AN ABSTRACT OF THE THESIS OF

Lakshman L. Ranasinghe for the degree of Doctor of Philosophy in Horticulture presented on July 05, 1995

Title: Enhancement of the Weed Competitive Ability of Rice (*Oryza sativa* L.) Cultivars.

Abstract approved: ______________________

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Most of the presently grown cultivars of rice (*Oryza sativa* L.) have poor competitive ability against weeds if compared with traditional cultivars. Therefore, effective weed control is an important but often costly and difficult management practice in rice crop production. If weed competitive ability of rice cultivars could be improved by changing the plant morphology and some agronomic practices, crop losses and the cost of weed control in rice production would be reduced. Three field experiments were conducted to identify weed competitive morphological traits of rice and to evaluate the effect of delaying starter fertilizer application on weed competition in rice.

The nature of rice-barnyardgrass competition varies greatly with rice cultivar morphology. In an addition series experiment, the semi-dwarf, erect leaved, high yielding cultivar BG 350, which possesses much of the plant characteristics required

for a high yield was affected much more than the cultivar BG 94-2, which has a tall stature, high leaf area index and good seedling vigor.

In the varietal testing experiment, as predicted by the sensitivity analysis, cultivars with rapid height growth, high leaf area growth and plant dry weight increase during seedling stage, height and leaf area at maturity were associated with high competitive ability. The weed competitive ability of tested cultivars varied from relatively high in cultivars PPL and BG 94-2, moderate in BW 267-3 to poor in BG 1611 and BG 350.

The delay of starter fertilizer application by 14 days in cultivar BG 350 improved its competitive ability against barnyardgrass (BYG). Under BYG competition, a 14-day delay of starter fertilizer application reduced the percent crop loss by weed competition 6.64 and 22.99% under the normal planting density in the Maha and Yala cultivation seasons, respectively.

The crop-weed competition model INTERCOM simulated yield losses for the tested cultivars followed the trends observed in field experiments. However the simulated values were always higher than the observed values.

Enhancement of the Weed Competitive Ability of Lowland Rice (*Oryza sativa* L.) Cultivars.

by
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I understand that my thesis will become part of the permanent collection of Oregon state University libraries. My signature below authorizes release of my thesis to any reader upon request.

Lakshman L. Ranasinghe, Author

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ENHANCEMENT OF THE WEED COMPETITIVE ABILITY OF LOWLAND RICE (*Oryza sativa* L.) CULTIVARS.

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of over half of the world's population and is the only major cereal grain used almost exclusively for human consumption. Eighty five percent of the total rice production is consumed directly by humans compared with 60% for wheat (*Triticum aestivum*) and 25% for maize (*Zea mays L.*). World rice requirements are predicted to increase at a rate of 1.7% per year between now and year 2025 (IRRI, 1993). Globally, rice ranks second to wheat in area harvested with 147 million hectares in 1991 (Juliano, 1993). In Sri Lanka, where this study was conducted, rice is the staple cereal food and the estimated cultivated area is 1.2 million hectares (Department of Agriculture, Sri Lanka, 1991).

Numerous weed species have infested rice cultivation throughout the world and cause considerable crop losses directly by competition for limited resources and in other indirect ways. According to Matsunaka (1976), 23% of the total potential rice production is lost by direct and indirect effects of weeds. In Sri Lanka, weeds are a more common threat in rice production than insect pests or diseases.

The widespread replacement of traditional tropical "Indica" type rice cultivars with high yielding subtropical "Japonica" type cultivars, which have different plant morphology, has increased weed problems in tropical rice cultivation (Moody, 1979). Therefore, weed control is an essential but costly management practice in modern rice cultivation. The use of herbicides is now considered indispensable for effective weed control in modern rice crop production. But economic and environmental costs of this weed control practice and increasing incidence of weed resistance to herbicides have brought forth the need for viable, environmentally sound weed management alternatives. The relatively small size of rice farms and other socio-economic limitations also limit the use of herbicides for weed control in Sri Lanka.

Under lowland irrigated conditions, weeds usually compete with rice to obtain mineral nutrients and for light. Erect, short leaves and slow seedling growth rate of these new cultivars allow more light to penetrate into the canopy and provide a suitable environment for germination and growth of weeds. Weeds usually grow rapidly as they are much more efficient than the crop, resulting in competition for light. According to Graf et al., (1990 b), 65% of the rice biomass reduction at maturity is caused by the competition for light. In addition to this, the high fertilizer need of these new cultivars has increased the weed problem in rice. High levels of soil nitrogen and phosphorous increase the germination of weed seeds (Smith et al., 1959; Klenig and Nobel, 1968). Many weeds have more efficient root systems that can derive more nutrients than rice (Zimdahl, 1980). More than 60% of the presently grown rice cultivars are crosses between these two sub species and possess the modified plant type described above (De Datta, 1981). Thus these cultivars have higher weed infestations and yield losses under low input farming situations.

Weed competitive cultivars of several crop species have shown promising yields under low weed management levels (McWhorter and Hartwig, 1968; Burnside, 1972; Forcella, 1987; Ford et al., 1990; Guneyli et al., 1969; Jenning and Herrera, 1968; Garrity et al., 1992). Some information is available on the weed competitive traits of rice, but much of this information is conflicting. Many studies have proved plant height is highly correlated with weed competitive ability (De Datta et al., 1985; Jenings and Jesus, 1968; Jennings and Harrera, 1968; Smith, 1974; Moody, 1987; Garrity et al., 1992). Similarly some others have concluded that leaf area, tiller number, and seedling growth rate are important for weed competitive ability (Jennings and Aquino, 1968; Jennings and Harrera, 1968; De Datta et al., 1969; Smith, 1974; Kawano et al., 1974; IRRI, 1968; IRRI, 1977).

Presently, new cultivars of rice are selected under weed-free conditions without considering their weed competitive ability. Little research work has been done on improving weed competitive ability of rice cultivars. It is of less interest among research needs of developed countries since chemical weed control is a promising, economical practice on their commercial farms.

If there is a possibility of improving the weed competitive ability of rice by some viable approaches it would contribute significantly to increased global rice production. Incorporating weed competitive traits into present high yielding rice cultivars and developing fertilizer management practices that enhance the fertilizer use efficiency of the crop would enhance the weed competitive ability of the rice crop. Therefore, using the above hypothesis, studies were undertaken to investigate the possibility of developing viable weed management alternatives for lowland irrigated rice by collecting the following research information:

a). the nature of intra- and interspecific competition in rice and weeds,

b). identification of important morphological traits of rice for weed competitive ability,

c). effects of delaying starter fertilizer application until the crop roots get established in the soil on weed competition and crop yield, and

d) investigating the possibility of using crop-weed competition simulation models for testing weed competitive ability of new rice cultivars and weed control decision making (This can save money and time compared to normal crop-weed competition studies).

A series of field experiments were conducted to collect information on the above at the Regional Agricultural Research Center, Aralaganwila, Sri Lanka during 1993/94 Maha (wet) and Yala (dry) cultivation seasons.

This thesis is written in the format followed by the "Weed Technology" journal. Chapter 1 is the general introduction and chapter 2 is literature review. Chapters 3 to 6 are manuscripts of articles for the above journal.

Chapter 3 focuses on the nature of rice-barnyardgrass (BYG), one of the worst weeds in tropical rice competition. This information is important to understand the mechanism of intra- and interspecific competition of rice and barnyardgrass under varying plant population densities.

Chapter 4 deals with rice cultivar differences in their weed competitive abilities. Identification of important morphological traits, differences in competitive response of rice to quantitative changes of these traits and weed density were studied in this experiment. A validation of the predictions of INTERCOM rice-BYG competition simulation model (Kropff and Van Larr, 1992) on the importance of some morphological traits was also done in this experiment.

Chapter V focuses on effects of timing starter fertilizer application on crop-weed competition. This information is important to develop fertilizer management practices that enhance the fertilizer use efficiency and weed competitive ability of rice.

Chapter VI is an attempt to simulate rice-BYG competition when rice cultivar morphology, fertilizer application time, and weed density are varied. The information collected from field experiments were used in this study to simulate interplant competition by the INTERCOM model.

Chapter VII contains general conclusions of the thesis research.

CHAPTER II

LITERATURE REVIEW

Rice (*Oryza sativa* L.) is the most important cereal crop in the developing world and is the staple food of over half the worlds population (Juliano, 1993). It is believed to have originated somewhere in Southeast Asia. Today it is cultivated in Asia, Africa, Europe, North, Central and South America and Oceanea (Yoshida, 1981) but the bulk of rice production is centered in wet tropical climates, mainly in South, Southeast and East Asia (IRRI, 1993).

The rice plant may be characterized as an annual grass with round, hollow, jointed culms, rather flat, sessile leaf blades and a terminal panicle. It varies in size from dwarf mutants only 0.3-0.4 m tall to floating varieties more than 7 m tall. However, the great majority of commercial varieties range from 1-2 m in height (Chang et al., 1972).

Modern high yielding rice cultivars are generally less competitive against weeds than traditional cultivars. Therefore potential yield losses due to weeds are greater in the modern cultivars and more time is spent in removing weeds from them. Furthermore high fertilizer rates used on modern rice varieties aggravate weed problems (De Datta, 1981). A greater yield response to weeding is also exhibited by these modern cultivars (Moody and De Datta, 1977).

1. Rice Growing Environments

Although rice flourishes in more than 70 countries in the humid subtropics and temperate climates the bulk of rice production is centered in South, Southeast and East Asia which accounts for 90% of the world rice production (Yoshida, 1981). Because of its long history of cultivation and selection under diverse environments the rice plant exhibits a broad range of adaptability and tolerance. It can be grown in a wide range of water/ soil regimes from deeply flooded land to dry hilly slopes (Lu and Chang, 1980). The method of rice production in these environments may be classified as lowland (irrigated or rainfed), upland (rainfed) or deep water (rainfed). In Sri Lanka 77% of the rice area is irrigated (Juliano, 1993). Mean size of the rice farms is small in most of the rice growing environments. It is less than 1 ha in Sri Lanka, Japan, and Bangladesh; over 1 ha in Indonesia, about 2 ha in Malaysia, Pakistan and the Philippines and about 3 ha in Thailand (Juliano, 1993).

2. Morphological Differences in Cultivated Rice

The thousands of cultivated varieties of rice (*Oryza sativa* L.) vary greatly in growth habit, form, size and structure (Chang et al., 1972). In 1928, Japanese workers divided cultivated *Oryza sativa* in to two sub-species; "Indica" and "Japonica", based on the morphological differences and geographical distribution. Generally Indica varieties have broad, light green leaves, profuse tillering and tall plant stature. Varieties of Japonica usually have narrow dark green leaves, medium tillering and short plant stature. More than 60% of the presently grown rice varieties are crosses between these two subspecies and have a modified plant type desirable for high yield under intensive management (Juliano, 1993). Most of these varieties have short culms and erect leaves which allows for more light to penetrate the canopy and more weeds to emerge and survive. Therefore the weed problem in rice has been exacerbated by the replacement of traditional rice cultivars by these improved cultivars (Smith, 1983).

3. Weed Interference in Rice

Interference among neighboring plants, often due to competition for resources, is a central process in general agronomy. Interference describes the general interactions which regulate crop yield due to density relationships, crop-weed competition, intercropping, crop stand mortality and loss of marketable yield of crops (Hashem, 1991).

Competition has been central to plant ecology, both in wild and managed situations. Darwin (1859) considered competition to be one of the powerful selective forces shaping the morphology and life history of plants and the dynamics of plant communities. A wide range of meanings have been ascribed to competition in operational, philosophical, phenominological and mechanistic points of view (Grace and Tilman, 1990). According to Grime (1977) competition is the tendency of neighboring plants to utilize the same quantum of light, ion of mineral nutrient, molecule of water or volume of space. However for competition to occur, an environmental resource must be limiting.

3.1. Mechanism of Rice-Weed Competition

When one or more resources are in short supply plants starts to compete for obtaining them in various ways. Harper (1977) stated that plants may compete with each other by reducing light intensity, changing light quality, transpiring limited water, absorbing limited nutrients, changing the humidity and changing soil reaction. The degree of competitive ability is determined by many morphological and physiological characteristics of competing plants.

Numerous weed species have infested rice cultivation throughout the world. Environmental and adaphic conditions favorable for growing rice are also favorable for growing and reproducing many terrestrial, aquatic, and semi-aquatic weeds. Weeds in rice produce an abundance of viable seeds or other propagules; and once these propagules infest soil, they are difficult to remove and remain viable for several years (Smith, 1988). Flooded or moist soils favor an abundant supply of viable weed seed in rice fields. According to an estimation by Vega and Sierra (1968) as cited by De Datta (1981), there are more than 800 million viable seeds per hectare within a soil depth of about 15 cm. Rice yield loss caused by weeds in flooded rice fields vary with the time of weed infestation, soil fertility, rice varietal type, and planting method (De Datta et al., 1969). Weed control is more critical and more difficult in broadcasted rice, which is a more common planting practice in many parts of Sri Lanka, North Eastern India, Bangladesh and the Philippines, than in transplanted rice (De Datta, 1981). In most of these situations serious competition is from grass alone or from a mixed population of grasses and sedges (De Datta, 1981).

