million
RGR	Relative growth rate
RLAGR	Relative leaf area growth rate
RLGR	Relative leaf growth rate
SLA	Specific leaf area
SLW	Specific leaf weight
SPD	Split plot design
WAT	Week after transplanting
WSA	Weed suppression ability
	WT Weed tolerance

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Introduction

Chapter 1 INTRODUCTION

Rice is the staple food for billions of people around the world, mainly rice growing about the largest single use of land for producing food, covering about 9% of the earth's arable land. Rice provides 21% of global human per capita energy and 15% of per capita protein (Anonymous, 2002a). Asia accounts for over 90% of the world's production of rice, with China, India and Indonesia producing the most (Anonymous, 2004). Rice belongs to the genus *Oryza* and has two cultivated and 22 wild species. The cultivated species are *Oryza sativa* and *Oryza glaberrima. Oryza sativa* is grown all over the world while *Oryza glaberrima* has been cultivated in West Africa for the last ~3500 years (Anonymous, 2001a). Rice is grown under many different conditions and production systems, that includes 57% grown on irrigated land, 25% on rainfed lowland, 10% on the uplands, 6% in deep water, and 2% in tidal wet lands (Chopra and Prakash, 2002).

In India rice is provincial food crop contributing about 40 per cent to total food grain production of the country. It is grown in a complex range of very different environment, from uplands at altitudes of 3000 m to rainfed low land, irrigated, tidal swamp and deep water areas. In India, rice is grown in two main seasons i.e. wet season (kharif) and dry season (rabi). In wet season it is sown during May-June. Delay in sowing reduces grain yield and seed quality because of poor seed setting and biotic stress due to high temperature and high humidity at flowering (Arumugam *et al.*, 2008).

Weeds are a major cause of yield reduction in almost all the production systems world wide. Losses caused by weeds vary from one country to another, depending on the predominant weed flora and on the control methods practiced by farmers. In China, 10 million tones (mt) of rice are lost annually due to weed competition (Zhang, 2001), such a huge quantity of rice is sufficient to feed at least 56 million people for one year. In Sri Lanka, a country considered self sufficient in rice; weeds are the major biotic stress in rice production which account for about 30-40 per cent of yield losses (Abeysekera and Anuruddhika, 2001). Weeds are the greatest yield limiting constraint to upland or aerobic rice, contributing about 50% to yield gaps, followed in importance by N-deficiency, pests and disease (Anonymous, 1996a). Weeds are estimated to cause rice yield losses of 35% in tropics (Oerke and Dehne, 2004) but losses can be much greater in aerobic rice or upland rice crop. Because upland rice is usually subject to much higher weed pressure than flooded rice (Balasubramanium and Hill, 2002). In the upland rice ecosystem, yield loss estimates from weed infestation range from 30 to 100 per cent (Hassan *et al.,* 1994; Pandey and Pingali, 1996; Jensen *et al.,* 2001).

The main weed control method in rice in Asian countries has been a combination of herbicides and manual weeding combined with water management. Upland rice growers usually hand weed their crops two to three times per season, investing up to 190 person days ha^{-1} (Roder, 2001). Hand weeding is complicated by the morphological similarity of rice and grassy weed seedlings (Moody, 1983).

Herbicide based weed management is becoming most popular and have proven effective in many cases. But intensive herbicide use can cause environmental contamination, pose a threat to the farmers health and in many cases, has lead to the development of herbicide resistance (Carey *et al.,* 1995; Fischer and Ramirez, 1993; Lemerle *et al.,* 2001; Valverde *et al.,* 2000). The most common herbicides used to control weeds in rice are butachlor, pretilachlor and 2,4-D.

The major weed flora of rice in *tarai* regions includes a broad range of monocot and broad leaved weeds such as *Echinochloa crusgalli, Echinochloa colona, Leptochloa chinensis, Ischaemum rugosum, Caesulia axillaris, Commelina benghalensis, Frimbristylis miliaceae, Cyperus rotundus, Cyperus iria* and *Cyperus difformis Alternanthera sessilis* (Anonymous, 2008).

Echinochloa weed species are a major constraint to rice production world wide. These weeds are widely associated with rice and the damage they cause to the crop is permanent. *Echinochloa* spp. have the capacity to adopt mimetic forms to rice with the result that their control by manual weeding is very difficult.

As herbicide application certainly controls several weeds, but does not eliminate others, thereby it provokes a weed shift towards tolerant species. Some herbicides if not properly used may cause problems of phytotoxicity sometimes with irreversible effects on the crop plants. Experience shows that although herbicide use has increased productivity, there are several weed problems that remain unsolved and for which other solutions need to be developed and implemented (Labrada, 1996). Using competitive varieties to suppress weeds might substantially reduce herbicide use and labor costs, permitting weeds to be controlled with a single herbicide application or hand weeding. Competitive cultivars may, therefore, be an important component of integrated weed management strategies (Pester *et al.,* 1999; Fischer *et al.,* 2001; Lemerle *et al.,* 2001).

Cultivar weed competitiveness is a function of weed tolerance, or the ability to maintain high yields despite weed competition and weed suppressive ability, or the ability to reduce weed growth through competition (Jannink *et al.,* 2000). Cultivar differences in weed suppressive ability are determined by assessing variation in weed biomass in plots under weed competition. Jannink *et al.* (2000) and Jordan (1993) advocated breeding for weed suppressive ability over weed tolerance, because suppressing weeds reduces weed seed production and benefits weed management in the future, while tolerating weeds only benefits the current growing season and may result in increased weed pressure from unsuppressed weeds. Competitive ability of rice cultivars can stem from their morpho-physiological characteristics influencing their growth patterns such as early vigour, leaf size, plant height tillering ability, faster growth rates etc. as well as from their alleopathic ability or from a combination of both the parameters (Grace, 1990; Kropff *et al.,* 1995; Caton *et al.,* 1999; Moolsri *et al.,* 1999). Rice cultivars that compete well against weeds are often thought to be tall and rapid in early growth and have droopy leaves and high specific leaf area. These traits have been linked to low yield potential in some studies (Jennings and Aquino, 1968; Jennings and De-Jesus, 1968; Jennings and Herrera, 1968; Kawano *et al.,* 1974) but not in other (Garrity *et al.,* 1992; Ni *et al.,* 2000; Fischer *et al.,* 2001). Evidence that there may be no trade off between yield and weed competitiveness has aroused interest in breeding for cultivars that combine high yield and weed suppressive ability.

Improving the competitive ability of crops might reduce the dependency on herbicides. Competitive ability is the weighted sum of the contributions of a range of traits. These traits are not only genetically controlled but also, to a large extent, affected by the environment in which the plant is grown. Genetics and environment together determine the competitive rice cultivar requires the identification of key traits conferring competitive ability that can be used as selection criteria by breeders (Pester *et al.,* 1999). Competitive ability in rice often associated with traits related to light capture (Khush, 1996). Plant height can be highly correlated with competitive ability (Jennings and Aquino, 1968) but is not always important. Fischer *et al.* (1997) associated leaf area index (LAI) and tiller production, but not height, with the competitive ability of irrigated rice cultivars. Leaf area and leaf weight were associated with the ability of upland rice cultivars to compete with weeds under green house conditions (Fischer *et al.,* 1995). Garrity *et al.* (1992) reported substantial differences in competitive ability among cultivars of the same height. Johnson *et al.* (1998) reported that in rice most competitive cultivar had larger leaf weight, greater specific leaf area and earlier production of tillers than less competitive cultivars. The growth analysis of both crop and weeds particularly during the earlier stages is essential to determine the critical stages of crop weed competitions. Physiological growth parameters such as RGR, LAI, SLW, NAR indicates different aspects of plant growth with respect to time Physiological analysis of growth has been carried out to compare their growth and competitiveness of wheat with wild oat (Thomas and Yaduraju, 2000).

When plants grow together, they compete with each other both physically and chemically. Traditionally, such competition has been divided into plant competition and allelopathy. Competition has been defined as sharing the same limited resources, such as space, light, water and nutrients, whereas allelopathy is understood as the effect of chemical interactions between plants.

Lambers *et al.* (1998), defined allelopathy as the growth suppression of one plant species by another due to the release of toxic compounds. Allelopatthy is defined as biochemical interactions among plants through the release of chemical compounds into the environments showing either negative or positive effects (Rice, 1984). Chemicals with allelopathic potential are present in almost all plants and in many tissues like leaves, stems, flowers, fruits, seeds and roots (Putnam, 1988). Under specific conditions, these chemicals are released into the environment (atmosphere or rhizosphere) by various means such as volatilization, leaching, decomposition of plant residues and plant (Rice, 1984; Putnam and Tang, 1986). It may cause reduction in plant emergence or growth, reducing their performance in the association. The allelochemical production and releases are influenced by abiotic and biotic factors such as plant age, temperature light and soil conditions, microflora, nutritional status and herbicide treatments (Duke, 1985; Hoagland and Williams, 1985). In particular, the importance of fluctuations with plant age need to be investigated in order to develop weed management strategies that use allelopathy at the right time to the season. Moreover, allelopthy needs to be expressed at an early stage of development when weed control is most important. A large number of rice varieties have been found to inhibit the growth of several plant species, when the rice varieties were grown together with the plants under field and or laboratory conditions (Dilday *et al.,* 1998; Hassan *et al.,* 1998; Olofsdotter *et al.,* 1999). These findings suggest that living rice may produce and release allelochemicals into the neighboring environment.

A number of secondary metabolites, phenolic acids, phenylalkanoic acids, hydroxamic acids, fatty acids, terpenes and indoles, were identified in rice extracts (Rimando and Duke, 2003). These compounds are ubiquitous in plants and some of these compounds have growth inhibitory activity against several plant species. It is not clear, that whether these compounds are released from living rice plants into the neighboring environment and act as allelochemicals in natural ecosystems. In addition, it was found that there was no significant correlation between the level of growth inhibitory substance in plants and their level in the root exudates (Wu *et al.,* 2001).

Wu *et al.* (1999) reported the possibilities of genetically improving crops with allelopathic potential and stated that allelopathy can play an important role in future weed management. Rice has thus become a model plant in successful progress towards using allelopathic rice cultivars for weed management. Allelopathy in rice could be used as a method for biological control of weeds in the rice ecosystems. The allelopathic affect of rice it self on weeds could be applied to reduce use of chemical herbicides which might result in improved water quality and less environmental contamination. It is well known that the crop residue left in soil are sometimes harmful to plant growth. The plant residues in soil could release phytotoxic acids. 2-hydroxyphenyl acetic acid, 4-hydroxybenzoic acid, vanillic acid, p-coumaric acid and ferulic acid were found in aqueous extracts of decomposing rice residues (Chou and Lin, 1976) and in soil from paddy fields where rice was grown (Chou and Chiou, 1979).

Kuwatsuka and Shindo (1973) isolated 13 different phenolic acids in decomposition of rice straw. They found that p-caumaric acid was released in the greatest amount from decomposing rice straw. Thus, a new approach of using rice straw for controlling weeds in different crops have been suggested by Mendoza and Samson (1999) who indicated that rice straw can be used for mulching, which benefits in prevent weed growth as well as supplies organic matter for N-fixation by heterotrophic N-fixing microorganisms, which could be observed by succeeding crop (Patnaik, 1978). The discovery of some rice cultivars capable of suppressing germination and development of weeds under field condition with something more likely to be chemical interaction than competition was the starting point for rice allelopathy research (Dilday *et al.,* 1991).

The laboratory and field experiments together can only quantify the importance of and reveal the interactions between different competition variables such as physical and chemical interference, including allelopathy that can play a role in weed management.

Keeping this in view the present investigation is undertaken with the following objectives :

1. To screen cultivars of rice for their competitive ability against weeds based on morpho-physiological parameters in a field experiment.
2. To study the effect of rice straw residues on controlling weed growth and the yield of rice plants under field conditions.
3. To study the effect of synthetic phenolic compounds and rice-allelochemicals on the germination and growth of weed seeds in pertidishes, pot cultures and hydroponics.
4. Biochemical characterization of allelochemicals produced by rice through HPLC or (chromatography).

Review of Literature

2.1 Rice crop

"Rice is life", is drawn from the understanding that rice-based systems are essential to everyone, directly or indirectly, for food security, poverty alleviation and global peace (Anonymous, 2004).

Rice is the staple food for more than half of the world population. In Asia, alone, more than 2,000 million people obtained 60 to 70 per cent of their calorie intake from rice and its products. Rice based production systems and their associated post harvest operations employ nearly 1,000 million people in rural areas of developing countries. About four-fifths of the world rice is grown by small scale farmers in low-income and developing countries (Anonymous, 2004). China is the world's largest rice consumer, with 60% of its population living on rice as their staple food (Anonymous, 2004). More than 90% of global rice is produced and consumed in Asia pacific region. In India, the annual per capita consumption is 86 kg and constitutes about 30% of the total calorific sources (Anonymous, 1996).

The world population is expected to increase by about 2 billion in the next two decades and half of this increase will be in Asia where rice is staple food. By the year 2025 about 760 million tones of rice will be required to feed the increasing population at the global level. Population growth and climatic change parameters by 2025 is critical for many Asian countries where rice is the staple food crop (Vorosmarty *et al.,* 2000). World rice production in 2007 was approximately 645 million. At least 114 countries grow rice and more than 50 have an annual production of 100,000 t or more. Asian farmers produce about 90% of the total, with two countries, China and India, growing more than half the total crop (Anonymous, 2008). World rice production is expected to increase in 2008 by 12 million tines or 1.8 per cent, assuming normal weather conditions (Anonymous, 2008).

Rice (*Oryza sativa* L.) in India accounts for ≈ 22% of total cropped area under cereals and 31% of total area under food grains. Rice is grown almost all the states of India, covering more than 30% of the total cultivated area. Its cultivation mostly concentrated in the river, valleys, deltas and low yielding coastal areas of north eastern and southern India, especially in the states of Andhra Pradesh, Assam, Bihar, Chattisgarh, Karantaka, Kerela, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal, which together contributes about 97% of the rice production in the country (Randhawa *et al.,* 2006). Rice is grown from 53°N altitude to 40°S and from sea level to an altitude over 3000 m. It is a semi-aquatic species usually cultivated in shallowly flooded conditions on puddled soils, but some ecotypes are well adapted to aerobic soil conditions are called aerobic or upland rice. The upland rice are cultivated on approximately 19 million ha world wide. Global average upland rice yields are estimated to be about 1 mg/ha (Garrity, 1984).

2.1.1 Weed problem in rice

Weeds are one of the most important causes of yield losses in rice. World wide, a 10% loss of agricultural production can be attributed to the competitive effects of weeds despite their intensive control. Direct seeded rice is extensively cultivated to reduce production costs, but the barnyard grass drastically reduces the rice yield (Smith, 1968; Lee *et al.,* 2004; Seal *et al.,* 2005). The upland rice suffers from a very severe crop weed competition upto 40 days after sowing and if the weeds are not managed tunely, the reduction in yield may be 50 per cent or even more depending upon weed species and its intensity. The species composition of weed communities in rice crops varies according to climate and the growing environment (Baltazar and De Datta, 1992). Regardless of the weed composition, weeds compete for resources, especially during establishment and early growth stages (Zindahl, 1980). Both *Echinochloa crusgalli* (barnyard grass) and *Cyprus difformis* (dirtydora) are among the top ten most important rice weeds (Smith, 1983). According to Smith (1968), barnyard grass can affect rice yield at densities as low as 1-3 plants/m^2. The total area of rice in

Bangladesh is about 10.50 million hectares with a production of 25.09 million tones. Transplanted Aman rice, in particular, covers 5.56 million hectares of land with a production of 11.25 m tones (Anonymous, 2001b). But the yield of this crop is much lower than that of transplant rice in other rice growing counties of the world due to the severe weed infestation in the crop (Mamum, 1988).

The extent of yield losses due to weed infestations is highly variable and it depends on the magnitude of weed infestation, type of weed species, time of weed association with crops, fertilization, competitive ability of the cultivar, plant spacing and the cultural management accomplished to control this pest (De Datta, 1988; Moody, 1981). The yield losses due to weed competition in transplanted Aman rice are about 40% in Bangladesh (Anonymous, 1991), 15% in USA (Smith *et al.,* 1977), 9-15% in India (Mani, 1968), 50% in Sudan (Ghobarial, 1981), 20-25% in Cuba (Cabello, 1982) and 20-40% in Japan (Arai, 1963).

Weed crop competition is one of the major causes of crop yield loss (Cao *et al.,* 2007). The weed infestation and the crop losses greatly vary with the rice cultivars. Although the impact of weeds on rice production is well recognized, it has not been addressed by breeding as have diseases and pests. Weeds may directly reduce profits by hindering harvest operations, lowering crop quality and weeds left uncontrolled may harbor insects and diseases and produce seed or rootstocks which infest the field and affect further crops. Inspite of using modern methods of weed management, weeds are still responsible for the decline in crop yield. Losses caused by weeds can be as high as 24% of the yield compared with 16.4 and 11.2% for disease and pests, respectively (Oerke and Steiner, 1996).

An aerobic rice or upland rice suffer serious weed infestation than transplanted rice. Because direct seeded rice germinates together with weeds, eliminating the “head start” of transplanted seedlings (Moody, 1983). In transplanted rice the weed problem may be less serious due to the puddling and flooded conditions, which suppress many weed species. Also, transplanting rice may provide a competitive advantage for the crop, as the rice seedlings are already 15-30 cm tall when the weeds are just emerging. More than 100 weed species have been reported to affect the rice crop. Among there, 13 are more serious weed species which include *Cyperus rotundus, Cynodon dactylon, Echinochloa crusgalli, E. colonum, Eleusine indica, Eicnhornia crassipes, Portulaca oleracea, Digitaria arvensis, Sorghum halepense, Imperata cylindrical* and *Amaranthus retroflexus.* In paddy fields, the largest numbers of weed species belong to Alismataceae, Poaceae, Asteraceae, Fabaceae, Lytheraceae and Sciphulariceae families. The type of weed species to infest mainly depends on weather, temperature and latitude, where rice crop is grown (Narwal, 2000; Putnam, 1985).

Echinochloa weed species are a major constraint to rice production world wide. Red/weedy rice is also a problem brought about by the increase in area of direct seeded rice. Both weed problems are the result of permanent monocropping in rice (Lee *et al.,* 2004).

Weedy rice commonly causes a considerable reduction in cultivated rice yield because of its competition for resources. The extent of yield losses depend on weed density (Fischer and Ramirez, 1993), type of weedy plants (Diarra *et al.,* 1985), the variety of rice grown (Elefhteronorines *et al.,* 2002) and competition duration (Kwon *et al.,* 1991). Yield loss due to weedy rice can be expressed not only in the quantity of the rice harvest (Estorninos *et al.,* 2000) but also in a decreased quality of the grain (Kwon *et al.,* 1991; Pantone and Baker, 1991).

The weeds that come up in upland situation are highly competitive because most of them are C_4 types with higher drought tolerance, water use efficiency and photosynthetic efficiency compared to rice, which is a C_3 plant. These weeds also have deeper root system. There may be more than 100 weed species that cause problem in rice, but many are of little concern to the farmers. Usually less than 10 number of weed species that comprise the major part in rice field (Moody and Drost, 1983; Moody, 1992; Li, 1992).

2.1.2 Weed management in rice and associated problems

Presence of weeds in rice field is found to reduce the grain yield by 50-70 per cent in upland, 30 per cent in drilled irrigated and 20-27 per cent in transplanted crop. Thus, it necessitates to grow crop in weed free situation. The main weed control method in rice in Asia has been a combination of water management and hand weeding, but with increasing labor-cost, latter is becoming less common. In rice cropping, water constitutes a powerful selective agent for weed management (Mortimer and Hill, 1999). Permanently flooded fields of transplanted rice that are unweeded by 45 days after transplanting (DAT) exhibit a weed flora different from fields where the soil remains saturated. Noticeable differences are also evident across top sequences where land formation imposes different drainage and flooding regimes in rainfed rice (Pane *et al.,* 2000). However, it is the timing, duration and depth of flooding events in association with the method of crop establishment that govern the precise nature of weed suppression by water. In the upland rice ecosystem, hand weeding is still the most common practice to control weeds. Although hand weeding is an effective remedy, it is extremely laborious and time consuming. The time required for hand weeding varies from 45 to 455 d/ha, corresponding to 40% to 50% of the total crop input (Roder *et al.,* 1997). In Asian rice production, herbicide use has increased exponentially during the last 20 years. Increasing herbicide use is related to several factors in the region, primarily the increasing cost of labour and the availability and efficacy of herbicides. Herbicide dependency is also accelerated with shifts from labour intensive transplanted rice systems to labour conserving direct seeded rice systems, which increase existing weed problems and induce new ones, such as red rice. In all rice ecosystems, herbicides have become one of the most important components in weed control. There are two reasons to explain the increased use of herbicides, the first being the wide spread adoption of high yielding varieties which created economic incentives for farmers and the second is the availability of cheap herbicides, indicating that the cost of weed control by herbicides in wet seeded rice is less than one fifth of the cost of a single hand weeding (Moody, 1991). Same situations exist in West Java, Indonesia and Mekangdelta, Vietnam (Pandey and Pingali, 1996).

Because of the availability of cheap herbicides, it is expected that herbicide will continue to increase, both in developed countries and even in developing countries, where herbicides are currently used sparingly and farm wages are relatively low. However, this does not indicate a lack of importance for hand weeding. Manual weeding is still the dominant weed control method in many parts of Asia, since management options for weed control are limited under diverse agro-ecological conditions (Kim, 2000).

All the recommended herbicides commonly used are known to be very safe not only for humans and cattle, but also for the environment, when they are used properly. Sulfonylurea type herbicides have been intensively used in far-east Asia since 1990 because of their high efficacy against a broad spectrum of paddy weeds even at very low dose. However, intensive and repeated application of this type of herbicide has resulted in several negative effects, such as evolving resistant weeds (Valverde *et al.,* 2000); residual effects on the following crops, disappearance of some susceptible weeds such as *Brasinia schreberi* and *Sagittaria aginashi,* which affects weed biodiversity (Itoh, 2000).

To control weeds in paddy fields, three million tones of herbicides per year are used in most agricultural systems (Stephenson, 2000). In Korea, herbicide use has increased to approximately 0.01 million tones per hectare over the last 30 years. The increasing use of herbicides has led to environmental problems, tolerant agricultural crops, and human health concerns (Chung *et al.,* 2006).

The application of herbicides was a major factor enabling the intensification of agriculture in past decades, but there has been increasing herbicide resistance in weeds and wide spread concern about adverse environmental effects from herbicide use (Chung *et al.,* 2003). Herbicide resistance is becoming a problem in rice based farming systems and poses a major threat to the sustainability of the rice industry. Already high levels of bensulfuran resistance have been detected in Australian weed populations of the Alismataceae family (Broster *et al.,* 2001) due to the high dependency on a very limited number of herbicides available for effective control against all rice weeds. Consequently, alternatives to conventional synthetic herbicide application have become the focus of much research in Australia and world wide (Dilday *et al.,* 1991, 1994, 1998).

Herbicide cause several problems, such as pollution of soil and ground water, residual toxicity etc. Thus, in recent years, the direct seeded rice, conservation tillage practices and ecological weed control have become necessary in rice production as alternative strategies for weed management.

If the trend of increasing dependence on the heavy use of chemicals for weed control is to be reversed more alternative strategies of weed management needs to be developed. This is not only true for rice, but a general statement that is valid for all crops grown in the world. One weed management strategy that has not been exploited to any great extent is varietal improvement of crops in terms of their competitive ability. The possibility of incorporating traits into cultivar that would enhance the competitive ability of the crop and thereby reduce or delay the need for applying herbicides is worth exploring. Such as strategy could also lead to improved water quality and reduced environmental contamination. The potential use of allelopathy as part of weed management or control programme is one option which has been gaining attention for quite a long time (Dilday *et al.,* 1998).

2.1.3 Competitive ability of rice cultivar: Morphophysiological parameters and allelopathic interaction

Growth parameters associated with competitive ability of rice in the tropics include seedling growth rate, leaf area, specific leaf area, plant height, tillering, leaf angle and root growth (Gibson and Fischer, 2002). Competitive response of cultivars, assessed by weed biomass suppression, was negatively correlated with time to crop emergence and positively correlated with early-season crop biomass accumulation (prior to bolting) and plant height (Beckie *et al.,* 2008).

Community composition and the co-existence of plant species may be strongly influenced by interactions between species (Indrajit and Callaway, 2003). These interactions may facilitate the growth of a particular species, for example via attracting shared mutualists or enhancing nutrient supply in the local microclimate. Conversely, some plants have negative impacts that sometimes directly affect another species, such as competition for resources or the negative chemical consequences of allelopathy. Alternatively, the harmful effects can be direct, for instance via attracting herbivoures to neighouring plants. These interactions are the ultimate competitive ability of a plant which dependent on its ecophysiological traits and the surrounding biotic and abiotic environment. These include external factors like soil composition, the presence of pathogens, sunlight and water availability, which are all in turn subject to temporal variation. The strategy of a species, for example whether it is conservative, explorative, ruderal or competitive is central to whether it grows in a particular environment (Lambers *et al.,* 1998).

In a series of studies, Jennings and Aquino (1968) defined varietal traits that made some cultivars more competitive than others. Competition was first observed when plants were 53 to 60 days old, which was 30 to 35 days after transplanting. Tall and dwarf cultivars differed genetically in ways that affected tillering, leaf number, leaf length and angle, and height. Tall genotypes were more competitive under normal growth conditions and become relatively more so in response to fertility and close spacing .The number of tillers, leaf number, leaf length, leaf area index, height and dry weight were always greater in successful competitors before competition was observed. Leaf length was a critical factor because it determined the angle or degree of erectness and the amount of light the leaf could receive. It was concluded that any plant trait that increased size and vigour during early growth conferred competitive ability Jennings and Aquino (1968).

Ni *et al.* (2000) described nearly the same traits that conferred competitive ability such as initial biomass, plant growth rate, leaf area index and biomass at tillering was the best predictor of competitiveness against weeds, which included newer varieties than those studied by Jennings and Aquino (1968).

The importance of high tillering capacity to breeding efforts to maximize the ability of rice cultivars to compete with weeds was again emphasized by Estorinos *et al.* (2002). A study of the competitiveness of upland rice cultivars under low-input conditions in the Ivory coast showed that cultivar competitiveness was correlated with root growth at early growth stages and with shoot and root growth at later growth stages (Fofana and Rauber, 2000). Work by Lindquist and Kroff (1996) emphasized the importance of early leaf area expansion to competitive ability because of the central role of light capture. Their eco-physiological approach predicted that the leaf area index 70 to 75 days after transplanting was a good indicator of leaf area expansion rate. The model showed that if the early leaf area expansion rate could be increased, barnyard grass seed production decreased. Therefore, competitive rice cultivars could reduce the need for other weed management techniques.

Detailed study of three rice cultivars showed that the cultivar that accumulated more biomass had a higher leaf area index, higher specific leaf area, and especially in early growth stages, partitioned more biomass to leaves was the most competitive with weeds (Johnson *et al.,* 1998).

Cultivar height is as an important characteristic. Yield reduction from weeds increased with decreasing plant height. It is a logical assumption that this is related to competition for light as described by Caton *et al.* (2001) who used a rice : weed model to analyze the effects of the leaf area density (LAD) of weeds, leaf angles and maximum height on growth and competition of weeds with rice crop.

In rice, intraspecific competition, competition with weeds and spacing responses were highly inter-correlated with each other, suggesting that these were controlled largely by the same genetic factors through the same physiological processes. Vegetative vigour, large leaf area, a high rate of N absorption in early growth stages and plant height were the most significant character related to competitive ability or to spacing responses (Kwano *et al.,* 1974; Kim and Moody, 1980).

The studies conducted on tropical rice that compared newly introduced semi-dwarf cultivars with their taller predecessors and concluded that rice yields were inversely correlated with competitive ability (Jennings and Herrera, 1968; Jennings and DeJesus, 1968; Kwano *et al.,* 1974). Given the apparent trade off between yield and competitive ability, Jennings and Aquino (1968) suggested that there would be little reason to develop competitive cultivars as long as alternative control methods were readily available. However, several recent studies that were also conducted on tropical rice suggest that competitive cultivars can be used under weed free conditions without substantially lowering yields. Fishcer *et al.* (1997) grew 14 semidwarf cultivars (indica and japonica types) under weed free conditions and with jungle rice [*Echinochloa colona* (L.) Link] at Palmira, Colombia. They found no negative correlation between competitive ability and weed free yields. Johnson *et al.* (1998), working in the Ivory Coast, compared African rice (*Oryza glabrima steudal*) cultivar and two rice cultivars with and without weed competition and found significant differences among the cultivars in their competitive ability, but no significant differences in the yields under weed free conditions. Garrity *et al.* (1992) evaluated 25 upland rice cultivars (improved semidwarf, intermediate height and traditional tall cultivars) in field experiments in the Philippines. In this study, several intermediate height (1.0 to 1.15 m) cultivar were found to be as competitive as the tall (1.4 m) traditional cultivars. The intermediate height cultivars were ranked among the top cultivars for yield in the International Upland Rice Nursery, suggesting that weed suppression could be combined with a high yield potential. Short stature and erect leaf canopies are sought for high productivity in modern rice plant types (Peng *et al.,* 1994). In earlier work in Asia, researchers associated low productivity in rice with the tall and leafy canopies of traditional land races (Jenning and Aquino, 1968; Jennings and Herrera, 1968; Jennings and DeJesus, 1968) as opposed to the high yield potential of short but less competitive modern plant types. By comparing traditional vs. modern cultivars, researchers concluded that rice competitiveness conferred a yield penalty and that there would be little reason to develop competitive cultivars as long as alternative weed control methods were available (Jennings and Aquino, 1968). However, more recent studies comparing competitiveness among modern rice cultivars found that rice could be both high yielding and competitive with weeds (Garrity *et al.,* 1992; Fischer *et al.,* 1997). Dingkuhn *et al.* (1999) suggested that some tradeoffs between compositeness and yield potential may exist but could be reduced by specifically expressing traits for competitiveness at an early developmental stage.

Fischer *et al.* (1997) and Haefele *et al.* (2004) reported that some vegetative traits measured in weed-free rice variety traits, including leaf area index (LAI) and tiller number, were uncorrelated with weed growth or competition induced for weed competitiveness would be effective. However, the work of Jannink *et al.* (2000) on seedling height of soybean. Ni *et al.* (2000) on rice seedling biomass and Gibson *et al.* (2003) on rice LAI and root growth during the vegetative stages suggests that some seedling traits measured in weed-free condition are highly correlated with weed growth and thus that indirect selection for weed suppression ability may be feasible. Assessing the weed tolerance can be problematic because researchers must determine first the varietal yield differences reflect weed interference and not genotypic differences in yield potential and second that difference among cultivars in yield do not arise from differences in weed suppressing ability (WSA) (Jordan, 1993). In addition to problems in quantifying the role of weed tolerance, researchers have argued that WSA rather than WT should be emphasized in breeding programmes because weed-suppressive cultivars have the potential to reduce within-season weed pressure, thereby limiting yield losses, and to lower weed seed production and recruitment into soil seed bank, thus potentially reducing weed control costs and yield losses in subsequent years (Gibson and Fischer, 2003; Jordan, 1993).

Physiological growth analysis of six cultivars of rice showed marked differences in NAR, RGR, relative leaf growth rate (RLGR) and relative leaf area growth rate (RLAGR) on partitioning to different plant parts, LAI and SLA. However, RLAGR was found to be a suitable growth parameters to fit in a regression equation to predict the yield potential of rice cultivars (Baruah and Singh, 1982).

Biomass accumulation can be a good measure of competitiveness as it reflects resource capture under the interference from neighbours (Fernando *et al.,* 2006; Gaudet and Keddy, 1988; Roush and Radosevich, 1985). Above and below ground biomass accumulation was, used as a measure of competitive success.

Wall (1983) suggested that trait evaluation under competition might result in more progress in selecting competitive genotypes than evaluation in monoculture. The closer spacing between the hills of transplant rice up to a certain limit the more competitive the crop is against the weeds with the more consequence of minimum yield loss due to weed competition (Moody, 1975; Moody and De Datta, 1989). The weed infestation and the crop losses greatly vary with the rice cultivars. Short statured, early maturing, erect rice cultivars allow more weeds to grow and become less competitive with weeds than the tall, late maturing drooping cultivars (Mamun *et al.,* 2003).

Studies on the competitive ability of rice cultivars with the weeds *Echnochloa colona, E. oryzoides* have indicated the necessity to develop high erect cultivars (normally susceptible to lodging) in order to achieve a high level of competitiveness (Fischer and Gibson, 2001); on the other hand modern high yielding, semi-dwarf cultivars are also able to compete with weeds efficiently.

Competitive rice cultivars (e.g. semidwarf cv. M-2002) effectively suppressed the infestation of *Echinochloa oryzoides* and *E. phyllopogon* in California and may help reduce herbicide dependency and decrease selective pressure for resistance (Gibson *et al.,* 2001).

2.2 Allelopathy

The term allelopathy was introduced by Hans Molisch in 1937, and is derived from the Greek Words allelon "of each other" and pathos "to suffer" and mean the injurious effect of one upon the other (c.f. Rizvi *et al.,* 1992). However, the term today generally accepted to cover both inhibitory and stimulatory effects of one plant on another plant (Rice, 1984).

Allelopathy can be defined as "any direct or indirect effect of one plant on another mediated through the production of chemical compounds that escape into the environment" (Rice, 1974). These chemical compounds, known as allelochemicals, are generally secondary metabolities and the byproducts of primary metabolic pathways. They can be present in various parts of a plant, ranging from the roots to stems or seeds and can be released by four mechanisms : root exudation, volatilization, above ground leaching or via the decomposition of plant material (Rice, 1984). Allelochemicals can have different effects depending on the receiving species in a community. Germination, growth and development can be disrupted in susceptible plants, while other species may remain unaffected (Kruse *et al.,* 2000). Common targets that allelochemicals interrupt include cell division, the production and balance of plant hormones, membrane stability and permeability, photosynthesis and respiration (Rizvi *et al.,* 1992). These deleterious or deadly effects on neighbouring plants confer competitive superiority to the allelopathic plant as it has less impeded access to natural resources. Allelopathy is a strategy for competitive, conservative species as sufficient carbon reserves are needed in order to produce allelochemicals (Kruse *et al.,* 2000). Allelopathy has also been implicated in plant invasion. The novel weapons hypothesis proposes that "invaders bring unique, species specific biochemical impacts to native plant and soil microbial communities" (Callaway *et al.,* 2005).

An ecological strategy of weed control, allelopathy has drawn increased attention. Many weed scientists have attempted to explore allelopathy directly as a weed management strategy through screening for allelopathic traits in germplasm of crops. Furthermore, the application of crop allelopathy in integrated weed control will enhance the competitive ability of the crop and thereby reduce for delay the need for applying herbicides (Lin *et al.,* 2000; Lin and He, 2003). To date, much progress had been made in crop allelopathy, such as screening for allelopathic rice accessions (Navarez and Olofsdotter

1996; Dilday *et al.*, 1998; Fujii, 1999), identifying allelochemicals (Chou *et al.,* 1998; Mattice *et al.,* 1998; Rimando *et al.,* 2001), and identifying QTLs for allelopathy (Louise *et al.,* 2000; Kaworu *et al.,* 2001). When a significant level of intra-accession variability in allelopathic expression became evident, the assessment of genetic diversity become necessary (Motiul *et al.,* 2001).

In 1966, the International Allelopathy Society defined allelopathy as follows: "any process involving secondary metabolites produced by plants, microorganisms, virus and biological systems (excluding animals), including positive and negative effects" (Torres *et al.,* 1996).

Investigations of allelopathic activity have often been initialized by field observations mainly related to changes in agricultural, horticultural or silvicultural periodicity or to changes in vegetation patterns in natural habitats. Problems of growing the same crop in succeeding years because of poor establishment and stunted growth has lead to investigations of possible causes, including allelopathy. Allelopathy occurring among individuals of the same species is termed autotoxicity. Autotoxicity is known for example in *Medicago sativa* (alfalfa). *Trifolium* spp. (clovers) and *Asparagus officinalis* (asparagus) e.g. (Miller, 1996; Chung and Miller, 1995; Young, 1986).

Inhibitory effects on germination and establishments of crops caused by residues of either crops or weeds have lead to investigation of the release of toxic compounds from such residues. For example, the allelopathic interference of both living plant and of plant residues of the highly aggressive weed *Elytrigia repens*, quackgrass has been strongly indicated (Weston and Putnam, 1985). Residues from several crop species have been examined for their potential to reduce weed germination (Creamer *et al.,* 1996; Moyer and Huang, 1997).

The potential use of allelopathy as part of a weed control program is one option which has been gaining attention. Dilday *et al.* (1991, 1994 and 1998) were the first to report the presence of allelopathy in rice more than 15 years ago in a field trial. This research sparked global interest as a result of which currently several international groups are involved in efforts to use allelopathy in rice to control problematic weeds in rice (Fujii, 1992; Hassan *et al.,* 1994, 1998; Olofsdotter *et al.,* 1995, 1999; Olofsdotter and Navarez, 1996; Marambe, 1998; Seal *et al.,* 2004).

A large number of rice varieties were found to inhibit the growth of several plant species, when the rice varieties were grown together with the plants under field and for laboratory conditions (Dilday *et al.,* 1998; Olofsdotter *et al.*, 1999). These findings suggest that living rice may produce and release allelochemicals into the neighboruing environment. Effective and affordable weed control is a continuing challenge to sustainable rice production in the U.S. Evaluation of the allelopathic potential of rice germplasm in drill seeded systems has been conducted in Stuttgart, AR since the early 1980's (Dilday *et al.,* 2001). These efforts led to the identification of several forcing lines with allelopathic activity against aquatic weeds and some of these lines (e.g. PI 312777 and PI 338046) also have suppressed *Echinochloa crusgalli* in Arkansas (Dilday *et al.,* 2001; Gealy *et al.,* 2003; Gealy *et al.,* 2005) and Asia (Olofsdotter *et al.,* 2002). Some of the suppressive lines have reduced *Echinochloa crusgalli* more effectively and economically under reduced herbicide inputs than have commercial cultivars (Gealy *et al.,* 2003).

Rice allelopathy has been extensively studied in part because many cultivars and ancestral lines have exhibited significant allelopathic potential in the field. Several international efforts to generate allelopathic rice varieties are underway (Olofsdotter *et al.,* 2002; Dilday *et al.,* 2001; Kong *et al.,* 2002).

Thousands of varieties have been screened for allelopathic potential and upto 4 per cent of varieties can suppress important weeds such as barnyard grass (*Ehinochloa crusgalli*) (Dilday *et el.,* 2001; Jensen *et al.,* 2001) and *Cyperus difformis* (Kong *et al.,* 2004a). While the level of weed management by allelopathy is not as good as that obtained with herbicides. Herbicides use rate can be substantially reduced in paddy field planted with such varieties (Gealy *et al.,* 2003).

Unlike most other crops, there is a relatively high occurrence of allelopathy in rice (about 4%). One factor that may contribute to this may be the fact that the highly allelopathic cultivar Taichung Native-1 is present in the genetic background of most of the post Green Revolution rice cultivars (Olofsdother, 2001). Since the allelopathic trait is inheritable, many of these cultivars may possess more of the allelopathic character of Taichung Native I, or that of other allelopathic lines in their background. The allelopathic potential of rice plants can be stimulated in the presence of other plants by increasing the production of allelochemicals that may help them repress the growth of competitors. The synthesis of some rice allelochemicals, such as the flavone and Cyclohexenone, can be stimulated in the presence of barnyard grass in the surrounding (Kong *et al.,* 2004b).

Genetic information related to the allelopathy of rice, such as quantitative trait loci mapping of allelopathic traits (Jenson *et al.,* 2001), have been developed, but no direct link between this genetic information to production of any particular allelochemical.

Cultivars with enhanced allelopathic traits, either via traditional breeding or biotechnological means, should be available in the future. Their use in conjunction with other allelopathic ground cover or mulches (Hong *et al.,* 2004) may suppress more than 80% of the weeds in paddy field.

Rice allelopathy has been on the IRRI research agenda for a decade. Results have shown that there is wide variation in allelopathy among rice cultivars. Allelopathic rice can suppress both monocot and dicot weed species (Olofsdotter, 2001). Planting of barnyard grass (*Echinochloa crus galli*) together with various varieties of rice in the greenhouse has shown the potential of some varieties to inhibit weed growth by upto 40 per cent (Mattice *et al.,* 1999). Similar research is taking place in the Republic of Korea (Lin *et al.,* 2000) where there is potential for improved weed management in the near future.

Some crops also such as sorghum, pearl millet and maize, may drastically suppress the weed population and reduce its biomass. Pearl millet may exhibit residual weed suppression in the following crops. The inclusion of these fodder crops before the rice crop in a rice-wheat rotation may provide satisfactory weed control and can minimize the use of herbicides (Narwal, 2000).

Some weeds have also allelopathic potential, an example is *Centaurea maculosa* (Spotted knapweed), which is allelopathic at rhizopshere level as it exudes the phytotoxin (-)-catechin from its roots. Originally from Europe, it has invaded plant communities in North America where it inhibits seed germination and root growth in some species (Bais *et al.,* 2003; Baldwin, 2003). For example, root elongation is reduced on average by 50% in *Festuca idahoensis* in the presence of (-)- catechin (Ridenour and Callaway, 2001). Bais *et al.* (2002) added *C. maculosa* root exudates to various weed and crop plants and each species wilted prior to premature senescence and seed germination was inhibited. The allelochemical that *C. maculosa* emits has specific effects on target plants. In *Arabidopsis thaliana* (-)- catechin elicits a burst of reactive oxygen species that travel from the root to the meristem, mediating Ca^{++} signaling cascades. These bring about gene expression changes that cause root senescence (Bais *et al.,* 2003).

Twenty seven rice cultivars were examined in the laboratory for their allelopathic potential against several important rice weeds in Australia such as barnyard (*Echinochloa crusgalli*), dirtydora (*Cyperus difformis*), lance leaved water plantain (*Alisma lanceolatum*), start fruit (*Damasonium minus*), arrowhead (*Sagittaria montevidensis*) and *S. graminea*. Weed root growth inhibition ranged from 0.3% to 93.6% of the control depending on the cultivar and the weed species being tested. Several rice varieties significantly inhibited root growth of more than one weed (Seal *et al.,* 2004a).

The level of resource availability can determine the quantity of secondary metabolites in plant tissues, for example plants growing in resource-limited environments or under stress often have higher tissues concentrations of secondary compounds than those in less stressful locations (Aerts and Chapin, 2000). This may mean that the allelopathic plants have greater capacity to ward off competitors. Root allelopathy has been shown to be dependent on plant densities, root distribution and soil and microbial composition in the field (Hierro and Callaway, 2003).

Now due to the importance of sustainability, modern agriculture research for new compounds which are environmentally friendly and challenges to reduce environmental damages and healthy hazards due to chemical inputs, minimizes soil erosion and yet maintains a high level of production (Einhellig, 1995).

Thus, allelopathy is a natural and an environment friendly technique which may prove to be a unique tool for weed control, increase crop yields, decrease our reliance on both synthetic pesticides and improve the ecological environment (Hess and Duke, 2000; Lovelace *et al.,* 2001; Minorsky, 2002). Many recent researches suggested that allelopathy may provide alternatives to synthetic herbicides for weed control (Romeo and Weidenhamer, 1999; Khanh *et al.,* 2005, 2006).

It is now known that molecular approaches in breeding allelopathic cultivars are potentially much more complicated than developing an herbicide-resistant crop or producing a crop with resistance to insects pathogens (Chung *et al.,* 2001, 2005).

2.3 Problems with studying allelopathy

Studying allelopathy is notoriously controversial. Many experiments have been criticized for their artificial nature and have little or no relevance in demonstrating the effects observed in the field (Hamdi *et al.,* 2001). It is difficult to separate allelopathy from other interference mechanisms as they are all so closely interlinked and dependent on local environmental conditions (Kruse *et al.,* 2000). Laboratory settings are typically less stressful than in the field, where plants are influenced by the level of sunlight, nutrients, water and disease (Inderjit and Del Moral, 1997; Inderjit and Weston, 2000). Einhellig (1996) proposed that in general, the sensitivity of target plants to allelochmicals is affected by stress and it is typically increased, therefore a laboratory experiment is not necessarily the best method of demonstrating allelopathy.

2.3.1 Allelopathic compounds

It has been suggested that allelochemicals may in fact mediate indirect chemical interactions among plants by altering aspects of the soil composition. This could include the regulation of nutrient cycling and availability and organic matter dynamics by changing the level of microbial activity (Castells and Valentine, 2004; Inderjit and Weiner, 2001). Allelopathic root exudates may serve as prospective organic carbon sources for microbes in the rhizosphere, or may suppress the growth of some species (Bais *et al.,* 2002). If they mediate an increase in microbial populations, then they could potentially inhibit local plant growth owing to direct competition for resources (Kruse *et al.,* 2000). Some allelochemicals can decrease soil nitrogen availability by forming complexes with proteins and, therefore, delay organic matter decomposition and mineralization (Castells and Valentine, 2004).

Not only is the active concentration of an allelochemical important for the impact on susceptible plant and microbial species, but in turn the biological and chemical characteristics of the soil can affect the amount of allelochemical. It has also been suggested that effective allelopathic inhibition of one species by another is more likely to occur in species-poor communities, than species-rich. This is because there is increased likelihood of one species dominating and therefore, manipulating the soil biochemistry with its allelochemicals (Wardle *et al.,* 1996).

El-Khatib *et al.* (2003) reported that soil associated with *Chenopodium murale* and soil amended with its leaves and roots suppressed the growth of *Melilotus indicus.* However, its roots and their exudates exert allelopathic effect on wheat by releasing water soluble phenolic acids as putative allelochemicals in soil (Batish *et al.,* 2007).

Autotoxity is an intraspecific allelopathy, occurs when a plant species releases chemical substances that inhibit or delay germination and growth of the same plant species (Putnam, 1985; Singh *et al.,* 1999). It has been reported in weed, for example, pokeweed (Edwards *et al.,* 1988). Some researches indicated that some *Chenopodiaceae* species produce allelopathic compounds. In some cases these compounds inhibit seed germination of the chenopods. Also the extracts of both *Avena sterilis* and *Chenopodium maculatum* inhibit seed germination of the chenopods themselves (Jefferson and Pennacchi, 2003; Kadioiglu and Yanar, 2004). In order to minimize the negative impacts of varietal autotoxicity, careful selection of suitable crop varieties is necessary in a continuous cropping system (Oueslati *et al.,* 2005; Wu *et al.,* 2007).

In a recent review on the effects of allelochemicals in natural systems. It was concluded that the most important influences of allelopathy occur through indirect effects rather than direct plant-plant interference. Plant chemicals can influence abiotic components of the ecosystem, for example, the availability and accumulation of inorganic ions. Additionally, allelochemicals can alter microbial ecology by affecting soil microbes and plant pathogens. The environment (i.e. nutrient limitation, light regime and moisture deficiency) can in return influence the activities of the allelochemicals (Inderjit and Weiner, 2001).

By sequestering water soluble organic constituents, carbon can remove allelochemicals from the soil *in situ* (Inderjit and Nilsen, 2003).

Bais *et al.* (2002) found phytotoxic chemicals in root exudates. As Harper (1977) and Stove (1979) pointed out nearly 30 years ago, most plants can be shown to have allelopathic properties, and this might have not related to patterns actually seen in the field. Additionally, these studies use a constant concentration of the allelochemical in bioassays and do not capture the potential effects of flux rates that would be seen in the field (Bais *et al.,* 2002; Bais *et al.,* 2003).

The process of isolating and identifying rice allelochemicals has started but has not yet yielded chemicals that could explain the allelopathic effect (Rimando *et al.,* 2001). None of the known chemicals released from rice can alone explain the weed suppression seen in the laboratory and fields. Phenolic acids have been identified in allelopathic germplasm (Rimando *et al.,* 2001) and they have previously been descried as allelochemicals (Inderjit, 1996; Mattice *et al.,* 2001; Blum, 1998). However, concentrations of single phenolic acids and combinations of all phenolic acids measured in rice ecosystems do not approach phytotoxic levels (Tanaka *et al.,* 1990; Olofsdotter, 2001). Identifying allelopathy mechanisms and for use as markers in gene identification.

It is well known that the crop residues left in the soil are sometimes harmful to plant growth. The plant residues in soil could release phytotoxic substances during decomposition period. Chou and Lin (1976) observed decrease in plant productivity of the second rice crop in a paddy field containing residues from the first rice crop. They found that aqueous extracts of decomposing rice residues in soil inhibited the growth of mungbean and lettuce as well as rice.

Several phenolic acids, 2-hydroxyphenylacetic acid, 4 hydroxybenzoic acid, vanillic acid, p-coumaric acid and ferulic acid were found in aqueous extracts of decomposing rice residues (Chou and Lin, 1976) and in soil from paddy field which rice was grown (Chou and Chiu, 1979).

Kim and Kim (2000) identified several compounds in the acidic fraction isolated from root exudates of allelopathic rice cv. Kouketsmochi. These compounds were 2-methyl-1,4-benzenediol, 1-ethyl-3,5-dimethylbenzene, 4-ethylbenzaldehyde, cinnamic aldehyde, octadecane, 3-epicosene, 1-eicosanol, 9, 12-octadecadinoic acid, 7-hexadecanoic acid methyl ester, 12-octadecenoic acid methyl ester, 12-methyl-tridecanoic acid methylester, cis-1-butyl-2-methylcyclopropane, dehydroabietic acid and cholest-5-en (β)-ol were candidates for allelochemicals of rice plants. However, the concentrations of these compounds were not provided and inhibitory activities of these compounds were relatively weak.

