ALLELOPATHIC EFFECT OF RICE STRAW AND WATER HYACINTH ON WEED CONTROL AND YIELD OF BORO RICE

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A Thesis
Submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
IN
AGRONOMY

SEMESTER: JULY-DECEMBER, 2010

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CERTIFICATE

This is to certify that the thesis entitled, "**ALLELOPATHIC EFFECT OF RICE STRAW AND WATER HYACINTH ON WEED CONTROL AND YIELD OF BORO RICE**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in the partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE in AGRONOMY,** embodies the result of a piece of *bona fide* research work carried out by **MD. ABDULLAH AL-MAMUN** Registration No. **05-01784** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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DEDICATED TO MY BELOVED PARENTS

ACKNOWLEDGEMENT

All praises are due to the Almighty Allah, the great, the gracious, merciful and supreme ruler of the universe to complete the research work and thesis successfully for the degree of Master of Science (MS) in Agronomy.

The author expresses the deepest sense of gratitude, sincere appreciation and heartfelt indebtedness to his reverend research supervisor Prof. Dr. Parimal Kanti Biswas, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka for his scholastic guidance, innovative suggestion, constant supervision and inspiration, valuable advice and helpful criticism in carrying out the research work and preparation of this manuscript.

The author deems it a proud privilege to acknowledge his gratefulness, boundless gratitude and best regards to his respectable co-supervisor Professor Dr. Md. Fazlul Karim, Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka for his valuable advice, constructive criticism and factual comments in upgrading the research work.

The author extends his special appreciation and warmest gratitude to all of the respected teachers of Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka who provided creative suggestions, sympathetic co-operation and constant inspiration from the beginning to the completion of the research work.

The financial support given by the Ministry of Science and Information & Communication Technology to conduct the research work is gratefully acknowledged.

The author expresses his heartiest thanks to Hasan, Opu, Rafiq, Elias, Shahin, Titumeer, Shahria, Shohag, Maruf, Shawon, Matin, Swapon, Shuvo, Shohan and Anne for their active co-operation during the entire period of the research.

The author is deeply indebted to his parents and grateful to his brothers and sisters and other relatives for their moral support, encouragement and love with cordial understanding.

Finally the author appreciates the assistance rendered by the staffs of the Department of Agronomy, lab attendants and labours of farm of Sher-e-Bangla Agricultural University, Dhaka who helped him during the period of the research work.

The Author

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ABSTRACT

The experiment was conducted at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka from November, 2009 to May, 2010 to find out the allelopathic effect of rice straw and water hyacinth biomass on weed control and yield of *boro* rice. The treatments of the experiment consisted of 2 rice varieties *viz*. BRRI dhan29 (V_1) and BRRI hybrid dhan2 (V_2); 2 allelopathic materials *viz*. rice straw (M_1) and water hyacinth (M_2); and 3 levels of biomass concentration *viz*. 0 kg biomass m^{-2} (C_0), 0.5 kg biomass m^{-2} (C_1) and 1.0 kg biomass m^{-2} (C_2). The experiment was laid out in a spilt split-plot design with 3 replications having varieties in the main plots, allelopathic materials in the sub plots and concentrations in the sub sub-plots. The lowest weed population (11.33 m^{-2} and 16.00 m^{-2} at 30 and 50 DAT respectively) and minimum dry weight (4.89 g m^{-2}) at 30 DAT was found from rice straw application irrespective of variety. The highest grain yield (7.50 t ha^{-1}) was obtained from BRRI hybrid dhan2 with water hyacinth @ 1.0 kg m^{-2}. The highest number of effective tillers $hill^{-1}$ (19.67) was observed from BRRI dhan29 with water hyacinth @ 1.0 kg m^{-2} and the lowest number of non-effective tillers $hill^{-1}$ (1.67) was recorded from the same variety with rice straw and at the same concentration. The highest panicle length (26.65 cm) was found in BRRI dhan29 with rice straw @ 1.0 kg biomass m^{-2}. BRRI hybrid dhan2, water hyacinth and 1.0 kg biomass m^{-2} and their interactions encouraged growth and dry weight of weeds as well as yield of rice. Rice straw reduced weed growth whereas water hyacinth enhanced weed growth as well as grain yield of rice.

CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF APPENDICES

LIST OF PLATES

Chapter 1
Introduction

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of over half the world's population. It is the grain with the second-highest worldwide production and predominant dietary energy source for 17 countries in Asia and the pacific, 9 countries in North and South America and 8 countries in Africa. Rice provides 20 percent of the world's dietary energy supply. The total acreage of rice is nearly 160 million hectares worldwide which produces more than 700 million tons grains every year (IRRI, 2010). Rice contains carbohydrate (80.0%), protein (7.10%), fat (0.66%), fibre (1.30%), calorie (350 Kcal per 100 g edible portion) and a considerable proportion of vitamins and minerals (USDA, 2005). The crop is grown under different environmental conditions ranging 39^0 S latitude to 50^0 N latitude and an altitude of 2000 meter.

The total production of rice in Bangladesh was 34.35 million metric tons from her 11.35 million hectares of land in the fiscal year 2010-2011 (BBS, 2011). But there was a deficit of 1.27 million metric tons of rice in that year. In Bangladesh rice is grown under diverse ecosystems, irrigated, rainfed and deep water condition in three distinct seasons namely *aus, aman* and *boro* where *boro* covers the lion share of about 4.70 million hectare of land producing 18.65 million metric tons of rice (BBS, 2010). Though rice is the main cereal crop in Bangladesh, the average yield of this crop is poor (4.34 t ha^{-1}) compared to other rice growing advanced countries of the world (BRRI, 2011). As the cultivable land of Bangladesh is decreasing to accommodate the rapidly growing population the production of rice needs to be increased in order to meet the on going food deficit and to cope with the food demand for the increasing population.

Bangladesh is an agriculture based country where about 84% of the total population lives in rural areas. Agriculture shares about 19.95% GDP (gross domestic product) of the country and 62% people directly involved with agriculture. The cultivation cost of different crops is gradually increasing due to the higher prices of inputs and non availability of labourers. The soil health of Bangladesh is tremendously deteriorated due to intensive agriculture that results lower organic matter status of the soil and causes lower yield. Hence, emphases have to be given on low cost, high profit and environmentally safety agriculture. Management plays an important role on crop production of which weed control is an important task that involves a lot of production cost. Weeds cause enormous losses to crops even more than other pests worldwide. Oerke and Dehne (1997) found that weeds cause around 33% of total crop loss in Asia and other countries. On an average 37.3% of crop produce is damaged by weeds in Bangladesh (Karim *et al.*, 1998) that valued approximately Tk. 59665.7 million (Karim, 2008). Production losses in Bangladesh due to weeds as 33.2% in food crops, 41.3% in cereals, 31.9% in pulses, 40.8% in oilseed crops, 34.2% in fibre crops and 40.3% in rice. However, an average of 13.1% of crop reproduce is actually lost in the farmers fields even after adopting traditional weed control measure (Mamun, 1990).

Weed management is a most expensive step in crop production due to unavailability of human labour in Bangladesh. As a result the alternate way to control weeds by the use of herbicide is gradually increased. The herbicide use in Bangladesh from 1998 to 2007 is increased from 239.15 mt to 3825.29 mt, the increase rate was 1499.54% (Karim, 2008). The residual effect of the herbicides to the soil, water, environment and health was not yet evaluated properly. Although weed management practices like hand weeding and herbicide application are effective in weed control but are uneconomical due to higher costs (Cheema *et al.*, 2003a). Moreover the chemical weed control method is hazardous for health and causes environmental pollution.

Use of Allelopathy (an eco-friendly measure) as an important ecological phenomena to control weeds in different crops is now practicing worldwide (Mansoor *et al.*, 2003; Cheema *et a*l., 2002; Khan *et al.*, 2004; Xuan *et al.*, 2005a; Inderjit, 2002 and Biswas *et al.*, 2008). Allelopathy refers to a plant's ability to chemically inhibit the growth of other plants. The most common effects of allelochemicals may occur through leaching, volatilization, root exudation and the death and decay of the fallen plant parts are either via biotic or abiotic means (Anoya *et al.*, 1990). In respect of soil, environment and health concern, allelopathic research to control weeds progress tremendously throughout the world but Bangladesh is lies far behind. Batish *et al.* (2008) from India reported that allelopahy if suitably manipulated, can help to control harmful weeds in an eco-friendly way and thus maintain soil sustainability since the allelochemicals are biodegradable and provide several other advantages. The allelopathic effect to control weeds by young rye plant was reported by Fomsgaard *et al.* (2008), by rice cultivar Noguchi and Salam (2008), by different plant residues Mahmood *et al.* (2008b) and by rapeseed and mustard biomass Biswas *et al.* (2008). The attempt was therefore undertaken to conduct the present research on allelopathic effect of rice straw and water hyacinth on weed control and yield of *boro* rice at department of Agronomy, Sher-e-Bangla Agricultural University, Bangladesh to find out the potentiality of rice straw and water hyacinth as allelopathic crops to control weeds in rice and to improve soil health. Considering the above context the experiment was designed with the following objectives:

i) To compare the effectiveness of rice straw and water hyacinth in controlling weeds in rice field

ii) To determine the suitability of using rice straw and water hyacinth in improving soil health

iii) To find out the optimum concentration of rice straw and water hyacinth to control weeds in rice field

Chapter 2
Review of Literature

REVIEW OF LITERATURE

The continuous and unbalanced use of chemical herbicides under intensive cropping systems has been considered to be the main cause for declining crop yield and environmental degradation. Using allelopathy in controlling weeds and increasing yield of different crops is studied by many researchers in the world. Considering the above points available literatures were reviewed on allelopathic potential of different crops and their residues.

2.1 Allelopathic potential of different crop varieties

2.1.1 Rice varieties

International Rice Research Institute (IRRI) developed a laboratory method for screening whole- plant bioassay for allelopathic rice screening (Navarez and Olofsdotter, 1996) to eliminate the effects of competitive interference for resources between rice and test plants. Interestingly using this method, inhibitory activity of 111 rice varieties in Philippines has shown inconsistent results between laboratory and field trails. (Olofsdotter, 1998) However in both laboratory screening and field experiments revealed that rice allelopathy was active both monocot and dicot weeds (Dildey *et al.,* 1991; Fujii, 1994; Olofsdotter and Navarez, 1996 ; Hassan *et al.,* 1998; Kim and Shin, 1998) whereas laboratories screenings for allelopathic in rice have also been undertaken and found that a marked difference among rice varieties for weed species inhibition activity (Fujii, 1994; Hassan *et al.,* 1998; Kim *et al.*,1999; Azim *et al.,* 2000) and suggesting that different rice cultivars are capable to suppress particular weed species.

To establish an alternative strategy to weed management in rice for sustainable agriculture the phenomenon "allelopathy" has been a subject of continued research for a long time (Olofsdotter, 2001; Takeuchi *et al.*, 2001) and already a large number of rice varieties have found to suppress the several weed species when grown together under field and laboratory conditions (Dilday *et al.*, 1998;

Kim *et al.*, 1999, Olofsdotter *et al.*, 1999; Azim *et al.*, 2000). The first observation of rice was made in field examination in Arkansas, USA (1988 cropping season) where about 191 of 5,000 rice accessions inhibited the growth of duck salad weed (*Heteranthera limosa*) (Dilday *et al.*, 1989) and thus finding led to a further large screening program. USDA-ARS have been screened more than 16,000 rice accessions from 99 countries and 412 rice accessions shown the allelopathic potentiality against *Heteranthera limosa* and 145 rice accessions shown the allelopathic potentiality against *Ammannia coccinea* (Dilday *et al.*, 1994) Dilday *et al.* (1998) evaluate the phytotoxic effects of 12,000 and 5000 rice accessions against ducksalad (*Heteranthera limosa*) and redstem (*Ammannia coccinea*) respectively and they found that 412 and 145 rice accessions developed an allelopathic zone around rice for ducksalad and redstem respectively. Several field screening was made in different countries such as Egypt, Korea, Japan, India, Thailand, United States and little bit in Bangladesh (Dilday *et al.*, 1998) In Egypt, more than 40 out of 1000 (were screened) rice varieties shown inhibitory activity with they were associate with *Echinichola crusgalli* and *Cyperus difformis* (Hassan *et al.*, 1998) and suggesting that genetic variation was the main factor to environment.

Field experiments revealed that allelopathy accounted for 34% of overall competitive ability in rice. For strongly allelopathic cultivars, allelopathy is the dominant factor determining competitive ability. Rice allelopathy plays role in field condition and allelopathic rice can suppress mono and dicot weed species (Olofsdotter, 2001).

Noguchi and Salam (2008) observed that rice allelopathy has received much attention, and might be an alternative to the chemical and mechanical control of weeds to reduce the use of chemical herbicides, which might results in improved water quality and less environmental contamination and also reduce labour for hand weeding. They conducted experiments to assess the allelopathic potential of Bangladesh rice cultivars for weed control purposes. The allelopathic potential of

102 Bangladesh rice (42 high yielding and 60 traditional cultivars) was determined against the seedling growth of cress, lettuce, *Echinochloa crusgalli* and *E. colonum.* High yielding rice cultivars, BRRI dhan 37, BRRI dhan 30 and BRRI dhan 38, respectively, had the most significant inhibiting effect on the growth of cress, lettuce and *E. colonum,* and traditional rice cultivar, Kartikshail had the most significant inhibiting effect on barnyard grass. The high yielding rice cultivar, BR 17 marked the greatest inhibitory activity with an average of 39.5% of the growth inhibition on roots and hypocotyls/shoots of cress, lettuce, barnyard grass and *E. colonum.*

Urteaga *et al.* (2008) conducted an experiment taking six rice cultivars (El Paso, Camba, Blue Bonnet, IRGA 417, Yerua and El Supremo) to find out their allelopathic potentials against one of the most troublesome weed barnyardgrass (*Echinochloa crus-galli)*. They recorded that El Paso and Blue Bonnet were the cultivars showing strong and consistent allelopathic activity against barnyardgrass whereas the remaining rice lines were weakly (or not) allelopathic.

Seal and Pratly (2008) tested several rice weed species belonging to the Alismataceae to ascertain whether the allelopathic potential of rice cultivars extended beyond a single weed if the weed species were related. They found significant differences between rice cultivars in their ability to suppress the root growth of each weed studied.

Biswas *et al.* (2011) conducted a field experiment in SRI (system of rice intensification) at Agronomy field of Sher-e-Bangla Agricultural University, Bangladesh during December 2010 to May 2011 including 16 popular inbred and hybrid rice varieties. They concluded that at 30 DAT, the significantly highest weed population of 119.00 and 117.00 m^{-2} was found in BRRI dhan29 and BRRI dhan45 respectively whereas BR3 and BRRI dhan50 resulted the lowest weed population of 31.00 and 38.00 m^{-2} respectively. Similar lowest weed population i.e. 35.33 and 36.00 m^{-2} was also found in BRRI dhan50 and

BRRI hybrid dhan1 respectively at 60 DAT.

Javaid *et al.* (2008) studied to exploit rice allelopathy to control the annual invasive weed parthenium (*Parthenium hysterophorus*). In a laboratory bioassay, effect of aqueous, methanol and n-hexane shoot extracts of 0, 2, 4, ...10% concentrations of three rice varieties (Basmati-385, Basmati-386 and Basmati Super) was tested against germination and seedling growth of parthenium. The highest phytotoxicity was recorded in methanol extracts of Basmati-386 where 10% extract suppressed germination, shoot length, root length and biomass by 85, 87, 95 and 98% respectively.

Cheema *et al.* (2008) reported that inclusion of allelopathic crops in rotation systems for weed suppression by early post-emergence application of the mixture of sorghum, sunflower, brassica or mulberry water extracts suppressed total weed dry weight by 40 to 75% and enhanced yield of wheat, maize, cotton and rice by 15 to 25%. Combined application of these water extracts reduced the herbicide(s) dose by 50 to 75%.

Kim *et al.* (1999) observed that rice seedlings grown under conditions of intensive competition with barnyard grass accumulated more allelochemicals than those grown in the absence of competition. Growing rice seedlings at the ratios of 5 rice seedlings: 1 barnyard grass plant and 5:5 provided 64.3 and 84.5% control, respectively.

In Taiwan, Chou (1990) found that rice (*Oryza sativa*) planted twice a year in a monoculture system reduced the second crop yield by about 25% in areas of poor water drainage. During the fallow period, rice stubble is left in the field after harvesting, and incorporated into the soil for decomposition. During decomposition, a great quantity of phytotoxins were produced resulting in the suppression of rice growth and subsequent grain yields.

2.1.2 Other crop varieties

Putnam *et al.* (1990) designed an experiment with rye into field plots during early October, over wintered and killed with glyphosate (N- phosphonomethyl glycine) when it attained about 5 metric tons/ha, and evaluated its weed control capacity in vegetable and fruit cropping systems over a 10-year period. Their experiments indicated that living rye has a strong interference ability against weeds, providing excellent weed control prior to annual crop establishment or provides soil cover during the dormant period in perennial crops.

Rye (*Secale cereale*) was used as a winter cover crop, often for the allelopathic weed suppression provided by the mulch. Rye produced several allelochemicals, the principal allelochemical group included the benzoxazinone (BX), represented by DIBOA (Burton *et al.*, 2008).

Gomes *et al.* (2007) reported that intercropping combined with competitive maize cultivars could reduce the use of herbicides to control weeds. The cowpea was inefficient in controlling weed, reducing the maize yields and not producing any grain. The maize cultivars 'BA 8512' and 'BA 9012' showed the highest mean green ear yield, and the highest grain yield in hand-weeded, no-weeded and intercropped split-plots. On the other hand, the maize cultivar 'EX 6004' showed such high means only in no-weeded and intercropped split-plots. 'EX 4001' presented the worst means in these variables for hand-weeded, no-weeded and intercropped split-plots.

Wu *et al.* (2000) in an experiment on allelopathy in wheat (*Triticum asetivum*) reported that Wheat (*Triticum aestivum*) allelopathy has potential for the management of weeds, pests and diseases. Both wheat residue allelopathy and wheat seedling allelopathy can be exploited for managing weeds, including resistant biotypes. Wheat varieties differ in allelopathic potential against weeds, indicating that selection of allelopathic varieties might be a useful strategy in integrated weed management. Several categories of allelochemicals for wheat allelopathy have been identified, namely, phenolic acids, hydroxamic acids and short-chain fatty acids. The negative impacts of wheat autotoxicity on agricultural production systems have also been identified when wheat straws are retained on the soil surface for conservation farming purposes.

Bellostas *et al.* (2007) reported that glucosinolates were amino acid derived allelochemicals present in all plants of the order Capparales. Species within the Brassicaceae were found to differ in their glucosinolate profile and glucosinolate concentrations. The glucosinolate profile of corresponding ripe seeds was also determined. The determined glucosinolate profiles were an initial step in assessing the biofumigation potential of these species of the Brassicaceae family.

Sorghum plants from seeds exposed to gama rays have more inhibitory activity in their root exudates, aqueous extracts, and decaying residues against growth of *Amaranthus retroflexus* (Alsaadawi *et al.*, 1985). They conducted a screening experiment to examine the activity of sorghum root exudates of 100 cultivars to inhibit germination and seedling development of Pigweed (*Amaranthus retroflexus*) in a sand culture medium. A high variability was observed in the ability of the test cultivars to alter seed germination and/or seedling growth of the weed. They found 82% of the control reduction in seed germination in 25 cultivars.

Sorghum (*Sorghum bicolor*) is known to provide a good weed killing capacity and researchers showed that it is also autotoxic and should be rotated with other crops for maximum yield (Putnam and Defrank, 1983).

Dhima *et al.* (2006) conducted a study to measure the effect of two barley (*Hordeum vulgare* L.) and six triticale (X *Triticosecale* Withmack) cultivars and three rye (*Secale cereale* L.) populations, used as cover crops, on the emergence and growth of barnyard grass [*Echinochloa crus-galli* (L.) P. Beauv.], bristly foxtail [*Setaria verticillata* (L.) P. Beauv.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and sugarbeet (*Beta vulgaris* subsp.

vulgaris). In the field, barnyard grass, bristly foxtail and large crabgrass emergence in mulched plots was 39 to 69%, 0 to 34%, and 0 to 78% lower, respectively, as compared with that in mulch-free plots.

Xuan *et al.* (2005 a) evaluated some higher plants with strong allelopathic properties of alfalfa (*Medicago sativa* L. cv. Rasen) and kava (*Piper methysticum* L.) after soil amendment. Both alfalfa and kava strongly inhibited barnyardgrass and monochoria growth for up to 10 days (80-100 % weed control). After 20-25 days, the magnitude of inhibition was drastically reduced, but was still effective (50 % weed control). Chemicals released from allelopathic plants incorporated into soil are toxic and cause inhibition of certain species and could be exploited as a biological tool for weed management.

Xuan *et al.* (2005 b) observed that the incorporation of the allelopathic plants to rice fields at 1-5 days after transplanting gave the greatest weed reduction. The selective impacts of these plants on major noxious paddy weeds (such as *Echinochloa crus-galli, Monochoria vaginalis, Rotala indica, Eleocharis acicularis, Scirpus juncoides, Doparium juncencum, Lindernia pyxidaria,* and *Cyperus difformis*) were demonstrated. Some species (*Alpinia zerumbet, Ageratum conyzoides, Azadirachta indica, Piper methysticum, Leucaena leucocephala,* and *Melia azedarach*) showed strong inhibition on major plant pathogens (such as *Corticium rolfsii, Fusarium solani, Pyricularia grisea, Pythium spp., Rhizopus stolonifer, Taphrina deformans*, and *Thanatephorus cucumeris*) and they might become effective tools in reducing plant pathogens and weeds. Numerous growth inhibitors (alkaloids, phenolics, fatty acids, lactones, and flavonoids) identified from these allelopathic plants were responsible for their allelopathic properties.

Gallandt and Haramoto (2004) found that allelopathic potential had been well documented for cover crops such as cereal rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth) and red clover (*Trifolium pratense* L.). They discussed unique attributes of Brassicas that make them promising options for pest management, as well as generally beneficial cover crops.

Hall *et al.* (2004) experimented hairy vetch (*Vicia villosa* Roth.), fall rye (*Secale cereal* L.), yellow sweet clover (*Melilotus officinalis* L.) and white clover (*Trifolium repens* L.) as cover crops with cauliflower (*Brassica oleracea* L. var. *botrytis*), and compared to monoculture cauliflower. Monoculture and rototilled hairy vetch plots showed the highest number of weeds throughout the experiment. Mowed plots showed the lowest weed densities. None of the experimental treatments tested (rototilled hairy vetch, yellow sweet clover and white clover and mowed white clover) showed significant allelopathic potential. The resultant yields in the plots showed that rototilling of the cover crop prior to planting improved cauliflower yield, compared to mowing. The rototilled plots generally had the most weeds, but presumably the increased nutrient availability and reduced competition from the cover crops resulted in improved cauliflower yields, compared to mowed plots. Mowing of the cover crop decreased weed numbers, but most likely the higher level of competition and lower nutrient availability resulted in smaller cauliflower yields.

An experiment was conducted by Mansoor *et al.* (2004) to investigate the efficacy of various weed management strategies in mungbean. Water extracts of sorghum, Eucalyptus and Acacia were used in comparison with hand weeding and pre-emergence herbicide. All the treatments significantly affected number of branches/plant, number of pods/plant, 1000 grain weight and grain yield. Application of water extract of Acacia ranked at the top in yield and almost all the yield components followed by two hand weeding + Pre-emergence herbicide treatments.

Kristiansen *et al.* (2003) tested *Brassica* varieties with high GSL levels (*Brassica juncea* cv. *Fumus* and *Raphanus sativus* cv. *Weedcheck*) in combination with mechanical weed control and another locally grown forage crop (*Lolium multiflorum* cv. *Conquest*) for their effects on weed growth during the pre-crop phase and subsequent weed and lettuce growth during the in-crop phase. Weed control was closely related to the amount of light reduction by the cover crops, while competition for nutrients and water appeared to be less important in weed suppression by the cover crops.

Xuan and Tsuzuki (2002) studied eight common varieties of Japanese alfalfa (*Medicago sativa* L.), namely Batasu, Hisawakaba, Kitawakaba, Makiwakaba, Natsuwakaba, Lucerne, Tachiwakaba and Yuba. Aqueous extracts of both fresh and dried material of alfalfa plants of all varieties significantly inhibited both germination and growth of lettuce (*Lactuca sativa* L.). Leachates from germinating seeds of almost all alfalfa varieties inhibited elongation of the radicle but produced a negligible increase in germination and only slightly inhibited elongation of the hypocotyl of lettuce plants. Results demonstrated that the degree of inhibition of germination and growth of lettuce varied with the variety of alfalfa. In particular, Lucerne was identified as having the strongest allelopathic potential of the varieties studied. The results suggested that the allelopathic potential of alfalfa might be relating to a gene.

Fujii (2001) stated that leguminous cover crops such as hairy vetch (*Vicia villosa*) and velvetbean (*Mucuna pruriens*), graminaceous cover crops, such as oat (*Avena sativa*) and rye (*Secale cereale*), certain cultivars of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) were promising. Fall-sown cover crops such as hairy vetch, rye, wheat, oat, grass pea, and mustard were more effective when compared to spring-sown cover crops. Hairy vetch was most promising for the weed control in abandoned fields because of its ability to die off during summer season to make thick straw-like mulch.

Five cover crop species were evaluated by Friedman *et al.* (1995) on nitrogen production and weed suppression in Sacramento Valley Farming Systems and found that the Lana vetch mixes and the Lana vetch provided more effective weed control than the purple vetch in both years. In 1993-94, weeds were negligible in all Lana vetch treatments, while the weeds in the purple vetch treatment made up almost 35% of the total biomass. In 1994-95, the Lana vetch and fava/Lana vetch treatments were considerably more effective at choking out weeds than the purple vetch, although the cowpea/Lana vetch treatment was not more effective. However, the vetch in mix was unable to compete effectively with the heavy weed growth.

Rose *et al.* (1984) experimented on 280 soybean cultivars and invented that soybean cultivars of later maturity tended to compete more effectively with weeds. Twenty soybean cultivars of varying competitive ability were selected and grown in the greenhouse during 1981 and 1982 to determine the importance of allelopathy in competing with weeds. Exudates from roots of soybean cultivars grown in sand reduced the dry weight of 4-week-old velvetleaf plants an average of 15%, but foxtail millet was not inhibited. Incorporation of 1% ground soybean dry matter into Sharpsburg silty clay loam inhibited germination and dry weight of greenhouse grown velvetleaf an average of 46% each. Foxtail millet germination and dry weights were reduced an average of 82 and 65%, respectively. Undiluted soybean plant extracts of all cultivars tested slowed the germination and dry weight accumulation of 6-day-old velvetleaf and foxtail millet, but dilution of the extracts caused quite variable responses.

Dayan (2008) suggested rotation with sorghum (*Sorghum bicolor* L.) because this species was allelopathic. This phytotoxicity is associated with a group of lipid benzoquinones called sorgoleone that exude from the root hairs of sorghum. Sorgoleone is released directly in the soil and acts like a pre-plant incorporated herbicide. Therefore, the allelopathic effect of sorgoleone strong on young developing plants, which might take up sufficient amount of sorgoleone.

Meschede (2007) evaluated seven treatments consisting of the following soil crop covers: Millet ADR 500 (*Penisetum americanum* L.), Millet ADR 300, Sorghum (*Sorghum bicolor* L.), Maize (*Zea mays* L.), Crotalaria (*Crotalaria* *juncea* L.), Castorbean plant (*Ricinus communis* L.) and spontaneous vegetation. Sorghum yielded the highest dry matter weight (11.890 kg ha^{-1}); sorghum, millet and crotalaria showed a better ability to suppress weeds. The spontaneous vegetation presented the lowest biomass values. Maize and Castorbean presented a lower crop cover potential.