Competition from weeds during early growth stages of the rice crop is more serious than no competition during early growth stages followed by competition during late growth stages (De Datta, 1981). The critical period of weed control, however, affects different rice varieties in different ways. For C 4-63, an intermediate-stature variety, the weed free period needed to avoid serious crop loss is the first 30 days after seeding while for the short-stature variety IR 8 it is for about the first 20 days after seeding (Vega et al., 1967). One estimate at the International Rice Research Institute (IRRI) suggests that weed growth in unweeded plots reduce yield by as much as 34% in transplanted rice, 45% in direct seeded rainfed lowland rice and 67% in upland rice (De Datta, 1981). In a rice crop weeds have a significant effect on crop height, number of panicles, straw weight, percent fertility and grain yield (De Datta, 1981).

In most of the rice growing environments, year-round moderately warm temperature and high soil moisture level encourage weed growth. The most common weeds in tropical lowland rice in South and Southeast Asia are *Echinochloa crus-galli, Echinochloa glabrescens, Sphenoclea zeylanica, Cyperus difformis, Cyperus iria, Fimbristylis miliacea, Paspalum distichum* and *Scirpus martimus* (De Datta, 1981). Holm et al. (1977) assert that the most important rice weeds in the world are *Echinochloa crus-galli*, *Echinochloa colona, Frimbristylis littoralis* and *Cyperus difformis*. In temperate East Asia, perennial weeds like *Paspalum distichum* and *Scirpus martimus* pose a serious threat to lowland rice. Ryang et al. (1976) reported that 22% of the Republic of Korea's total rice growing area was infested with perennial weeds (De Datta, 1981). In Taiwan yield reductions were 85% for *Echinochloa crus-galli*, 72% for *Cyperus difformis*, 62% for *Marsilea quadrifolia* and *Monochoria vaginalis* and 9% for *Spirodela polyrhiza*.(De Datta, 1981).

Direct and indirect crop losses due to weeds is considered one of the main reasons for low yield under farmer's crop management. Crops and weeds compete for the same resources: nutrients, water, space and light. Competition begins when crops and weeds grow in close proximity and the supply of any necessary growth factor falls below the demand of both. The over-all effect of crop-weed competition is a reduction in the crop biomass and final yield.

Crop loss due to competition from weeds is dependent on factors such as the environment, the variety grown and its density, the stage of the crop at the time of competition, the weed species and their density, and measures taken by the farmer to control weeds. The level of weed growth in rice varies with the type of rice culture (upland, lowland or deep water); method of planting (transplanting or direct seeding); variety (tall or semi-dwarf, low or high tillering) and cultural practices (land preparation, spacing, fertilization, seed purity etc.). Environment associated with the crop determines the weed community growing in association with the crop (De Datta, 1981). Therefore manipulation of the rice growing environment to reduce weed growth presents an opportunity to develop weed management practices to minimize weed interference in rice.

3.2. Competing Resources in Lowland Rice Cultivation

The impact of neighboring weeds is considered to be competition for resources when it reduces the amount of resources available for the crop. Weeds compete with rice for light, nutrients, water and other growth requirements (Smith et al., 1977). Usually in lowland rice cultivation there is no water limitation for the crop.

3.2.1. Competition for Light

The quantity and the quality of light received is an important growth limiting resource in plants. Kays and Harper (1974), found that the final weight of tillers of *Lolium perenne* L. was highest in full (100%) light intensity and was reduced as the light intensity was reduced. Quality of light is also important in plant growth. Wheat (*Triticum aestivum*) plants treated with red light produced more tillers than those treated with far-red light (Casel, 1988). Similar effects of red and far-red light treatments were observed in *Lolium* species (Deregibus, 1983; Casel, 1985). According to the crop simulation studies by Graf et al., (1990), 65% of the rice biomass reduction at maturity is caused by competition for light.

3.2.2. Competition for Nutrients

According to Alkamper (1976), as cited by Zimdahl (1980), weeds usually absorb fertilizer faster and in large amounts than crops and therefore derive greater benefit from applied fertilizer. The importance of competition for nutrients has been demonstrated in several experiments. Appleby et al. (1976) demonstrated that wheat grain yield declined when nitrogen levels and ryegrass density were increased. Similar effects were reported for wild oat in wheat and flax by Bowden and Friesen (1967). Leibl and Worsham (1987), found that the growth response of ryegrass to NO_3^- was greater than that of wheat. At high nutrient levels, ryegrass shoot production was double that of wheat while root production remained almost the same for both species.

Many researchers have recorded that above ground competition (competition for light) is more important in yield reduction than below ground competition (root competition for nutrients) in lowland rice. But Perera et al. (1992) recorded inhibition of root growth of rice plants, leading to a reduced ability to obtain nutrients, as the major factor responsible for this growth reduction in lowland rice. According to Jennings (1976) traditional rice cultivars extract nitrogen and other nutrients from the soil with great efficiency. They develop extensive root systems, drawing on a large soil volume and exhibit vigorous early growth which suppresses weeds that compete for the available nutrients. Other studies also have shown differences in root growth and nutrient uptake rate in roots (IRRI, 1972), but no documented information is available on the relationship between varietal differences in root growth and activity on seedling vigor and competitiveness against weeds.

Competitive rice cultivars have a high initial growth rate and a slower rate later in the growth cycle. In contrast, improved varieties have slow initial growth and a higher late growth rate (Jennings and Aquino, 1968). According to these researchers this is the main reason for differences in yielding and competing abilities between these two types of rice.

3.2.3. Time of Weed Emergence and Crop-Weed Competition

Many research results reveal that early weed emergence is detrimental to crop growth. Therefore, reduction of the factors enhancing early weed emergence should help to increase crop yields by increasing the ability of the crop to compete against weeds. The outcome of interspecific competition may depend not only on the competitive ability of the crop but also the density of weed species and the level of soil nutrient supply (Bleasdale, 1960). Adiar et al. (1962), Kleinig and Noble (1968) and Smith (1983) have recorded stimulation in weed growth with the addition of inorganic N and P fertilizers just before seeding the rice crop. They found an increase in the competitive ability of weeds with the addition of P; especially with the addition of P, weeds grew faster and tillered earlier. It is clear that present rice fertilizer application practices influence the rice field weed population and also a relatively small weed population can cause a serious yield reduction under high fertility conditions. According to Smith et al. (1959), as cited by Adair et al. (1962) application of both N and P fertilizers too soon before seeding rice greatly increases the competitive ability of native weed species. He has suggested the application of P to the preceding rotational crop or delaying fertilizer application to just before the rice is first flooded, to reduce the utilization of the added N and P by weeds. This is a potential agronomic practice that can be incorporated into low input rice farming systems, but to be a viable option the possible crop yield increase due to weed suppression should be significantly greater than the yield reduction due to the delayed fertilizer application.

4. Methods of Weed Control in Rice

Though there are several methods used to control weeds in rice none of them will provide continuously effective weed control when used in isolation. Also none of these methods is best to use in all situations, because weeds have the plasticity to vary their growth habit according to the growing environment. Basically these weed management practices reduce weed interference by increasing crop resource use efficiency, reducing weed resource use efficiency, or by some system-level approaches.

4.1. Cultural and Physical Methods of Weed Control

Land preparation and water management are field operations that can substitute for another operation to provide a certain degree of weed control. The procedure and the intensity of land preparation varies depending on the type of rice culture (lowland or upland) and the method of planting (transplanting or direct seeding). Some farmers in South and Southeast Asia repeat plowing and harrowing several times to reduce weed problems. The number of weed species growing in association with rice declines as the number of pre-plant harrowings increases (De Datta and Baker, 1977). Tillage alone effectively controls some perennial grassy weeds such as *Paspalum distichum* (De Datta, 1981). In addition, puddling of soils aids the quick establishment and tillering of transplanted rice and results in greater competition and suppression of weed growth (De Datta, 1981). This puddling operation incorporates weed seeds and stubble into the reduced soil layer, where lack of oxygen inhibits weed seed germination (De Datta, 1981). However, land preparation will not control all annual and perennial weeds in rice.

Good water management is also an important factor in weed control in rice. Emergence of weeds and the type of weed flora is closely related to the moisture content of the soil and the depth of irrigation (De Datta, 1981). Many weeds will not germinate under flooding and continuous submergence with 10 cm of water suppresses weed growth (De Datta, 1969; Kleining and Nobel, 1968; Smith, 1988).

Environmental factors, emergence characteristics, growth rates and other components of plant size and function influence the process of competitive ability of plants by changing the resource use efficiency (Harper, 1977). Manipulation of the time and method of planting, variety selection, planting density, fertilizer management, and crop rotation have significant effects on reducing weed problems in rice.

Straight row planting either by transplanting or by direct seeding makes weeding by hand pulling or by mechanical tools easier. Thorough puddling before transplanting incorporates weeds, thus giving the rice seedlings a head start over weeds that germinates later. Therefore this size difference makes rice plants more competitive against weeds. If land preparation and water management are adequate, this competitive advantage due to size difference is retained throughout most of the growth period of transplanted crops (De Datta, 1981). Furthermore, transplanting aids in the effective use of pre-emergence herbicides due to this size difference (De Datta, 1981).

Seedling height and the age at transplanting are also important factors in determining competitive ability. Tall, old seedlings (21-30 days) are more competitive against weeds than short, young rice seedlings (De Datta, 1981). Introduction of shorter (14 cm) seedlings for mechanical transplanting in Japan caused as much as a 89% yield loss by weeds while it was only 59% for normal (23 cm) seedlings under unweeded conditions (Matsunaka, 1976). Many farmers of tropical Asia, where land preparation and water management in lowland rice are generally poor, still prefer to use older (30-40 days old) and taller seedlings than the 21-day-old seedlings normally recommended by rice researchers (De Datta, 1981).

The closer the rice plants are sown/ transplanted, the greater their competition against weeds that grow in association with rice. In a study by Estorninos and Moody (1976) as reported by De Datta (1981), the grain yield reduction due to weeds averaged 18% at 15 x 15 cm, 30% at 20 x 20 cm and 52% at 25 x 25 cm; compared with weed free plots. According to Moody and De Datta (1977) less weed competition was observed as seeding rates increased in the range of 80-200 kg ha^{-1}. Rainfed low-land rice farmers in Eastern Sri Lanka use a seeding rate of 200 kg ha^{-1} which is double the normal seeding rate of rice. Though this practice reduces the weed level in the crop there remain high pest (insect) and disease incidences due to the high density planting.

It is critical to apply fertilizer when it will benefit the crop most and the weeds least (De Datta, 1981). In dry-seeded rice application of nitrogen fertilizer at the time of planting is unwise unless pre-emergent herbicides are used. Top dressing the crop with nitrogen after weeding is desirable to maximize nitrogen fertilizer use efficiency and minimize weed growth (De Datta, 1981). According to Kleinig and Nobel (1968), application of phosphorous and nitrogen fertilizer at the time of seeding stimulate the growth and tillering of barnyardgrass (*Echinochloa crus-galli*), a serious weed in rice.

The possibility of building up the number of certain species of weeds or group of weed species is greater if the same crop is grown each cultivation season. Crop rotation, therefore minimizes the undisturbed development of weed populations (De Datta and Jereza, 1976). But in areas where the soil is poorly drained continuous cultivation of rice is usually done since the land is not suitable for other crops. In such situations the weed population increases rapidly.

Hand weeding is a common weed control practice in all tropical rice growing areas. This is more common in transplanted rice. Usually one hand weeding, or two at the most should be sufficient to control weeds adequately in transplanted rice. According to De Datta (1981), one properly timed hand weeding (about 21 days after transplanting) may be adequate to reduce weed populations enough to obtain high yields.

The use of rotary weeders for weed control when rice is planted in straight rows can reduce labor requirements for weed control by 50%, but due to their inability to remove weeds close to rice hills weeding by hand one time is important to obtain good results (De Datta, 1981).

4.2. Use of Herbicides

Herbicides are now considered indispensable for cost-efficient weed control in lowland rice, particularly broadcast seeded flooded rice. The area of transplanted rice on which herbicides are used has been increasing steadily in both temperate and tropical Asia (IRRI, 1989). According to Moody (1994), bensulfuron-methyl, pyrazosulfuron-ethyl, bentazon, butachlor, pretilachlor, 2,4-D, MCPA, piperophos + 2,4-D, propanil, oxadiazon, thiobencarb, quinclorac and fenoxaprop-ethyl are widely used herbicides in rice. Selection of a suitable herbicide depends on many factors like type of rice culture, weed species and the age of weeds. In rice growing areas in the USA the most common weed control measure is sequential application of propanil [N(3,4-dichlorophenyl) propanamide]. Since propanil has no residual activity, two applications are usually required to control grass and broadleaf weeds prior to establishing the permanent flood (Street and Muller, 1993). The auxin-type herbicide quinclorac is also effective for post-emergence control of *Echinochloa* species in direct seeded and transplanted rice (Caseley, 1994).

5. Use of Weed Competitive Cultivars

Economic and environmental costs of present weed control practices and increasing incidence of weed resistance to herbicides have stressed the need of viable, environmentally sound weed management alternatives. Utilization of the weed suppression ability in crop cultivars is a preventive method that reduces resource use efficiency of weeds considerably in integrated weed management systems.