Fifteen compounds were identified and quantified in the root exudates of allelopathic and non allelopathic rice cultivars (Seal *et al.,* 2004a). The concentrations of 4-hydroxybenzoic acid, caffeic acid and ferulic acid were greater in the exudates of allelopathic rice cultivars than those of non-allelophatic rice cultivars, while the concentration of abiotic acid was greater in those of non-allelopathic rice cultivars than those of allelopathic rice cultivars. The other 11 compounds, resorcinol, 2-hydroxyphenylacetic acid, 4-hydroxyphenpylacetic acid, 4-phenoylbutsic acid, cinnamic acid, vanillic acid, syringic acid, salicylic acid, p-coumaric acid, 5-hydroxyindole-3-acetic acid and indole-5-carboxylic acid did not differ in the concentrations between allelopathic and non-allelopathic rice cultivars (Seal *et al.,* 2004a). 5-(12Heptadecenyl)-resorcinol(1) was also found in rice root exudates (Bouillant *et al.,* 1994).

About 5,000 rice seedlings, cv. Koshihikari, were hydroponically grown for 14 days in order to find out an allelochemical in rice root exudates. Keeping track of the biological activity, culture solution was purified by several chromatographic fractionations and finally 2.1 mg of putative compound causing the inhibitory effect of the rice seedlings was isolated (Kato-Noguchi *et al.,* 2002; Kato-Noguchi and Ino, 2003). The chemical structure of the inhibitor was determined from its high resolution MS, and ^{1}H-and ^{13}C-NMR spectral data and has been identified as momilactone B. Momilactone B is quite active at sub-millimolar concentrations (Takahashi *et al.,* 1976; Kato *et al.,* 1977; Lee *et al.,* 1999). Momilactone B was later found in the rice root exudates of another allelopathic rice cultivars in addition to 5,7,4'-trihydroxy-3'5'-dimethoxyflavone and 3-isopropyl-5-acetoxycyclohexene 2-one-1 (Kong *et al.,* 2004).

2.3.2 Phenolic acids

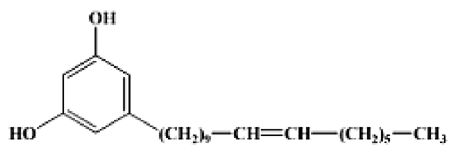
Phenolic acids are often mentioned as putative allelochemicals and the most commonly investigated compounds among potential allelochemicals since they have been found in a wide range of soils

(Hartley and Whitehead, 1985; Inderjit, 1996; Dalton, 1999). Hsu *et al.* (1989) evaluated the inhibitory activities of phenolic acids against germination of lettuce and alfa-alfa. 4-hydroxybenzoic acid and salicylic acid were the most active and they inhibited the germination at concentrations greater than 0.5-1.5 mM.

Olofsdotter *et al.* (2002) evaluated whether phenolic acids are responsible for rice allelopathy. They found that allelopathic rice cultivars did not release significantly greater amount of phenolic acids than non-allelopathic cultivars. The maximum release rate of phenolic acids from rice plant was approximately 10 μg plant^{-1} day^{-1}. Therefore, at conventional plant density (100 rice plant m^{-2}). The release rate of phenolic acids, would be approximately 1 mg m^{-2} day^{-1}. Considering the inhibitory activity of phenolic acids, it was concluded that, even all phenolic acids were as phytotoxic as 4-hydroxybenzoic acid, the release level of phenolic acids from rice is not sufficient to cause growth inhibition of neighboring plant.

Five major phenolic acids in rice root exudates, 4-hydroxybenzoic acid, vanillic acid, syringic acid, p-coumaric acid and caffeic acid, were mixed and their biological activities were determined against *Sagittaria monotevidensis* (Seal *et al.,* 2004b). The concentration required for 50% growth inhibition (I_{50}) of the mixture of these five phenolic acids was 502 μM. The concentrations of these phenolic acids detected in the rice root exudates were considerably less than 500 µM (Seal *et al.,* 2004b). Inhibitory activity of mixture of all 15 compounds identified in rice root exudates was also determined and I_{50} was found to be 569 µM (Seal *et al.,* 2004a, b).

Phenolic acids reported in rice:



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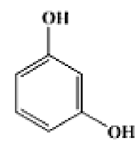

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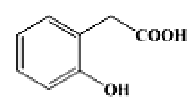

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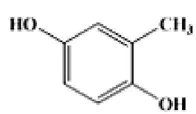

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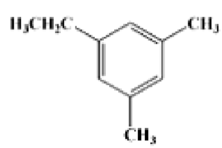

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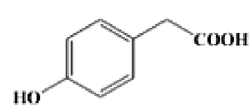

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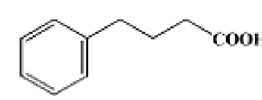

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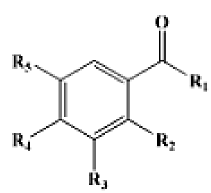
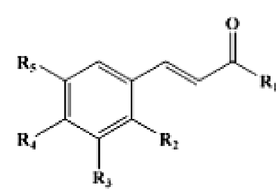
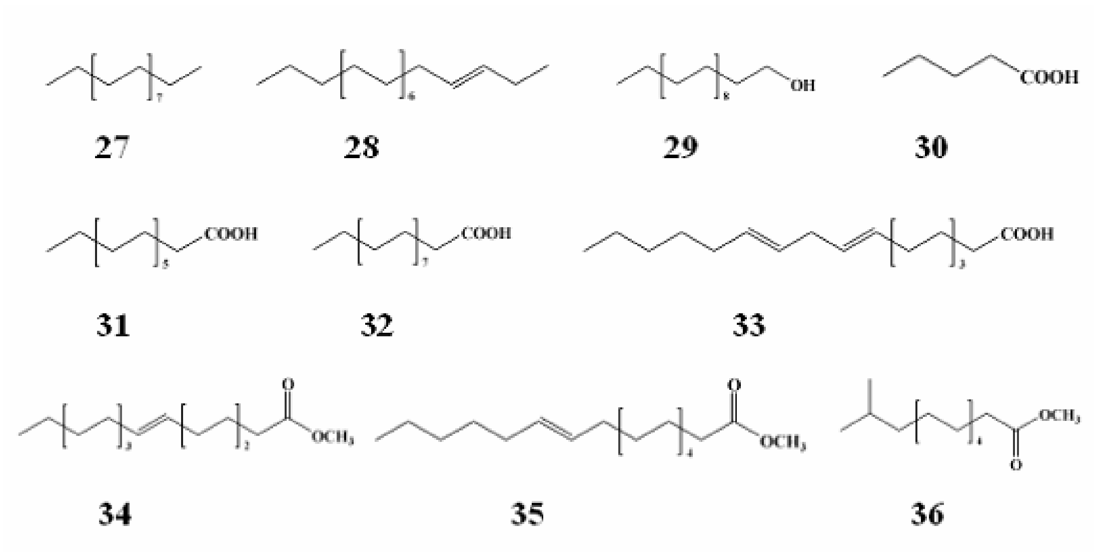




	R_1	R_2	R_3	R_4	R_5
8	H	H	H	CH_2CH_3	H
9	H	H	H	OH	H
10	OH	H	H	H	H
11	OH	H	H	OH	H
12	OH	H	OH	H	H
13	OH	H	OH	OH	H
14	OH	H	OH	OH	OH
15	OH	H	OH	OCH_3	H
16	OH	H	OCH_3	OH	H
17	OH	H	OCH_3	OH	OCH_3

	R_1	R_2	R_3	R_4	R_5
18	OH	OH	H	H	H
19	OH	OH	H	H	OH
20	OH	OH	H	OH	H
21	H	H	H	H	H
22	OH	H	H	H	H
23	OH	H	H	OH	H
24	OH	H	OH	OH	H
25	OH	H	OCH_3	OH	H
26	OH	H	OCH_3	OH	OCH_3

1, 5-(12-heptadecenyl)-resorcinol; 2, resorcinol; 3, 2-hydroxyphenylacetic acid; 4, 2-methyl-1,4-benzenediol; 5, 1-ethyl-3,5-dimethylbenzene; 6, 4-hydroxyphenylacetic acid; 7, 4-phenylbutyric acid; 8, 4-ethylbenzaldehyde; 9, 4-hydroxybenzaldehyde; 10, benzoic acid; 11, 4-hydroxybenzoic acid; 12, 3-hydroxybenzoic acid; 13, protocatechuic acid; 14; gallic acid; 15, 3-hydroxy-4-methoxybenzoic acid; 16, vanillic acid; 17, syringic acid; 18, salicylic acid; 19, gentisic acid; 20, β-resorcylic acid; 21, cinnamic aldehyde; 22, cinnamic acid; 23, *p*-coumaric acid; 24, caffeic acid; 25, ferulic acid; 26, sinapinic acid.



27, octadecane; **28**, 3-epicosene; **29**, 1-eicosanol; **30**, valeric acid; **31**, tetradecanoic acid; **32**, stearic acid; **33**, 9,12-octadecadienoic acid; **34**, 7-hexadecenoic acid methyl ester; **35**, 12-octadecenoic acid methyl ester, **36**, 2-methyl-tridecanoic acid methyl ester; **37**, *cis*-1-butyl-2-methylcyclopropane; **38**, 5-hydroxyindole-3-acetic acid; **39**, indole-5-carboxylic acid; **40**, 5,7,4'-trihydroxy-3',5'-dimethoxyflavone; **41**, 3-isopropyl-5-acetoxycyclohexene- 2-one-1; **42**, abietic acid; **43**, dehydroabietic acid; **44**, momilactone B; **45**, cholest-5-en-3(β)-ol. (Kim and Kim, 2000)

Cinnaminic acids are some of the most common phenolics implicated in allelopathy, and also have the least specific effects. Produced via the phenylpropanoid pathway from phenylalanine, they interfere with several enzymes and almost all major physiological processes in receptive plants (Einhellig, 1996, 2004). The extent of their inhibitory action is largely dependent on their concentration and the toxicity of the derivative. Membrane effects include non-specific efflux of cations and anions, inhibition of ion uptake, changes in membrane proteins and free radical formation leading to lipid peroxidation (Balke, 1985; Baziramakenga *et al.,* 1995). Phenols also alter the normal water balance and cellular synthesis in tissues and reduce net respiration and photosynthesis, leading to a decrease in growth (Barkosky *et al.,* 2000; Einhellig, 2004).

The identification of an active phytotoxic compound from a suspected allelopathic plant does not establish that this is the only compound involved in allelopathy. The release of allelochemicals of different chemical classes from allelopathic plant species has been documented including tannins, cyanogenic glycosides, several flavonoids and phenolic acids such as p-coumaric acid, syringic, vanillic and p-hydroxybenzoiic acids (Einhellig, 1995a, b).

Both simple phenolic acids and cyclic hydroxamic acids with allelopathic effect are released from the living intact roots of *Elytrigia repens* (Friebe *et al.,* 1995; Friebe *et al.,* 1996). Einhellig (1995a) states that an allelopathic inhibition under natural conditions in the result of the combined effect of several compounds. Several laboratory experiments indicate that mixture solutions of allelochemicals have greater effect than the same concentrations of compounds used separately e.g. Blum *et al.* (1999), Einhellig (1995b), Chaves and Escudero (1997).

Furthermore, these experiments have indicated that mixtures of some allelochemicas, e.g. phenolic acids and other organic compounds such as carbohydrates and amino acids can possess allelopathic activity even though concentrations of individual compounds are significantly below their inhibitory levels (Blum *et a.,* 1993; Blum, 1996).

Phenolic acids have been identified in rice germplasm (Rimando *et al.,* 2001). The concentrations of single phenolic acids and combination of all phenolic acids measured in rice ecosystems do not approach phytotoxic leels (Tanaka *et al.,* 1990; Olofsdotter *et al.,* 2001). Identifying allelochemicals in rice is important for understanding allelopathy mechanism and for use as markers in gene identification.

Phenolic compounds are universally distributed in the plant kingdom as secondary metabolic products, evidence indicates that phenolic compounds have potent antioxidant properties and free radical scavenging capabilities, phenolic compounds are known to exert various physiological effects in humans, such as preventing oxidative damage of lipid and low-density lipoproteins, inhibiting platelet aggregation and reducing the risk of coronary heart disease and cancer. Fruits and vegetables are known to be major dietary source of phenolic compounds whereas substantial research was demonstrated that cereal consumption is also an excellent way to increase phenolic compounds and their glycosides, which exist in solution and a significant amount of insoluble phenolic compounds. Most of which are bound to polysaccharides in the cell wall. Both types are important source of phenolic compounds, until recently, many studies verified the mechanisms of a self defence system, including allelopathy in plants, particularly phenylpropanoid, and isoterpenoid metabolism. Plants, respond to environmental stress through a variety of biochemical reactions, which may provide protection against casual agents. The increase of allelopathic phenolic and terpenoid compounds under environmental stress has been well documented, such as enhanced UV-B light induces the accumulation of phenyl propanoids and flavonoids in different plant species such as bean, parsley, potato, tomato, maize, rye, barley and rice (Liu *et al.,* 1995; Kim *et al.,* 2000). All phenylpropanoids are derived from cinnamic acid, which is formed from phenylalanine by the catalytic action of phenylalanine ammonialyase (PAL). The branch point enzyme between primary (Shikimate pathway) and secondary (Phenyl propanoid), metabolism. It is known that many phenolic compounds not only have a physiologically functional ability, but also plant allelopathic potential.

2.3.3 Allelopathic substances in rice straw

Kuwatsuka and Shindo (1973) isolated 13 different phenolic acids in decomposition of rice straw; benzoic acid, 4-hydroxybenzoic acid, protocatechic acid, gallic acid vanillic acid, syringic acid, salicylic acid, gentisic acid, β-resorcylic acid, p-coumaric acid, caffeic acid, ferulic acid and sinapinic acid. They found that p-coumaric acid was released in the greatest amount from decomposition of rice straw. However, Tanaka *et al.* (1990) doubt that the involvement of phenolic acids found in rice soil are not sufficient to cause phytotoxic effects. In support of this view, phenolic acids were usually present in rice soils concentrations below 5 mg kg^{-1} soil, which is below the bioactive threshold (Olofsdotter *et al.,* 2002). Several phenolic acids and fatty acids were found in water obtained from soils in which allelopathic or non allelopathic rice plants were incubated for 48 hours (Mattice *et al.,* 1998). Concentrations of 4-hydroxybenzaldenyde, 4-hydroxybenzoic acid, 3-hydroxybenzoic acid p-coumaric acid and caffeic acid were greater in water obtained from soils containing allelopathic rice plants than water obtained from soils containing non-allelopathic rice plants. concentrations of 4-hydroxybenzaldehyde, 4-hydroxybenzoic acid, 3-hydroxybenzoic acid, p-coumaric acid and caffeic acid were greater in water obtained from soil contaning allelopathic rice plants than water obtained from soil containing non-allelopathic rice plants. Mattice *et al.* (1998) also identified compounds contained in these soils, and found that concentrations of 4-hydroxybenzaldehyde, 4-hydroxybenzoic acid, 3-hydroxymethoxy benzoic acid, valeric acid, tetradecanoic acid and stearic acid water greater in soils of allelopathic rice than soils of non-allelopathic rice plants. Based on these experiments, it was suggested that allelopathy of rice against weeds was correlated with the amount of phenolic acids released by living rice roots (Mattice *et al.,* 1998). Phenolic acids are shown phytotoxicity against various plants of concentrations greater than about 1 mM (Hartley and Whitehead, 1985; Dalton, 1999). However, Matteic *et al.* (1998) did not provide the exact values of phenolic acid concentrations in the water and oils containing rice plants. Thus, it is impossible to evaluate whether phenolic acids are responsible for the allelopathy of rice.

A considerable attention has been given to use rice straw wastes in composting and feeding animals for being cheap and abundant (Abdelhamid *et al.,* 2004). Mendoza (1989) demonstrated that recycling rice straw could substitude 2-4 bags of fertilizers per hectare per cropping or about 2.5 kg N per ton straw (Wantanabe, 1978). However, new approaches of using rice straw for controlling weeds in different crops have been suggested by Mendoza and Samson (1999) who indicated that rice straw can be used for mulching, which benefits in preventing weed growth as well as supplies organic matter for N-fixation by heterotrophic N-fixing micro-organisms, which could be observed by succeeding crop (Patnaik, 1978). The plant derived compounds from rice straw or even survival plants are another promising issue, where it could serve as a renewed source of natural herbicides or probably as a good skeleton to buildup new groups of synthetic herbicides (Olofsdotter *et al.,* 1997; Duke *et al.,* 2002). Research evolving good results has seriously been conducted on the isolation and identification of rice phytotoxins, however, in the majority of cases they were found to be as phenolic acids. Chou (1980) isolated six phenolic acids e.g. salicylic acid, p-coumaric, vanillic, syringic, ferulic and mandolic acids from decomposed rice straw and paddy soil, which have been described as highly allelopathic compounds in many plant species (Lydon and Duke, 1989; Duke, 1992). Moreover, 16 potential allelochemicals were also identified and recognized as strong inhibitors and because of that finding the phytotoxicity existed in different rice body parts of certain cultivars has found reasonable explanation (Olofsdotter *et al.,* 1995). Mattic *et al.* (1997) attributed the herbicidal activity of different allelopathic rice cultivars to containing significantly higher level of the phenolic derivatives (3-hydroxyhydrocinnamic acid, 4-hydroxy benzoic acid, 3-4 dihydroxycinnamic acid, 4-hydroxyphenylacetic acid) when compared with non allelopathic cultivars such as rexmund species.

Chung *et al.* (2001) found more than one type of phenolic substances (e.g. p-hydroxybenzoic acid, p-coumaric acid, ferulic acid) to be responsible for the allelopathic influences in different rice cultivars, referring to the fact that the concentration and composition of such allelochemicals and hence their allelopathic capability were return in the first standing to the rice phenotype it self not the surrounding situations or any other affecting factors.

Wheat straw has been reported to possess allelopathic activities (Guenzi and McCalla, 1962; Guenzi *et al.,* 1967). Guenzie and McCalla (1966) advocated phytotoxicity of phenolic acids, particularly p-coumaric acid from residues of wheat and other cereals. Alam (1990) studied the effect of wheat straw extracts on the germination and seedling growth of wheat. Hicks *et al.* (1989) reported allelopathic effects of wheat straw on the germination, emergence and yield of cotton (*Gossypium hirsutum* L.). They found that the maximum inhibition of cotton germination and emergence occurred when wheat straw was mixed throughout the soil. Later, Opoku *et al.* (1997) implicated phenolics in the allelopathic interference of wheat straw to corn (*Zea mays* L.). They reported that the total phenolic levels of soil in surface placed straw were higher compared with soil alone. However, the phenolics content of soil mixed with straw was not different from that of soil alone.

Allelopathy can be used in weed management in two ways. The first is to be selecting an appropriate crop variety or incorporating an allelopathic character into a desired crop variety. The second way is by applying residues and straw as mulches or growing an allelopathic variety in a rotational sequence that allow residues to remain in the field (Rice, 1995).

2.3.4 Estimation of allelopathic compounds

To screen rice allelopathic potential, several methods such as the stair step method (Bonner, 1950; Liu and Lovett, 1993), hydroponic culture test (Einhellig, 1985), relay seedling technique (Navarez and Olofsdoter, 1996), agar medium test (Fujii, 1992; Wu *et al.,* 2001) and 24-well plate bioassay (Rimando *et al.,* 1998) have been suggested. Each of the methods mentioned above can be used as a valuable tool to evaluate allelopathic potential. However, it has also been observed that the screened accessions or cultivars in one method may not be always active in another method employed. In terms of screening, the direct field test might be the best method to evaluate allelopathic potential, but it has many difficulties when dealing with a large number of germplasms. Collection of compounds released from plants roots through exudates traps can be used to provide a test solution which is biologically meaningful since it contains allelochemicals actually released from the plants. One way of trapping exudates is by the use of hydroponics, where donor plants are grown in a nutrient solution that is changed periodically. The nutrient exudates solution can be used as the test solution in a bio-assay. Hydroponics has been used successfully for evaluating allelopathic potential in barley, *Hordeum vulgare,* using *Sinapis alba* as a test plant (Liu and Lovett, 1993).

Analysis of allelochemicals by using high-performance liquid chromatography (HPLC) (Mattice *et al.,* 1999), water extraction method (Ahn and Chung, 2000; Kaworu *et al.,* 2001), and agar medium selection (Fuji, 1992; Wu *et al.,* 1999) have been reported and tested for bio-assays. To determine possible allelochemical agents, a variety of techniques are used. The development of chemicals, chromatographic and mass spectrometric methods have allowed for easier identification of the variety of chemicals used in allelopathy by plants using gas chromatography, volatiles can be identified from various sources. Study of rice allelochemicals by thin layer chromatography was conducted on silica gel plates using various solvents. Then column chromatography was performed on silica gel and C-18 solvents. Identification of the pure compounds used nuclear magnetic resonance mass spectroscopy. Fractions were analyzed by gas chromatography- mass spectroscopy with a film capillary column and the carrier gas used was helium (Rimando, 2001).

High-performance liquid chromatography (HPLC) is widely used for the analysis of phenolic compounds. Adom *et al.* (2002) determined the free, soluble conjugate bound ferulic acid content of rice, wheat, corn and oat using HPLC and compared the total content of free and bound phenolic acids using the folin-ciocalteu method. Nishizawa *et al.* (1998) reported the bound ferulic acid content in well milled rice, well milled rice with embryo and brown rice using alkaline hydrolysis and HPLC analysis, Ayumi *et al.* (1999) analyzed and quantified free ferulic and p-coumaric acid as well as bound ferulic. p-coumaric and 5,5' diferulic acid contents in 21 *japonica* cultivars (*Oryza sativa*) of rice bran and polished rice by HPLC with a photdiode array detector. Bunzel *et al.* (2002) evaluated several bound hydroxycinnamic acid, hydroxybenzoic acid and phenolic aldehyde contents in insoluble wild rice fiber.

Lee *et al.* (2003) compared four methods (relay seedling, ratooning, straw meal mixtures and hydrponic culture) for quicker mass screening of 39 rice varieties from *japonica* types (7 including asominori) and Indica types (32 including AC1423) for allelopathic potential against barnyard grass. These studies suggest the potential to develop and utilize the allelopathy to suppress barnyard grass through plant breeding. p-hydroxy-benzoic, vanillic, p-coumaric and ferulic acids are most common inhibitory allelopathic compounds in plants. Few investigations have identified allelopathic compounds in rice.

Using a laboratory bioassay called the relay seedling technique, rice varieties suppressing *E. crus galli* in the field have significantly reduced the root length of *E. crus galli* under laboratory conditions (Olofsdotter and Navarez, 1996). This technique has been routinely used in screening hundreds of rice varieties at IRRI for allelopathy, resulting in the identification of several accessions with strong allelopathic potential.

The results of laboratory screening for allelopathic activity of rice cultivars are not always applicable to the field because other components of plant competition play a more important role in the total interference between crop and weeds and these factors can not be differentiated directly in the field (Kim *et al.,* 2005).

Very limited knowledge exists on allelopathy genetics. Moreover, no international breeding effort has been made to genetically improve the allelopathic potential of crops, mainly because of our poor knowledge of this phenomenon. The recent work conducted by Jensen *et al.* (2001) on quantitative trait loci (QTL) mapping using 142 DNA markers were located in 142 recombinant inbred lines derived from a cross between cultivar IAC 165 (*japonica* upland variety), which has strong allelopathic potential and cultivar Co 39 (indica irrigated variety), which has weak allelopathic potential. Three main loci, each accounting for about 10% of the regulation of allelochemical production were localized to rice chromosome 2 and 3. The two QTL traits on chromosome 3 were closely linked, so they could easily be manipulated. Although QTL for allelopathic effect against barnyard grass were identified it is not presently known what kinds of gene are responsible for the allelopathic effect or the production of allelochemicals proteomics are an effective tool for physiological and genetic studies in rice allelopathy. Proteomics can contribute to the identification of positional, functional and expressional genes (Lin, 2000).

Materials and Methods

Chapter 3 MATERIALS AND METHODS

3.1.1 Experimental site

The field experiment in the present investigation was carried out at the Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar (Uttrakhand) during the rainy season of 2007-08. The laboratory experiments were carried out in the Department of Plant Physiology, College of Basic Sciences and Humanities, Pantnagar. Geographically, the site lies in the *tarai* plains about 30 km southwards of foothills of Shivalik range of Himalayas at 29°N latitude, 79°29′E longitude and at an altitude 243.8 metre above the sea level.

3.1.2 Climate and weather conditions

The *tarai* region experiences humid subtropical climate with hot dry summers and cool winters. Winter season extends from November to March. The monsoon sets during second or third week of June and continues till September end. Winter may or may not receive few showers.

The weather parameters like minimum or maximum temperature, relative humidity and rainfall during the period of experimentation, recorded at the meteorological observatory located at Crop Research Centre are presented in Appendix Ia and Ib.

3.1.3 Source of chemicals

The chemicals used in the present investigation were of analytical grade and were obtained from different sources mentioned below.

E. Merck (India) Ltd., Mumbai	:	Sodium carbonate, chloroform, methanol (HPLC grade), sulphuric acid, nitric acid, hydrochloric acid, calcium chloride. Potassium nitrate, calcium nitrate tetra hydrate, magnesium sulfate hepta hydrate, potassium chloride, ferrous sulfate and
Hi-Media Lab Pvt. Ltd., Mumbai	:	Ferulic acid, salicylic acid, resorcinol, gallic acid, p-hydroxybenzoic acid and cinnamic acid.
Sigma Aldrich (U.S.A.)	:	EDTA, vanillic acid, syringic acid, stearic acid etc.
SRL (Mumbai)	:	Acetonitrile (HPLC grade), Methanol (HPLC grade), Diethyl ether.
Waters	:	Sep Pak (C-18) columns
AnalR (S.D. Fine-Chem. PVF Ltd., Boisar)	:	Glacial acetic acid
Lobachemie (Mumbai)	:	Distilled water (HPLC grade)

3.1.4 Equipments and glasswares

The glassware and equipment used were as follows:

Glassware	:	Schot Duran, Germany; Borosil, Bombay, India
Single Pan Electric Balance	:	K Roy & Co., Varanasi, India

Digital pH metre	:	Electronic Coorporation of India Ltd.
Hot Air Oven	:	Narang Scientific Works Pvt. Ltd., New Delhi, India
UV-Visible Spectrophotometer	:	Milton Roy Spectronic 1201, India
Portable Leaf Area Meter	:	LICORL1 3000A, USA
Centrifuge	:	Remi C-24, Remi Instruments Ltd., Mumbai, India
Refrigerator	:	Godrej, India
Micropipette	:	Nicipet, Japan
Eppendorf	:	Tarson, India
Centrifuge tube	:	Tarson, India
Syringes	:	Hamilton
BOD incubator	:	Popular Trading Co., Ambala Cant
Deep Freezer	:	Vestfrost
HPLC	:	Shimadzu, Japan
Magnetic Stirrer	:	Atto, Japan
Water Bath Shaker	:	Narang Scientific Works Pvt. Ltd., New Delhi

3.1.5 Rice cultivars

Five rice cultivars *viz.,* Pant Sugandha Dhan 15, Pant Sugandha Dhan 17, Pant Dhan 18, Govind and Pusa 44 were used in the present experiment to study their relative competitiveness against weeds. The seeds of all the varieties were obtained from Department of Genetics and Plant Breeding, Pantnagar, U.S. Nagar (Uttarakhand).

Pant Sugandha Dhan 15

This variety has been developed through single plant selection from a population of NIRI 145-153, which was developed from Cross Bas 370/Sadari//Baharal/Muskan 41. The plants of this variety are semi-tall and it matures in 135-140 days. The average yield is 35-40 q/ha. The kernels are long slender, white, aromatic and free from chalkiness. Non-chalkiness is a highly desirable trait for export purposes. The amylase content and gelatinization temperature of this variety is medium.

Pant Sugandha Dhan 17

This is a new variety of basmati rice released in 2004 by Uttarakhand State Variety Release Committee. This has been developed from a cross between Pusa Basmati 1 and UPRI 95-154. The average yield of this variety is 40-45 q/ha. This matures in 135-140 days. The height of the plant is 115-120 cm. The kernels are white, long slender and aromatic.

Pant Dhan 18

This is a new variety of rice. Pant Dhan 18 (UPRI 99-1) is released by CVRC in April 2007 for irrigated ecosystem. This variety is mainly grown in the states of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Bihar, Chattishgarh and West Bengal. The average yield of this variety is 62-65 q/ha. This matures in 130-135

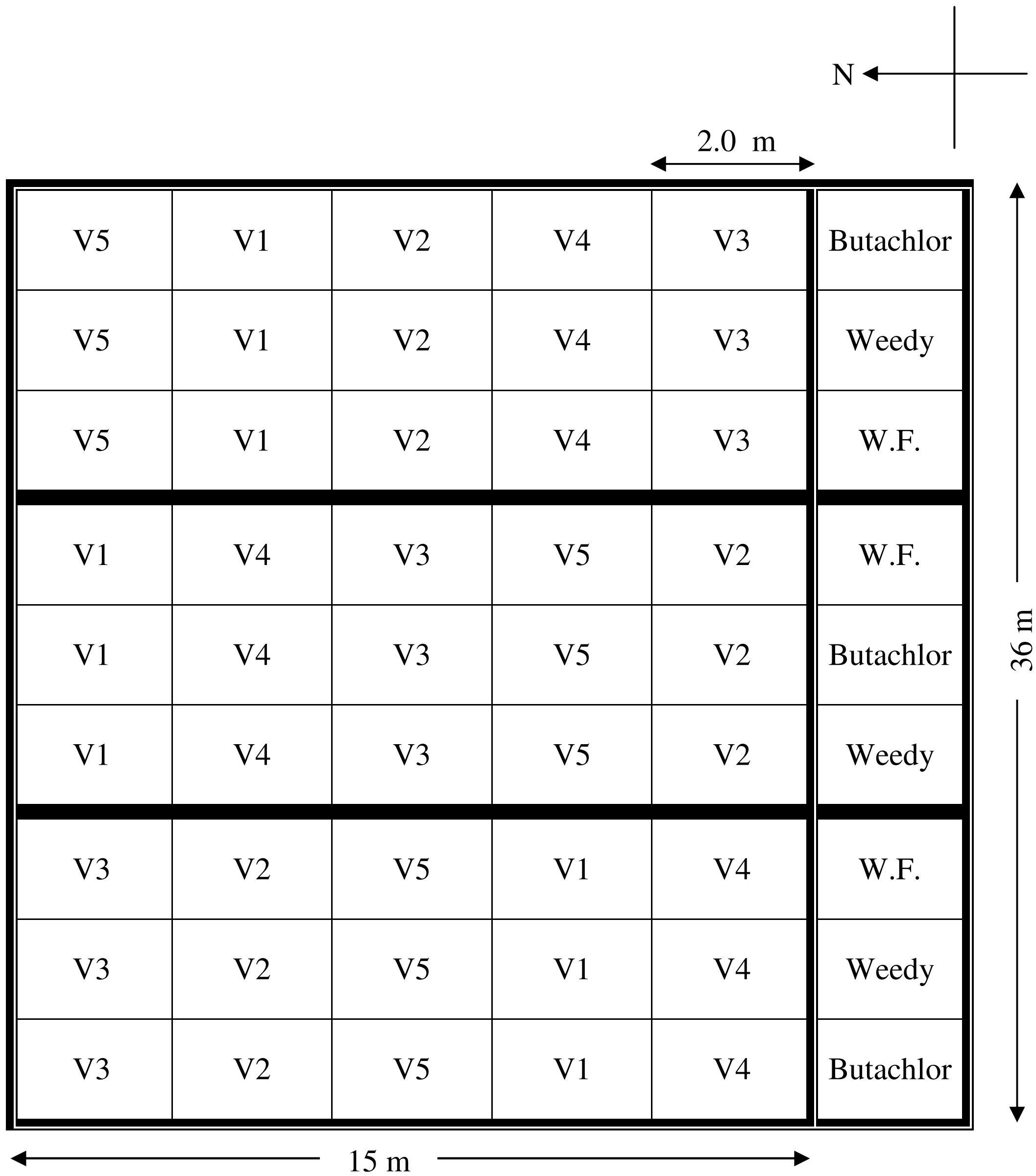
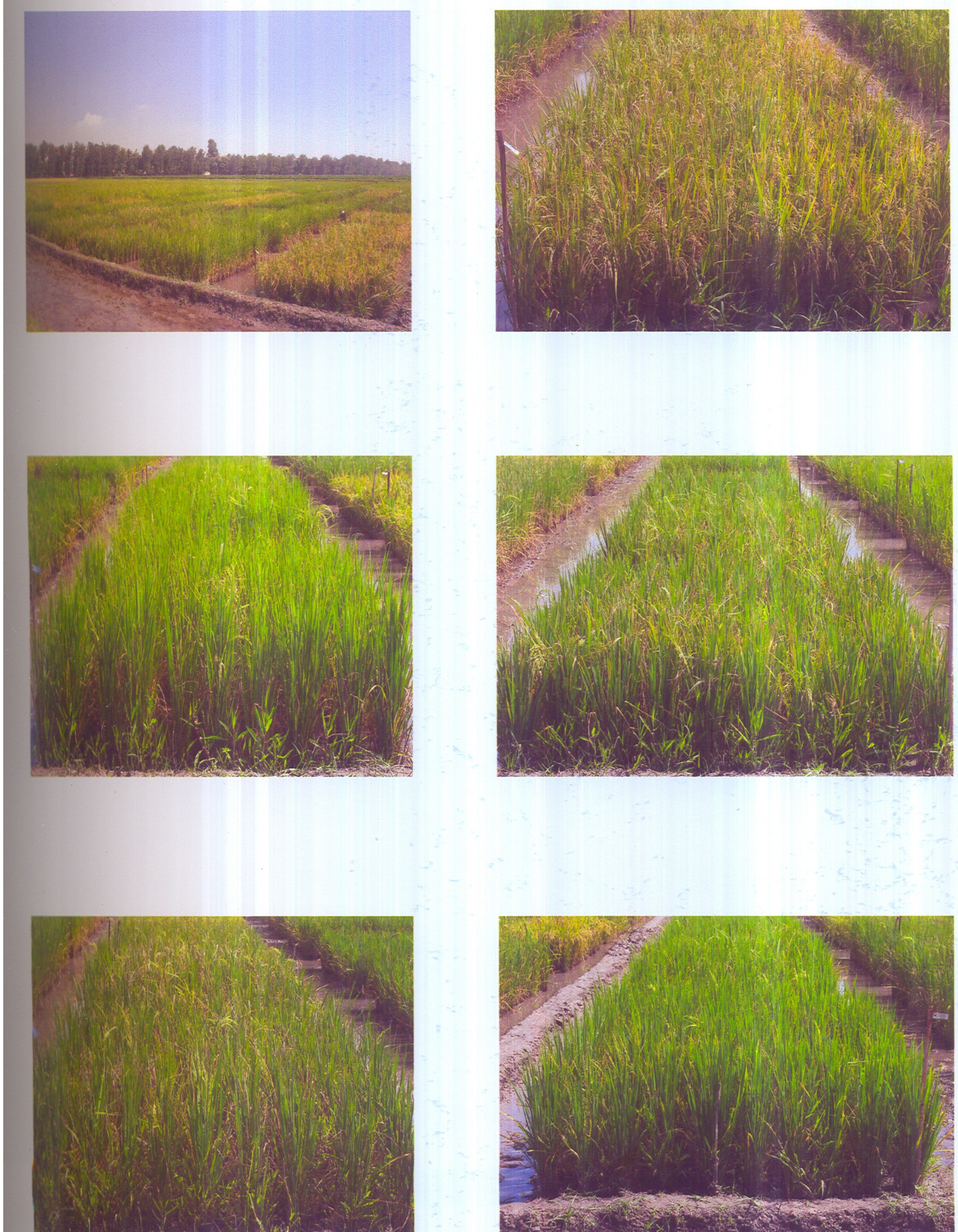


Fig. A : Plan of layout of the experimental field

Details of the treatments

Varieties :	V_1	-	Pant Sugandha Dhan 15
	V_2	-	Pant Sugandha Dhan 17
	V_3	-	Pant Dhan-18
	V_4	-	Govind
	V_5	-	Pusa 44
Replications		-	Three
Treatments		-	3 (weedy, weed free, butachlor)
Spacing		-	Row tow row : 20 cm
			Plant to plant : 10 cm
Plot size		-	3.0 m × 2.0 m
Herbicide application-			3 DAT (Butachlor @ 1.5 kg a.i./ha)



Photoplate 3.1: Layout of Experimental field with five rice cultivars, Crop Research Center, Pantnagar

days. The grains are long slender this variety have higher degree of resistance to leaf and neck blast diseases.

Govind

This is an early maturing variety developed from the cross IR20/IR 24. The grains are long slender and panicles are tip awned. In the valleys and lower hills this variety matures in 115-120 days and gives an average yield of 40-45 q/ha. Recently this variety has also moved to Punjab and Haryana due to very early maturity and long slender grains. In Punjab and Haryana it is known as 'Govinda'.

Pusa 44

This is a semi dwarf variety having coarse grains and yielding ability of 45-50 q/ha. This variety was released from IARI (Indian Agriculture Research Institute) New Delhi.

3.1.6 Field experiment

3.1.6.1 Experiment to study competitiveness of cultivars

A field experiment to study cultivar competitiveness was conducted during the rainy seasons of 2007 and 2008. The experiment was laid out in a split plot design (SPD) with three weed control methods as the main plot treatment and cultivars as the sub-plot treatment. Seedbeds were prepared in nursery by dry bed method. A day before sowing, the beds were flooded with water and

RIII	V3**T2**	V4	V3**T4**	V4	V3**T3**	V4	V3**T5**	V4	V3**T1**	V4
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
RII	V2**T3**	V1	V2**T5**	V1	V2**T1**	V1	V2**T2**	V1	V2**T4**	V1
	V4	V3	V4	V3	V4	V3	V4	V3	V4	V3
RI	V3**T4**	V4	V3**T2**	V4	V3**T5**	V4	V3**T1**	V4	V3**T3**	V4
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2

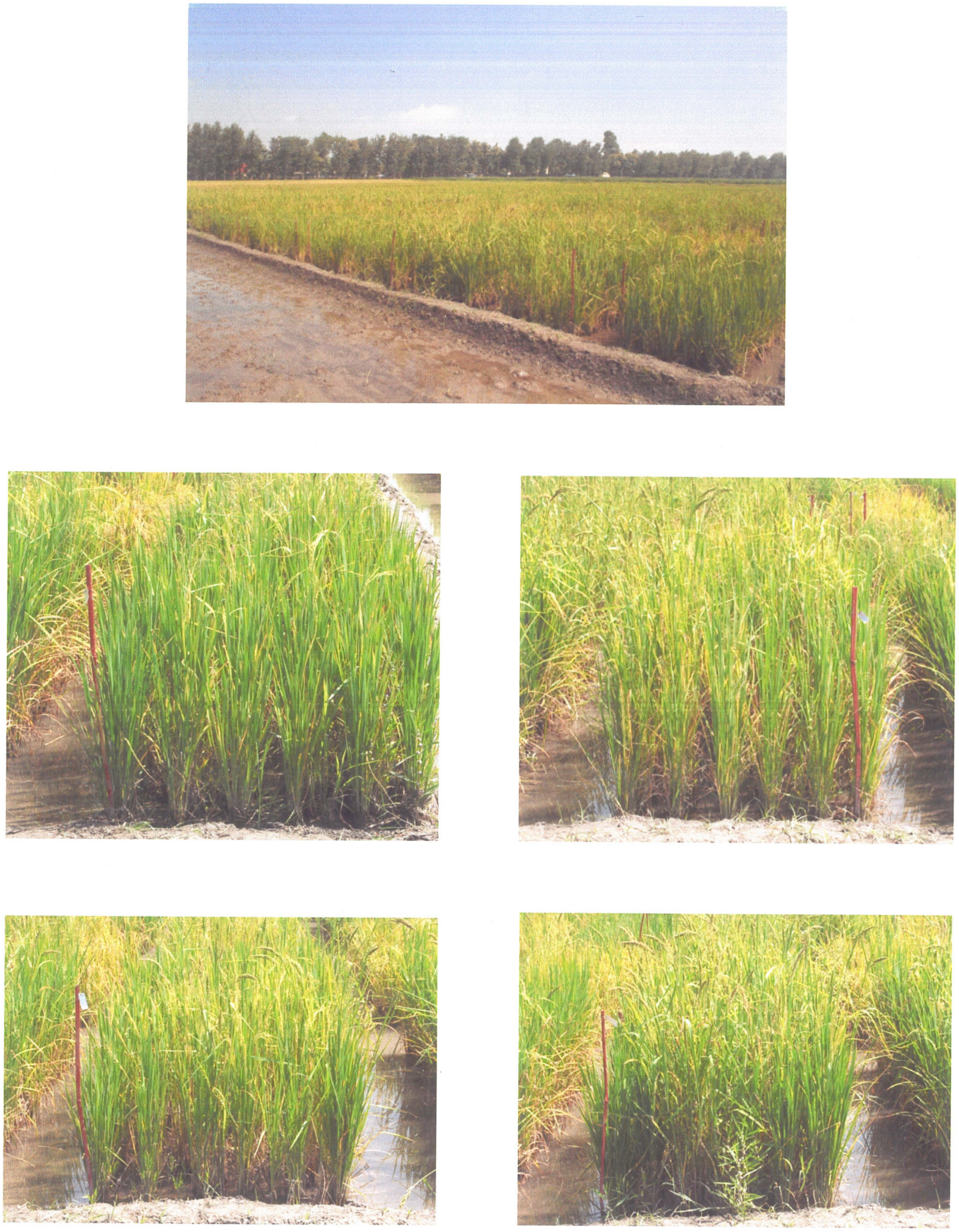
Treatments: T1 100g/m2
T2 200g/m2
T3 500g/m2
T4 Buta 1b 2, 4-D
T5 Weedy

Plot size: 3.0m (EW) X2.8m (NS)

Fig. B : Plan of Layout of the experimental field

Details of the treatments

Varieties :	V_1	-	Plant Sugandha Dhan 15
	V_2	-	Pant Dhan 18
	V_3	-	Govind
	V_4	-	Pusa 44
Replications		-	3
Treatments		-	5
	T_1	:	100 g/m^2 rice straw
	T_2	:	200 g/m^2 rice straw
	T_3	:	300 g/m^2 rice straw
	T_4	:	3 DAT (Butachlor @ 1.5 kg a.i./ha)
	T_5	:	Weedy
Spacing		-	Row to row : 20 cm
			Plant to plant : 10 cm
Plot size		-	3 m (EW) × 2.8 (NS)
Herbicide application-			3 DAT (Butachlor @ 1.5 kg ai/ha)



Photoplate 3.2 : Effect of rice straw incorporation into the soil on weed flora and crop yield in rice (Crop Research Centre, Pantnagar)

puddle the following day. After sowing, the seedbeds were kept saturated initially upto a week and then submerged to about 5 cm throughout. The main field was harrowed and cross-harrowed in dry conditions. 30 day old seedlings were transplanted in small plots (size 2.0 × 3.0 m) with row-to-row distance of 20 cm and a plant-to-plant distance of 10 cm. During the growth of the crop, weeds were removed manually in the hand weeding treatment, as and when they appeared. After three days the butachlor @ 1.5 kg/ha was sprayed in the butachlor plots.

3.1.6.2 Field experiment to evaluate effects of rice straw incorporation on weed flora

Another field experiment was conducted during the rainy season of 2008 to study effect of incorporation of rice straw residues at different rates into the soil of application for controlling weeds in rice (*Oryza sativa* L.) prior (about two week) to transplanting. The experiment was laid out in a split plot design (SPD) with different concentrations of rice straw as the main plot treatment and cultivars as the sub-plot treatment. Four out of five cultivars used in the first experiment were used here. Transplanting was done after 30 days in small plots of size 3.0 m (EW) × 2.8 (NS) size. During transplanting, a plant to plant distance of 10 cm and row to row distance of 20 cm, followed the same method as the previous experiment.

Harvesting was done manually when more than 90% of the grains in the panicle were fully matured and free greenish tint. The individual replication of each variety from each treatment was harvested manually. The product of individual variety was threshed by Pullman threshers after harvesting.

3.2 Laboratory experiment: Effect of synthetic phenolic acids and rice straw residues on weed seed germination

3.2.1 Effect of different phenolic compounds on germination of weed seeds

The effect of six synthetic phenolic compounds, alone or in combination on the germination behaviour of eleven weed species *viz., Echinochloa crusgalli, Echinochloa colona, Commelina banghalensis, Ischaemum rugosum, Celosia argentia, Celomon viscosa, Caesulia axillaris, Cyperus rotundus, Cyperus iria*, *Cyperus difformis* and *Leptochloa chinensis* was studied in laboratory using glass petri plates. Seeds of the weed species were collected from the Weed Control Laboratory, and then surface sterilized in 10% (v/v) hydrogen peroxide solution for 10 min, rinsed with deionized water and then washed 4-5 times with distilled water. Fifteen seeds of each weed species were transferred onto a layer of cotton in the petri plates. A thin layer of agar was laid below the cotton layer so as to keep the cotton pad moist. $CaCl_2$ (0.1 M) was poured into each petriplate to prevent leaching losses of seeds. The petri plates were then covered with a layer of perforated, transparent polythene sheet and kept either at room temperature. In the incubator, temperature was maintained at 27±2°C. Seed germination was recorded after 7-15 days depending upon the species. To study the effect of different synthetic phenolic compounds on the germination behaviour, 100 ppm solution each of *Gallic acid, Vanillic acid, Syringic acid, Ferulic acid, Salicylic acid* and *p-hydroxy benzoic acid* alone or in different combination were applied to the seeds at the starting of the experiment. The effect of these chemicals on the germination percentage was recorded. The treatments were replicated thrice.

3.2.2 Effect of ground rice straw on weed seed germination and development

3.2.2.1 Preparation of ground rice straw

To evaluate the effect of rice straw on the germination of weed seeds, dry ground rice straw was taken in Petri dishes on filter paper (Whatman No. 1). It was wetted by 10 ml of distilled water. The quantity of rice straw was three grams in each Petri dishes.

Seeds of six weed species as mentioned earlier. The weed seeds were laid over the wet rice straw and left to germinate at room temperature. The dishes were watered to keep it moist with distilled water as required. Distilled water was used as control. Data on germination (%), root and shoot length were recorded in 20 days.

3.2.2.3 Effect of dry ground straw and roots of five rice cultivars on weed seed germination and seedling growth

Dry ground rice straw (leaves and shoots) and rice roots were used for their biological activity on weed seeds. Rice straw and roots of 30 DAT and 45 DAT were dried and ground separately in a grinder. The powder of shoots and roots were obtained.

Rice straw and roots powder were laid over the soil layer in small pots. Each pot contained 3 g of powder form of straw and roots separately.

To evaluate the allelopathic potential of straw and roots on weed seed germination & growth. The seeds of weed species, viz. *Echinochloa crusgalli, Echinochloa colona, Commelina benghalensis, Ischaemum rugosum, Caesulia axillaris, Cyperus difformis* etc. were collected from CRC. The weed seeds (10 seeds/per pot) were placed in the pots. Data on germination (%) of root and shoot elongation (cm) were recorded within 20 days of the experiment. The length of roots and shoots of ten randomly selected different weed seedlings were measured. Three replications were done for each test.

3.2.3 Sand culture: (Donor-Receiver Bioassay) : Effect of rice seedlings of five cultivars on weed seed germination in sand culture

The autoclaved sand was used for laboratory bioassay. Firstly the autoclaved sand was kept into the Petri dishes. The seeds of 5 different rice varieties were surface sterilized in 70% (v/v) aqueous ethanol for 15 min, rinsed five times in distilled water and allowed to germinate on sand in Petri dishes. After the five-six days, the uniform rice seedlings were germinated at room temperature then the sterilized 10-12 seeds of different weed species were laid over the Petri dishes and allowed to germinate and grow with the rice seedlings at room temperature. The medium in the Petri dishes were kept at the same level by adding distilled water at 25 h intervals. On day fifteen, the length of roots and shoots of weed seedlings and germination percentage were measured. Control seedlings were incubated without rice seedlings at room temperature, each Petri dish contained five rice seedlings.

3.2.4 Hydroponics: Effect of root exudates of five rice cultivars grown in hydroponics on weed seeds germination and growth

3.2.4.1 Preparation of nutrient solution/Hoagland solution

One-fourth concentrations of Hoagland solution was prepared for the 200 litre water.

Hydroponics culture test (Einhelling, 1985) and bioassay

Seed of 5 different rice varieties were germinated and hydroponically grown for 14 days as described by Kato-Noguchi *et al.* (2002). Then the culture solution was filtered. To evaluate the allelopathic potential of rice root exudates, the culture solution was poured into the Petri dishes containing seeds of different weed species .On day 15, The germination percentage was recorded and the length of roots and shoot of weed seedlings were measured. Control seedlings were incubated without the culture solution. The Petri dishes were kept in the incubator at ±27°C temperature throughout the experiment.

3.2.5 Seedling vigour index (SVI)

Seeds of five rice cultivars were germinated in the pots and five seedlings from each replication of five different rice varieties were selected at randomly on the 14th day after germination and seedling length was measured. The same seedlings were dried at 80±1°C for 24 hours and weighed. The mean seedling length and dry weight were used for estimation of SVI in two different methods using the formula (Abdul Baki and Aderson, 1973).

1. SVI based on seedling length :

   SVI = Mean seedling length (cm) × Germination (%)

2. SVI based on seedling dry weight

   SVI = Mean seedling dry weight (mg) × Germination (%)

3.3 Observations

3.3.1 Field experiment

3.3.1.1 Weed flora

The weed flora of the experimental plots was recorded in each plot in the weedy and butachlor treated plots at 60 DAT. Their dry weights (air dried) were also recorded.

3.3.1.2 Morphological parameters of plant growth

Morphological parameters such as plant height and tiller number at different growth stages and panicle number at reproductive stage were recorded at regular intervals from five rice plants in each plot, tagged for that purpose. For measuring leaf area, leaf number and shoot dry matter production, three plants in each plot were harvested at random during each observation.

3.3.1.2.1 Plant height and tiller number

Height of the plants were measured in centimeter from soil level up to the base of top most fully expanded leaf until flowering and there after height was measured up to the base of panicle (Neck-node joint). Plant height and tiller numbers were recorded at 30, 45 and 90 DAT.