Brassicaceae cover crops suppressed weeds due to fast emergence and vigorous competitive growth during fall establishment and allelopathic substances released during degradation of the cover crop residues (Boydston, 2008). Early season weed emergence was often suppressed following fall-planted *S. alba* or *B. napus* cover crops. The mechanisms of weed suppression with Brassicaceae cover crops were not completely understood, but breakdown products of glucosinolates, such as isothiocyanates and ionic thiocyanate are believed to contribute to weed suppression.

Luxurious use of chemical fertilizers, synthetic herbicides and pesticides in agriculture may cause environmental degradation in the near future (Chung *et al.*, 1997) Extreme use of weedicide may also cause a problem of weedicide resistant weed species in rice fields. Due to the water shortage and overcome the direct seeding of rice is encouraging and spreading throughout the Asia, while these are key limiting factors for transplanted rice. In direct seeded rice, weeds are a major problem as rice and weeds emerge together, at early stage of each crops are very sensitive to weeds, toxic metal contamination from herbicide in soils as well as water (Xuan *et al.*, 2005a) which is threat for sustainable agriculture.

Several categories of chemical compounds have already been reported as an allelochemicals and there is a several allelochemicals remain identified especially from wild cultivars of rice (Einhelling, 1996). By extraction and modifying these chemicals then, the final product could be more active, selective and these can be use as pre or post emergence weedicide. eg. alkaloids benzoxazinones, cinnamic acid derivatives, cyanogenetic compounds, ethylene, some weed seed germination stimulates and flavonoids these six classes of allelochemicals already have isolated from different thirty families of terrestrial and aquatic plants those possess actual or potential phytotoxicity.

2.2 Allelopathic potential of crop residue

Proper and judicial management of rice residue may be one of the readily applicable uses for weed management (Lovett, 1990). Rice straw produces a number of humic acids during their decay, which exhibit inhibitory effect on weeds (Jung *et al.,* 2006) because during decomposition of rice residue, it inhibit or stimulate some selective weed's growth through this acids and by extending this inhibitory period of decaying residues, weeds may be controlled more effectively e.g. 70% weed biomass can be reduced together with 20% high yield through incorporation of the allelopathic plant material (1-2 tones ha^{-1}) in rice field (Xuan *et al.,* 2005b). On the other hand rice flour and husk are potential components in organic farming for weed management those are traditionally using by Korean farmers.

Biswas *et al.* (2008) reported that wheat crop was frequently affected by weeds that cause about 20 to 30% yield reduction. A two year research project was initiated at Agronomy department, Sher-e-Bangla Agricultural University, Bangladesh to study the allelopathic effects of *Brassica spp.* to control weeds in wheat. *Brassica* crops were uprooted at initiation of flowering and applied in the same field. *Amaranthus spinosus, Amaranthus viridis, Heliotropium indicum, Polygonum hydropiper, Celosis argentina, Ageratum conyzoides, Brassica kaber and Digitaria ischaemum* were not found to the wheat field. The highest weed dry matter yields was recorded in *Brassica juncea* plots (1.72 g m^{-2}) at 30 DAS and in *Brassica napus* field (1.44 g m^{-2}) at 50 DAS. The lowest weed dry matter (0.89 g m^{-2}) was recorded when total *Brassica* biomass was incorporated into the soil in 30 DAS and 50% incorporation plus 50% spreading in 50 DAS. Weed population densities were not affected by *Brassica* species in 30 and 50 DAS and by the incorporation methods 50 DAS, although the lowest weed population (15.33 m^{-2}) was recorded in spreading between lines that were similar to complete incorporation and 50% spreading plus 50% incorporation in 30 DAS. Interaction of *Brassica* species and incorporation methods showed lowest weed dry matter (0.74 g m^{-2}) in 30 DAS with *Brassica napus* biomass incorporated into the soil.

Chou (1983) found rice seedlings growing poorly in the decomposed straw and soil mixture. He found dark brown roots with abnormal and enlarged cells in the retarded plants. Furthermore, he observed an increase in phytotoxicity with increased straw level, and the toxicity of aqueous extracts of decomposing rice residue was still persistent after 16 weeks of decomposition. He also extracted the rice straw and soil mixture with ethanol, purified, and identified the phytotoxic compounds to be p-hydroxybenzoic, syringic, vanillic, ferulic, acetic, o-hydroxyphenylacetic, propionic, and butryric acids.

Khan *et al.* (2001) observed that residues from mature harvested crops of sorghum (*Sorghum bicolor*),wheat (*Triticum aestivum*) and rice (*Oryza sativa*) had phytotoxic effects on germination and dry matter production of *Physalis minima*. The most common effects of allelochemicals may occur through leaching, volatilization, root exudation, and the death and decay of the fallen plant parts are either via biotic or abiotic means.

Khan *et al.* (2005) investigated the allelopathic potential of aqueous extracts of leaves of *Prosopis juliflora* and *Eucalyptus camaldulensis* and bark of *Acacia nilotica*. The results showed that the germination percentage, seedling length (mm) and biomass yield (mg) plant^{-1} of *Ipomoea* sp., *Asphodelus tenuifolius*, *Brassica campestris* and *Triticum aestivum* were significantly affected by tree extracts as compared to control. Eucalyptus and Acacia had stimulatory effect on germination percentage of *A. tenuifolius*, while *P. juliflora* and *E. camaldulensis* had inhibitory effect on *B. campestris*. All extracts had inhibitory effects on seedling length of *T. aestivum* and *B. campestris*. Treatment means indicated that *P. juliflora* and *E. camaldulensis* are more allelopathic than Acacia. Effect of Acacia on the test species was statistically comparable with control, exhibiting its non-inhibitory role in the test species. Species means indicated that *Ipomoea* sp. and *T. aestivum* were less negatively affected than *B. campestris* and *A. tenuifolius*.

Jones *et al.* (1998) reported that some crop residues were known to have a chemical (allelopathic) as well as physical effect on the growth of subsequent crops and weeds consisted of plots planted to barley, canola, chickpea, fieldpea, mungbean, sorghum and a fallowed control. Four target weed species were planted following these crops. Barley was found to be the most inhibitory (64% and 47% of the fallow treatment for incorporated residue and surface residue treatments respectively). Fieldpea was found to have a significant stimulatory effect on overall weed dry matter production (127%), on incorporated plots, yet did not affect the survival rate of target weeds.

Allelochemicals could be leached from rye shoot residue and used as a control to separate the physical effects of weed suppression of surface rye mulch from other types of interference. Leached rye inhibited emergence of eastern black nightshade (*Solanum ptycanthum* Dun.) by 98% (Creamer *et. al.*, 1996).

Daar (1986) said that rye residue contained generous amounts of allelopathic chemicals. When rye is killed in place and left undisturbed on the soil surface, these chemicals leach out and prevent germination of small-seeded weeds. Weed suppression is effective for about 30–60 days.

Merise and Singh (1987) examined the allelopathic effect of dried lantana shoot residues on wheat, corn, soybean, Virginia pepperweed and velvetleaf on growth over a 30-day period. Significant differences in the growth of the test species were observed. Corn was the most sensitive and wheat was least affected by lantana residues. The other three species were intermediate in their growth response to lantana. Shoot lengths were affected in corn and velvetleaf while root length was reduced in all species except wheat. The shoot dry weights of wheat and soybean were not reduced by lantana residues. In the other three species there was a significant reduction of shoot dry weight due to lantana.

Teasdale and Mohler (1993) reported rye cover crop residue to be effective at reducing light transmittance (quality and quantity) and soil temperature which in turn reduced or delayed germination and emergence of certain weed species.

Extracts of lentil (*Lens culinaris* Medic), oat (*Avena sativa* L.), canola (*Brassica napus* L.), and barley (*Hordeum vulgare* L.) were more toxic to flixweed (*Descurainia sophia* L. Webb), stinkweed (*Thlaspi arvense* L.), and downy brome (*Bromus tectorum* L.) than extract of canola was to wheat (Moyer and Huan, 1996). The greater toxicity of these crop residues to flixweed, stinkweed and downy brome than to wheat might permit selective management of these weeds in wheat. Flixweed, stinkweed and downy brome are major winter annual weeds in winter wheat and usually required late fall or early spring herbicide treatments in no-tillage systems. Therefore, residues of canola, lentil, oat and barley had potential for reducing herbicide use in winter wheat production and in no-tillage direct seeding farming systems. Crop extracts were not toxic enough to affect the growth in the field of seven other weeds.

Aqueous leaf leachates of *Prosopis cineraria. P juliflora* reduced germination of *Parthenium hysterophorus* seeds from 68% to 22% whereas aqueous extracts of leaves of both *Prosopis* species reduced the germination of *Parthenium hysterophorus* seeds to 7.35 - 8.82%. The vigour index of the seedling treated with *Prosopis* species was also reduced (Dhawan, 1995).

Guenzi *et al.* (1967) reported that wheat, oat, corn and sorghum residues collected at the time of harvest were toxic to growth of wheat seedlings. The order of increasing toxicity was wheat, oat, corn and sorghum residues.

Bezidenhout and Reinhardt (1999) observed that the aqueous extract form tubers or leaves of either immamature or mature *Cyperus esculentus* plants inhibited germination of lettuce at 2 per cent concentration irrespective of growth stage. At 5 per cent however, leaf extract from immamature weed plants was most inhibitory.

Yamamata *et al.* (1999) found that the root exudates of young barnyard grass showed allelopathic effects activity and inhibited root elongation of rice and did not show the inhibition of shoot growth. The allelopathic substance p-hydroxyl madelic acid was identified.

An evaluation was conducted by Uremis *et al.* (2009) on the allelopathic potential of residues of some brassica species, which were round white radish (*Raphanus sativus* L.), garden radish (*R. sativus* L.), black radish (*R. sativus* L. var. *niger*), little radish (*R. sativus* L. var. *radicula*), turnip (*Brassica campestris* L. subsp. *rapa*) and rapeseed (*Brassica napus* L. *oleifera* DC.) on johnsongrass under both laboratory and field conditions. All species suppressed johnsongrass in field and laboratory conditions. The lowest suppression was from garden radish, which had already been used to control johnsongrass by few farmers in Turkey. It was concluded that the plants studied could be used to control johnsongrass. Higher amount of isothiocyanates (isothiocyanate benzyl, Isothiocyanate allyl) in black radish extract and lower amount of isothiocyanates at garden radish extract were determined. Parallel results for johnsongrass suppression and amount of isothiocyanates showed that allelopathy play roles in johnsongrass suppression by brassica species.

Turk and Tawaha (2002) reported that Black mustard (*Brassica nigra*) contains water-soluble substances that inhibited the germination and seedling growth of wild oat (*Avena fatua*). Aqueous extracts of *B. nigra* leaf, stem, flower and root plant part strongly reduce the germination and dry weights of hypocotyl and radicle length of 8 day old *A. fatua*. *A. fatua* germination, seedling length and weight was significantly inhibited by increasing aqueous extract concentrations of separated *B. nigra* L., plant parts. Radicle length was more sensitive to extract source than seed germination or hypocotyl length. Based on 8 day old *A. fatua* L. plant radicle length growth, averaged across all extract concentrations, the degree of toxicity of different plant parts can be classified in order of decreasing inhibition as follows: leaf, mixture of all plant parts, flower, stem and root. Soil incorporation of fresh B. nigra roots only or both roots and shoots reduced *A. fatua* emergence, plant height, and dry weight per plant.

Bioassay studies of aqueous extract of inflorescence, stems and leaves of *Parthenium hysterophorus* on germination and seedling establishment of *Cassia occidentalis* showed that all concentration from plant parts had inhibitory effect on seed germination and seedling growth. Leaf extract appeared to be more potent compare to extracts from stems and inflorescence (Rahman and Acharia.1998).

Natural compounds released from leaves, roots and other parts of weeds and crops inhibit the growth of nearby weeds and plants. The perennial weeds like Bermuda grass (*Cynodon dactylon*) can be controlled by *Euphorbia prostrata.* Similarly, *Polygonum ariculare* is also known to have phytotoxic effect on cynodon and purple nutsedge .The most troublesome weed worlds wide can be controlled by pigeonpea. Dodder (*Cuscuta spp*) a parasitic weed that attacks many legumes including alfalfa can be controlled by cynodon weed extract (Hiremath and Hunshal, 1998). Experiment was conducted to determine the allelopathic potential of rice body parts on seed germination and growth of barnyard grass (*E. crusgalli*). Results indicated that highest inhibition rate 76.9% in straw extract, 74.5% in leaves and 31.7% in hull extract (Chung *et al.*, 2003).

Narwal and Sharmha (1995) reported that the aqueous extract of wheat straw stimulated the germination of carpet weed (*Trianthema portulacastrum)*, barnyard grass (*Echinocloa crusgalli*) and crow foot grass (*Dactyloctenium *aegyptium*) and slightly inhibited that of pig weed (*Amaranthus spp.*) and sunberry (*Physalis minima*)

Peterson *et al.* (1999) evaluated the sweet potato germplasm for allelopathic effect and reported that suppression of yellow nutsedge and prosomillet seed germination. Vegetation distribution around eucalyptus tree is attributed to its allelopathic effect (Alves *et al.*, 1999).

James *et al.* (1982) evaluated allelopathic potential of wheat straw residues on weedseed germination and seedling growth. The extract prepared by agitating and soaking caused greater inhibition than those obtained by leaching. The descending order of species susceptibility was ivy leaf morningglory (*Ipomoea hederacea*), velvet leaf (*abutilon theophrasti*), pitted moorningglory (*Ipomoea lacunosa*), hemp sesbenia (*Sesbenia exaltata*), sickle pod (*Cassia obtusifolia*) and Japanese barnyard millet (*Echinocloa crusgalli*).

Gupta (2000) studied the root extract of *Parthenium hysterophorus* from four phonological phases (juvenile, rosette, vegetative and maturity) on three test crops (Cluster bean, Amaranthus and Lady finger) in a Petriplate bioassay. Results indicated that all aqueous extracts inhibited the germination and dry matter accumulation in seedlings in the order Cluster bean > Amaranthus >Ladies finger. He opined that the variation in the effect at different stages of donor plant affects recipient plant through allelopathy might be due to changes in plant composition and allelochmicals at given stage.

The potential uses of crop residues were explored by Barker and Bhowmik (2001) who reported that crop residues have many potential uses in cropping systems, among which are imparting weed control. In one experiment, residues were imported to the vegetable plots and applied as surface mulches or incorporated shallowly into the ground. In another experiment, the residues were grown on site as cover crops in the year preceding vegetable production and disked into the plots. Application of imported residues was more effective in weed control and yield enhancement than the cover crop residues. Imported residues were effective in control of early emerging weeds, whereas with the cover crops supplemental weed management was required for early weed control. Weed control did not differ substantially with species of residue, but control increased as amount of incorporated residues increased from 6 to 24 Mg/ha. Weed control with residue incorporation at 6 Mg/ha was as effective as a mulch of 24 Mg/ha. If weed control was imparted by the residues, crop yields with any residue treatment were equivalent to those from plots kept relatively weed-free by tillage. Yields did not vary with amounts of residues applied.

2.3 Allelopathic potential of concentration of materials

Jayakumar (1995) studied allelopathic effects of *Cassia serecia* on *Parthenium* and reported that aqueous extracts of different plant organs of *Cassia sericea* viz, root, stem, pod wall and leaf inhibited seed germination and seedling vigour of *Parthenium*.Inhibition was statistically significant over control at higher concentration of aqueous extract (undiluted 1:10) than at lower concentration.

Adkins and Sowerby (1996) observed that aqueous leachates of *Parthenium* weed leaves on the germination and seedling growth of five test species. Germination of climbing buckwheat (*Polygonum convolvulus*), liver seed grass (*Urochloa pannicoides*), buffel grass (*Cenchurus ciliaris*) and *Parthenium* weed were significantly ($P< 0.05$) depressed (92,95,98 and 80 per cent respectively) at highest leachates concentration used (250 mg fresh leaf material / ml). While, lowest concentration (50 mg fresh leaf material / ml) significantly ($P< 0.05$) depressed climbing buckwheat, liver seed grass and buffel grass (80, 80 and 87 per cent respectively) but not *Parthenium* weed.

Khan *et al.* (2008) noted that aqueous extracts of Eucalyptus (*Eucalyptus camaldulensis L.)* at a concentration of 10, 15 and 20% had inhibitory effect on wheat germination and effect was found significantly higher than control treatment. Fresh and dry weight of seedling was also reduced significantly over control. The inhibitory effects were increased as the extract concentration increased. These findings indicated that wheat sown in fields which had leaf litter of *E. camaldulensis* L. adversely affected regarding germination, growth and ultimately resulting in lower yields of wheat.

Tripathi and Viashya (1997) observed that the aqueous extracts (0, 10, 20, 30 and 40 per cent) of weeds (*Pluchea lanceolata, Imperata cylindrica* and *Parthenium hysterophorus*) on test weed species (*Phylaris minor* and *Echinochloa colonum*) in Petriplate bioassays. The 40% extracts of *Pluchea lanceolata* and *Imperata cylindrica* reduced germination of *Phylaris minor* by 30 and 35 % respectively. While, 30 % extract *Parthenium hysterophorus* completely inhibited (100.0%) germination of *Phylaris minor*. On the other hand 10 % extracts of *Pluchea lanceolata* and *Imperata cylindrica* caused 40 % inhibition in *Echinochloa colonum.* The extracts of *Parthenium* proved most inhibitory and caused complete inhibition at 40% concentration.

Phawa *et al.* (2000) reported that the allelopathic effects of *Parthenium hysterophorus* on *Cyperus rotundus* and three species of *Echinochloa* i.e. *Echinochloa colonum, E. crusgalli, E. glaberscence. Parthenium hysterophorus* extracts at 5, 10 and 15% (w/v) as preemergence and post emergence at 30 days after sowing and even soil drenching with 15, 30 and 45 % solution of Parthenium extract did not cause any allelopathic effects on the growth of any of weeds.

Ashrafi *et al.* (2007) reported that Barley [*Hordeum vulgare* (L.) Koch.] contained water soluble allelochemicals that inhibited the germination and growth of other species. Growth of Wild Barley, as indicated by plant height and weight, was significantly reduced when grown in soil previously cropped to Barley compared with that cropped to Wild Barley. In bioassays, Barley extracts reduced Wild Barley hypocotyl length, hypocotyl weight, radicle weight, seed germination, and radicle length by as much as 44, 57, 61, 68 and 79 %, respectively, when compared with water control. Increasing the water extract concentrations from 4 to 20 g per 100 ml of water of all Barley parts significantly increased the inhibition of Wild Barley germination, seedling length and weight. Based on 8-day-old wild barley radicle length, averaged across all extract concentrations, the degree of toxicity of different Barley plant parts can be ranked in the following order of inhibition: leaves > flowers > mixture of all plant parts > stems > roots.

Cheema *et al.* (2003 a) revealed that atrazine (150 g a.i. ha^{-1}) in combination with sorgaab (12 L ha^{-1}) gave 39% maize grain yield increase over control while atrazine alone (300 g a.i. ha^{-1}) gave 41% higher yield than control in maize.

Cheema *et al.* (2003 b) tested the response of wheat and its weeds to foliar application of sorghum (*Sorghum bicolor*), sunflower (*Helianthus annuus*) and eucalyptus (*Eucalyptus camaldulensis*) water extracts individually and in combinations with each other at different doses under field conditions. Concentrated sunflower water extract @ 12 L ha-1 sprayed at 30 and 40 days after sowing gave consistently better weed control and increased wheat yield by 5.5% over control. A combination of water extracts of sorghum, sunflower and eucalyptus each @ 12 L ha^{-1} and 8 L ha^{-1} were also economical. However, conventional methods like hand weeding and herbicides, though effective in weed control, were uneconomical due to higher costs.

Sinha and Singh (2004) revealed that germination inhibition and growth of *Parthenium hysterophorus* was found restricted by 25 % leaf extract of *Xanthium stromanium.* A significant reduction was also recorded in root/shoot length, seedling vigour and vigour index of Parthenium by leaf extract treatment of *Xanthium stromanium*. The aqueous extracts from fresh and dry leaves of *Lantana camera* inhibited the growth of water hyacinth and killed the plant within six days because of salicylic acid which is major allelochmicals in lantana (Zhung *et al.*, 2005).

Smith *et al.* (1999) reported that Canola extract at 0.1% concentration stimulated redroot pigweed shoot growth compared to water. Germination of redroot pigweed was only inhibited by lentil extracts at 1 and 2%. Root growth was reduced by all extracts at 1 and 2% compared to water but was only reduced by lentil extract at 0.1%. Shoot growth was only reduced compared to water by lentil extract at 2% .Green foxtail germination was not suppressed by any of the extracts. Root growth was suppressed by lentil, canola, and oat extracts at 0.1 %. At 1 % and 2% all extracts suppressed root growth. Shoot growth was not affected by any plant extracts at 0.1% and was only suppressed by lentil extract at 1%. Lentil, canola, and barley extracts at 2% suppressed green foxtail shoot growth.

Xuan and Tsuzuki (2001) reported that Alfalfa (*Medicago sativa* L.) contained allelopathic chemicals that inhibit the growth of weeds. The results indicated that alfalfa pellet significantly inhibited germination and growth of 4 weed species, viz., *Echinochloa orygicola, Digitaria ciliaris, Cyperus difformis and Monocholia vaginalis* in rice paddies. Among the 4 tested weeds, the maximum inhibitory effect of alfalfa pellet was seen against *Cyperus difformis*. The degree of inhibition of weed growth by alfalfa pellet became stronger as the application of concentration increased.

In vivo studies were conducted to asses the allelopathic effects of *eucalyptus* leaf, bark and root extracts at different concentrations (1.0 to 10.0 per cent) on germination and seedling growth of cucumber. Germination and seedling growth were severely hampered by leaf extract than bark and root. Whereas increase in concentration from 1 to 10 per cent there was decrease in germination percentage and seedling growth (Alloli and Narayanreddy, 2000).

Moyer and Huan (1993) conducted an experiment to observe the effect of crop residue on germination and growth of weeds. In this experiment they used the aquas extract of six different crop residue which were Canola (*Brassica napus* L.), Rye (*Secale cereale* L.), Barley (*Hordeum vulgare* L.), Oats (Avena sativa

L.), Indian Head lentil (*Lens culinaris* Medic), and Wheat (*Triticum aestivum* L.). They noticed that crop extract also reduce germination and growth of other crops. Wheat germination was reduced by lentil, oat, and canola extracts at 4%. Wheat root growth was suppressed by all plant extracts except wheat at 1 %. None of the extracts inhibited shoot growth at 1 %. At 2% extracts of lentil, oat, and canola inhibited wheat shoot growth, and at 4% all plant extracts inhibited shoot growth.

Basotra *et al.* (2005) tested an aqueous leaf and root/tuber extracts of three important medicinal plant species (e.g., *Bergenia ciliata, Hedychium spicatum* and *Potentilla fulgens*) for their allelopathic effects on germination, radicle and plumule elongation of *Amaranthus caudatus, Eleusine coracana, Fagopyrum esculantum, Phaseolus mungoo, Phaseolus vulgaris* and *Triticum aestivum*. The results revealed that the allelopathic effects increased with increasing concentration of leachats from 2%, 5% to 10%. The susceptible crops were *Amaranthus caudatus* and *Phaseolus mungoo* whose germination, radicle and plumule growth were reduced significantly under aqueous extracts of all three medicinal species.

Dongre *et al*. (2004) studied two black gram varieties that were treated with different concentration of aqueous leaf leachates of eight dominant weeds (*Ageratum conyzoides, Anagelis arvensis, Eclipta alba, Lippia nodiflora, Parthenium hysterophorus, Phylanthus niruri, Pluchea lanceolata* and *Polygonumm plebejum)* to asses their allelopathic effects on seed germination. Leachates of all weed species inhibited both seed germination and seedling growth of both test varieties at 10 per cent concentration. Increase in concentration of leachates was invariably associated with decrease in germination of test cultivars irrespective of weed species.

Norsworthy (2003) evaluated the allelopathic potential of wild radish in controlled environments. Germination and radical growth of all species were reduced by the extract compared with distilled water. However, topical applications of the aqueous extract failed to induce injury on any species by 7 d after treatment. Emergence and shoot fresh weight of the bioassay plants were reduced by wild radish residue incorporated into soil, with the level of suppression dependent on the quantity of residue incorporated. Sickle pod and prickly sida were extremely sensitive to incorporated wild radish residues, with > 95% fresh weight reduction at 0.5% (wt/wt) residue, compared with an untreated control. Conversely, yellow nutsedge showed a high degree of tolerance in all trials. Of the crops evaluated, cotton emergence and growth were most sensitive to incorporated wild radish residues.

An experiment was conducted by Iqbal and Cheema (2008) where crop water extracts (sorghum, sunflower and brassica) @ 12 and 15 L ha^{-1} in different combinations were tank mixed with reduced rates of glyphosate at 67% (767 g a.e. ha^{-1}) of label rate (2.3 kg a.e. ha^{-1}) and sprayed as directed post emergence at 40 days after sowing (DAS). It was observed that purple nutsedge density was decreased by 59-99% and dry weight by 66-99% as compared to control. The high rate of crop water extracts (15 L ha^{-1}) significantly reduced the growth of purple nutsedge more than the lower rates (12 L ha^{-1}). Seed cotton yield in these treatments was comparable to herbicide applied at recommended rates.

Green house experiments were conducted to study the effect of yellow nutsedge (*Cyperus rotundus*) plant residues on the growth of corn and soybean. At equal concentration tuber residues reduced the dry weight of corn and soybeans more than foliage residues. As the concentration increased growth decreased, and the effect was more in corn (Drost and Doll, 1980).

Javaid *et al.* (2006) evaluated herbicidal effects of aqueous root and shoot extracts of three allelopathic crops, viz. sunflower (*Helianthus annuus* L.), sorghum (*Sorghum bicolor* L.) and rice (*Oryza sativa* L.) against germination and growth of the noxious alien weed *Parthenium hysterophorus* L. The study indicated insignificant effects on shoot length and seedling biomass while germination and root length were significantly reduced by extracts of all the test crops. In a foliar spray bioassay, aqueous shoot extracts of 50 and 100% w/v (on a fresh weight basis) of sunflower and sorghum were applied to 10 day old *Parthenium* plants. The root biomass of *Parthenium* plants was significantly suppressed by 50 and 100% extracts of both the test allelopathic extracts. Both concentrations of sorghum extracts significantly reduced shoot biomass, but sunflower extract was effective only at the lower concentration.

Experiments were conducted to investigate allelopathic effect of 1 to 10 per cent aqueous leaf extract on germination and seedling growth in sunflower and sorghum. Results indicated that the germination of both species decreased with increase in extract concentration and with 10 per cent extract concentration the germination was 35 and 20 per cent in sunflower and sorghum respectively. Shoot and root length and dry weight were also decreased by increasing concentration (Murthy *et al*., 1995).

Rippin *et al.*, (1994) incorporated plant residues of *Erythrina poeppigiana* trees (10 t/ha dry matter) at 6 by 3 m reduced weed biomass by 52%, while *Gliricidia sepium* trees (12 t/ha dry matter) planted at 6 by 0.5 m reduced weed biomass by 28%, in comparison to controls. *Erythrina* had a considerable impact on grass weeds, while *Gliricidia* reduced the incidence of some dicot weeds. Weed competition significantly reduced maize yield in all systems. Nevertheless weed suppression contributed to the higher maize grain yield under *Erythrina* and *Gliricidia* alley cropping of 3.8 t per hectare as opposed to the unmulched control yield of 2.0 t per hectare.