5.1. Weed Competitive Ability of Crop Cultivars

Weed competitive cultivars of several crop species have shown promising yields under low weed management levels. McWhorter and Hartwig (1968) reported that "Brag" soybean competed better than other common cultivars with johnsongrass. They also found that "Semmes" was more competitive than other soybean cultivars with Common cocklebur. Burnside (1972) reported that "Harosoy 63", "Amsoy" and "Corsoy" soybeans were damaged less by weed competition than "Hawkeye 63", "Shelby", and "Lindarin 63" cultivars. Soybean cultivar differences such as height and time required to reach maturity contributed heavily to their crop-weed competitive ability. Tall late-maturing soybean cultivars frequently competed better with weeds than short, early-maturing cultivars (Burnside, 1972). In an another study Forcella (1987) evaluated the characteristics associated with competitive soybean varieties. They found competitive varieties have a high leaf area expansion (LAE) rate and fast branch production (BP) during the first month of growth. The observed LAE rate was two-fold greater and BP was several times greater in competitive than noncompetitive varieties. Ford and Pleasant (1990) evaluated maize hybrids for their competitive ability against weeds under low input conditions and found a significant "weed control level x variety" interaction. Montgomery (1912), as cited by Guneyli et al. (1969), found that "Turkey Red" wheat was much more competitive than "Big Frame" wheat. Guneyli et al. (1969) found that the competitive advantage of grain sorghum cultivars over weeds was largely associated with rapid germination, emergence and root and shoot growth during early stages of plant development. They also observed high root cation exchange capacity (CEC) values in competitive hybrids and concluded that the high competitive ability of some sorghum hybrids was due to early seedling vigor, which was enhanced by the above characteristics. Jennings and Herrera (1968) reported that the number of tillers of sorghum and rice is correlated with their ability to compete with weeds.

5.2. Weed Competitive Ability of Rice Cultivars

Cultivars of rice vary in their ability to compete with weeds. In the Philippines transplanted "IR 8", a short-stature, lodging resistant cultivar competed less effectively than "H4", a tall, lodging susceptible cultivar (De Datta, 1981). Most of the modern high yielding rice cultivars are generally less competitive against weeds than the traditional cultivars. This may be due to the loss of their competitive fitness during the process of selection and improvement for high yield under intensively managed stress-free situations. Thus these cultivars have higher weed infestations and yield losses when compared with traditional cultivars under low input farming situations (De Datta, 1981).

Some information is available on the weed competitive traits of rice, but much of this information is conflicting. Many authors have mentioned plant height as highly correlated with weed competitive ability of rice (Jennings and Jesus, 1968; Jennings and Herrera, 1968; Smith, 1974; Moody, 1979; Garrity et al., 1992). But in a another paper, Jennings and Aquino (1968) recorded competitively inferior tall rice varieties. Here the shorter variety "BJ" dominated the taller variety "MTU" in interphenotypic competition in varietal mixtures. But interestingly they found that the variety "BJ" has better seedling vigor and a greater leaf growth rate than "MTU" even though "BJ" is shorter at maturity. Tillering capacity is reported to be correlated with competitive ability in some studies (Jennings and Aquino, 1968) while in others it is concluded that tillering is not important (IRRI, 1977). A high tillering variety, "IR 8", is fairly competitive with weeds despite its short stature. Low tillering varieties, with the same yield potential as "IR 8" when grown under ideal conditions, have not performed well under farm conditions (De Datta, 1981). The same variety, "IR 8", suffered greater yield reduction than the variety "H 4", a tall, low tillering cultivar under both transplanted and wet-seeded situations (De Datta, 1969). But another study on weed competition (IRRI, 1968), indicated the reduction of dry matter at heading was more severe for "H 4" than "IR 8", indicating that as far as weed competition is concerned, tiller number is more important than plant height (IRRI, 1968). Similarly, some researchers have concluded that the leaf area index (LAI) has no relation to yield reduction due to weeds (IRRI, 1977) yet in another study early LAI appeared to be an important factor in weed competitive ability (Jennings and Aquino, 1968). Leaf characteristics of rice plants largely control the amount of light penetration into the crop canopy and are also critical factors in determining dry weight accumulation (Jennings and Harrera, 1968). They tested five plant types of rice and found that the varieties "BJ" and "MTU", which are exceptionally more competitive than others, had numerous long lax leaves and relatively large LAI values. The less competitive varieties had fewer leaves and these were short and erect. Varieties which have droopy leaves at an early stage of growth and erect leaves 'later are good in both weed competing and yielding abilities. Guneyli et al. (1969) reported that early leaf area development and fast growth in sorghum (*Sorghum vulgarae*) hybrids increased their weed competitive ability. According to Sarkar and Ghosh (1977), as cited by Moody (1979), light transmission ratio (LTR) at 60 days after planting for tall (> 120 cm in height), medium (100-120 cm) and dwarf (< 100 cm) rice cultivars were 23, 36 and 47% respectively. Corresponding values of weed weight for these were 3.8, 4.0 and 4.4 g 0.2 m^{-2}, respectively. They have observed a higher LTR for "Ratna", a dwarf cultivar than for "Saket-1", a tall cultivar, resulting in twice the weight of weeds growing in association with the shorter cultivar. Jennings and Jesus (1968) and Jennings and Aquino (1968) indicated that cultivars with long lax leaves are more competitive than those with short erect leaves. They also mentioned that different strong weed competitors of rice probably have different combinations of morphological characters while maintaining the same morphological advantage.

Short-growth duration cultivars appear to be less competitive against weeds than cultivars having a longer growth duration. Variety "Starbonnet" was less affected by competition from *Echinochloa crus-galli* than the shorter maturing "Bluebelle" (Smith, 1974). According to Jennings et al., (1979) plants with early vegetative vigor are desirable if such vigor does not carry through to excessive growth and mutual shading after panicle initiation. Early vigor is associated with various combinations of rapid seedling emergence and development, early tillering, moderately long, initially droopy leaves and early and rapid increase of seedling height. Kawano et al., (1974) noted that vegetative vigor, large leaf area, a high rate of nitrogen absorption in the early growth stages and plant height were the most significant characters related to competitive ability.

Some researches have recorded a negative correlation between competitiveness and yield of rice (Jennings and Jesus, 1968; Jennings and Aquino, 1968). According to their findings this is probably largely associated with the negative relationship between plant height and yield and leaf length (laxness) and yield. However Jensen and Federer (1965), as cited by Jennings and Aquino (1968) suggested that competitive ability and yield are positively correlated in wheat. Garrity et al. (1992) have also identified some upland rice cultivars with superior yield potential and weed suppression ability similar to traditional rice cultivars. They concluded that it would be possible to breed or select upland rice cultivars with acceptable yield and high competitive ability against weeds if a correct screening strategy is followed.

Rice farmers in tropical Asia had depended on tall, vigorously tillering plants to provide weed competition. The introduction of modern semi-dwarf rice varieties increased weed problems and the need for weed control became more obvious. Most modern rice varieties allow more light to penetrate the crop canopy, thus allowing more weed seed to germinate and grow better. Furthermore the need of high fertilizer rates for these improved varieties aggravate the weed problem.

Little research has been done to develop varietal screening procedures of plant selection that consider the crop's ability to compete with weeds. New crop varieties have been selected under weed-free conditions or without any specific regard to their ability to compete with weeds, resulting in varieties that are less competitive against weeds than traditional varieties. Weed competitive ability in crops is of less importance for commercial farmers in developed countries since they are in a position to manage weeds using high input cultural practices such as herbicides. This also may be one reason for the lack of research interest in this field among researchers in developed countries.

6. Methods of Studying Crop-Weed Competition

Several approaches have been developed to study plant competition in mixed stands. Each of these consider density, spacial arrangement, and proportion of species to varying degrees (Radosevich, 1986). These approaches fall into four different types of experimental methods, namely: additive, substitutive, systematic (nelder), and neighborhood methods. In each method, total or individual plant yield, plant growth rate or plant mortality is measured.

6.1. Additive Experiments

The additive method of competition study involves growing weeds at varying densities in association with a constant population of a crop plant. This method is perhaps the most common approach used to study crop-weed competition because of its relevance to field situations in which one or more weed species infest an area occupied by a crop.

Though it is close to the practical situation, this approach has been criticized because of its failure to account for the effect of density and species proportion on the outcome of competition. In the additive approach the total plant density always varies, while the proportion among species also changes simultaneously with total density (Radosevich, 1987). Thus two major factors in the experiment vary, making interpretation of effects of either factor difficult.

In additive experiments, spatial arrangement among plants is assumed to be uniform. Therefore the influence of intraspecific competition is assumed to be constant. But practically the placement of weed plants is often unknown and is not uniform. Therefore with this uncertainty in proximity factors and the inability to differentiate between intra and interspecific effects, determining interspecific interaction effects is difficult. The practical usage of this method is debatable.

6.2. Substitutive Experiments (Replacement Series)

In the substitutive or replacement series experiments (De Wit, 1960) the total plant density is constant, while the mixture proportions of two species vary. In this approach a range of mixtures is generated by starting with a monoculture of each species and gradually replacing plants of one species by the other, until the monoculture of the other is obtained. Therefore there is no confounding of experimental variables in this approach. Harper (1977) suggested that much of the deficiencies in additive experiments could overcome by this method.

In this method the outcome of competition can be represented graphically. The shape of the graph explains the type of interaction between species and which species are more successful in the mixture. Utomo (1981) used the replacement series concept to describe the complex environmental factors that affect plant growth and interaction between weed species and upland rice. Connolly (1986) evaluated different indices proposed for analysis and interpretation of results obtained from replacement series experiments. According to his analysis the assessment of species aggressiveness is influenced by the replacement lines selected, and indices generally varied significantly. The relative yield total (RYT) was the most stable of all indices tested. This experimental design is most valuable for assessing the competitive effects of species proportion at a single total density (Radosevich, 1987).

Difficulties associated with this approach also include the confounding effects of intra and interspecific competition (Harper, 1977; Connolly, 1986; Radosevich, 1986). In most of the studies the total density is held constant and this prevents the assessment of the density dependence of RYT. Therefore, to obtain information with a practical value it is necessary to have a range of total density of mixtures and monocultures of each species which are close to the field situations. Jolliffe et al. (1984) suggested including several monoculture densities in the experiment and use relative yield responses of the species in the mixture to alleviate these problems. In many of these studies yield is frequently the only parameter assessed (Jolliffe et al., 1984). However, the basis of yield variations in monocultures and mixtures could be better understood if observations on other plant characteristics such as leaf area and dry matter partitioning are made. Similarly when species of different individual sizes are involved in mixtures and the yield is measured in terms of biomass rather than relative aggresivity, competitive ratio or seed production, it tends to favor the large species (Connolly, 1986).

6.3. Systematic Designs

The concept of systematic design was initially developed by Nelder (1962) for spacing studies involving single species. These designs are important for competition studies focusing on proximity factors (density, proportion and spatial arrangement). There are several experimental designs under systematic methods.

6.3.1. Nelder Experiments

Nelder experiments (Nelder, 1962) have been restricted predominantly to studies of interference among individuals of a single species. Here the plant density and spatial arrangement are varied systematically. Therefore this design is useful for intraspecific competition studies in row crops such as soybean, corn and vegetables. Here the area per plant or amount of space available to each plant changes in a consistent manner. In this experimental arrangement it is possible to account for spatial relationships among plants and the effects of density and proportion of the species under study. Spitters (1983) has criticized this design, pointing out that plant arrangement in this design is not consistent with a situation in which weeds are partially controlled and the influence of total density is not adequately addressed.

6.3.2. Addition Series Experiments

Based on the concept of the reciprocal yield law, Spitters (1983) introduced the concept of the addition series experimental design. In this approach to competition studies, the densities of the species under study vary in two directions, generating a wide range of species proportions. The response of each species to density and proportion of the components of the mixtures is influenced by intra and interspecific competition. The concept of this model was derived from the yield-density models developed by Shinosaki and Kira (1956), Willey and Heath (1969) and Watkinson (1980). The reciprocal yield law used in this approach can be expressed by the following equation (Radosevich, 1987).

$$1/W = A + BN$$

Where,

1/W - reciprocal of the individual plant weight.

A - constant equal to the reciprocal of the theoretical maximum size of a plant grown alone.

B - slope of the line reflecting the relationship between individual plant weight (W) and density (N). (This is considered as an indicator co-efficient for intraspecific competition.)

The equation predicts that as the density of species increases, the size, weight or yield of individuals in the population decreases due to competition. When the population consists of one species this competition is only intraspecific but when there are more than one species, there are intra- and interspecific competitive interactions. With the assumption that the effects from intraspecific and interspecific competition are additive, and considering the proportion or ratio of each species in the mixed stand, Spitters (1983) suggested that the reciprocal yield law can be expanded to include a two or multi species equation as follows;

$$1/W_1 = A_1 + B_{1.1}N_1 + B_{1.2}N_2 + B_{1.i}N_i$$

Where,

W_1 - Weight of individual plants of species 1

N_1,N_2 and N_i - Densities of species 1 through i.

A_1 - Intercept of the reciprocal of maximum plant weight for species 1.

$B_{1.1}$ - Regression coefficient for intraspecific competition of species 1.

$B_{1.2}$ - Regression coefficient for interspecific competition between species 1 and 2.

These regression coefficients indicate that the density of each species relative to that of the other influences the yield of both species. Therefore this equation can be used to predict the competitive ability of one species, based on the total and relative density of all other species in the mixture (Radosevich, 1987). Spitters (1983) defined the relative competitive ability of each species as the ratio of regression coefficients. The relative competitive ability of species 1 in association with species 2 is defined by the ratio $B_{1.1}/B_{1.2}$, Similarly intra- and interspecific competitive effects are quantified by coefficients, $B_{1.1}$ and $B_{1.2}$ respectively.