3.3.1.2.2 Number of panicles

Total number of panicles per plant was recorded at the time of harvest.

3.3.1.2.3 Shoot dry matter production and partitioning

Dry matter production and its partitioning into different plant parts were recorded from time to time. The plant samples were collected and then separated into stem and leaf. The separated plant parts were kept in paper bags and dried in an oven at 90°C for 48 hr. Dry weight of the plant parts was measured with the help of a balance and expressed as g/plant.

3.3.1.2.4 Leaf area

The leaf area of three random plants in each plot for each replication was measured using a portable leaf area metre (LiCOR LI-3000A) at 30, 45, 60 and 90 DAT and was expressed as cm^2/plant.

3.3.1.3.5 Biological yield

Rice plants in one-metre square for each plot were uprooted from the ground level at maturity, bundled and labeled and after sufficient drying the weight of intact bundle was determined before threshing. The total plant weight per square meter was recorded as biological yield.

3.3.1.2.6 Grain yield

Total weight of grains in grams per m^2 (economic yield) was recorded for each treatment after harvest.

3.3.1.2.7 Harvest index

The harvest index was calculated by using the standard formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.3.1.3 Physiological growth parameters

Physiological growth parameters as mentioned below were calculated by using the data on leaf area and shoot dry matter, recorded as mentioned earlier. Parameters such as RGR, NAR, SLW, SLA, LAR, LWR, RLGR and RLAGR were calculated using the following formulae.

a) Relative growth rate (RGR)

The increase in dry weight per unit original dry weight of the plant per unit time is called relative growth rate. The RGR was calculated according the following formula (Leopold, 1964).

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

where,

W_1 = dry weight of the whole plant at start of the test period.

W_2 = dry weight of whole plant at the end of the test period.

(t_2-t_1) = period in weeks between initial and final observations.

b) Net assimilation rate (NAR)

NAR is the increase in weight of dry matter of a plant per unit leaf area per unit time. It was calculated according to the following formula.

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\ln A_2 - \ln A_1}{A_2 - A_1}$$

where,

W_1 = dry weight of the whole plant at start of the test period.

W_2 = dry weight of whole plant at the end of the test period.

A_1 = total leaf area of the whole plant at the start of the test period.

A_2 = total leaf area of the whole plant at the end of the test period.

(t_2-t_1) = period in weeks between initial and final observations.

c) Leaf area ratio (LAR)

LAR is defined as the ratio between leaf area (A) and total plant dry weight (W). It reflects the leafiness of the plant.

$$LAR = \frac{A}{W}$$

d) Specific leaf weight (SLW)

SLW is the ratio between leaf dry weight (W_L) and leaf area (A). It gives as an idea about the thickness of the leaf.

$$SLW = \frac{W_L}{A}$$

e) Specific leaf area (SLA)

SLA is the ratio between leaf area (A) and leaf dry weight (W_L).

$$SLA = \frac{A}{W_L}$$

f) Relative leaf growth rate (RLGR)

The grain in dry weight per unit original leaf dry weight per unit time is called relative leaf growth rate. The RLGR is calculated according the following formula :

$$RLGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

where,

W_1 = dry weight of the leaf at start of the test period.

W_2 = dry weight of the leaf at the end of the test period.

(t_2-t_1) = period in weeks between initial and final observations.

g) Relative leaf area growth rate (RLAGR)

The gain in leaf area per unit original leaf area per unit time is called relative leaf area growth rate. RLAGR was calculated according to he following formula :

$$\text{RLAGR} = \frac{\ln A_2 - \ln A_1}{t_2 - t_1}$$

where,

A_1 = leaf area of the whole plant at start of the test period.

A_2 = leaf area of the whole plant at end of the test period.

(t_2-t_1) = period in weeks between initial and final observations.

3.3.2 Biochemical parameters

3.3.2.1 Sampling

Biochemical parameter such as phenol contents of the rice species were estimated at different dates of sampling mentioned earlier.

3.3.2.3 Estimation of total phenol content

Extraction and quantification of total phenol was done at three different stages of five different rice cultivars using the procedure described by Sadasivam and Manickam (1997).

Reagents

Ethanol	:	80%
Folin ciocalteau reagent	:	Commercially available reagent was used
Sodium carbonate	:	20% (w/v) in distilled water

3.3.2.3.1 Extraction of total phenols

Shoot or root samples, one gm each were ground in 10 ml of 80% ethanol. The extract was centrifuged at 10,000 rpm for 20 min. The supernatant was saved and the residue was re-extracted with 5 times the volume of 80% ethanol, centrifuge and pool the supernatant. The supernatant was evaporated to dryness and the residue was again redissolved in 5 ml distilled water and 0.5 ml aliquot was used for estimation of phenols.

3.3.2.3.2 Estimation

To 0.5 ml sample, 2.5 ml of distilled water was added to make the final volume 3 ml. To this, 0.5 ml Folin's reagent was added and the mixture was incubated for 3 min at room temperature. After the incubation, 2 ml of 20% sodium carbonate solution was added, mixed thoroughly and cooled and placed in boiling water bath for exactly one min. absorbance was recorded at 650 nm. Prepared a standard curve by using different concentration of catechol. Standard concentration of catechol 1mg/1 ml. the amount of total phenols was estimated form the standard curve and expressed as mg phenol/gm fresh weight.

3.3.2.4 Estimation of phenols and characterization/profiling by using High Performance Liquid Chromatography (HPLC)

Extraction of the total phenolics from the rice shoot and root samples was carried out by the method outlined by Harborne (1973). Fresh rice root (60 DAT) was slightly crush in pestle mortor and rice dry shoot samples were ground in grinder. One gram root/shoot sample of each rice variety were treated with 12.5 ml 2N HCL separately and heated in water bath for 30 min and filtered. The filtrate was cooled and taken into a separatory funnel and was extracted thrice with equal volumes of diethyl ether. The combined ether fractions were washed twice with equal volumes of glass distilled water and dried over anhydrous Na_2SO_4. Ether was evaporated in desiccators.

3.3.2.4.1 HPLC analysis of phenolic compounds

Separation of phenolics was achieved by a slight modification of the method outlined by Ramakrishna *et al.* (1989). Authentic compounds, namely ferulic acid, gallic acid, p-hydroxybenzoic acid, resorcinol, vanillic acid, syringic acid, cinnamic acid and hydroquinone were used for HPLC analysis. HPLC grade solvents and distilled water were used for HPLC and degassed before use. Solvent ratios are expressed on a volume basis. The dried phenolic residue was dissolved in 2 ml water: methanol (75: 25, v/v). Prior to analysis the samples were filtered through 0.22 μm flour pore filters (Millipore) before injecting into the HPLC column. Twenty μl samples were injected into HPLC column for analysis using a micro Hamilton syringe. Absorbance was recorded at 254-280 nm with PDA (Photo-diode-anode) detector.

Conditions

Column	:	C_{18} reverse phase
Mobile phase	:	Acetonitrile: Water: Acetic acid (85:12:3)
Flow rate	:	1 ml/min
Detector	:	Photo-diode-anode detector
Range (λ max)	:	254-280 nm

Standards

Phenols standards were prepared in the organic solvent methanol. The stock solution of each standard was prepared in methanol (1 mg/1 ml). Different concentration of each standard was prepared in the mobile phase acetonitrile : water (85: 15) i.e. 1, 2, 3, 5, 10 and 50 ppm, etc. In order to identify peaks in the standard mixtures, the compounds were first chromatographed individually followed by the mixtures form.

Statistical analysis

The data obtained from field trials during the course of present investigation were analyzed statistically by using split plot design (SPD) and laboratory experiment was analyzed by completely randomized design (CRD). Standard error of means (S.Em.±) and critical difference (CD) was evaluated at 5% level of significance.

Experimental Results

I. Field experiments

4.1 Competitive ability of five rice cultivars against weeds

Effect of cultivars and weed treatments on weed flora and plant growth and yield of five rice cultivars.

4.1.1 Weed flora

The weed flora at 60 DAT in the experimental field during both the seasons is presented in Table 4.1a and 4.1b. In the both the seasons, experimental area was infested with grasses, broad leaves weeds and sedges. During both the seasons major grassy weeds such as *E. crusgalli, E. colona, L.chinensis* and *I. rugosum* and in bLWs includes *C. axillaris, Mollago pentaphyla* and in sedges*, F. miliaceae.* Among the sedges *C. iria, C. difformis* in 2007 where as C*. rutondus* dominated in season 2008, and in bLWs *A. basifera and* minor weeds *Eclipta alva, C. benghalensis* dominated in 2008. The weed population was highest in weedy treatment as compared to Butachlor treatment in both the years. During both the seasons maximum weed population was recorded in cv. Pant Sugandha Dhan 17 followed by Govind and lowest in Pusa 44 in 2007, where as in 2008, lowest recorded in cv. Pant Sugandha Dhan 15.

Table 4.1a: Effect of cultivars and weed treatments on weed population at 60 DAT (no.m²) during 2007

Variety	Weed species / Treatment	*E. crusgalli*	*E. colona*	*Leptochloa chinensis*	*caesulia axillaris*	*Frimbristylis milliaceae*	*Cyperus rotundus*	*Cyperus iria*	*Cyperus difformis*	*Ischaemum rugosum*	*Mollugo pentaphyla*	*Commelina benghalensis*	Total no. of weeds in each treatment
Pant Sugandha Dhan 15	B	12	20	8	24	–	8	–	8	–	–	–	80
	W	36	12	4	30	4	12	12	–	–	24	4	138
Pant Sugandha Dhan 17	B	12	8	–	4	–	4	–	–	4	4	8	44
	W	40	30	4	8	12	20	4	44	–	24	–	186
Pant Dhan 18	B	24	–	8	8	4	–	–	–	–	4	–	48
	W	12	20	–	–	12	4	4	–	12	20	4	88
Govind	B	–	20	8	16	–	–	–	12	4	4	–	64
	W	32	28	–	24	8	4	16	8	8	40	–	168
Pusa 44	B	24	4	4	4	–	4	–	12	–	8	–	60
	W	20	12	–	8	12	8	–	–	–	16	–	80
Total		212	154	36	126	52	64	36	84	28	144	16	

B = Butachlor; W = Weedy

Table 4.1b : Effect of cultivars and weed treatments on weed population at 60 DAT (no./m²) 2008

Variety	Weed species / Treat-ment	*Echinochloa crusgalli*	*Echinochloa colona*	*Leptochloa chinensis*	*Caesulia axillaris*	*Frimbristylis milliaceae*	*Ammania basifera*	*Paspalum scrobiculatum*	*Ischaemum rugosum*	*Cyperus rotundus*	*Eclipta alva*	*Mollugo pentaphyla*	*Commelina benghalensis*	Total no. of weeds in each treatment
Pant Sugandha Dhan 15	B	–	16	–	12	–	12	–	–	–	–	–	8	48
	W	8	8	12	8	–	12	–	4	4	–	–	4	60
Pant Sugandha Dhan 17	B	4	16	8	16	–	–	–	12	12	12	–	–	80
	W	8	18	16	32	–	32	–	12	12	16	–	–	146
Pant Dhan 18	B	–	16	–	28	–	16	8	–	–	–	–	–	68
	W	20	8	20	–	–	32	16	12	–	–	–	12	108
Govind	B	4	12	12	12	–	–	–	20	12	–	–	–	72
	W	8	4	12	20	–	12	–	16	20	–	–	20	112
Pusa 44	B	4	8	8	8	–	12	–	–	12	–	–	–	52
	W	8	8	12	20	8	4	–	4	12	–	12	–	88
Total		**64**	**114**	**100**	**156**	**8**	**132**	**24**	**80**	**84**	**28**	**12**	**44**	

B = Butachlor; W = Weedy

Table 4.2: Weed dry weight (g/m²) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	Weed dry weight (g/m²)	
	2007	**2008**
Weed control method		
Butachlor	29.32	35.63
Weedy	105.44	87.64
S.Em.±	2.07	2.47
CD (5%)	8.69	10.33
Cultivar		
PSD 15	79.55	62.90
PSD 17	94.80	81.43
PD 18	49.20	56.43
Govind	54.43	64.85
Pusa 44	58.70	42.50
S.Em.±	0.396	0.664
CD (%)	0.840	1.40

Table 4.2a: Interaction effect between weed control methods and cultivars on weed dry weight (g/m²) at 60 DAT of five rice cultivars during rainy season 2007 and 2008

Cultivar	Weed dry weight (g/m³)			
	2007		2008	
	Butachlor	Weedy	Butachlor	Weedy
PSD 15	31.10	128.00	35.60	90.20
PSD 17	40.40	149.20	61.86	101.00
PD 18	27.00	71.40	23.46	89.40
Govind	27.66	81.20	32.06	97.73
Pusa 44	20.00	97.40	25.20	59.90
S.Em.±	0.56		0.93	
CD (%)	1.18		1.99	

4.1.2 Weed dry weight (g/m²)

The weed dry weight at 60 DAT in the experimental field during both the seasons is presented in Table 4.2. In the weedy plots, maximum dry weight of weed (105.44 g/m^2 in 2007 and 87.64 g/m^2 in 2008) and minimum in Butachlor treatment (29.32 g/m^2 in 2007 and 35.63 g/m^2 in 2008) in both the year. Weed dry weight significantly differed among the treatment and cultivars in both the years.

In both the growing seasons, weed dry weight was found to be maximum in the cultivar Pant Sugandha Dhan 17 (94.80 g/m^2 in 2007 and 81.43 g/m^2 in 2008) while minimum weed dry weight in 2007 was recorded in Pant Dhan 18(49.20) and in 2008, it was minimum in Pusa44.Weed dry weight followed an overall order, Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 > Govind=Pusa44 > the least in Pant Dhan 18.

The mean value of weed dry weight at 60 DAT of five rice cultivars in each treatment is presented in Table 4.2a. Weed dry weight was highest in cultivar Pant Sugandha Dhan 17 in weedy and Butachlor treatments in both the years, while lowest in cv. Pusa44 in Butachlor and cv. Pant Dhan 18 in weedy plots in 2007,whereas in 2008, lowest in cv. PD18 in butachlor and cv. Pusa44 in weedy plots at 60 DAT.

4.1.3 Morphological parameters and yield components

4.1.3.1 Seedling Vigour Index (SVI)

SVI of five rice cultivars during 2008 is presented in Table 4.3.

Table 4.3 : Seedling vigour index (SVI) of five rice cultivars based on (a) mean seedling length and (b) mean seedling dry weight

(a) SVI based on mean seedling length

Cultivars	SVI
PSD 15	1037
PSD 17	968
PD 18	1125
Govind	1058
Pusa 44	1092

(b) SVI based on mean seedling dry weight

Cultivars	SVI
PSD 15	4250
PSD 17	3750
PD 18	6775
Govind	6650
Pusa 44	6600

Table 4.4: Plant height (cm) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30 DAT		45 DAT		60 DAT		90 DAT		Harvest	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Weed control method										
Butachlor	55.73	59.92	78.81	77.66	82.84	84.90	84.59	96.25	90.75	98.82
Weed free	60.24	62.17	80.63	80.58	84.28	88.25	87.54	98.49	92.16	99.92
Weedy	53.89	56.96	73.88	75.16	80.07	82.55	82.01	95.16	88.68	96.71
S.Em.±	1.39	1.13	2.33	1.08	1.34	1.85	1.01	0.70	0.122	0.50
CD (p = 0.05)	3.86	3.31	6.44	3.00	3.71	3.13	2.80	1.94	0.338	1.38
Cultivar										
PSD 15	57.00	61.60	78.40	83.66	85.51	95.64	91.15	115.81	100.16	117.33
PSD 17	63.08	65.46	81.86	76.95	87.44	86.71	88.34	96.39	93.34	99.26
PD 18	54.95	60.31	82.68	82.15	89.42	90.11	92.64	104.57	102.81	106.58
Govind	56.37	58.20	75.85	79.06	77.76	83.43	78.61	85.01	81.53	86.38
Pusa 44	51.68	52.84	70.06	67.17	71.85	70.28	72.82	81.37	74.81	82.85
S.Em.±	2.27	1.54	2.52	1.63	1.54	1.67	2.18	1.31	0.45	1.10
CD (p = 0.05)	4.68	3.18	5.21	3.37	3.19	3.18	4.50	2.70	0.93	2.28

Table 4.4a: Interaction effect between weed control methods and cultivars on plant height (cm) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	56.86	61.06	53.06	62.80	64.26	57.73	80.26	81.73	73.20	83.00	87.20	80.80
PSD 17	60.20	67.46	61.59	64.93	70.46	61.00	84.06	84.26	77.26	77.80	79.60	73.46
PD 18	52.46	58.46	53.93	60.53	63.26	57.13	84.00	85.06	79.00	81.60	85.46	79.40
Govind	55.86	61.20	52.06	57.26	59.73	57.60	75.86	81.23	70.46	79.40	82.33	75.46
Pusa 44	53.26	53.00	48.80	54.06	53.13	51.33	69.86	70.86	69.46	66.53	68.33	66.66
S.Em.±		3.93			2.67			4.37			2.83	
CD (p = 0.05)		8.11			5.52			9.03			5.85	

Table 4.4a: Contd...

Cultivar	60 DAT						90 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	86.60	87.20	82.73	96.80	100.30	89.80	91.66	95.40	86.40	115.86	117.53	114.06
PSD 17	86.33	88.19	87.80	85.46	89.06	85.60	86.19	89.56	89.26	93.93	97.80	97.46
PD 18	90.23	91.13	86.86	90.00	93.13	87.20	92.53	96.33	89.06	104.20	107.26	102.26
Govind	78.46	82.40	72.43	83.26	85.20	81.83	79.13	83.30	73.40	85.26	87.40	82.36
Pusa 44	72.56	72.46	70.53	69.00	73.53	68.33	73.43	73.10	71.93	82.00	82.46	79.66
S.Em.±		2.68			2.89			3.78			2.27	
CD (p = 0.05)		5.53			5.52			7.80			4.68	

Table 4.4a: Contd...

Cultivar	**Harvest**					
	2007			**2008**		
	Butachlor	**Weed free**	**Weedy**	**Butachlor**	**Weed free**	**Weedy**
PSD 15	100.40	103.46	96.63	117.60	119.00	115.40
PSD 17	93.53	94.00	92.50	98.46	101.06	98.26
PD 18	102.60	103.40	102.43	106.26	109.26	104.23
Govind	81.80	85.36	77.43	90.30	86.46	82.40
Pusa 44	75.46	74.56	74.40	81.46	83.80	83.30
S.Em.±		0.785			1.91	
CD (p = 0.05)		1.62			3.95	

(a) SVI based on mean seedling length

Among the five rice genotypes viz., PSD 15, PSD 17, PD 18, Govind, Pusa 44 and PD 18 (1125) had maximum seedling vigour followed by Pusa 44 (1092) and Govind (1058) and maximum was recorded in PSD 17 (968).

(b) SVI based on mean seedling dry weight

On the basis of seedling dry weight maximum SVI was recorded in cultivar PD 18 (6775) followed by Govind (6650), Pusa 44 (6600) and minimum was recorded in PSD 17 (3750).

4.1.3.2 Plant height (cm)

Plant height of the five rice cultivars recorded at different growing stages after transplanting up to harvest during both the seasons is presented in Table 4.4. During both the growing seasons plant height was highest in weed free and butachlor treatments as compared to weedy plots. Plant height increased from 30 DAT up to harvest in all the five rice cultivars and highest in cv. Pant Dhan18(102.81cm) in 2007 and cv. Pant Sugandha Dhan 15 (117.33 cm) in 2008 and lowest in Pusa 44 (74.81cm in 2007 and 82.85 cm in 2008)in both the years at harvest. Govind a dwarf cultivar, height at 30 DAT similar to the tall cultivars, where as height of Pusa 44 was lowest among all the cultivars.

In the first growing season (2007), plant height followed an order Pant Dhan 18 > Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17 >

Govind > Pusa 44. In the second growing season (2008) plant height followed an order Pant Sugandha Dhan 15 > Pant Dhan 18 > Pant Sugandha Dhan 17 > Govind > Pusa 44 at the time of harvest.

The mean value of height of all five rice cultivars in each treatment in both the seasons at different growing stages after transplanting is presented in Table 4.4a. The plant height differed significantly among cultivars and was highest in cultivar Pant Sugandha Dhan 15 (103.46 cm in 2007 and 119.00 cm in 2008) followed by Pant Dhan 18 (103.40 cm in 2007 and 107.26 cm in 2008) at harvest and lowest in cultivar Pusa 44 (75.46 cm in 2007 and 83.80 cm in 2008) at harvest. Cultivar Pant Sugandha 17 and Pant Dhan18 (tall cv.) and Pusa 44(semi-dwarf cv.) had no effect of weed control treatments where as cv. Pant Sugandha Dhan15(tall cv.) and cv. Govind had lower plant height in weedy treatments as compared to weed free treatment in both the seasons at harvest. Pant Sugandha Dhan 15, Pant Sugandha Dhan 17, Pant Dhan 18 and Govind maintained a higher plant height under weed free situations at all the growth stages as compared to the weedy plots but in Pusa 44, no difference between the treatments. The mean per cent reduction in the plant height in both the years in weedy situation was maximum for Govind (6.99) and Pant Sugandha Dhan 15 (4.81) and minimum for Pusa 44 (0.40), Pant Sugandha Dhan 17 (2.15) and Pant Dhan 18 (2.76).

Table 4.5: Tiller number per plant of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30 DAT		45 DAT		60 DAT		90 DAT	
	2007	2008	2007	2008	2007	2008	2007	2008
Weed control method								
Butachlor	9.46	10.30	13.28	15.11	15.45	18.84	13.37	16.77
Weed free	10.56	11.85	14.40	16.84	16.18	20.39	14.24	18.38
Weedy	8.33	8.77	11.83	13.88	13.42	16.24	11.74	14.32
S.Em.±	0.739	0.561	0.832	0.591	0.710	0.428	0.507	0.428
CD (p = 0.05)	2.04	1.55	2.30	1.63	3.03	1.18	1.40	1.18
Cultivar								
PSD 15	8.88	9.16	12.41	14.13	13.87	17.56	11.80	15.33
PSD 17	7.86	7.45	11.35	12.35	13.02	14.26	11.32	12.30
PD 18	10.76	12.67	15.06	18.01	16.92	21.58	15.41	19.71
Govind	9.53	10.98	12.97	15.15	15.22	19.01	13.10	16.97
Pusa 44	10.20	11.60	14.04	16.74	16.05	20.03	13.86	18.14
S.Em.±	0.677	0.886	1.12	0.855	1.00	0.717	0.853	0.728
CD (p = 0.05)	1.39	1.82	2.31	1.76	2.07	1.48	1.76	1.50

Table 4.5a: Interaction effect between weed control methods and cultivars on number of tillers/plant of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	8.80	10.00	7.60	9.60	10.40	7.36	12.20	13.96	11.06	13.66	16.96	11.76
PSD 17	8.00	9.26	6.33	7.50	8.00	6.80	11.76	12.13	10.16	12.26	13.70	1.10
PD 18	10.86	12.06	9.36	12.63	14.33	11.06	15.33	16.26	13.60	17.93	19.40	16.70
Govind	9.43	10.20	8.96	10.36	13.33	9.26	13.03	14.33	11.56	15.40	16.03	14.03
Pusa 44	10.20	11.00	9.40	11.36	13.13	10.30	14.06	15.30	12.76	16.30	18.13	15.80
S.Em.±		1.17			1.53			1.94			1.48	
CD (p = 0.05)		2.42			3.16			4.01			3.05	

Table 4.5a: Contd…

Cultivar	60 DAT						90 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	14.26	15.30	12.03	18.86	19.63	14.16	12.13	13.03	10.50	17.00	16.73	12.26
PSD 17	13.40	14.13	11.53	14.76	15.96	12.06	11.70	12.46	9.80	12.60	13.96	10.33
PD 18	17.36	17.76	15.63	21.33	23.36	20.06	15.36	16.40	14.46	19.26	21.40	18.46
Govind	15.73	16.13	13.80	19.10	21.26	16.66	13.16	14.23	11.90	16.76	19.96	14.20
Pusa 44	16.50	17.53	14.13	20.00	21.73	18.30	14.50	15.06	12.03	18.23	19.86	16.33
S.Em.±		1.73			2.56			1.47			1.26	
CD (p = 0.05)		3.59			1.19			3.05			2.60	

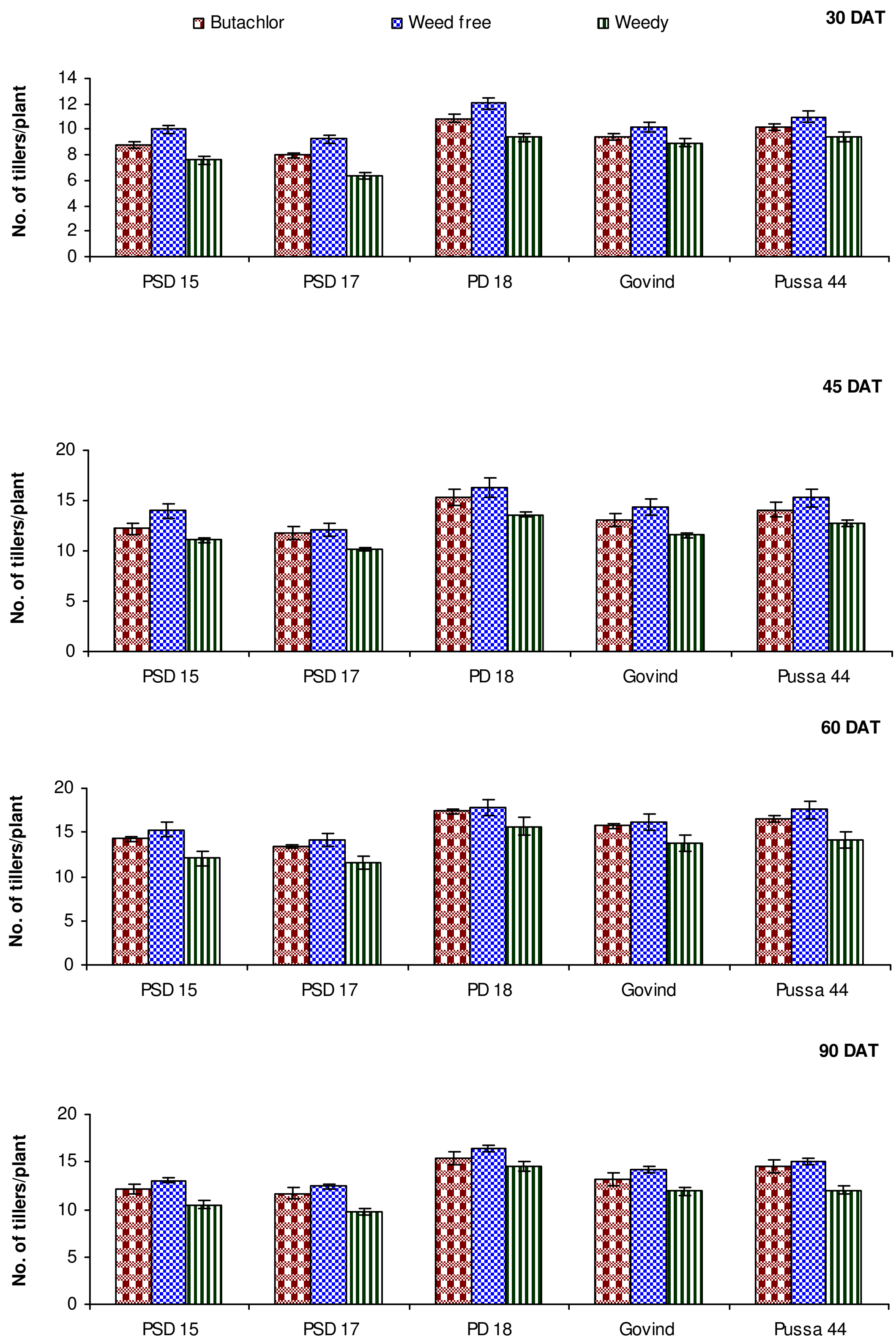


Fig. 4.1a: No. of tillers/plant of five rice cultivars at different growth stages during rainy season 2007

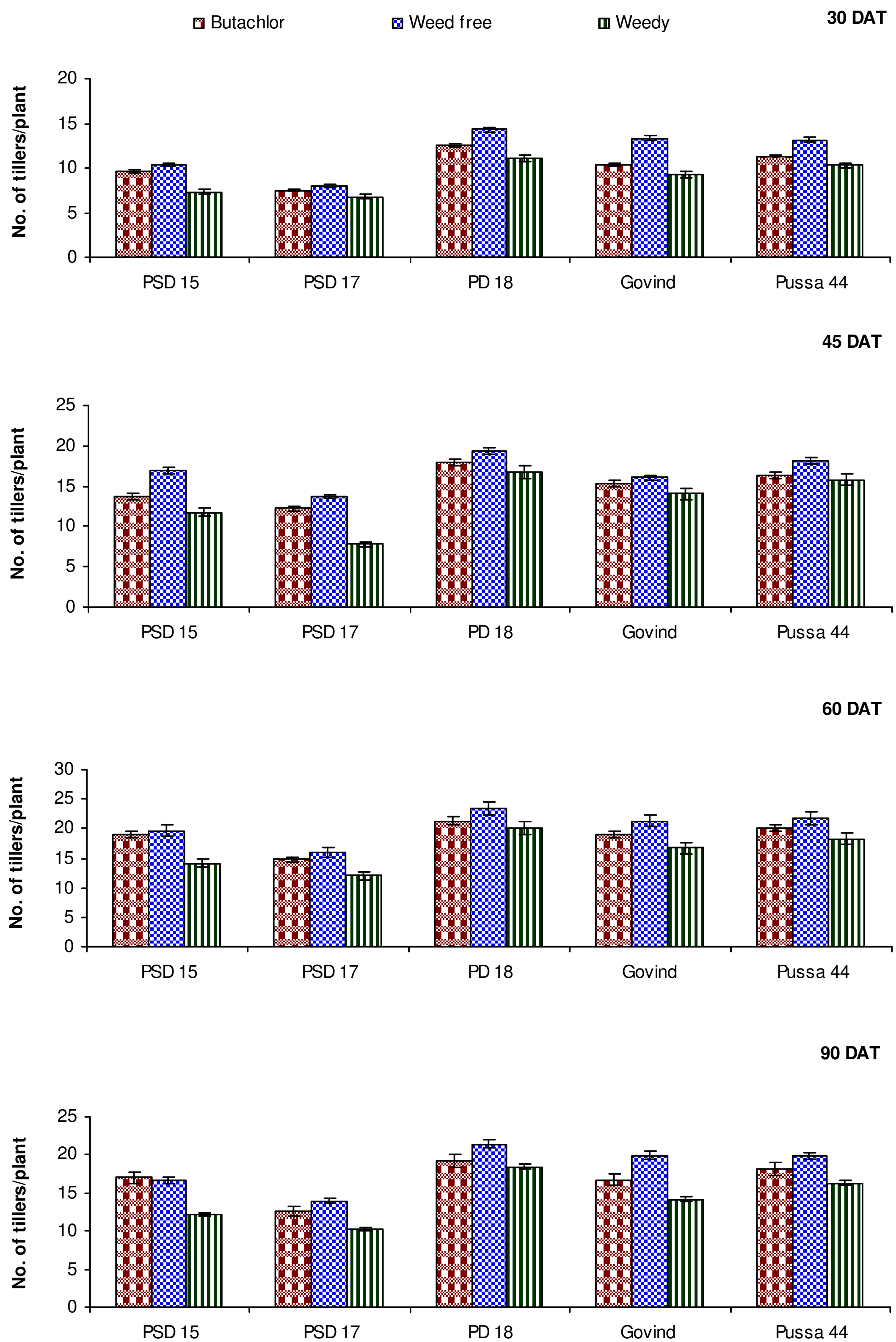


Fig. 4.1b: No. of tillers/plant of five rice cultivars at different growth stages during rainy season 2008

4.1.3.3 Tiller number per plant

Tiller number per plant of five rice cultivars recorded at different growing stages after transplanting in both the seasons is presented in Table 4.5. Tiller number gradually increased from 30 to 60 DAT and declined thereafter in both the years. During both the growing seasons tiller number was highest in weed free and butachlor treatments as compared to weedy plots at all the growth stages.

Tiller number was highest for cultivar Pant Dhan 18 (16.92in 2007 and 21.58 in 2008) lowest for cultivar Pant Sugandha Dhan 17 (13.02 in 2007 and 14.26 in 2008) at 60 DAT during both the seasons.

Cultivars Pant Dhan 18, Pusa 44 and Govind had higher number of tillers as compared to Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 at all the growth stages during both the seasons. The tiller number followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 at 60 DAT in both the years.the mean value of tiller numbers of five rice cultivars at different growth stages is presented in table 4.5a. Among the cultivars no effect of weed control treatments on number of tillers in 2007,where as in 2008, significant effect of weed control treatments on tiller numbers of all the cultivars at 60 DAT. Cv. Pant Dhan 18 and Pusa 44 had recorded highest number of tillers in weed free treatments at all the

Table 4.6: Leaf number per plant of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30 DAT		45 DAT		60 DAT		90 DAT	
	2007	2008	2007	2008	2007	2008	2007	2008
Weed control method								
Butachlor	32.26	45.30	52.00	60.43	58.10	65.52	49.63	55.32
Weed free	34.70	53.40	54.66	66.70	62.80	69.23	53.51	61.40
Weedy	30.13	41.13	47.74	59.96	55.06	63.04	44.30	53.08
S.Em.±	3.49	2.10	3.87	4.42	2.64	4.09	1.00	3.38
CD (p = 0.05)	9.66	5.81	10.70	12.23	7.32	11.32	2.78	9.36
Cultivar								
PSD 15	30.20	45.66	53.27	61.50	56.72	65.05	47.57	44.61
PSD 17	26.05	40.61	39.72	55.11	43.77	57.38	44.11	46.94
PD 18	37.20	53.44	58.73	73.00	66.72	75.74	59.94	70.85
Govind	33.30	51.55	51.55	58.55	59.05	62.66	38.61	57.05
Pusa 44	35.00	41.77	53.72	63.61	67.00	68.81	55.50	63.53
S.Em.±	2.49	5.33	5.24	5.98	3.67	3.55	2.26	3.52
CD (p = 0.05)	5.14	11.01	10.83	12.35	7.58	7.34	4.68	7.26

Table 4.6a: Interaction effect between weed control methods and cultivars on leaf number/plant of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	30.50	33.33	26.83	43.50	53.16	40.33	53.83	57.33	48.66	61.50	62.66	60.33
PSD 17	27.60	26.66	23.83	40.16	48.00	33.66	42.16	42.66	34.33	49.83	60.50	55.00
PD 18	37.50	38.66	35.50	52.33	63.16	44.83	60.16	61.33	54.66	70.50	75.66	73.00
Govind	31.00	38.00	31.00	50.50	59.16	45.00	51.16	55.33	47.83	58.00	65.66	52.00
Pusa 44	34.60	36.83	33.50	40.00	43.50	41.83	52.33	55.66	53.16	62.33	69.00	59.50
S.Em.±		4.32			9.245			9.09			10.36	
CD (p = 0.05)		8.91			19.07			18.76			21.36	

Table 4.6a: Contd…

Cultivar	60 DAT						90 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	57.00	60.50	52.66	67.00	64.66	63.50	46.66	52.40	43.66	46.50	48.66	38.66
PSD 17	46.33	45.50	39.50	57.00	63.16	52.00	47.16	48.50	36.60	40.16	55.83	44.83
PD 18	67.33	69.00	63.83	74.16	78.66	74.40	60.66	62.50	56.60	69.33	74.16	69.06
Govind	53.16	67.16	56.83	59.00	67.50	61.50	37.66	42.60	35.50	54.16	62.16	54.83
Pusa 44	66.66	71.83	62.50	70.43	72.16	63.83	56.00	61.50	49.00	66.43	66.16	58.00
S.Em.±		6.36			6.16			3.93			6.10	
CD (p = 0.05)		13.13			12.71			8.10			12.59	

growth stages as compared to the weedy plots. The mean per cent reduction was maximum for cultivar Pant Sugandha Dhan 17 (21.41) and Pant Sugandha Dhan 15 (24.7) and minimum for cultivar Pant Dhan 18 (13.00) and Pusa 44 (17.50) in weedy situation, while in Butachlor treatment; it was maximum for Pant Sugandha Dhan 17 (8.33) and minimum in Pant Sugandha Dhan 15 (5.1) and Pant Dhan 18 (5.40) at 60 DAT in both the years.

4.1.3.4 Leaf number per plant

Leaf number of five rice cultivars at different growth stages after transplanting during both the seasons is presented in the Table 4.6. Leaf number gradually increased from 30 to 60 DAT and declined thereafter in both the years. During both the seasons, leaf number was highest in weed free (62.80) and butachlor (58.10) treatments as compared to weedy treatment (55.06) at 60 DAT.

Leaf number was recorded highest for cv. Pusa 44(67.00) in 2007 and cv. Pant Dhan 18 (75.71) in 2008,where as lowest in cv. Pant Sugandha Dhan 17 (43.77 in 2007 and 57.38 in 2008) during both the years at 60 DAT . At 30 DAT leaf number was highest in cv. PD 18, Pusa 44 and Govind in year 2007, while in year 2008, highest in PD 18 and Govind than rest of the cultivars. The mean value of leaf number per plant of five rice cultivars at different growth stages is presented in table 4.6a. Leaf number not differed significantly among the cultivars. During all the growth stages cv. PD18, Pusa 44

Table 4.7 : Leaf area (cm²/plant) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Weed control methods	Leaf area (cm^2/plant)					
	30 DAT		45 DAT		60 DAT	
	2007	2008	2007	2008	2007	2008
Butachlor	369.25	482.17	780.04	912.56	1359.29	1652.79
Weed free	445.86	525.85	1026.50	934.60	1740.99	1874.97
Weedy	346.11	404.97	985.24	910.25	1430.94	1478.42
S.Em. ±	5.47	0.754	1.45	13.04	3.60	4.21
CD (p = 0.05)	15.15	2.08	4.02	36.06	9.97	13.05
Cultivar						
PSD 15	373.94	445.74	951.19	912.49	1706.90	1734.00
PSD 17	307.96	414.91	675.83	817.42	1115.00	1102.73
PD 18	441.26	534.18	1000.40	1063.20	1917.54	2274.76
Govind	395.16	466.74	936.09	869.36	1258.24	1356.17
Pusa 44	417.04	493.42	1089.40	933.22	1559.36	1743.60
S.Em. ±	6.88	0.744	5.55	13.65	6.89	7.00
CD (p = 0.05)	14.21	1.53	11.45	28.17	14.22	21.75

Table 4.7a: Interaction effect between weed control methods and cultivars on leaf area (cm²/plant) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	350.20	398.10	373.53	450.36	497.73	389.12	770.00	948.00	1137.40	923.82	934.40	879.25
PSD 17	290.13	360.06	273.70	431.16	460.16	353.40	615.00	815.20	597.30	806.19	868.73	777.34
PD 18	425.73	500.06	398.00	550.20	600.20	452.16	908.00	989.30	1104.00	1035.42	1127.63	1026.57
Govind	380.13	480.10	325.26	480.06	520.10	400.06	711.00	900.00	1197.30	837.19	912.21	858.67
Pusa 44	400.06	491.00	360.06	499.06	551.06	430.13	898.00	1480.00	890.20	960.21	931.07	908.36
S.Em.±		11.92			1.28			9.61			6.21	
CD (p = 0.05)		24.61			2.63			19.84			13.05	

Table 4.7a: ***Contd...***

Cultivar	60 DAT					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	1632.98	1986.43	1501.30	1725.00	1998.00	1479.00
PSD 17	1143.16	1347.53	854.32	1053.72	1277.26	977.21
PD 18	1678.43	2123.90	1950.30	2284.00	2550.00	1990.00
Govind	1090.83	1386.60	1297.30	1334.16	1541.40	1192.00
Pusa 44	1251.08	1860.50	1551.50	1867.08	2008.00	1478.64
S.Em.±		11.93			9.01	
CD (p = 0.05)		24.64			21.75	

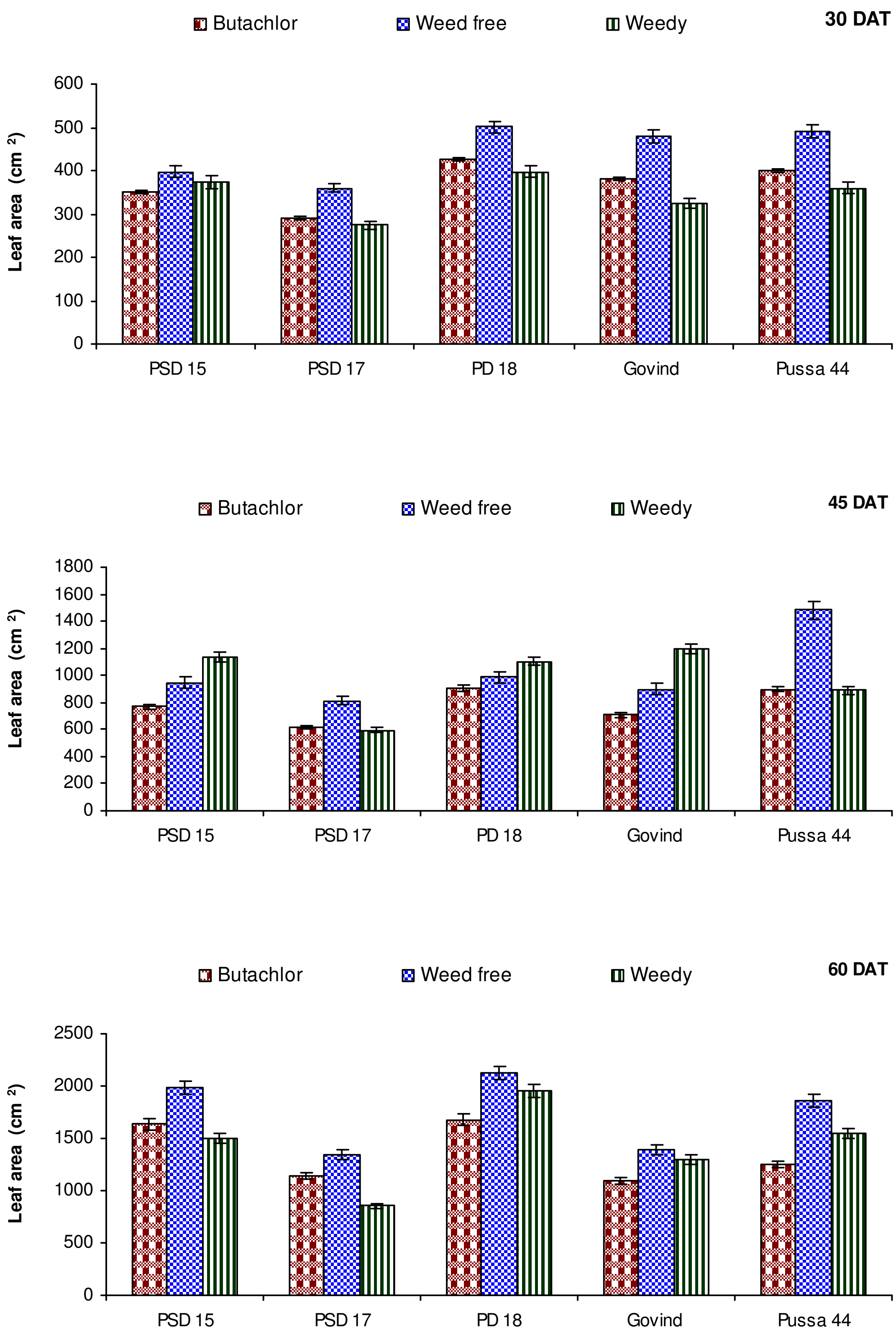


Fig. 4.2a: Leaf area of five rice cultivars at different growth stages during rainy season 2007

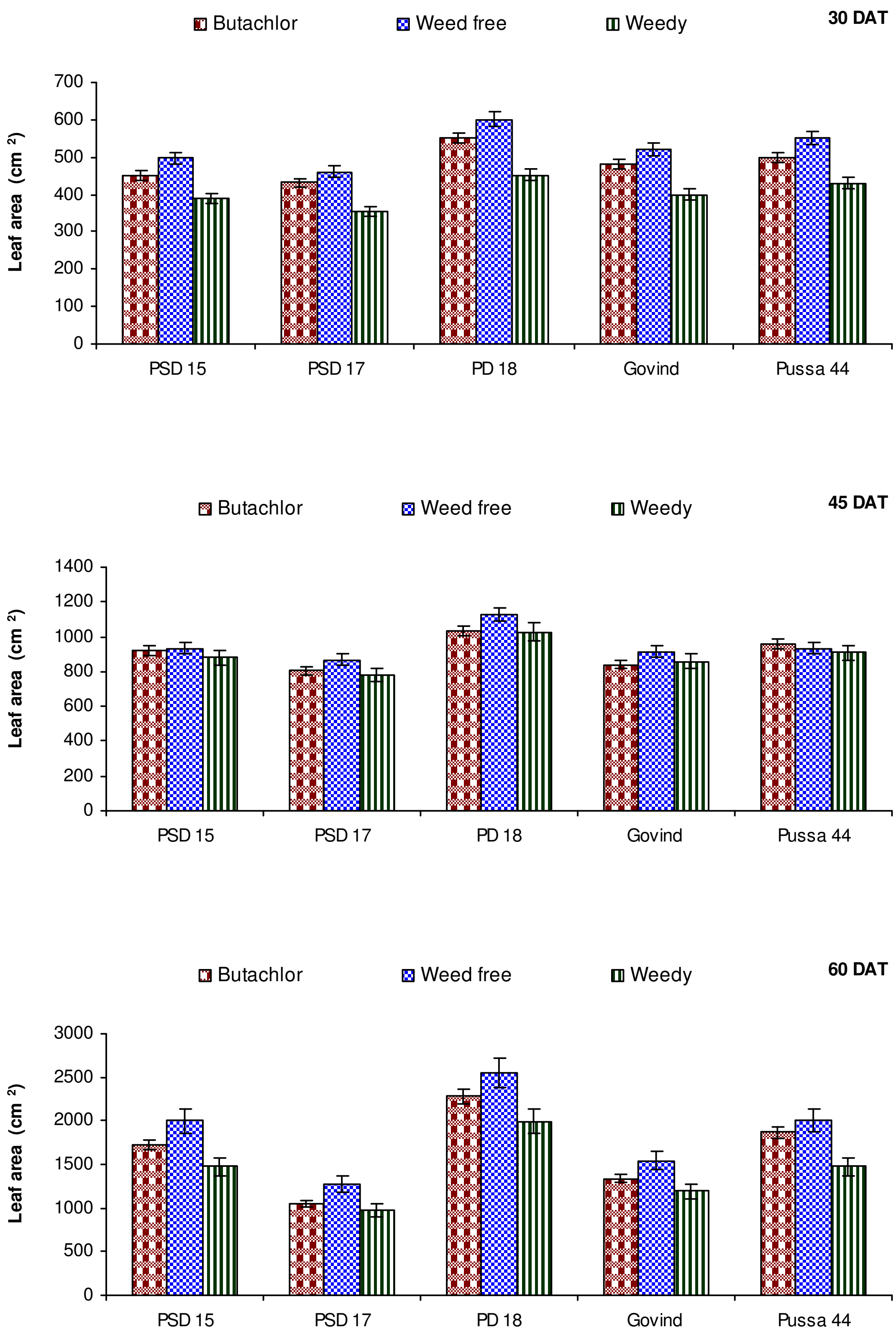


Fig. 4.2b: Leaf area of five rice cultivars at different growth stages during rainy season 2008

and Govind maintained higher number of leaves and no effect of weed control treatments on final number of leaves. The mean per cent reduction in leaf number in both the year was maximum for the cultivar Pant Sugandha Dhan 17 (15.42) and minimum for the cultivar Pant Dhan 18 (6.44) followed by Pant Sugandha Dhan 15 (7.37) in weedy situation at 60 DAT. The leaf number followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17 at 60 DAT in both the years.

4.1.3.5 Leaf area (cm^2/plant)

Leaf area of five rice cultivars recorded at different growth stages during both the years is presented in Table 4.7. Leaf area differed significantly among the treatments and cultivars in both the years. Leaf area was highest in the weed free treatment as compared to butachlor and weedy treatment at 60 DAT during both the seasons.