Mahmood *et al.* (2008a) explored possibilities of reducing herbicide dose in combination with different allelopathic plant water extracts for weed management in maize by applying Atrazine (Atrazine 38SC) at 0.167 kg a.i. ha^{-1} was tank mixed with 18 L ha^{-1} water extracts each of sorghum + brassica + mulberry, sorghum + brassica + sunflower, sorghum + sunflower + rice, sorghum + sunflower + maize and sorghum + maize + rice as early post-emergence, i.e., 15 days after sowing (DAS). Weed species present in the experimental area were *Trianthema portulacastrum, Cyprus rotundus, Dactyloctenium aegyptium, Cynodon dactylon* and *Cleome viscosa.* Combination of sorghum + sunflower + brassica each at 18 L ha^{-1} and 1/3 dose of atrazine (0.167 kg ha^{-1}) reduced total weed dry weight by 86 to 75% at 45 DAS respectively. Maize yield increased by 48 to 51 % by the combination treatment of sorghum + sunflower + brassica water extracts each at 18 L ha^{-1} and with 1/3 dose of atrazine (0.167 kg ha^{-1}) as early post emergence (15 DAS) over the control, respectively, and yields were equal to the yields obtained from the recommended rate of S-metolachlor + atrazine and atrazine alone.

Rehman *et al.* (2008) investigated the effect of plant population (0.20, 0.25 and 0.30 million plants ha^{-1}) against sorghum, sunflower and rice water extracts each at 15 and 18 L ha^{-1} (20, 40 and 60 DAT) and a post-emergence herbicide Nominee (bispyribac-sodium 100 SC) at 21 g a.i. ha^{-1} 20 days after transplanting (DAT), on weeds in rice. On an average, 45 and 52% reduction in total weed dry weight during three years of experimentation was recorded at 75 DAT. Foliar spray of allelopathic extract mixtures at 15 and 18 L significantly suppressed (46 to 61%) total weed dry matter production.

Chapter 3

Materials and Methods

MATERIALS AND METHODS

This chapter presents a brief description of the experimental site, soil, climate, experimental design, treatments, cultural operations, collection and preparation of soil samples and analysis of different parameters for both BRRI dhan29 and BRRI hybrid dhan2 under the following headings-

3.1 Location

The experiment was carried out during *boro* season (November to May) of 2009–2010, at central farm of Sher-e-Bangla Agricultural University, Dhaka-1207. The experimental field was located at $90^{0}22'$ E longitude and $23^{0}41'$ N latitude at an altitude of 8.6 meters above the sea level. The experimental site was located under the agro-ecological region of "Madhupur Tract" (AEZ No. 28). For better understanding, the experimental site is shown in the map of AEZ of Bangladesh in Appendix I.

3.2 Climate

The experimental area falls under the sub-tropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in *kharif* season (April-September) and less rainfall associated with moderately low temperature during the *rabi* season (October-March).

3.3 Soil

The farm belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. The land was above flood level and sufficient sunshine was available during the experimental period.

3.4 Crop/planting material

3.4.1 Description of rice variety BRRI dhan29

BRRI dhan29 is a high yielding rice variety released for commercial cultivation in 1994. It is the most popular variety for *Boro* season and it gives the highest yield. It has a hard stem which prevents lodging. It's height is 95 cm and longevity is 160 days. It's milled rice is medium slender and white in colour. It is intermediately resistant to leaf blight and sheath blight disease. Many farmers of our country say that BRRI dhan29 is the hybrid variety of Bangladesh for it's highest yield. The average yield of this variety is 7.5 t ha^{-1}.

3.4.2 Description of rice variety BRRI hybrid dhan2

BRRI hybrid dhan2 is a high yielding hybrid variety released by national seed board in 2008. The suitable locations for cultivating this variety are Dhaka, Comilla, Jessore and Rajshahi district of Bangladesh. It's cultivated in Boro season and it's longevity is 145 days. It's stem and leaves are dark green in color and erect. It's height is 105 cm. The milled rice of this variety is medium slender and cooked rice is non-sticky and it contains 9% protein and 23.30% amylase.

3.5 Allelopathic materials

3.5.1 Description of water hyacinth

Water hyacinth (*Eichhornia crassipes*) are free-floating perennial aquatic plant native to tropical and sub-tropical South America. With broad, thick, glossy, ovate leaves they grow in our country as an aquatic weed. They have long, spongy and bulbous stalks. Water hyacinth contains only 4.50% dry matter of which 75.80% organic matter, 1.5% nitrogen and 24.20% ash those enhances plant growth (Gohl, 1981). In our country most of the produced water hyacinth remain unused. Fresh water hyacinth was used in the present experiment.

3.5.2 Description of rice straw

The stems of rice plant left after collecting rice grains are rice straw. Rice straw has been studied more intensively with positive results in controlling weed (Ramalan and Nwokeocha 2000; Tiwari *et al.*, 1998). Also with this material, crop yield is found to be higher than bare soil. Considering that rice straw is an abundant residue in Bangladesh with little use, it was considered interesting to include it in the present study. Moreover, rice straw is known to have allelopathic properties, which can contribute to weed suppression (Chung *et al.*, 2001; Inderjit *et al.*, 2004). Straw of BRRI dhan30 was chopped and incorporated into the plots for the present experiment.

3.6 Experimental treatments

There were three sets of treatments in the experiment. The treatments were variety, allelopathic materials and concentration of allelopathic materials. They are shown below:

Main plot (Variety) - 2

V_1 - BRRI dhan29
V_2 - BRRI hybrid dhan2

Sub plot (Allelopathic material) - 2

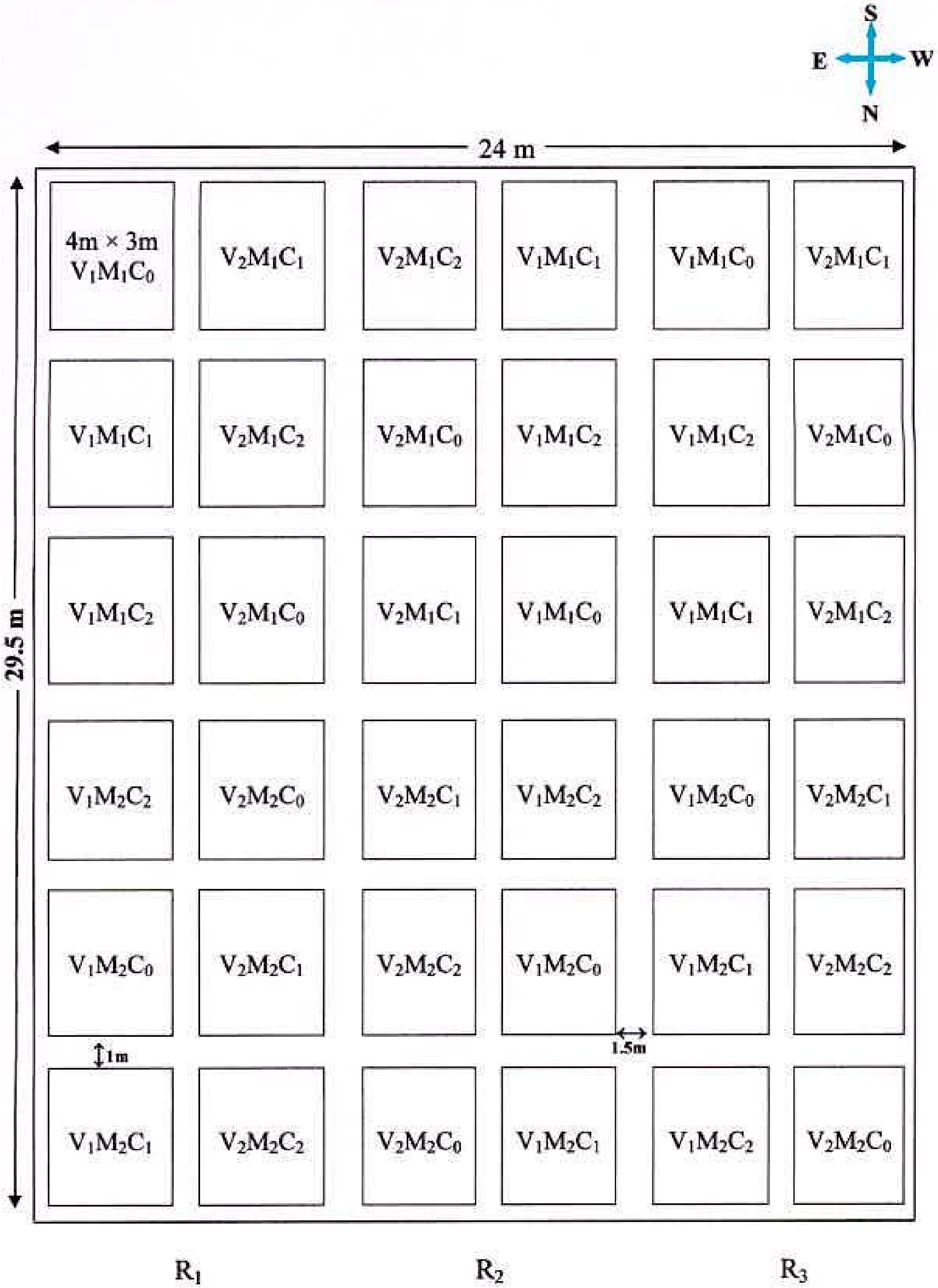
M_1 - Rice straw
M_2 - Water hyacinth

Sub Sub-plot (concentration) – 3

C_0 - control (No allelopathic material)
C_1 - 0.50 kg biomass m^{-2}
C_2 - 1.00 kg biomass m^{-2}

3.7 Layout of the experiment

The experiment was laid out in split split-plot design with three replications. The experimental unit was divided into three blocks each of which representing a replication. Each block was divided into two main plots (BRRI dhan29 was transplanted in one and BRRI hybrid dhan2 was transplanted in another). Each main plot was further divided into two sub-plots for incorporating allelopathic materials (rice straw biomass in one and water hyacinth biomass in another). Then both of the two sub-plots were further divided into three sub sub-plots for incorporating biomass of allelopathic materials with 3 different concentrations. So, the total number of unit plots in the entire experiment was $3 \times 2 \times 2 \times 3 = 36$. Size of each unit plot was 4m × 3m = 12 m^2. A distance of 1 m, 1 m and 1.5 m was maintained in between subplots, main plots and replications respectively for proper management (Figure 1).



Main Plot:
Variety
V_1: BRRI dhan29
V_2: BRRI hybrid dhan2

Sub Plot:
Allelopathic material
M_1: Rice straw
M_2: Water hyacinth

Sub sub-plot:
Concentration:
C_0: 0 kg biomass m^{-2} (control)
C_1: 0.5 kg biomass m^{-2}
C_2: 1.0 kg biomass m^{-2}

Figure 1. Layout of the experimental plot of rice field

3.8 Details of the field operations

The particulars of the cultural operations carried out during the experiment are presented below:

3.8.1 Preparation of land

The experimental field was first ploughed on December 25, 2009 with the help of a power tiller and prepared by three successive ploughings and cross-ploughings. Each ploughing was followed by laddering to have a desirable fine tilth. All kinds of weeds and residues of previous crop were removed from the field. Then the field was puddled properly. Final land preparation was done on January 17, 2010 incorporating biomass of rice straw and water hyacinth following experimental design.

3.8.2 Manure and Fertilizer application

Cowdung was applied @10 t ha^{-1}. Other chemical fertilizers were applied @ 120, 40, 45, 10 and 5 kg ha^{-1} urea, triple super phosphate (TSP), muriate of potash (MP), gypsum and Zinc Sulphate respectively. Cowdung was applied 15 days before transplanting and all the fertilizers were applied as basal dose during final land preparation except urea that top dressed in 3 equal splits at the stages of seedling recovery (7 days after transplanting), maximum tillering and before panicle initiation.

3.8.3 Raising and Transplanting of Seedling

Seeds of the two rice varieties were collected from Bangladesh Rice Research Institute. Seeds were raised in wet seed bed in another nearby field. The seeds required 24 hours soaking in water and extra 48 hours covered with sack to raise internal temperature for enhancing sprouting. Seeds were sown in the seed bed on December 15, 2009. On January 22, 2010 the seedling were uprooted carefully and transplanted to the main field keeping a space of 25 cm between two rows and 15 cm between two hills. Two seedlings were transplanted in a hill.

3.8.4 Weeding

Two hand weedings at 30 and 50 days after transplanting (DAT) were practiced.

3.8.5 Irrigation and drainage

Initially 7-10 cm water was maintained up to tillering. After maximum tillering higher water level (12-15cm) was kept to suppress late tiller formation. Proper drainage system was maintained to remove the excess amount of water from the plot.

3.8.6 Diseases and pests management

In the whole experiment there was not mentionable infestation of diseases and pests. There was a slight infestation of rice stem borer which was successfully controlled by two times application of Diazinone 60 EC. During the ripening period special attentions were undertaken to protect the crop from the attack of pigeons and other birds.

3.8.7 Harvesting and sampling

The variety BRRI hybrid dhan2 and BRRI dhan29 was harvested at maturity on April 30, 2010 and May 21, 2010 respectively. Samples were collected from the central six rows of each plot leaving another six rows of two boundaries. The selected sample plants were then tagged and carefully carried out to the threshing floor of Agronomy field laboratory in order to collect data. Crop of the rest six rows was harvested separately plot-wise, bundled and tagged. The crop bundles were threshed on the threshing floor. The grains and straw were separated and dried for constant moisture and the weight was recorded in t ha^{-1}.

3.9 Recording of data

The following data were collected during the study period:

3.9.1 Data regarding weed

1. Weed population (m^{-2})
2. Dry weight of weed biomass (m^{-2})

3.9.1.1 Weed population

From the 1 m^2 area of each plot, the total weeds were uprooted and the species were identified and counted at 30 DAT and 50 DAT.

3.9.1.2 Dry weight of weed

The fresh weeds were counted and oven dried at 80^0C until a constant weight was obtained. The samples were then transferred into desiccators and allowed to cool down to the room temperature and then final weight of the samples was taken.

3.9.2 Data regarding different crop characters and yield of rice

1. Dry weight of plants (g $hill^{-1}$) at different dates
2. Plant height at different dates after transplanting
3. Tiller number $hill^{-1}$ at different dates after transplanting
4. Number of effective tillers $hill^{-1}$
5. Number of non-effective tillers $hill^{-1}$
6. Panicle length (cm)
7. Number of filled grains $panicle^{-1}$
8. Number of unfilled grains $panicle^{-1}$
9. Weight of 1000 grains
10. Grain yield (t ha^{-1})
11. Straw yield (t ha^{-1})
12. Harvest index (%)

3.9.2.1 Dry weight of rice plants

Five hills from each plot were uprooted at 30 DAT, 60 DAT and 90 DAT leaving the boarder rows and harvest area and oven dried at 80^0C. The samples were then transferred into desiccators and allowed to cool down to the room temperature and then final weight of the samples was taken.

3.9.2.2 Plant height

The height of rice plant was recorded in centimeter (cm) at every 15 days after transplanting (DAT) and during harvest from the same five pre-selected hills. The height was measured from base of soil surface to tip and mean height was recorded.

3.9.2.3 Tiller number

The total number of tillers was counted from the same pre-selected five hills of each plot. Tillers having at least three leaves were considered for counting.. The average value of tiller number was recorded.

3.9.2.4 Number of effective tillers

The total number of effective tillers hill^{-1} was counted from five hills of each plot. Average data were recorded from the panicle bearing plants of the pre-selected hills during the time of harvest.

3.9.2.5 Number of non-effective tillers

The total number of non-effective tillers hill^{-1} was counted. Average data were recorded from the pre-selected hills during the time of harvest.

3.9.2.6 Panicle length

The length of panicles was measured by using a meter scale. The measurement was taken from base to tip of the panicle. Average length of panicle was taken from ten randomly selected panicles of each plot. Data was recorded at harvest time. Mean data was expressed in centimeter (cm).

3.9.2.7 Number of filled grains panicle^{-1}

The total number of filled grains panicle^{-1} was counted. Average data were recorded from ten randomly selected panicles from the pre-selected hills of each plot during the time of harvest.

3.9.2.8 Number of unfilled grains panicle^{-1}

The total number of unfilled grains panicle^{-1} was also counted. Average data were recorded from the same panicles at the time of harvest.

3.9.2.9 Weight of 1000 grains

Thousand grains were counted randomly from the seed sample and weighed in gram (g) at about 12% moisture level using an electric balance.

3.9.2.10 Grain yield

The crop plants of central six rows of each plot were harvested for recording yield data leaving the boarder rows. After threshing, proper drying (12% moisture level) and cleaning, yield of each sample plot was weighed and values were converted to t ha^{-1}.

3.9.2.11 Straw yield

The central six rows of each plot were harvested from which straw weight was taken after threshing and drying and finally converted them into t ha^{-1}.

3.9.2.12 Harvest index

Harvest index (%) was determined by dividing the economic (grain) yield by the total biological yield (grain yield + straw yield) from the same area (Gardner *et al.*, 1985) and multiplying by 100.

$$\text{Harvest index} = \frac{\text{Grain yield (t ha}^{-1})}{\text{Biological yield (t ha}^{-1})} \times 100$$

3.9.2.13 Statistical analysis

The experiment was conducted following Split split-plot design. The collected data were analyzed by IRRISTAT software. The means for all recorded data were calculated and the analyses of variance of all characters were performed. The mean differences were evaluated by least significant difference (LSD) test at 0.05 level of probability (Gomez and Gomez, 1984).

Chapter 4
Results and Discussion

RESULTS AND DISCUSSION

The experiment was conducted to study the allelopathic effect of rice straw and water hyacinth biomass on weed control and yield of *boro* rice. The analysis of variance data on different crop and yield contributing characters as well as yield of rice as influenced by different concentrations of rice straw and water hyacinth biomass has been presented and interpreted in this chapter. The results on main and combined effects of varieties, allelopathic materials and their concentrations are also presented and discussed under this section.

4.1. Effect of variety

4.1.1 Weed population

There found no significant variations of weed population (m^{-2}) for the two rice varieties i.e. BRRI dhan29 and BRRI hybrid dhan2 (Appendix II). The recorded numerical number of weed population m^{-2} was maximum (29.72 and 58.94) in BRRI hybrid dhan2 at 30 DAT and 50 DAT respectively. In similar way, the minimum weed number m^{-2} (24.50 and 50.17) was found in BRRI dhan29 at the studied days (Table 1). The variety BRRI dhan29 reduced weed population by 16.20% and 14.88% at 30 DAT and 50 DAT respectively compared to the variety BRRI hybrid dhan2. Similar result was observed by Noguchi and Salam (2008) who found that some high yielding and some traditional rice cultivars of Bangladesh have allelopathic effect against the seedling growth of cress, lettuce, *Echinochloa crus-galli* and *Echinochloa colonum.* High yielding rice cultivars BRRI dhan37, BRRI dhan30 and BRRI dhan38 had the most significant inhibiting effect on the growth of cress, lettuce and *E. colonum* respectively. The high yielding rice cultivar, BR 17 marked the greatest inhibitory activity with an average of 39.50% of the growth inhibition on roots and shoots of cress, lettuce, barnyard grass and *E. colonum.* The result was also in agreement with the findings of Biswas *et al.* (2011) who reported that at 30 DAT the significantly highest weed population of 119.00 m^{-2} and 117.00 m^{-2} was found in BRRI dhan29 and BRRI dhan45 respectively whereas

BR3 and BRRI dhan50 resulted the lowest weed population of 31.00 m^{-2} and 38 m^{-2} respectively. Similarly, lowest weed population i.e. 35.33 m^{-2} and 36.00 m^{-2} was also found in BRRI dhan50 and BRRI hybrid dhan1 respectively at 60 DAT. There was another observation conducted by Argentinean scientist Urteaga *et al.* (2008). They conducted an experiment taking six rice cultivars (El Paso, Camba, Blue Bonnet, IRGA 417, Yerua and El Supremo) to find out their allelopathic potentials against one of the most troublesome weed *Echinochloa crus-galli*. They recorded that El Paso and Blue Bonnet were the cultivars showing strong and consistent allelopathic activity against *Echinochloa crus-galli* whereas the remaining rice lines were weakly (or not) allelopathic.

Table 1. Effect of variety on weed population, weed dry weight and plant dry weight of rice

Treatments	Weed population (no.m^{-2})		Weed dry weight (g m^{-2})		Plant dry weight (g $hill^{-1}$)		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
V_1	24.50	50.17	13.72	31.82	0.16	7.80	34.48
V_2	29.72	58.94	14.60	44.63	0.26	7.88	37.87
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS
CV (%)	9.66	19.39	66.97	55.79	158.67	36.52	21.51

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant

4.1.2 Weed dry weight

Variation in weed dry weight of the two rice varieties (BRRI dhan29 and BRRI hybrid dhan2) was statistically insignificant at both 30 DAT and 50 DAT (Appendix II). The maximum weed dry weight (14.60 g m^{-2} and 44.63 g m^{-2}) was observed in BRRI hybrid dhan2 at 30 DAT and 50 DAT respectively whereas the minimum (13.72 g m^{-2} and 31.82 g m^{-2}) was found in BRRI dhan29 at 30 DAT and 60 DAT respectively (Table 1). The dry weight of weed is 6.03% and 28.70% lower in BRRI dhan29 at 30 DAT and 50 DAT respectively compared to BRRI hybrid dhan2. Similar observation was recorded by Biswas *et al.* (2011) who reported that the highest weed dry matter of 5.08 g m^{-2} and 24.15 g m^{-2} were found in BRRI dhan29 at 30 and 60 DAT respectively. On the other hand the lowest weed dry matter at 30 DAT was found in BR3, BRRI dhan28 and BRRI dhan50 but at 60 DAT, it was found in BRRI hybrid dhan1 and BRRI dhan50.

4.1.3 Dry weight of plants

No significant variations were found for dry weight of the rice varieties (Appendix III). The numerically maximum dry weight (0.26 g hill^{-1}, 7.88 g hill^{-1}, and 37.87 g hill^{-1}) was recorded in BRRI hybrid dhan2 at 30DAT, 60 DAT and 90 DAT respectively. Similarly, the minimum dry weight (0.16 g hill^{-1}, 7.80 g hill^{-1}, and 34.48 g hill^{-1}) was found in BRRI dhan29 at 30DAT, 60 DAT and 90 DAT respectively (Table 1).

4.1.4 Plant height

No significant variations were found for height of the rice varieties i.e. BRRI dhan29 and BRRI hybrid dhan2 (Appendix IV). The maximum height of rice plant (11.66 cm, 20.35 cm, 33.09 cm, 53.23 cm, 65.49 cm, 85.13 cm and 92.11 (cm) was recorded in BRRI hybrid dhan2 at 15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at harvest respectively. The minimum height of rice plant (10.86 cm, 20.11 cm, 33.22 cm, 52.94 cm, 64.28 cm, 79.01 cm and 90.28 cm) was recorded in BRRI dhan29 at the same respective DAT (Table 2).

Table 2. Effect of variety on plant height of rice

Treatments	**Plant height (cm) at DAT**						
	15	**30**	**45**	**60**	**75**	**90**	**Harvest**
V_1	10.86	20.11	33.22	52.94	64.28	79.01	90.28
V_2	11.66	20.35	33.09	53.23	65.49	85.13	92.11
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.91	12.20	9.14	8.74	5.25	9.747	7.05

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant

4.1.5 Tiller number hill^{-1}

There were no significant variations of tiller number hill^{-1} of the rice varieties i.e. BRRI dhan29 and BRRI hybrid dhan2 (Appendix V). The maximum tiller number hill^{-1} of rice plant (1.89, 3.78, 12.94, 23.22, 23.50 and 17.50) was recorded in BRRI dhan29 at 15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT and 90 DAT respectively. In similar way the minimum number of tiller hill^{-1} (1.50, 3.39, 9.94, 17.22, 20.06 and 14.61) was found in BRRI hybrid dhan2 at the same respective DAT (Table 3).

Table 3. Effect of variety on tiller numbers hill^{-1} of rice

Treatments	Tiller number hill^{-1} at					
	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
V_1	1.89	3.78	12.94	23.22	23.50	17.50
V_2	1.50	3.39	9.94	17.22	20.06	14.61
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS
CV (%)	26.02	49.22	20.02	24.89	12.31	14.52

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant

4.1.6 Number of effective tillers hill^{-1}

There were significant variations observed for the number of effective tillers *hill*$^{-1}$ in the two rice varieties (Appendix VI). The higher number of effective tillers hill^{-1} (16.89) was recorded in BRRI dhan29 and the lower (12.72) was found in BRRI hybrid dhan2 (Table 4).

4.1.7 Number of non-effective tillers hill^{-1}

Statistically significant variations were found for the number of non-effective tillers hill^{-1} in the two rice varieties (Appendix VI). The higher number of non-effective tillers hill^{-1} (4.17) was recorded in BRRI hybrid dhan2 and the lower (2.28) was found in BRRI dhan29 (Table 4).

4.1.8 Panicle length

There were significant variations observed for panicle length in BRRI dhan29 and BRRI hybrid dhan2 (Appendix VI). The higher panicle length (26.27) was recorded in BRRI dhan29 and the lower (23.31) was found in BRRI hybrid dhan2 (Table 4).

Table 4. Effect of variety on effective tillers, non-effective tillers, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1} of rice

Treatments	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
V_1	16.89 a	2.28 b	26.27 a	117.78	17.33 a
V_2	12.72 b	4.17 a	23.31 b	123.67	14.67 b
$LSD_{(0.05)}$	3.312	0.632	2.346	NS	1.897
CV (%)	15.60	13.68	6.60	9.02	8.27

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant

4.1.9 Number of filled grains panicle^{-1}

Statistically insignificant variations were found for the number of filled grains panicle^{-1} in the rice varieties (Appendix VI). The numerically maximum number of filled grains panicle^{-1} (117.78) was recorded in BRRI dhan29. But the minimum number of filled grains panicle^{-1} (123.67) was found in BRRI hybrid dhan2 (Table 4).

4.1.10 Number of unfilled grains panicle^{-1}

Significant variations were found for the number of unfilled grains panicle^{-1} in the two rice varieties (Appendix VI). The higher number of unfilled grains panicle^{-1} (17.33) was recorded in BRRI dhan29 and the lower (14.67) was found in BRRI hybrid dhan2 (Table 4).

4.1.11 Weight of 1000 grains

Statistically significant variations were found for weight of 1000 grains (g) in BRRI dhan29 and BRRI hybrid dhan2 (Appendix VII). The higher weight of

1000 grains (26.04 g) was recorded in BRRI hybrid dhan2 and BRRI dhan29 gave the lower (19.58 g) weight of 1000 grains (Table 5).

4.1.12 Grain yield

There were significant variations observed for grain yield in the two rice varieties (Appendix VII). Grain yield of 6.92 t ha^{-1} was recorded as higher value which was given by BRRI hybrid dhan2 and BRRI dhan29 gave the lower grain yield (6.08 t ha^{-1}). BRRI hybrid dhan2 gave 12.14% higher grain yield than the another variety (Table 5).

Table 5. Effect of variety on weight of 1000 grains, grain yield, straw yield and harvest index of rice

Treatments	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
V_1	19.58 b	6.08 b	8.64 a	41.27 b
V_2	26.04 a	6.92 a	7.15 b	49.27 a
$LSD_{(0.05)}$	1.460	1.634	0.808	7.326
CV (%)	4.46	17.53	7.14	11.28

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2

4.1.13 Straw yield

Significant variations were found for straw yield in the rice varieties (Appendix VII). The higher straw yield (8.64 t ha^{-1}) was obtained from BRRI dhan29 whereas BRRI hybrid dhan2 produced the lower amount of straw (7.15 t ha^{-1}). BRRI hybrid dhan2 produced 17.25% lower straw yield than BRRI dhan29 (Table 5).

4.1.14 Harvest index

Statistically significant variations were found for harvest index in the two rice varieties (Appendix VII). The higher percentage of harvest index (49.27%) was recorded in BRRI hybrid dhan2 and the lower percentage (41.27%) was found in BRRI dhan29 (Table 5).