In some cases, inclusion of other terms such as interaction effects of species or data transformation improves the predictability of the model (Roush et al., 1989). Shainsky and Radosevich (1991) used a similar approach to study the yield-density relationships in douglas fir (*Pseudotsuga menziesii*) and red alder (*Alnus rubra*) seedlings. In this experiment apart from the main effect of density on the other species growth, they found an interdependency between the two species' densities resulting in an unusual pattern in which douglas fir individual stem volume increased as douglas-fir density increased at high densities of red alder.

6.3.3. Neighborhood Experiments

In most of the previously mentioned designs, plant stand or density was used to measure the outcome of competitive relationships. When individual responses to the proximity of other plants is of primary interest, a neighborhood method (Weiner, 1982) may be appropriate to assess interference. According to Weiner, this approach can be used to describe the behavior of individual plants as well as those of plant populations. In neighborhood designs, "performance" of a target individual is recorded as a function of its distance from or the number, biomass, cover or aggregation of its neighbors.

Several workers have reported the importance of spatial arrangement in plant interference studies. In a study on spatial and density interference of barnyardgrass (*Echinochloa crus-galli*) with rice by Stauber et al. (1991), weeds growing within 25 cm from the crop caused yield losses. According to Smith (1988), hemp sesbania - rice distance interactions occur when they are grown as far as 100 cm apart. Mack and Harper (1977) reported that the seedling growth of dune grasses was a function of the biological space available to each of the individual seedlings. Therefore increased proximity of neighbors may lead to a lower growth rate and dry matter production in individuals. Goldberg and Weiner (1983), described the effect of neighboring plants on a target species using the slope of a regression model relating the performance of target individuals with the amount of neighbors. The main advantage in their design is that it measures competition on the basis of individual plant biomass. Sano et al. (1984) mentioned that different types of neighbor effects might be achieved by a variety of character combinations in response to the associated species and environments.

6.3.4. Eco-Physiological Simulation Models

In all of the above approaches of studying interplant competition the outcome of competition is described at a given moment in time. They use a descriptive regression model and are based on the same principle as the approach of De Wit (1960), the non-linear hyperbolic relationship between yield and plant density (Cousens, 1987; Spitters et al., 1989). These regression models provide a simple and accurate description of competition effects in a particular experiment in which only weed density is varied. However, practically these regression coefficients may vary strongly among experiments due to factors other than the weed density, like the period between crop and weed emergence (Cousens, 1987; Kropff, 1988 a). Weeds often emerge in successive flushes in field situations making it difficult to apply a descriptive regression model. Therefore the accuracy of predictions made by these regression models is debatable. In all of these approaches no explanation is given of the whole process of interference. These approaches only account for a small number of factors that influence the competition process. Therefore these models cannot help in identifying the mechanisms of the changes in structure and dynamics of plant populations or communities (Tilman, 1988; Kropff 1988 a).

Relationships between morphological and physiological characteristics of species and their competitive strengths have been widely studied (Pearcy et al., 1981; Ampong-Nyarko and De Datta, 1989). It is well known that plants having a C_4 photosynthetic pathway have higher photosynthetic capacity at high radiation and high temperature levels than plant species having a C_3 photosynthetic pathway. According to Kropff and Van Larr (1992), high competitive advantage is coupled to higher photosynthetic capacity. Tilman (1988), using a simple mechanistic model, demonstrated the importance of morphological processes, which is fully governed by dry matter allocation in his model, for competitive interactions between species. Similar findings were reported by Kropff (1988 a). Many researchers have recognized these complex relationships between morphological and physiological characteristics and the competitive ability of plant species in mixtures, but the qualitative and quantitative studies which are focused on these relationships are rare.

Spitters and Aerts (1983) developed an eco-physiological model for interplant competition based on eco-physiological models for monoculture crops (Kropff, 1988 b). In these studies they focused on crop-weed competition for light and water. Several others (Graf et al., 1990b; Wilkerson and Jones, 1990; Kropff and Van Larr, 1992) followed similar approaches to quantify crop-weed interactions.

In the soybean - common cocklebur (*Xanthium strumarium*) growth model (Wilkerson and Jones, 1990) the competition is simulated by defining "an area of influence" for each weed. That is the area where the weeds compete with and account for the horizontally heterogeneous distribution of the weeds. In this model they have derived a light distribution factor by fitting the model to growth and leaf area data. The effect of height, one of the key factors, is not included in a mechanistic way in this model.

The model by Graf et al. (1990 b) for nitrogen and light competition in rice is based on a general crop growth model developed by these researchers. (Graf et al., 1990 a). The approach used in this model is similar to the soybean-cocklebur model. In this work the rice field weed flora is divided into six groups based on differences in leaf shape, growth form, height and phenology. In this model these researchers were able to simulate the dry matter production of the crop and weed accurately.

The model for interplant competition (INTERCOM) by Kropff and Van Larr, (1992) simulates the phenological development, competition for capture of light, water and nutrients, morphological development, dry matter allocation and accumulation under competitive situations. This simulation is done by integrating the parameters that define the physiological and morphological characteristics of the crop and weed in the competition process. This model can also account for the influence of environmental factors, plant density, date of emergence and species characteristics on competition. Therefore it can be used to analyze the impact of different morphological and physiological characteristics on the competitive strength of a species.

One general problem in developing and evaluating eco-physiological competition models is the unavailability of detailed data on parameters which are important as inputs to simulate the competition process with more accuracy. It is also well recognized that the actual mechanisms for competition for resource capture by plants are not simple. Plants are morphologically and physiologically extremely plastic in their response to the environment. Therefore generalization of plant responses to environment is a difficult task.

7. Plant Growth Analysis

Plant growth analysis is a technique which separates growth into component processes to study the effects of endogenous and exogenous influences. It is a dynamic technique, focusing on rates of growth, rather than on final yields (Hunt, 1982). The components of growth include both aspects of function, such as rates of photosynthesis, respiration and aspects of structure, such as the proportion of photosynthetic to non-photosynthetic tissue and the way it is distributed in space (Hunt, 1982).

Growth analysis utilizes measurements of dry weight and leaf area from periodic harvests to partition growth among component characteristics. Therefore the technique of mathematical growth analysis provides a convenient means of examining the processes of total dry matter production and leaf area expansion that are important in determining the vegetative growth of a plant and competitiveness under a variety of environmental conditions (Patterson, 1982). This technique requires the collection of data on dry matter production of roots, leaves, stems and reproductive organs and leaf area throughout the growing period. Calculation of dry matter production per unit leaf area [net assimilation rate (NAR)], relative growth rate (RGR), relative leaf expansion rate (LER) and other partition coefficients for plant biomass and leaf area under competitive situations provide valuable information for understanding the basis of the "competitive nature" of plants (Radosevich and Holt, 1984). Jolliffe et al. (1984) has mentioned the importance of analysis of plant growth characteristics to explain the yield variations in monocultures and mixtures. Although considerable amount of research has been conducted to measure the influence of weed competition on crop yield, few experiments have directly used plant growth analysis to elucidate mechanism of competition in weed populations or community dynamics (Roush, 1988).

Roush (1988) observed that two broad-leaved summer annual weeds were more competitive than annual grass competitors due to their high leaf area ratio (LAR), even though the grasses had higher NAR. Porter (1989), found a negative correlation between NAR and RGR, but strong correlation between LAR and RGR. He concluded that LAR and specific leaf weight (SLW) are important in determining the RGR, and thus, the competitiveness of the herbaceous species. However, according to Roush (1988), such relationships between components of RGR and species competitiveness may change with other factors such as plant growth and environment. Thus it is important to know which parameters should be considered to explain the dynamics of competitiveness of species in monoculture and mixture.

CHAPTER III

THE NATURE OF RICE (*Oryza sativa* L.) - BARNYARDGRASS (*Echinochloa crus-galli* (L.) Beauv) COMPETITION [1]

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1. ABSTRACT

Field studies were conducted in the low country dry zone of Sri Lanka to study the nature of barnyardgrass (BYG) competition with two cultivars of rice, BG 350 and BG 94-2. These cultivars are morphologically different but both belong to the 3.5 month age class. They were transplanted in densities of 0, 33, 66 and 100 plants m^{-2} with 0, 3, 9 and 27 plants m^{-2} of BYG density in an addition series design under lowland irrigated conditions. At 4 and 8 weeks after planting (WAP) monocultures of cultivar BG 350 were much more affected by intraspecific competition (B_{RR}) but at maturity monocultures of the cultivar BG 94-2 had high B_{RR} values. In rice-BYG mixtures, increasing density of either species reduced the per plant biomass of rice. Cultivar BG 350 suffered by interspecific competition (B_{WR}) for a longer period than the cultivar BG 94-2 and increasing density of BYG affected the biomass production of BG 350 more than that of the cultivar BG 94-2. At low crop densities BYG caused high yield losses in both cultivars, but the overall yield reduction due to competition

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of BYG was about two times as much in the cultivar BG 350 as that in the cultivar BG 94-2.

Nomenclature: Barnyardgrass, *Echinochloa crus-galli* (L.)Beauv. #[3] ECHCG.

Additional index words. Intraspecific competition, interspecific competition.

2. INTRODUCTION

Barnyardgrass (*Echinochloa crus-galli* L. Beauv.), a troublesome weed of rice (*Oryza sativa* L.) culture throughout the world causes large yield reductions (Holm et al., 1969). Its interference with rice varies with crop and weed plant densities, competition duration, fertilization and the competitive ability of the rice cultivar (Smith, 1968, 1988). Even a low density of barnyardgrass (BYG) can cause serious yield reductions under high fertility and low crop density situations (Noda et al., 1968; Smith, 1968; De Datta et al., 1969 and Hill et al., 1985). Among the weeds in the rice, BYG is difficult to control and has become a serious problem since it produces abundant seeds and has a similar morphology and growth habit similar to rice during their seedling stages, making BYG identification more difficult (Noda et al., 1968).

Most of the presently cultivated rice cultivars with improved plant type suffer more from weed competition than those grown earlier due to their altered plant morphology (De datta, 1981; Smith, 1974). Plant height, tiller number, early seedling

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci., Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

vigor, leaf area index and leaf characteristics of rice have significant effects on weed competitive ability (IRRI, 1968, 1977; Moody, 1979; Smith, 1974).

Many have researched BYG - rice competition but most of their experiments were conducted as additive experiments that determined the final crop yield response to weed density. In these experiments a single density of crop is subjected to several densities of a weed species and the final crop yields compared with yield of monocultures. Therefore in this approach intra- and interspecific competition effects on crop growth and yield cannot be quantified (Radosevich, 1987). Several other studies of rice-BYG competition were done as replacement series (De Wit, 1960) experiments, but this design has problems of confounding as the density and proportion of the two species are changing simultaneously.

The addition series design (Watkinson, 1981; Spitters, 1983; Radosevich, 1987, 1991) which simultaneously manipulates the densities of two or more species overcomes the problems in additive and replacement series designs and is useful to quantify intra- and interspecific competition in agricultural systems. This design generates several densities of monocultures of each species and an array of mixtures by changing the species densities and proportions in a systematic manner.

Data analysis of an addition series experiment utilizes mathematical models which have been derived from the model of hyperbolic yield-density relationship (Kira et al., 1953) and the equation for reciprocal yield law (Shinozaki and Kira, 1956) for monoculture situations (Spitters, 1983; Roush, 1988; Radosevich, 1991).

Equation for hyperbolic yield-density relationship

$$W = W_0 N^{-B} \quad (1) \quad \text{or}$$

$$Ln(W) = Ln(W_0) - B\,Ln(N) \quad (2)$$

Equation for reciprocal yield density relationship

$$1/W = 1/W_0 + BN \quad (3)$$

Where W = Mean plant size

W_0 = Maximum plant size in the absence of competitors

N = Plant density

B = Coefficient quantifying the effect of density on plant size

Expanded versions of equation 2 and 3 (equations 4 and 5) quantify both intra- and interspecific competition in plant mixtures (Spitters, 1983; Roush, 1988; Radosevich, 1991).

$$1/W = B_{i0} + B_{ii}(N_i) + B_{ji}(N_j) \quad (4)$$

$$Ln(W_i) = Ln(W_{i0}) - B_{ii}Ln(N_i) - B_{ji}Ln(N_j) \quad (5)$$

Where B_{i0} = Theoretical mean yield of individual plants of species i under competitor-free growing conditions.

B_{ii} = Regression coefficient quantifying the intraspecific effects of the density (N_i).

B_{ji} = Regression coefficient quantifying the interspecific effects of the density (N_j) of species j.

Other terms, such as the effect of another species and the effect of the product of the species densities or interdependency of intra- and interspecific competitive effects on crop performances, may also be added to the model to test the species interactions.

The model statistics can be used to explain the components of competition (Table 3.1) and the model parameter estimates can be used to explain the intensity (the amount of crop loss relative to the density of competitors) and the relative importance (the degree to which competition influences plant yield relative to other factors) of competition.

Table 3.1. Statistical components of competition and their interpretation.