Leaf area gradually increased from 30 DAT upto 60 DAT in both the years. Leaf area was recorded highest in cultivar Pant Dhan 18 (1917.54 in 2007 and 2274.76 in 2008) and lowest in cultivar Pant Sugandha Dhan 17 (1115.0 in 2007 and 1102.73 in 2008) at 60 DAT in both the growing seasons. Leaf area was highest in cv. PD 18 and Pusa 44 at all the growth stages, where as at 30 DAT, cv. PSD 15(tall cv.) and Govind (dwarf) had similar to the cv. PD18 and Pusa 44.Leaf area followed an order Pant Dhan 18 > Pant Sugandha

Table 4.8: Shoot dry weight (g/plant) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30 DAT		45 DAT		60 DAT		90 DAT	
	2007	2008	2007	2008	2007	2008	2007	2008
Weed control method								
Butachlor	4.45	5.62	28.74	31.51	38.15	41.43	39.70	42.51
Weed free	4.98	6.02	30.69	35.91	40.60	46.14	41.49	47.11
Weedy	3.79	4.56	25.93	28.44	34.48	38.63	37.14	39.43
S.Em.±	0.423	0.128	0.486	0.702	0.721	0.333	0.495	0.327
CD (p = 0.05)	1.17	0.356	1.34	1.94	1.99	0.921	1.36	0.906
Cultivar								
PSD 15	4.82	4.72	21.58	29.23	29.85	37.96	33.41	38.88
PSD 17	3.38	5.19	28.11	30.89	37.29	40.19	38.88	41.48
PD 18	5.60	6.18	32.33	35.80	42.48	47.74	43.96	48.62
Govind	4.16	5.23	29.51	30.33	38.89	39.92	39.87	40.78
Pusa 44	4.08	5.68	30.74	33.50	39.30	44.51	41.10	45.31
S.Em.±	0.360	0.322	0.713	0.703	0.861	0.618	0.778	0.609
CD (p = 0.05)	0.744	0.665	1.47	1.45	1.77	1.27	1.60	1.25

Table 4.8a: Interaction effect between weed control methods and cultivars on shoot dry weight (g/plant) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	4.95	5.76	3.75	4.73	5.26	4.16	21.49	23.89	19.36	29.78	31.50	26.43
PSD 17	3.66	3.78	2.70	5.55	5.94	4.08	28.45	30.30	25.59	29.90	35.56	27.21
PD 18	5.61	5.85	5.33	6.31	6.80	5.44	33.15	35.01	28.82	34.95	42.26	30.18
Govind	3.96	5.16	3.35	5.67	5.76	4.26	29.19	31.51	27.83	31.43	33.49	26.08
Pusa 44	4.05	4.33	3.85	5.84	6.34	4.87	31.43	32.74	28.07	31.51	36.72	32.28
S.Em.±		0.62			0.55			1.23			1.21	
CD (p = 0.05)		1.28			1.15			2.55			2.51	

Table 4.8a: ***Contd...***

Cultivar	60 DAT						90 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	31.47	31.90	26.18	37.56	40.93	35.40	33.18	34.17	32.89	38.46	41.86	36.33
PSD 17	38.22	39.91	33.74	38.31	45.26	37.00	39.73	41.50	35.40	40.30	46.60	37.56
PD 18	42.83	45.36	39.24	46.98	52.96	43.28	43.80	47.06	41.02	47.87	53.90	44.10
Govind	38.69	41.23	36.76	40.52	44.15	35.10	40.09	42.06	37.46	41.53	44.70	36.13
Pusa 44	39.54	41.89	36.48	43.78	47.40	42.36	41.73	42.65	38.93	44.40	48.52	43.02
S.Em.±		1.49			1.07			1.34			1.05	
CD (p = 0.05)		3.07			2.21			2.78			2.18	

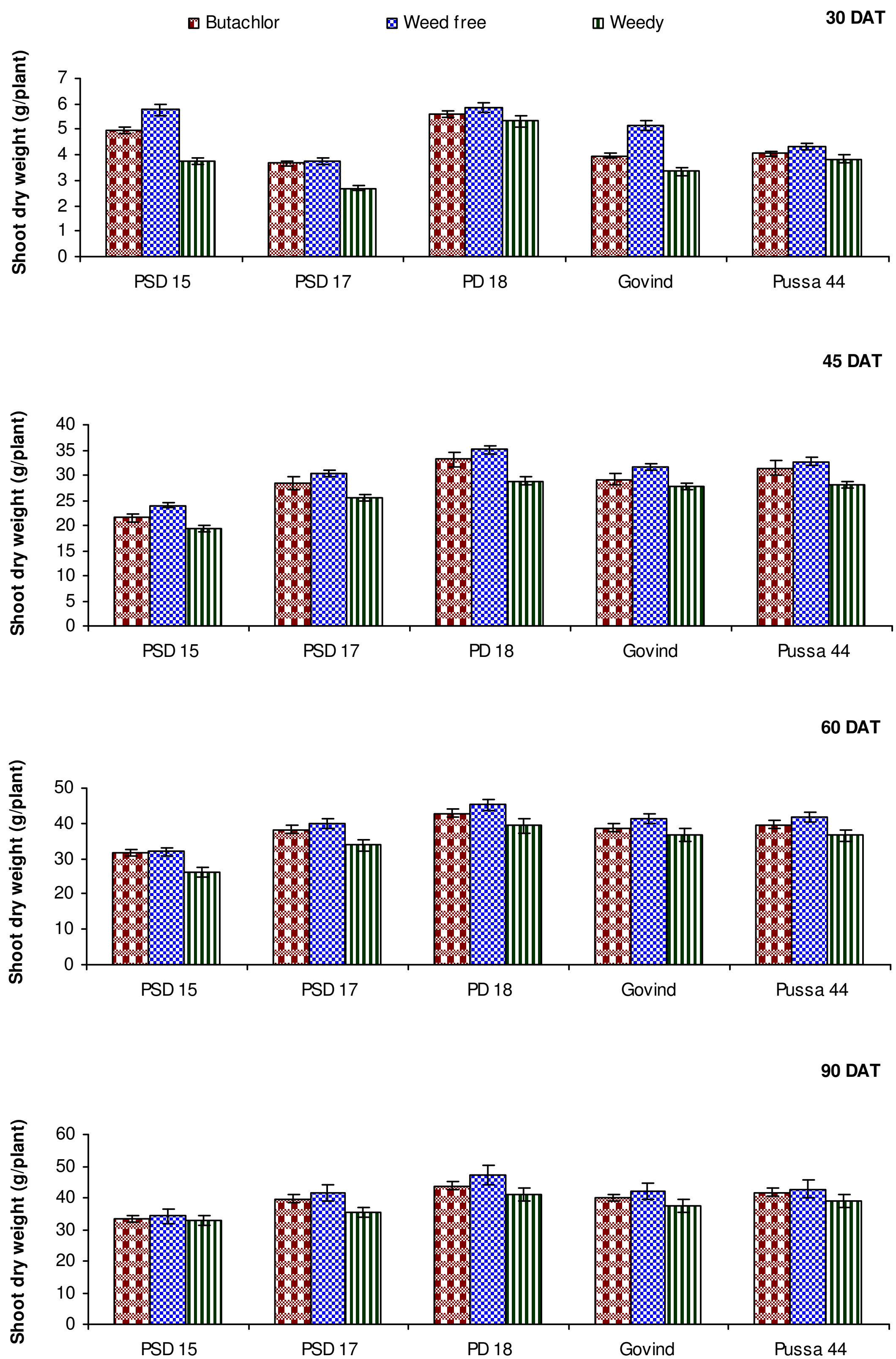


Fig. 4.3a: Shoot dry weightof five rice cultivars at different growth stages during rainy season 2007

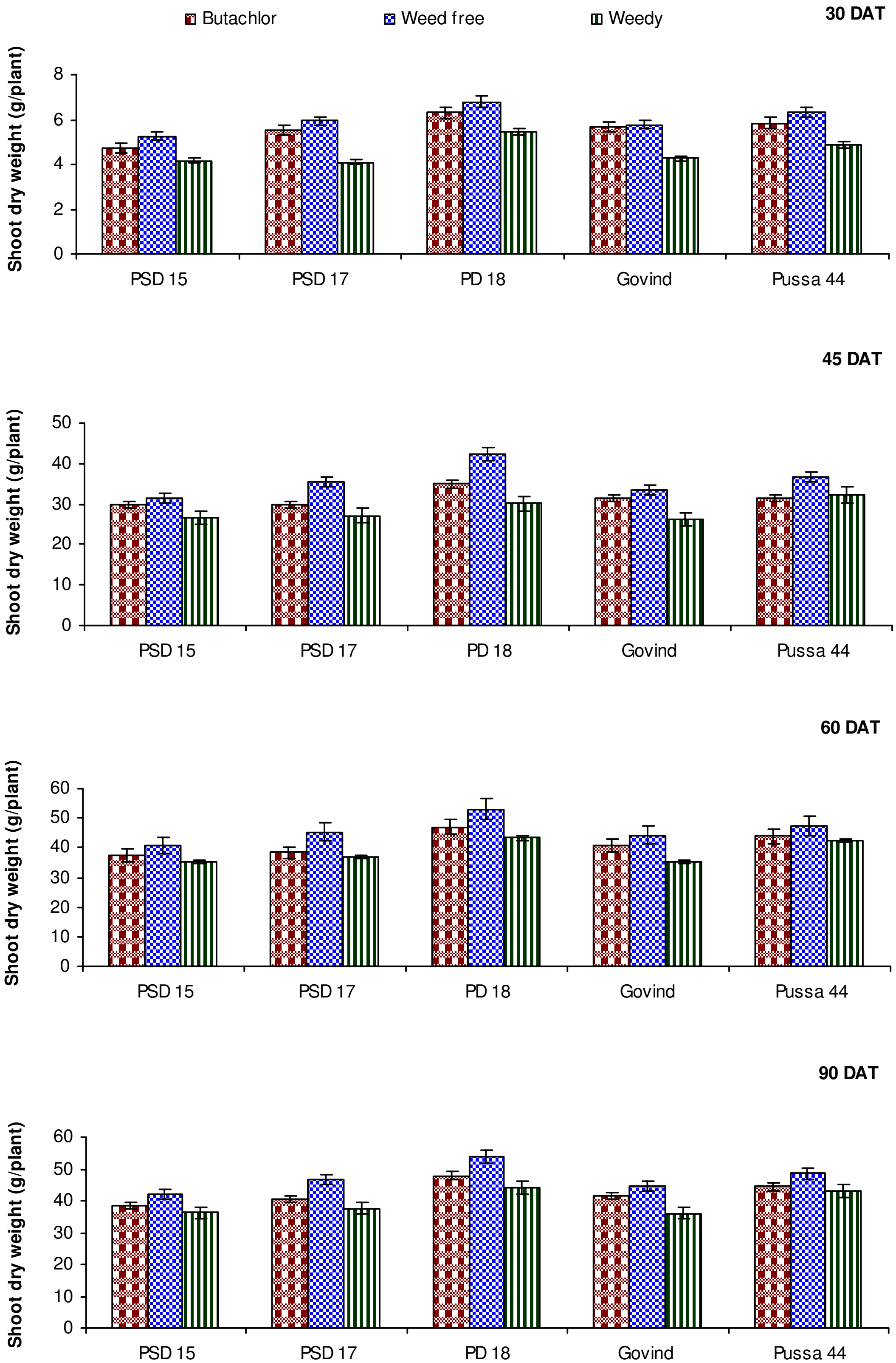


Fig. 4.3b: Shoot dry weightof five rice cultivars at different growth stages during rainy season 2008

Dhan 15 > Pusa 44 > Govind > Pant Sugandha Dhan 17 in 2007 while in 2008, it was Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 15 > Govind > Pant Sugandha Dhan 17 at 60 DAT.The mean value of leaf area of five rice cultivars at different growth stages during both the seasons is presented in Table 4.7a. During all the growth stages leaf area was higher in cv. PSD 15, PSD 17, PD 18 and Pusa 44 under butachlor and weed free situations as compared to weedy plots in both the years, but in cv. Govind, no difference between the treatments in 2007 where as lower leaf area recorded in cv. PSD 17 under weedy plots than weed free plots. The mean per cent reduction in weedy situation was maximum in cultivar Pant Sugandha Dhan 17 (30.04) and minimum in cultivar Pant Dhan 18 (15.06) in both the years, while in Butachlor treatment maximum in cultivar Pusa 44 (19.88) and minimum in cultivar Pant Dhan 18 (15.70).

4.1.3.6 Shoot dry weight (g/plant)

Shoot dry weight of five rice cultivars recorded at different growing stages after transplanting in both the years is presented in the Table 4.8. During both the growing years shoot dry weight was highest in weed free and butachlor treatments at all the growth stages as compared to weedy plots. Shoot dry weight differed significantly among the treatments and cultivars and was recorded highest in cultivar PD 18 (43.96 in 2007 and 48.62 in 2008) and

Table 4.9: Number of panicles per plant of five rice cultivars at harvest during rainy season 2007 and 2008

Treatment	Panicle number/plant	
	2007	2008
Weed control method		
Butachlor	44.73	49.66
Weed free	48.66	57.06
Weedy	35.60	46.00
S.Em.±	4.00	3.32
CD (p = 0.05)	11.07	9.18
Cultivar		
PSD 15	32.00	39.66
PSD 17	33.50	40.55
PD 18	59.66	69.77
Govind	40.66	48.88
Pusa 44	49.11	55.66
S.Em.±	3.79	3.43
CD (p = 0.05)	7.84	7.09

Table 4.9a: Interaction effect between weed control methods and cultivars on panicle number/plant of five rice cultivars at harvest during rainy season 2007 and 2008

Cultivar	Panicle number/plant					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	34.00	38.33	23.66	35.00	51.66	32.33
PSD 17	33.66	37.00	30.00	38.33	46.00	37.33
PD 18	62.33	67.33	49.33	73.66	74.33	61.33
Govind	41.66	45.33	35.00	49.66	51.33	45.66
Pusa 44	52.00	55.33	40.00	51.66	62.00	53.33
S.Em.±		6.58			5.95	
CD (p = 0.05)		13.58			12.28	

lowest in cv. PSD 15 (33.41 in 2007 and 38.88 in 2008) during both the years at 90 DAT. Shoot dry weight followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 in 2007 at 90 DAT, while in 2008, it was Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 17 > Govind > Pant Sugandha Dhan 15 at 90 DAT. The mean value of shoot dry weight (g/plant) of five rice cultivars at different growth stages during both the seasons is presented in Table 4.8a. SDW was maximum in cv. PD 18, Pusa 44, Govind and PSD 17 under weed free situation as compared to weedy plots where as PSD 15 was lowest, but no difference between the treatments. The mean per cent reduction in the shoot dry weight in both the years in weedy situation was maximum in Pant Sugandha Dhan 17 (17.04) and minimum in Pant Sugandha Dhan 15 (8.47) at 90 DAT while in Butachlor treatment, maximum in Pant Dhan 18 (9.05) and minimum in Pusa 44 (5.3) at 90 DAT. A gradual increase in shoot dry weight were observed upto 90 DAT in all treatments as well as in cultivars.

4.1.3.7 Panicle number

Panicle number per plant at harvest of five rice cultivars during both the growing seasons is presented in Table 4.9 and it was maximum in weed free treatment (48.6 in 2007 and 57.06 in 2008) and lowest in weedy treatment (35.60 in 2007 and 46.00 in 2008) in both the growing seasons.

Panicle number was maximum in cultivar Pant Dhan 18 (59.66 in 2007 and 69.77 in 2008) and minimum in Pant Sugandha Dhan 15 (32.00 in 2007 and 39.66 in 2008) during both the years at harvest.

It followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 in both the years. Panicle number was significantly higher in cultivar Pant Dhan 18 in both the seasons. The mean value of panicle numbers at harvest during both the years is presented in Table 4.9a. Panicle number was higher in butachlor and weed free treatments as compared to weedy plots, but lowest in PSD 17 and no difference between the treatments. The mean per cent reduction in weedy situation was maximum in Pant Sugandha Dhan 15 (37.84) and minimum in Govind (16.91) while in Butachlor treatment, maximum in Pant Sugandha Dhan 15 (21.76) and minimum in Pant Dhan 18 (4.16) at harvest.

4.1.3.8 Total dry matter production (g/m^2)

Total dry matter production (g/m^2) at harvest of the five rice cultivars during both the seasons is presented in Table 4.10. In 2007, both weed free and butachlor treatment had higher dry matter production than weedy where as in 2008, all the three treatments recorded similar dry matter production. in the first growing season (2007) total dry matter was highest in cultivar Pant Dhan 18

Table 4.10: Total dry matter production (g/m^2) at harvest of five rice cultivars during rainy season 2007 and 2008

Weed control method	Total dry matter production (g/m^2)	
	Harvest	
	2007	2008
Butachlor	1275.33	1293.33
Weed free	1213.33	1356.66
Weedy	1002.00	1206.65
S.Em. ±	39.89	109.62
CD (p = 0.05)	110.29	303.09
Cultivar		
PSD 15	1177.77	1216.60
PSD 17	955.55	616.60
PD 18	1647.97	1733.30
Govind	816.66	1416.60
Pusa 44	1220.00	1444.40
S.Em. ±	81.97	94.39
CD (p = 0.05)	169.19	194.82

Table 4.10a: Interaction effect between weed control methods and cultivars on total dry matter production (g/m²) of five rice cultivars at harvest during rainy season 2007 and 2008

Cultivar	Total dry matter production (g/m²)					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	1516.66	1166.66 (23.07)	850.00 (27.14)	1216.66 (1.37)	1233.00	1200.00 (2.67)
PSD 17	1016.66 (1.61)	1033.33	816.60 (20.97)	583.33 (18.60)	716.66	550.00 (23.25)
PD 18	1660.00 (2.35)	1700.00	1583.00 (6.88)	1766.66 (1.85)	1800.00	1633.33 (9.25)
Govind	900.00 (1.74)	916.66	633.33 (30.83)	1433.33 (1.17)	1450.00	1366.60 (5.75)
Pusa 44	1283.33	1250.00 (2.57)	1126.60 (9.87)	1466.66 (7.34)	1583.00	1283.33 (18.93)
S.Em.±		141.98			163.49	
CD (p = 0.05)		293.04			337.40	

Figures in parentheses represent per cent reduction in total dry matter as compared to weed free treatment

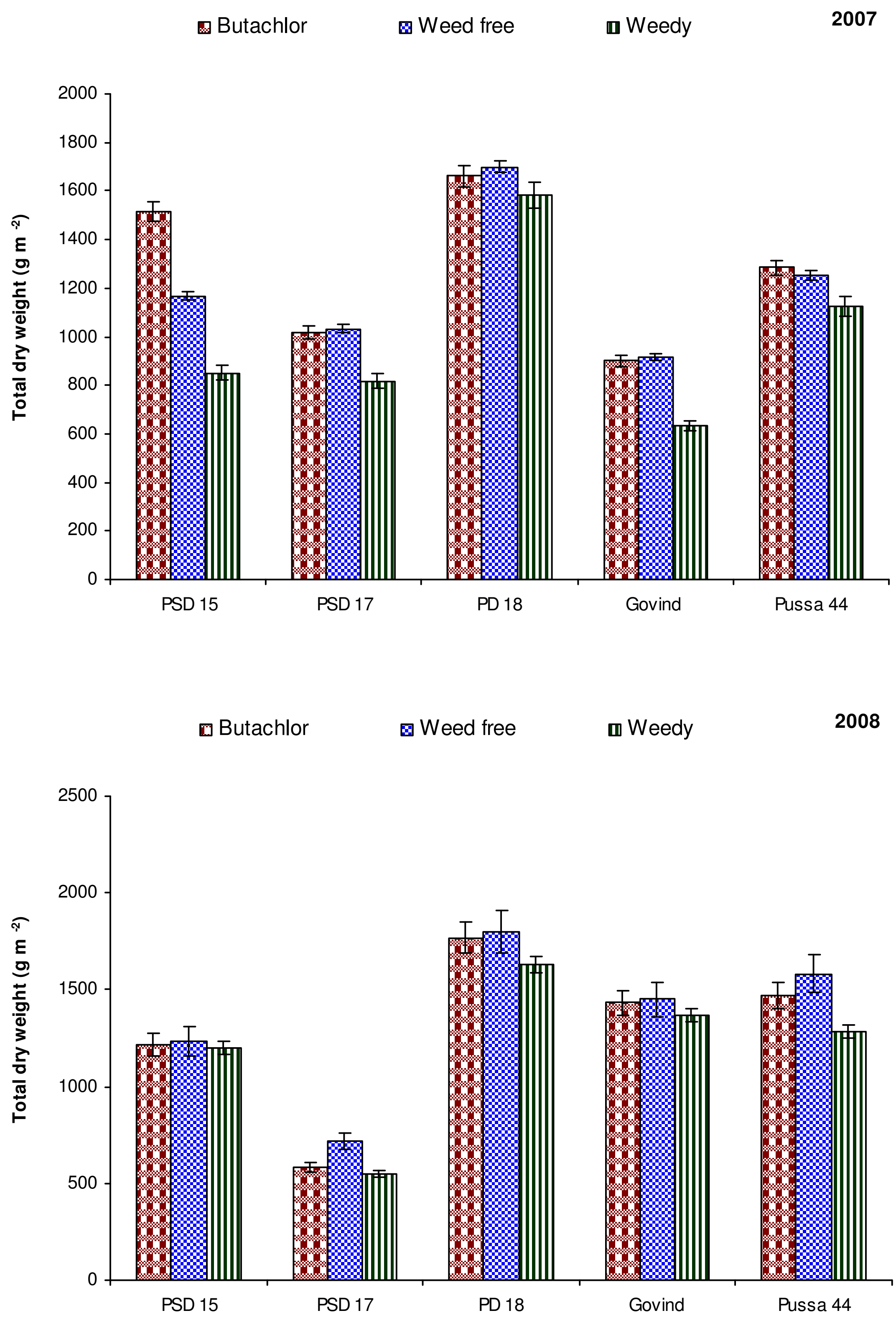


Fig. 4.4: Total dry matter of five rice cultivars at harvest during rainy season 2007 and 2008

(1647.77) and lowest in cultivar Govind (816.66) at harvest. It followed an order Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17 > Govind. Total dry matter differed significantly between weed free and weedy treatment in 2007.

In the second growing season (2008) total dry matter was highest in cultivar Pant Dhan 18 (1733.30) and lowest in cultivar Pant Sugandha Dhan 17 (616.60) at harvest. It followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17.

The mean value of total dry matter production of five rice cultivars in each treatment is presented in Table 4.10a. The per cent reduction in weedy situation was maximum for Govind (30.83) and minimum for Pant Dhan 18 (6.88) in 2007, while in 2008, maximum in Pant Sugandha Dhan 17 (23.25) and minimum for Pant Sugandha Dhan 15 (2.60) cultivar. The per cent reduction in Butachlor treatment was maximum for cultivar Pant Dhan 18 (2.35) and minimum for Pant Sugandha Dhan 17 (1.61) in 2007, while in 2008 maximum for Pant Sugandha Dhan 17 (18.60) and minimum for Pusa 44 (1.14) at harvest. A gradual reduction in total dry matter production of all cultivars were observed at harvest in Butachlor treatment except Pant Sugandha Dhan 15 (23.07%) and Pusa 44 (2.59%) showed per cent loss in weed free treatment in 2007 at harvest. The mean per cent reduction in TDM during both the years

Table 4.11: Grain yield (g/m^2) of five rice cultivars at harvest during rainy season 2007 and 2008

Treatment	Grain yield (g/m^2)	
	2007	2008
Weed control method		
Butachlor	451.00	627.00
Weed free	440.00	670.00
Weedy	364.66	549.30
S.Em.±	23.42	48.94
CD (p = 0.05)	64.77	135.32
Cultivar		
PSD 15	294.44	565.55
PSD 17	342.22	225.55
PD 18	574.44	940.00
Govind	415.55	660.00
Pusa 44	465.55	686.66
S.Em.±	29.31	64.69
CD (p = 0.05)	60.50	133.52

Table 4.11a: Interaction effect between weed control methods and cultivars on grain yield (g/m²) of five rice cultivars at harvest during rainy season 2007 and 2008

Cultivar	Grain yield (g/m²)					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	343.33	323.33 (5.82)	216.66 (32.99)	563.33 (3.42)	583.33	550.00 (5.71)
PSD 17	383.33	340.00 (11.30)	303.33 (10.78)	200.00 (28.57)	280.00	196.66 (29.76)
PD 18	603.33 (0.82)	598.33	521.66 (12.81)	986.66 (1.33)	1000.00	833.33 (16.66)
Govind	421.66 (7.32)	455.00	370.00 (18.68)	860.00 (2.85)	700.00	600.00 (14.28)
Pusa 44	503.30	483.33 (3.96)	410.00 (15.18)	706.66 (10.16)	786.66	566.66 (27.96)
S.Em.±		50.78			112.05	
CD (p = 0.05)		104.80			231.27	

Figures in parenthesis represent per cent reduction in total dry matter as compared to weed free treatment in weedy situation, was maximum in cultivar Pant Sugandha Dhan 17 (22.07) and minimum for cultivar Pant Dhan 18 (8.06) while in Butachlor treatment it was maximum in Pant Sugandha Dhan 17 (10.10) and minimum in Pant Sugandha Dhan 15 (0.66) at harvest.

4.1.3.9 Grain yield (g/m²)

Grain yield (g/m²) of the five rice cultivars for both the growing season is presented in Table 4.11. The grain yield was highest in weed free treatment (440 in 2007 and 670 in 2008) and lowest in weedy treatment (364.66 in 2007 and 549.3 in 2008) at the time of harvest in both the growing seasons. During 2007, grain yield was higher in butachlor and weed free treatment as compared to weedy plots, while in 2008, all the three treatments recorded similar grain yield. The grain yield was significantly higher in cultivar Pant Dhan 18 during both the years and was significantly differed between weed free and weedy treatments in 2007 while during 2008, between Butachlor and weedy treatments.

Grain yield was highest for cultivar Pant Dhan 18 (574.44 in 2007 and 940.00 in 2008) in both the years and lowest for Pant Sugandha Dhan 15 (294.44) in 2007, while in 2008, lowest for cultivar Pant Sugandha Dhan 17 (225.55) at harvest. The grain yield followed an order, Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 in 2007 while in 2008, it followed Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha

Dhan 15 > Pant Sugandha Dhan 17 at harvest. The mean value of total grain yield five rice cultivars in each treatment is presented in Table 4.11a. The per cent reduction in weedy situation, was maximum for cultivar Pant Sugandha Dhan 15 (32.99) and minimum in cultivar Pant Sugandha Dhan 17 (10.78) in 2007 while in 2008, maximum in cultivar Pant Sugandha Dhan 17 (29.76) and minimum for cultivar Govind (14.28) at harvest. Grain yield under weedy condition followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 in 2007, while in 2008, it was Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17 at harvest.

The per cent reduction in Butachlor treatment was maximum for cultivar Govind (7.32) and rest four cultivars showed % increment in Butachlor treatment, such as Pant Sugandha Dhan 15 (5.82), Pant Sugandha Dhan 17 (11.30), Pant Dhan 18 (0.82) and Pusa 44 (3.96) against weed free treatment in 2007 while during 2008, in Butachlor treatment, the per cent reduction was maximum for cultivar Pant Sugandha Dhan 17 (28.57) and minimum for cultivar Pant Dhan 18 (1.33) and all five rice cultivars showed % reduction in grain yield against the weed free treatment at harvest.

The mean per cent reduction in weedy treatment was maximum for cultivar Pusa 44 (21.56) and minimum for cultivar Pant Dhan 18 (14.73) where as in Butachlor treatment, the mean per

Table 4.12: Harvest index of five rice cultivars during rainy season 2007 and 2008

Treatment	Harvest index (%)	
	2007	2008
Weed control method		
Butachlor	38.60	46.30
Weed free	40.40	47.79
Weedy	35.85	41.16
S.Em.±	1.57	1.54
CD (p = 0.05)	4.35	4.25
Cultivar		
PSD 15	30.76	46.30
PSD 17	37.16	36.63
PD 18	37.71	53.68
Govind	46.34	46.34
Pusa 44	39.44	47.47
S.Em.±	2.16	1.51
CD (p = 0.05)	4.46	3.12

Table 4.12a: Interaction effect between weed control methods and cultivars on harvest index (%) of five rice cultivars during rainy season 2007 and 2008

Cultivar	Harvest index (%)					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	30.56	32.66	29.07	46.00	47.00	45.90
PSD 17	38.47	41.93	31.11	35.33	38.80	35.76
PD 18	36.34	43.83	32.97	54.50	55.33	51.23
Govind	48.85	41.27	48.91	47.36	48.06	43.60
Pusa 44	38.83	42.30	37.20	48.33	49.76	44.33
S.Em.±		3.74			2.62	
CD (p = 0.05)		7.73			5.42	

cent reduction was maximum for cultivar Pant Sugandha Dhan 17 (14.28) and minimum for cultivar Pant Dhan 18 (0.66) in both the years at harvest.

4.1.3.10 Harvest index (%)

Harvest index of five rice cultivars during both the growing seasons is presented in Table 4.12. It differed significantly between weed free and weedy treatments in both the years. In the first growing season (2007) harvest index was highest for weed free treatment (40.40) and lowest for weedy treatment (35.85) where as during 2008, it was higher in both weed free and butachlor treatments. During 2007, harvest index was higher Govind (46.34) and lowest in Pant Sugandha Dhan 15 (30.76) where as during 2008, it was highest in PD 18 (53.68) and lowest in PSD 17 (36.63).there were no significant differences in the HI of rest of the cultivars during both the seasons. The values ranged between 30.76 to 46.34 in 2007 and 36.63 to 53.68 in 2008.

The mean value of harvest index of five rice cultivars in each treatment is presented in Table 4.12a.

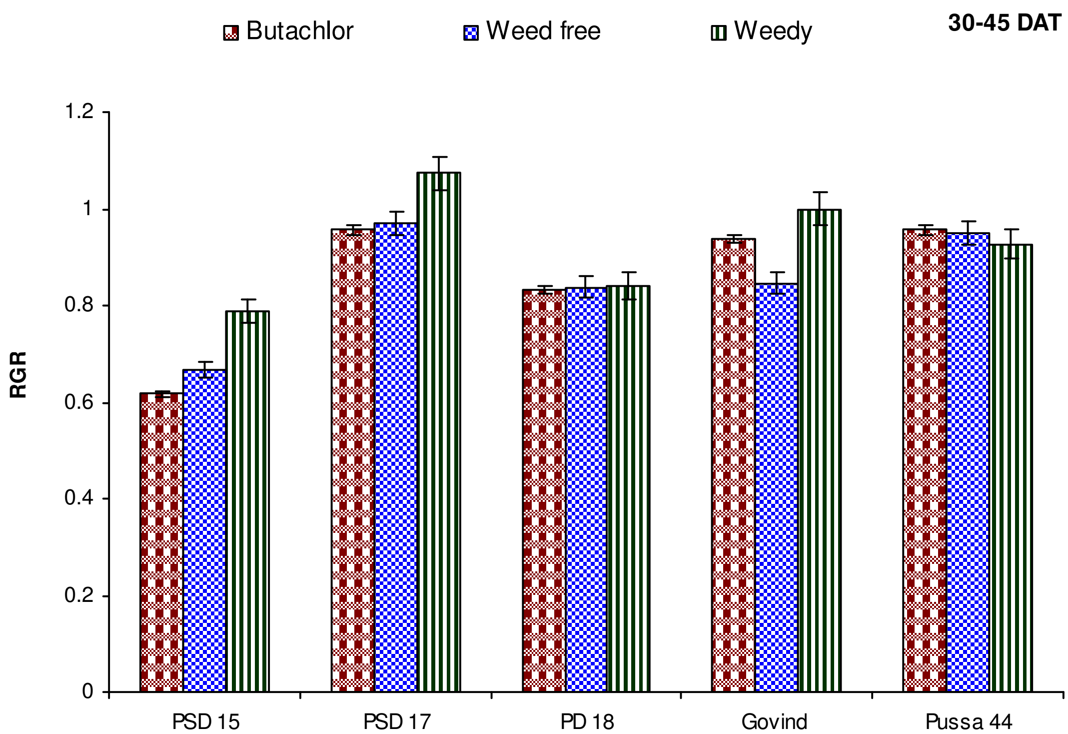
Harvest index was highest in Butachlor treatment for cultivar Govind (48.85) and lowest for cultivar Pant Sugandha Dhan 15 (30.56) in 2007, while in 2008 it was highest for cultivar Pant Dhan 18 (54.50) and lowest for Pant Sugandha Dhan 17 (35.33). Under weedy conditions harvest index recorded highest for cultivar Govind

Table 4.13: Relative growth rate (g/g/week) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30-45 DAT		45-60 DAT	
	2007	2008	2007	2008
Weed control method				
Butachlor	0.860	0.762	0.136	0.127
Weed free	0.854	0.821	0.125	0.117
Weedy	0.926	0.806	0.134	0.148
S.Em.±	0.057	0.035	0.008	0.006
CD (p = 0.05)	0.159	0.098	0.020	0.010
Cultivar				
PSD 15	0.691	0.859	0.150	0.122
PSD 17	1.000	0.838	0.131	0.123
PD 18	0.837	0.816	0.127	0.146
Govind	0.928	0.639	0.130	0.128
Pusa 44	0.944	0.829	0.119	0.135
S.Em.±	0.048	0.078	0.021	0.006
CD (p = 0.05)	0.099	0.162	0.040	0.010

Table 4.13a: Interaction effect between weed control methods and cultivars on RGR (g/g/week) of five rice cultivars at different growth stages of five rice cultivars during rainy season 2007 and 2008

Cultivar	30-45 DAT						45-60 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	0.617	0.667	0.788	0.867	0.835	0.876	0.178	0.134	0.138	0.108	0.121	0.136
PSD 17	0.957	0.971	1.074	0.794	0.835	0.886	0.139	0.127	0.128	0.116	0.111	0.141
PD 18	0.832	0.838	0.841	0.797	0.852	0.799	0.118	0.121	0.144	0.140	0.105	0.195
Govind	0.937	0.846	1.000	0.565	0.765	0.586	0.133	0.125	0.132	0.116	0.129	0.139
Pusa 44	0.957	0.948	0.927	0.786	0.819	0.883	0.113	0.118	0.127	0.153	0.121	0.130
S.Em.±	0.083			0.013			0.022			0.012		
CD (p=0.05)	0.173			0.280			0.040			0.024		



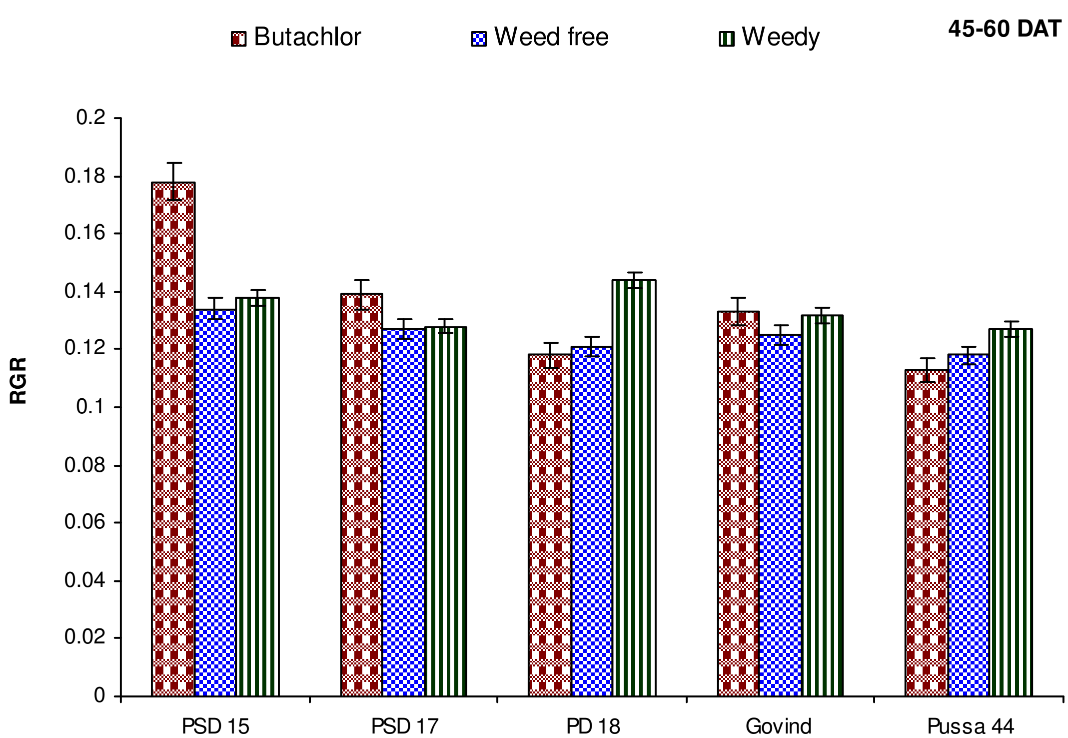
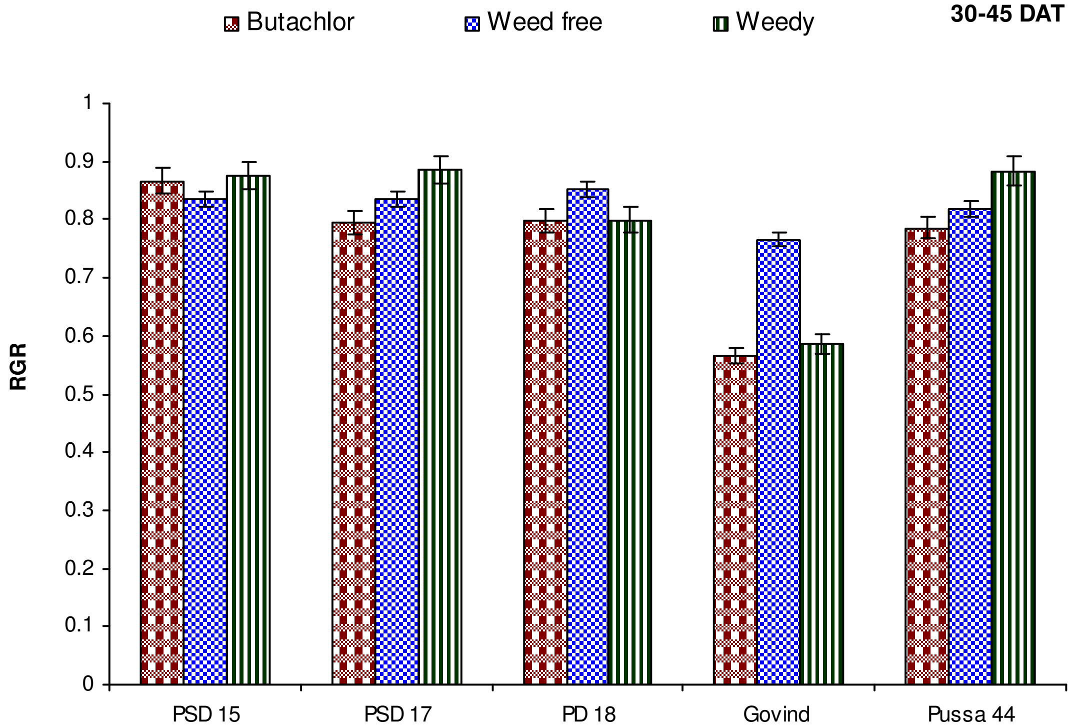


Fig. 4.5a: Relative growth rate of five rice cultivars at different growth stages during rainy season 2007



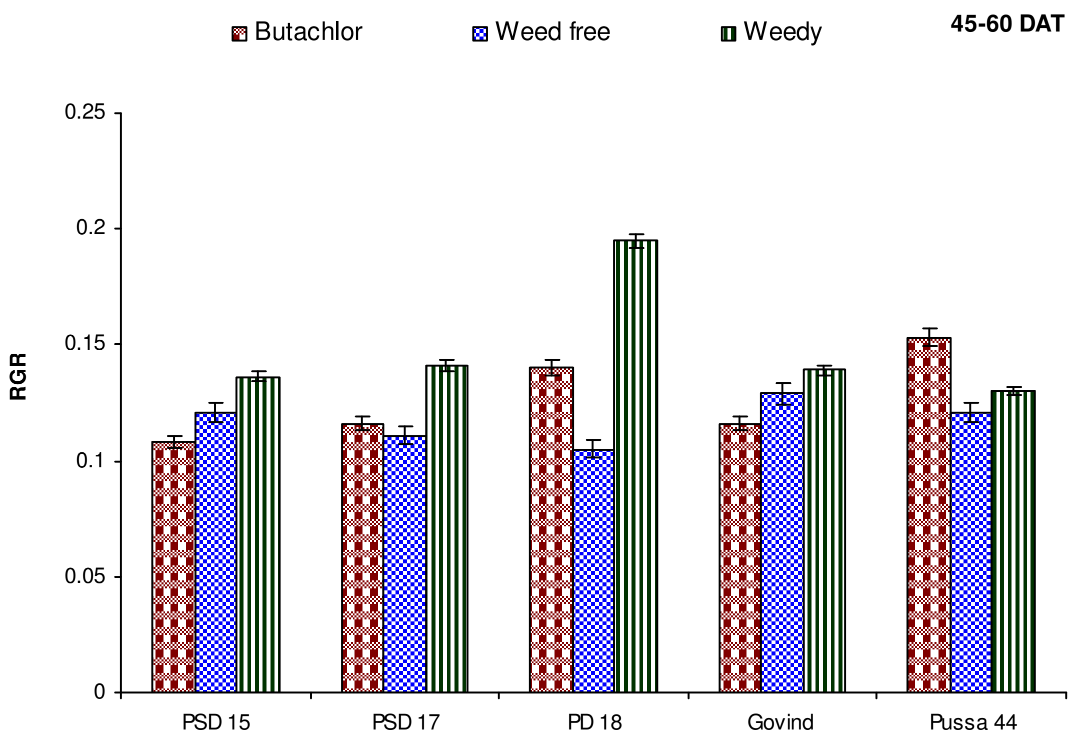


Fig. 4.5b: Relative growth rate of five rice cultivars at different growth stages during rainy season 2008

(48.91) and lowest for Pant Sugandha Dhan 15 (29.07) in 2007, while in 2008 it was highest for cultivar Pant Dhan 18 (51.23) and lowest for cultivar Pant Sugandha Dhan 17 (35.76) at harvest.

The mean harvest index of both years was in the order Govind > Pant Dhan 18 (45.69) > Pusa 44 (43.45) > Pant Sugandha Dhan 15 (38.53) > Pant Sugandha Dhan 17 (36.89).

4.1.4 Physiological growth parameters

4.1.4.1 Relative growth rate (g/g/week)

Relative growth rate of five rice cultivars calculated at different growth stages after transplanting during both the growing seasons is presented in Table 4.13. During 2007, RGR was highest under weedy (0.928) plots than butachlor (0.860) and weed free (0.854) treatments where as in 2008, highest under weed free (0.821) and weedy (0.806) and lowest under butachlor (0.762) at 30-45 DAT. During 45-60 DAT, RGR was highest in butachlor (0.136) and weedy (0.134) than weed free treatment (0.125) in 2007, while during 2008, highest for weedy (0.148) treatment as compared to weed free (0.117) and butachlor (0.127) treatments.

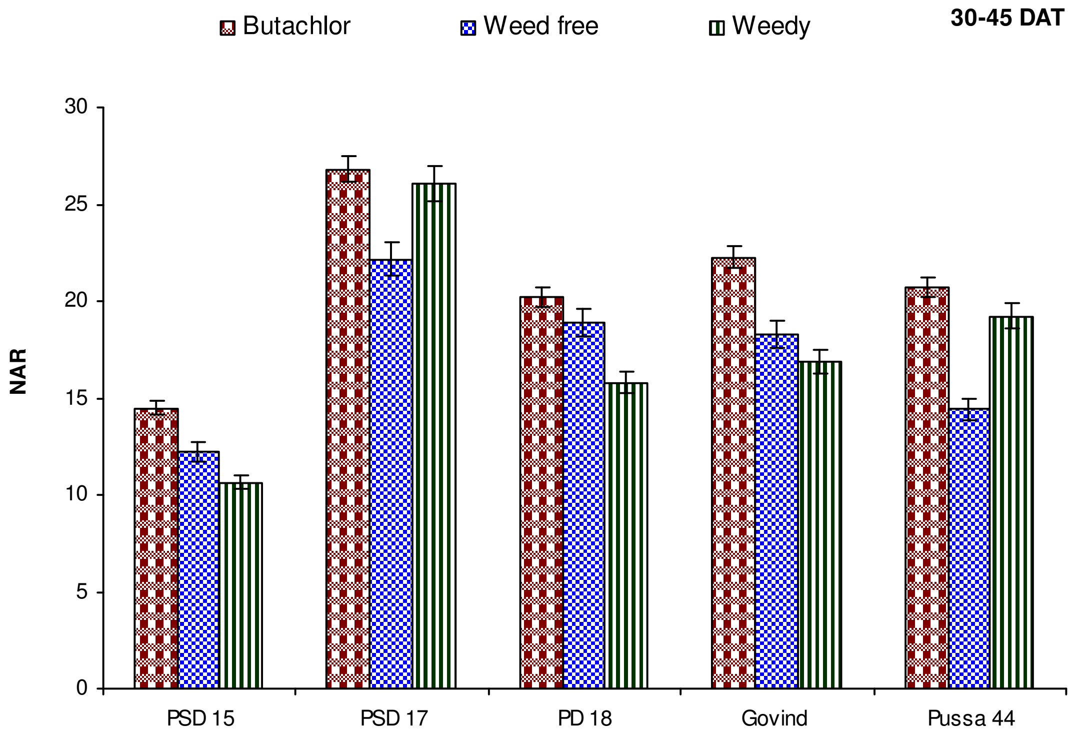
In 2007, RGR was highest for cultivar Pant Sugandha Dhan 17 (1.00) and lowest for cultivar Pant Sugandha Dhan 15 (0.691) where as in 2008, highest for cv. Pant Sugandha Dhan 15 (0.859) and minimum for cv. Govind (0.639) at 30-45 DAT. During 45-60 DAT, maximum for cultivar Pant Sugandha Dhan 15 (0.150) and minimum

Table 4.14: Net assimilation rate (mg/cm²/week) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30-45 DAT		45-60 DAT	
	2007	2008	2007	2008
Weed control method				
Butachlor	20.87	17.61	4.38	4.71
Weed free	17.21	19.91	3.12	3.20
Weedy	17.71	19.28	3.98	4.06
S.Em.±	0.424	0.685	0.513	0.921
CD (p = 0.05)	1.17	1.89	1.41	2.54
Cultivar				
PSD 15	12.45	17.30	3.04	4.17
PSD 17	25.00	21.06	5.01	4.33
PD 18	18.25	18.79	4.23	3.62
Govind	19.13	18.44	4.21	4.09
Pusa 44	18.12	19.07	2.67	3.75
S.Em.±	0.763	1.40	0.547	0.618
CD (p = 0.05)	1.57	2.89	1.12	1.27

Table 4.14a: Interaction effect between weed control methods and cultivars on NAR (mg cm^{-2}/wk) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30-45 DAT						45-60 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	14.47	12.24	10.64	16.31	17.93	17.67	4.08	2.65	2.39	6.29	3.79	4.31
PSD 17	26.79	22.17	26.06	19.02	22.20	21.97	5.46	4.27	5.29	5.88	1.82	5.30
PD 18	20.17	18.89	15.77	17.70	21.02	17.66	3.82	3.49	5.38	4.12	3.46	4.80
Govind	22.24	18.32	16.84	18.76	18.25	18.31	5.04	4.02	3.58	4.15	4.45	4.47
Pusa 44	20.70	14.42	19.23	16.25	20.16	20.80	3.53	1.19	3.29	5.05	4.66	4.70
S.Em.±	1.32			2.42			0.948			1.18		
CD (p = 0.05)	2.73			5.00			1.95			2.44		



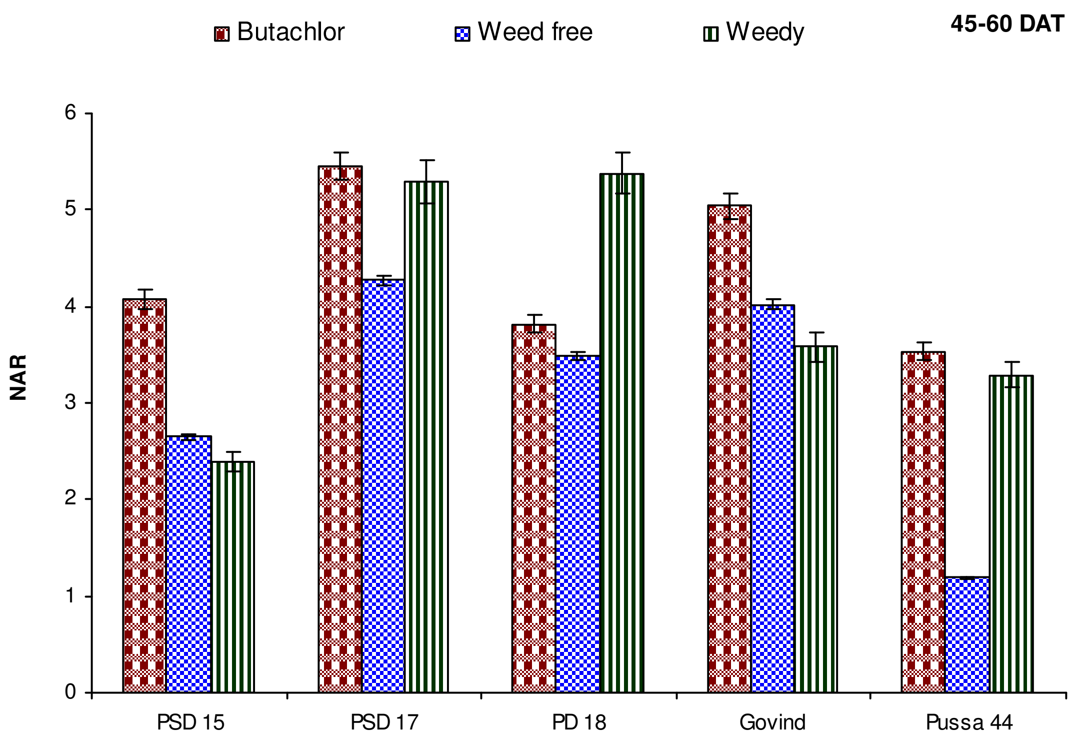


Fig. 4.6a: Net assimilation rate of five rice cultivars at different growth stages during rainy season 2007

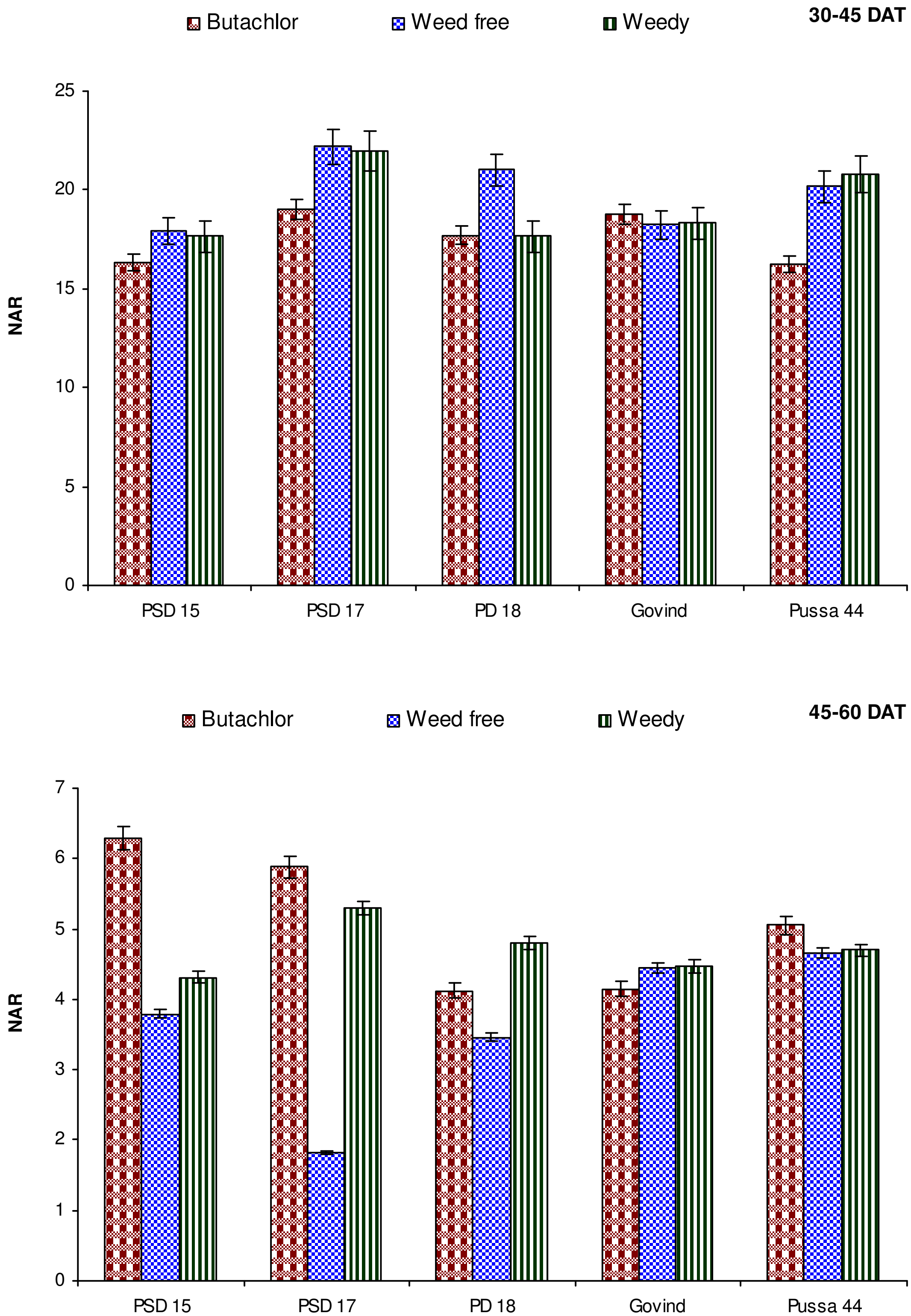


Fig. 4.6b: Net assimilation rate of five rice cultivars at different growth stages during rainy season 2008

for cultivar Pusa 44 (0.119) while in 2008, maximum for Pant Dhan 18 (0.146) and minimum for Pant Sugandha Dhan 15 (0.122). The RGR followed an order Pant Sugandha Dhan 17 > Pusa 44 > Govind > Pant Sugandha Dhan 15 in 2007, while in 2008, it was Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17 > Pusa 44 > Pant Dhan 18 > Govind at 30-45 DAT. The mean value of RGR of five rice cultivars at different growth stages during both the years is presented in Table 4.13a. RGR was highest in cv. PSD 17 (0.971) in 2007 and PD 18 (0.852) in 2008 where as lowest for cv. PSD 15 (0.66) in 2007 and cv. Govind (0.76) in 2008 at 30-45 DAT. During 45-60 DAT, RGR was highest in cv. PSD 15 in 2007 and cv. Govind in 2008, where as lowest in cv. Pusa 44 in 2007 and cv. PD 18 in 2008.