4.2 Effect of allelopathic materials

4.2.1 Weed population

There were significant variations for weed population observed due to incorporation of rice straw and water hyacinth in the rice field (Appendix II). The higher number of weed (36.89 m^{-2} and 69.78 m^{-2}) was recorded in the rice field incorporated with water hyacinth at 30 DAT and 50 DAT respectively (Table 6). Similar result was found by Gohl (1981) who observed that water hyacinth contains 75.80% organic matter, 1.5% nitrogen and 24.20% ash of it's total dry matter those enhances plant growth. The lower number of weed (17.33 m^{-2} and 39.33 m^{-2}) was found in the rice field incorporated with rice straw at 30 DAT and 50 DAT respectively. Similar result was observed by Chung *et al.* (2001) and Inderjit *et al.* (2004) who found that rice straw has allelopathic properties, which can contribute to weed suppression. Similar result was also found by Ashraf *et al.* (2011) who concluded that weed density was decreased by 40% with applying residue of sorghum in rainfed wheat crop.

4.2.2 Weed dry weight

No significant variations were found for the dry weight of weed due to the two allelopathic materials at 30 DAT (Appendix II). The numerically maximum weed dry weight (15.68 g m^{-2}) was recorded in water hyacinth incorporated plots and the minimum weed dry weight (12.64 g m^{-2}) was found in rice straw incorporated plots at 30 DAT (Table 6). But the variations were significant at 50 DAT. The higher value of weed dry weight (46.15 g m^{-2}) was recorded in water hyacinth incorporated plots and the lower value (30.31 g m^{-2}) was found in rice straw incorporated plots at 50 DAT. Similar result was found by Biswas *et al.* (2008) who recorded the highest weed dry matter (1.72 g m^{-2}) in *Brassica juncea* incorporated plots at 30 DAS and in *Brassica napus* field (1.44 g m^{-2}) at 50 DAS. The lowest weed dry matter (0.89 g m^{-2}) was recorded when total *Brassica* biomass was incorporated into the soil at 30 DAS and 50% incorporation plus 50% spreading at 50 DAS. Ashraf *et al.* (2011) also found that weed dry weight was reduced by 34% with applying residue of sorghum in rainfed wheat crop.

Table 6. Effect of allelopathic materials on weed population, weed dry weight and plant dry weight of rice

Treatments	Weed population ($no.m^{-2}$)		Weed dry weight ($g\ m^{-2}$)		Plant dry weight ($g\ hill^{-1}$)		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
M_1	17.33 b	39.33 b	12.64	30.31 b	0.21	7.53	35.86
M_2	36.89 a	69.78 a	15.68	46.15 a	0.26	8.14	36.49
$LSD_{(0.05)}$	8.866	13.437	NS	9.472	NS	NS	NS
CV (%)	35.34	26.62	50.05	26.78	319.65	35.50	16.05

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant

4.2.3 Dry weight of plants

No significant variations were found for dry weight of rice plants in allelopathic materials incorporated field (Appendix III). The numerically maximum dry weight (0.26 g $hill^{-1}$, 8.14 g $hill^{-1}$, and 36.49 g $hill^{-1}$) was recorded in water hyacinth incorporated plots at 30 DAT, 60 DAT and 90 DAT respectively. Similarly, the minimum dry weight (0.21 g $hill^{-1}$, 7.53 g $hill^{-1}$, and 35.86 g $hill^{-1}$) was found in rice straw incorporated plots at 30DAT, 60 DAT and 90 DAT respectively (Table 6).

4.2.4 Plant height

No significant variations were found for plant height due to effect of the two allelopathic materials (Appendix IV). The maximum height of rice plant (11.55 cm, 20.29 cm, 34.72 cm, 55.42 cm, 66.36 cm, 86.25 cm and 92.30 cm) was recorded in water hyacinth incorporated plots at 15 DAT, 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at harvest respectively (Table 7). The minimum height of rice plant (11.46 cm, 20.28 cm, 31.59 cm, 54.75 cm, 63.41 cm, 82.88 cm and 92.08 cm) was found in rice straw incorporated plots at the studied days respectively. Similar findings were recorded by Khorshidi and Yarnia

(2011) who concluded that residuals of *Convolvulus arvensis* from different organs and *Cynodon dactylon* L. decreased wheat plant height significantly.

Table 7. Effect of allelopathic materials on plant height of rice

Treatments	Plant height (cm) at DAT						
	15	30	45	60	75	90	Harvest
M_1	11.46	20.28	31.59	54.75	63.41	82.88	92.08
M_2	11.55	20.29	34.72	55.42	66.36	86.25	92.30
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS
CV (%)	13.72	12.67	8.94	3.62	5.91	5.91	1.93

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant

4.2.5 Tiller number hill^{-1}

Statistically significant variations were found for tiller number hill^{-1} for the two allelopathic materials except 90 DAT (Appendix V). The higher number of tillers hill^{-1} (2.00, 3.89, 13.22, 21.44, and 22.50) was recorded in water hyacinth incorporated field at 15, 30, 45, 60 and 75 DAT respectively (Table 8). The lower number of tillers hill^{-1} (1.39, 3.28, 9.67, 19.00, and 20.06) was recorded in rice straw incorporated field at the same respective DAT. But at 90 DAT there were no significant variations observed for tiller number hill^{-1}. The maximum number of tillers hill^{-1} (15.11) was recorded in water hyacinth incorporated field and the minimum number of tiller hill^{-1} (15.00) was found in rice straw incorporated field at 90 DAT.

Table 8. Effect of allelopathic materials on tiller numbers hill^{-1} of rice

Treatments	Tiller numbers hill^{-1} at DAT					
	15	30	45	60	75	90
M_1	1.39 b	3.28 b	9.67 b	19.00 b	20.06 b	15.00
M_2	2.00 a	3.89 a	13.22 a	21.44 a	22.50 a	15.11
$LSD_{(0.05)}$	0.436	0.308	1.610	1.272	1.932	NS
CV (%)	27.82	9.30	15.20	6.80	9.81	14.00

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant

4.2.6 Number of effective tillers hill^{-1}

No significant variations were observed for the number of effective tillers hill^{-1} due to incorporation of allelopathic materials (Appendix VI). The numerically maximum number of effective tillers hill^{-1} (14.83) was recorded in rice straw incorporated plots and the minimum (14.78) was found in water hyacinth incorporated plots (Table 9).

4.2.7 Number of non-effective tillers hill^{-1}

Statistically insignificant variations were observed for the number of non-effective tillers hill^{-1} due to incorporation of allelopathic materials (Appendix VI). The maximum number of non-effective tillers hill^{-1} (3.56) was recorded in water hyacinth incorporated plots and the minimum (2.89) was found in rice straw incorporated plots (Table 9).

4.2.8 Panicle length

There were no significant variations found for the panicle length in allelopathic materials incorporated plots (Appendix VI). The maximum length of panicle (24.90 cm) was recorded in rice straw incorporated plots and the minimum (24.68) was found in water hyacinth incorporated plots (Table 9).

Table 9. Effect of allelopathic materials on effective tillers, non-effective tillers, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1} of rice

Treatments	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
M_1	14.83	2.89	24.90	121.89	16.50
M_2	14.78	3.56	24.68	119.56	16.00
$LSD_{(0.05)}$	NS	NS	NS	NS	NS
CV (%)	15.02	35.46	3.40	7.33	5.31

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant

4.2.9 Number of filled grains panicle^{-1}

Statistically insignificant variations were found for the number of filled grains panicle^{-1} in the rice varieties for incorporation of allelopathic materials (Appendix VI). The numerically maximum number of filled grains panicle^{-1} (121.89) was recorded in rice straw incorporated field and the minimum number of filled grains panicle^{-1} (119.56) was found in water hyacinth incorporated field (Table 9).

4.2.10 Number of unfilled grains panicle^{-1}

No significant variations were found for the number of unfilled grains panicle^{-1} in the rice varieties for incorporation of allelopathic materials (Appendix VI). The numerically maximum number of unfilled grains panicle^{-1} (16.50) was recorded in rice straw incorporated plots and the minimum number of unfilled grains panicle^{-1} (16.00) was found in water hyacinth incorporated plots (Table 9).

4.2.11 Weight of 1000 grains

Statistically insignificant variations were found for weight of 1000 grains in the allelopathic materials incorporated plots (Appendix VII). The maximum weight of 1000 grains (22.94 g) was recorded for water hyacinth incorporation and rice straw incorporation gave the minimum (22.68 g) weight of 1000 grains (Table 10). Similar result was found by Khorshidi *et al.* (2011) who studied that 1000 kernel weight was reduced by minimum 11.28% and maximum 16.83% by applying residuals of *Convolvulus arvensis* in wheat field.

4.2.12 Grain yield

No significant variations were observed for grain yield for applying allelopathic materials in rice field (Appendix VII). Grain yield of 6.74 t ha^{-1} was recorded as maximum value which was given by water hyacinth incorporated plots and rice straw incorporated plots gave the minimum (6.26 t ha^{-1}) grain yield (Table 10). Water hyacinth incorporated plots gave 7.12% higher grain yield than the another. Such type of result was also found by

Khorshidi *et al.* (2011) who concluded that wheat grain yield reduced by 7.01% for applying residues of *Cynodon dactylon* L.

Table 10. Effect of allelopathic materials on weight of 1000 grains, grain yield, straw yield and harvest index of rice

Treatments	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
M_1	22.68	6.26	7.48 b	45.68
M_2	22.94	6.74	8.31 a	44.86
$LSD_{(0.05)}$	NS	NS	0.729	NS
CV (%)	4.69	10.01	9.98	9.16

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant

4.2.13 Straw yield

Statistically significant variations were found for straw yield (t ha^{-1}) in the allelopathic materials incorporated plots (Appendix VII). The higher straw yield (8.31 t ha^{-1}) was obtained from water hyacinth incorporated plots whereas rice straw incorporated plots produced the lower amount (7.48 t ha^{-1}) of straw (Table 10).

4.2.14 Harvest index

There were no significant variations found for harvest index (%) for allelopathic materials incorporation (Appendix VII). The maximum percentage of harvest index (45.68) was recorded in rice straw incorporated plots and the minimum percentage (44.86) was found in water hyacinth incorporated plots (Table 10).

4.3 Effect of concentration of the allelopathic materials

4.3.1 Weed population

No significant variations in weed population were observed for concentration of allelopathic materials at 30 DAT (Appendix II). At the same date, the minimum weed population (24.50 m^{-2}) was recorded in the plots with no allelopathic materials application and the maximum weed population (29.08 m^{-}

^{2}) was found in the plots of 1.0 kg biomass m^{-2} (Table 11). But at 50 DAT there were significant variations in weed population. The highest weed population (90.92 m^{-2}) was found with 1.0 kg biomass m^{-2}. The lowest weed population (28.67 m^{-2}) was with 0 kg biomass m^{-2} that was similar to the application of 0.5 kg biomass m^{-2}. Dissimilar results were obtained by Ashrafi *et al.* (2007) who reported that Barley (*Hordeum vulgare* L.) contained water soluble allelochemicals and increasing the water extract concentrations from 4 to 20 g per 100 ml of water of all Barley parts significantly increased the inhibition of wild barley germination, seedling length and weight. Xuan and Tsuzuki (2001) also reported that the degree of inhibition of weed growth by alfalfa pellet became stronger as the application of concentration increased. Turk and Tawaha (2002) also observed that increasing the aqueous extract concentrations of separated *B. nigra* L., plant parts significantly inhibited *A. fatua* L. germination, seedling length and weight. Such dissimilar results might be due to opposite characteristics of two allelopathic materials where rice straw had the suppressive and water hyacinth had the impressive behavior on weed growth.

4.3.2 Weed dry weight

There were significant variations in dry weight of weed for different concentrations of allelopathic materials at both 30 DAT and 50 DAT (Appendix II). The highest dry weight of weed (22.01 g m^{-2}) was found with no biomass concentration at 30 DAT but at 50 DAT it was found in 1.0 kg biomass m^{-2} (57.74 g m^{-2}). The lowest (9.32 g m^{-2} and 26.80 g m^{-2}) was with 1.0 kg biomass m^{-2} at 30 DAT and 0 kg biomass m^{-2} at 50 DAT respectively that was similar to the application of 0.5 kg biomass m^{-2} (Table 11). The result was also in agreement with Basotra *et al.* (2005) who observed that the allelopathic effects of three important medicinal plant species (e.g., *Bergenia ciliata, Hedychium spicatum* and *Potentilla fulgens*) increased with increasing concentration of leachates from 2%, 5% to 10%. These results were also found by Tawaha and Turk (2003) who observed that increasing the water extract concentrations from 4 to 20 g per 100 ml of water of all black mustard parts significantly increased the inhibition of germination, seedling length and weight of wild barley.

Table 11. Effect of concentration of allelopathic materials on weed population, weed dry weight and dry weight of rice plant

Treatments	Weed population ($no.m^{-2}$)		Weed dry weight ($g\ m^{-2}$)		Plant dry weight ($g\ hill^{-1}$)		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
C_0	24.50	28.67 b	22.01 a	26.80 b	0.25	8.88 a	35.47
C_1	27.75	44.08 b	11.14 b	30.15 b	0.20	7.74 ab	36.36
C_2	29.08	90.92 a	9.32 b	57.74 a	0.17	7.50 b	36.70
$LSD_{(0.05)}$	NS	30.05	9.609	18.70	NS	1.40	NS
CV (%)	89.36	63.65	78.42	56.53	462.53	20.66	19.24

C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.3.3 Dry weight of plants

No significant variations were found for dry weight of rice plants for concentration of allelopathic materials (Appendix III). The numerically maximum dry weight (0.25 g $hill^{-1}$, 8.88 g $hill^{-1}$, and 36.70 g $hill^{-1}$) was recorded with control at 30 DAT, 60 DAT and 1.0 kg biomass m^{-2} at 90 DAT respectively (Table 11). Similarly, the minimum dry weight (0.17 g $hill^{-1}$, 7.50 g $hill^{-1}$, and 35.47 g $hill^{-1}$) was found with 1.0 kg biomass concentration m^{-2} at 30 DAT and 60 DAT and control at 90 DAT respectively.

4.3.4 Plant height

Statistically insignificant variations were observed in plant height of rice for biomass concentration at different dates after transplanting (Appendix IV). The maximum plant height (11.73 cm, 21.01 cm, 53.34 cm, 65.27 cm and 92.44 cm) was recorded from the land with 0 kg biomass concentration m^{-2} at 15, 30, 60, 75 DAT and at harvest respectively (Table 12). The minimum plant height (10.74 cm, 19.50 cm, 32.54 cm, 52.96 cm, and 84.07 cm) was found from the land with 1.0 kg biomass concentration m^{-2} at 15, 30, 45, 60 and 90 DAT respectively. These results were similar with the findings of Iqbal and Cheema (2008) who noted that the high rate of crop water extracts (15 L ha^{-1}) significantly reduced the growth of purple nutsedge more than the lower rates (12 L ha^{-1}).

Table 12. Effect of concentration of allelopathic materials on plant height of rice

Treatments	Plant height (cm) at DAT						
	15	30	45	60	75	90	Harvest
C_0	11.73	21.01	33.23	53.34	65.27	84.78	92.44
C_1	11.31	20.18	33.69	52.95	64.13	84.86	91.72
C_2	10.74	19.50	32.54	52.96	65.26	84.07	92.42
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS
CV (%)	12.28	11.69	8.27	6.65	4.90	4.646	3.98

C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.3.5 Tiller number $hill^{-1}$

No significant variations were found in tiller numbers $hill^{-1}$ of rice for biomass concentration at different dates after transplanting (Appendix V). The maximum tiller number $hill^{-1}$ (1.83, 11.92, 21.08, 22.50 and 15.75) was recorded from the land with 0.5 kg biomass concentration m^{-2} at 15, 45, 60, 75 and 90 DAT respectively. The minimum number of tiller $hill^{-1}$ (1.58, 10.67, 18.58, 19.25 and 14.08) was found from the land with 0 kg biomass concentration m^{-2} at the same respective dates (Table 13).

Table 13. Effect of concentration of allelopathic materials on tiller numbers $hill^{-1}$ of rice

Treatments	Tiller number $hill^{-1}$ at DAT					
	15	30	45	60	75	90
C_0	1.58	3.92	10.67	18.58	19.25	14.08
C_1	1.83	3.67	11.92	21.08	22.50	15.75
C_2	1.67	3.17	11.75	21.00	22.08	15.33
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	NS
CV (%)	53.88	28.48	25.60	3.06	16.21	17.34

C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.3.6 Number of effective tillers hill^{-1}

Insignificant variations were observed for the number of effective tillers hill^{-1} due to concentration of allelopathic materials (Appendix VI). The numerically maximum number of effective tillers hill^{-1} (15.75) was recorded with 0.5 kg biomass concentration m^{-2} and the minimum (13.58) was found in control treatment (Table 14).

4.3.7 Number of non-effective tillers hill^{-1}

No significant variations were observed for the number of non-effective tillers hill^{-1} due to concentration of allelopathic materials (Appendix VI). The maximum number of non-effective tillers hill^{-1} (3.42) was recorded with 0.5 kg biomass concentration m^{-2} and the minimum (3.00) was found in 1.0 kg biomass concentration m^{-2} (Table 14).

4.3.8 Panicle length

There were no significant variations found for the panicle length for concentration of allelopathic materials (Appendix VI). The maximum length of panicle (24.91 cm) was recorded with 1.0 kg biomass concentration m^{-2} and the minimum (24.68) was found in control (Table 14).

Table 14. Effect of concentration of allelopathic materials on effective tillers, non-effective tillers, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1}

Treatments	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
C_0	13.58	3.25	24.68	120.67	15.92
C_1	15.75	3.42	24.79	122.17	15.75
C_2	15.08	3.00	24.91	119.33	16.33
$LSD_{(0.05)}$	NS	NS	NS	NS	NS
CV (%)	18.55	29.71	2.85	9.65	12.21

C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.3.9 Number of filled grains panicle^{-1}

Statistically insignificant variations were found for the number of filled grains panicle^{-1} with different concentrations of allelopathic materials (Appendix VI). The numerically maximum number of filled grains panicle^{-1} (122.17) was recorded with 0.5 kg biomass concentration m^{-2} and the minimum number of filled grains panicle^{-1} (119.33) was found with 1.0 kg biomass m^{-2} (Table 14).

4.3.10 Number of unfilled grains panicle^{-1}

No significant variations were found for the number of unfilled grains panicle^{-1} due to different concentrations of allelopathic materials (Appendix VI). The numerically maximum number of unfilled grains panicle^{-1} (16.33) was recorded with 1.0 kg biomass concentration m^{-2} and the minimum number (15.75) was found with 0.5 kg biomass concentration m^{-2} (Table 14).

4.3.11 Weight of 1000 grains

Statistically insignificant variations were found for weight of 1000 grains (g) with allelopathic materials' concentration (Appendix VII). The maximum weight of 1000 grains (22.99 g) was recorded with 0 kg biomass concentration m^{-2} and 1.0 kg biomass concentration m^{-2} gave the minimum (22.67 g) weight of 1000 grains (Table 15). These results were inconsistent with the findings of Mansoor *et al.* (2004) who stated that water extracts of sorghum, eucalyptus and acacia affected the number of branches plant^{-1}, number of pods plant^{-1}, 1000 grain weight and grain yield of mungbean.

4.3.12 Grain yield

No significant variations were observed for grain yield (t ha^{-1}) for concentration of allelopathic materials in rice field (Appendix VII). Grain yield of 6.60 t ha^{-1} was the recorded as maximum value which was given by 1.0 kg biomass concentration m^{-2} and 0 kg biomass concentration m^{-2} gave the minimum (6.35 t ha^{-1}) grain yield (Table 15). These results were similar to the findings of Cheema *et al.* (2003 b) who noted that concentrated sunflower water extract @

12 L ha^{-1} gave consistently better weed control and increased wheat yield by 5.5% over control. Similar results also obtained by Naseem *et al.* (2009) who showed that inhibitory effects of sunflower plant water extract increased with increasing the water extract application frequency and increased the wheat yield significantly over control.

Table 15. Effect of concentration of allelopathic materials on weight of 1000 grains, grain yield, straw yield and harvest index of rice

Treatments	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
C_0	22.99	6.35	7.77	44.81
C_1	22.76	6.55	8.05	45.22
C_2	22.67	6.60	7.86	45.77
$LSD_{(0.05)}$	NS	NS	NS	NS
CV (%)	2.13	10.34	13.77	11.59

C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.3.13 Straw yield

Statistically insignificant variations were found for straw yield (t ha^{-1}) due to different concentrations of biomass (Appendix VII). The maximum straw yield (8.05 t ha^{-1}) was obtained from 0.5 kg biomass concentration m^{-2} whereas 0 kg biomass concentration m^{-2} produced the minimum (7.77 t ha^{-1}) amount of straw (Table 15).

4.3.14 Harvest index

There were no significant variations for harvest index with allelopathic materials' concentration (Appendix VII). The maximum percentage of harvest index (45.77) was recorded with the application of 1.0 kg biomass m^{-2} and the minimum percentage (44.81) was found with control (Table 15).

4.4 Interaction effect of variety and allelopathic materials

4.4.1 Weed population

Statistically significant variations were observed for weed population from the interaction effect of variety and allelopathic materials both at 30 DAT and 50 DAT (Appendix II). The highest weed population (40.78 m^{-2}) was recorded from BRRI dhan29 with water hyacinth incorporation that was statistically similar to BRRI hybrid dhan2 with the same allelopathic material and the lowest population (16.44 m^{-2}) was found in BRRI hybrid dhan2 with rice straw that was similar to BRRI dhan29 with the same biomass at 30 DAT (Table 16). At 50 DAT, the highest weed population (73.44 m^{-2}) was found from BRRI hybrid dhan2 with water hyacinth that was similar to BRRI dhan29 with the same material and the lowest population (34.22 m^{-2}) was recorded from BRRI dhan29 with rice straw that showed similar result with BRRI hybrid dhan2 with the same biomass.

4.4.2 Weed dry weight

No significant variations were found for the interaction of variety and allelopathic materials on dry weight of weed at 30 DAT (Appendix II). The numerically maximum dry weight of weed (16.23 g m^{-2}) was obtained from BRRI dhan29 with the incorporation of water hyacinth biomass and the minimum weight (12.31g m^{-2}) was found in BRRI dhan29 with rice straw (Table 16). At 50 DAT the highest dry weight of weed (55.16 g m^{-2}) was recorded from BRRI hybrid dhan2 with water hyacinth incorporation that did not show any similar result. The lowest weight (26.50 g m^{-2}) was found from BRRI dhan29 with rice straw that was similar to both BRRI dhan29 with water hyacinth and BRRI hybrid dhan2 with rice straw incorporation.

Table 16. Interaction effect of variety and allelopathic materials on weed population, weed dry weight and plant dry weight of rice

Treatments	Weed population (no.m^{-2})		Weed dry weight (g m^{-2})		Plant dry weight (g hill^{-1})		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
$V_1 \times M_1$	18.22 b	34.22 b	12.96	26.50 b	0.15	7.36	33.70
$V_1 \times M_2$	40.78 a	66.11 a	16.23	37.14 b	0.15	7.93	35.25
$V_2 \times M_1$	16.44 b	44.44 b	12.31	34.11 b	0.25	7.40	38.02
$V_2 \times M_2$	33.00 a	73.44 a	15.13	55.16 a	0.26	8.35	38.73
$LSD_{(0.05)}$	12.539	19.003	NS	13.395	NS	NS	NS
CV (%)	35.34	26.62	50.05	26.78	19.65	35.50	16.05

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant
M_1 = Rice straw M_2 = Water hyacinth

4.4.3 Dry weight of plants

No significant variations were found for dry weight of rice plants for the interaction effect of variety and allelopathic materials (Appendix III). The numerically maximum dry weight (0.26 g hill^{-1}, 8.35 g hill^{-1} and 38.73 g hill^{-1}) was recorded from BRRI hybrid dhan2 with the incorporation of water hyacinth biomass at 30, 60 and 90 DAT respectively. Similarly, the minimum dry weight (0.15 g hill^{-1}, 7.36 g hill^{-1} and 33.70 g hill^{-1}) was found in BRRI dhan29 with rice straw at the same respective dates (Table 16).

4.4.4 Plant height

There was insignificant variation observed for the interaction between variety and allelopathic materials on plant height at 15, 30, 45, 60 and 75 DAT (Appendix IV). The maximum plant height (11.91 cm, 20.93 cm, 35.30 cm, 52.56 cm and 67.41 cm) was found from BRRI hybrid dhan2 with water hyacinth at 15, 30, 45, 60 and 75 DAT respectively whereas the minimum height (11.02 cm, 19.62 cm, 31.30 cm, 50.41 cm and 63.26 cm) was recorded from BRRI dhan29 with rice straw incorporation (Table 17). At 90 DAT and at harvest significant variation was found in plant height of rice. At 90 DAT, the highest plant height (91.37 cm) was recorded from BRRI hybrid dhan2 with water hyacinth that was statistically similar to the same variety with rice straw and the lowest height (76.88 cm) was found in BRRI dhan29 with rice straw which was similar to the same variety with water hyacinth. At harvest, the highest plant height (95.22 cm) was recorded from BRRI dhan29 with rice straw which was similar to the same variety with water hyacinth application and the lowest height (89.94 cm) was found in BRRI hybrid dhan2 with rice straw which was similar to the same variety with water hyacinth incorporation.

Table 17. Interaction effect of variety and allelopathic materials on plant height

Treatments	Plant height (cm) at DAT						
	15	30	45	60	75	90	Harvest
$V_1 \times M_1$	11.02	19.62	31.30	50.41	63.26	76.88 b	95.22 a
$V_1 \times M_2$	10.70	20.61	35.14	52.48	65.31	81.14 b	94.33 a
$V_2 \times M_1$	11.41	19.77	31.88	51.09	63.57	88.88 a	89.94 b
$V_2 \times M_2$	11.91	20.93	35.30	52.56	67.41	91.37 a	91.27 b
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	6.538	2.328
CV (%)	13.72	12.67	8.94	3.62	5.91	5.91	1.93

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant
M_1 = Rice straw M_2 = Water hyacinth

4.4.5 Tiller number hill^{-1}

The interaction effect of variety and allelopathic materials showed statistically significant variations for tiller number hill^{-1} at different dates after transplanting (Appendix V). The highest number of tillers hill^{-1} (2.11, 4.22, 15.33, 24.44, 24.78 and 17.78) was recorded from BRRI dhan29 with water hyacinth at 15, 30, 45, 60, 75 and 90 DAT respectively which were similar to the same variety with rice straw (1.67) and BRRI hybrid dhan2 with water hyacinth (1.89) at 15 DAT, to the same variety with rice straw (22.22) at 75 DAT and to the same variety with rice straw (17.22) at 90 DAT (Table 18). The lowest number of tillers hill^{-1} (1.11, 3.22, 8.78, 16.00, 17.89 and 12.78) was recorded from BRRI hybrid dhan2 with rice straw incorporation that was similar to the same variety with water hyacinth, BRRI dhan29 with rice straw at 30 DAT, to BRRI dhan29 with rice straw at 45 DAT, to BRRI hybrid dhan2 with water hyacinth at 75 DAT and BRRI hybrid dhan2 with water hyacinth at 90 DAT.

Table 18. Interaction effect of variety and allelopathic materials on tiller numbers hill^{-1}

Treatments	Tiller number hill^{-1} at DAT					
	15	30	45	60	75	90
$V_1 \times M_1$	1.67 a	3.33 b	10.56 bc	22.00 b	22.22 ab	17.22 a
$V_1 \times M_2$	2.11 a	4.22 a	15.33 a	24.44 a	24.78 a	17.78 a
$V_2 \times M_1$	1.11 b	3.22 b	8.78 c	16.00 d	17.89 c	12.78 b
$V_2 \times M_2$	1.89 a	3.56 b	11.11 b	18.44 c	20.22 bc	12.44 b
$LSD_{(0.05)}$	0.617	0.436	2.277	1.799	2.733	2.759
CV (%)	27.82	9.30	15.20	6.80	9.81	14.00

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
M_1 = Rice straw M_2 = Water hyacinth

4.4.6 Number of effective tillers hill^{-1}

Significant variations were observed for the number of effective tillers hill^{-1} due to variety and biomass interactions (Appendix VI). The highest number of effective tillers hill^{-1} (16.89) was recorded from BRRI dhan29 with rice straw that was identical (16.89) to the same variety with water hyacinth. The lowest number of effective tillers hill^{-1} (12.67) was recorded from BRRI hybrid dhan2 with water hyacinth that was similar (12.78) to the same variety with rice straw (Figure 2).