Statistic	Component of competition	Parameter estimate
Intercept	Maximum potential size of the response in the absence of competitors.	B_{R0}, B_{W0}
Regression coefficients	Intensity of intra- and inter- specific competitive effects on response variable.	B_{RR},B_{RW} B_{WW},B_{WR}
Interaction term	Interaction between intra- and interspecific density effects on response variable	B_{PR}, B_{PW}
Ratio of coefficients	Competitive effects of the density of species R relative to the density of species W in mixture	B_{RR}/B_{WR} B_{WW}/B_{RW}
Model R^2	The overall importance of the competition on performances of response variable relative to other factors.	adjusted R^2
Partial R^2	Importance of competitive effects of each species density.	pR^2_{RR}, pR^2_{RW} pR^2_{WW}, pR^2_{WR}

The objectives of this experiment were to:

1. Study the dynamics of rice-BYG competition with special emphasis on the effect of morphological differences of rice cultivars relative to their competitive ability.
2. Quantify the intra- and interspecific competitive effects on rice plant growth and yield at different rice and BYG densities.

3. MATERIALS AND METHODS

Two field experiments were conducted during the 1994 Yala (dry) cultivation season at the Regional Agricultural Research Center, Aralaganwila, Sri Lanka to study the competitive effects of BYG on two rice cultivars. Both cultivars, BG 350 and BG 94-2, belong to the 3.5-month age class but have contrasting morphological characteristics. Cultivar BG 350 has short, wide and erect leaves, short culms, medium-high tillering and slow initial growth. The cultivar BG 94-2 has fairly long, wide and leaves, fast growth at the late vegetative phase and a medium-tall culm. Both experiments were conducted under low-land, irrigated conditions. The soil type at the experimental site was a sandy, old alluvial soil (p^H 6.5 and organic matter 1.8%).

Four planting densities of rice 0, 33, 67, 100 plants m^{-2} (no rice and 15 x 20 cm, 15 x 10 cm, and 10 x 10 cm rice spacing respectively) and four densities of BYG (0, 3, 9, 27 plants m^{-2}) were used in the experiment. These were arranged in an addition series design (Watkinson, 1981; Spitters, 1983; Radosevich, 1987, 1991) with four replications in a factorial randomized complete block arrangement.

Therefore the design included all combinations of mixtures and monocultures of the above densities.

BYG (*Echinochloa crus-galli var. Hispidula*) seeds collected from rice fields in the area during the previous growing season, and rice were raised in wet-bed nurseries and were transplanted into 2x2 m experimental plots when they were 18-days-old. BYG seedlings were uniformly planted with relevant densities just after planting rice seedlings.

Hand weeding was practiced with two-week intervals for 8 weeks to remove volunteer weeds. All plots received the recommended level of rice fertilizer mixture for the low country dry zone of Sri Lanka (Department of Agriculture, Sri Lanka 1991). The total amount of fertilizer, N 100, P_2O_5 25 and K_2O 25 Kg ha^{-1}, was split between starter (at planting), N 25, P_2O_5 25 and K_2O 25 Kg ha^{-1}, and top dressings of 25 and 50 N Kg ha^{-1} at 3 and 7 weeks after planting.

Sampling was done for per plant biomass (four plants/plot) of rice and BYG at 4 and 8 weeks after planting (WAP) and at maturity. Rice grain yields were obtained from a $1m^2$ harvesting area and measured at 14% moisture level. Panicle numbers per plant of rice and BYG also were determined at maturity.

Effects of the density of each species on per plant biomass of rice and BYG, per plant grain yield of rice and per plant panicle number for each species were quantified using multiple regression (SAS Institute Inc. 1991). The expanded log-log model for hyperbolic yield-density relationship (equation 5) showed a better fit than the expanded reciprocal yield equation (equation 4) for these data. Residuals from the reciprocal yield model were fan-shaped and revealed a non-random distribution.

Intraspecfic competitive ability and relative competitive ability of each species in monoculture and mixture were calculated using ratios of regression coefficients. The statistical components of competition and their interpretation using the model parameters are summarized in Table 3.1. The model forms used in the data analysis and calculations are given below;

Monocultures: $Ln(Y_i) = B_{i0} - B_{ii}\ Ln(N_i)$

Mixtures: $Ln(Y_i) = B_{i0} - B_{ii}\ Ln(N_i) - B_{ji}\ Ln(N_j) + BP_i\ Ln(N_i)Ln(N_j)$

Intraspecific competitive ability in monocultures $= B_{i0} / B_{ii}$

Relative competitive ability of mixtures $= B_{ii} / B_{ij}$

Rice $= B_{RR}/B_{WR}$

BYG $= B_{WW}/B_{RW}$

4. RESULTS AND DISCUSSION

Rice monoculture: For monocultures of both tested rice cultivars statistically significant reductions were recorded in per plant biomass, panicle number and grain yield with increasing rice density (Table 3.2). Slopes of the regression lines for rice biomass at 4 and 8 WAP were greater in cultivar BG 350 than BG 94-2 indicating that BG 350 biomass was more affected by its own density than BG 94-2. This effect changed at the late growth stages and BG 94-2 was more affected by its density at maturity (Table 3.2). These models accounted for 88-95% of the total variation of the per plant rice biomass.

Rice panicle number and grain yield per plant were more affected by intraspecific competition in BG 94-2 than in BG 350, suggesting that the high intraspecific competition in BG 94-2 at late vegetative and reproductive phases of the crop had affected the yield components and the final yield of BG 94-2 (Table 3.2).

Table 3.2. Log-log models explaining per plant biomass, panicle number and grain yield of two cultivars of rice in monoculture.

Stage of growth	Cultivar	B_{RO}	B_{RR}	R^2	n
4 WAP	BG 350	Ln(RBM) = 7.7012	- 1.3479Ln(N_R)	.94	16
8 WAP	BG 350	Ln(RBM) = 7.8612	- 1.2572Ln(N_R)	.94	16
Maturity	BG 350	Ln(RBM) = 7.0516	- 0.8977Ln(N_R)	.88	16
,,	BG 350	Ln(RPN) = 3.5159	- 0.3499Ln(N_R)	.45	16
,,	BG 350	Ln(RYLD)= 8.4034	- 0.8856Ln(N_R)	.85	16
4 WAP	BG 94-2	Ln(RBM) = 7.0729	- 1.1816Ln(N_R)	.88	16
8 WAP	BG 94-2	Ln(RBM) = 6.0239	- 0.8073Ln(N_R)	.90	16
Maturity	BG 94-2	Ln(RBM) = 7.5891	- 0.9326Ln(N_R)	.92	16
,,	BG 94-2	Ln(RPN) = 4.1573	- 0.5384Ln(N_R)	.85	16
,,	BG 94-2	Ln(RYLD)= 6.3852	- 0.0922Ln(N_R)	.91	16

(B_{RO} =Intercept, B_{RR} = Regression coefficient, N_R = Rice density, WAP = weeks after planting, RBM= rice biomass, RPN= rice panicle number, RYLD=rice grain yield, P values for parameters are $<.01$)

Barnyardgrass monoculture: At early seedling stage BYG monocultures exhibited a more vigorous, spreading growth habit than either cultivar of rice. These monocultures had higher per plant biomass, tiller number than the BYG in rice-BYG mixtures. Plants in BYG monocultures in both experiments had statistically significant reductions in per plant biomass and panicle number with increased BYG density. The tested log-log models explained 69- 87% of the total variation of per plant BYG biomass (Table 3.3).

Calculated values of relative intraspecific competitive ability for each species in monoculture revealed a higher intensity of intraspecific competitive effects in BYG biomass production than that of the rice cultivars (Table 3.4). The intensities of relative intraspecific competitive ability in rice cultivars were similar at 4 WAP, but in later stages, higher values were recorded in cultivar BG 94-2 than BG 350, suggesting an increase in intraspecific competition. The observed high crop growth in BG 94-2 at late vegetative phase had increased intraspecific competition at a higher rate than that in the cultivar BG 350.

Similarly, increasing rice density in monocultures resulted in an increase in crop yield per unit area (Table 3.2). The rate of increase in cultivar BG 350 was higher than that of the cultivar BG 94-2, suggesting that BG 350 was less affected by intraspecific competition. This information indicates that under weed free situations the cultivar BG 350 is less affected by its density and there is a possibility of further yield increase if the crop is planted at a higher density. But in the cultivar BG 94-2 high density planting would reduce the yield as the intraspecific competitive ability of this cultivar is high.

Table 3.3. Log-log models explaining per plant biomass of barnyardgrass in monoculture.

Stage of growth	Experiment		B_{WO}	B_{WW}	R^2	n
4 WAP	1	Ln(WBM) =	4.0090	- 0.4403Ln(N_W)	.58	16
8 WAP	1	Ln(WBM) =	5.0110	- 0.4465Ln(N_W)	.84	16
Maturity	1	Ln(WBM) =	5.3312	- 0.3769Ln(N_W)	.69	16
4 WAP	2	Ln(WBM) =	3.5221	- 0.2627Ln(N_W)	.69	16
8 WAP	2	Ln(WBM) =	5.5049	- 0.6662Ln(N_W)	.77	16
Maturity	2	Ln(WBM) =	5.7382	- 0.3831Ln(N_W)	.67	16

(B_{WO} =Intercept, B_{WW} = Regression coefficient, WAP = weeks after planting, WBM= BYG biomass, N_W= BYG density. P values for parameters are $<.01$)

Table 3.4. The relative intraspecific competitive ability of two cultivars of rice and barnyardgrass in monoculture.

Stage of growth	Experiment 1		Experiment 2	
	Rice (BG 350)	BYG	Rice (BG 94-2)	BYG
4 WAP	5.713	9.106	5.986	13.407
8 WAP	6.253	11.223	7.462	8.264
Maturity	7.855	14.144	8.141	14.979

WAP= weeks after planting,

Rice and BYG in mixture: Log-log models for rice density (N_R), BYG density (N_W) and their interactions ($N_R x N_W$) explained 80-87% of the total variation in per plant biomass production (at 4 and 8 WAP and at maturity) in rice cultivar BG 350 and 82-85 % in the cultivar BG 94-2. Increasing density of either species reduced the per plant biomass of rice cultivars. The intensity of the reduction of per plant rice biomass due to the increase in BYG density was high in low densities of rice but diminished as rice density increased (Figures 3.1 and 3.2). According to the model estimates for cultivar BG 350, the intensity of intraspecific competitive effects of rice (B_{RR}) was less than that of interspecific competitive effects (B_{WR}) at 4 WAP and 8 WAP, but at maturity B_{RR} was greater than B_{WR} (Table 3.5). In the cultivar BG 94-2, B_{WR} was greater than B_{RR} at 4 weeks after planting but at 8 WAP and at maturity B_{RR} was greater than B_{WR} (Table 3.6). This information suggests that the biomass of BG 350 is affected by BYG density for a longer duration (up to 8 WAP) as compared to the biomass production in cultivar BG 94-2 which was affected by BYG density only for a four-week duration.

Calculated ratios of coefficients (the intensity of relative competitive ability of rice against BYG in mixture or competitive response of rice to BYG in mixture) were 0.81, 0.89 and 1.28 for the cultivar BG 350 and 0.80, 0.88 and 2.24 for cultivar BG 94-2 at the above growth stages. This suggests that interspecific competitive effects from BYG plants were higher than intraspecific competitive effects of rice at 4 and 8 WAP in both rice cultivars, BG 350 and BG 94-2. But at mature stages cultivar BG

350 was 1.28 times and cultivar BG 94-2, 2.24 times more competitive than BYG on the basis of per plant rice biomass production (Table 3.7).

Table 3.5. Intensity of competition: Regression coefficients for equations quantifying the response of rice (cultivar BG 350) and barnyardgrass (BYG) biomass per plant to densities of rice, BYG and rice x BYG interaction.

Rice (BG 350) biomass (Regression coefficients)						
Stage of growth		B_{RO}	B_{RR}	B_{WR}	B_{PR}	n
4 WAP		10.46(1.06)	-1.97(.25)	-2.42(.43)	0.49(.10)	64
	R^2=0.84	pR^2	0.47	0.22	0.15	
8 WAP		10.97(.90)	1.96(.22)	-2.19(.37)	0.45(.09)	64
	R^2=0.88	pR^2	0.55	0.23	0.10	
Maturity		7.48(.84)	-0.96(.20)	-0.75(.33)	0.13(.08) ns	64
	R^2=0.80	pR^2	0.57	0.23	0.00	
BYG biomass (Regression coefficients)						
Stage of growth		B_{RO}	B_{RW}	B_{WW}	B_{PW}	n
4 WAP		3.81(.65)	-0.41(.16)	-0.08(.26) ns	0.00 ns	64
	R^2=.68	pR^2	0.61	0.06	0.01	
8 WAP		6.76(1.17)	-0.91(.28)	-0.81(.47) ns	-0.81(.47) ns	64
	R^2=.56	pR^2	0.43	0.12	0.01	
Maturity		6.06(1.18)	-0.57(.28)	-2.19(.37) ns	0.00 ns	64
	R^2=.64	pR^2	0.54	0.10	0.00	

(ns = not significant at 5% probability level. P values for parameters are $<.05$ unless specified. Standard errors are given in parentheses)

Table 3.6. Intensity of competition: Regression coefficients for equations quantifying the response of rice (cultivar BG 94-2) and barnyardgrass (BYG) biomass per plant to densities of rice, BYG and rice x BYG interaction.