4.1.4.2 Net assimilation rate (mg/cm^2/week)

Net assimilation rate (NAR) of five rice cultivars calculated at different growing stages during both the seasons is presented in Table 4.14. NAR was maximum in butachlor (20.87 in 2007 and 17.61 in 2008)treatment as compared to weed free (17.21 in 2007 and 19.91 in 2008) and weedy (17.71 in 2007 and 19.28 in 2008) at 30-45 DAT during both the years, where as at 45-60 DAT, maximum in butachlor (4.38) treatment than weed free (3.12) and weedy (3.98) plots in 2007, while in 2008, all the three treatments recorded similar NAR value .NAR was highest for cv. PSD 17 (25.00 at 30-45 DAT and 5.01 at 45- 60 DAT in 2007 and 21.06 at 30-45 DAT and

Table 4.15: Relative leaf growth rate (g/g/week) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30-45 DAT		45-60 DAT	
	2007	2008	2007	2008
Weed control method				
Butachlor	0.869	0.858	0.305	0.247
Weed free	0.906	0.939	0.320	0.455
Weedy	0.883	0.892	0.268	0.330
S.Em.±	0.074	0.074	0.026	0.154
CD (p = 0.05)	0.207	0.205	0.073	0.428
Cultivar				
PSD 15	0.876	0.928	0.273	0.241
PSD 17	1.023	0.911	0.296	0.297
PD 18	0.883	0.852	0.290	0.322
Govind	0.783	0.892	0.358	0.268
Pusa 44	0.865	0.898	0.270	0.591
S.Em.±	0.102	0.086	0.025	0.205
CD (p = 0.05)	0.210	0.179	0.0516	0.423

Table 4.15a : Interaction effect between weed control methods and cultivars on RLGR (g/g/wk)of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30-45 DAT						45-60 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	0.967	0.945	0.716	0.965	1.000	0.813	0.284	0.262	0.273	0.265	0.188	0.269
PSD 17	0.112	1.020	0.927	0.704	0.849	1.110	0.258	0.377	0.255	0.265	0.296	0.330
PD 18	0.853	0.925	0.870	0.845	0.875	0.838	0.318	0.281	0.271	0.207	0.314	0.446
Govind	0.681	0.746	0.923	0.932	0.985	0.758	0.379	0.338	0.358	0.214	0.266	0.326
Pusa 44	0.725	0.892	0.979	0.843	0.980	0.870	0.285	0.340	0.184	0.285	1.210	0.277
S.Em.±	0.176			0.150			0.043			0.355		
CD (p = 0.05)	0.365			0.310			0.089			0.733		

4.33 at 45-60 DAT in 2008) and lowest for cv. PSD 15 (12.45 in 2007 and 17.30 in 2008) at 30-45 DAT in both the years, while at 45-60 DAT, lowest in Pusa 44(2.67)in 2007 and PD 18 (3.62) in 2008. The NAR followed an order Pant Sugandha Dhan 17 > Govind > Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 15 in 2007 while n 2008 it was Pant Sugandha Dhan 17 > Pusa 44 > Pant Dhan 18 > Govind > Pant Sugandha Dhan 15 at 30-45 DAT whereas at 45-60 DAT followed an order Pant Sugandha Dhan 17 > Pant Dhan 18 > Govind > Pant Sugandha Dhan 15 > Pusa 44 in 2007 and in 2008, Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 > Govind > Pusa > Pant Dhan 18. The mean value of NAR of five rice cultivars at different growth stages during both the years is presented in Table 4.14a. NAR was highest in cv. PSD 17 and lowest in cv. PSD 15 at 30-45 DAT during both the years and no effect of weed control treatments, where as at 45-60 DAT, maximum in cv. PSD 17 in 2007 and cv. Pusa 44 in 2008 and no difference between the treatments.

4.1.4.3 Relative leaf growth rate(g/g/week)

Relative leaf growth rate of five rice cultivars at different growing stages after translating during both the seasons is presented in Table 4.15. RLGR not differed significantly among the treatments at 30-45 DAT during both the years, where as it differed significantly at 45-60 DAT in 2007 but not in 2008. RLGR was similar in all the three treatments at 30-45 DAT in both the seasons, where as during

45-60 DAT, RLGR was maximum in weed free (0.320) and minimum in butachlor (0.305) in 2007, but in 2008 highest in weed free (0.455) and weedy (0.330) treatments than butachlor (0.247) treatment. RLGR was highest for cv. Pant Sugandha Dhan 17 (1.023) and lowest for Govind (0.783) at 30-45 DAT whereas at 45-60 DAT highest for Govind (0.358) and lowest for Pusa 44 (0.270) in 2007, where as during 2008, it was maximum for cultivars Pant Sugandha Dhan 15 (0.928) and minimum for Pant Dhan 18 (0.852) at 30-45 DAT, whereas at 45-60 DAT, it was maximum for Pusa 44 (0.591) and minimum for Pant Sugandha Dhan 15 (0.241).

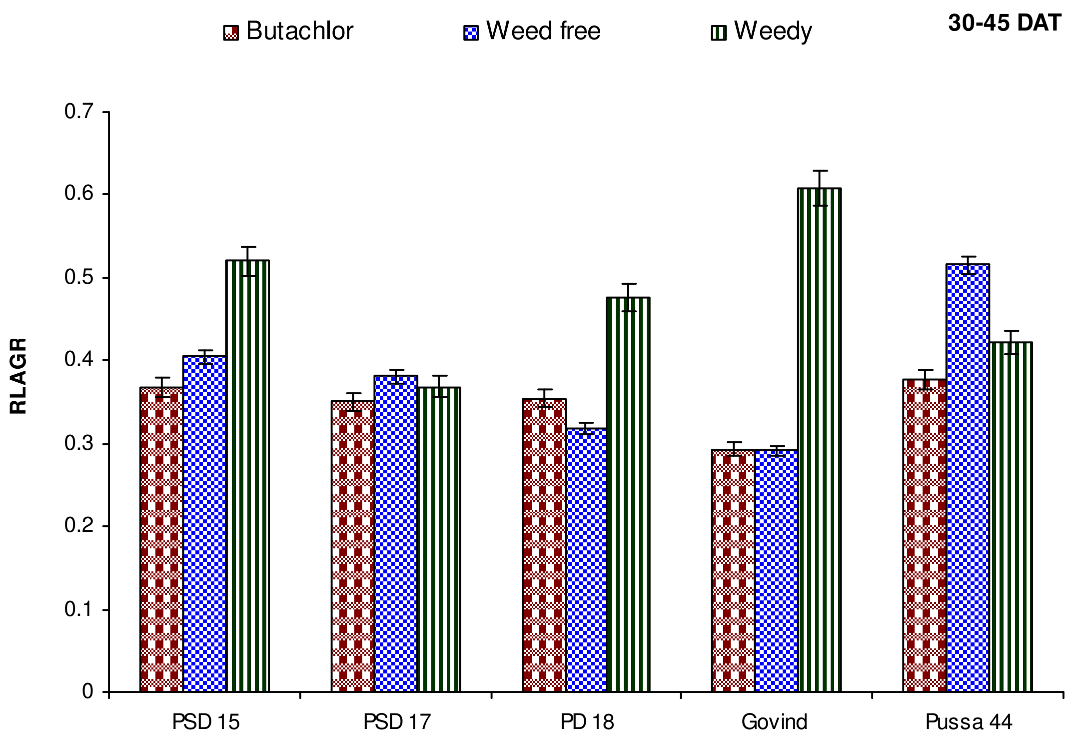
RLGR followed an order Pant Sugandha Dhan 17 > Pant Dhan 18 > Pant Sugandha Dhan 15 > Pusa 44 > Govind in 2007,while in 2008, it was Pant Sugandha Dhan 15 > Pant Sugandha Dhan 17 > Pusa 44 > Govind > Pant Dhan 18 at 30-45 DAT, whereas at 45-60 DAT, followed Govind > Pant Sugandha Dhan 17 > Pant Dhan 18 > Pant Sugandha Dhan 15 > Pusa 44 in 2007 and in 2008, it followed Pusa 44 > Pant Dhan 18 > Pant Sugandha Dhan 17 > Govind > Pant Sugandha Dhan 15. The mean value of RLGR of five rice cultivars at different growth stages during both the years is presented in Table 4.15a. RLGR was highest in cv. PSD 17 (1.02) in 2007 and cv. PSD 17 (0.849) in 2008 at 30-45 DAT, where as during 45-60 DAT, highest in cv. PSD 17 (0.377) in 2007 and cv. Pusa 44 (1.210) in 2008 and there is no difference between the treatments.

Table 4.16: Relative leaf area growth rate (cm^2/cm^2/week) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30-45 DAT		45-60 DAT	
	2007	**2008**	**2007**	**2008**
Weed control method				
Butachlor	0.348	0.293	0.245	0.261
Weed free	0.382	0.258	0.341	0.322
Weedy	0.479	0.370	0.170	0.209
S.Em.±	0.009	0.045	0.062	0.041
CD (p = 0.05)	0.025	0.124	0.172	0.114
Cultivar				
PSD 15	0.431	0.328	0.363	0.303
PSD 17	0.366	0.308	0.221	0.146
PD 18	0.382	0.319	0.296	0.368
Govind	0.398	0.289	0.209	0.208
Pusa 44	0.438	0.292	0.172	0.296
S.Em.±	0.010	0.041	0.041	0.042
CD (p = 0.05)	0.022	0.084	0.846	0.087

Table 4.16a: Interaction effect between weed control methods and cultivars on RLAGR (cm^2/cm^2/week) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30-45 DAT						45-60 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	0.368	0.405	0.520	0.332	0.284	0.368	0.346	0.614	0.128	0.127	0.218	0.134
PSD 17	0.351	0.381	0.368	0.288	0.276	0.359	0.266	0.233	0.163	0.127	0.200	0.113
PD 18	0.354	0.318	0.476	0.287	0.245	0.425	0.267	0.356	0.265	0.254	0.318	0.116
Govind	0.293	0.292	0.608	0.258	0.260	0.350	0.194	0.397	0.370	0.181	0.223	0.104
Pusa 44	0.377	0.515	0.422	0.302	0.227	0.347	0.153	0.106	0.258	0.163	0.167	0.087
S.Em.±	0.018			0.045			0.071			0.080		
CD (p = 0.05)	0.039			0.124			0.146			0.166		



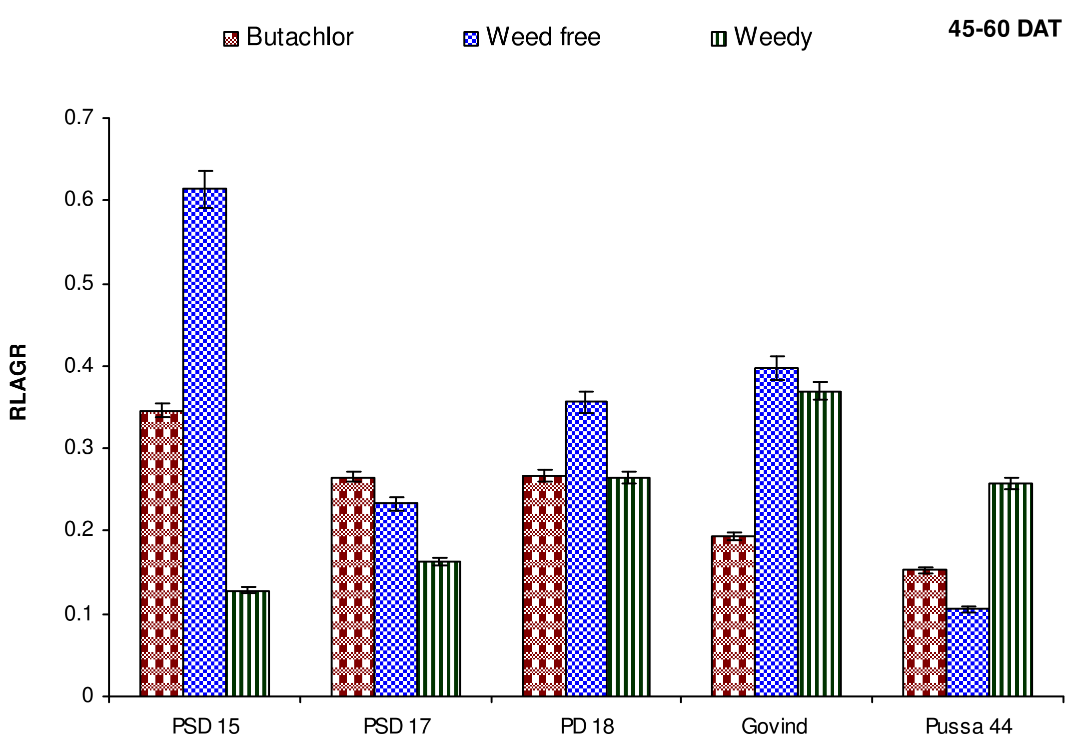
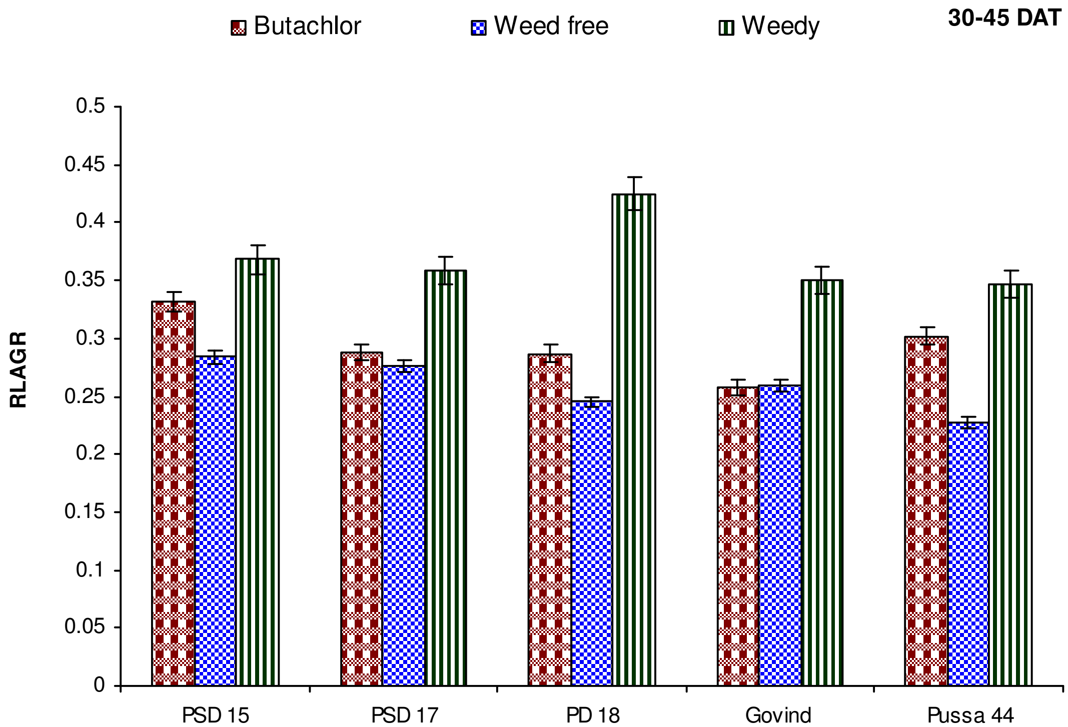


Fig. 4.7a: Relative leaf area growth rate of five rice cultivars at different growth stages during rainy season 2007



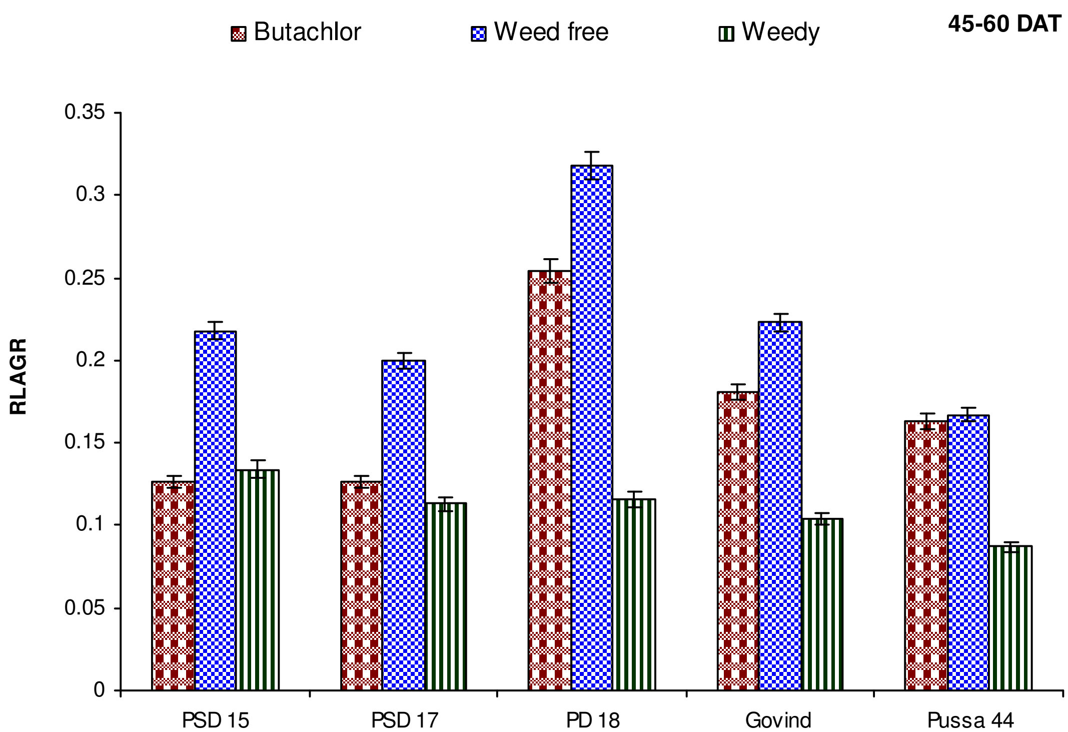


Fig. 4.7b: Relative leaf area growth rate of five rice cultivars at different growth stages during rainy season 2008

4.1.4.4 Relative leaf area growth rate (cm^2/ cm^2/week)

Relative leaf area growth rate of five rice cultivars at different growing stages after transplanting during both the seasons is presented in Table 4.16. RLAGR was differed significantly between the treatments at 30-45 DAT in 2007 and highest in weedy (0.479) plots as compared to weed free (0.382) and butachlor (0.348) treatments, while in 2008, RLAGR had similar value in all the three treatments. During 45-60 DAT, RLAGR was highest in weed free (0.258) and butachlor (0.293) than weedy plots (0.170) in 2007, while in 2008, RLAGR recorded similar value in all the three treatments. RLAGR was maximum in cultivar Pusa 44 (0.438) and minimum in Pant Sugandha Dhan 17 (0.366) at 30-45 DAT whereas at 45-60 DAT maximum in cultivar Pant Sugandha Dhan 15 (0.363) and minimum in Pusa 44 (0.172) in 2007, while in 2008, RLAGR was maximum for cultivar Pant Sugandha Dhan 15 (0.328) and minimum for Govind (0.289) at 30-45 DAT whereas at 45-60 DAT it was maximum in cultivar Pant Dhan 18 (0.368) and minimum in cultivar Pant Sugandha Dhan 17 (0.146) in 2008. RLAGR followed an order Pusa 44 > Pant Sugandha Dhan 15 > Govind > Pant Dhan 18 > Pant Sugandha Dhan 17 in 2007 while in 2008, it was Pant Sugandha Dhan 15 > Pant Dhan 18 > Pant Sugandha Dhan 17 > Pusa 44 > Govind at 30-45 DAT. At 45-60 DAT followed an order Pant Sugandha Dhan 15 > Pant Dhan 18 > Pant Sugandha Dhan 17 >

Table 4.17: Leaf area ratio (cm^2/g) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30 DAT		45 DAT		60 DAT	
	2007	2008	2007	2008	2007	2008
Weed control method						
Butachlor	85.40	86.84	27.63	29.07	36.25	38.62
Weed free	92.67	87.71	33.75	26.26	44.22	40.51
Weedy	98.76	90.57	39.10	32.16	42.20	36.99
S.Em.±	11.25	2.49	0.175	3.05	3.41	0.427
CD (p = 0.05)	31.10	6.89	0.484	8.45	9.44	1.000
Cultivar						
PSD 15	83.68	97.68	44.90	31.47	57.49	45.52
PSD 17	94.55	81.80	23.94	26.61	29.61	27.35
PD 18	81.15	86.35	31.37	30.67	45.49	47.64
Govind	98.91	88.85	32.08	29.03	32.34	33.94
Pusa 44	103.09	87.19	35.18	28.04	39.53	39.06
S.Em.±	7.47	5.79	1.01	2.69	2.52	0.548
CD (p = 0.05)	15.42	11.95	2.09	5.56	5.21	1.13

Table 4.17a: Interaction effect between weed control methods and cultivars on leaf area ratio (cm²/g) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	70.92	70.75	109.37	99.17	94.98	98.90	35.80	39.80	59.02	31.20	29.74	33.47
PSD 17	79.86	95.57	108.22	80.83	77.55	87.03	21.62	26.91	23.31	26.94	24.46	28.44
PD 18	77.42	87.08	78.93	87.36	88.25	83.46	27.53	28.25	38.34	30.12	24.37	37.54
Govind	99.20	94.11	103.42	81.33	90.64	94.59	24.52	28.60	43.13	26.63	27.30	33.15
Pusa 44	99.60	115.84	93.84	85.53	87.13	88.90	28.59	45.22	31.72	30.46	25.45	28.22
S.Em.±		12.94			10.02			1.75			4.66	
CD (p = 0.05)		26.71			20.69			3.62			9.63	

Table 4.17a : *Contd….*

Cultivar	60 DAT					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	51.89	62.39	58.18	45.95	48.82	41.80
PSD 17	29.79	33.79	25.27	27.47	28.23	26.36
PD 18	39.88	46.87	49.71	48.66	48.21	46.05
Govind	28.04	33.63	35.36	32.92	34.92	34.00
Pusa 44	31.67	44.41	42.51	38.08	42.35	36.74
S.Em.±		4.37			0.950	
CD (p = 0.05)		9.03			1.960	

Govind > Pusa 44 in 2007 while in 2008, followed Pant Dhan 18 > Pant Sugandha Dhan 15 > Pusa 44 > Govind > Pant Sugandha Dhan 17. The mean value of RLAGR of five rice cultivars at different growth stages during both the years is presented in Table 4.16a. RLAGR was highest for cv. Pusa 44 (0.515) and lowest for cv. Govind (0.292) in 2007, while in 2008, highest for cv. PSD 15 (0.284) and lowest for cv. Pusa 44 (0.227) at 30-45 DAT. During 45-60 DAT, RLAGR was highest for cv. PSD 15(0.614) in 2007 and cv. PD 18 (0.318) in 2008 while lowest for Pusa 44 (0.106 in 2007 and 0.167 in 2008) in both the years and no difference between the treatments.

4.1.4.5 Leaf area ratio(cm^2/g)

Leaf area ratio of the five rice cultivars at different growing stages after transplanting during both the seasons is presented in Table 4.17. LAR was highest at 30 DAT in both the growing season. A gradual decreased at 45 DAT then after increased at 60 DAT in both the growing seasons. LAR was similar in all the three treatments at 30 DAT during both the years. LAR differed significantly among the treatment at 45 DAT in 2007 and at 60 DAT in 2008. LAR was maximum in weedy plots and lowest in butachlor in 2007, while in 2008, LAR had similar value in all the three treatments at 45 DAT. During 60 DAT, LAR was similar in all the treatments in 2007 and during 2008, maximum in weed free (40.51) and minimum in weedy plots (36.99). In the first growing season (2007) LAR was highest for cultivar Pusa 44 (103.09) and lowest for cultivar Pant Dhan 18 (81.15) at 30 DAT while at 45 DAT and 60 DAT it was maximum for cultivar Pant Sugandha Dhan 15 (44.90 at 45 DAT and 57.44 at 60 DAT) and minimum for cultivar Pant Sugandha Dhan 17 (23.94 at 45 DAT and 29.61 at 60 DAT). In the second growing season (2008) LAR was highest in cultivar Pant Sugandha Dhan 15 (97.68 at 30 DAT, 31.47 at 45 DAT) and lowest in cultivar Pant Sugandha Dhan 17 (81.80 at 30 DAT, 26.61 at 45 DAT) at both 30 and 45 DAT whereas at 60 DAT, it was highest for cultivar Pant Dhan 18 (47.64) and lowest for cultivar Pant Sugandha Dhan 17 (27.35) in 2008. LAR followed an order Pusa > 44 > Govind > Pant Sugandha Dhan 17 > Pant Sugandha Dhan 15 > Pant Dhan 18 in 2007 whereas in 2008 it followed an order Pant Sugandha Dhan 15 > Govind > Pusa 44 > Pant Dhan 18 > Pant Sugandha Dhan 17 at 30 DAT. The mean value of LAR of five rice cultivars at different growth stages during both the years is presented in Table 4.17a. LAR was highest in cv. PSD 15 in both the years, while lowest in cv. Govind in 2007 and cv. PSD 17 in 2008 at 60 DAT and no difference between the treatments.

4.1.4.6 Specific leaf weight (mg/cm^2)

Specific leaf weight of the five rice cultivars at different growing stages after transplanting during both the seasons is presented in Table 4.18. SLW was similar in all the treatments at 30 DAT during both the years. At 45 DAT, SLW was maximum in butachlor and weed

Table 4.18: Specific leaf weight (mg/cm^2) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Treatment	30 DAT		45 DAT		60 DAT	
	2007	2008	2007	2008	2007	2008
Weed control method						
Butachlor	3.39	3.25	11.00	10.93	12.67	10.98
Weed free	3.18	3.15	9.11	13.48	10.56	11.99
Weedy	3.11	3.12	7.37	10.06	8.95	12.34
S.Em.±	0.427	0.557	0.448	0.756	0.975	0.207
CD (p = 0.05)	1.18	1.54	1.24	2.09	2.69	0.572
Cultivar						
PSD 15	3.17	2.78	8.08	10.68	7.75	9.22
PSD 17	3.12	3.91	12.21	12.18	14.25	16.47
PD 18	3.37	3.69	9.46	11.31	9.35	8.98
Govind	3.43	2.68	8.50	12.06	12.98	13.53
Pusa 44	3.03	2.82	7.54	11.22	9.30	10.65
S.Em.±	0.668	0.557	0.545	1.16	0.917	0.541
CD (p = 0.05)	1.38	1.15	1.12	2.40	1.89	1.11

Table 4.18a: Interaction effect between weed control methods and cultivars on specific leaf weight (mg/cm^2) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	2.88	3.35	3.29	2.41	2.74	3.20	10.40	9.19	4.66	9.32	13.97	9.77
PSD 17	3.13	2.84	3.39	4.70	4.37	2.65	15.58	9.78	11.26	11.53	14.34	10.69
PD 18	3.54	3.16	3.43	3.75	3.46	3.86	9.75	10.94	7.69	11.66	12.87	9.41
Govind	3.44	3.99	2.87	2.71	2.59	2.74	10.54	9.96	5.00	12.34	13.83	10.01
Pusa 44	3.95	2.56	2.57	2.70	2.59	3.17	8.75	5.65	8.23	9.82	13.40	10.44
S.Em.±		1.15			0.96			0.94			2.01	
CD (p = 0.05)		2.39			1.99			1.94			4.16	

Table 4.18a: ***Contd...***

Cultivar	60 DAT					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	9.21	7.71	6.33	12.71	12.16	13.83
PSD 17	15.76	13.22	13.78	15.58	16.97	16.87
PD 18	11.16	9.17	7.73	10.39	11.77	13.42
Govind	15.71	13.35	9.88	13.24	16.51	15.87
Pusa 44	11.53	9.35	7.04	12.85	16.86	15.40
S.Em.±		1.58			1.45	
CD (p = 0.05)		3.27			3.00	

free treatments than weedy plots in 2007, while in 2008, maximum in weed free treatment as compared to butachlor and weedy treatments. During 60 DAT, SLW was similar in all the treatments in both the years .SLW was highest in cv. Govind (3.43) in 2007 and cv. PSD 17(3.91) in 2008, where as lowest in cv. Pusa 44 (3.03) in 2007and cv. Govind (2.68) at 30 DAT in both the years. During 45 DAT and 60 DAT SLW was maximum in cv. PSD 17 (12.21 in 2007 and 12.18 in 2008 at 45 DAT and 14.25 in 2007 and 16.47 in 2008 at 60 DAT) in both the years and lowest in cv. Pusa 44 (7.54) in 2007 and cv. PSD 15 (10.68) in 2008, where as at 60 DAT lowest in cv. PSD 15 (7.75) in 2007 and cv. PD 18 (8.98) in 2008. SLW differed significantly among the cultivars at 60 DAT in both the years. SLW gradually increased from 30 DAT up to 60 DAT in all the treatments in both the seasons except decreased in weed free treatment at 60 DAT in 2008.

The SLW followed an order Pant Sugandha Dhan 17 > Pant Dhan 18> Govind > Pant Sugandha Dhan 17 > Pusa 44 in 2007, while in 2008, it followed Pant Sugandha Dhan 17 > Govind > Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 15 at 45 DAT. The mean value of SLW of five rice cultivars at different growth stages during both the seasons is presented in Table 4.18a. SLW was highest in cv. Govind (13.35) in 2007 and cv. PSD 17 (16.97) in 2008, while lowest in cv. PSD 15 (7.71) in 2007 and cv. PD 18 (11.77) in 2008 at 60 DAT and no difference between the treatments in both the years.

Table 4.19: Effect of rice straw incorporation into the soil and butachlor on the weed population at 60 DAT (No. m^{-2})

S. No.	Weed species	Number of population per m^2				
		T_1	T_2	T_3	T_4	T_5
1.	*Echinochloa crusgalli*	96 (37.94)	84 (31.46)	84 (37.5)	100 (34.60)	104 (32.19)
2.	*E. colona*	28 (11.06)	16 (5.99)	16 (7.14)	28 (9.68)	36 (11.14)
3.	*Leptocloa chinensis*	–	–	20 (8.92)	12 (4.15)	24 (7.43)
4.	*Caesulia axillaris*	56 (22.13)	84 (31.46)	40 (17.85)	88 (30.44)	23 (7.12)
5.	*Frimbristylis miliaceae*	–	–	16 (7.14)	20 (6.92)	32 (9.90)
6.	*Cyperus iria*	8 (3.16)	10 (3.74)	12 (5.35)	9 (3.11)	20 (6.19)
7.	*Cyperus difformis*	16 (6.32)	9 (3.37)	8 (3.57)	–	8 (2.47)
8.	*Amania basifera*	9 (3.55)	24 (8.98)	12 (5.35)	16 (5.53)	32 (9.90)
9.	*Paspalum scrobiculatum*	28 (11.06)	40 (14.98)	16 (7.14)	16 (5.53)	24 (7.43)
10.	*Ischimum rugosum*	4 (1.58)	–	–	–	8 (2.47)
11.	*Alternathera sessilis*	8 (3.16)	–	–	–	12 (3.71)
	Total no. of population in each treatment	253	267	224	289	323

Per cent composition of each weed species in each treatment.
T_1 : Rice straw 100 g/m^2; T_2 : Rice straw 200 g/m^2; T_3 : Rice straw 500 g/m^2;
T_4 : Butachlor; T_5 : Weedy

4.2 Effect of rice straw incorporation and weed treatment on weed flora and plant growth and yield of four rice cultivars

The experiment was conducted during the rainy season 2008.The data recorded for different parameters are presented below.

4.2.1 Weed flora

The weed flora at 60 DAT is presented in Table 4.19. The experimental field was mainly infested with grassy weeds which included *E. crusgalli, E. colona, Leptochloa chinensis*, *Paspalum scrobiculatum, Ischaemum rugosum.* The sedges consisted of *Cyperus iria,Cyperus difformis, Frimbristylis miliaceae* and broad leaved weeds such as *Caesulia axillaris, Ammania basifera* and *Alternanthera sessilis* were present. Among the treatments T_5 (weedy plots) treatment had highest population of weeds (323 no./m^2) followed by T_4 (butachlor)treatment (289 no./m^2). Weed population was lower in all the three treatments where rice straw was incorporated. It was lowest in T_3 (500gm-^{2} rice straw) treatment (224 no./m^2). In all the treatments, Grassy weed *E. crusgalli* had highest population followed by *C. axillaris*, *F. miliaceae, C. difformis* and *Paspalum scrobiculatum, E. colona* .The lowest population of *A. sessilis, Ergotis japonica, A. basifera* ,*L. chinensis* and *I. rugosum.* were recorded in all the treatments. Weed flora followed an order among the treatments T5 >T4 >T2 >T1 >T3.

Table 4.20: Effect of rice straw incorporation into the soil and butachlor on the weed dry weight at 60 DAT during rainy season 2008

Weed control	Weed dry weight(g/m^2)
Rice straw 100 g/m^2	312.30
Rice straw 200 g/m^2	338.00
Rice straw 500 g/m^2	283.70
Butachlor	387.75
Weedy	480.30
S.Em. ±	83.69
CD (p = 0.05)	192.89
Cultivar	
PSD 15	500.50
PD 18	281.90
Govind	374.40
Pusa 44	284.60
S.Em. ±	64.03
CD (p = 0.05)	130.78

Table 4.20a: Interaction effect between rice cultivars and rice straw incorporation into the soil and butachlor on the weed dry weight (g/m^2) at 60 DAT during rainy season 2008

Cultivar	Weed dry weight (g/m^2)					
	Rice straw (g/m^2)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	454.6	440.0	326.6	626.6	654.6	500.5
PD 18	294.6	280.0	258.3	263.3	313.3	281.9
Govind	213.3	372.0	293.3	386.6	606.6	374.8
Pusa 44	286.6	260.0	256.6	273.3	346.6	284.6
Mean	312.3	338.0	283.7	387.5	480.3	360.3
S.Em.±	143.19					
CD (p = 0.05)	292.43					

Table 4.21a: Interaction effect between rice cultivars and rice straw incorporation into the soil and butachlor on the total dry matter production at harvest during rainy season 2008

Cultivar	Total dry matter production (g/ m^2)					
	Rice straw (g/m^2)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	783.3	733.3	783.3	633.3	650.0	716.66
PD 18	933.3	900.0	1083.3	1233.3	866.6	1003.3
Govind	616.6	673.3	933.3	816.6	716.6	751.3
Pusa 44	700.0	833.3	916.6	800.0	700.0	970.0
Mean	758.3	785.0	929.1	870.8	733.3	815.3
S.Em.±	160.67					
CD (p = 0.05)	328.15					

Table 4.21: Effect of rice straw incorporation into the soil and butachlor on the total dry matter production of four rice cultivars at harvest during rainy season 2008

Weed control	Total dry matter production(g/m^2)
Rice straw 100 g/m^2	758.30
Rice straw 200 g/m^2	785.00
Rice straw 500 g/m^2	929.16
Butachlor	870.83
Weedy	733.30
S.Em. ±	81.32
CD (p = 0.05)	187.48
Cultivar	
PSD 15	716.66
PD 18	1003.33
Govind	751.33
Pusa 44	790.00
S.Em. ±	71.85
CD (p = 0.05)	146.75

4.2.2 Weed dry weight

Dry weight of weeds at 60 days after transplanting (DAT) of four rice cultivars during 2008 is presented in Table 4.20. Weed dry weight was maximum in weedy treatment (480.3 g/m^2) and minimum in T_3 treatment (283.7 g/m^2) and weed dry weight followed an order $T_5 > T_4 > T_2 > T_1 > T_3$. Among the cultivars, highest weed dry weight was recorded in cultivar Pant Sugandha Dhan 15 (500.5 g/m^2) while lowest recorded in cv. Pant Dhan 18 (281.9 g/m^2) and Pusa 44 (284.6 g/m^2). Weed dry weight followed an order in T_1 treatment, Pant Sugandha Dhan 15 > Pant Dhan 18 > Pusa 44 > Govind while in T_2 treatment, it followed Pant Sugandha Dhan 15 > Govind > Pant Dhan 18 > Pusa 44 and in T_3 treatment, Pant Sugandha Dhan 15 > Govind > Pant Dhan 18 > Pusa 44, whereas T_4 and T_5 treatment followed same order Pant Sugandha Dhan 15 > Govind > Pusa 44 > Pant Dhan 18. The mean value of weed dry weight of four rice cultivars at 60 DAT is presented in Table 4.20a. Weed dry weight was highest in cv. PSD 15 and lowest in cv. PD 18.

4.2.3 Total dry matter Production

Total dry matter production (g/m^2) of four rice cultivars at the time of harvest during 2008 is presented in Table 4.21. Total dry matter production was maximum in treatment (T_3) (929.16) and minimum in (T_5) weedy treatment (733.3) at harvest. The treatment followed an order $T_3 > T_4 > T_2 > T_1 > T_5$. The per cent reduction in weedy treatment was 21.07 per cent while in Butachlor (T_4) treatment was 6.27 per cent at harvest.

Total dry matter (TDM) was highest in cultivar Pant Dhan 18 (1003.33) and lowest in cultivar Pant Sugandha Dhan 15 (716.66) and TDW followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15. TDM was significantly higher in cultivar Pant Dhan 18 at harvest.

The per cent reduction in TDM in weedy treatment was maximum for cultivar Govind (24.99) followed by Pusa 44 (23.63), Pant Dhan 18 (20.00) and minimum in cultivar Pant Sugandha Dhan 15 (17.02) while in Butachlor (T_4) treatment maximum reduction in cultivar Pant Sugandha Dhan 15 (19.15) and minimum in Govind (12.50) and Pusa 44 (12.72), whereas cultivar Pant Dhan 18 showed 12.61 per cent increment in T_4 treatment as compared to T_3. In T_4 and T_3 dry matter followed an order Pant Dhan 18 > Govind > Pusa 44 > Pant Sugandha Dhan 15 while in T_1 and T_2 treatment, followed an order Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 15 > Govind. The mean value of TDM of four rice cultivars at harvest is presented in Table 4.21a and TDM was highest in cv. PD 18 and lowest in cv. PSD 15 in all the treatments.

4.2.4 Grain yield

Grain yield (g/m^2) of four rice cultivars at the time of harvest during 2008 is presented in Table 4.22. Grain yield was highest in

Table 4.22: Effect of rice straw incorporation into the soil and butachlor on the grain yield of four rice cultivars at harvest during rainy season 2008

Weed control	Grain yield(g/m^2)
Rice straw 100 g/m^2	303.30
Rice straw 200 g/m^2	318.30
Rice straw 500 g/m^2	392.50
Butachlor	356.60
Weedy	265.83
S.Em. ±	29.51
CD (p = 0.05)	68.01
Cultivar	
PSD 15	265.30
PD 18	439.30
Govind	277.30
Pusa 44	327.30
S.Em. ±	37.94
CD (p = 0.05)	77.49

Table 4.22a: Interaction effect between rice cultivars and rice straw incorporation into the soil and butachlor on the grain yield at harvest during rainy season 2008

Cultivar	Grain yield (g/ m²)					
	Rice straw (g/m²)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	280.0	290.0	313.3	263.3	180.0	265.3
PD 18	396.6	416.6	473.3	526.6	383.3	439.3
Govind	216.6	243.3	380.0	316.6	230.0	277.3
Pusa 44	320.0	323.3	403.3	320.0	270.0	327.3
Mean	303.3	318.3	392.5	356.6	265.8	327.3
S.Em.±	84.84					
CD (p = 0.05)	173.27					

Table 4.23a: Interaction effect between rice cultivars and rice straw incorporation into the soil and butachlor on the harvest index at harvest during rainy season 2008

Cultivar	Harvest index (%)					
	Rice straw (g/m²)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	36.30	40.16	41.01	39.72	28.33	37.10
PD 18	42.76	55.83	47.33	42.63	41.23	45.96
Govind	34.96	35.43	41.36	39.26	30.00	45.24
Pusa 44	37.90	37.73	51.26	40.36	38.36	41.12
Mean	37.98	42.29	45.24	40.49	34.48	
S.Em.±	8.95					
CD (p = 0.05)	18.28					

Table 4.23: Effect of rice straw incorporation into the soil and butachlor on the harvest index of four rice cultivars at harvest during rainy season 2008

Weed control	Harvest index
Rice straw 100 g/m^2	37.98
Rice straw 200 g/m^2	42.29
Rice straw 500 g/m^2	45.24
Butachlor	40.49
Weedy	34.48
S.Em. ±	3.97
CD (5%)	9.14
Cultivar	
PSD 15	37.10
PD 18	45.96
Govind	45.24
Pusa 44	41.12
S.Em. ±	4.00
CD (%)	8.17

treatment T_3 (393.50) and lowest in weedy treatment (T_5) (265.83) at harvest. The per cent reduction in weedy treatment was 32.27 per cent and in Butachlor T_4 treatment was 9.14 per cent as compared to T_3 treatment. The grain yield followed an order in treatments as $T_3 > T_4 > T_2 > T > T_1$ .The grain yield was highest in cultivar Pant Dhan 18 (439.3) and lowest in cultivar Pant Sugandha Dhan 17 (265.3) at harvest. The grain yield followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15. The grain yield of Pant Dhan 18 (439.3) was significantly higher than other cultivars. The per cent reduction in weedy situation was maximum in cultivar Pant Sugandha Dhan 15 (42.5%) and minimum in cultivar Pant Dhan 18 (19.0%) while in Butachlor (T_4) treatment maximum reduction in cultivar. Pusa 44 (20.65) and minimum in Pant Sugandha Dhan 15 (15.90) whereas cultivar Pant Dhan 18 (10.12%) showed % increment in T_4 treatment as compared to T_3 treatment. The grain yield followed an order in all treatments, Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15. The mean value of four rice cultivars at harvest is presented in Table 4.22a. Grain yield was maximum in cv. PD 18 and lowest in cv. PSD 15 in all the treatments.

4.2.5 Harvest index

The harvest index of four rice cultivars at harvest during 2008 is presented in Table 4.23. The harvest index was highest for T_3

treatment (45.24) and lowest for T_5 weedy treatment (34.48) and harvest index followed an order $T_3 > T_2 > T_4 > T_1 > T_5$ among the treatments. The per cent reduction in weedy treatment (T_5) was 23.78 per cent while in Butachlor T_4 reduction was 10.4 per cent as compared to T_3 treatment. The harvest index ranged between 34.48 to 45.24 % among the treatments.

Harvest index was maximum for cultivar Pant Dhan 18 (45.96) followed by Govind (45.24) and minimum for cultivar Pant Sugandha Dhan 15 (37.10). Harvest index followed an order Pant Dhan 18 > Govind > Pusa 44 > Pant Sugandha Dhan 15. The per cent reduction in weedy situation was maximum in cultivar Pant Sugandha Dhan 15 (30.9) and minimum in Pant Dhan 18 (12.86) while in (T_4) Butachlor treatment, maximum reduction in cultivar Pusa 44 (21.26) and minimum in Pant Sugandha Dhan 15 (3.1) followed by Govind (5.07) and Pant Dhan 18 (9.93) as compared to T_3 treatment. The harvest index ranged among the cultivars between 45.96 to 37.10 %. The harvest index followed an order in T_3 treatment Pusa 44 (51.26) > Pant Dhan 18 (47.33) > Govind (41.36) > Pant Sugandha Dhan 15 (41.01) whereas in T_4 5 (Butachlor) treatment followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 and in T_5 (weedy) treatment it followed Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15. The mean value of HI of four rice cultivars is presented in Table 4.23a. HI was highest was highest in cv. PD 18 and lowest in cv. PSD 15 in all the treatments.

Table 4.24: Effect of rice straw incorporation into the soil and butachlor on the plant height (cm) of four rice cultivars at different growth stages during rainy season 2008

Weed control	Plant height (cm)		
	30 DAT	60 DAT	Harvest
Rice straw 100 g/m^2	74.61	87.80	94.40
Rice straw 200 g/m^2	73.41	90.98	96.69
Rice straw 500 g/m^2	78.63	93.86	99.97
Butachlor	76.35	92.73	96.91
Weedy	74.21	88.83	94.23
S.Em. ±	1.46	2.69	1.35
CD (p = 0.05)	3.37	6.20	3.11
Cultivar			
PSD 15	84.78	104.48	110.39
PD 18	76.25	95.26	105.22
Govind	71.48	86.38	89.85
Pusa 44	69.23	77.24	80.30
S.Em. ±	1.34	1.61	1.14
CD (p = 0.05)	2.75	3.29	2.40

Table 4.24a: Effect of rice straw incorporation into the soil and butachlor on the plant height of four rice cultivars at 30 and 60 days after transplanting (DAT) during rainy season 2008

Cultivar	30 DAT						60 DAT					
	Rice straw (g/m^2)			Butachlor	Weedy	Mean	Rice straw (g/m^2)			Butachlor	Weedy	Mean
	100	200	500				100	200	500			
PSD 15	88.33	73.00	87.60	83.86	85.40	84.78	101.13	105.86	106.86	106.20	102.33	104.48
PD 18	73.00	74.86	80.13	79.86	73.40	76.25	92.20	95.00	98.26	99.33	91.53	95.26
Govind	68.93	70.53	76.20	72.13	69.60	71.48	81.86	85.33	90.80	88.06	85.86	86.38
Pusa 44	68.20	69.53	70.60	69.53	68.46	69.26	76.00	77.73	79.53	77.33	75.60	77.24
Mean	74.61	73.41	78.63	76.35	74.21	75.40	87.80	90.98	93.86	92.73	88.83	90.84
S.Em.±	3.01						3.456					
CD (p = 0.05)	6.162						7.359					

Table 4.24a: ***Contd...***

Cultivar	Harvest					
	Rice straw (g/m^2)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	107.00	109.30	118.56	108.26	108.80	110.39
PD 18	101.86	105.66	109.06	106.73	102.80	105.22
Govind	87.03	90.93	91.33	91.86	88.13	89.85
Pusa 44	81.73	80.86	80.93	80.80	77.20	80.30
Mean	94.40	96.69	99.97	96.91	94.23	96.44
S.Em.±	2.63					
CD (p = 0.05)	5.38					

4.2.6 Growth parameters

4.2.6.1 Plant height

Plant height of the four rice cultivars at different growth stages during 2008 is presented in Table 4.24 and differed significantly among the treatments. Plant height recorded maximum in treatment Pant T_3 (500 g/m^2) rice straw (99.97 cm) at and minimum in weedy treatment T_5 (94.23) at harvest. Plant height was highest in cultivar Pant Sugandha Dhan 15 (110.39) followed by Pant Dhan 18 (105.22) and lowest in cultivar Pusa 44 (80.30) at harvest. The treatment followed an order $T_3 > T_4 > T_2 > T_1 > T_5$ at harvest. The per cent reduction was maximum in weedy situation in cultivar Govind (8.66) followed by Pant Dhan 18 (8.39) and lowest in cultivar Pant Sugandha Dhan 15 (2.51) followed by Pusa 44 (3.03) while in maximum in Pant Sugandha Dhan 15 (8.68) and minimum in Pant Dhan 18 (2.13) followed by Pusa 44 (3.06) whereas cultivar Govind had similar height in both the treatments (T_3 and Butachlor). At harvest plant height followed an order Pant Sugandha Dhan 15 > Pant Dhan 18 > Govind > Pusa 44 at harvest. The mean value of plant height of four rice cultivars at different growth stages is presented in Table 4.24a and was maximum in cv. PSD 15 and lowest in Pusa 44 at all the growth stages as well as in the treatments.