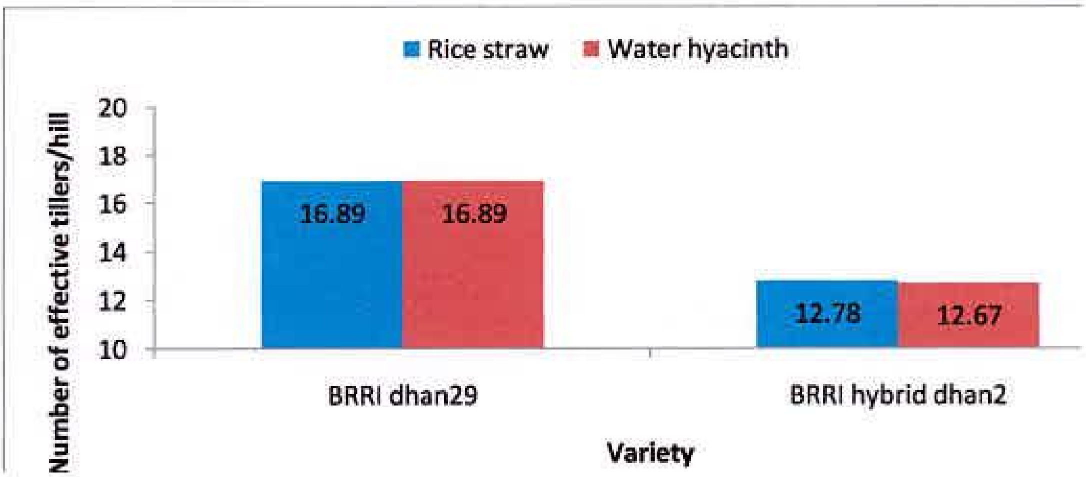


Figure 2. Interaction effect of variety and allelopathic materials on effective tillers hill^{-1} of rice ($LSD_{(0.05)}$ = 2.909)

4.4.7 Number of non-effective tillers hill^{-1}

There found significant variations for the number of non-effective tillers hill^{-1} for variety and biomass interactions (Appendix VI). The highest number of non-effective tillers hill^{-1} (4.78) was recorded from BRRI hybrid dhan2 with water hyacinth that was similar to the same variety with rice straw. The lowest number of non-effective tillers hill^{-1} (2.22) was observed from BRRI dhan29 with rice straw that was similar to the same variety with water hyacinth and BRRI hybrid dhan2 with rice straw (Figure 3).

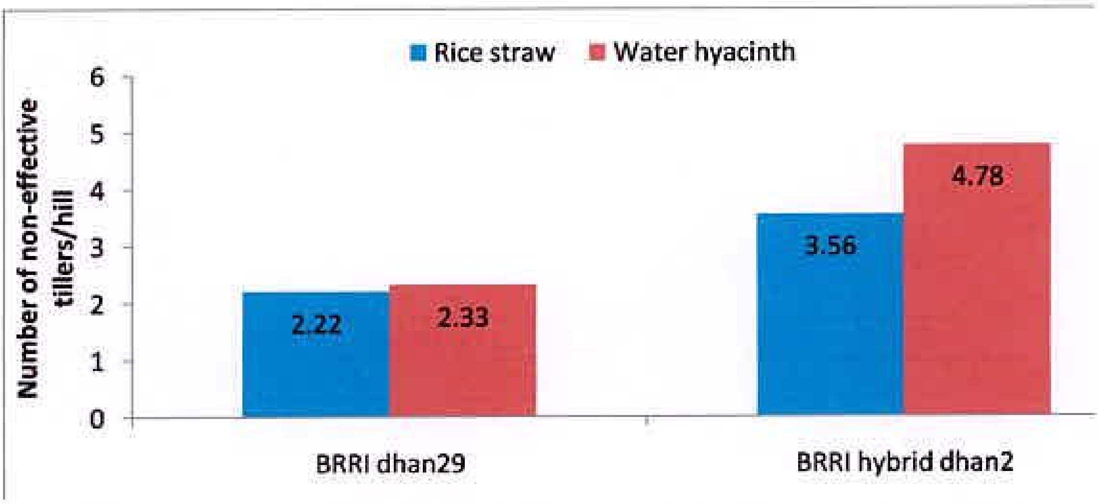


Figure 3. Interaction effect of variety and allelopathic materials on non-effective tillers hill^{-1} of rice ($LSD_{(0.05)}$ = 1.495)

4.4.8 Panicle length

There was significant variation observed for the panicle length of rice with the interactions of variety and allelopathic materials (Appendix VI). The highest length of panicle (26.42 cm) was recorded from BRRI dhan29 with rice straw that was similar (26.12) to the same variety with water hyacinth. The lowest panicle length (23.24 cm) was observed from BRRI hybrid dhan2 with water hyacinth that was similar (23.39) to the same variety with rice straw incorporation (Figure 4).

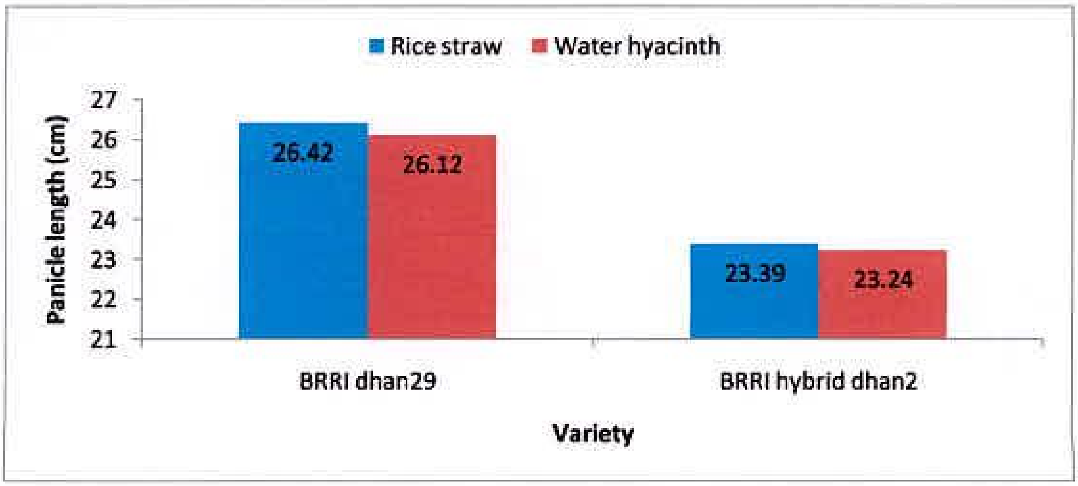


Figure 4. Interaction effect of variety and allelopathic materials on panicle length of rice ($LSD_{(0.05)}$ = 1.105)

4.4.9 Number of filled grains panicle^{-1}

Statistically significant variations were found for the number of filled grains panicle^{-1} with variety and biomass interaction (Appendix VI). The highest number of filled grains panicle^{-1} (128.89) was recorded from BRRI hybrid dhan2 with rice straw that was similar to BRRI dhan29 with water hyacinth and BRRI hybrid dhan2 with the same biomass. The lowest number of filled grains panicle^{-1} (114.89) was recorded from BRRI dhan29 with rice straw that was similar to the same variety with water hyacinth and BRRI hybrid dhan2 with the same biomass (Figure 5).

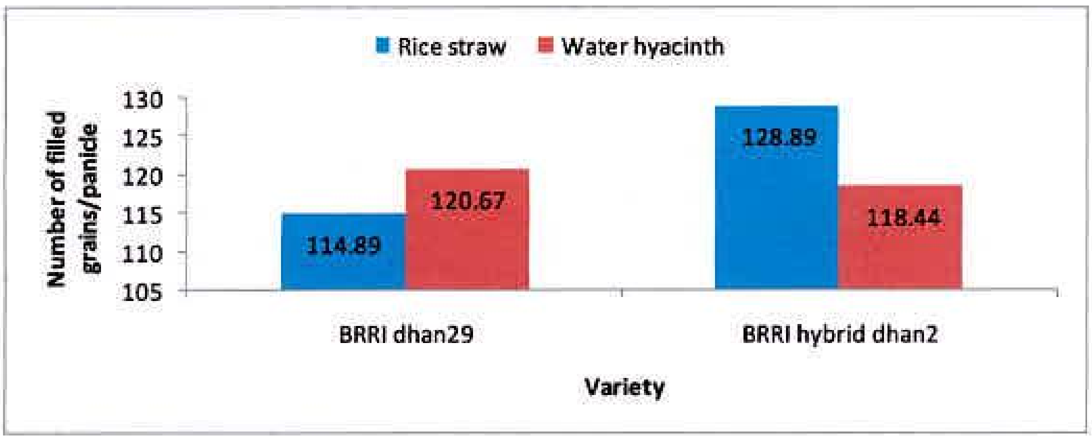


Figure 5. Interaction effect of variety and allelopathic materials on filled grains panicle^{-1} of rice ($LSD_{(0.05)}$ = 11.58)

4.4.10 Number of unfilled grains panicle^{-1}

Significant variations were found for the number of unfilled grains panicle^{-1} with the interaction of variety and allelopathic materials (Appendix VI). The highest number of unfilled grains panicle^{-1} (17.56) was observed from BRRI dhan29 with rice straw that was similar (17.11) to the same variety with water hyacinth. The lowest number of unfilled grains panicle^{-1} (14.44) was recorded from BRRI hybrid dhan2 with rice straw that was similar (14.89) to the same variety with water hyacinth (Figure 6).

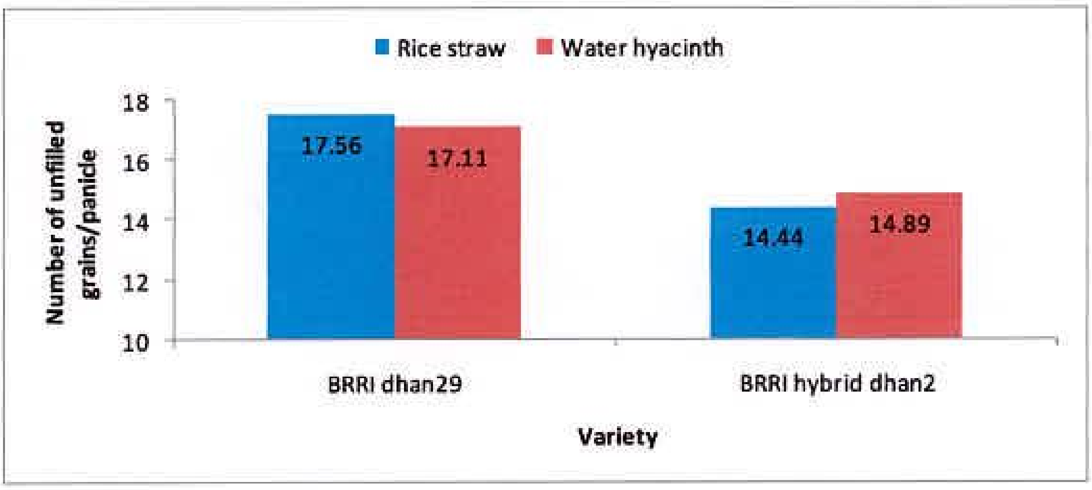


Figure 6. Interaction effect of variety and allelopathic materials on unfilled grains panicle^{-1} of rice ($LSD_{(0.05)}$ = 1.112)

4.4.11 Weight of 1000 grains

Statistically significant variations were observed for the interaction of variety and allelopathic materials on weight of 1000 grains (Appendix VII). The highest weight of thousand grains (26.20 g) was recorded from BRRI hybrid dhan2 with water hyacinth incorporation which was similar (25.88) to the same variety with rice straw biomass. The lowest weight of thousand grains (19.48 g) was found from BRRI dhan29 with rice straw incorporation which was similar (19.68) to the same variety with water hyacinth biomass (Figure 7).

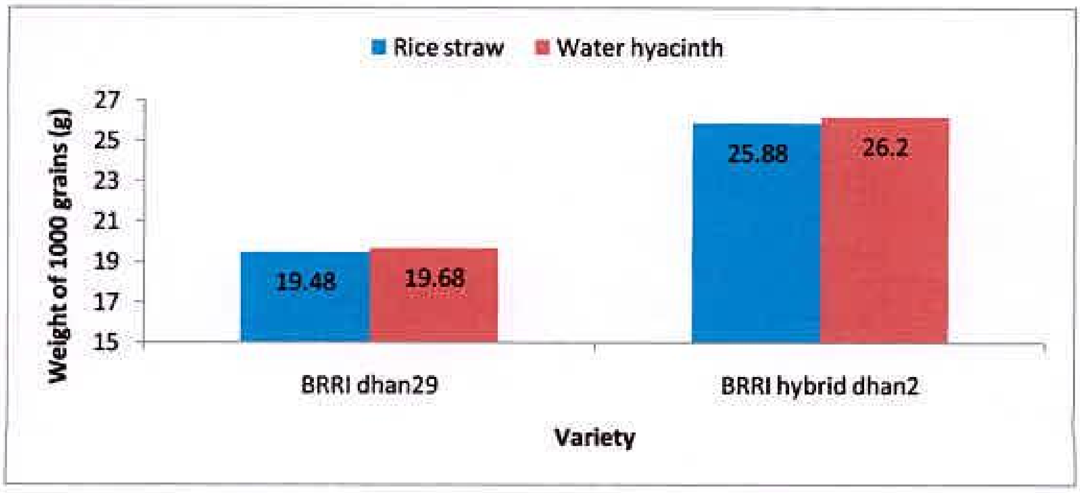


Figure 7. Interaction effect of variety and allelopathic materials on weight of 1000 grains of rice ($LSD_{(0.05)}$ = 1.399)

4.4.12 Grain yield

Significant variations were found for the interaction of variety and biomass on grain yield (Appendix VII). The highest grain yield (7.33 t ha^{-1}) was recorded from BRRI hybrid dhan2 with water hyacinth incorporation which was similar to the same variety with rice straw. The lowest grain yield (6.00 t ha^{-1}) was found from BRRI dhan29 with rice straw incorporation which was similar to the same variety with water hyacinth (Figure 8).

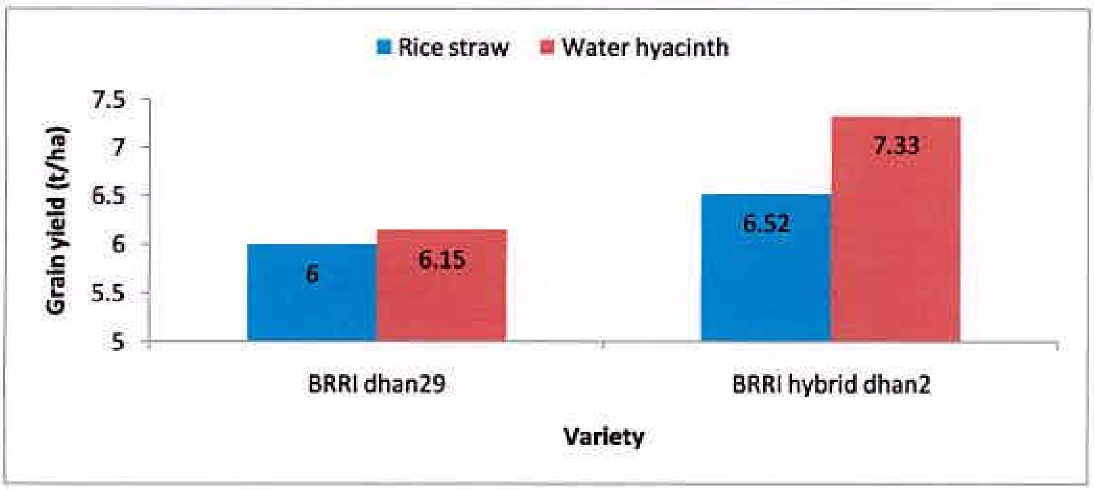


Figure 8. Interaction effect of variety and allelopathic materials on grain yield of rice ($LSD_{(0.05)}$ = 0.851)

4.4.13 Straw yield

The interaction effect of variety and allelopathic materials showed statistically significant variations on straw yield (Appendix VII). The highest straw yield (9.23 t ha^{-1}) was recorded from BRRI dhan29 with water hyacinth incorporation. The lowest straw yield (6.91 t ha^{-1}) was found from BRRI hybrid dhan2 with rice straw which was similar to the same variety with water hyacinth incorporation (Figure 9).

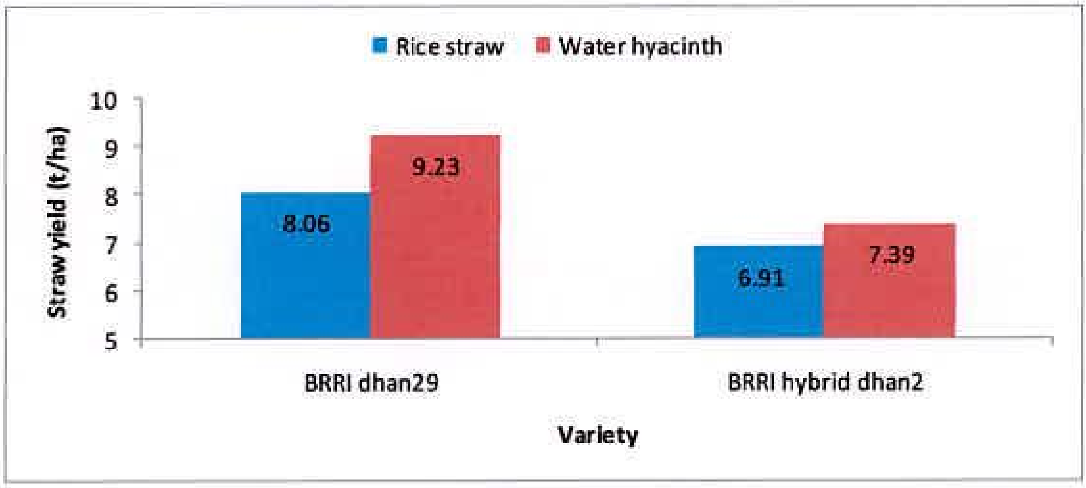


Figure 9. Interaction effect of variety and allelopathic materials on straw yield of rice ($LSD_{(0.05)}$ = 1.031)

4.4.14 Harvest index

The interaction effect of variety and allelopathic materials showed statistically significant variations on harvest index of rice crop (Appendix VII). The highest harvest index (49.84%) was recorded in BRRI hybrid dhan2 with water hyacinth application that was statistically similar (48.69) to the same variety with rice straw. The lowest harvest index (39.87%) was found in BRRI dhan29 with water hyacinth application that was similar (42.66) to the same variety for the application of rice straw (Figure 10).

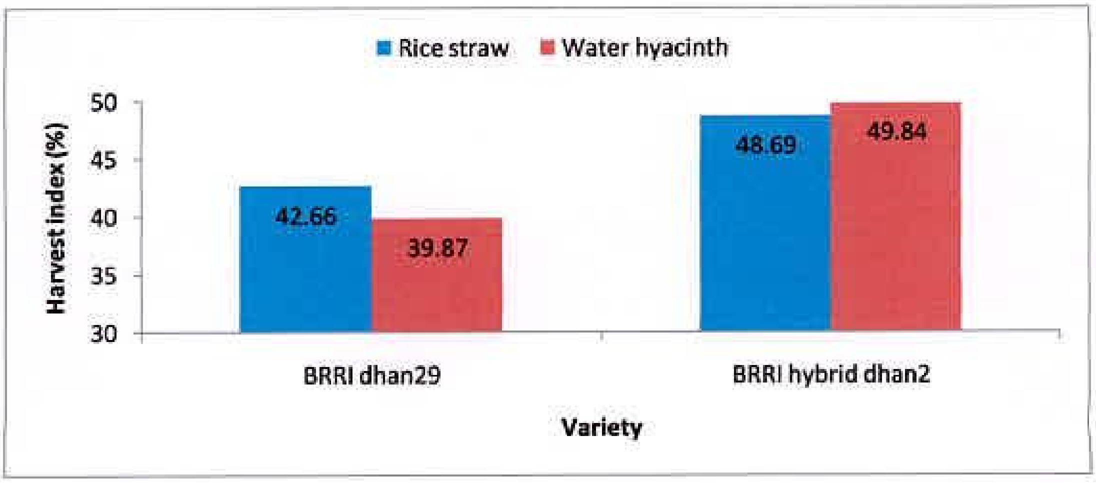


Figure 10. Interaction effect of variety and allelopathic materials on harvest index of rice ($LSD_{(0.05)}$ = 5.425)

4.5 Interaction effect of variety and concentration of allelopathic materials

4.5.1 Weed population

The combined effect of variety and concentration of allelopathic materials showed statistically insignificant variations for weed population at 30 DAT but the result was significant at 50 DAT (Appendix II). At 30 DAT, the maximum weed population (36.83 m^{-2}) was recorded from BRRI dhan29 with 0.5 kg biomass m^{-2} and the minimum (18.67 m^{-2}) was counted from BRRI hybrid dhan2 with the application of the same concentration of biomass (Table 19). At 50 DAT, the highest weed population (105.00 m^{-2}) was observed from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} that showed similar result from BRRI dhan29 with the same concentration and the lowest (24.67 m^{-2}) was recorded from BRRI dhan29 with no biomass application that was similar to BRRI hybrid dhan2 with no biomass (32.67 m^{-2}), BRRI hybrid dhan2 with 0.5 kg biomass m^{-2} (39.17 m^{-2}) and BRRI dhan29 with 0.5 kg biomass m^{-2} (49.00 m^{-2}).

Table 19. Interaction effect of variety and biomass concentration on weed population, weed dry weight and plant dry weight of rice

Treatments	Weed population ($no.m^{-2}$)		Weed dry weight ($g\ m^{-2}$)		Plant dry weight ($g\ hill^{-1}$)		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
$V_1 \times C_0$	24.67	24.67 c	22.91 a	20.01 b	0.19 ab	9.83 a	35.15
$V_1 \times C_1$	36.83	49.00 bc	10.89 ab	30.02 b	0.15 b	7.10 b	33.63
$V_1 \times C_2$	27.00	76.83 ab	9.99 ab	45.42 ab	0.14 b	6.45 b	34.65
$V_2 \times C_0$	24.33	32.67 c	21.10 ab	33.59 b	0.30 a	7.93 ab	35.78
$V_2 \times C_1$	18.67	39.17 bc	11.40 ab	30.28 b	0.26 ab	8.37 ab	39.08
$V_2 \times C_2$	31.17	105.00 a	8.66 b	70.04 a	0.20 ab	7.33 b	38.76
$LSD_{(0.05)}$	NS	42.50	13.59	26.45	0.118	1.982	NS
CV (%)	89.36	63.65	78.42	56.53	462.53	20.66	19.24

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.5.2 Weed dry weight

Statistically significant variations were observed for the interaction of variety and biomass concentration on dry weight of weed at both 30 DAT and 50 DAT (Appendix II). AT 30 DAT, the highest dry weight of weed (22.91 g m^{-2}) was measured from BRRI dhan29 with no biomass application that was similar to all other interactions except BRRI hybrid dhan2 with 1 kg biomass m^{-2} (8.66 g m^{-2}) (Table 19). At 50 DAT, the highest weed dry weight (70.04 g m^{-2}) was recorded from BRRI hybrid dhan2 with the application of 1 kg biomass m^{-2} that showed similar outcome from BRRI dhan29 with the same concentration. The lowest dry weight (20.01 g m^{-2}) was recorded from BRRI dhan29 with no biomass that was similar to other interactions except the former mentioned ones.

4.5.3 Dry weight of plants

There were significant variations observed for dry weight of rice plants due to the interaction effect of variety and biomass concentration at 30 and 60 DAT but the variation was insignificant at 90 DAT (Appendix III). At 30 DAT, the highest dry weight (0.30 g $hill^{-1}$) was recorded from BRRI hybrid dhan2 with no biomass that was similar to the same variety with other concentrations and

BRRI dhan29 with control. At that time the lowest dry weight (0.14 g $hill^{-1}$) was observed from BRRI dhan29 with 1.0 kg biomass m^{-2} that was similar to the same variety with other concentrations and BRRI hybrid dhan2 with 0.5 kg biomass m^{-2} and 1.0 kg biomass m^{-2} (Table 19). At 60 DAT, the highest dry weight (9.83 g $hill^{-1}$) was found from BRRI dhan29 with no biomass that was statistically similar to BRRI hybrid dhan2 with no biomass and 0.5 kg biomass m^{-2}. At the same date, the lowest dry weight (6.45 g $hill^{-1}$) was found from BRRI dhan29 with 1.0 kg biomass m^{-2} that was statistically similar to all other possible interactions. At 90 DAT, the maximum dry weight (39.08 g $hill^{-1}$) was recorded from BRRI hybrid dhan2 with 0.5 kg biomass m^{-2} and the minimum dry weight (33.63 g $hill^{-1}$) was found from BRRI dhan29 with the same concentration.

4.5.4 Plant height

The interaction effect of variety and biomass concentration on plant height of rice was observed statistically insignificant at 15, 30, 45, 60 and 75 DAT but it was significant at 90 DAT and at harvest (Appendix IV). At the same dates after transplanting, the maximum plant height (12.17, 21.60, 34.31, 54.17 and 66.59 cm) was observed from BRRI hybrid dhan2 with no biomass application (Table 20). The minimum height was found from BRRI dhan29 with 1.0 kg biomass m^{-2} (10.95 cm), from the same combination (19.50 cm), BRRI dhan29 with no biomass (32.16 cm), from the previous combination (52.51cm), and from BRRI dhan29 with 0.5 kg biomass m^{-2} at 15, 30, 45, 60 and 75 DAT respectively. At 90 DAT, the highest plant height (92.09 cm) was recorded from BRRI hybrid dhan2 with no biomass which was similar to the same variety with other combinations and the lowest height (77.47 cm) was found from BRRI dhan29 with no biomass that showed similar result from the same variety with other interactions. At harvest, the highest plant height (96.08 cm) was recorded from BRRI dhan29 with 1.0 kg biomass m^{-2} which was statistically similar to the other interactions of the same variety and BRRI hybrid dhan2 with control. The lowest height (88.75 cm) was found from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} that showed similar result from the same variety with 0.5 kg biomass m^{-2}, BRRI hybrid dhan2 and BRRI dhan29 with no biomass.