Rice (BG 94-2) biomass (Regression coefficients)					
Stage of growth	B_{R0}	B_{RR}	B_{WR}	B_{PR}	n
4 WAP	9.33(.81)	-1.69(.19)	-2.12(.32)	0.46(.08)	64
	R^2=.83	pR^2 0.46	0.20	0.17	
8 WAP	7.74(.67)	-1.17(.16)	-1.34(.27)	0.28(.07)	64
	R^2=.82	pR^2 0.51	0.21	0.10	
Maturity	8.53(.83)	-1.12(.20)	-0.50(.33) ns	0.10(.08) ns	64
	R^2=.85	pR^2 0.82	0.03	0.00	

BYG biomass (Regression coefficients)					
Stage of growth	B_{R0}	B_{RW}	B_{WW}	B_{PW}	n
4 WAP	5.63(.62)	-0.87(.15)	-0.94(.25)	0.20(0.06)	64
	R^2=.70	pR^2 0.52	0.08	0.10	
8 WAP	5.63(.62)	-0.75(.15)	-0.58(.25)	0.12(.06)	64
	R^2=.74	pR^2 0.67	0.05	0.02	
Maturity	6.14(1.93)	-0.56(.47) ns	-0.12(.78) ns	-0.06(.19) ns	64
	R^2=.54	pR^2 0.43	0.11	0	

(ns = not significant at 5% probability level. P values for parameters are $<.05$ unless specified. Standard errors are given in parentheses)

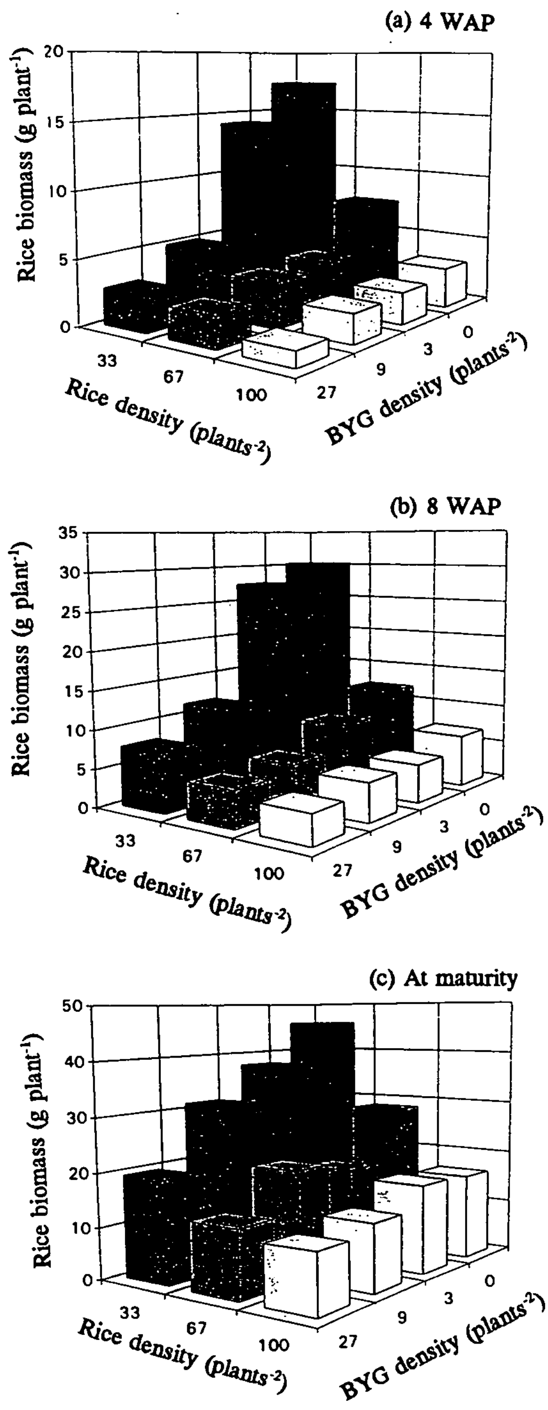

Figure 3.1. Effects of rice (cultivar BG 350) and barnyardgrass density on biomass production of rice. (a) 4 weeks after planting (b) 8 weeks after planting (c) At maturity.

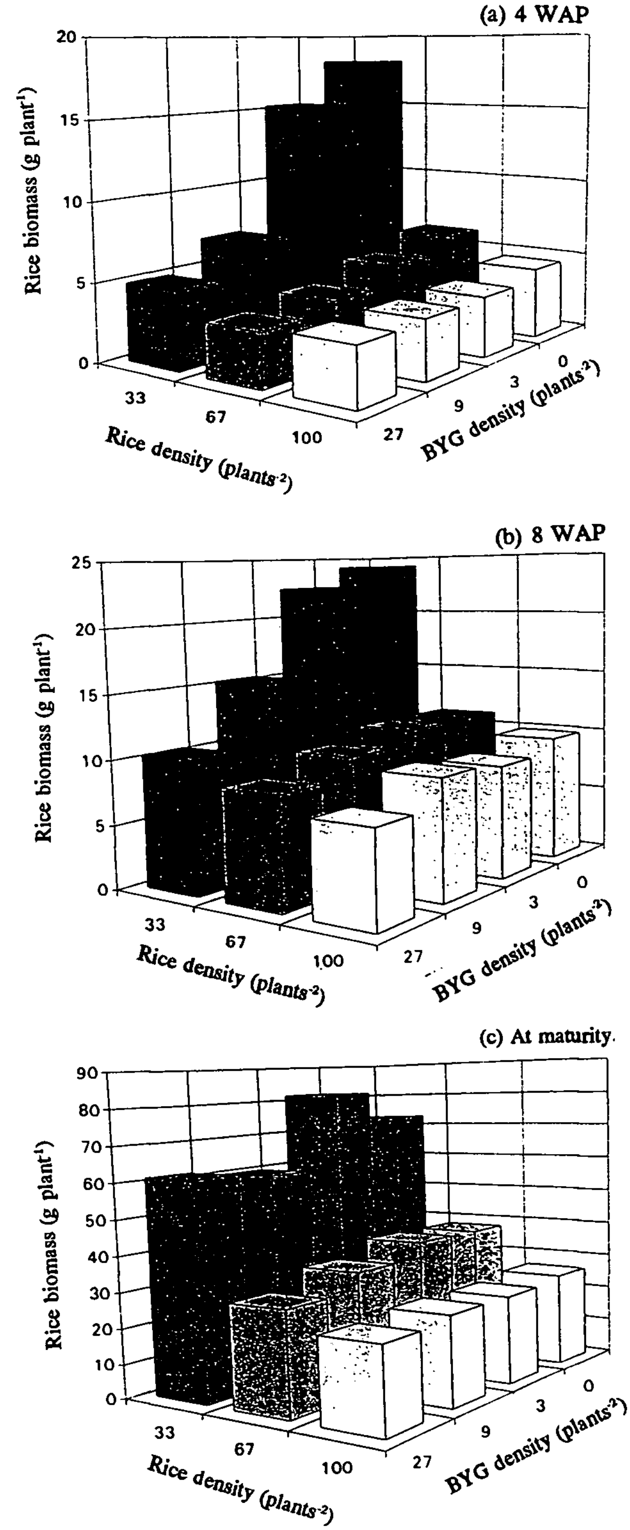

Figure 3.2. Effects of rice (cultivar BG 94-2) and barnyardgrass density on biomass production of rice. (a) 4 weeks after planting (b) 8 weeks after planting (c) At maturity.

Table 3.7. Relative competitive ability of rice and barnyardgrass in mixture.

Stage of growth	Experiment 1		Experiment 2	
	BG 350	BYG	BG 94-2	BYG
4 WAP	.81	.20	.80	1.08
8 WAP	.89	.89	.89	.78
Maturity	1.28	.01	2.24	.22

(Calculations are based on the coefficients for per plant biomass in rice and BYG in mixture)

According to the pR^2 values of these models, which explains the relative importance of competitive effects of each species density in determining the biomass, the density of rice was more important than BYG density in determining the biomass of rice and BYG (Tables 3.5 and 3.6). The pR^2 for rice density explained much of the total variation of biomass in both rice cultivars and in BYG (Tables 3.5 and 3.6). This indicates that although there was a highly intense interspecific competitive effect of BYG in the rice-BYG mixture, the relative importance of this competitive effect on rice biomass production was low. The intraspecific competitive effects of rice density had had a great effect on determining the per plant biomass of rice. Higher values were recorded in the pR^2 for BYG density in the per plant biomass model for rice cultivar BG 350 than that for the cultivar BG 94-2. At maturity 23% of the total variation of BG 350 per plant biomass was explained by BYG density, but in the cultivar BG 94-2 this explained only 3% of the total variation of the model. This indicates that the final biomass of cultivar BG 350 was much affected by BYG but the cultivar BG 94-2 was able to overcome the effects of interspecific competition by BYG.

The tested log-log models of rice and BYG density on per plant BYG biomass in mixture at 4,6 and 8 WAP and at maturity explained 56-66% of its total variation in BG 350 mixture. It was 52- 74% for the BYG in mixture with BG 94-2. At all sampling dates the density of rice cultivar BG 350 significantly reduced the per plant weed biomass. But the rice cultivar BG 94-2 does not have significant effects on per plant BYG biomass production at mature stages. In general, much of the model R^2 of per plant BYG biomass was explained by the pR^2 of rice density at all sampling dates in both rice cultivars. This indicates the density of rice was more important than the density of BYG in determining the biomass of BYG in mixture. At the highest tested rice density (which is higher than the normal planting density) BYG growth was severely affected while in the lowest rice density plots it produced a high biomass. Therefore this clearly shows that interspecific competition of rice was much greater than the intraspecific competition of BYG on the BYG per plant biomass growth (Tables 3.5 and 3.6). These interspecific competitive effects varied with rice cultivar characteristics. Calculated ratios of coefficients (relative competitive ability of BYG against rice) were 0.20, 0.89 and 3.84 for BG 350 and 1.08, 0.77 and 0.22 for BG 94-2 samples collected at 4 and 8 WAP and maturity. This information suggests that the relative competitive ability of BYG had increased with time in the rice-BYG mixture of rice cultivar BG 350 while in cultivar BG 94-2, this had decreased with time.

Interaction between species: The interaction terms for rice per plant biomass were highly significant ($p < .001$) at 4 and 8 WAP in both rice cultivars. It was significant at the $p < .05$ level at the final sampling in BG 350 but in BG 94-2 it was not significant. The model coefficients were .49 and .45 for cultivar BG 350 and .49 and .28 for cultivar BG 94-2. This information suggests that the intra- and interspecific competitive effects were not independent and these densities interact to influence the per plant rice biomass in rice. These interaction effects of rice and BYG densities on the per plant biomass of rice were studied in more detail by analyzing each density of rice and BYG separately to determine the changes in response with the change of the density of each species. When logarithmically transformed per plant rice biomass data were plotted as a function of logarithmically transformed rice density for each density of BYG, the slope of each isoline (for each density of BYG) indicates the intensity of intraspecific competition among rice plants for that density of BYG (Figures 3.3 and 3.4). In general, isolines of rice monocultures had greater slopes than that of rice-BYG mixtures. Slopes of isolines became more negative with increasing BYG density. But the sensitivity of these isolines to the increase of BYG density was higher in cultivar BG 350 than the cultivar BG 94-2 (Figures 3.3 and 3.4). This also indicates the high competitive ability of BG 94-2 against BYG in the tested densities.

Effects of BYG and rice density on rice yield and yield components: The interspecific competitive effects of BYG density reduced the per plant panicle number in rice cultivar BG 350 more than that in the cultivar BG 94-2. According to the model predictions the interspecific competitive effects of BYG on rice cultivar BG

350 was about 3 times greater than that on the cultivar BG 94-2 for the per plant rice panicle number. But the intraspecific competitive effects on rice panicle number were high in the cultivar BG 94-2.

The model fitting results indicated that the intensity of intra- and inter specific competition on per plant grain yield of cultivar BG 350 was higher than that of cultivar BG 94-2 (Table 3.8). These model coefficients indicated the per plant grain yield reduction due to interspecific competition of BYG is about 2 times as much in cultivar BG 350 compared to cultivar BG 94-2. A likely reason for this reduced grain yield in BG 350 is the reduction of panicle number per plant by BYG competition (Table 3.8).

According to the calculated percent yield reductions, the grain yield of cultivar BG 350 was much more affected by BYG competition than the yield of cultivar BG 94-2. Both rice cultivars had relatively high yield losses at low rice densities and the magnitude of yield loss decreased with the increase of rice planting density (Table 3.9).

Therefore the cultivar BG 94-2 seems to be less affected by BYG than BG 350 and BG 94-2 seems to possess a good combination of traits which determines its competitive ability. Intraspecific competitive effects were high in cultivar BG 94-2 and at high rice densities this affected its biomass and grain yield more than that in the cultivar BG 350.