4.2.6.2 Tiller number/plant

Tiller number of the four rice cultivars at different growth stages during 2008 is presented in Table 4.25. Tiller number was

Table 4.25: Effect of rice straw incorporation into the soil and butachlor on the tiller number per plant of four rice cultivars at different growth stages during rainy season 2008

Weed control	Tiller number/plant	
	30 DAT	**60 DAT**
Rice straw 100 g/m^2	9.68	15.06
Rice straw 200 g/m^2	10.56	17.33
Rice straw 500 g/m^2	11.17	19.39
Butachlor	11.06	19.13
Weedy	8.94	12.84
S.Em. ±	0.810	0.932
CD (p = 0.05)	1.86	2.14
Cultivar		
PSD 15	9.12	14.96
PD 18	11.50	18.54
Govind	11.80	16.24
Pusa 44	9.19	17.26
S.Em. ±	0.606	0.596
CD (p = 0.05)	1.23	1.21

Table 4.25a : Effect of rice straw incorporation into the soil and butachlor on the tiller number per plant of four rice cultivars at 30 and 60 days after transplanting (DAT) during rainy season 2008

Cultivar	30 DAT						60 DAT					
	Rice straw (g/m²)			Butachlor	Weedy	Mean	Rice straw (g/m²)			Butachlor	Weedy	Mean
	100	200	500				100	200	500			
PSD 15	7.60	8.80	10.15	10.40	8.59	9.12	13.60	15.53	18.06	16.66	10.93	14.96
PD 18	9.20	11.13	13.30	13.40	10.40	11.50	15.96	19.50	21.53	21.20	14.53	18.54
Govind	12.00	11.56	12.66	12.56	10.16	11.80	14.36	16.73	19.13	18.33	12.66	16.24
Pusa 44	9.80	10.73	10.96	7.90	6.56	9.19	16.33	17.56	18.83	20.33	13.23	17.26
Mean	9.68	10.56	11.17	11.06	8.94	10.40	15.06	17.33	19.39	19.13	12.84	16.75
S.Em.±	0.606						1.34					
CD (p = 0.05)	2.77						2.72					

maximum in treatment T_3 (19.39) and minimum in weedy treatment (12.84) at 60 DAT. The treatment followed an order $T_3 = T_4 > T_2 > T_1 > T_5$ at 60 DAT. Number of tillers differed significantly among the cultivars at 60 DAT.

The per cent reduction in tiller numbers in weedy treatment (33.78) as compared to T_3, whereas T_3 (19.39), T_4 (1913). Tiller number was maximum in cultivar Pant Dhan 18 (18.54) and minimum in cultivar Pant Sugandha Dhan 15 (14.96) at 60 DAT. The per cent reduction in weedy situation was maximum in cultivar Pant Sugandha Dhan 15 (39.47) and minimum in cultivar Pusa 44 (29.73) at 60 DAT while in Butachlor treatment (T_4) maximum reduction in cultivar Pant Sugandha Dhan 15 (7.75) and minimum in Govind (4.18) as compared to treatment 3 or T_3, whereas cultivar Pusa 44 (7.37) showed reduction in T_3 treatment and cultivar Pant Dhan 18 (21.53- T_3 and 21.20 – T_4) showed similar number of tillers in both the treatments. The tiller number followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 at 60 DAT. The mean value of tiller no. of four rice cultivars at different growth stages is presented in Table 4.25a. Tiller no. was maximum in cv. PD 18 and minimum in cv. PSD 15 at all the growth stages as well as in the treatments.

4.2.6.3 Shoot dry weight (g/plant)

Shoot dry weight of four rice cultivar at 60 DAT during 2008 is presented in Table 4.26. The dry weight of plant differed significantly

Table 4.26: Effect of rice straw incorporation into the soil and butachlor on the shoot dry weight (g/plant) of four rice cultivars at 60 days after transplanting during rainy season 2008

Weed control	Shoot dry weight (g/plant)
Rice straw 100 g/m^2	35.90
Rice straw 200 g/m^2	37.10
Rice straw 500 g/m^2	49.03
Butachlor	44.88
Weedy	33.51
S.Em. ±	0.326
CD (p = 0.05)	0.752
Cultivar	
PSD 15	36.53
PD 18	45.94
Govind	36.00
Pusa 44	41.86
S.Em. ±	0.422
CD (p = 0.05)	0.862

Table 4.26a: Effect of rice straw incorporation into the soil and butachlor on the shoot dry weight of four rice cultivars at 60 days after transplanting (DAT) during rainy season 2008

Cultivar	Shoot dry weight (g/plant)					
	Rice straw (g/m^2)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	37.26	35.33	42.80	34.26	33.00	36.53
PD 18	43.33	41.06	52.00	55.00	38.33	45.94
Govind	29.73	32.00	46.13	42.13	30.00	36.00
Pusa 44	33.26	40.00	55.20	48.13	32.73	41.86
Mean	35.90	37.10	49.03	44.88	33.51	40.00
S.Em.±			0.945			
CD (p = 0.05)			1.931			

among the treatments and was maximum in (T_3) treatment (49.03) and minimum in (T_5) treatment (33.51). Shoot dry weight followed an order $T_3 > T_4 > T_2 > T_1 > T_5$. The per cent reduction in SDW in weedy (T_5) treatment was 31.65 per cent and in (Butachlor) T_4 treatment was 8.46 per cent as compared to T_3 treatment. Among the cultivars SDW dry weight differed significantly among the cultivars except not significantly differed between the Pant Sugandha Dhan 15 (36.53) and Govind (36.00). The SDW dry weight followed an order Pant Dhan 18 > Pusa 44 > Pant Sugandha Dhan 15 > Govind. The per cent reduction in weedy (T_5) treatment was maximum in cultivar Pusa 44 (40.70) and minimum in Pant Sugandha Dhan 15 (22.87) while in (Butachlor) T_4 treatment maximum in cultivar Pant Sugandha Dhan 15 (19.95) and minimum in cultivar Govind (8.67) whereas Pant Dhan 18 (5.45) showed % increment in dry weight of shoot in Butachlor (T_4) treatment. Dry weight followed an order in (T_3) treatment among the cultivars Pusa 44 > Pant Dhan 18 > Govind > Pant Sugandha Dhan 15 while in T_4 treatment, it was, Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 and in (T_5) treatment Pant Dhan 18 > Pant Sugandha Dhan 15 > Pusa 44 > Govind at 60 DAT. The mean value of SDW of four rice cultivars at 60 DAT is presented in Table 4.26a. SDW differed significantly among the cultivars and was maximum in cv. PD 18 and minimum in cv. Govind and PSD 15 than rest of the cultivars.

Table 4.27: Effect of rice straw incorporation into the soil and butachlor on the panicle number per plant of four rice cultivars at harvest during rainy season 2008

Weed control	Panicle number/plant
	Harvest
Rice straw 100 g/m^2	35.16
Rice straw 200 g/m^2	37.16
Rice straw 500 g/m^2	39.58
Butachlor	37.58
Weedy	34.75
S.Em. ±	2.04
CD (p = 0.05)	4.72
Cultivar	
PSD 15	29.13
PD 18	43.40
Govind	34.73
Pusa 44	40.13
S.Em. ±	2.10
CD (p = 0.05)	4.30

Table 4.27a: Effect of rice straw incorporation into the soil and butachlor on the panicle number of four rice cultivars at harvest during rainy season 2008

Cultivar	Harvest					
	Rice straw (g/m²)			Butachlor	Weedy	Mean
	100	200	500			
PSD 15	29.00	31.00	31.00	29.00	25.66	29.13
PD 18	40.00	41.00	46.30	47.00	42.60	43.40
Govind	33.33	36.00	37.00	34.00	33.33	34.73
Pusa 44	38.30	40.60	44.00	40.30	37.30	40.13
Mean	35.16	37.16	39.58	37.58	34.75	36.85
S.Em.±			4.71			
CD (p = 0.05)			9.63			

4.2.6.4 Panicle number

Panicle number per plant of four rice cultivars at harvest during 2008 is presented in Table 4.27. Panicle number was highest in treatment T_3 (500gm^{-2}rice straw) (39.58) and lowest in weedy treatment T_5 (34.75). The mean value of panicle no./plant of four rice cultivars at harvest is presented in Table 4.27a and was highest in cv. PD 18 and lowest in cv. PSD 15 in all the treatments. The per cent reduction in panicle no./plant in weedy treatment (T_5) was 12.20 while in Butachlor treatment reduction was 5.32 as compared to T_3. The treatment followed an order $T_3 > T_4 > T_2 > T_1 > T_5$. The panicle number was maximum in cultivar Pant Sugandha Dhan 15 (29.13). The panicle number were significantly differed among the cultivars but not differed significantly between Pant Dhan 18 and Pusa 44. The panicle number followed an order Pant Dhan 18 > Pusa 44 > Govind > Pant Sugandha Dhan 15 at harvest.

The per cent reduction in weedy situation (T_5) was maximum in cultivar Pant Sugandha Dhan 15 (17.22) and minimum in Pant Dhan 18 (7.99), while in Butachlor treatment (T_4) maximum in cultivar in Pant Sugandha Dhan 15 (6.45) whereas cultivar Pant Dhan 18 had 1.48% increment in Butachlor (T_4) treatment.

4.3 Germination studies: Effect of synthetic phenolic compounds and plant parts or their exudates on germination of weeds

4.3.1 Petri dish assay

Germination studies were carried out in Petri dishes. Out of 11 weed species six species germinated (*Echinochloa crusgalli,*

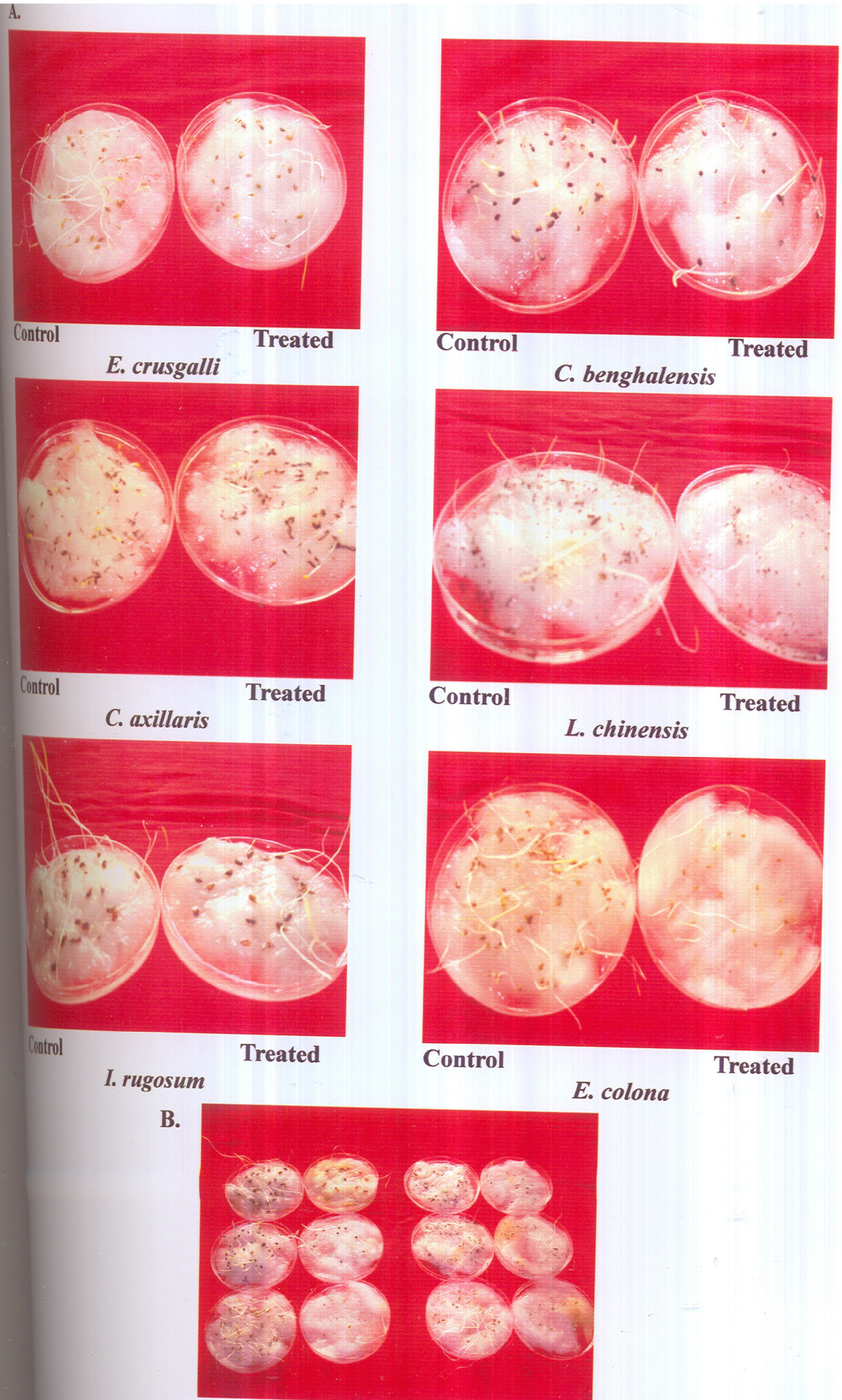
Table 4.28a: Effect of synthetic phenolic compounds on germination of six weed species (data represent per cent inhibition of germination as compared to control)

Phenolic acid (100 ppm)	***I. rugosum***	***C. benghalensis***	***E. crusgalli***	***E. colona***	***C. axillaris***	***L. chinensis***
Gallic acid	40	10	40	10	20	10
Vanillic acid	90	60	80	80	70	95
p-hydroxy benzoic acid	60	32	10	10	20	30
Ferulic acid	90	70	80	30	70	95
Syringic acid	70	50	70	70	80	90
Salicylic acid	40	40	60	15	40	50
CD (p=0.05)	10.45	5.38	5.98	4.68	4.68	6.39

Table 4.28b: Effect of mixture of synthetic phenolic compounds on germination of six weed species (data represent per cent inhibition of germination as compared to control)

***Mixture of synthetic phenolic compounds**	***I. rugosum***	***C. benghalensis***	***E. crusgalli***	***E. colona***	***C. axillaris***	***L. chinensis***
Mixture 1	80	40	90	90	80	90
Mixture 2	80	20	80	80	90	90
Mixture 3	50	70	90	80	90	80
Mixture 4	70	30	80	50	80	70
CD (p = 0.05)	11.64	5.74	11.91	8.74	14.01	10.94

*Mixture 1 = Ferulic acid + Vanillic acid +*p*-hydroxy benzoic acid
Mixture 2 = Ferulic acid + Vanillic acid +*p*-hydroxy benzoic acid + gallic acid
Mixture 3 = Ferulic acid + Vanillic acid +*p*-hydroxy benzoic acid + gallic acid + salicylic acid
Mixture 4 = Ferulic acid + Vanillic acid +*p*-hydroxy benzoic acid + gallic acid + salicylic acid + syringic acid



Photoplate 4.1 : Effect of synthetic phenolic compounds on germination of six weed species (A) Individual phenloic acid (Ferulic acid), (B) Combinaton of phenolic acids (Mix 1)

Echinochloa colona, Commelina benghalensis, Ischaemum rugosum, Leptochloa chinensis and *Caesulia axillaris*) while rest of the five species viz., *Cyperus rotundus, Cyperus difformis, Cyperus iria, Celome visoca* and *Celosia argentia* failed to germinate.

(i) Effect of synthetic phenolic compounds on weed seed germination

The effect of synthetic phenolics such as gallic acid, vanillic acid, ferulic acid, p-Hydroxy Benzoic acid and syringic acid 100 ppm each, alone or in different combinations on the germination of weed species was studied and the data,(as per cent inhibition as compared to control) is presented in Table 4.28a and 4.28b.

In general, all the phenolics have inhibitory effects on weed seeds germination whether it was used individually or in combination. The degree of inhibition varied among the weed species. Ferulic acid, vanillic acid and syringic acids had maximum inhibitory effects (30-90% inhibition as compared to control). Inhibition of germination was least in presence of Gallic acid (10 to 40%). Maximum reduction was recorded in the species *L. chinensis, E. crusgalli* and *I. rugosum*.. The combination of phenolic compounds had more inhibitory effects than individual compounds. Mixture 1(ferulic acid + vaillic acid + p Hydroxy benzoic acid) and mixture 2 (ferulic acid + vanillic acid +p Hydroxy benzoic acid + gallic acid) had inhibited 20 to 90 % weed seeds germination and all the combinations of phenolic compounds had inhibitory effects 30 to 90 % on weed seeds germination.

Table 4.29a: Effect of rice straw on germination of six weed species (data represent per cent inhibition of germination as compared to control)

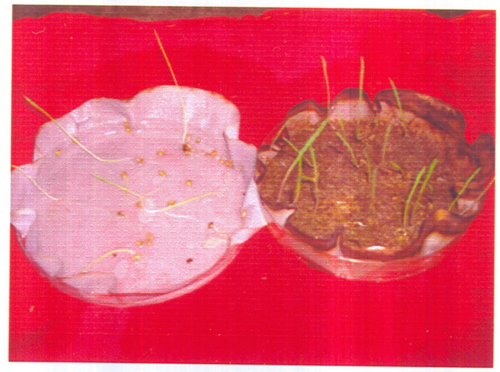
Weed species	Germination (% inhibition on germination as compared to control)
I. rugosum	80
C. benghalensis	50
E. crusgalli	30
E. colona	30
Caesulia axillaris	65
Leptochloa chinensis	75
CD (p = 0.05)	5.55

Table 4.29b: Effect of rice straw on seedling growth of six weed species (data represent per cent inhibition in seedling growth of weed species as compared to control)

Weed species	Seedling growth (% inhibition as compared to control)	
	Root	Shoot
I. rugosum	88	45
C. benghalensis	52	50
E. crusgalli	34	20
E. colona	50	38
Caesulia axillaris	73	67
Leptochloa chinensis	51	40
CD (p = 0.05)	5.97	5.88

Control Treated

C. benghalensis

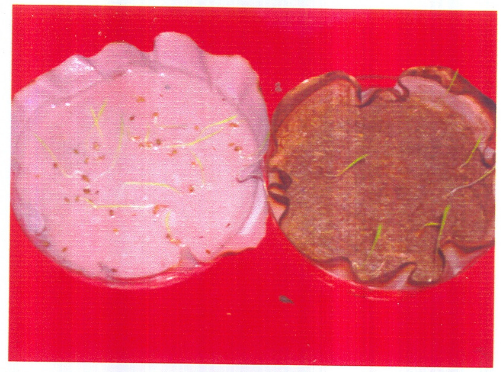


Control Treated

E. crusgalli

Control Treated

C. axillaris

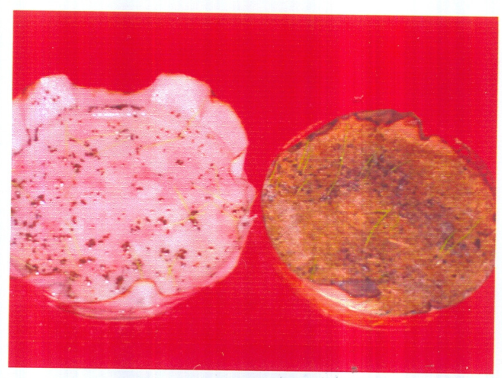


Control Treated

E. colona

Control Treated

I. rugosum



Control Treated

L. chinensis

Photoplate 4.2 : Effect of rice straw on germination and seedling growth of six weed species

(ii) Effect of rice straw on germination and growth of weeds

a. Effect of rice straw on germination of weeds species

Germination medium was prepared through rice straw into the Petri dish. Effect of rice straw on the weed seed germination and growth of weeds is presented in Table 4.29a. The rice straw had an inhibitory effect on germination of all the weed species. Inhibition percentage ranged between 30 to 80% among the weed species. Highest per cent inhibition was recorded in *Ischaemum rugosum* (80%) followed by *Leptochloa chinensis*(75%) and the lowest in *E. crusgalli* (30%) and *E. colona* (30%).

b. Effect of rice straw on seedling growth of six weed species

Effect of rice straw on seedling growth(i.e. shoot and root length)of six weed species is presented in Table 4.29b. Seedling growth of all the weed species was reduced in the presence of rice straw. Root growth was more sensitive than shoot growth in all the species. Inhibition of root growth was maximum in *I. rugosum* (88%) followed by *C. axillaris* (73%) where as in shoot growth had maximum reduction in the species *C. axillaris* (67%).

(iii) Effect of rice root

a. Effect of roots of five rice cultivars on germination and growth of weed seeds

Effect of roots of five rice cultivars on germination of weed seeds is presented in Table 4.30a. Roots of five rice cultivars had

Table 4.30a: Effect of roots of five rice cultivars on germination of six weed species (data represent per cent inhibition of germination as compared to control)

Cultivar	*I. rugosum*	*C. benghalensis*	*E. crusgalli*	*E. colona*	*C. axillaris*	*L. chinensis*
Pant Sugandha Dhan 15	10	30	20	25	60	20
Pant Sugandha Dhan 17	20	40	10	10	45	80
Pant Dhan 18	30	80	30	35	80	20
Govind	20	20	20	60	69	71
Pusa 44	20	40	50	40	72	30
CD (p = 0.05)	5.33	6.15	2.09	2.16	4.50	5.24

Table 4.30b: Effect of roots of five rice cultivars on seedling growth of six weed species (data represent per cent inhibition in seedling growth of weed species as compared to control)

Cultivar	*I. rugosum*		*C. benghalensis*		*E. crusgalli*		*E. colona*		*C. axillaris*		*L. chinensis*	
	Shoot	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**
Pant Sugandha Dhan 15	30	45	20	35	10	38	18	40	31	46	40	51
Pant Sugandha Dhan 17	17	28	21	30	20	29	15	34	20	41	30	38
Pant Dhan 18	40	55	42	66	15	42	20	31	40	53	28	49
Govind	30	50	37	49	22	46	29	49	25	50	30	45
Pusa 44	35	52	28	51	20	50	21	52	35	48	40	53
CD (p = 0.05)	3.11	3.78	2.52	5.24	2.52	4.50	2.52	4.50	3.11	5.24	5.24	5.24

inhibitory effects on weed seed germination. Cultivars PD 18 and Govind had maximum inhibitory effects (up to 70-80%) in *C. axillaris*. Among the weed species highest reduction in germination was recorded in *C. axillaries* and *L. chinensis* (up to 80%), while minimum in *I. rugosum* and *E. crusgalli* (10 to 50 %).

b. Effect of roots of five rice cultivars on seedling growth of six weed species

Effect of roots of five rice cultivars on seedling growth of weed species is presented in Table 4.30b. Roots of five rice cultivars had more inhibitory effects on root growth of all the six weed species as compared to shoot growth. Cultivars PD18, Govind and Pusa 44 had maximum inhibitory effects on weed species than PSD15 and PSD17. In root growth maximum reduction in *I. rugosum* and *C. benghalensis* and minimum reduction in *E. crusgalli* and *E. colona*, where as in shoot growth, maximum reduction in *I. rugosum* and minimum in *E. crusgalli* (10 to 20%). Cultivars PD 18 and Govind reduced the root growth as well as shoot growth effectively.

(iv) Effect of straw of five rice cultivars on germination of six weed species

Effect of straw of five rice cultivars on germination of six weed species is presented in Table 4.31a. All the five rice cultivars had inhibitory effects on germination of six weed species and reduced the germination of all the weed species. The cv. PD18, Govind and Pusa 44 had maximum inhibitory action than PSD15 and PSD17.cultivar

Table 4.31a: Effect of straw of five rice cultivars on germination of six weed species (data represent per cent inhibition of germination as compared to control)

Cultivar	*I. rugosum*	*C. benghalensis*	*E. crusgalli*	*E. colona*	*C. axillaris*	*L. chinensis*
Pant Sugandha Dhan 15	40	45	30	20	56	30
Pant Sugandha Dhan 17	20	30	20	20	52	34
Pant Dhan 18	60	45	40	25	65	50
Govind	62	40	50	35	60	80
Pusa 44	50	70	20	70	50	80
CD (p = 0.05)	3.78	6.46	3.44	2.98	5.24	4.42

Table 4.31b: Effect of straw of five rice cultivars on seedling growth of six weed species (data represent per cent inhibition in seedling growth of weed species as compared to control)

Cultivar	*I. rugosum*		*C. benghalensis*		*E. crusgalli*		*E. colona*		*C. axillaris*		*L. chinensis*	
	Root	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**
Pant Sugandha Dhan 15	40	34	38	27	34	20	30	22	42	30	45	32
Pant Sugandha Dhan 17	25	29	35	30	20	10	30	20	28	22	50	31
Pant Dhan 18	45	36	48	33	31	26	32	27	46	37	61	39
Govind	46	32	40	28	38	30	40	32	32	25	52	40
Pusa 44	42	35	64	48	50	36	60	45	32	36	65	51
CD (p = 0.05)	4.50	5.24	5.24	4.79	3.78	2.20	5.24	4.72	5.24	3.99	5.93	4.79

PSD17 had least inhibitory effects on germination of weed seeds. Weed species which were more sensitive to straw were, *C. axillaris, L. chinensis, C. benghalensis, I. rugosum* and least sensitive, *E. crusgalli, E. colona.*

Effect of straw of five rice cultivars on the seedling growth of six weed species

Effect of straw of five rice cultivars on the seedling growth i.e. shoot and root length of six weed species is presented in Table 4.31b. Seedling growth of all the six weed species was reduced in presence of rice straw. Among both shoot and root growth, the root growth was more sensitive in all the six weed species. Straw of cultivars PD18, Govind, Pusa 44 had maximum inhibitory effects on seedling growth of all six weed species. In root and shoot growth maximum reduction was recorded in species *L. chinensis* (50- 65% in root and 31- 51% in shoot) in both root and shoot growth.

4.3.2 Hydroponics: Effect of root exudates of five rice cultivars grown in hydroponics on weed seeds germination and seedling growth

Effect of root exudates of five rice cultivars grown in hydroponics on effect of germination of six weed species is presented in Table 4.32a. The root exudates of five rice cultivars had inhibitory effects on germination of all the six weed species. Highest per cent inhibition in germination was recorded in species *Leptochloa chinensis* (80%), followed by *C. axillaris* (75%), *I. rugosum* (75%) and

Table 4.32a: Effect of root exudates of five rice cultivars grown in hydroponics on germination of six weed species (data represent per cent inhibition of germination compared to control)

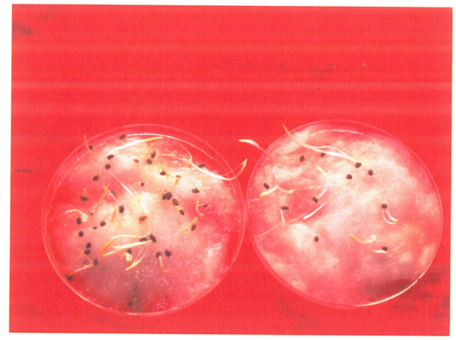
Weed species	Germination (% inhibition as compared to control)
I. rugosum	75
C. benghalensis	70
E. crusgalli	60
E. colona	55
Caesulia axillaris	75
Leptochloa chinensis	80
CD (p = 0.05)	8.79

Table 4.32b: Effect of root exudates of five rice cultivars grown in hydroponics on seedling growth of six weed species (data represent per cent inhibition in seedling growth of weed species as compared to control)

Weed species	Seedling growth(% inhibition as compared to control)	
	Shoot	Root
I. rugosum	42	67
C. benghalensis	50	61
E. crusgalli	35	45
E. colona	32	51
Caesulia axillaris	65	72
Leptochloa chinensis	62	75
CD (p = 0.05)	7.08	7.52

Control Treated

I. rugosum



Control Treated

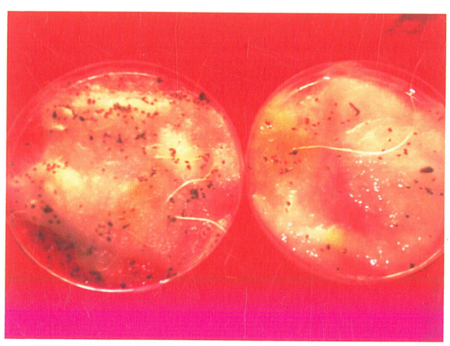
C. benghalensis

Control Treated

E. crusgalli

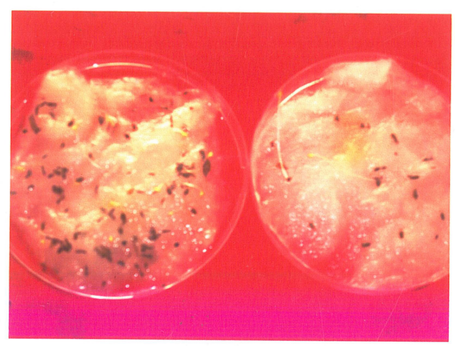
Control Treated

E. colona



Control Treated

L. chinensis



Control Treated

C. axillaris

Photoplate 4.3 : Effect of root exudates of five rice cultivars grown in hydroponics on germination and seedling growth of six weed species

C. benghalensis (70%) where as lowest per cent reduction was recorded in species *E. crusgalli* (60%), *E. colona* (55%). Root exudates delayed the time of germination of all the weed species.

Effect of root exudates of five rice cultivars grown in hydroponics on seedling growth i.e. shoot and root length of all the six weed species is presented in Table 4.32b. Root exudates had inhibitory effect on seedling growth of weed species. root growth was more sensitive than shoot growth. Per cent inhibition in root growth was maximum in *Leptochloa chinensis* (75%) followed by *C. axillaris* (72%), *and minimum in E. crusgalli* (45%) followed by *E. colona* (51%) whereas in shoot growth maximum in *C. axillaris* (65%) followed by *L. chinensis* (62%) and *C. benghalensis* (61%). The root exudates of five rice cultivars had greater inhibitory effects on seedling growth of all the weed species and it significantly reduced the growth of weed species. Root exudates delayed the germination of all weed seeds.

4.3.3 Sand Culture: (Donor – Receiver Bioassay): Effect of rice seedlings on germination and seedling growth of six weed species

Effect of rice seedlings on germination of six weed species is presented in Table 4.33a and 4.33b Seedlings of five different rice cultivars had inhibitory effects on the germination of all the six weed species. The cultivars PD18, Govind, Pusa 44, PSD 15 had maximum inhibitory effects on the germination and seedling growth of weed species whereas PSD 17 was least effective. In the presence of

Table 4.33a: Donor-receiver bioassay: effect of rice seedlings (grown on sand) on germination of six weed species (data represent per cent inhibition of germination as compared to control)

Cultivar	*I. rugosum*	*C. benghalensis*	*E. crusgalli*	*E. colona*	*C. axillaris*	*L. chinensis*
Pant Sugandha Dhan 15	40	70	50	10	40	50
Pant Sugandha Dhan 17	60	40	80	5	20	30
Pant Dhan 18	80	80	40	50	60	20
Govind	80	60	50	80	50	20
Pusa 44	50	50	20	90	10	95
CD (p = 0.05)	6.70	5.24	5.56	2.03	3.49	4.13

Table 4.33b: Donor-receiver bioassay: effect of rice seedlings (grown on sand) on seedling growth of six weed species (data represent per cent inhibition in seedling growth of weed species as compared to control)

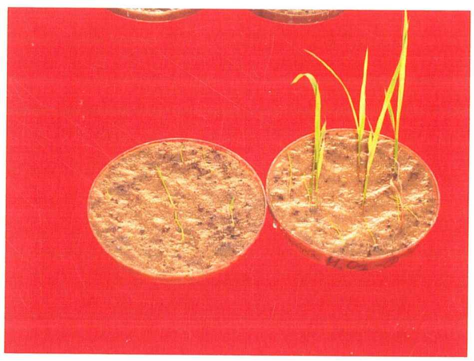
Cultivar	*I. rugosum*		*C. benghalensis*		*E. crusgalli*		*E. colona*		*C. axillaris*		*L. chinensis*	
	Root	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**
Pant Sugandha Dhan 15	50	54	32	13	53	49	50	67	84	74	67	63
Pant Sugandha Dhan 17	43	48	30	29	38	31	37	40	26	31	50	25
Pant Dhan 18	67	60	43	32	69	66	52	64	55	46	51	47
Govind	50	62	17	40	50	55	38	57	50	48	29	34
Pusa 44	47	33	15	40	70	56	59	62	69	71	31	24
CD (p = 0.05)	4.50	5.24	4.13	5.40	5.70	5.70	4.50	4.87	3.78	5.97	6.01	5.24

Control Treated

C. benghalensis

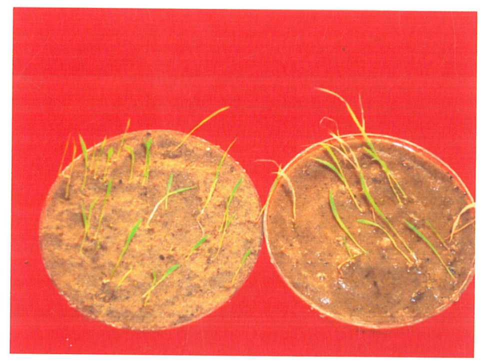
Control Treated

E. crusgalli



Control Treated

L. chinensis



Control Treated

E. colona

Control Treated

C. axillaris

Control Treated

I. rugosum

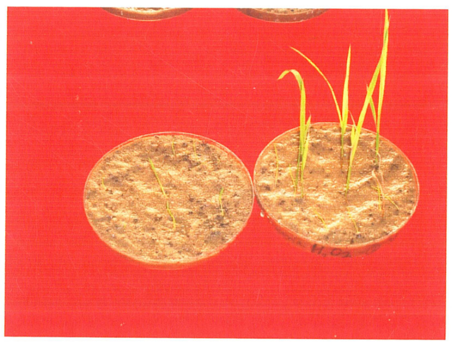
Photoplate 4.4a : Effect of seedlings of cv. PSD 15 on germination and seedling growth of six weed species (donor-receiver bioassay)

Control Treated

E. crusgalli

Control Treated

L. chinensis



Control Treated

C. benghalensis

Control Treated

E. colona

Control Treated

C. axillaris

Control Treated

I. rugosum

Photoplate 4.4b : Effect of seedlings of cv. PSD 17 on germination and seedling growth of six weed species (donor-receiver bioassay)

Control Treated

I. rugosum

Control Treated

E. crusgalli

Control Treated

L. chinensis

Control Treated

C. benghalensis

Control Treated

E. colona

Control Treated

C. axillaris

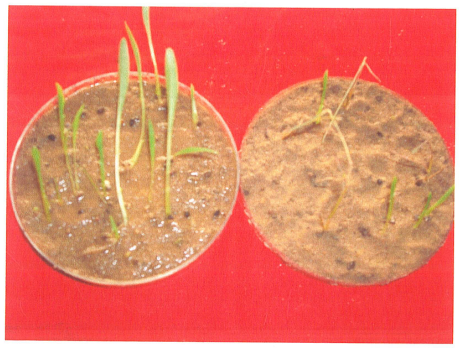
Photoplate 4.4c : Effect of seedlings of cv. PD 18 on germination and seedling growth of six weed species (donor-receiver bioassay)

Control Treated

E. crusgalli

Control Treated

L. chinensis



Control Treated

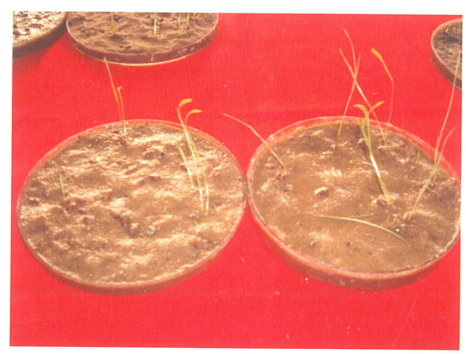
C. benghalensis

Control Treated

E. colona

Control Treated

C. axillaris



Control Treated

I. rugosum

Photoplate 4.4d : Effect of seedlings of cv. Govind on germination and seedling growth of six weed species (donor-receiver bioassay)

Control Treated

E. crusgalli

Control Treated

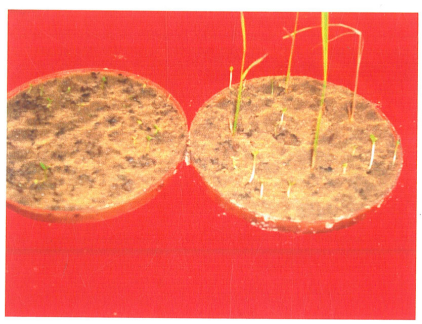
L. chinensis

Control Treated

C. benghalensis

Control Treated

E. colona



Control Treated

C. axillaris

Control Treated

I. rugosum

Photoplate 4.4e : Effect of seedlings of cv. Pusa 44 on germination and seedling growth of six weed species (donor-receiver bioassay)

Table 4.34 : Phenol content (μg/g FW) of shoot of five rice cultivars at different growth stages during rainy season 2007 and 2008

Weed control methods	Phenol content (μg/g FW)					
	30 DAT		45 DAT		60 DAT	
	2007	2008	2007	2008	2007	2008
Butachlor	4.55	5.41	5.47	6.16	5.26	5.75
Weed free	4.79	5.74	5.99	6.59	5.67	6.17
Weedy	3.94	4.82	4.90	5.61	4.33	5.06
S.Em. ±	0.007	0.093	0.074	0.122	0.093	0.139
CD (p = 0.05)	0.002	0.259	0.206	0.339	0.259	0.384
Cultivar						
PSD 15	4.18	5.13	6.19	6.07	5.65	5.91
PSD 17	3.70	4.53	4.61	5.27	4.02	4.62
PD 18	4.54	5.70	5.38	6.45	5.02	5.88
Govind	4.74	5.28	4.89	5.75	4.76	5.28
Pusa 44	4.97	5.96	6.20	7.06	6.06	6.60
S.Em. ±	0.008	0.144	0.088	0.157	0.144	0.152
CD (p = 0.05)	0.016	0.298	0.183	0.325	0.298	0.314

Table 4.34a: Interaction effect between weed control methods and cultivars on phenol content of shoot (μg/g FW) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	4.32	4.62	3.60	5.08	5.49	4.83	6.02	6.67	5.89	6.28	6.60	5.34
PSD 17	3.98	4.11	3.03	4.67	5.05	3.88	4.66	5.08	4.10	5.12	5.91	4.78
PD 18	4.62	4.90	4.12	5.88	6.03	5.18	5.21	5.98	4.96	6.43	6.78	6.13
Govind	4.86	5.06	4.32	5.23	5.72	4.91	5.10	5.45	4.13	5.87	6.11	5.29
Pusa 44	5.01	5.28	4.63	6.18	6.41	5.30	6.40	6.79	5.42	7.09	7.58	6.51
S.Em.±	0.013			0.250			0.154			0.272		
CD (p = 0.05)	0.028			0.516			0.317			0.563		

Table 4.34a: Contd...

Cultivar	60 DAT					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	5.80	6.03	5.13	6.12	6.42	5.21
PSD 17	4.16	4.83	3.07	4.64	5.32	3.91
PD 18	5.13	5.71	4.23	5.95	6.14	5.57
Govind	5.08	5.23	3.98	5.26	5.81	4.79
Pusa 44	6.16	6.59	5.27	6.80	7.16	5.85
S.Em.±	0.250			0.263		
CD (p = 0.05)	0.516			0.544		

Table 4.35 : Phenol content (μg/g FW) of root of five rice cultivars at different growth stages during rainy season 2007 and 2008

Weed control methods	Phenol content (μg/g FW)					
	30 DAT		45 DAT		60 DAT	
	2007	2008	2007	2008	2007	2008
Butachlor	5.45	5.42	7.90	8.35	7.26	7.38
Weed free	5.76	5.87	8.61	8.82	7.82	8.33
Weedy	4.44	4.93	7.76	8.02	6.91	7.55
S.Em. ±	0.111	0.092	0.175	0.156	0.175	0.181
CD (p = 0.05)	0.307	0.255	0.484	0.433	0.484	0.502
Cultivar						
PSD 15	5.71	6.35	9.06	9.47	7.65	8.99
PSD 17	5.47	4.64	8.14	7.47	6.90	6.79
PD 18	4.92	5.71	7.93	8.67	7.80	8.39
Govind	5.13	5.04	8.18	8.23	7.99	8.00
Pusa 44	4.81	5.28	7.14	8.14	6.32	7.43
S.Em. ±	0.112	0.107	0.084	0.082	0.084	0.086
CD (p = 0.05)	0.232	0.221	0.174	0.169	0.174	0.178

Table 4.35a: Interaction effect between weed control methods and cultivars on phenol content of root (μg/g FW) of five rice cultivars at different growth stages during rainy season 2007 and 2008

Cultivar	30 DAT						45 DAT					
	2007			2008			2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	5.92	6.19	5.01	6.12	6.86	6.08	9.02	9.54	8.62	9.46	9.97	9.00
PSD 17	5.80	6.00	4.62	4.80	5.06	4.08	8.30	8.90	7.23	7.51	7.89	7.02
PD 18	5.20	5.50	4.24	5.95	6.13	5.06	7.50	8.30	8.00	8.62	9.00	8.40
Govind	5.33	5.72	4.37	5.03	5.52	4.59	7.80	8.54	8.20	8.16	8.54	8.00
Pusa 44	5.01	5.42	4.01	5.21	5.78	4.86	6.92	7.77	6.75	8.04	8.70	7.69
S.Em.±		0.195			0.185			0.146			0.142	
CD (p = 0.05)		0.402			0.383			0.302			0.293	

Table 4.35a: Contd...

Cultivar	60 DAT					
	2007			2008		
	Butachlor	Weed free	Weedy	Butachlor	Weed free	Weedy
PSD 15	8.00	8.61	6.36	9.12	9.26	8.61
PSD 17	7.25	7.42	6.04	6.83	7.12	6.42
PD 18	7.38	8.11	7.91	8.27	8.79	8.11
Govind	7.63	8.27	8.07	7.96	8.40	7.65
Pusa 44	6.03	6.73	6.21	7.22	8.11	6.98
S.Em.±		0.146			0.149	
CD (p = 0.05)		0.302			0.309	

seedlings of five rice cultivars both root and shoot growth of weed seeds was affected. Root growth was more sensitive than shoot growth. In root growth maximum reduction in *C. axillaris* where as in shoot growth maximum reduction in *E. colona* and minimum in *C. benghalensis* in both root and shoot growth.

4.4 Biochemical parameters

4.4.1 Total phenol content of shoot and root of five rice cultivars

Phenol content in the shoot and roots of five rice cultivars at different growth stages is presented in the Table 4.34 and 4.35. The phenol content of shoot was maximum in weedy treatment (4.9) at 45 DAT in the first growing season (2007). In the second growing season (2008), phenol content was highest in weed free treatment (6.59) and lowest for weedy treatment (5.61) at 45 DAT. In both the growing years, phenol content increased from 30 to 45 DAT in all the treatments and declined there after. The phenol content differed significantly among the treatments. Shoot phenol content varied among the treatments as well as different growth stages. At all the stages and all the treatments, was higher in the second growing season (2008) as compared to the first growing season. Among the cultivars, it was highest in Pusa 44 (6.2) followed by Pant Sugandha Dhan 15 (6.19) and lowest in cultivar Pant Sugandha Dhan 17 (4.61) in 2007, while in 2008, phenol content was highest in cultivar Pusa 44 (7.06) followed by Pant Dhan 18 (6.45) and lowest in cultivar Pant Sugandha Dhan 17 (5.27) at 45 DAT in 2007. The phenol content followed an order Pusa 44 > Pant Sugandha Dhan 15 > Pant Dhan 18 > Govind > Pant Sugandha Dhan 17 whereas in 2008, it followed Pusa 44 > Pant Dhan 18 > Pant Sugandha Dhan 15 > Govind > Pant Sugandha Dhan 17 at 45 DAT. The mean value of phenol content of shoot at different growth stages in both the seasons is presented in Table 4.34a and was highest in cv. Pusa 44(6.79 in 2007 and 7.58 in 2008) and lowest in cv. PSD 17 (5.08 in 2007 and 5.91 in 2008) during both the years at 45 DAT. The mean per cent reduction was maximum in cv. PSD 17 (19.20 in weedy and 13.88 in butachlor), where as minimum in cv. PD 18 in weedy and cv. Govind in butachlor treatment at 45 DAT in both the years.

Phenol content of roots was highest in cultivar Pant Sugandha Dhan 15 (9.06) and lowest in cultivar Pusa 44 (7.14) in 2007, while in 2008, maximum in Pant Sugandha Dhan 15 (9.47) and lowest in cultivar Pant Sugandha Dhan 17 (7.47) at 45 DAT. A gradual increase in phenol content of root was observed up to 45 DAT and declined thereafter the phenol content followed an order Pant Sugandha Dhan 15 > Govind > Pant Sugandha Dhan 17 > Pant Dhan 18 > Pusa 44 in 2007, while in 2008, it followed Pant Sugandha Dhan 15 > Pant Dhan 18 > Govind > Pusa 44 > Pant

Sugandha Dhan 17 at 45 DAT. The phenol content of root was higher than shoot. The mean value of phenol content of five rice cultivars at different growth stages during both the seasons is presented in Table 4.35a and was highest in cv. PSD 15 (9.54 in 2007 and 9.97 in 2008) and lowest in cv. Pusa 44 (7.77) in 2007 and cv. PSD 17 (7.89) in both the years at 45 DAT. The mean per cent reduction in both the years in weedy situation was maximum in cultivar Pusa 44 (14.45) followed by Pant Dhan 18 (14.78), Govind (14.98) while in Butachlor treatment maximum in cultivar Pusa 44 (7.57) and minimum in cultivar Pant Sugandha Dhan 15 (3.30) at 45 DAT.

4.4.2 Estimation and profiling of phenolics of rice cultivars by high performance liquid chromatography (HPLC)

The phenol content of both roots and shoots of five rice cultivars were analyzed by HPLC and the data is presented in Table 4.36. The retention time of different phenolic standard compounds such as p-Hydroxy benzoic acid, gallic acid, vanillic acid, syringic acid, Benzoic acid, ferulic acid, hydroquinone and cinnamic acid is presented in Table 4.37. Different standards were identified by plotting their standard curves (Fig. 4.8a and 4.8b).

This was used as a reference for detecting phenolics of the root and shoot extracts of all the cultivars.