Table 20. Interaction effect of variety and biomass concentration on plant height of rice

Treatments	Plant height (cm) at DAT						
	15	30	45	60	75	90	Harvest
$V_1 \times C_0$	11.29	20.43	32.16	52.51	63.94	77.47 c	92.83 abc
$V_1 \times C_1$	10.98	20.41	34.66	52.99	63.49	79.31 c	93.92 ab
$V_1 \times C_2$	10.95	19.50	32.84	53.33	65.41	80.25 c	96.08 a
$V_2 \times C_0$	12.17	21.60	34.31	54.17	66.59	92.09 a	92.05 abc
$V_2 \times C_1$	11.64	19.95	32.72	52.92	64.77	90.40 ab	89.52 bc
$V_2 \times C_2$	11.17	19.51	32.24	52.59	65.11	87.89 ab	88.75 c
$LSD_{(0.05)}$	NS	NS	NS	NS	NS	4.809	4.486
CV (%)	12.28	11.69	8.27	6.65	4.90	4.646	3.98

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2 NS = Not Significant
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.5.5 Tiller number hill^{-1}

The interaction effect of variety and allelopathic materials showed statistically significant variations for tiller number hill^{-1} at different dates after transplanting (Appendix V). At 15 DAT, the highest number of tillers hill^{-1} (2.00) was obtained from the combination of BRRI dhan29 and 0.5 kg biomass m^{-2} that was similar to the same variety with the remaining concentrations and BRRI hybrid dhan2 with 0.5 kg biomass m^{-2}. The lowest number of tillers hill^{-1} (1.33) was found from BRRI hybrid dhan2 with control which was similar to the same variety with 1.0 kg biomass m^{-2} (Table 21). At 30 DAT, the highest number of tillers hill^{-1} (4.00) was obtained from BRRI dhan29 with control which was similar to all other interactions except BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} and the lowest was found from the exceptional interaction that was similar to BRRI dhan29 with 0.5 kg biomass m^{-2}. At 45 DAT, the highest number of tillers hill^{-1} (14.17) was recorded from BRRI dhan29 with 1.0 kg biomass m^{-2} which was similar to the same variety with other concentrations and the lowest number of tillers hill^{-1} (9.33) was recorded from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} which was similar to the same variety with other concentrations and BRRI dhan29 with no biomass. At 60 DAT, the highest number of tiller hill^{-1} (25.83) was observed from BRRI dhan29 with 1.0 kg biomass m^{-2} which was similar to the same variety with 0.5 kg biomass m^{-2} and the lowest number of tillers hill^{-1} (16.17) was found from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} which was similar to the same variety with other concentrations and BRRI dhan29 with no biomass. At 75 DAT, the highest number of tillers hill^{-1} (25.83) was recorded from BRRI dhan29 with 1.0 kg biomass m^{-2} which was similar to the same variety with 0.5 kg biomass m^{-2} and the lowest number of tillers hill^{-1} (18.33) was found from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} which was similar to the same variety with other concentrations and BRRI dhan29 with no biomass. At 90 DAT, the highest number of tillers hill^{-1} (18.83) was recorded from BRRI dhan29 with 1.0 kg biomass m^{-2} which was similar to the same variety with other concentrations and the lowest number of tillers hill^{-1} (11.83) was found from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} which was similar to the same variety with 0.5 kg biomass m^{-2}.

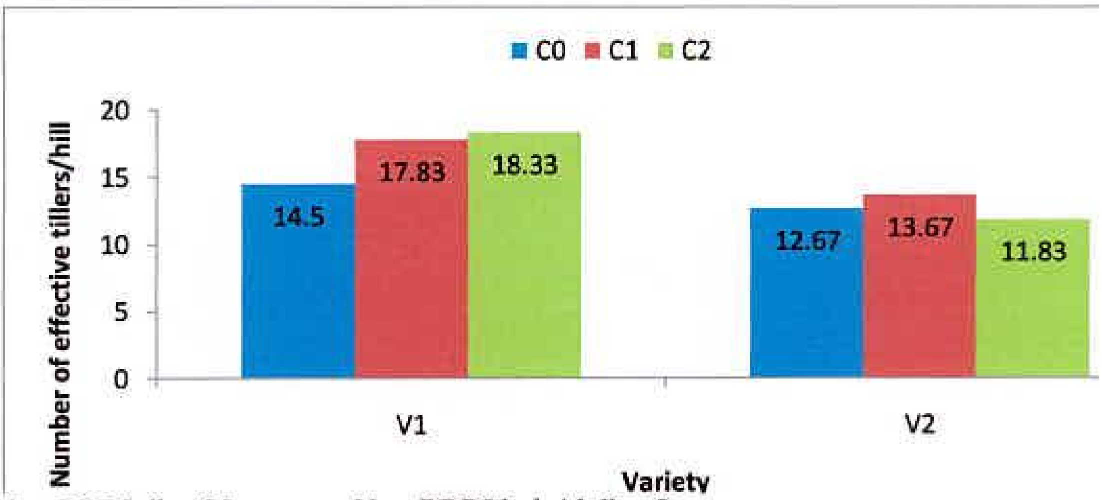
Table 21. Interaction effect of variety and biomass concentration on tiller numbers hill^{-1} of rice

Treatments	Tiller numbers hill^{-1} at DAT					
	15	30	45	60	75	90
$V_1 \times C_0$	1.83 ab	4.00 a	11.17 abc	19.83 bc	19.67 b	15.67 ab
$V_1 \times C_1$	2.00 a	3.50 abc	13.50 ab	24.00 ab	25.00 a	18.00 a
$V_1 \times C_2$	1.83 ab	3.83 ab	14.17 a	25.83 a	25.83 a	18.83 a
$V_2 \times C_0$	1.33 c	3.83 ab	10.17 bc	17.33 c	18.83 b	12.50 b
$V_2 \times C_1$	1.67 ab	3.83 ab	10.33 bc	18.17 c	20.00 b	13.50 bc
$V_2 \times C_2$	1.50 bc	2.50 c	9.33 c	16.17 c	18.33 b	11.83 c
$LSD_{(0.05)}$	0.353	1.249	3.586	4.330	4.22	3.196
CV (%)	53.88	28.48	25.60	17.49	16.21	17.34

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.5.6 Number of effective tillers $hill^{-1}$

Significant variations were observed for the number of effective tillers $hill^{-1}$ due to the interaction of variety and biomass concentration (Appendix VI). The highest number of effective tillers $hill^{-1}$ (18.33) was recorded from BRRI dhan29 with 1.0 kg biomass m^{-2} that was similar to the same variety with 0.5 kg biomass m^{-2}. The lowest number of effective tillers $hill^{-1}$ (11.83) was found from BRRI hybrid dhan2 with 1.0 kg biomass m^{-2} that was statistically similar to the same variety with other concentrations and BRRI dhan29 with no biomass (Figure 11).



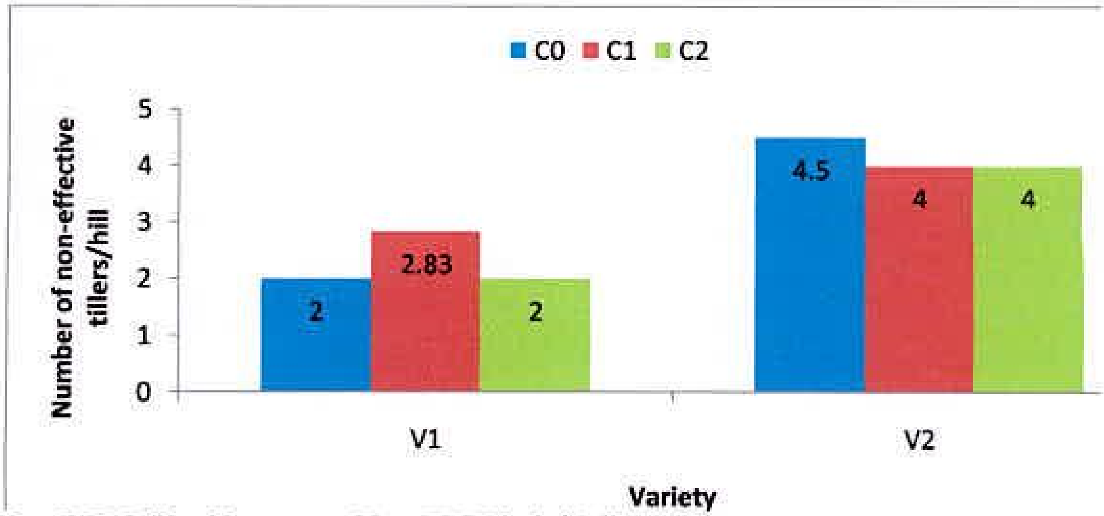
V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 11. Interaction effect of variety and concentration of allelopathic materials on number of effective tillers $hill^{-1}$ of rice ($LSD_{(0.05)}$ = 3.36)

4.5.7 Number of non-effective tillers $hill^{-1}$

There were significant variations observed for the number of non-effective tillers $hill^{-1}$ due to the interaction of variety and biomass concentration (Appendix VI). The highest number of non-effective tillers $hill^{-1}$ (4.50) was recorded from BRRI hybrid dhan2 with no biomass that was statistically similar to the same variety with other concentrations. The lowest number of non-effective tillers $hill^{-1}$ (2.00) was found from BRRI dhan29 with control and

1.0 kg biomass m^{-2} that was similar to the same variety with 0.5 kg biomass m^{-2} (Figure 12).

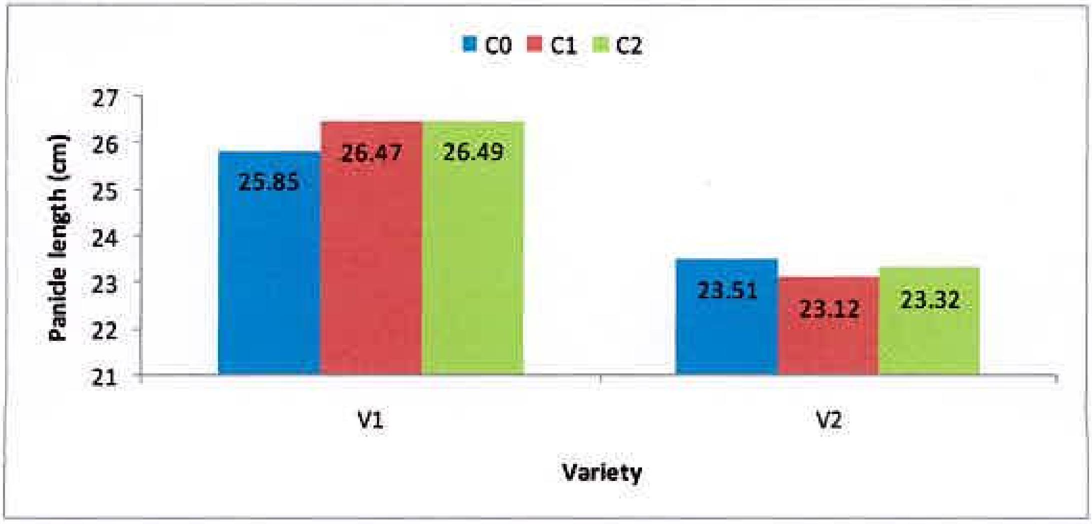


V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 12. Interaction effect of variety and concentration of allelopathic materials on number of non-effective tillers hill^{-1} of rice ($LSD_{(0.05)}$ = 1.172)

4.5.8 Panicle length

There was significant variation observed for the panicle length of rice with the interactions of variety and concentration of allelopathic materials (Appendix VI). The highest length of panicle (26.49 cm) was recorded from BRRI dhan29 with 1.0 kg biomass m^{-2} that was similar to the same variety with other two concentrations. The lowest panicle length (23.12 cm) was observed from BRRI hybrid dhan2 with 0.5 kg biomass m^{-2} that was similar to the same variety with other two concentrations (Figure 13).

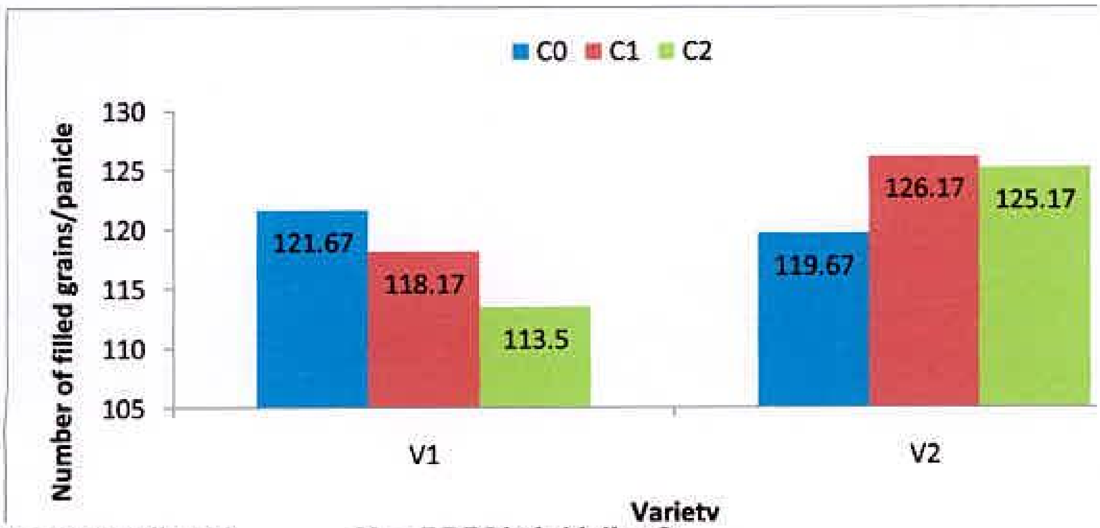


V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 13. Interaction effect of variety and concentration of allelopathic materials on panicle length of rice ($LSD_{(0.05)}$ = 0.865)

4.5.9 Number of filled grains panicle^{-1}

Statistically insignificant variations were found for the number of filled grains panicle^{-1} with variety and biomass concentration interactions (Appendix VI). The maximum number of filled grains panicle^{-1} (126.17) was recorded from BRRI hybrid dhan2 with 0.5 kg biomass m^{-2} and the minimum number of filled grains panicle^{-1} (113.50) was found from BRRI dhan29 with 1.0 kg biomass m^{-2} (Figure 14).

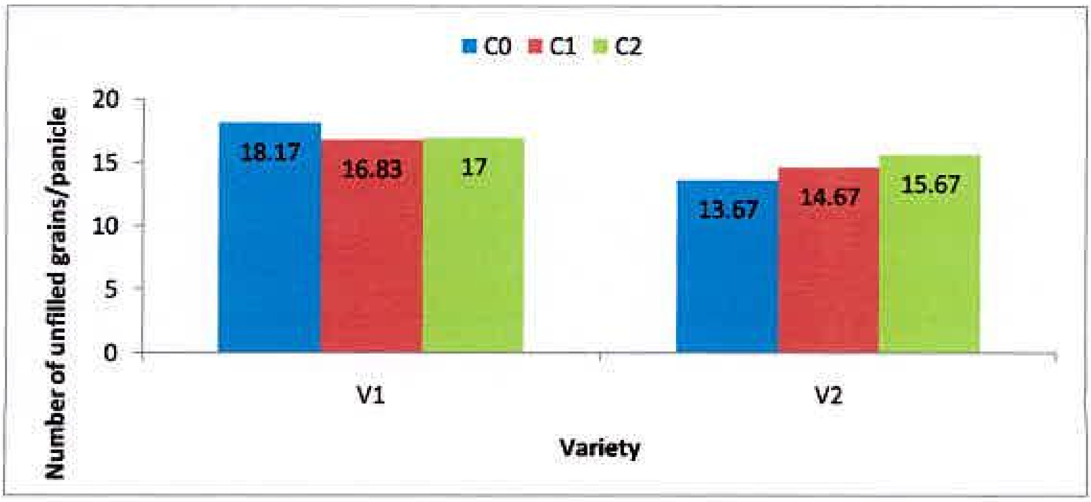


V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 14. Interaction effect of variety and concentration of allelopathic materials on number of filled grains panicle^{-1} of rice ($LSD_{(0.05)}$ = 14.26)

4.5.10 Number of unfilled grains panicle^{-1}

Statistically significant variations were found for the number of unfilled grains panicle^{-1} with variety and biomass concentration interactions (Appendix VI). The highest number of unfilled grains panicle^{-1} (18.17) was recorded from BRRI dhan29 with no biomass which was statistically similar to the same variety with other two concentrations and the lowest number of unfilled grains panicle^{-1} (13.67) was found from BRRI hybrid dhan2 with control that was similar to the same variety with other concentrations (Figure 15).

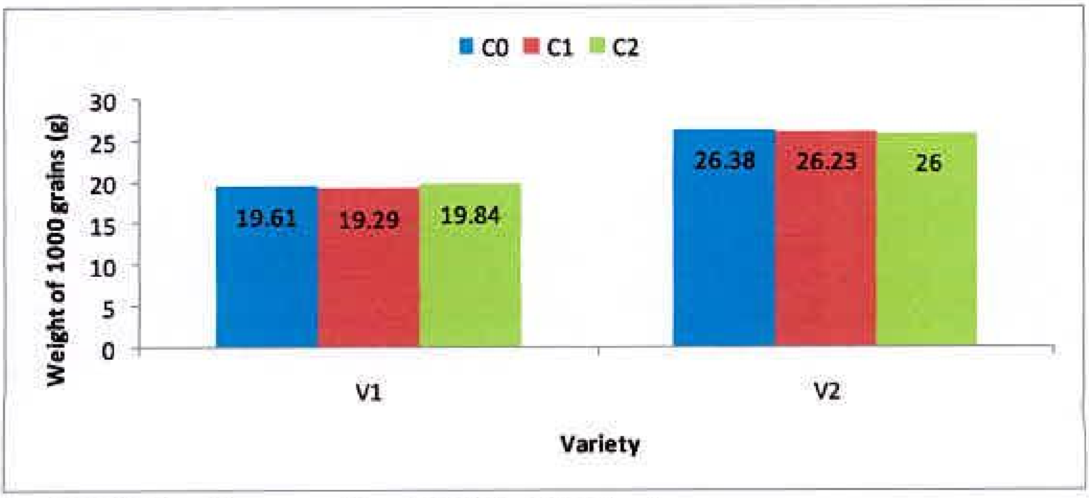


V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 15. Interaction effect of variety and concentration of allelopathic materials on number of unfilled grains panicle^{-1} of rice ($LSD_{(0.05)}$ = 2.392)

4.5.11 Weight of 1000 grains

Significant variations were observed for the interaction of variety and concentration of allelopathic materials on weight of 1000 grains of rice (Appendix VII). The highest weight of thousand grains (26.38 g) was recorded from BRRI hybrid dhan2 with no biomass incorporation which was similar to the same variety with other interactions. The lowest weight of thousand grains (19.29 g) was found from BRRI dhan29 with 0.5 kg biomass m^{-2} which was similar to the same variety with other interactions (Figure 16).

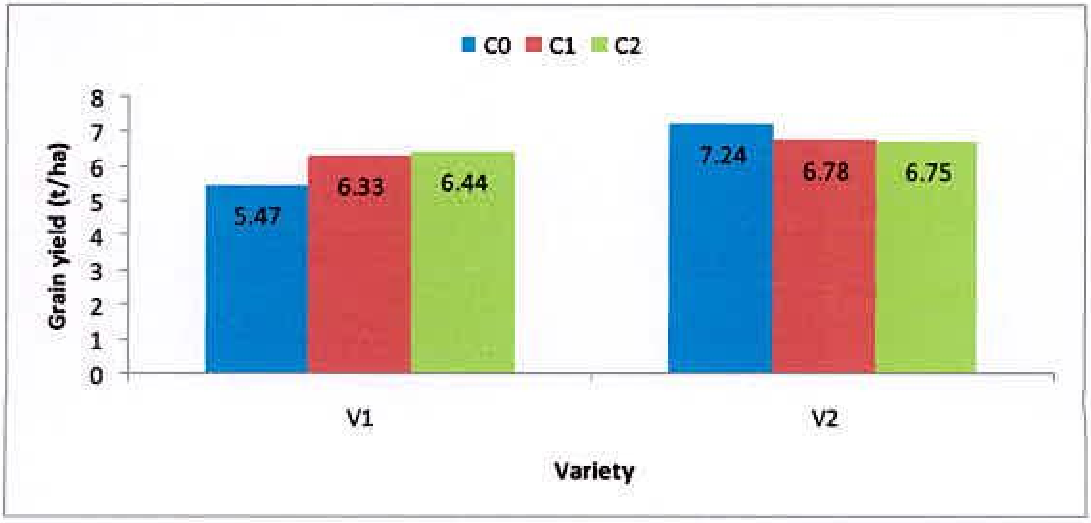


V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 16. Interaction effect of variety and concentration of allelopathic materials on weight of 1000 grains of rice ($LSD_{(0.05)}$ = 0.594)

4.5.12 Grain yield

There was significant variation observed for the interaction of variety and biomass concentration on grain yield (Appendix VII). The highest grain yield (7.24 t ha^{-1}) was recorded from BRRI hybrid dhan2 with control which was similar to the same variety with other concentrations and BRRI dhan29 with 1.0 kg biomass m^{-2}. The lowest grain yield (5.47 t ha^{-1}) was found from BRRI dhan29 with no biomass incorporation (Figure 17).

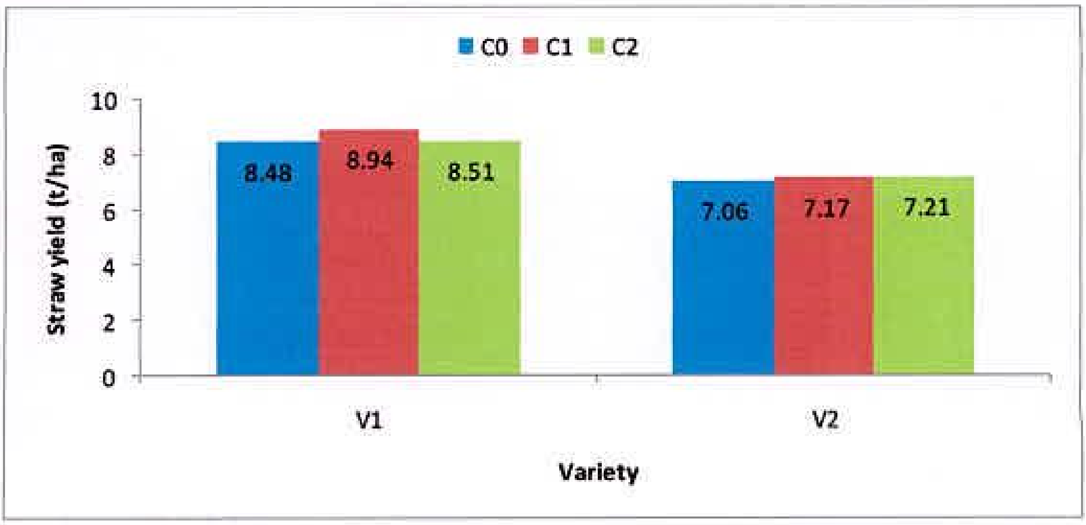


V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 17. Interaction effect of variety and concentration of allelopathic materials on grain yield of rice ($LSD_{(0.05)}$ = 0.823)

4.5.13 Straw yield

The interaction effect of variety and concentration of allelopathic materials showed statistically significant variations on straw yield (Appendix VII). The highest straw yield (8.94 t ha^{-1}) was recorded from BRRI dhan29 with 0.5 kg biomass m^{-2} which was similar to the same variety with other two interactions. The lowest straw yield (7.06 t ha^{-1}) was found from BRRI hybrid dhan2 with control which was similar to the same variety with other interactions (Figure 18).

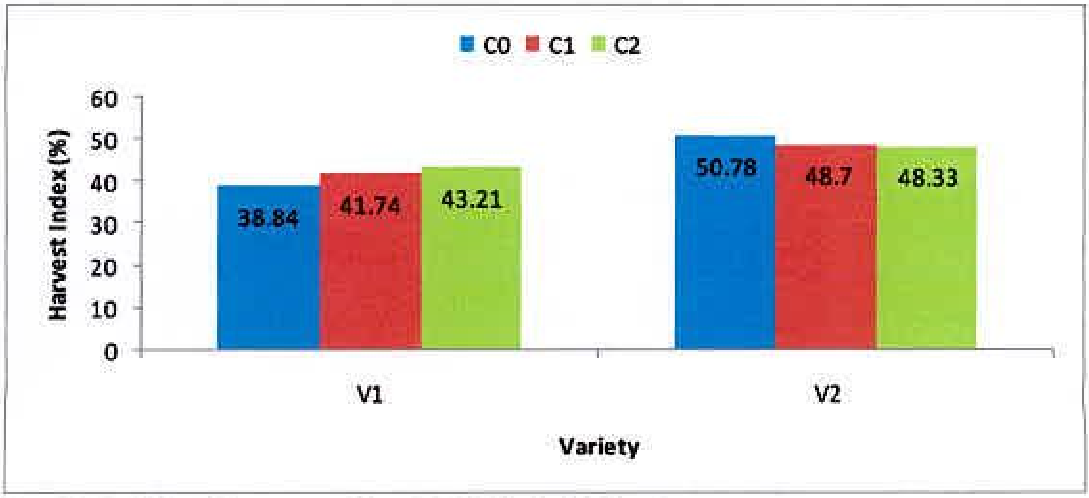


V_1 = BRRI dhan29 $\quad$ V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} $\quad$ C_1 = 0.5 kg biomass m^{-2} $\quad$ C_2 = 1.0 kg biomass m^{-2}

Figure 18. Interaction effect of variety and concentration of allelopathic materials on straw yield of rice ($LSD_{(0.05)}$ = 1.33)

4.5.14 Harvest index

The interaction effect of variety and concentration of allelopathic materials showed statistically significant variations on harvest index of rice crop (Appendix VII). The highest harvest index (50.78%) was recorded in BRRI hybrid dhan2 with no biomass application that was similar to the same variety with other interactions. The lowest harvest index (38.84%) was found in BRRI dhan29 with control that was similar to the same variety due to other concentrations (Figure 19).



V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

Figure 19. Interaction effect of variety and concentration of allelopathic materials on harvest index of rice ($LSD_{(0.05)}$ = 6.422)

4.6 Interaction effect of allelopathic materials and their concentrations

4.6.1 Weed population

The combined effect of allelopathic materials and their concentrations showed statistically insignificant variations for weed population at 30 DAT but the result was significant at 50 DAT (Appendix II). At 30 DAT, the maximum weed population (43.83 m^{-2}) was recorded from the interaction of water hyacinth and 0.5 kg biomass m^{-2} and the minimum (14.67 m^{-2}) was counted from rice straw with the application of the same concentration of biomass (Table 22). At 50 DAT, the highest weed population (103.50 m^{-2}) was observed from water hyacinth with 1.0 kg biomass m^{-2} that showed similar result from the same material with 0.5 kg biomass m^{-2} and from rice straw with 1.0 kg biomass m^{-2} and the lowest (15.33 m^{-2}) was recorded from rice straw with no biomass application that was similar to the same material with 1.0 kg biomass m^{-2} and water hyacinth with no biomass.

Table 22. Interaction effect of allelopathic materials and their concentrations on weed population, weed dry weight and plant dry weight of rice

Treatments	Weed population ($no.m^{-2}$)		Weed dry weight ($g\ m^{-2}$)		Plant dry weight ($g\ hill^{-1}$)		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
$M_1 \times C_0$	22.00	15.33d	22.53a	23.74b	0.25	8.31ab	34.43
$M_1 \times C_1$	14.67	24.33cd	8.62b	20.86b	0.20	7.89ab	36.87
$M_1 \times C_2$	18.33	78.33ab	8.56b	46.33ab	0.19	6.40b	36.28
$M_2 \times C_0$	27.00	42.00bcd	21.49ab	29.86b	0.24	9.46a	36.50
$M_2 \times C_1$	43.83	63.83abc	13.66ab	39.44b	0.21	7.59ab	35.84
$M_2 \times C_2$	39.83	103.50a	11.88ab	69.15a	0.16	7.38b	37.12
$LSD_{(0.05)}$	NS	42.503	13.589	26.449	NS	1.982	NS
CV (%)	89.36	63.65	78.42	56.53	462.53	20.66	19.24

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.6.2 Weed dry weight

Statistically significant variations were observed for the interaction of allelopathic materials and biomass concentration on dry weight of weed at both 30 DAT and 50 DAT (Appendix II). AT 30 DAT, the highest dry weight of weed (22.53 g m^{-2}) was measured from the interaction of rice straw and no biomass application that was similar to water hyacinth with all concentrations and the lowest dry weight (8.56 g m^{-2}) was found from rice straw with 1.0 kg biomass m^{-2} which was similar to the same material with 0.5 kg biomass m^{-2} and water hyacinth with all concentrations (Table 22). At 50 DAT, the highest weed dry weight (69.15 g m^{-2}) was recorded from water hyacinth with the application of 1.0 kg biomass m^{-2} that showed similar outcome from rice straw with the same concentration. The lowest dry weight (20.86 g m^{-2}) was recorded from rice straw with 0.5 kg biomass m^{-2} that was similar to all other interactions except the highest one.