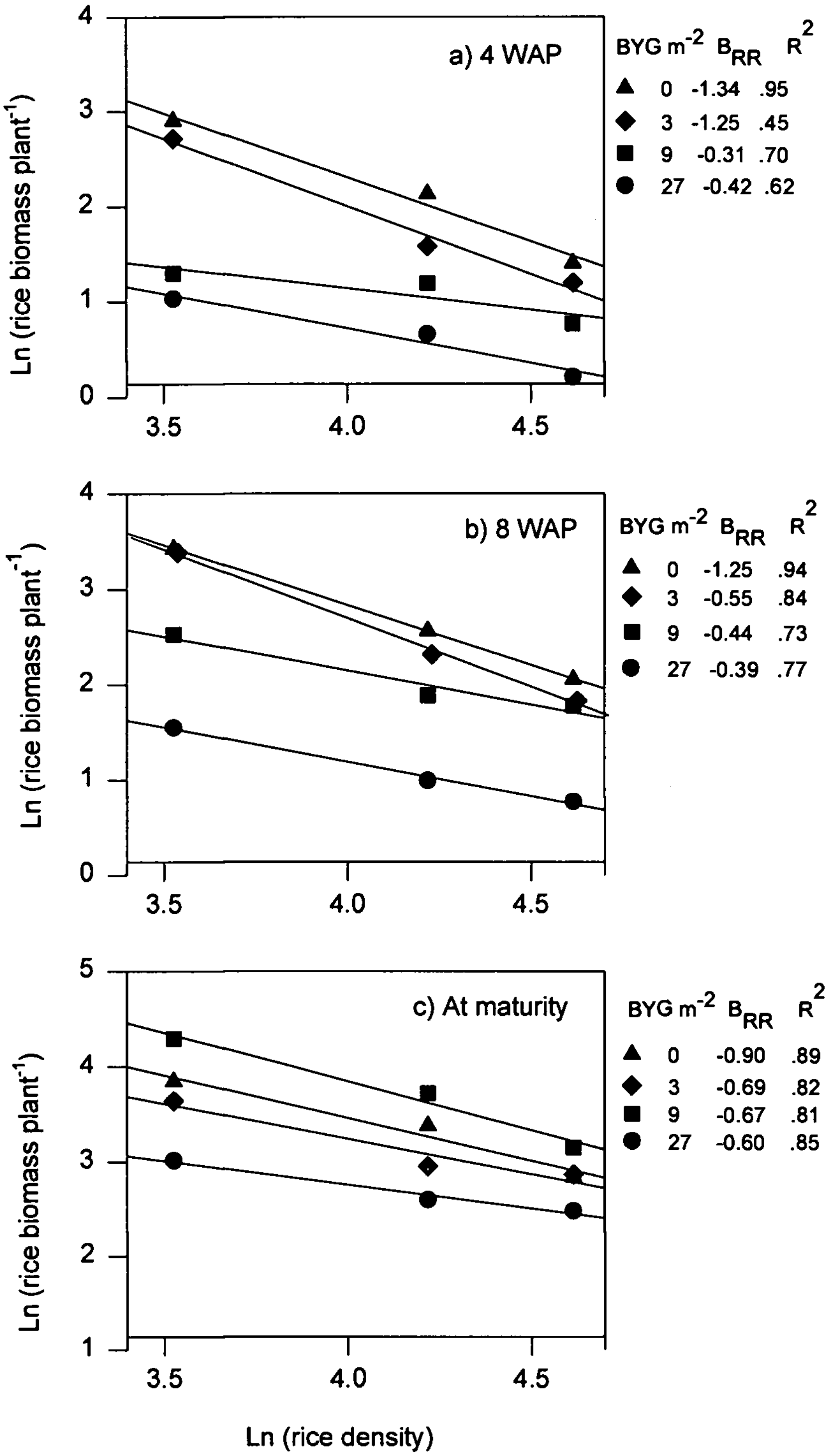

Figure 3.3: Effects of barnyardgrass (BYG) density on rice (cultivar BG 350) biomass production. (a) 4 weeks after planting (b) 8 weeks after planting (c) At maturity.

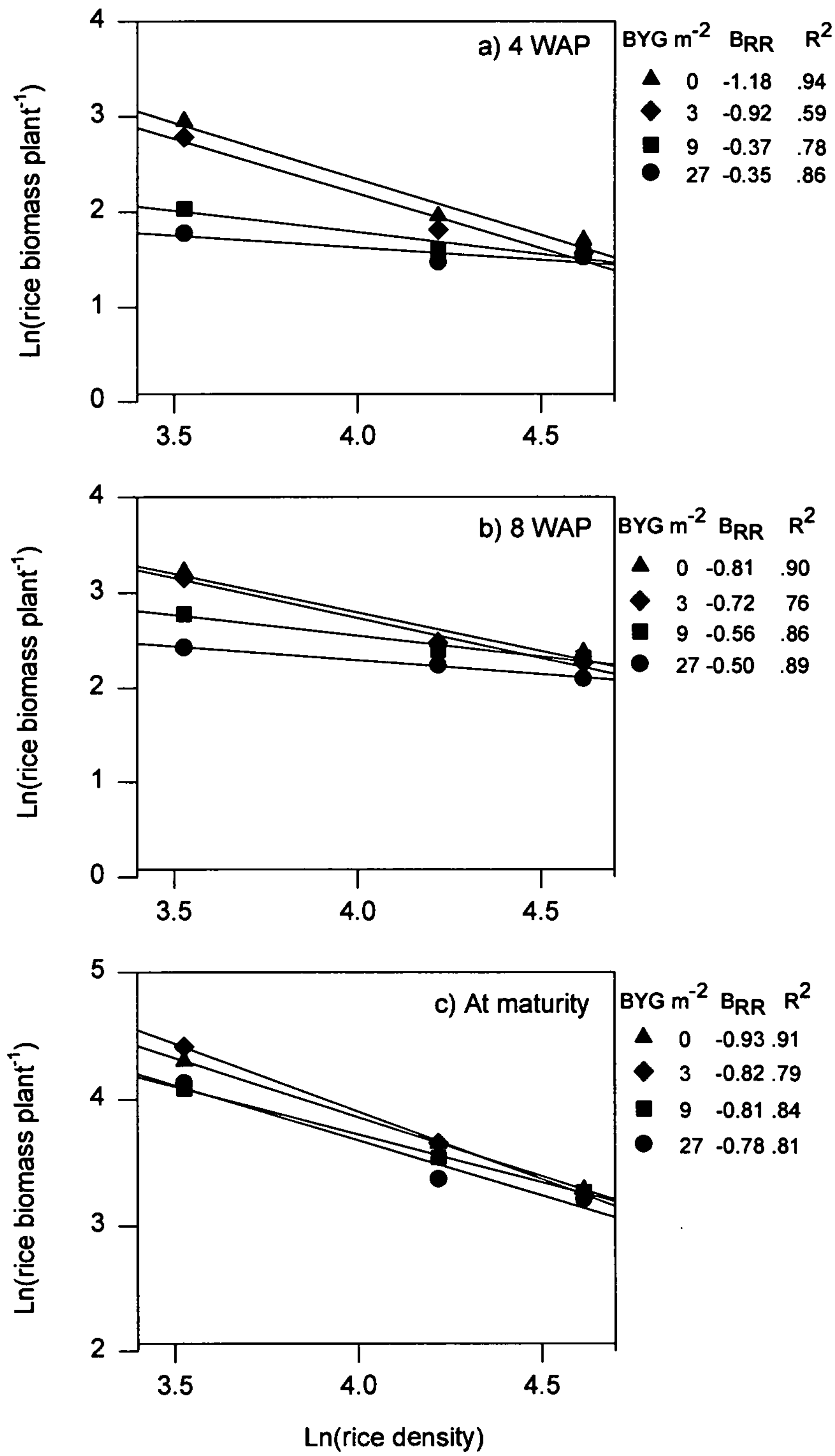

Figure 3.4: Effects of barnyardgrass (BYG) density on rice (cultivar BG 94-2) biomass production. (a) 4 weeks after planting (b) 8 weeks after planting (c) At maturity.

Table 3.8. Intensity of competition in two cultivars of rice: Regression coefficients for equations quantifying the response of rice panicle number and grain yield per plant to densities of rice, barnyardgrass and their products.

Cultivar BG 350				
$Ln(YLD) =$	10.37	$- 1.27\ Ln(N_{RR})$	$- 1.14 Ln(N_{WW})$	$+ 0.21\ Ln(N_{RR})Ln(N_{WW})$
$R^2 = .78$	pR^2	.53	.23	.02
$Ln(PN) =$	3.42	$- 0.32\ Ln(N_{RR})$	$- 0.59\ Ln(N_{WW})$	$+ 0.03\ Ln(N_{RR})Ln(N_{WW})$
			ns	ns
$R^2 = .56$	pR^2	.48	.10	0.00
Cultivar BG 94-2				
$Ln(YLD) =$	6.77	$- 0.99\ Ln(N_{RR})$	$- 0.51\ Ln(N_{WW})$	$+ 0.10\ Ln(N_{RR})Ln(N_{WW})$
			ns	ns
$R^2 = .78$	pR^2	.73	.04	.01
$Ln(PN) =$	4.37	$- 0.57\ Ln(N_{RR})$	$- 0.18\ Ln(N_{WW})$	$+ 0.12\ Ln(N_{RR})Ln(N_{WW})$
			ns	ns
$R^2 = .53$	pR^2	.35	.15	.03

ns = not significant at 5% probability level. P values for parameters are <.05 unless specified. YLD = Grain yield/plant, PN = Panicle number/plant)

Similarly, because of its relatively low interspecific competitive ability, the observed yield losses at low rice densities were higher in the cultivar BG 350 than that in the cultivar BG 94-2. This suggests high density planting would result in greater increases in yield in the cultivar BG 350 than in the cultivar BG 94-2, and under weedy situations a high density of cultivar BG 350 would perform better than that a low density (Table 3.9). The cultivar BG 94-2 recorded little or no yield increase due to increase in rice plant density. Therefore a high density planting would not be as effective, compared to the cultivar BG 350, in producing high yields under weedy situations. But since it has an ability to compete with weeds, generally the cultivar BG 94-2 would record less yield loss than the cultivar BG 350 at any weed density.

Table 3.9. Grain yields of two rice cultivars and yield losses from barnyardgrass interference compared to each monoculture rice density yield.

Plant density		Grain yield		Rice yield reduction by BYG	
Rice	BYG	BG 350	BG 94-2	BG 350	BG 94-2
— Plants m^{-2} —		kg ha^{-1}		%reduction	
33	0	6552 ac	7525 a	0	0
33	3	7200 ac	7312 a	-9.89	2.83
33	9	4850 bd	5050 b	25.98	32.89
33	27	3210 bd	5100 b	51.00	32.23
67	0	7102 ac	7075 a	0	0
67	3	6048 ac	6950 a	14.84	1.77
67	9	6300 ac	6812 a	11.29	3.72
67	27	4208 bd	5562 b	40.75	21.38
100	0	7552 ac	7787 a	0	0
100	3	7550 ac	7525 a	0.03	3.36
100	9	6258 ac	6800 a	17.24	12.67
100	27	5210 ad	6562 a	31.01	15.73

(Means followed by the same letter are not significantly different at the 5% probability level of Duncan's Multiple Range Test)

CHAPTER IV

PLANT CHARACTERISTICS ASSOCIATED WITH RICE (*Oryza sativa* L.) - BARNYARDGRASS (*Echinocloa crus-galli* L. Beauv.) COMPETITION.[1]

Lakshman L. Ranasinghe and Garvin D. Crabtree[2]

1. ABSTRACT

Five cultivars of rice possessing high, medium and low levels of weed competitive morphological traits (based on the INTERCOM model sensitivity analysis) were evaluated for their performances and competitive ability against barnyardgrass (BYG) under lowland irrigated conditions in the low country dry zone of Sri Lanka. Each cultivar of rice was planted with 0, 3, 9, 27 and 81 plants m^{-2} of BYG to determine cultivar differences in competitive ability. Significant variations were observed in cultivar performances and also in the suppression of the weed. Growth and yield of cultivars PPL and BG 94-2 were least affected by BYG competition while cultivars BG 1611 and BG 350 were most affected by BYG competition. Rice leaf area, plant height and plant dry weight data taken at 4 weeks after planting (WAP) were negatively correlated with BYG dry weight at maturity (Leaf area $r = -.40^{*}$ to $-.62^{**}$, plant height $r= -.39^{*}$ to $-.61^{**}$ and plant dry weight $r = -.41^{*}$ to $-.78^{**}$). At high BYG densities rice plant height at maturity was positively

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correlated with the grain yield. Nomenclature: Barnyardgrass, *Echinochloa crus-galli* (L.)Beauv. #[3] ECHCG.

Additional index words. Simulation, INTERCOM model

2. INTRODUCTION

Most of the modern cultivars of rice (*Oryza sativa* L.) with improved plant type have been developed with a reduced ability to compete with weeds and poorer adaptation to weedy situations (Moody, 1979). Therefore farmers spend much time and money for weed control to obtain good yields. During the last 30 years, coincident with the "green revolution", farmers have applied increasing quantities of herbicides, gradually replacing traditional cultural and mechanical weed control practices. The use of herbicides however has not eliminated weed problems in agriculture (Firbank and Watkinson, 1986). Economic and environmental costs associated with the use of herbicides and increasing incidence of weed resistance to herbicides have made apparent the need of environmentally sound alternative weed management practices.

Weed competitive cultivars of several crop species have produced promising yields under low weed management levels (McWhorter and Hartwig, 1968; Burnside, 1972; Forcella, 1987; Ford et al., 1990; Guneyli et al., 1969; Jennings and Herrera, 1968; Garrity et al., 1992). Cultivars of rice vary in their ability to compete with

[3]Letters following this symbol are a WSSA-approved computer code for Composite List of Weeds, Revised 1989. Available from WSSA, 309, W. Clark St., Champaign, IL 61820.

weeds. Most of the modern high yielding rice cultivars are generally less competitive against weeds than traditional cultivars.