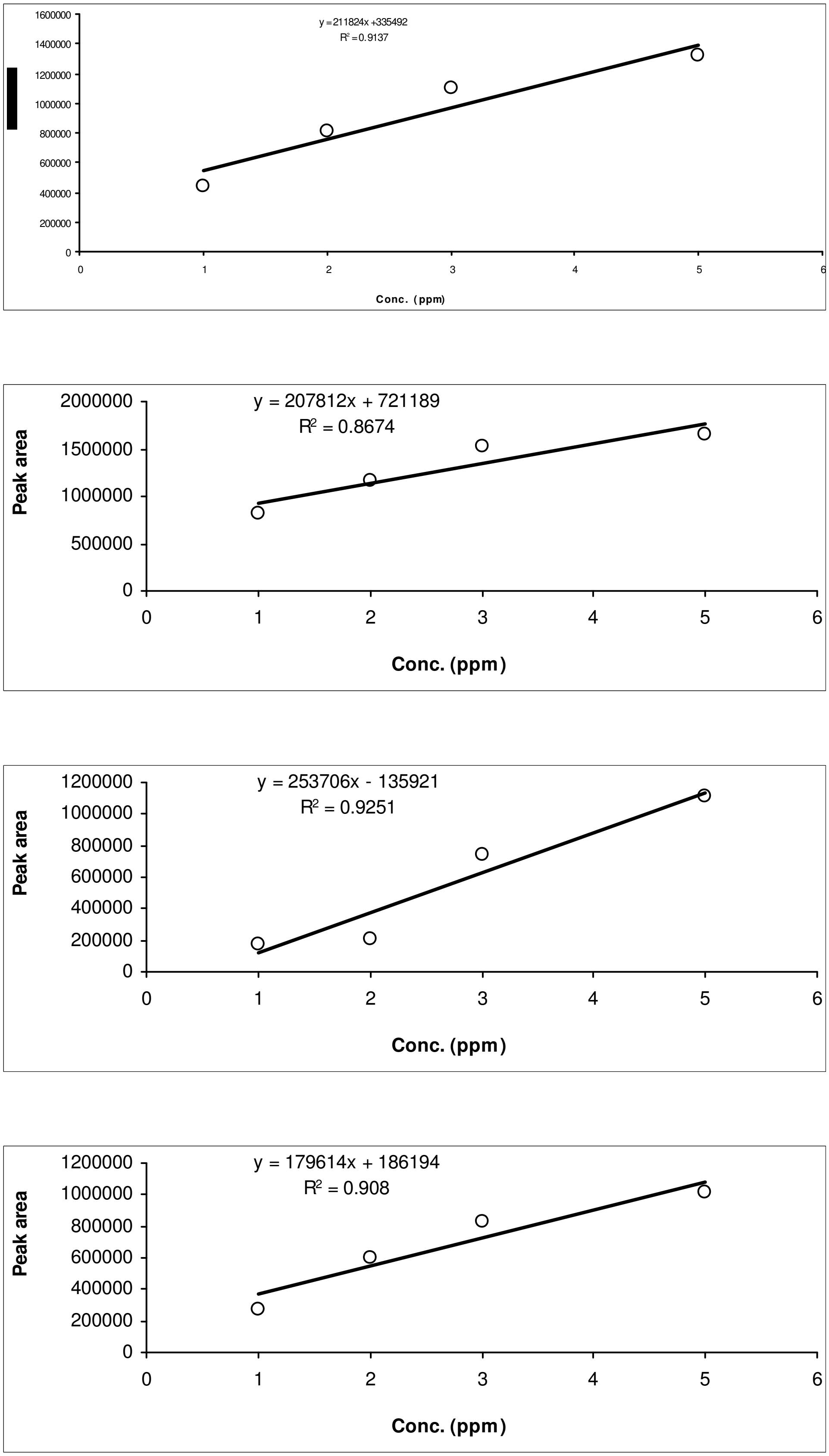


Fig. 4.8a : Standard curve of phenolics

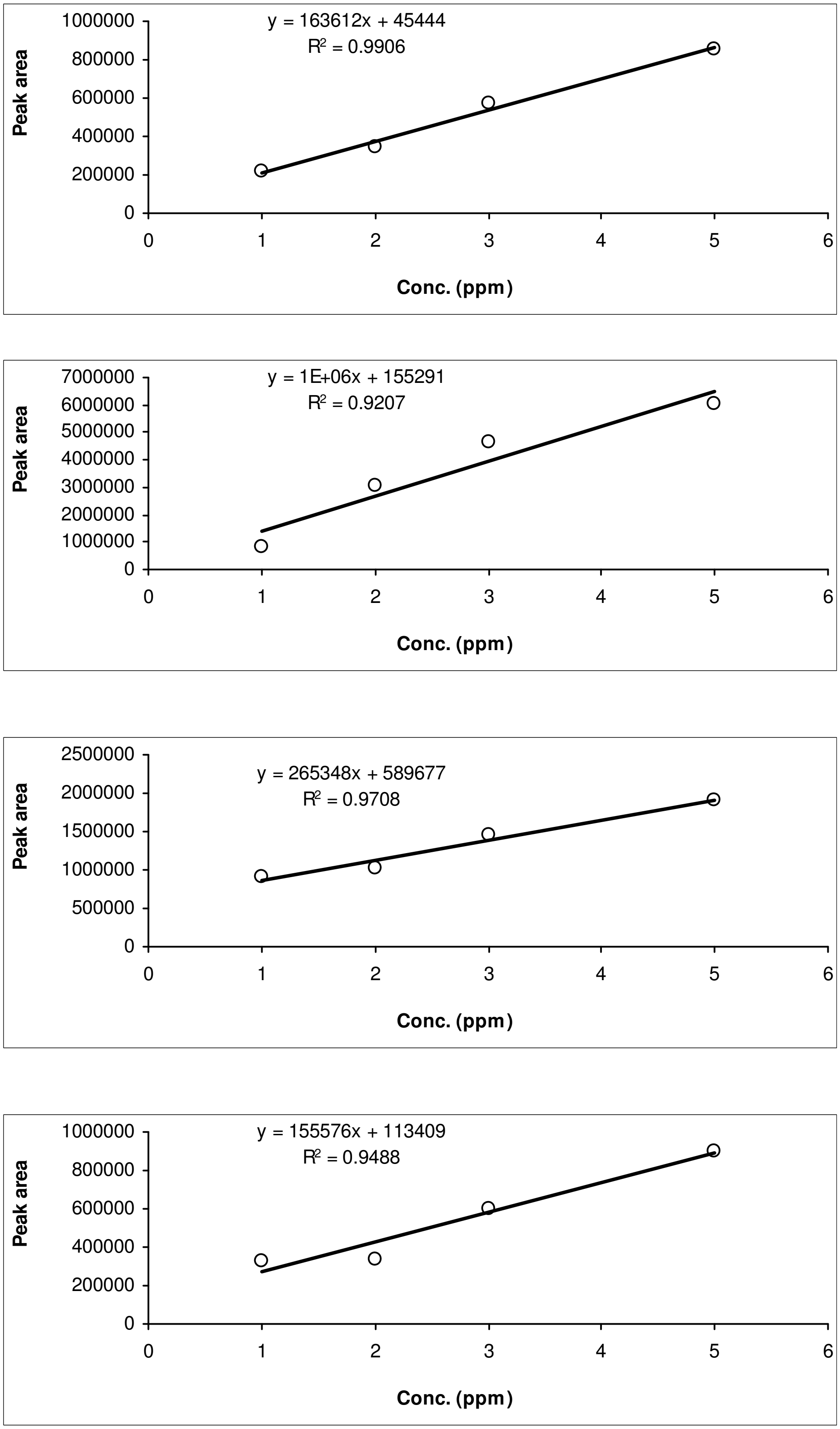


Fig.4.8b : Standard curve of phenolics

Table 4.36: Phenolic compounds analyzed by HPLC present in root and shoot tissue of five rice cultivars

Cultivars	Root			straw at 30 DAT			Straw at 45 DAT			Straw at 60 DAT		
	Total no. of comp.	No. of phenolic comp. identified	Name of phenolic	Total no. of comp.	No. of phenolic comp. identified	Name of phenolic	Total no. of comp.	No. of phenolic comp. identified	Name of phenolic	Total no. of comp.	No. of phenolic comp. identified	Name of phenolic
PSD 15	7	4	HQ, *p*HBA, VA, SyA	11	6	HQ, *p*HBA, VA, SyA, CA, BA	12	5	HQ, *p*HBA, VA, SyA, CA	15	5	HA, GA, VA, SyA, CA
PSD 17	7	3	GA, *p*HBA, VA	11	5	CA, VA, GA, FA, BA	12	4	CA, SyA, VA, GA	11	5	HQ, GA, *p*HBA, VA, CA
PD 18	6	3	BA, GA, *p*HBA	11	6	HQ, GA, VA, FA, *p*HBA, CA	14	4	HQ, GA, VA, FA	13	5	GA, VA, SyA, HQ, CA
Govind	9	4	HQ, GA, *p*HBA, VA	12	4	HQ, VA, FA, *p*HBA	10	4	HQ, GA, VA, SyA,	10	3	SyA, CA, GA
Pusa 44	7	4	GA, *p*HBA, VA, FA	14	4	SyA, VA, HQ, *p*HBA	8	4	SyA, VA, HQ, GA	9	4	BA, HQ, *p*HBA, VA

HQ = Hydro quinone; *p*HBA = Para hydrooxy benzoic acid; VA = Vanillic acid; FA = Ferulic acid; BA = Benzoic acid; CA = Cinnamic acid; SyA = Syringic acid; GA = Gallic acid

Table 4.37: Retention time (RT, min.) of standards phenolic compounds

S. No.	Phenolic standards	Retention time (min.)
1.	Ferulic acid	5.6
2.	Vanillic acid	5.2
3.	Hydroquinone	3.5
4.	p-Hydroxy benzoic acid	4.5
5.	Gallic acid	4.2
6.	Syringic acid	5.4
7.	Benzoic acid	3.4
8.	Cinnamic acid	7.2

In root samples of rice cultivars, the total number of phenolic compounds ranged from 6 to 9 in different cultivars. Cultivar Govind recorded as highest nine phenolic compounds whereas there were only 6 in Pant Dhan 18. In The straw extract sample, the total number of compounds ranged between 8 to 15. The highest number of phenolics in cultivar Pant Sugandha Dhan 15 (15.0) and lowest in Pusa 44 (8.0). At 45 DAT, highest number of compounds in cultivar Pant Dhan 18 (14.0) and lowest in Pusa 44 (8.0), whereas at 30 DAT highest in Pusa 44 (14) and lowest (11) in Pant Sugandha Dhan 17 and Pant Dhan 18,while at 60 DAT, highest in cultivar Pant Sugandha Dhan 15 (15.0) and lowest in Pusa 44 (9.0).

In root samples of three cultivars Pant Sugandha Dhan 16 (4), Govind (4) and Pusa 44 (4), four phenolic could be identified, after

Table 4.38 : Phenolic content in different parts of rice cultivars

Cultivars	Phenolic content (ppm)	Root	Straw		
			30 DAT	45 DAT	60 DAT
Pant Sugandha Dhan 15	Benzoic acid	–	0.132	–	–
	Cinnamic acid	–	2.108	2.150	2.946
	Ferulic acid	–	–	–	–
	Gallic acid	–	–	–	2.067
	Hydroquinone	0.656	0.581	0.479	0.516
	p-hydroxy benzoic acid	3.42	2.788	2.100	–
	Syringic acid	0.107	0.419	0.088	1.158
	Vanillic acid	0.865	0.284	0.602	2.492
Pant Sugandha Dhan 17	Benzoic acid	–	0.144	–	–
	Cinnamic acid	–	1.857	1.249	0.690
	Ferulic acid	–	1.114	–	–
	Gallic acid	0.574	1.050	1.902	7.355
	Hydroquinone	–	–	–	0.107
	p-hydroxy benzoic acid	3.39	–	–	3.071
	Syringic acid	–	–	0.544	–
	Vanillic acid	0.942	0.657	0.606	0.637
Pant Dhan 18	Benzoic acid	0.141	–	–	–
	Cinnamic acid	–	1.112	–	0.136
	Ferulic acid	–	1.541	1.475	–
	Gallic acid	0.586	2.218	2.235	1.523
	Hydroquinone	–	2.585	1.775	0.109
	p-hydroxy benzoic acid	3.43	2.007	–	–
	Syringic acid	–	–	–	0.422
	Vanillic acid	–	–	1.550	0.361
Govind	Benzoic acid	–	–	–	–
	Cinnamic acid	–	–	–	1.217
	Ferulic acid	–	0.469	–	–
	Gallic acid	0.701	–	1.213	1.911
	Hydroquinone	0.618	5.160	0.066	–
	p-hydroxy benzoic acid	3.281	3.564	–	–
	Syringic acid	–	–	0.024	0.446
	Vanillic acid	0.888	4.188	0.200	–
Pusa 44	Benzoic acid	–	–	–	0.609
	Cinnamic acid	–	–	–	–
	Ferulic acid	1.290	–	–	–
	Gallic acid	0.671	–	0.993	–
	Hydroquinone	–	0.347	0.388	0.212
	p-hydroxy benzoic acid	3.282	2.26	–	2.62
	Syringic acid	–	0.604	0.168	–
	Vanillic acid	0.855	0.100	0.914	0.665

comparing their retention time with those of standards. These were hydroquinone, p-Hydroxy benzoic acid, vanillic acid, syringic acid, gallic acid and ferulic acid. In all, the five rice cultivars almost similar phenolics were found except ferulic acid and syringic acid in root samples.

In straw samples, seven compounds could be identified as benzoic acid, p-Hydroxy benzoic acid, vanillic acid, syringic acid, cinnamic acid, ferulic acid and gallic acid. The maximum six compounds could be identified as benzoic acid, hydroquinone, p-hydroxy benzoic acid, vanillic acid, syringic acid and cinnamic acid in cultivar Pant Sugandha Dhan 15 at 30 DAT. Among these phenolics p-hyroxy benzoic acid, syringic acid, vanillic acid, gallic acid, hydroquinone were found to be major phenolics where as ferulic acid, benzoic acid and cinnamic acid being minor. The content of individual phenolics obtained from all the five rice cultivars in the root and shoot samples are presented in Table 4.38. The quantification was done by using standard curve and retention time of phenolic standard (Fig. 4.9).

4.4.3 Phenolics in rice straw

The rice straw that was incorporated into the soil to see its effects on weed control was analyzed by HPLC for the presence of phenolics. It was observed that the total 17 compounds were present in the straw out of which four compounds could be identified, after comparing their retention time with those of standards. These were gallic acid, p-Hydroxy benzoic acid, ferulic acid and vanillic acid (Table 4.39).

Table 4.39: Phenolic acid content of rice straw analyzed by HPLC

Total number of compounds	Phenolic acid detected	Concentration (ppm) phenolic acids
17	Ferulic acid	1.211
	Gallic acid	2.519
	p-hydroxy benzoic acid	2.659
	Vanillic acid	1.166

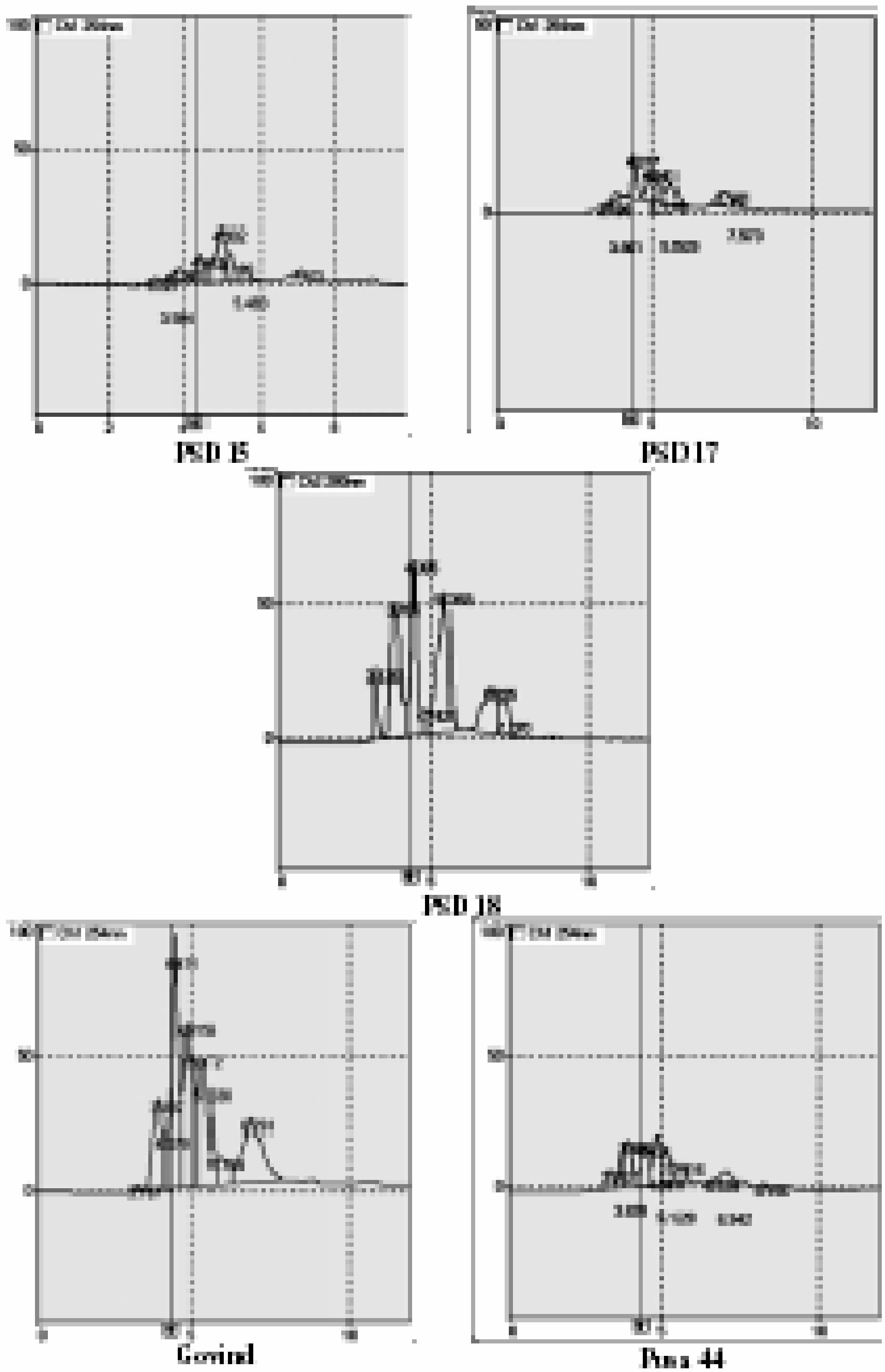
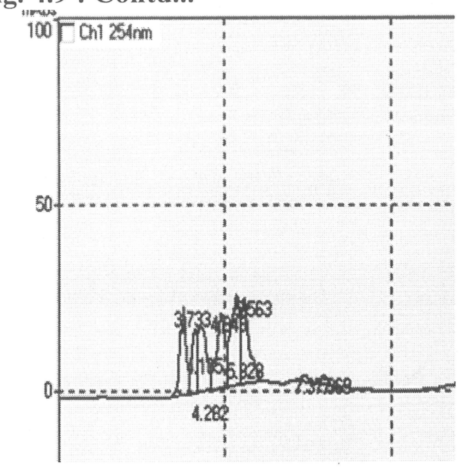
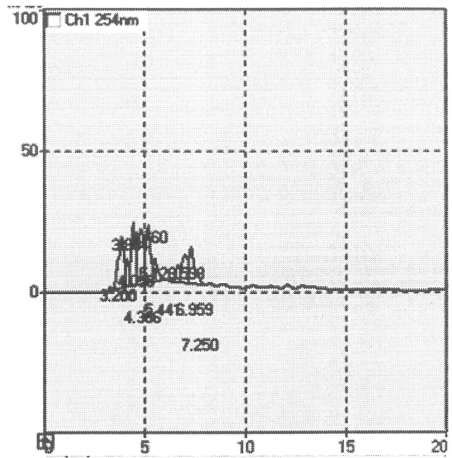


Fig. 4.9 : Phenolic chromatograms analyzed by HPLC from straw of five rice cultivars at 30 DAT

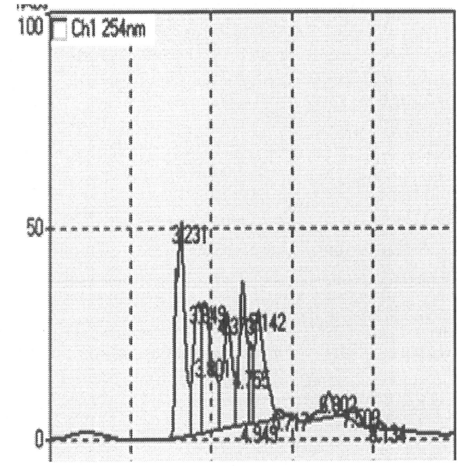
Fig. 4.9 : Contd...



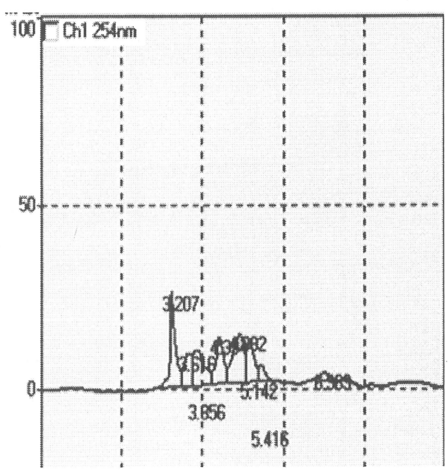
PSD 15



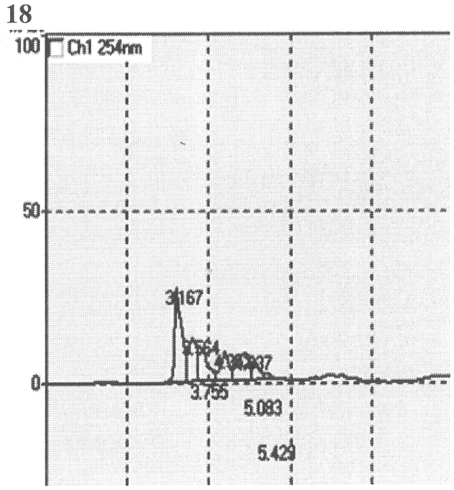
PSD 17



PD 18



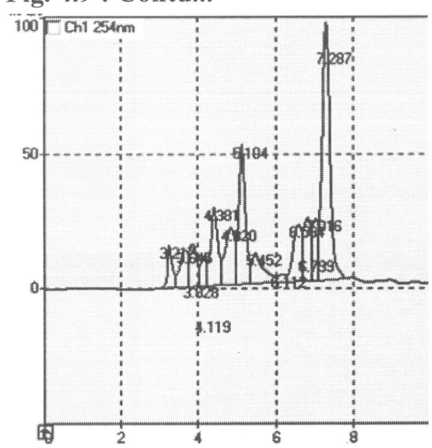
Govind



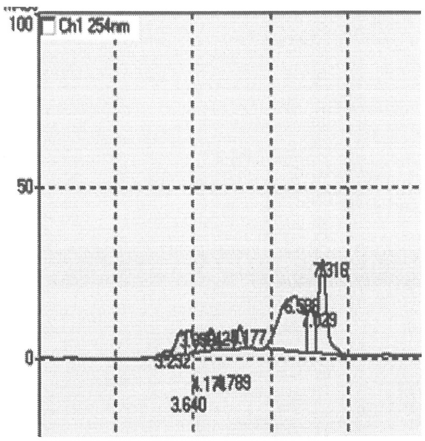
Pusa 44

Phenolic chromatograms anlyzed by HPLC from straw of five rice cultivars at 45 DAT

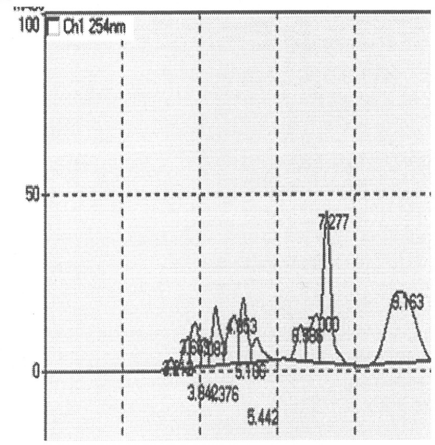
Fig. 4.9 : Contd...



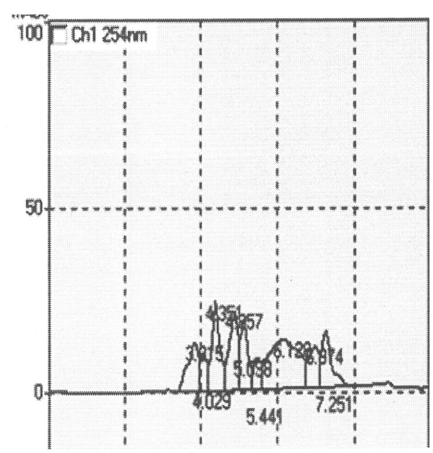
PSD 15



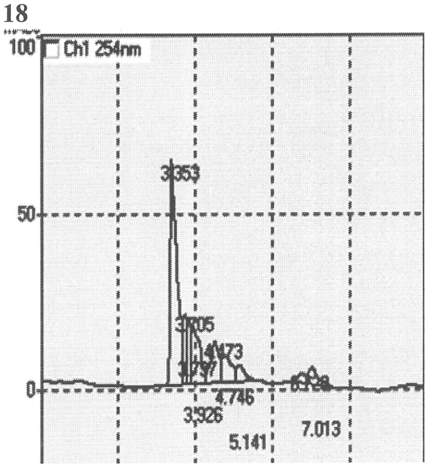
PSD 17



PD 18



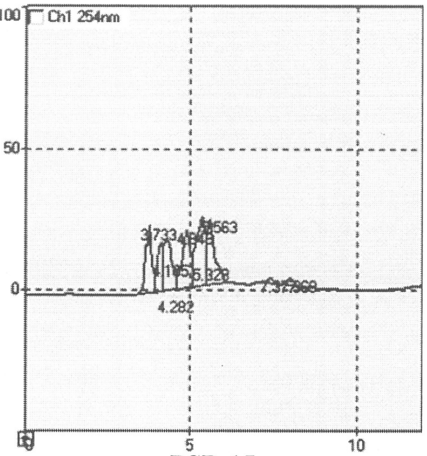
Govind



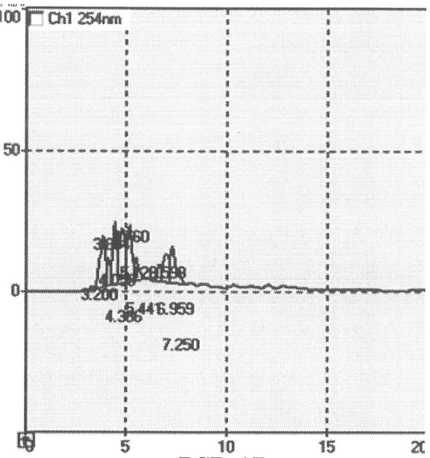
Pusa 44

Phenolic chromatograms anlyzed by HPLC from straw of five rice cultivars at 60 DAT

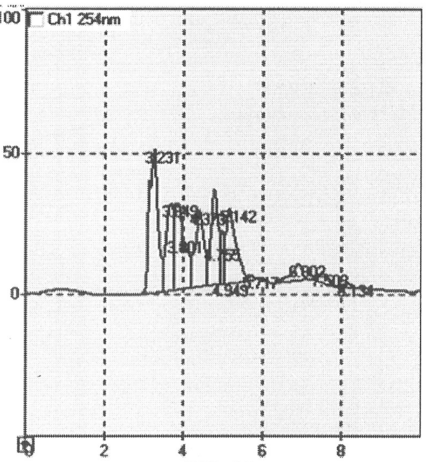
Fig. 4.9 : Contd...



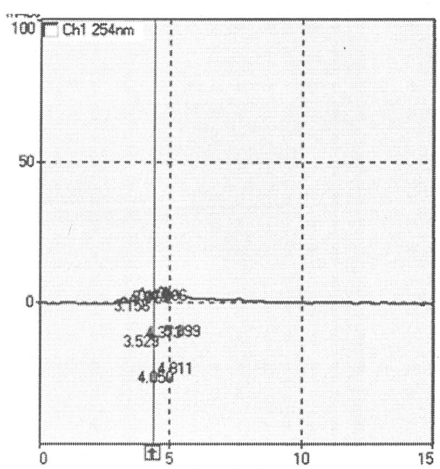
PSD 15



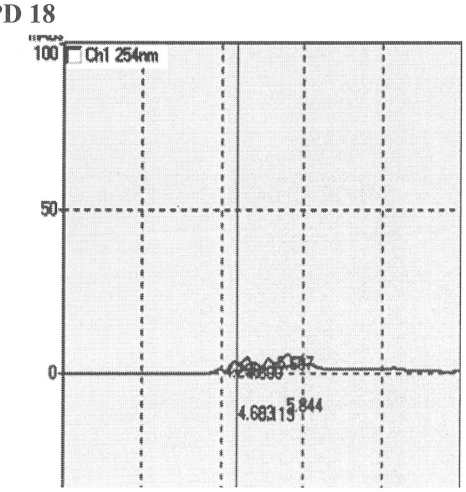
PSD 17



PD 18



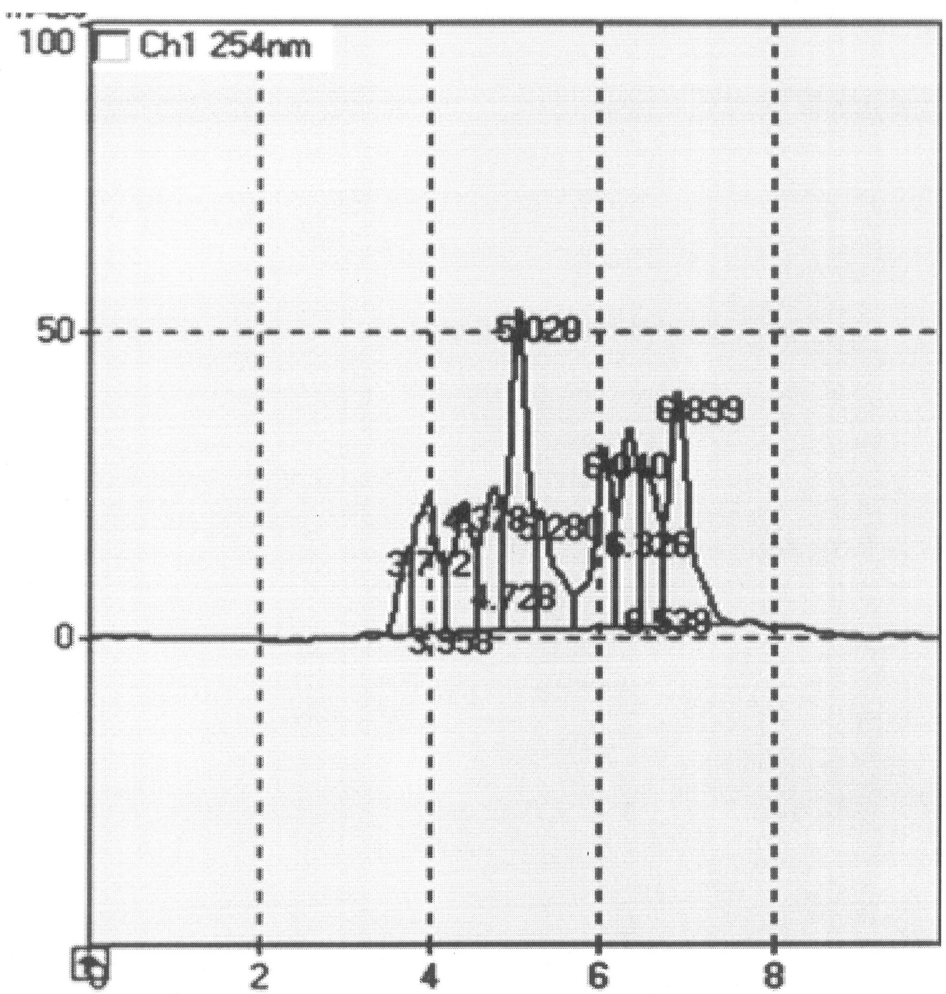
Govind



Pusa 44

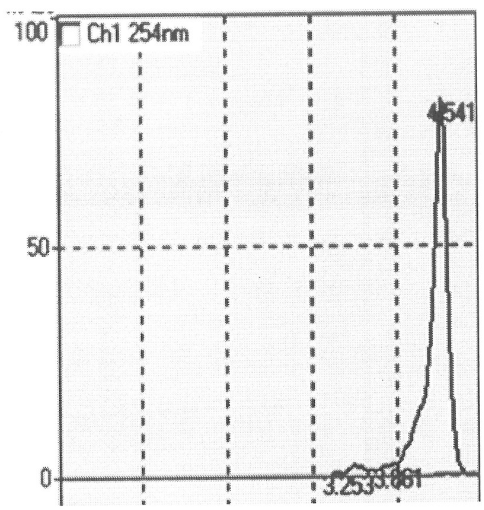
Phenolic chromatograms anlyzed by HPLC from root tissues of five rice cultivars

Fig. 4.9 : Contd...

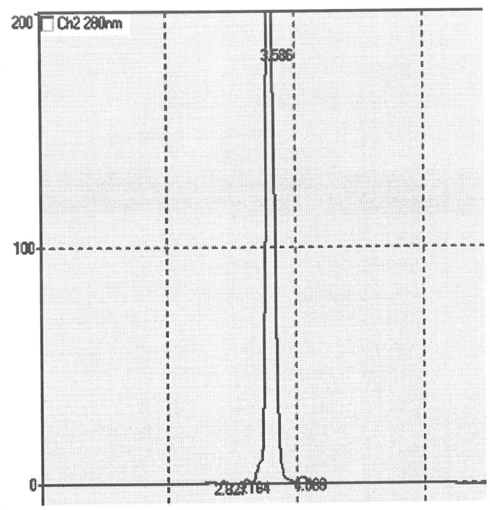


Phenolic chromatogram anlyzed by HPLC from rice straw i.e. incorpated into the soil

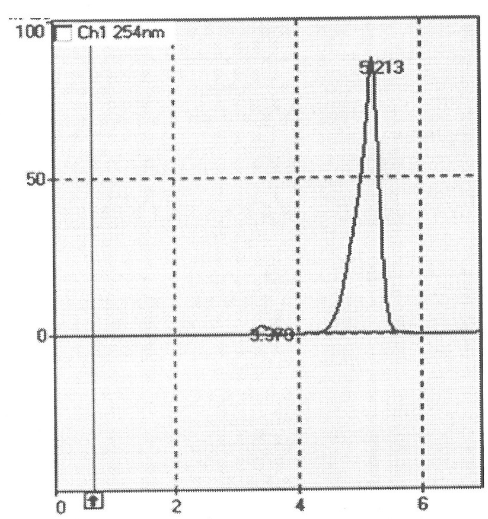
Fig. 4.9 : Contd...



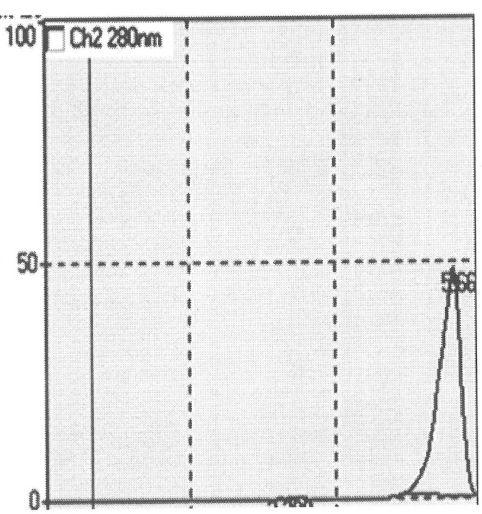
p-hydroxybenzoic acid



Hydroquinone



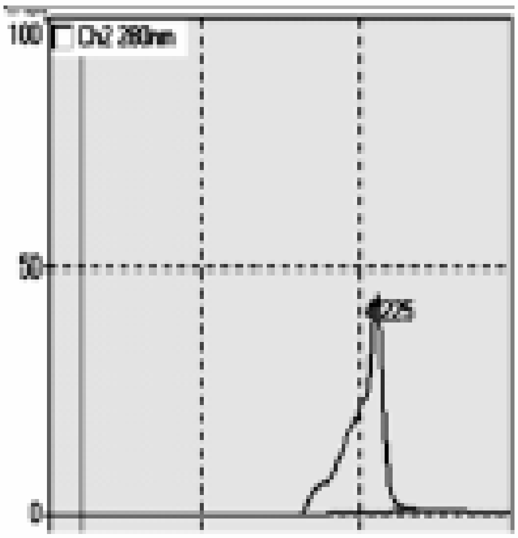
Vanillic acid



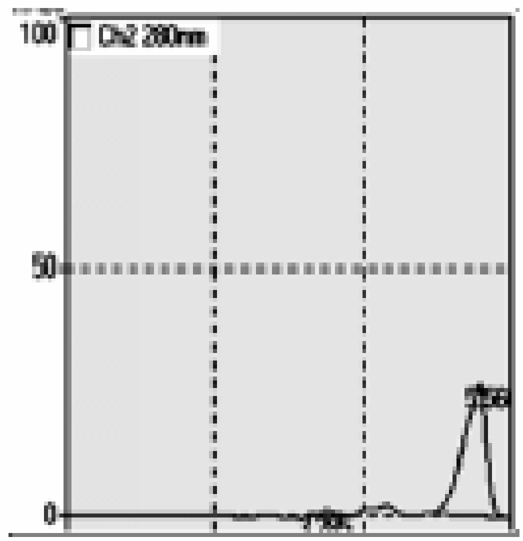
Ferulic acid

Chromatograms of phenolic standards

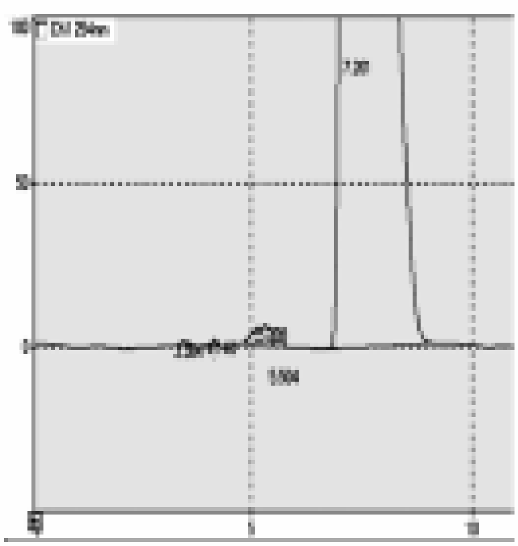
Fig. 4.9 : Contd...



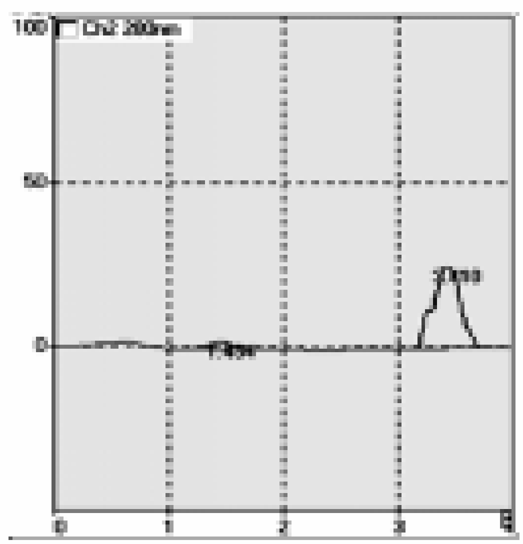
Gallic acid



Syringic acid



Cinriamic acid



Benzoic acid

Chromatograms of phenolic standards

Discussion

Chapter 5 DISCUSSION

Rice (*Oryza* spp.) being an important staple food for more than 50 per cent of the world's population has considerable economic and agricultural importance (Fageria and Baligar, 2003). Weeds are the major biotic stress in rice production world wide, accounting for about 35 per cent of yield losses in the tropics (Oerke and Dehne, 2004). They cause serious yield reduction particularly in upland rice. In aerobic rice, weeds are the greatest yield limiting constraint, contributing about 50 per cent to yield gaps, followed in importance by N-deficiency, pest and diseases (Anonymous, 1996). Losses can be much higher in aerobic rice crops (Balasubramanium and Hill, 2002). Herbicide based weed management, though has become very popular, poses a threat to the environment and farmer's health. It also leads to the development of herbicide resistance in weeds as indicated by several reports for various herbicide classes (Valverde *et al.*, 2000). Experience shows that although herbicide use has increased productivity, there are several weed problems that remain unsolved and warrant solutions that should be cost effective and environment friendly. Attempts to increase competitive ability of crop cultivars to suppress weeds might substantially reduce herbicide loads and labor costs. Competitive cultivars have therefore become an important component of integrated weed management strategies

(Pester *et al.,* 1999; Fischer *et al.,* 2001; Lemerle *et al.,* 2001). The development of competitive cultivars would provide a safe and environmentally benign tool for integrated weed management. Weed competitive upland rice cultivars have been developed in West Africa for areas where herbicides are too expensive or unavailable (Johnson *et al.,* 1998).Traits that determine competitive ability can be morphological or physiological traits linked with canopy establishment such as early vigour, plant height, growth rate, biomass, leaf area, leaf angle expansion, tillering capacity, etc. (Grace, 1990; Kropff *et al.,* 1995; Caton *et al.,* 1999; Moolsri *et al.,* 1999; Ranasinghe and Crabtree, 1999).Plant height, plant dry weight, the no. of tillers, leaf area index, specific leaf area, crop growth rate, relative growth rate, and net assimilation rate were the important growth parameters that enhancing the competitive ability of corn (*Zea mays* L.) against weeds(Mohammadi,2007).Competitive response of canola and mustard cultivars, assessed by weed biomass suppression, was negatively correlated with early season crop biomass accumulation and plant height.(Beckie et al.,2008).

In the present investigation an attempt was made to evaluate the competitive ability of five rice cultivars in terms of their growth physiology and allelopathic potential against weeds. The salient findings are discussed below :

The field experiment was conducted during the rainy seasons of 2007 and 2008 to evaluate the competitive ability of five rice cultivars against weeds by subjecting these cultivars to weed free, weedy and butachlor (commonly used herbicide in rice) situation. and to check the consistency of cultivars performance. Among the Cultivars, Pant Sugandha Dhan 15, Pant Sugandha Dhan 17 and Pant Dhan 18 are semitall cultivars, whereas the Govind and Pusa 44 are semi dwarf cultivars. Consistency performance of cultivars is essential for the adoption of more competitive cultivars as a tool to reduce farmer's reliance on herbicides (Cousens and Mokhtari, 1998).

Weeds that infest the paddy fields included grasses, broad leaved weeds, sedges. These include *E. crusgalli, E. colona, I. rugosum, C. banghalensis, A. sessilis, C. iria, C. difformis, C. rotundus, F. miliaceae, L. chinensis, C. axillaris* etc. (Anonymous, 2008). In the present investigation, the major weed flora that infested the experimental field during both the years include, *E. crusgalli, E. colona, C. axillaris, L. chinensis* and *I. rugosum*

Garrity *et al.* (1992) found upto a 75 per cent difference in weed suppression in Asia among the cultivars. Fischer *et al.* (1997) observed yield losses raining from 27 to 60 per cent among Latin American irrigated rice cultivars growing in competition with jungle rice (*E. colona*).

Cultivar weed competitiveness is a function of weed tolerance or the ability to maintain high yields despite weed competition and weed suppressive ability (WSA) or the ability to reduce weed growth through competition (Jannink *et al.,* 2000). WSA are determined by assessing variation in weed biomass in plots under weed competition.

The cultivars Pant Dhan 18, Pusa 44 and Govind had higher weed suppression ability(WSA) due to they had lower weed dry weight during 2007 whereas in 2008, Pusa 44 had higher WSA followed by Pant Sugandha Dhan 15 and Govind but Pant Sugandha Dhan 17 had lowest during both the seasons. Competitive ability can be conceptualized as the ability of a cultivar to suppress weed growth or to maintain crop yields by tolerating weed competition (Jordan, 1993). Researchers have argued in favour of breeding programmes that select for suppression or tolerance (Callaway and Forcella, 1992; Jordan, 1993).

The cultivars Pant Dhan 18, Pusa 44 and Govind have higher yield potential as well as total dry matter than cultivar Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. Yield reduction in cultivar Pant Sugandha Dhan 17, Pant Dhan 18, Pusa 44 and Govind under weedy condition was less than cultivar Pant Sugandha Dhan 15 in year 2007 while in 2008, reduction was lowest in cultivar Pant Sugandha Dhan 15 than Pant Dhan 18 and Govind whereas maximum reduction in cultivar Pant Sugandha Dhan 17 and Pusa 44. During both the years, cultivar Pant Dhan 18 and Govind have exhibited similar trends in grain yield under weedy situations. Their ranged between 12-16% in PD 18 and 14-18% in Govind. It seems they are able to maintain competitiveness across seasons. Cultivar Pant Dhan 18 have highest total dry matter production than cultivar Pusa 44, Pant Sugandha Dhan 15, while lowest in cultivar Pant Sugandha Dhan 17 and Govind in 2007, whereas in 2008, total dry matter production was highest in Pant Dhan 18 than Pant Sugandha Dhan 15, Pusa 44 and Govind and lowest in Pant Sugandha Dhan 17. Under weedy condition, reduction in total dry matter was lowest in cultivar Pant Dhan 18 and Pusa 44(7-10%) and maximum in Govind and Pant Sugandha Dhan 15 in 2007 while in 2008, lowest reduction in Pant Sugandha Dhan 15, Pant Dhan 18, Govind and maximum in Pant Sugandha Dhan 17 and Pusa 44. Thus cultivar Pant Dhan 18 is more competitive than rest of the cultivars and performed consistently during both the years. Cultivar Pant Dhan 18, Pant Sugandha Dhan 17, Govind and Pusa 44 had higher harvest index than Pant Sugandha Dhan 15 in 2007 whereas in 2008, harvest index was highest in Pant Dhan 18, Pusa 44, Govind and Pant Sugandha Dhan 17 while lowest in Pant Sugandha Dhan 15. Yield under weed competition is a function of yield potential without competition and relative yield loss caused by weed competition; breeding programmes designed to produce weed competitive cultivars thus need to focus on both yield potential and weed suppressive ability. Our data confirm the feasibility of this

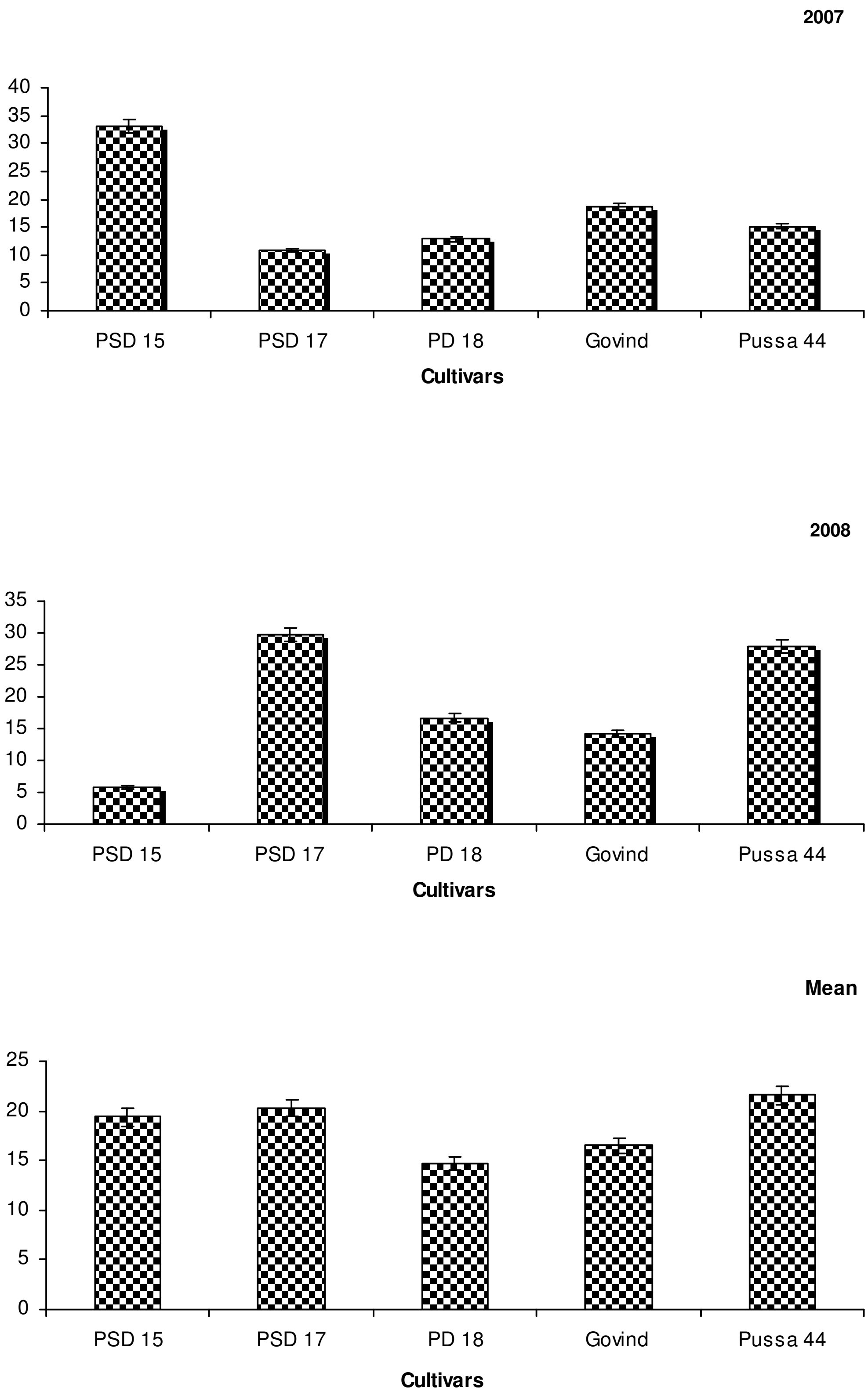


Fig. 5.1 : Crop weed competitive index of five rice cultivars in the year 2007, 2008 and mean of 2007 and 2008

strategy. The hypothesis is that enhancing the WSA is necessary when the goal is to decrease relative yield reduction. However, selection for weed suppressive ability alone may not result in improvements in yield under competition (Zhao *et al*, 2006).

The Crop weed competitive index (CWCI) exhibited that the cultivars Pant Sugandah Dhan 17, Pant Dhan 18, Pusa 44 and Govind were more competitive than Pant Sugandha Dhan 15 in 2007, but in 2008, Pant Sugandah Dhan 15 was highly competitive followed by Pant Dhan 18 and Govind where as Pant Sugandha Dhan 17 and Pusa 44 were least competitive. The average CWCI during both the year depicted that, Pant Dhan 18 and Govind were highly competitive than Pant Sugandha Dhan 15, Pant Sugandha Dhan 17 and Pusa 44 cultivars (Fig. 5.1).

Cultivar differences in weed competitiveness(CWC) have been documented in wheat (*Triticum aestivum* L.) (Challaiah *et al.,* 1986; Blackshaw, 1994; Lemerle *et al.,* 1996), barley (*Hordeam vulgare* L.) (Chirstensen, 1995), soybean [*Glycine max* (L.) Merr.] (Jannink *et al.,* 2000) and rice (Quintero, 1986; Chavez, 1989; Garrity *et al.,* 1992; Fischer *et al.,* 2001; Haefele *et al.,* 2004)

Competitive ability in terms of Morphological growth parameters and biomass accumulation

The development of competitive rice cultivars requires the identification of key traits conferring competitive ability that can be used as selection criteria by breeders (Pester *et al.,* 1999). Competitive ability in rice is often associated with traits related to light capture (Khush, 1996). According to Fischer and Gibson (2001), competition for light is a critical factor in the process of interference between rice and weeds. Leaf area and number of tillers are characteristics directly correlated with the capacity of the crop to intercept light and suppress weed growth. This suggests the importance of combining phenological characteristics to maximize the level of competitiveness of rice against weeds.

In rice (*Oryza sativa*), competition was first observed when rice plants were 53 to 60 days old, which was 30 to 35 days after transplanting and any plant trait that increased size and vigour during early growth conferred competitive ability (Jennings and Aquino, 1968).

In the present investigation, the vigour index was higher in cultivars Pant Dhan 18, Pusa 44 and Govind that Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. The higher vegetative vigour contributes to its competitive ability to that Pant Dhan 18, Pusa 44 and Govind are more competitive than cultivars Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17.