4.6.3 Dry weight of plants

There were insignificant variations for dry weight of rice plants due to the interaction effect of materials and concentration at 30 and 90 DAT but the variation was significant at 60 DAT (Appendix III). At 30 DAT, the maximum plant dry weight (0.25 g $hill^{-1}$) was weighed from rice straw with no biomass and the minimum (0.16 g $hill^{-1}$) was found from water hyacinth with 1.0 kg biomass m^{-2}. At 60 DAT, the highest plant dry weight (9.46 g $hill^{-1}$) was weighed from water hyacinth with no biomass that was similar to the same material with 0.5 kg biomass m^{-2} and rice straw with control and 0.5 kg biomass m^{-2} and the lowest (6.40 g $hill^{-1}$) was found from rice straw with 1.0 kg biomass m^{-2} that was similar to all possible combinations except the highest one. At 90 DAT, the maximum plant dry weight (37.12 g $hill^{-1}$) was recorded from water hyacinth with 1.0 kg biomass m^{-2} and the minimum (34.43 g $hill^{-1}$) was found from rice straw with control (Table 22).

4.6.4 Plant height

The interaction effect of materials and biomass concentration on plant height of rice was observed statistically insignificant at 15, 30 DAT and at harvest but it was significant at 45, 60, 75 and 90 DAT (Appendix IV). At 15 and 30 DAT, the maximum plant height (12.16 cm and 21.70 cm) was observed from rice straw with no biomass application. The minimum height (10.64 cm and 19.54 cm) was found from water hyacinth with 1.0 kg biomass m^{-2} (Table 23). At 45 DAT, the highest plant height (35.73 cm) was recorded from water hyacinth with 0.5 kg biomass m^{-2} which was similar to the same material with other combinations and the lowest height (31.34 cm) was found from rice straw with 1.0 kg biomass m^{-2} that showed similar result from the all possible interactions except the highest one. At 60 DAT, the highest plant height (56.55 cm) was recorded from water hyacinth with 1.0 kg biomass m^{-2} which was statistically similar to the other interactions of the same material and the lowest height (49.37 cm) was found from rice straw with 1.0 kg biomass m^{-2} that showed similar result from the same material with other interactions. At 75 DAT, the highest plant height (68.62 cm) was recorded from water hyacinth with 1.0 kg biomass m^{-2} which was similar to the other interactions of the same material and rice straw with control and the lowest height (61.91 cm) was found from rice straw with 1.0 kg biomass m^{-2} that showed similar result from the all possible interactions except the highest one. At 90 DAT, the highest plant height (86.91 cm) was recorded from water hyacinth with 1.0 kg biomass m^{-2} that was similar to all possible interactions except rice straw and 1.0 kg biomass m^{-2} which was the lowest height (81.23 cm) that showed similar result from the other interactions of the same material. At harvest, the maximum plant height (93.67 cm) was observed from water hyacinth with 1.0 kg biomass m^{-2} and the minimum height (91.17 cm) was found from rice straw with 1.0 kg biomass m^{-2}.

Table 23. Interaction effect of allelopathic materials and their concentrations on plant height of rice

Treatments	Plant height (cm) at DAT						
	15	30	45	60	75	90	Harvest
$M_1 \times C_0$	12.16	21.70	31.79b	52.17bc	65.32ab	83.82abc	93.13
$M_1 \times C_1$	11.40	19.67	31.64b	50.71c	63.02b	83.60abc	91.95
$M_1 \times C_2$	10.83	19.67	31.34b	49.37c	61.91b	81.23c	91.17
$M_2 \times C_0$	11.30	20.33	34.67ab	54.51abc	65.22ab	85.75abc	91.75
$M_2 \times C_1$	11.22	20.70	35.73a	55.20ab	65.24ab	86.11ab	91.48
$M_2 \times C_2$	10.64	19.54	33.74ab	56.55a	68.62a	86.91a	93.67
$LSD_{(0.05)}$	NS	NS	3.356	4.322	3.89	4.809	NS
CV (%)	12.28	11.69	8.27	6.65	4.90	4.646	3.98

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.6.5 Tiller number $hill^{-1}$

The combined effect of allelopathic materials and concentrations showed statistically insignificant variations for tiller numbers $hill^{-1}$ at 15, 30 and 90 DAT but at 45, 60 and 75 DAT the variations were significant (Appendix V). At 15 and 30 DAT, the maximum tiller numbers $hill^{-1}$ (2.17 and 4.17) were counted from water hyacinth with 0.5 kg biomass m^{-2} and the minimum (1.83 and 2.93) was found from rice straw with 1.0 kg biomass m^{-2} (Table 24). At 45 DAT, the highest tiller numbers $hill^{-1}$ (14.17) was recorded from water hyacinth with 1.0 kg biomass m^{-2} that was similar to the same material with other concentrations and the lowest (9.33) was found from rice straw with 1.0

kg biomass m^{-2} which was similar to the same material with other concentrations. At 60 DAT, the highest tiller number $hill^{-1}$ (23.83) was recorded from water hyacinth with 1.0 kg biomass m^{-2} that was similar to the same material with 0.5 kg biomass m^{-2} and the lowest (18.17) was found from rice straw with 1.0 kg biomass m^{-2} which was similar to all possible interactions except the highest one. At 75 DAT, the highest tiller number $hill^{-1}$ (25.00) was recorded from water hyacinth with 1.0 kg biomass m^{-2} that was similar to the same material with 0.5 kg biomass m^{-2} and the lowest (19.00) was found from the same material with no biomass application which was similar to all possible interactions except the water hyacinth with 0.5 kg biomass m^{-2} and 1.0 kg biomass m^{-2}. At 90 DAT, the maximum tiller number $hill^{-1}$ (16.33) was counted from water hyacinth with 1.0 kg biomass m^{-2} and the minimum (13.33) was found from the same material with control.

Table 24. Interaction effect of allelopathic materials and their concentrations on tiller numbers $hill^{-1}$ of rice

Treatments	Tiller number $hill^{-1}$ at DAT					
	15	30	45	60	75	90
$M_1 \times C_0$	1.83	3.83	9.67 b	18.67 b	19.50 bc	14.83
$M_1 \times C_1$	1.85	3.17	10.00 b	20.17 ab	21.50 abc	15.83
$M_1 \times C_2$	1.83	2.93	9.33 b	18.17 b	19.17 c	14.33
$M_2 \times C_0$	1.83	4.00	11.67 ab	18.50 b	19.00 c	13.33
$M_2 \times C_1$	2.17	4.17	13.83 a	22.00 ab	23.50 ab	15.67
$M_2 \times C_2$	2.00	3.50	14.17 a	23.83 a	25.00 a	16.33
$LSD_{(0.05)}$	NS	NS	3.586	4.330	4.223	NS
CV (%)	53.88	28.48	25.60	17.49	16.21	17.34

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.6.6 Number of effective tillers $hill^{-1}$

No significant variations were observed for the number of effective tillers $hill^{-1}$ due to material and biomass concentration interactions (Appendix VI). The maximum number of effective tillers $hill^{-1}$ (16.17) was recorded from rice straw incorporated field with 0.5 kg biomass m^{-2} and the minimum number of effective tillers hill^{-1} (13.17) was found from water hyacinth with control (Table 25).

4.6.7 Number of non-effective tillers hill^{-1}

There was significant variation observed for the number of non-effective tillers hill^{-1} for interactions of material and biomass concentration (Appendix VI). The highest number of non-effective tillers hill^{-1} (3.67) was recorded from water hyacinth incorporated field with 1.0 kg biomass m^{-2} that was similar to other possible interactions except rice straw with 1.0 kg biomass m^{-2} which was the lowest (2.33) number of non-effective tillers hill^{-1} that was similar to the same variety with other combinations (Table 25).

4.6.8 Panicle length

Insignificant variations were observed for the panicle length of rice with the interactions of allelopathic materials and their concentration (Appendix VI). The maximum length of panicle (24.98 cm) was recorded from rice straw with 1.0 kg biomass m^{-2} and the minimum panicle length (24.48 cm) was found from water hyacinth with no biomass application (Table 25).

Table 25. Interaction effect of allelopathic materials and their concentrations on effective tillers, non-effective tillers, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1}

Treatments	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
$M_1 \times C_0$	14.00	3.17 ab	24.88	122.00	16.33
$M_1 \times C_1$	16.17	3.17 ab	24.86	124.67	15.83
$M_1 \times C_2$	14.33	2.33 b	24.98	119.00	15.83
$M_2 \times C_0$	13.17	3.33 ab	24.48	119.33	15.50
$M_2 \times C_1$	15.33	3.67 a	24.73	119.67	15.67
$M_2 \times C_2$	15.83	3.67 a	24.84	119.67	16.83
$LSD_{(0.05)}$	NS	1.172	NS	NS	NS
CV (%)	18.55	29.71	2.85	9.65	12.21

M_1 = Rice straw; M_2 = Water hyacinth; NS = Not Significant

C_0 = 0 kg biomass m^{-2}; C_1 = 0.5 kg biomass m^{-2}; C_2 = 1.0 kg biomass m^{-2}

4.6.9 Number of filled grains panicle^{-1}

Statistically insignificant variations were found for the number of filled grains panicle^{-1} with biomass and concentration interactions (Appendix VI). The maximum number of filled grains panicle^{-1} (124.67) was recorded from rice straw with 0.5 kg biomass m^{-2} and the minimum number of filled grains panicle^{-1} (119.00) was found from the same biomass with 1.0 kg biomass m^{-2} (Table 25).

4.6.10 Number of unfilled grains panicle^{-1}

There was insignificant variation observed for the number of unfilled grains panicle^{-1} with biomass and their concentrations (Appendix VI). The maximum number of unfilled grains panicle^{-1} (16.83) was recorded from water hyacinth with 1.0 kg biomass m^{-2} and the minimum number of unfilled grains panicle^{-1} (15.50) was found from the same biomass with control (Table 25).

4.6.11 Weight of 1000 grains

Insignificant variation was observed for the interaction of allelopathic materials and their concentrations on weight of 1000 grains of rice (Appendix VII). The maximum weight of thousand grains (23.03 g) was recorded from water hyacinth with no biomass incorporation and the minimum (22.43 g) was found from rice straw with 1.0 kg biomass m^{-2} (Table 26).

4.6.12 Grain yield

Statistically insignificant variations were found for the interaction of materials and their concentrations on grain yield of rice (Appendix VII). The maximum grain yield (7.11 t ha^{-1}) was recorded from water hyacinth with 1.0 kg biomass m^{-2} and the minimum grain yield (6.29 t ha^{-1}) was found from rice straw with 1.0 kg biomass m^{-2} (Table 26).

Table 26. Interaction effect of allelopathic materials and their concentrations on weight of 1000 grains, grain yield, straw yield and harvest index of rice

Treatments	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
$M_1 \times C_0$	22.96	6.31	7.62	45.25
$M_1 \times C_1$	22.65	6.38	7.50	46.96
$M_1 \times C_2$	22.43	6.29	7.56	44.82
$M_2 \times C_0$	23.03	6.40	7.93	44.38
$M_2 \times C_1$	22.87	6.73	8.82	43.48
$M_2 \times C_2$	22.92	7.11	8.17	46.71
$LSD_{(0.05)}$	NS	NS	NS	NS
CV (%)	2.13	10.34	13.77	11.59

M_1 = Rice straw M_2 = Water hyacinth NS = Not Significant
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2} C_2 = 1.0 kg biomass m^{-2}

4.6.13 Straw yield

Insignificant variations were found for the interactions of allelopathic materials and their concentrations on straw yield of rice (Appendix VII). The maximum straw yield (8.82 t ha^{-1}) was weighed from water hyacinth with 0.5 kg biomass m^{-2} and the minimum straw yield (7.50 t ha^{-1}) was found from rice straw with 0.5 kg biomass m^{-2} (Table 26).

4.6.14 Harvest index

The interaction effect of allelopathic materials and their concentration showed statistically insignificant variations on harvest index of rice crop (Appendix VII). The maximum harvest index (46.96%) was recorded in rice straw with 0.5 kg biomass m^{-2} and the minimum harvest index (43.48%) was found in water hyacinth with the same concentration of biomass (Table 26).

4.7 Interaction effect of variety, allelopathic material and concentration

4.7.1 Weed population

Statistically insignificant variation was observed for the interaction of variety, allelopathic material and biomass concentration on weed population at 30 DAT but significant at 50 DAT (Appendix II). The maximum weed population

($52.33\ m^{-2}$) was recorded from BRRI dhan29 with water hyacinth and 0.5 kg biomass m^{-2} and the minimum (11.33) was found from the same variety with rice straw and the same concentration at 30 DAT (Table 27). At 50 DAT, the highest weed population ($134.33\ m^{-2}$) was observed from BRRI hybrid dhan2 with water hyacinth and 1.0 kg biomass m^{-2} that showed similar result from BRRI dhan29 with water hyacinth and 0.5 kg biomass m^{-2} and from the same variety with rice straw and 1.0 kg biomass m^{-2}. The lowest weed population ($15.67\ m^{-2}$) was observed from BRRI dhan29 with rice straw and control that showed similar result from the same variety with the same material and 0.5 kg biomass m^{-2}.

4.7.2 Weed dry weight

Statistically insignificant variation was observed for the interaction of variety, biomass and biomass concentration on weed dry weight at both cases of 30 DAT and 50 DAT (Appendix II). The maximum dry weight of weed (24.06 g m^{-2}) was recorded from BRRI dhan29 with water hyacinth and no biomass application and the minimum weight (7.29 g m^{-2}) was observed from the same variety with rice straw and the application of 0.5 kg biomass m^{-2} at 30 DAT (Table 27). At 50 DAT, the maximum dry weight of weed (52.94 g m^{-2}) was found from BRRI hybrid dhan2 with water hyacinth and 1.0 kg biomass m^{-2} and the minimum weight (16.07 g m^{-2}) was found from BRRI dhan29 with rice straw and no biomass application.

Table 27. Interaction effect of variety, allelopathic materials and their concentrations on weed population, weed dry weight and plant dry weight of rice

Treatments	Weed population ($no.m^{-2}$)		Weed dry weight ($g\ m^{-2}$)		Plant dry weight ($g\ hill^{-1}$)		
	30 DAT	50 DAT	30 DAT	50 DAT	30 DAT	60 DAT	90 DAT
$V_1 \times M_1 \times C_0$	18.67	15.67 c	21.77	16.07	0.17	7.73 bc	33.71
$V_1 \times M_1 \times C_1$	11.33	16.00 c	7.29	18.91	0.16	8.39 bc	32.83
$V_1 \times M_1 \times C_2$	24.67	81.00 ab	9.83	46.52	0.19	6.86 bc	34.56
$V_1 \times M_2 \times C_0$	30.67	43.67 bc	24.06	25.95	0.21	11.94 a	36.58
$V_1 \times M_2 \times C_1$	52.33	82.00 ab	14.49	41.13	0.15	5.92 c	34.43
$V_1 \times M_2 \times C_2$	29.33	72.67 bc	10.14	44.35	0.40	6.05 c	34.74
$V_2 \times M_1 \times C_0$	25.33	25.00 bc	23.28	33.40	0.32	8.88 a	35.14
$V_2 \times M_1 \times C_1$	12.00	32.67 bc	9.96	22.80	0.24	7.39 bc	40.92
$V_2 \times M_1 \times C_2$	12.00	75.67 abc	4.89	46.13	0.19	5.9 4c	38.00
$V_2 \times M_2 \times C_0$	23.33	40.33 bc	18.92	33.77	0.27	6.98 bc	36.42
$V_2 \times M_2 \times C_1$	25.33	45.67 bc	12.84	37.76	0.28	9.36 ab	37.25
$V_2 \times M_2 \times C_2$	50.33	134.33 a	13.63	52.94	0.23	8.72 bc	39.51
$LSD_{(0.05)}$	NS	60.109	NS	NS	NS	2.803	NS
CV (%)	89.36	63.65	78.42	56.53	462.53	20.66	19.24

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
M_1 = Rice straw M_2 = Water hyacinth
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.7.3 Dry weight of plants

There were insignificant variations for dry weight of rice plants due to the interaction effect of variety, allelopathic materials and concentration at 30 and 90 DAT but the variation was significant at 60 DAT (Appendix III). At 30 DAT, the maximum plant dry weight (0.40 g $hill^{-1}$) was weighed from BRRI dhan29 with water hyacinth and 1.0 kg biomass m^{-2} and the minimum (0.15 g $hill^{-1}$) was found from the same variety with the same material and 0.5 kg biomass m^{-2} (Table 27). At 60 DAT, the highest plant dry weight (11.94 g $hill^{-1}$) was weighed from BRRI dhan29 with water hyacinth and control that was similar to BRRI hybrid dhan2 with no biomass application. The lowest (5.92 g $hill^{-1}$) was found from BRRI dhan29 with water hyacinth and 0.5 kg biomass m^{-2} that was similar to the same variety with the same material and 1.0 kg biomass m^{-2} and from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2}. At 90 DAT, the maximum plant dry weight (40.92 g $hill^{-1}$) was recorded from BRRI hybrid dhan2 with rice straw and 0.5 kg biomass m^{-2} and the minimum weight (32.83 g $hill^{-1}$) was found from BRRI dhan29 with the same material and the same concentration.

4.7.4 Plant height

The interaction effect of variety, biomass and their concentration showed statistically insignificant variation for plant height at 15 and 30 DAT and significant variation at 45, 60, 75, 90 DAT and at harvest (Appendix IV). At 15 and 30 DAT, the maximum plant height (12.30 cm and 22.60 cm respectively) was found from BRRI hybrid dhan2 with rice straw and application of no biomass and the minimum height (10.14 cm and 18.67 cm) was found from BRRI dhan29 with rice straw and 1.0 kg biomass m^{-2} (Table 28). At 45 DAT, the highest plant height (36.97 cm) was recorded from BRRI dhan29 with water hyacinth and the application of 0.5 kg biomass m^{-2} that was similar to the same variety with the same material and no biomass application and from BRRI hybrid dhan2 with water hyacinth and all level of concentrations. The lowest plant height (30.25 cm) was recorded from BRRI dhan29 with rice straw and application of no biomass that was similar to the same variety with the same material and 1.0 kg biomass m^{-2} and from BRRI hybrid dhan2 with rice straw and 0.5 kg and 1.0 kg biomass m^{-2}. At 60 DAT, the highest plant height (57.08 cm) was recorded from BRRI dhan29 with water hyacinth and the application of 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and 0.5 kg biomass m^{-2} and from BRRI hybrid dhan2 with water hyacinth and 1.0 kg biomass m^{-2}. The lowest plant height (49.16 cm) was recorded from BRRI hybrid dhan2 with rice straw and application of 1.0 kg biomass m^{-2} that was similar to BRRI dhan29 with rice straw and 0.5 kg and 1.0 kg biomass m^{-2}. At 75 DAT, the highest plant height (69.26 cm) was recorded from BRRI dhan29 with water hyacinth and the application of 1.0 kg biomass m^{-2} that was similar to BRRI hybrid dhan2 with water hyacinth and all level of concentrations. The lowest plant height (61.57 cm) was found from BRRI dhan29 with rice straw and application of 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and 0.5 kg biomass m^{-2} and from BRRI hybrid dhan2 with the same material and 0.5 kg and 1.0 kg biomass m^{-2}. At 90 DAT, the highest plant height (93.49 cm) was recorded from BRRI hybrid dhan2 with water hyacinth and the application of no biomass that was similar to the same variety with the same material and other two concentrations. The lowest plant height (76.15 cm) was found from BRRI dhan29 with rice straw and application of 1.0 kg biomass m^{-2} that was similar to the same variety with the same material other two concentrations. At harvest, the highest plant height (97.67 cm) was recorded from BRRI dhan29 with water hyacinth and the application of 1.0 kg biomass m^{-2} that was similar to the same variety with rice straw and all level of concentrations. The lowest plant height (87.83 cm) was found from BRRI hybrid dhan2 with rice straw and the application of 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and 0.5 kg biomass m^{-2}.

Table 28. Interaction effect of variety, allelopathic materials and concentrations on plant height of rice

Treatments	Plant height (cm) at DAT						
	15	30	45	60	75	90	Harvest
$V_1 \times M_1 \times C_0$	12.01	20.81	30.25c	51.23abcd	64.74abcd	76.94e	95.67ab
$V_1 \times M_1 \times C_1$	10.91	19.39	32.35abc	50.43bcd	63.46bcd	77.56de	95.50ab
$V_1 \times M_1 \times C_2$	10.14	18.67	31.30bc	49.58cd	61.57d	76.15e	94.50abc
$V_1 \times M_2 \times C_0$	10.57	20.06	34.06abc	53.79abcd	63.15bcd	78.00de	90.00bcd
$V_1 \times M_2 \times C_1$	11.05	21.43	36.97a	55.56abc	63.51bcd	81.06cde	92.33abcd
$V_1 \times M_2 \times C_2$	10.47	20.33	34.38abc	57.08a	69.26a	84.35bcd	97.67a
$V_2 \times M_1 \times C_0$	12.30	22.60	33.33abc	53.12abcd	65.89abcd	90.69ab	90.00bcd
$V_2 \times M_1 \times C_1$	11.89	19.94	30.93bc	51.00abcd	62.58bcd	89.64ab	88.40cd
$V_2 \times M_1 \times C_2$	11.53	20.27	31.37bc	49.16d	62.25cd	86.31bc	87.83d
$V_2 \times M_2 \times C_0$	12.03	20.59	35.29ab	55.23abcd	67.29abc	93.49a	93.50abcd
$V_2 \times M_2 \times C_1$	11.39	19.97	34.50abc	54.83abcd	66.96abcd	91.16ab	90.62bcd
$V_2 \times M_2 \times C_2$	10.82	18.75	33.11abc	56.02ab	67.98ab	89.46ab	89.67bcd
$LSD_{(0.05)}$	NS	NS	4.746	6.113	5.503	6.801	6.344
CV (%)	12.28	11.69	8.27	6.65	4.90	4.646	3.98

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
M_1 = Rice straw M_2 = Water hyacinth
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.7.5 Tiller number hill^{-1}

The combined effect of variety, allelopathic materials and concentrations showed statistically significant variations for tiller number hill^{-1} at 15, 45, 60, 75 and 90 DAT but at 30 DAT the variation was insignificant (Appendix V). At 15 DAT, the highest tiller number hill^{-1} (2.33) was counted from BRRI dhan29 with water hyacinth and 0.5 kg biomass m^{-2} that was similar to the same variety with the same material and control and 1.0 kg biomass m^{-2} and the lowest tiller number hill^{-1} (1.00) was counted from BRRI hybrid dhan2 with rice straw and control that was similar to the same variety with the same material and 1.0 kg biomass m^{-2} (Table 29). At 30 DAT, the maximum tiller number hill^{-1} (4.33) was counted from BRRI dhan29 with water hyacinth and no biomass and the minimum (2.57) was found from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2}. At 45 DAT, the highest tiller number hill^{-1} (17.67) was recorded from BRRI dhan29 with water hyacinth and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and 0.5 kg biomass m^{-2} and the lowest tiller number hill^{-1} (8.00) was counted from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and other two levels of concentrations. At 60 DAT, the highest tiller number hill^{-1} (30.00) was recorded from BRRI dhan29 with water hyacinth and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and 0.5 kg biomass m^{-2} and the lowest tiller number hill^{-1} (14.67) was counted from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and other two levels of concentrations. At 75 DAT, the highest tiller number hill^{-1} (30.33) was recorded from BRRI dhan29 with water hyacinth and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and 0.5 kg biomass m^{-2} and the lowest tiller number hill^{-1} (17.00) was counted from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and other two levels of concentrations. At 90 DAT, the highest tiller number hill^{-1} (21.00) was recorded from BRRI dhan29 with water hyacinth and 1.0 kg biomass m^{-2} that was similar to the same variety with rice straw and 0.5 kg biomass m^{-2} and the lowest tiller number $hill^{-1}$ (12.00) was counted from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2} that was identical to the same variety with water hyacinth and no biomass application.

Table 29. Interaction effect of variety, allelopathic materials and their concentrations on tiller number of rice

Treatments	Tiller number $hill^{-1}$ at DAT					
	15	30	45	60	75	90
$V_1 \times M_1 \times C_0$	1.67 bc	3.67	9.67 c	20.33 bcd	20.33 bc	16.67 abcd
$V_1 \times M_1 \times C_1$	1.67 bc	3.00	11.33 bc	24.00 ab	25.00 ab	18.33 ab
$V_1 \times M_1 \times C_2$	1.67 bc	3.33	10.67 bc	21.67 bc	21.33 bc	16.67 abcd
$V_1 \times M_2 \times C_0$	2.00 ab	4.33	12.67 abc	19.33 bcd	19.02 bc	14.67 bcd
$V_1 \times M_2 \times C_1$	2.33 a	4.00	15.67 ab	24.00 ab	25.00 ab	17.67 abc
$V_1 \times M_2 \times C_2$	2.00 ab	4.33	17.67 a	30.00 a	30.33 a	21.00 a
$V_2 \times M_1 \times C_0$	1.00 d	4.00	9.67 c	17.00 cd	18.67 c	13.00 de
$V_2 \times M_1 \times C_1$	1.33 cd	3.33	8.67 c	16.33 cd	18.00 c	13.33 cde
$V_2 \times M_1 \times C_2$	1.00 d	2.57	8.00 c	14.67 d	17.00 c	12.00 e
$V_2 \times M_2 \times C_0$	1.67 bc	3.67	10.67 bc	17.67 cd	19.02 bc	12.00 e
$V_2 \times M_2 \times C_1$	2.00 ab	4.33	12.00 c	20.00 bcd	22.00 bc	13.67 cde
$V_2 \times M_2 \times C_2$	2.00 ab	2.67	10.67 bc	17.67 cd	19.67 bc	11.67 de
$LSD_{(0.05)}$	0.50	NS	5.071	6.123	5.972	4.520
CV (%)	53.88	28.48	25.60	17.49	16.21	17.34

V_1 = BRRI dhan29 　　V_2 = BRRI hybrid dhan2
M_1 = Rice straw 　　M_2 = Water hyacinth
C_0 = 0 kg biomass m^{-2} 　　C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} 　　NS = Not Significant

4.7.6 Number of effective tillers $hill^{-1}$

There was significant variation for the number of effective tillers $hill^{-1}$ due to the interaction effect of variety, allelopathic material and biomass concentration (Appendix VI). The highest number of effective tillers $hill^{-1}$ (19.67) was recorded from BRRI dhan29 with water hyacinth and the incorporation of 1.0 kg biomass m^{-2} that was similar to the same variety with rice straw and 0.5 kg biomass m^{-2} and the lowest number of effective tillers $hill^{-1}$ (11.67) was found from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with water hyacinth and all levels of concentration (Table 30).

4.7.7 Number of non-effective tillers hill^{-1}

Significant variation was found for the number of non-effective tillers hill^{-1} with the interaction effect of variety, allelopathic material and biomass concentration (Appendix VI). The highest number of non-effective tillers hill^{-1} (5.00) was recorded from BRRI hybrid dhan2 with water hyacinth and the incorporation of 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and other two concentrations and the lowest number of non-effective tillers hill^{-1} (1.67) was found from BRRI dhan29 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with water hyacinth and all levels of concentration (Table 30).

4.7.8 Panicle length

There was significant variation for the panicle length of rice with the interactions of variety, allelopathic materials and their concentration (Appendix VI). The highest length of panicle (26.65 cm) was recorded from BRRI dhan29 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with all possible combinations and the lowest panicle length (23.30 cm) was found from BRRI hybrid dhan2 with rice straw and 1.0 kg biomass m^{-2} that was similar to the same variety with all possible combinations (Table 30).