Biomass accumulation can be a good measure of competitiveness as it reflects resource capture under the interference from neighbours. Above and below ground biomass accumulation was used as a measure of competitive success in *O. punctata* (Fernando *et al.,* 2006; Gaudet and Keddy, 1988; Roush and Radosevich, 1985). In the present study, the dry matter accumulation was higher in the cultivar Pant Dhan 18, Govind and Pusa 44 than Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 at all the growth stages except at 30 DAT in 2007,when Pant Sugandha Dhan 15 had high dry matter than Govind, Pusa 44 and Pant Sugandha Dhan 17. The greater biomass early in the rice cropping period remains the better competitor throughout growth (Cousens *et al*, 2003). Thus, the cultivar Pant Sugandha Dhan 18 was highly competitive than Govind and Pusa 44 while Pant Sugandha Dhan 17 and Pant Sugandha Dhan 15 were least competitive. The traits that conferred competitive ability such as initial biomass, plant growth rate, leaf area index and biomass at tillering were the best predictor of competitiveness against weeds (Ni *et al.,* 2000).

Johnson *et al.* (1998) reported that the most competitive cultivar had a large leaf weight, a higher specific leaf area and earlier tiller production than less competitive cultivars. In the present investigation, the tiller number was highest in cultivar Pant Dhan 18, Pusa 44 and Govind than Pant Sugandha Dhan 17 and Pant Sugandha Dhan 15 cultivars. The importance of high tillering capacity to breeding efforts to maximize the ability of rice cultivars to compete with weeds has been emphasized by Estorinos *et al.* (2002), thus the cultivar Pant Dhan 18 and Govind are more competitive than cultivar Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. Cultivars Pant Dhan 18, Pusa 44 and Govind had more leaf numbers than cultivars Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. The number of tillers, leaf number, leaf length, leaf area index, height and dry weight are always greater in successful competitors before the competition is observed (Jennings and Aquino, 1968). the panicle number was highest in cultivar Pant Dhan 18, Pusa 44 and Govind than cultivar Pant Sugandha Dhan 17 and Pant Sugandha Dhan 15. Thus, in the terms of growth, cultivar Pant Dhan 18, Pusa 44 and Govind are more competitive than cv. Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17.

Rice cultivars that compete well against weeds are often thought to be tall and rapid in early growth and have droopy leaves and high specific leaf area. These traits have been linked to low yield potential in some studies (Jennings and Aquino, 1968; Jenning and Jesus, 1968; Jennings and Herrera, 1968; Kwano *et al.,* 1974) but not in others (Garrity *et al.,* 1992; Ni *et al.,* 2000; Fischer *et al.,* 2001).

Cultivars Pant Dhan 18, Pant Sugandha Dhan 15 Pant Sugandha Dhan 17 were tall and early growth than cultivar Pusa 44 and Govind and PSD 15 and PSD 17 had low yield potential where as

PD 18 had high yield potential thus, our findings are supported by the earlier reports that tall cultivars competes well with weeds but have low yield potential refers to cv. PSD 15 & PSD 17 but cv. PD 18 have high yield potential and it is competitive cultivar.

In rice intraspecific competition, competition with weeds and spacing responses were highly inter correlated with each other, suggesting that these were controlled largely by the same genetic factors through the same physiological processes. Vegetative vigour, large leaf area, a high rate of N-absorption in early growth stages and plant height were the most significant character related to competitive ability or to spacing responses (Kwano *et al.,* 1974; Kim and Moody, 1980).

Ahmed and Hoque (1981), defined cultivar height is an important characteristics. Yield reduction from weeds increased with decreasing plant height.

Plant height can be highly correlated with competitive ability (Jennings and Aquino, 1968) but is not always important. For example, Fischer *et al.* (1997) found that leaf area index and tiller production were the key traits associated with competitiveness, not plant height.

Garrity *et al.* (1992) found a strong correlation between height and competitive ability but also reported that cultivars of the same height differed in weed suppression ability.

Plant height and Biomass at early stages of growth are reported to be the most significant characters related to competitive ability (Kawano *et al.,* 1974). A positive correlation between growth duration and plant height has also been reported which confers the competitive ability of crops. In the present study, Pant Sugandha Dhan 15, Pant Sugandha Dhan 17 and Pant Dhan 18 are semi tall cultivars the other two cultivars Govind and Pusa 44, are semidwarf cultivars. Among these, Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 recorded lower grain yield potential during 2007. the cv. PSD 17 recorded lowest dry matter production and grain yield during both the years. Pant Dhan 18 despite tall recorded highest dry matter and grain yield production during both the years. Height is reported to be inversely correlated with yield which was true in case of Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. But, in case of Pant Dhan 18 that have taller height as well as high yield potential is also consistent with the findings that plant height can be highly correlated with competitive ability but is not always important (Fischer *et al*., 1997) so, therefore there may be no trade off between yield and weed competitiveness will arise the interest in breeding for cultivars that combine high yield and weed suppressive ability. Vegetative vigour and plant height are the major characters controlling competitive ability. If breeder desires competitive ability with weeds, he may breed for high vegetative vigour and tall growth habit. Aside from the higher tolerance to weeds, the genotypes with high vegetative vigour perform better under low nitrogen levels (Kawano *et al.,* 1974). Among the present rice cultivars, Pant Sugandha Dhan 15 had maximum height followed by Pant Dhan 18 and Pant Sugandha Dhan 17 respectively that contribute to its competitiveness. Being a semidwarf cultivar Govind aquired good height than Pusa 44 that contributes to its competitive ability.

Physiological growth parameters

Leaf growth and development

Growth parameters associated with competitive ability of rice in the tropics include seedling growth rate, leaf area, specific leaf area, plant height, tillering, leaf angle and root growth (Gibson and Fischer, 2002).

Leaf area plays an important role in the growth and development of plants and a significant factor contributing to final yield (Singh and Gupta, 1970). Detailed study of three rice cultivars showed that the cultivar that accumulated more biomass had a higher leaf area index, higher specific leaf area and especially in early growth stages, partitioned more biomass to leaves, was the most competitive with weeds.

Lindquist and Kroff (1996) emphasized the importance of early leaf area expansion to competitive ability because of the central role of light capture. In the present study cultivar Pant Dhan 18, Pusa 44 and Govind had more leaf area at 30 DAT therefore had a higher vegetative vigour than cultivar Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 which contributes to their competitiveness.

Leaf growth and leaf area development can be measured by several parameters such as leaf area/plant, RLGR, RLAGR, LAR and SLW as well as LWR. RLAGR is a useful tool in the analysis of leaf area changes, which is used for comparison of growth in leaf area at different times (Watson, 1952). LAR indicates that amount of leaf area per unit dry weight of the plant, while SLW indicates leaf thickness and it varies with leaf position and growth stages. The difference in the pattern of leaf area and dry matter production affect the LAR. A change in both the parameter affects the LAR significantly.

Kawano *et al.* (1974) associated the plant height and leaf area with competitive ability while tillering ability was unimportant. In the present investigation LAR was maximum at 30 DAT in cultivar Pusa 44 and rest of cultivars had similar LAR while in 2008, LAR was maximum in cultivar Pant Sugandha Dhan 15 and other four cultivar had similar LAR. During 2007, all the cultivars had similar SLW while in 2008, maximum cultivar Pant Dhan 18 and Pant Sugandha Dhan 17 and rest of the cultivars had similar SLW at 30 DAT.

Leaf area growth rate has also been identified as the primary trait related to competitive ability in efforts to model rice weed competition in the tropics (Lindquist and Kropff, 1996; Bastiaans *et al.,* 1997). Physiological growth analysis of six rice cultivars showed marked differences in NAR, RGR, relative leaf growth rate (RLGR) and relative leaf area growth rate (RLAGR) on relative leaf area growth rate (RLAGR) on partitioning to different plant parts, LAI and SLA. However, RLAGR was found to be suitable growth parameters to fit in a regression equation to predict the yield potential of rice cultivars (Baruah and Singh, 1982).

Kroff *et al.* (1993) and Rajan *et al.* (1995) demonstrated that the most important trait that determines competitive ability of *O. sativa* cultivar is relative growth rate of leaves early in the season. Their study also showed that a rapid development of leaf area in the early growth stage could contribute to competitiveness by increasing CGR, which helps in rapid accumulation by the crop.

In the present study, the cultivar Govind had highest RLGR in 2007 while in 2008, highest in cultivar Pusa 4 at 45-60 DAT than rest of the four cultivars. RLAGR was highest in cultivar Pant Sugandha Dhan 15 in 2007 while in 2008, highest in Pant Dhan 18 whereas rest of the four cultivars had similar RLAGR during both the years at 45-60 DAT. From our findings, it suggested that RLAGR and RLGR poorly correlate with the competitive ability or competitiveness.

Relative growth rate and net assimilation rate

RGR is a fundamental measure of dry matter production with respect to time. It is important key characteristics of plant that is positively correlated with competitive ability (Grace, 1990; Grime, 1997). NAR is a measure of net gain in dry weight of a plant per unit leaf area per unit time and it represents crop capacity to increase its dry weight in terms of area of its assimilatory surface (Redford, 1967).

Some other workers, Roush and Radosevich (1985) investigated the competitive relationship among four annual weed species and found that RGR was poorly correlated with their aggressiveness. NAR varies little among modern *O. sativa* cultivars and higher NAR is not a character for selection of competitive cultivar from the population stand point as it decreases with increase in density (Ni *et al.,* 2000).

In the present investigation, the RGR was at 45-60 DAT maximum in cultivar Pant Sugandha Dhan 15 in 2007 while in 2008, maximum in cultivar Pant Dhan 18 whereas rest of the cultivars had similar RGR. Thus, RGR poorly correlate with competitiveness. NAR was found to be highest in cultivar Pant Sugandha Dhan 17 during both the years at 30-45 DAT and 45-60 DAT while rest of the cultivars had similar value. Thus in the present investigation NAR could not correlate with the competitiveness.

In *Oryza sativa* L. initial biomass (IB), crop growth rate (CGR), leaf area index (LAI) and biomass at tillering were associated with their competitiveness against weeds, whereas relative growth rate, net assimilation rate and tillering capacity of *O. sativa* were not correlate (Ni *et al.,* 2000).

The traits adding to competition are often negatively correlated with yield and are therefore seldom primary selection criteria in breeding programme. Several researchers have dealt with rice cultivar competitiveness (Ni *et al.,* 2000), the work of Jannink *et al.*(2000) on seedling height of soyabean, Ni *et al.* (2000) on rice seedling biomass and attempts to increase competitive ability, however have had limited success and no crop cultivar has been released with superior competing ability as a marketing argument. The lack of progress in creating competitive cultivars might be due to the complexity and lack of understanding of the components and mechanism of competition.

Allelopathy

The potential use of allelopathy as part of a weed control program is one option that has been gaining attention for quite a long time. Allelopathy can be used in weed management in two ways. The first is by selecting an appropriate crop variety or incorporating an allelopathic character into a desired crop variety. The second way is by applying residues and straw as mulches or growing an allelopathic variety in a rotational sequence that allows residues to remain in the field (Rice, 1995).The possibility of incorporating allelopathic traits into improved rice cultivars, which would reduce the need for applying herbicides to the crop, is worth exploring (Khush, 1996).

Many weed scientists have attempted to explore allelopathy directly as a weed management strategy through screening for allelopathic traits in germplasm of several crops such as rice plant. The use of alleopathic rice cultivars may provide an alternative to minimize the risk of agro-ecosystems by serving in a complementary fashion with herbicides (Chung *et al.,* 2002, 2003).

Rice (*Oryza sativa* L.) has been extensively studied with respect to its allelopathy in part because many cultivars and ancestral lines have exhibited significant allelopathic potential in the field. At present, several international efforts to generate allelopathic rice cultivars are underway (Olofsdotter *et al.,* 2002; Dilday *et al.,* 2001; Kong *et al.,* 2002).

Allelopathic potential has been also reported from numerous crops like barley (Lovett and Hoult, 1995); cucumber (Putnam and Duke, 1974); oats (Fay and Duke, 1997); rice (Dilday *et al.* 1998); sorghum (Nimbal *et al.*1996);sunflower (Leather, 1983); tobacco (Patrick *et al.* 1963); and wheat (Wu *et al.* 1999).

The substances with allelopathic potential are present in virtually all plant tissues, including stems, leaves, roots and seeds, these substances are released through processes such as volatilization, root exudation, leaching and decomposition of plant residues (Putnam and Weston, 1986). Allelopathic activity is believed to be the joint action of several secondary metabolites that may act synergistically (Chou *et al.,* 1991; Olofsdotter *et al.,* 1995; Gealy *et al.,* 2000; Chung *et al.,* 2001). Most plant chemicals associated with allelopathic activity are secondary metabolites from shikimic acid or acetate pathways (Rice, 1984, 1985; Rizvi and Rizvi, 1992).

To quantify allelopathy in rice, several laboratory and field screening procedures have been developed and tested (Fujii, 1992; Dilday *et al.,* 1998; Navarez and Olofsdotter, 1996; Olofsdotter and Navarez, 1996).Many different secondary metabolites i.e. phenolics, terpenoids, alkaloids, polyacetylenes, fatty acids and steroids can act as allelochemicals (Rice, 1984; Waller 1987; Inderjit and Dakshini, 1995).

To screen rice allelopathic potential, several methods such as the stairstep method (Bonner, 1950; Liu and Lovett, 1993), hydroponic culture test (Einhellig *et al.,* 1985), relay-seeding technique (Navarez and Olofsdotter, 1996), agar medium test (Fujii, 1992; Wu *et al.,* 1999), cluster analysis using HPLC (Mattice *et al.,* 2001), water extract method (Kim *et al.,* 1999; Ebana *et al.,* 2001) and 24-well plate bioassay (Rimando *et al.,* 1998) have been suggested. Each of the methods mentioned above can be used as a valuable tool to evaluate allelopathic potential. Seed germination is an important parameter for evaluating allelopathic potential of phenolic compounds and widely used for bioassays (Rice, 1984; Waller, 1987).

Seedling growth is reported to be more responsive to certain categories of allelochemicals such as phenolics (Rasmussen and Einhellig, 1977, Einhellig and Rasmussen, 1978).

In the present investigation, both seed germination and seedling growth of weeds were used as a bioassay to study the effects of standard phenolic compounds as well as straw and roots of five rice cultivars. The purpose of using various bioassay methods was to cross check the effects of phenolics (@100ppm) on weed seed germination and seedling growth. Our results depicted that among the phenolics, ferulic acid, vanillic acid and syringic acids had maximum inhibitory effects whether used alone or in different combinations .Combinations of (Ferulic acid, Vanillic acid, *p*-hydroxy benzoic acid) and (Ferulic acid, Vanillic acid, *p*-hydroxy benzoic acid, Gallic acid) had the highest inhibitory effects on weed seed germination. Among the weed species, *L. chinensis, E. crusgalli* and *I. rugosum* were more sensitive to the phenolic compounds than other weed species.

p-coumaric acid, a known allelochemical, inhibited the germination of lettuce (*Lactuca sativa* L.) seedlings at 1 mM but was active against *E. crusgalli* only at concentrations higher than 3 mM (Rimando *et al.,* 2001). *p*-hydroxybenzoic acid and several other benzoic acid derivatives at 500 μM inhibited seedling growth of velvet leaf (*Abutilon theophrastimedic*) (Einhellig, 1996).

A number of secondary metabolites, phenolic acids, phenylalkanoic acids, hydroxamic acids, fatty acids, terpenes and indoles, were identified in rice extracts (Rimando and Duke, 2003). These compounds are ubiquitous in plants and some of these compounds have growth inhibitory activity against several plant species. The inhibitory activities of phenolic acids against germination of lettuce or alfalfa and *p*-hydroxy benzoic acid and salicylic acid were the most active and they inhibited the germination of at concentrations greater than 0.5-1.5 mM (Hsu *et al.* 1989).

The allelopathy of rice against weeds was correlated with the amount of phenolic acids released by living rice roots (Mattice *et al.,* 1998). But quantification of released phenolics under natural systems is a real challenge as it is under the influence of several factors.

In the present investigation, among the rice root and rice straw (shoot), the straw had more inhibitory effect on weed seed germination and seedling growth. Roots of the cultivars Pant Dhan 18 and Govind had maximum inhibitory effects than that of Pant Sugnadha Dhan 15, Pant Sugnadha Dhan 17 and Pusa 44. Among the weed species studied, maximum reduction in germination was in *C. axillaris* and *L. chinensis.* Pant Dhan 18, Govind and Pusa 44 had maximum inhibitory effects on seedling growth.

The straw of cultivar Pant Dhan 18, Govind and Pusa 44 had maximum inhibitory effects on the germination and seedling growth of weed seeds. The weed species which were more sensitive to straw were *C. axillaris, L. chinensis, C. benghalensis* and *I. rugosum* and in seedling growth (root and shoot) maximum reduction was recorded in species *L. chinensis*. Rice roots and straw effect on seedling growth of weed species revealed that root growth was more sensitive than shoot growth of weed species as reported earlier (He, 2000).

Our findings are consistent with earlier reports that the root growth was more sensitive than shoot growth of weed species and rice straw had more inhibitory effects than rice root (Kim *et al.,* 2005; He, 2000). Thus the unextracted ground rice straw was more effective than rice roots and efficiently controlling the major paddy weeds.

The effect of rice cultivars on germination and seedling growth of weed species by Donor-receiver bioassay suggested that the cultivar Pant Dhan 18, Govind, Pusa 44 and Pant Sugnadha Dhan 15 had maximum inhibitory effects on seedling growth of weed species whereas cultivar Pant Sugnadha Dhan 17 was least effective. All the five rice cultivars had inhibitory effects on germination. The greater inhibitory effect on root growth was observed in *C. axillaries* whereas in shoot growth *E. colona.*

Allelochemicals in living rice seedlings are thought to be released from their root tissues and most of the alleopathic effects resulted from a faint action of several metabolites that may act as synergistic or antagonistic (Rice, 1984; Gealy *et al.,* 2000).

A large number of rice varieties were found to inhibit the growth of several plant species when the rice varieties were grown together with the plants under field or laboratory conditions (Dilday *et al.,* 1998; Hassan *et al.,* 1998; Olofsdotter *et al.,* 1999).

Allelopathic cultivars of rice can control both grassy and dicot weeds under field conditions with some degree of selectivety (Olofsdotter *et al.,* 2002; Olofsdotter, 2001).

Hydroponics has been used successfully for evaluating allelopathic potential in barley, *Hordeum vulgare,* using *Sinapis alba* as a test plant (Liu and Lovett, 1993).

Rice seedlings of cv. Koshikari were hydroponically grown for 14 days to detect allelochemicals in rice root exudates. Keeping track of the biological activity, culture solution was purified by several chromatographic fractionations and finally 2.1 mg of putative compound causing the inhibitory effect of the rice seedlings was isolated (KatoNoguchi *et al.,* 2002; KatoNoguchi and Ino, 2003).

Most of the allelochemicals are released during germination and early growth (Dekker and Meggitt, 1983). Barley (*Hordeum vulgare* L.) has been reported to release allelopathic alkaloids (≈2g plant^{-1} g^{-1}) 36 d after germination in hydroponics culture (Lin and Lovett, 1993).

In the present investigation, root exudates of all the five rice cultivar's grown in hydroponics were found to have inhibitory effects on germination of weed seeds with highest reductions observed in the weed species *L. chinensis, C. axillaris, I. rugosum* and *C. benghalensis*. The inhibitory activity of water extracts from the shoots and roots of three rice cultivars, Taichung native 1 (TN1), IAC 165 (both allelopathic rice) and AUS 196 (non allelopathic rice), grown in hydroponics and evaluated the release of some germination inhibitor or root exudates of TN1 inhibited root elongation of *E. crusgalli* from 2 weeks after transplanting (WAT) and the inhibition continued for 4 WAT (Olofsdotter and Kim, 2005). The compounds released from plant root through exudates trap can be used to provide a test solution which is biologically meaningful and exudates can be trapped by the use of hydroponics.

From all these findings, it is suggested that all the rice cultivars have allelochemicals that inhibit the germination and development of weed species significantly and the cultivars Pant Dhan 18, Govind and Pusa 44 had highest allelopathic effects than Pant Sugandha Dhan 15 and least in Pant Sugandha Dhan 17. Therefore, the cultivar Pant Dhan 18, Govind and Pusa 44 are competitive cultivars and the competitive ability can also be attributed the allelopathic effects of their phenolic compounds (Rasmussen and Einhellig, 1977).

The allelopathic compounds identified in aqueous extracts of rice (leaves, stems and hulls) such as *p*-hydroxy benzoic acid, vanillic acid, *p*-coumaric and ferulic acids were reported (Ayumi *et al.,* 1999; Chung *et al.,* 2002).

In 'Juma 10' rice cultivar. Identified nine compounds, was most inhibitory to barnyard grass growth in field study and the identified compounds, *p*-hydroxy benzoic acid caused maximum inhibitory effects on germination and seedling growth and dry weight of barnyard grass (*E. crusgalli*). These findings suggest that living rice may produce and release allelochemical(s) into the neighboring environment. Chung *et al.* (2002)

The direct contact of allelochemicals with seeds only delays and does not substantially inhibit germination. This is contrary to some previous reports (Rasmussen and Einhellig, 1977) and indicates that, in most cases, inhibition of germination may not be the primary site for allelopathic action.

Phenolic content and profiling by HPLC

Phenolic compounds are universally distributed in the plant kingdom as secondary metabolic products and are major allelochemicals implicated in crop allelopathy. Phenolic acids are the most commonly investigated compounds among potential allelochemicals since they have been found in a wide range of soils (Hartley and Whitehead, 1985; Inderjit, 1996; Dalton, 1999). In the present investigation, the total phenol content of shoot was higher in the cultivars Pusa 44, Pant Sugandha Dhan 15 and Pant Dhan 18.

The higher phenol content of cv. Pant Dhan 18 and Pusa 44 is supposed to contribute their competitiveness. Though cv. Pant Sugandha Dhan 15 had also higher amount of phenol content, but it did not seem to contribute towards its competitive ability. In root, the higher phenol content was in cultivar Pant Sugandha Dhan 15 than the rest of the four cultivars.

The advanced techniques such as HPLC, GC-MS, Nuclear magnetic resonance mass spectroscopy have been used by several workers for analysis and quantification of phenolics in different crops (Adom *et al.*, 2002; Kim *et al.*, 2000; Rimando *et al.*, 2001). The advantages of these techniques are the precision and reproducibility.

Higher performance liquid chromatography (HPLC) is widely used for the analysis of phenolic compounds and determined the free and soluble conjugate, bound ferulic acid content of rice, wheat, corn and oat by using HPLC and compared the total content of free and bound phenolic acids using the folin-ciocalteau method (Adom *et al.,* 2002.)

Kim *et al.* (2000) Several compounds identified by GC/MS analysis from cv. Kouketsumochi (potential allelopathic rice) such as sterols, benzaldehyde, benzene derivatives long-chain fatty acid esters, aldehydes, ketones and amines from fractions with biological activity. In the present investigation, HPLC was used for detection of rice phenolics. A few phenolics such as hydroquinone, *p*-hydroxybenzoic acid, vanillic acid, syringic acid, cinnamic acid, ferulic acid, gallic acid and benzoic acid could be identified in the rice tissue extracts. Common phenolics were identified in all the cultivars and their presence in either roots or shoots. In roots, highest numbers of compounds were identified in cv. PSD 17, Govind, Pusa 44, where as in straw of cultivar Pant Dhan 18 and Pant Sugandha Dhan 15 had higher number of phenolic compounds in all the growth stages (30, 45 and 60 DAT). The major phenolics were identified as *p*-hydroxy benzoic acid, hydroquinone, vanillic acid, gallic acid, syringic acid.

Phenolic acids have been identified in allelopathic rice germplasm (Rimando *et al.,* 2001). Extensive studies of allelochemicals in rice plants have led to identification of a range of phenolic compounds, including *p*-hydroxy benzoic acid, vanillic acid, *p*-coumaric acid and ferulic acid.

Potential of incorporating rice straw into soil to control weeds

As Rice crop yields a large amount of straw, recycling of the same could substitute 2-4 bags of fertilizers per hectare equivalent to about 2.5 kg N per tones straw(Mendoza, 1989).In addition, it can help in controlling weeds in different crops as reported by Mendoza and Samson (1999), It has been demonstrated that rice straw can be used for mulching, which prevents weed growth as well as supplies organic matter for N-fixation by hetrotrophic N-fixing microorganisms, which could be absorbed by succeeding crop (Patnaik, 1978).

The incorporation of rice straw at 100g/m², 200g/m², 500 g/m², one month before transplanting of rice plants could control some of the weeds as recorded in the present investigation. The compounds derived from rice straw or even survival plant parts are the good way that could be serves as a renewed source of natural herbicides or probably as a good skeleton to build up new groups of synthetic herbicides (Olofsdotter *et al.,* 1997; Duke *et al.,* 2002).

In our findings, the incorporation of rice straw into the soil at different concentrations prior (about two week) to transplanting of rice significantly reduces the population of both grassy & dicot weeds such as *E. colona, I. rugosum, L. chinensis, Cyperus iria* and *Frimbristylis miliaceae.* Best controls were obtained at the dose of 500 g/m² rice straw.

In the present investigation, the rice straw suppressing the weeds growth as well as promoting the growth of rice plants in field condition. The height, tiller number, and biomass production of four rice cultivars was highest in the 500g/m² rice straw incorporated treatment as compared to butachlor and weedy plots. The total dry matter production and grain yield was highest in 500g/m² rice straw incorporated treatment. Rice straw of 100 and 200 g/m² was also effective and had similar effects to butachlor treatment. Thus, rice straw worked as good fertilizer as well as supplies organic matter for N_2 fixation and effective in controlling weed growth due to its allelopathic nature and maintaining the crop growth by providing the organic matter.

Wheat straw has also been reported to posses allelopathic activities. *p*-coumaric acid has been reported from residues of wheat and other cereals(Guenzi and McCalla, 1962; Guenzi *et al.,* 1967). Several phenolic acids, 2-hydroxyphenylacetatic acid, 4 hydroxy benzoic acid, vanillic acid, *p-coumaric* acid and ferulic acid were found in aqueous extracts of decomposing rice straw or residue (Chou and Lin, 1976) and in soil from paddy fields where rice was grown (Chou and Chiou, 1979).

In the present investigation, the total dry matter production was highest in 500 g/m^2 rice straw treatment and the same pattern was obtained in the grain yield and panicle numbers. Harvest index was maximum, in 500 g/m^2 rice straw treatment followed by 200 g/m^2 rice straw treatment.

Our findings are more consistent with the reports that rice straw suppresses the weed growth and significantly increased the plant height, shoot biomass, grain yield and total dry matter production of the rice crop as compared to weedy and Butachlor treatment. Applying the rice straw (500 g/m^2) at the higher concentrations was more effective than low concentrations of rice straw to suppress weed growth.

Some crops such as sorghum, pearl millet and maize may drastically suppress the weed population and reduce its biomass.

Pearl millet may exhibit residual weed suppression in the succeeding crops. The inclusion of these fodder crops before the rice crop in a rice-wheat rotation may provide satisfactory weed control and can minimize the use of herbicides (Narwal, 2000).

In the present investigation the rice straw which was incorporated into the field was also used in laboratory experiments to check the allelopathic nature of rice straw in controlling weeds. The rice straw had inhibited the germination and seedling growth of weed species. Maximum reduction was observed in species *I. rugosum* and *L. chinensis* and maximum reduction in shoot growth was recorded in *C. axillaries* whereas in root growth, maximum in *I. rugosum* and *C. axillaris.*

Thirteen different phenolic acids in have been isolated from decomposition of rice straw such as benzoic acid, 4-hydroxy benzoic acid, gallic acid, vanillic acid, syringic acid, salicylic acid, ferulic acid, *p*-coumaric acid etc., and released in the greatest amount from decomposition of rice straw and suppressed the weed growth (Kuwatsuka and Shindo, 1973).

Thus, our findings are consistent with the earlier reports that rice straw have allelopathic potential and crop allelopathy in integrated weed control will enhance the competitive ability of the crop and thereby delay the need for applying herbicides (Lin *et al.,* 2000; Lin *et al.,* 2003). Certain phytotoxins are released by rice during their growth or even after dying via straw degradation (Chung *et al.,* 2001).

In the present in investigation, the rice straw had 17 number of total phenolic compounds and four compounds could be identified through HPLC. These were gallic acid, *p*-hydroxybenzoic acid, cinnamic acid and ferulic acid, found in rice straw by the HPLC analysis.

Ferulic acid was found in rice straw and identified by the HPLC analysis and their contents were calculated through comparing peakings as described by Fujii *et al.* (1991).

Our findings are consistent with the above findings that ferulic acid, a major allelochemical in rice (Chung *et al.,* 2001; Matsuo, 2001). The concentrations of single phenolic acids and combinations of all phenolic acids measured in rice ecosystems do not approach phytotoxic levels (Tanaka *et al.,* 1990; Olofsdotter, 2001). Identifying allelochemicals in rice is important for understanding allelopathy mechanisms and for use as markers in gene identification.

Summary and Conclusion

Chapter 6 SUMMARY AND CONCLUSION

The present study was conducted in the Crop Research Centre and Department of Plant Physiology at G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, with an objective to evaluate the competitive ability and allelopathic potential of rice cultivars against weeds, with an emphasis on the role of growth physiology and allelopathic potential of rice straw. The experimental findings have been summarized below:

1) Cultivars Pant Dhan 18 and Govind found to be more competitive while cultivar Pusa 44, Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 were less competitive cultivars on the basis of their mean crop weed competitive index (CWCI).

2) Among the five rice cultivars Pant Sugandha Dhan 15, Pant Sugandha Dhan 17 and Pant Dhan 18 are semi tall where as Pusa 44 and Govind are semidwarf cultivars. The tall cultivars Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 have low grain yield potential where as Pant Dhan 18 have high yield potential, while being a semidwarf cultivars Pusa 44 and Govind have higher yield potential.

3) The biomass accumulation was higher in cultivar Pant Dhan 18, Govind, Pusa 44 than Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 at all the growth stages except at 30 DAT

in 2007, when Pant Sugandha Dhan 15 had high biomass than Govind, Pusa 44 and Pant Sugandha Dhan 17. The increased size and vigour during early growth stages confers competitive ability so therefore cv. PD 18 is more competitive than Govind and Pusa 44 whereas Pant Sugandha Dhan 17 and Pant Sugandha Dhan 15 are least competitive.

4) The tiller number, leaf number and leaf area at 30 DAT was highest in cultivar Pant Dhan 18, Pusa 44 and Govind than Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. The number of tillers, leaf number, leaf length, height, leaf area index and dry weight are always greater in successful competitor so, therefore, cultivar Pant Dhan 18, Pusa 44 and Govind are more competitive than Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17 cultivars.

5) In the present study, the cultivar Govind had highest RLGR in 2007 while in 2008, highest in cultivar Pusa 44 at 45-60 DAT than rest of the cultivars. RLAGR was highest in cultivar Pant Sugandha Dhan 15 in 2007 while in 2008, highest in Pant Dhan 18 where as rest of the four cultivars had similar RLAGR during both the years at 45-60 DAT. So that RLGR and RLAGR are poorly correlated with the competitive ability of cultivars.

6) LAR was highest in cv. Pusa 44 in 2007 while in 2008 highest in cv. Pant Sugandha Dhan 15 and rest of the cultivars had

similar LAR during both the years at 30 DAT. In 2007, all the cultivars had similar SLW while in 2008, highest in cultivar Pant Dhan 18 and Pant Sugandha Dhan 17 and rest of the cultivars had similar SLW at 30 DAT. From these findings LAR and SLW are poorly correlated with competitive ability.

7) Relative growth rate was maximum in cv. Pant Sugandha Dhan 15 in 2007 while in 2008, maximum in cv. Pant Dhan 18 where as rest of the cultivars had similar RGR at 45-60 DAT. Net assimilation rate was maximum in cv. Pant Sugandha Dhan 17 during both the years at 30-45 DAT and 45-60 DAT while rest of the cultivars had similar value. Thus in the present investigation RGR and NAR could not correlate with the competitive ability. RGR and NAR are not a character for selection of competitive cultivars.

8) Standard synthetic phenolic compounds (100 ppm) such as ferulic acid, vanillic acid and syringic acids alone and in combination, Mixture 1 (Ferulic acid + vanillic acid + *p*-hydroxy benzoic acid) and Mixture 2 (Ferulic acid + vanillic acid + *p*-hydroxy benzoic acid + gallic acid) had the highest inhibitory effects on weed seeds germination. Among the weed species, *L. chinensis, E. crusgalli* and *I. rugosum* were more sensitive to synthetic phenolic compounds than other weed species. The combination of phenolics was more effective than individual phenolic compounds.

9) Among the straw and roots of five rice cultivars, the straw had more inhibitory effects than roots on weed seeds germination and seedling growth. Roots of the cultivars Pant Dhan 18 and Govind had maximum inhibitory effects than rest of the cultivars. Among the six weed species, maximum reduction in germination and seedling growth due to five rice cultivars roots was observed in *C. axillaris* and *L. chinensis*. The straw of cultivars Pant Dhan 18, Govind and Pusa 44 had maximum inhibitory effects on the germination and seedling growth of the weed seeds. The weed seeds which were more sensitive to straw were *C. axillaris, L. chinensis, C. benghalansis* and *I. rugosum.* Rice roots and straw effect on seedling growth of weed species revealed that root growth was more sensitive than shoot growth of weed species.

10) The effect of rice cultivars on germination and seedling growth of weed species was judged through donor-receiver bioassay. The seedlings of cultivar Pant Dhan 18, Govind, Pusa 44 and Pant Sugandha Dhan 15 had maximum inhibitory effects on the seedling growth of weed species and all the five rice cultivars had inhibitory effects on weed seed germination. The maximum inhibitory effects on root growth was observed in *C. axillaris* whereas in shoot growth, maximum inhibition in *E. colona.*

11) Hydroponic culture test : Root exudates of all the five rice cultivars grown in hydroponics were found to have inhibitory

effects on germination and seeding growth of weed seeds. Highest reduction observed in the species *L. chinensis*, *C. axillaries, I. rugosum* and *C. benghalensis*.

12) The total phenol content of shoot was higher in cultivars Pusa 44 and Pant Dhan 18 that is supposed to contribute their competitiveness. Though Pant Sugandha Dhan 15 had also higher amount of phenol content, but it did not seem to contribute towards its competitive ability. In roots, higher phenol content was in cultivar Pant Sugandha Dhan 15 than rest of the four cultivars. Phenol profiling by HPLC depicted the major phenolics such as hydroquinone, *p*-hydroxybenzoic acid, vanillic acid, syringic acid and gallic acid were present in all the five rice cultivars and their presence in either roots or shoots. In roots cultivar Govind had highest number of compounds and culivar Pant Sugandha Dhan 17, Govind and Pusa 44 had maximum number of identified phenolic compounds. In straw of five rice cultivars, Pant Dhan 18 and Pant Sugandha Dhan 15 had higher number of phenolic compounds in all the growth stages (30, 45 and 60 DAT).

13) The incorporation of rice straw into the soil at different concentrations prior (about two week) to transplanting of rice significantly reduces the population of both grassy and dictos weeds such as *E. colona, I. rugosum, L. chinensis, C. iria* and *F.*

miliaceae. Best controls were obtained at the dose of 500 g/m^2 rice straw, it worked as natural herbicide.

14) The incorporation of rice straw suppressing the weeds through allelopathic potential of straw along with promoting the growth of four rice cultivars. The plant height, tiller number, biomass production was highest in 500 g/m^2 rice straw incorporated treatment.

15) Total dry matter production and grain yield was highest in 500 g/m^2 straw incorporated treatment thus, rice straw worked as fertilizer as well as supplies organic matter for N_2 fixation.

16) To check the allelopathic activity of incorporated rice straw in to the soil, was also used in laboratory bioassay and it effectively inhibited the germination and seedling growth of weed species. Maximum reduction in germination was observed in species *I. rugosum* and *L. chinensis*. In shoot growth, maximum reduction was recorded in *C. axillaris* whereas in root growth, maximum in *I. rugosum* and *C. axillaris.*

17) The phenolic content of incorporated rice straw was identified by HPLC analysis. The rice straw had 17 number of total phenolic compounds and four compounds could be identified. These were gallic acid, *p*-hydroxybenzoic acid, cinnamic acid and ferulic acid. It is concluded that these phenolics are responsible for the allelopathic activity of rice straw.

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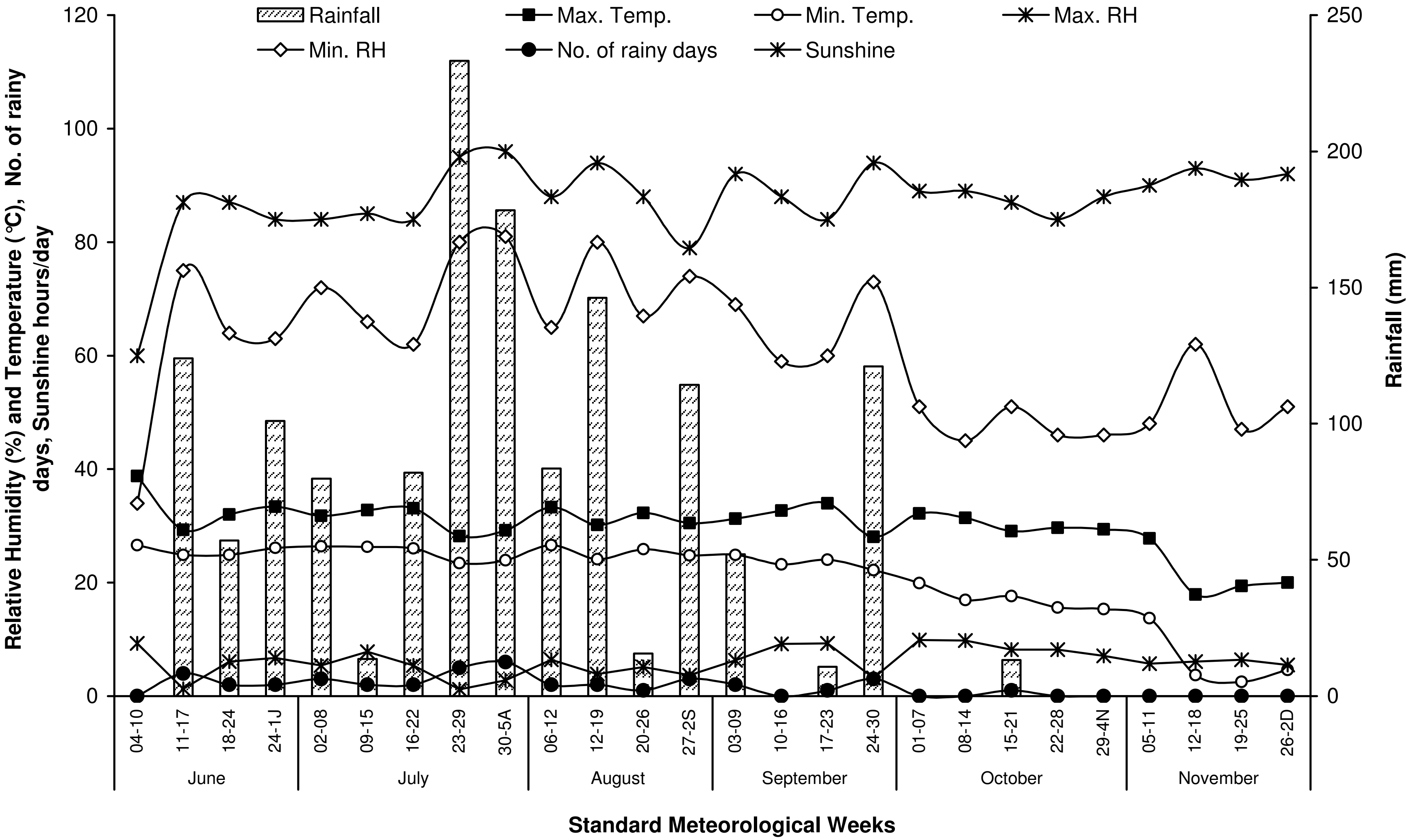
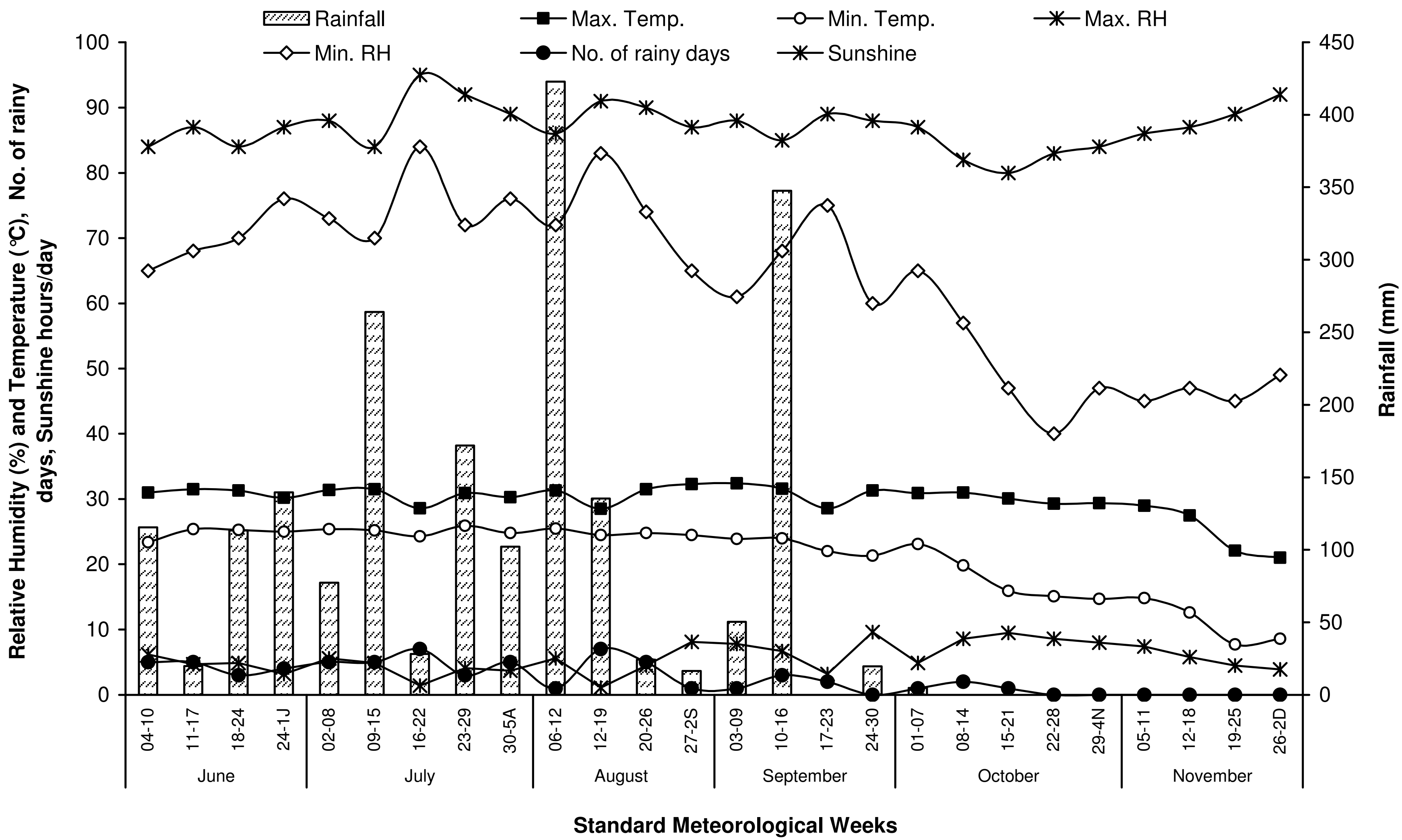
Appendices

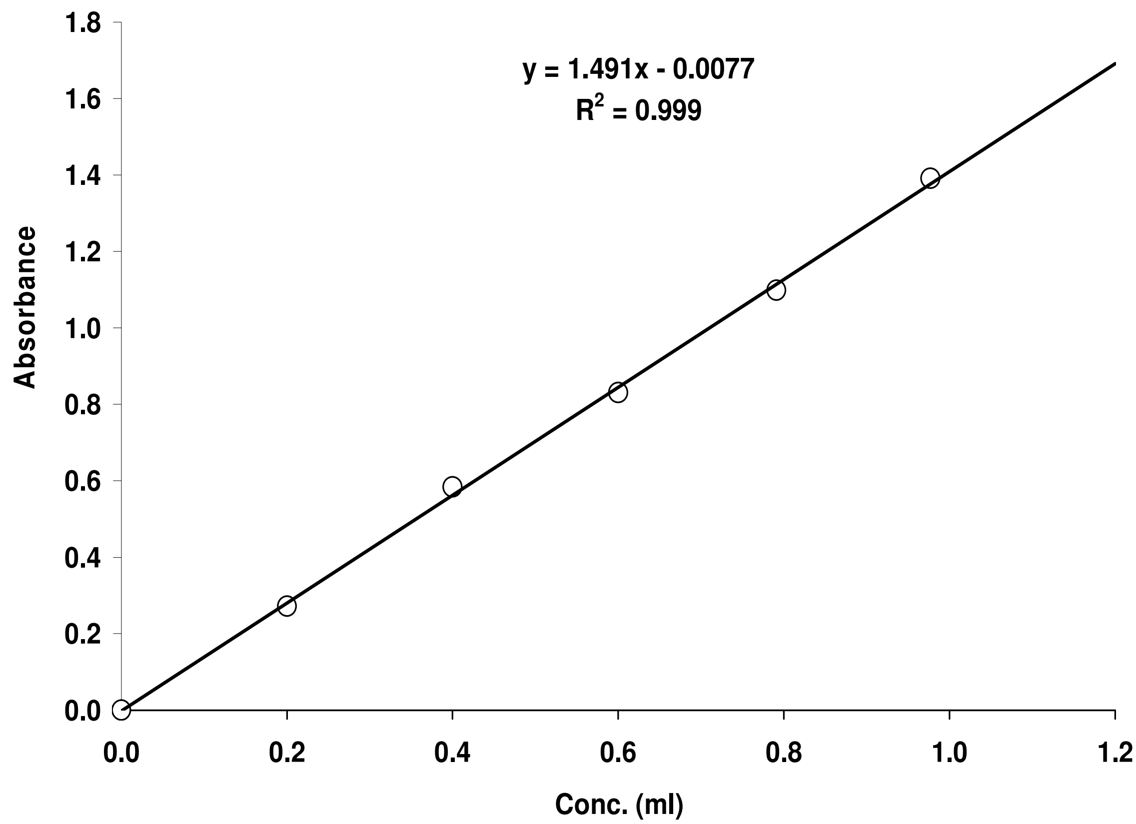


Appendix Ia: Weekly weather conditions at Pantnagar during crop period (2007)



Appendix Ib: Weekly weather conditions at Pantnagar during crop period (2008)

Appendix-II



Standard curve of catechol

Appendix-III

Composition of a modified Hoagland nutrient solution for growing plants

Compound	Molecular weight (g mol^{-1})	Conc. of stock solution (mM)	Conc. of stock solution (g L^{-1})	Volume of stock solution per litre of final solution (ml)	For 200 L
Macronutrients					
KNO_3	101.10	1,000	101.10	6.0	300 ml
$Ca(NO_3)_2.4H_2O$	236.16	1,000	236.16	4.0	200 ml
$NH_4H_2PO_4$	115.08	1,000	115.08	2.0	100 ml
$MgSO_4.7H_2O$	246.48	1,000	246.49	1.0	50 ml
Micronutrients					
KCl	74.55	25.0	1.864	2	100 ml
H_3BO_3	61.83	12.5	0.773		
$MnSO_4.H_2O$	169.01	1.0	0.169		
$ZnSO_4.7H_2O$	287.54	1.0	0.288		
$CuSO_4.5H_2O$	249.68	0.25	0.062		
H_2MoO_4 (85% MoO_3)	161.97	0.25	0.040		
NaFeDTPA (10% Fe)	468.20	64.0	30.0	0.3-1.0	50 ml
Optional					
$NiSO_4.6H_2O$	262.86	0.25	0.066	2.0	
$Na_2SiO_3.9H_2O$	284.20	1,000	284.20	1.0	

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ABSTRACT

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Advisor : **Dr. S.K. Guru**

The present study was conducted in the Crop Research Centre and the Deptt. of Plant Physiology, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, with an objective to evaluate the competitive ability and allelopathic potential of five rice cultivars against weeds. The field experiment were conducted during rainy season of 2007 and 2008. The experiment was laid out in a split plot design with three replications with weed control methods as main plots and cultivars as subplot treatments. The treatment consisted of weedy, weed free and butachlor. Morphological as well as Physiological growth parameters and total dry matter production were measured at different growth stages. Total phenol content and phenol profiling through HPLC were also done. To study the effect of phenolics and rice tissue extracts on germination of weed seeds were carried out through petridish bioassay as well as hydroponic cultures.

Among the different phenolics ferulic acid, vanillic acid and syringic acid and *p*-hydroxybenzoic acids had maximum inhibitory effects on germination and seedling growth of weed species. The straw and roots of rice cultivars had inhibitory effects on weed seedling growth. Traits that were found to be correlated with competitiveness were vegetative vigour and biomass production at early growth stages whereas physiological growth parameters such as RGR, NAR, RLGR, RLAGR were poorly correlated with competitive ability. Among the five rice cultivars, Pant Dhan 18, Govind and Pusa 44 were competitive than Pant Sugandha Dhan 15 and Pant Sugandha Dhan 17. The phenolic profiling through HPLC exhibited that major phenolics hydroquinone, *p*-hydroxy benzoic acid, vanillic aicd, syringic and gallic acid were major phenolic acid present in roots which contributes towards allelopathy. Incorporation of rice straw at transplanting or prior to that has been reported to have an controlling effect on the weed population. In a second experiment, incorporation of rice straw at 100-500 gm m^{-2}, 15 days prior to transplanting was found to have significant effect on reducing the weed biomass as well as promoting both growth and yield of four rice cultivars. Four phenolic acids such as gallic acid, p-hydroxybenzoic acid, cinnamic acid and ferulic acid were identified by HPLC in the rice straw which are supposed to have some allelopathic effect.

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Advisor

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