Table 30. Interaction effect of variety, allelopathic materials and their concentrations on effective tillers, non-effective tillers, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1}

Treatments	Number of effective tillers hill^{-1}	Number of non-effective tillers hill^{-1}	Panicle length (cm)	Number of filled grains panicle^{-1}	Number of unfilled grains panicle^{-1}
$V_1 \times M_1 \times C_0$	15.33 abcd	2.33 de	26.29 a	116.00	19.00 a
$V_1 \times M_1 \times C_1$	18.33 ab	2.67 bcde	26.31 a	116.33	17.33 ab
$V_1 \times M_1 \times C_2$	17.00 abc	1.67 e	26.65 a	112.33	16.33 abc
$V_1 \times M_2 \times C_0$	13.67 bcd	1.67 e	25.42 a	127.33	17.33 ab
$V_1 \times M_2 \times C_1$	17.33 abc	3.00 bcde	26.63 a	120.00	16.33 abc
$V_1 \times M_2 \times C_2$	19.67 a	2.33 de	26.33 a	114.67	17.67 ab
$V_2 \times M_1 \times C_0$	12.67 bcd	4.00 abc	23.47 b	128.00	13.67 c
$V_2 \times M_1 \times C_1$	14.00 bcd	3.67 abcd	23.40 b	133.00	14.33 bc
$V_2 \times M_1 \times C_2$	11.67 d	3.00 bcde	23.30 b	125.67	15.33 bc
$V_2 \times M_2 \times C_0$	12.67 cd	5.00 a	23.54 b	111.33	13.67 c
$V_2 \times M_2 \times C_1$	13.33 cd	4.33 ab	22.83 b	119.33	15.00 bc
$V_2 \times M_2 \times C_2$	12.00 d	5.00 a	23.34 b	124.67	16.00 abc
$LSD_{(0.05)}$	4.753	1.657	1.223	NS	3.383
CV (%)	18.55	29.71	2.85	9.65	12.21

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
M_1 = Rice straw M_2 = Water hyacinth
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.7.9 Number of filled grains panicle^{-1}

Statistically insignificant variation was found for the number of filled grains panicle^{-1} with variety, biomass and concentration interactions (Appendix VI). The maximum number of filled grains panicle^{-1} (133.00) was recorded from BRRI hybrid dhan2 with rice straw and 0.5 kg biomass m^{-2} and the minimum number of filled grains panicle^{-1} (111.33) was found from the same variety with water hyacinth and no biomass application (Table 30).

4.7.10 Number of unfilled grains panicle^{-1}

Statistically significant variation was found for the number of unfilled grains panicle^{-1} with variety, biomass and concentration interactions (Appendix VI). The highest number of unfilled grains panicle^{-1} (19.00) was recorded from BRRI dhan29 with rice straw and 0 kg biomass m^{-2} which was similar to the same variety with all possible combinations and the lowest number of unfilled grains panicle^{-1} (13.67) was found from the same variety with all possible combinations (Table 30).

4.7.11 Weight of 1000 grains

Significant variation was found for the weight of 1000 grains with variety, biomass and concentration interactions (Appendix VII). The highest weight of thousand grains (26.45 g) was recorded from BRRI hybrid dhan2 with rice straw and control which was similar to the same variety with all possible combinations and the lowest weight of thousand grains (19.18 g) was found from BRRI dhan29 with rice straw and 0.5 kg biomass m^{-2} that was similar to the same variety with all possible combinations (Table 31).

4.7.12 Grain yield

Statistically significant variation was found for the interaction of variety, allelopathic materials and their concentrations on grain yield of rice (Appendix VII). The highest grain yield (7.50 t ha^{-1}) was recorded from BRRI hybrid dhan2 with water hyacinth and 1.0 kg biomass m^{-2} that was similar to the same variety with the same material and other two levels of concentration and the lowest grain yield (5.56 t ha^{-1}) was found from BRRI dhan29 with rice straw and no biomass which was similar to the same variety with water hyacinth and control (Table 31).

Table 31. Interaction effect of variety, allelopathic materials and concentrations on weight of 1000 grains, grain yield, straw yield and harvest index of rice

Treatments	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
$V_1 \times M_1 \times C_0$	19.47 b	5.56 c	8.12 abc	39.79 bc
$V_1 \times M_1 \times C_1$	19.18 b	6.47 abc	7.96 bc	45.03 abc
$V_1 \times M_1 \times C_2$	19.80 b	6.17 bc	8.11 abc	43.23 abc
$V_1 \times M_2 \times C_0$	19.76 b	5.57 c	8.85 ab	37.96 c
$V_1 \times M_2 \times C_1$	19.41 b	6.18 bc	9.91 a	38.45 c
$V_1 \times M_2 \times C_2$	19.89 b	6.71 abc	8.92 ab	43.20 abc
$V_2 \times M_1 \times C_0$	26.45 a	7.26 ab	7.12 bc	50.77 a
$V_2 \times M_1 \times C_1$	26.13 a	6.28 bc	6.60 c	48.88 ab
$V_2 \times M_1 \times C_2$	25.65 a	6.10 bc	7.00 c	46.42 abc
$V_2 \times M_2 \times C_0$	26.31 a	7.22 ab	7.03 bc	50.79 a
$V_2 \times M_2 \times C_1$	26.34 a	7.27 ab	7.73 bc	48.51 ab
$V_2 \times M_2 \times C_2$	25.95 a	7.50 a	7.42 bc	50.23 a
$LSD_{(0.05)}$	0.839	1.164	1.882	9.082
CV (%)	2.13	10.34	13.77	11.59

V_1 = BRRI dhan29 V_2 = BRRI hybrid dhan2
M_1 = Rice straw M_2 = Water hyacinth
C_0 = 0 kg biomass m^{-2} C_1 = 0.5 kg biomass m^{-2}
C_2 = 1.0 kg biomass m^{-2} NS = Not Significant

4.7.13 Straw yield

There was significant variation observed for the interaction of variety, allelopathic materials and their concentrations on straw yield of rice (Appendix VII). The highest straw yield (9.91 t ha^{-1}) was recorded from BRRI dhan2 with water hyacinth and 0.5 kg biomass m^{-2} that was similar to the same variety with the same material and other two levels of concentration and the lowest straw yield (6.60 t ha^{-1}) was found from BRRI hybrid dhan2 with rice straw and 0.5 kg biomass m^{-2} which was similar to the same variety with the same material and 1.0 kg biomass m^{-2} (Table 31).

4.7.14 Harvest index

The interaction effect of variety, allelopathic materials and their concentration showed statistically significant variations on harvest index of rice crop

(Appendix VII). The highest harvest index (50.79%) was recorded from BRRI hybrid dhan2 with water hyacinth and control which was similar to the same variety with rice straw and the same concentration and the lowest harvest index (37.96%) was found from BRRI dhan29 with water hyacinth and no biomass that was similar to the same variety with the same material and 0.5 kg biomass m^{-2} (Table 31).

Chapter 5
Summary and Conclusion

SUMMARY AND CONCLUSION

The experiment was conducted at the Agronomy research field, Sher-e-Bangla Agricultural University, Dhaka from November, 2009 to May, 2010 to find out the allelopahtic effect of rice straw and water hyacinth biomass on weed control and yield of *boro* rice. The experimental treatments included 2 crop varieties *viz.* BRRI dhan29 (V_1) and BRRI hybrid dhan2 (V_2); 2 allelopathic materials *viz.* rice straw (M_1) and water hyacinth (M_2); and 3 levels of biomass concentration *viz.* 0 kg biomass m^{-2} (C_0), 0.5 kg biomass m^{-2} (C_1) and 1.0 kg biomass m^{-2} (C_2). The experiment was laid out in a spilt split-plot design with 3 replications having varieties in the main plots, allelopathic materials in the sub plots and concentrations in the sub sub-plots. The total number of unit plots were 36 and the unit plot size was 4m x 3m = 12 m^2. Rice seedlings were transplanted on January 22, 2010.

Observations were made on rice as weed population, dry weight of weed, Dry weight of rice plant, plant height, tiller number $hill^{-1}$, number of effective tillers $hill^{-1}$, number of non-effective tillers $hill^{-1}$, panicle length, number of filled grains $panicle^{-1}$, number of unfilled grains $panicle^{-1}$, weight of 1000 grains, grain yield, straw yield and harvest index. One square meter area were randomly selected from each unit plot for taking data on weed population at 30 and 50 days after transplanting, dry weight of weed at the same dates. Five hills were randomly selected per plot for taking plant height, tiller number $hill^{-1}$, number of effective tillers $hill^{-1}$, number of non-effective tillers $hill^{-1}$ at harvest, number of filled grains $panicle^{-1}$ and number of unfilled grains $panicle^{-1}$ at harvest. Thousand grains weight was measured from sample seed. An area of 6.0 m^2 from each plot was harvested for grain yield and straw yield. Harvest index was calculated from grain yield and straw yield.

The findings showed that varieties influenced weight of 1000 grains, grain yield, straw yield, panicle length, number of effective tillers $hill^{-1}$, number of non-effective tillers $hill^{-1}$ at harvest and harvest index. The highest weight of thousand grains (26.04 g), grain yield (6.92 t ha^{-1}), number of non-effective tillers $hill^{-1}$ (4.17) and harvest index (49.27%) was found from BRRI hybrid dhan2 and the highest panicle length (26.27 cm), number of effective tillers $hill^{-1}$ (16.89) and straw yield (8.64 t ha^{-1}) was found from BRRI dhan29.

Allelopathic materials influenced weed population, dry weight of weed at 50 DAT and straw yield. The lowest weed population (17.33 m^{-2} and 39.33 m^{-2}) at 30 and 50 DAT respectively and weed dry matter (30.31 m^{-2}) at 50 DAT was found from rice straw. The highest straw yield (8.31 t ha^{-1}) was recorded from water hyacinth incorporation.

Concentration of allelopathic biomass influenced weed population and dry weight of weed. At 50 DAT, the lowest weed population (28.67 m^{-2}) and dry weight of weed (26.80 g m^{-2}) was found with no biomass application in the field.

The interaction effect of variety and allelopathic materials was found significant in cases of weed population, tiller number $hill^{-1}$, number of effective and non-effective tillers $hill^{-1}$ at harvest, panicle length, number of filled and unfilled grains $panicle^{-1}$, weight of 1000 grains, grain yield, straw yield and harvest index. The lowest weed population (16.44 m^{-2} and 34.22 m^{-2}) was found in BRRI hybrid dhan2 and BRRI dhan29 with rice straw at 30 and 50 DAT respectively. The highest number of tiller $hill^{-1}$ was found from BRRI dhan29 with water hyacinth biomass. The highest number of effective tillers $hill^{-1}$ (16.89) was found in BRRI dhan29 with both materials and the lowest number of non-effective $tiller^{-1}$ (2.22) was found in the same variety with rice straw biomass. The highest panicle length was observed in BRRI dhan29 with rice straw. The highest number of filled grains $panicle^{-1}$ (128.89) and the lowest number of unfilled grains $panicle^{-1}$ (14.44) was found from BRRI hybrid dhan2 with rice straw. The highest weight of thousand grains (26.20 g) and grain yield (7.33 t ha^{-1}) was found in the interaction of BRRI hybrid dhan2 and water hyacinth. The highest straw yield (9.23 t ha^{-1}) was recorded from BRRI dhan29 with water hyacinth. The highest harvest index (49.84%) was observed from BRRI hybrid dhan2 with water hyacinth.

The interaction effect of variety and concentration of biomass showed significant result on weed population and weed dry weight at 50 DAT. At that date the lowest weed population (32.67 m^{-2}) was found in BRRI hybrid dhan2 with control and the lowest dry weight of weed was measured from the same variety with 1.0 kg biomass m^{-2}. The highest tiller number $hill^{-1}$ was found in BRRI dhan29 with 1.0 kg biomass m^{-2}. At harvest, the highest number of effective tiller $hill^{-1}$ (18.33), the lowest number of non-effective tiller $hill^{-1}$ (2.00) and the highest panicle length (26.49 cm) was recorded from BRRI dhan29 with the previous concentration. The highest weight of 1000 grains (26.38 g) and grain yield (7.24 t ha^{-1}) was found in BRRI hybrid dhan2 with no biomass application. The highest straw yield (8.94 t ha^{-1}) was measured from BRRI dhan29 with 0.5 kg biomass m^{-1}. The highest harvest index (50.78%) was recorded from BRRI hybrid dhan2 with control.

The interaction effect of allelopathc material and their concentration showed significant results in cases of weed population and dry weight at 50 DAT, plant height at 60, 75 and 90 DAT and tiller number $hill^{-1}$ at 45,60 and 75 DAT. The lowest number of weed (15.33 m^{-2}) was recorded from rice straw with control and the lowest weed dry weight (20.86 m^{-2}) was found from the same material with 0.5 kg biomaas m^{-2} at 50 DAT. The highest plant height (56.55cm, 68.62 cm and 86.91 cm) was recorded from water hyacinth with 1.0 kg biomass m^{-1} at 60, 75 and 90 DAT respectively. The highest tiller number $hill^{-1}$ (14.17, 23.83 and 25.00) was counted from the previous interaction at 45, 60 and 75 DAT respectively.

The interaction effect of variety, allelopathic material and concentration showed significant result in all cases of yield contributing characters, panicle length, yield and harvest index of rice except number of filled grains $panicle^{-1}$.

The highest plant height (36.97 cm) was found from BRRI dhan29 with water hyacinth and 0.5 kg biomass m^{-2} at 45 DAT. At 60, 75 DAT and harvest, the highest plant height (57.08 cm, 69.26 cm and 97.67 cm respectively) was recorded from the same variety with the same material and 1.0 kg biomass m^{-2}. The highest tiller number $hill^{-1}$ (17.67, 30.00, 30.33 and 21.00) at 45, 60, 75 and 90 DAT respectively was recorded from the previous interaction. The highest number of effective tiller $hill^{-1}$ (19.67) was observed from BRRI dhan29 with water hyacinth and 1.0 kg biomass m^{-2} and the lowest number of non-effective tiller $hill^{-1}$ (1.67) was recorded from the same variety with rice straw and no biomass application. The highest panicle length (26.65 cm) was found in BRRI dhan29 with rice straw and 1.0 kg biomass m^{-2}. The highest weight of thousand grains (26.45 g) was found from BRRI hybrid dhan2 with rice straw and control. The highest grain yield (7.50 t ha^{-1}) was recorded from the previous variety with water hyacinth and 1.0 kg biomass m^{-2}. The highest straw yield (9.92 t ha^{-1}) was obtained from BRRI dhan29 with water hyacinth and 0.5 kg biomass m^{-2}. The highest harvest index (50.79%) was recorded from BRRI hybrid dhan2 with water hyacinth and control.

It may be concluded that BRRI hybrid dhan2, water hyacinth and 1.0 kg biomass m^{-2} and their interactions encouraged growth and dry weight of weeds in all cases. But, rice straw biomass reduced weed growth in all levels of application. Weed control was quite positive with rice straw biomass. On the other hand, BRRI hybrid dhan2, water hyacinth and 1.0 kg biomass m^{-2} and their interactions encouraged increasing yield of rice.

However, to reach a specific conclusion and recommendation, more research work is needed at wider range on allelopathic effect of rice straw and water hyacinth biomass on weed management and yield of *boro* rice over different Agro-ecological zones of Bangladesh.

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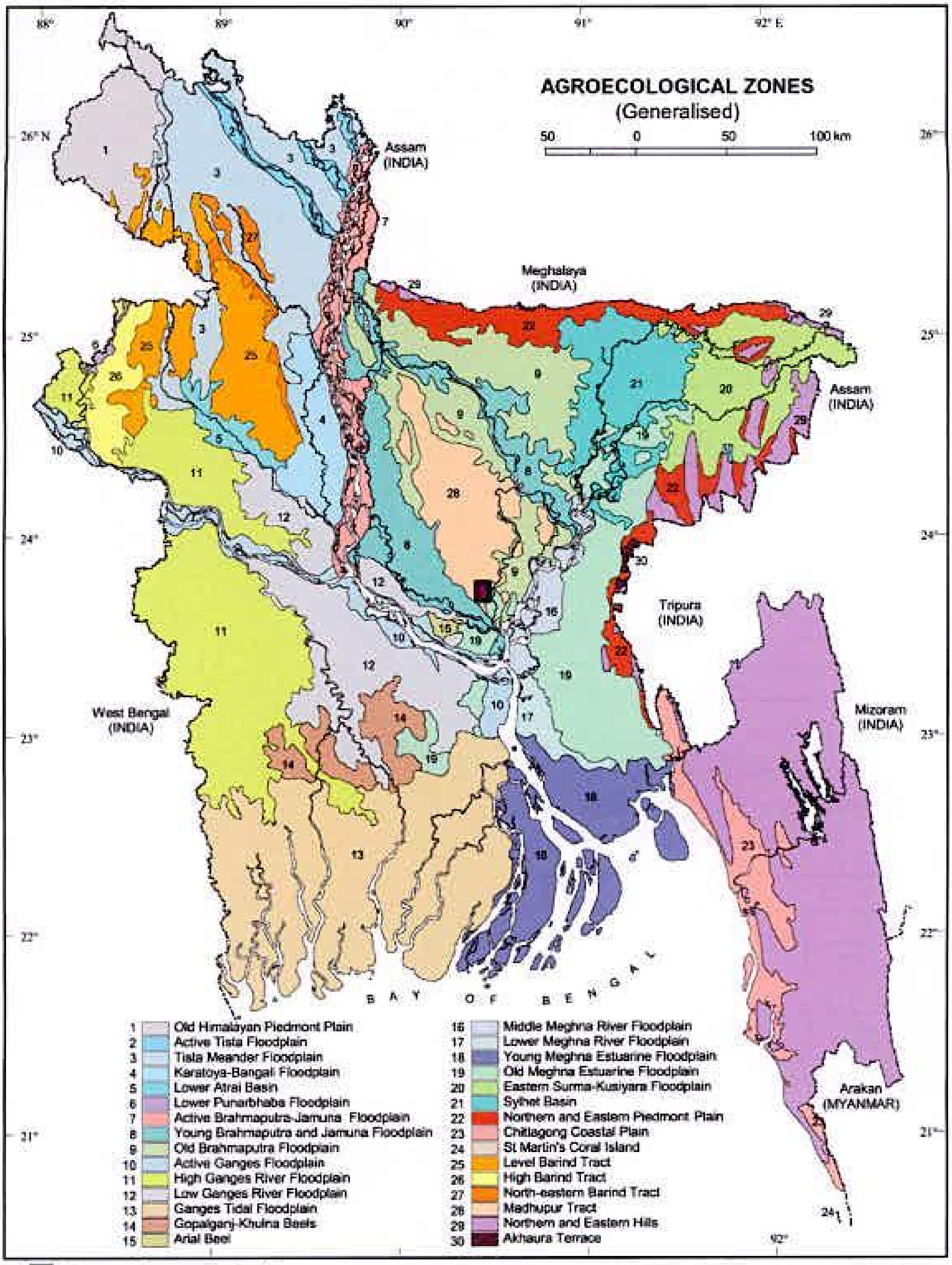
Appendices

APPENDICES

Appendix I. Map showing the experimental site under study



■ **Experimental site**

Appendix II. Mean square values for weed population and weed dry weight at different days after transplanting

Sources of variation	DF	Number of weed (m^{-2})		Dry weight of weed (m^{-2})	
		30 DAT	50 DAT	30 DAT	50 DAT
Replication	2	2794.53	6379.53	9.20	1149.37
Variety(V)	1	205.44	693.44 ^{NS}	6.93 ^{NS}	1477.38 ^{NS}
Error (a)	2	6.86	111.86	89.90	454.86
Material (M)	1	3441.78 *	8341.77**	83.29 ^{NS}	2259.10 *
V x M	1	81.00 ^{NS}	18.78 ^{NS}	0.44 ^{NS}	243.36 ^{NS}
Error (b)	4	91.81	210.86	50.19	104.77
Concentration (C)	2	66.69 ^{NS}	12612.20 *	564.54*	3459.11 **
V x C	2	418.53 ^{NS}	1084.36 ^{NS}	4.51 ^{NS}	445.64 ^{NS}
M x C	2	562.03 ^{NS}	186.19 ^{NS}	37.44 ^{NS}	226.18 ^{NS}
V x M x C	2	990.08 ^{NS}	2920.03 ^{NS}	58.14 ^{NS}	884.58 ^{NS}
Error (c)	16	586.92	1205.94	123.27	466.10

^{NS} = Not Significant
** = Significant at 1% level
* = Significant at 5% level

Appendix III. Mean square values for dry weight of rice plant at different days after transplanting

Sources of variation	DF	Dry weight of rice plant (g $hill^{-1}$)		
		30 DAT	60DAT	90 DAT
Replication	2	0.12	1.06	55.67
Variety(V)	1	0.82**	0.62 ^{NS}	103.84 ^{NS}
Error (a)	2	0.11	8.19	60.54
Material (M)	1	0.71 ^{NS}	3.37 ^{NS}	3.56 ^{NS}
V x M	1	0.28 ^{NS}	1.02 ^{NS}	7.67 ^{NS}
Error (b)	4	0.44	7.74	33.70
Concentration (C)	2	0.15 ^{NS}	11.97*	4.89 ^{NS}
V x C	2	0.17 ^{NS}	8.98 ^{NS}	18.53 ^{NS}
M x C	2	0.10 ^{NS}	1.89 ^{NS}	7.36 ^{NS}
V x M x C	2	0.10 ^{NS}	26.06 **	8.19 ^{NS}
Error (c)	16	0.92	2.62	48.42

^{NS} = Not Significant
** = Significant at 1% level
* = Significant at 5% level

Appendix IV. Mean square values for plant height of rice at different days after transplanting

Sources of variation	DF	Mean square values at different DAT						
		15	30	45	60	75	90	Harvest
Replication	2	3.01	16.14	3.98	2.99	0.78	13.77	4.94
Variety(V)	1	5.78 NS	0.51 NS	0.15 NS	0.72 NS	13.20 NS	1112.4**	156.67**
Error (a)	2	0.31	6.09	9.18	21.55	11.60	67.94	42.29
Material (M)	1	1.51 NS	0.74 NS	87.92**	196**	78.03*	102.35*	0.42 NS
V x M	1	0.63 NS	10.40 NS	4.51 NS	1.432 NS	7.18 NS	7.01 NS	39.90 NS
Error (b)	4	2.39	6.58	8.78	3.69	14.70	24.96	3.17
Concentration (C)	2	2.97 NS	6.89 NS	4.01 NS	0.59 NS	5.18 NS	2.27 NS	2.03 NS
V x C	2	0.45 NS	2.09 NS	13.08 NS	4.63 NS	6.54 NS	36.58 NS	32.29 NS
M x C	2	0.44 NS	4.41 NS	2.26 NS	17.68 NS	35.97 NS	12.2 NS	12.36 NS
V x M x C	2	1.04 NS	0.70 NS	0.13 NS	0.15 NS	8.23 NS	8.68 NS	19.17 NS
Error (c)	16	1.91	5.59	7.52	12.47	10.11	15.44	13.43

NS = Not Significant
** = Significant at 1% level
* = Significant at 5% level

Appendix V. Mean square values for tiller number hill^{-1} of rice at different days after transplanting

Sources of variation	DF	Mean square values at different DAT					
		15	30	45	60	75	90
Replication	2	0.69	6.33	6.36	44.11	43.86	8.44
Variety(V)	1	1.36 **	1.36 ^{NS}	81.00 **	324 **	177.78**	215.11**
Error (a)	2	0.19	3.11	5.25	25.33	6.86	4.78
Material (M)	1	3.36 **	3.36 ^{NS}	113.78**	53.78 ^{NS}	53.78*	0.11 ^{NS}
V x M	1	0.25 ^{NS}	0.69 ^{NS}	13.44 ^{NS}	0.84 ^{NS}	0.11 ^{NS}	1.78 ^{NS}
Error (b)	4	0.22	0.11	3.03	1.89	4.36	4.44
Concentration (C)	2	0.19 ^{NS}	1.75 ^{NS}	5.53 ^{NS}	24.19 ^{NS}	37.53 ^{NS}	9.03 ^{NS}
V x C	2	0.28 ^{NS}	2.19 ^{NS}	11.08 ^{NS}	38.58 ^{NS}	34.03 ^{NS}	11.36 ^{NS}
M x C	2	0.28 ^{NS}	0.53 ^{NS}	6.19 ^{NS}	26.36 ^{NS}	30.53 ^{NS}	9.36 ^{NS}
V x M x C	2	0.83 ^{NS}	0.19 ^{NS}	2.19 ^{NS}	16.75 ^{NS}	22.03 ^{NS}	8.03 ^{NS}
Error (c)	16	0.83	1.04	8.58	12.51	11.90	6.82

^{NS} = Not Significant
** = Significant at 1% level
* = Significant at 5% level

Appendix VI. Mean square values for effective tillers, non-effective tillers, panicle length, filled grains panicle^{-1} and unfilled grains panicle^{-1}

Sources of variation	DF	Mean square values				
		Effective tiller (no. hill^{-1})	Non effective tiller (no. hill^{-1})	Panicle length (cm)	Filled grains (no. panicle^{-1})	Unfilled grains (no. panicle^{-1})
Replication	2	7.444	0.194	0.271	10.361	0.250
Variety(V)	1	156.250**	32.111**	78.736**	312.111^{NS}	64.00**
Error (a)	2	5.333	0.194	2.676	118.694	1.750
Material (M)	1	0.278^{NS}	4.000*	0.444^{NS}	49.00^{NS}	0.00^{NS}
V x M	1	0.278^{NS}	2.778^{NS}	0.441^{NS}	592.111^{NS}	1.778^{NS}
Error (b)	4	4.944	1.306	0.712	78.306	0.722
Concentration (C)	2	14.778^{NS}	0.528^{NS}	0.158^{NS}	24.111^{NS}	1.083^{NS}
V x C	2	16.333^{NS}	1.361^{NS}	0.878^{NS}	150.111^{NS}	8.083^{NS}
M x C	2	5.444^{NS}	1.083^{NS}	0.726^{NS}	24.333^{NS}	2.583^{NS}
V x M x C	2	3.111^{NS}	1.301^{NS}	0.671^{NS}	114.778^{NS}	1.361^{NS}
Error (c)	16	7.542	0.917	0.499	135.750	3.819

^{NS} = Not Significant
** = Significant at 1% level
* = Significant at 5% level

Appendix VII. Mean square values for weight of 1000 grains, grain yield, straw yield and harvest index of rice

Sources of variation	DF	Mean square values			
		Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
Replication	2	0.267	2.385	1.696	65.924
Variety(V)	1	375.086**	6.426**	20.205**	576.320**
Error (a)	2	1.036	1.298	0.318	26.089
Material (M)	1	0.624^{NS}	2.107*	6.076*	6.068^{NS}
V x M	1	0.324^{NS}	0.990^{NS}	1.051^{NS}	35.007^{NS}
Error (b)	4	1.143	0.423	0.621	17.186
Concentration (C)	2	0.333^{NS}	0.200^{NS}	0.243^{NS}	2.761^{NS}
V x C	2	1.447**	1.961*	0.179^{NS}	37.453^{NS}
M x C	2	0.135^{NS}	0.695^{NS}	1.246^{NS}	21.621^{NS}
V x M x C	2	0.303^{NS}	0.482^{NS}	0.463^{NS}	3.658^{NS}
Error (c)	16	0.235	0.452	1.182	27.533

^{NS} = Not Significant

** = Significant at 1% level

* = Significant at 5% level

PLATES

Plate 1. Rice seedlings in the nursery bed

Plate 2. Allelopathic material (Rice straw)

Plate 3. Allelopathic material (Water hyacinth)

Plate 4. Spreading and incorporation of Allelopathic materials to the plots

Plate 5. Transplantation of Rice seedlings to the plots

Plate 6. Field view of the experiment at tillering stage

Plate 7. Weed status m^{-2} of different treatments during first weeding

Plate 8. Field view of the experiment during maturity period