Some information is available on the weed competitive traits of rice, but much of this information is conflicting. Many authors have mentioned plant height as highly correlated with weed competitive ability of rice (Jennings and Jesus, 1968; Jennings and Herrera, 1968; Smith, 1974; Moody, 1979; Garrity et al., 1992). But in another paper, Jennings and Aquino (1968) reported competitively inferior tall rice varieties. Tillering capacity is reported to be correlated with competitive ability in some studies (Jennings and Aquino, 1968) while in others it is concluded that tillering is not important (IRRI, 1977). A high tillering variety, "IR 8", is fairly competitive with weeds despite its short stature. Low tillering varieties, with the same yield potential as "IR 8" when grown under ideal conditions, have not performed well under farm conditions (De Datta, 1981). In another study on weed competition (IRRI, 1968), the reduction of dry matter at heading was more severe for "H 4" than "IR 8", indicating that as far as weed competition is concerned, tiller number is more important than plant height (IRRI, 1968). Similarly, some researchers have concluded that the leaf area index (LAI) has no relation to yield reduction due to weeds (IRRI, 1977) yet in another study early LAI appeared to be an important factor in weed competitive ability (Jennings and Aquino, 1968). Leaf characteristics of rice plants largely control the amount of light penetration into the crop canopy and are also critical factors in determining dry weight accumulation (Jennings and Harrera, 1968). Jennings and Jesus (1968) and Jennings and Aquino (1968) indicated that cultivars with long lax leaves are more competitive than those with short, erect leaves. According to Jennings et al., (1979) plants with early vegetative vigor are desirable if such vigor does not carry through to excessive growth and mutual shading after panicle initiation. According to Perera et al. (1992) root competition for obtaining mineral nutrients is more important than above ground competition for light. Therefore different strong weed competitors of rice probably have different combinations of morphological characters while maintaining the same morphological advantage. Kawano et al., (1974) noted that vegetative vigor, large leaf area, a high rate of nitrogen absorption in the early growth stages and plant height were the most significant characters related to competitive ability.

Little research has been done to develop varietal screening procedures of plant selection that consider the crop's ability to compete with weeds. New crop cultivars have been selected under weed-free conditions or without any specific regard to their ability to compete with weeds, resulting in cultivars that are less competitive against weeds than traditional cultivars.

Objectives of this research were to identify the important morphological traits responsible for weed competitive ability of rice and study the possibility of using crop-weed competition simulation models to predict the weed competitive ability of rice cultivars.

3. MATERIALS AND METHODS

Field experiments of various barnyardgrass densities with rice cultivars were conducted on a sandy old alluvial soil (p^H 6.5, organic matter 1.8%) at Regional

Agricultural Research Center, Aralaganwila, Sri Lanka during the 1993/94 Maha (wet) and 1994 Yala (dry) cultivation seasons. The crop - weed competition simulation model, INTERCOM (Kropff and Van Laar, 1992) was used to select cultivars of rice for field experiments. Yield responses of rice cultivars to quantitative changes in morphological characteristics such as plant height, tiller number, relative growth rate, leaf area and root dry weight were studied by a sensitivity analysis. It was conducted by calculating the percent change of simulated yield loss to an increase in the value of a morphological parameter of rice (Subroutine Plant 1.dat) by 20%, while keeping all other parameters constant.

$$\text{Sensitivity value} = \frac{\Delta\ \text{output}}{\text{output}} \Big/ \frac{\Delta\ \text{parameter}}{\text{parameter}}$$

Based on results of the sensitivity analysis (Table 4.1), cultivars of rice with high, medium and low combinations of these morphological traits were selected from available variety catalog records at the Central Rice Breeding Station, Batalagoda, Sri Lanka. These selected rice cultivars were tested in field experiments to identify the important traits and validate the model predictions. A general description of morphological and yield characteristics of the selected rice cultivars for field experiments is listed in Table 4.2.

During the 1993/94 Maha season four cultivars, and during the 1994 dry season five cultivars, of rice (3.5 month age class) were evaluated in field experiments. A split-split plot with three replications was used during 1993/94 Maha season in which rice density (15x10 or 15x15 cm) formed main plots, barnyardgrass density (0, 3, 9, 27 or 81 plants m^{-2}) was the variable in sub plots and rice cultivars (BG 1611, BW 267-3, BG 350 and a traditional cultivar PPL (Pachcha-perumal) in sub-sub plots. During the 1994 dry season a split plot design was used as only one density of rice was tested. Another cultivar of rice (BG 94-2) which possesses a good combination of competitive morphological traits was added to the experiment during the 1994 Yala season.

Table 4.1. Sensitivity of rice yield loss to a 20% increase in the value of each morphological parameter.

Parameter	Sensitivity value
Seedling height	2.83
Leaf area of seedlings	4.05
Relative growth rate of leaf area	6.69
plant height at maturity	2.85
Leaf area at maturity	2.73
Tiller number at maturity/ plant density	4.06
Initial root dry weight	0.001

Experiments were conducted under lowland irrigated conditions. Seedlings of rice cultivars and BYG were raised in separate wet-bed nurseries and planted at the specified densities when they were 18 days old. During the 1993/94 Maha season 2.5x3.5 m size sub-sub plots and during the 1994 Yala season 4x3 m sub-plots were used to plant rice seedlings. The crop received the recommended rice fertilizer mixture for the low country dry zone of Sri Lanka (Department of Agriculture, 1991). The total amount of fertilizer, N 100, P_2O_5 25 and K_2O 25 Kg ha^{-1}, was split between starter (planting) N 25, P_2O_5 25 and K_2O 25 Kg ha^{-1}, and top dressings of 25 and 50

Table 4.2. Morphological characteristics of the tested rice cultivars collected from variety catalog records and an observation experiment (1993/94 Maha season).

Cultivar	Plant height		Tillers	Leaf characteristics*				Grain yield
	3 WAP	Maturity		3 WAP		Maturity		
				length	width	length	width	
	—— cm ——		no./plant	—————— cm ——————				
BG 1611	38.5	104.8	11.3	24.7	0.59	40.8	1.3	High
BW 267-3	39.2	114.1	16.9	25.4	0.64	45.3	1.2	High
BG 350	34.3	85.1	12.0	21.2	0.68	31.6	1.3	High
PPL	51.3	124.3	11.6	28.9	0.68	47.1	1.0	Low
BG 94-2	41.1	118.6	10.2	26.2	0.62	46.2	1.2	High

* Average of 10 leaves. WAP= Weeks after planting.

N Kg ha^{-1} at 3 and 7 weeks after planting (WAP). Hand weeding was practiced at two-week intervals for 8 weeks to remove all volunteer weeds. Benomyl (*methyl 1-(butylcarbamoyl)-2-benzimidazole carbamate*) at 1.1 kg ai ha^{-1} was applied during the panicle initiation and booting stages to control blast (*Pyricularia oryzae* Cav.) disease since the cultivar PPL was highly susceptible to the disease. Plant height, tiller number, dry weight and leaf area were measured in both species throughout the growing season. A growth analysis was done to calculate relative growth rate of leaf area (RGR_{LA}) and leaf area index (LAI) of rice at different stages of growth. Rice grain yields were obtained from a harvesting area of 3.45 m^2 (1993/94 Maha season) and 4 m^2 (1994 Yala season) and measured at the 14% moisture level. Standard analysis of variance (SAS Institute Inc. 1991) and a correlation analysis (Statistical Graphics Co. 1993) was done to draw inferences of the relationship between the rice cultivar traits and weed competitive ability.

Since it was not possible to study root growth in the experiment, another observation study was conducted to study the root growth differences under varying densities of BYG. In this experiment, plants were grown in polyethylene bags (diameter 30 cm and depth 45 cm) which were buried in soil. A seedling of rice was planted into the center of each bag and then either 0, 1, 2 or 4 seedlings of barnyardgrass were planted around the rice seedling in each bag. At 4 and 8 WAP rice plants were carefully removed, cleaned and roots were separated for dry weight measurements.

4. RESULTS AND DISCUSSION

Model Predictions: According to the results of the sensitivity analysis, simulated rice yield loss was highly sensitive to relative growth rate of leaf area (RGR_{LA}), leaf area of seedlings, seedling height and number of plants/unit area at maturity (tillering capacity and/or planting density). Other morphological outputs such as leaf area at maturity and initial root dry weight were less sensitive to quantitative increases of these morphological traits (Table 4.1).

Weed competition: During its seedling stage, BYG grew faster and was taller than rice cultivars (Tables 4.3 and 4.4). This weed also had higher plant dry weights than rice during early seedling stages. But at maturity the average dry weight of BYG was less than that of rice cultivars (Tables 4.5 and 4.6). Similarly, increased BYG density also had significant negative effects on the per plant BYG dry weight. Competitive effects of BYG on rice increased with the increase of the BYG density (Table 4.5). It significantly reduced the rice plant dry weight (Table 4.5), tiller number (Table 4.7), leaf area (Table 4.8) and the grain yield (Table 4.9). Similarly significant differences were observed among rice cultivars in terms of the dry weight of BYG at crop maturity (Table 4.6). Even though it was not statistically significant during the Maha season, BYG dry weights in rice cultivars BG 94-2 and PPL were consistently lower than other cultivars and these were least affected by the BYG competition, suggesting the presence of a good combination of competitive traits in these two rice cultivars. The cultivar BG 350 had high weed dry weights during both seasons across all weed densities and also suffered from weed competition more than any other cultivar.

Significant differences were also observed among the tested two rice densities in terms of the BYG dry weight during 1993/94 Maha season. There were not significant interactions between cultivar x rice density, but the rice density x weed density interaction was highly significant for rice plant dry weight, yield and many other growth parameters.

Table 4.3. Plant height of rice as affected by rice cultivar and barnyardgrass (BYG) density.

Treatment	1993/94 Wet season (Maha)		1994 Dry season (Yala)	
	4 WAP	Maturity	4 WAP	Maturity
	cm			
Rice cultivar:				
BG 1611	40.23	89.41	32.45	89.40
BW 267-3	43.57	103.62	39.65	103.68
BG 350	35.95	73.89	33.17	89.57
PPL	51.01	109.16	47 66	104.01
BG 94-2	-	-	49.54	120.06
LSD (0.05)	1.69	4.27	1.68	8.71
BYG density:				
0 (no m^{-2})	42.86	94.60	40.71	100.94
3	42.99	94.47	40.67	100.26
9	42.36	94.27	39.98	98.40
27	41.82	94.23	40.39	98.19
81	43.43	94.42	40.73	105.21
LSD (0.05)	3.00	10.30	1.89	7.85
Rice spacing:				
15 x 15 cm	43.17	94.89	-	-
15 x 10 cm	42.21	93.15		
LSD (0.05)	1.69	3.41		

WAP- Weeks after planting.

Table 4.4. Plant height of barnyardgrass (BYG) as affected by rice cultivar and BYG density.

Treatment	1993/94 Wet season (Maha)		1994 Dry season (Yala)	
	4 WAP	Maturity	4 WAP	Maturity
	cm			
Cultivar:				
BG 1611	60.26	119.59	47.18	109.08
BW 267-3	60.80	120.48	47.17	112.33
BG 350	59.05	119.25	46.76	115.79
PPL	61.46	121.90	49.25	122.42
BG 94-2	-	-	49.41	125.13
LSD (0.05)	1.73	3.50	2.66	15.26
BYG density:				
3 (no m^{-2})	58.82	123.38	49.21	116.93
9	60.47	118.57	48.53	123.22
27	60.99	118.40	47.99	115.53
81	61.27	120.87	46.04	112.12
LSD (0.05)	5.28	7.85	3.64	22.06
Rice density:				
15 x 15 cm	61.10	121.14		
15 x 10 cm	59.68	119.46	-	-
LSD (0.05)	1.66	2.51		

WAP- Weeks after planting.

Table 4.5. Dry matter of rice as affected by rice cultivar and barnyardgrass (BYG) density.

Treatment	1993/94 Wet season (Maha)		1994 Dry season (Yala)	
	4 WAP	Maturity	4 WAP	Maturity
	g. $hill^{-1}$			
Cultivar:				
BG 1611	4.68	9.03	4.75	11.06
BW 267-3	5.01	8.90	5.10	11.22
BG 350	3.90	7.64	4.39	10.38
PPL	5.82	11.48	5.82	13.76
BG 94-2	-	-	5.75	13.44
LSD (0.05)	0.59	0.99	0.44	1.19
BYG density:				
0 ($no.m^{-2}$)	5.94	12.17	6.40	15.53
3	5.68	10.93	5.61	12.37
9	5.90	9.52	5.09	10.51
27	6.00	7.00	4.17	10.08
81	6.01	6.69	4.54	11.37
LSD (0.05)	0.86	1.79	1.01	1.73
Rice density:				
15 x 15 cm	4.24	9.81		
15 x 10 cm	3.97	8.71		
LSD (0.05)	0.42	1.04	-	-

WAP- Weeks after planting.

Table 4.6. Dry matter of barnyardgrass (BYG) as affected by rice cultivar and BYG density.

Treatment	1993/94 Wet season (Maha)		1994 Dry season (Yala)	
	4 WAP	Maturity	4 WAP	Maturity
	g. $hill^{-1}$			
Rice cultivar:				
BG 1611	4.05	10.21	3.04	7.90
BW 267-3	4.05	10.88	2.29	8.91
BG 350	4.02	10.97	2.85	9.00
PPL	3.98	10.44	2.37	7.19
BG 94-2	-	-	2.24	7.49
LSD (0.05)	0.18	2.61	0.72	1.18
BYG density:				
3 (no. m^{-2})	4.02	12.24	3.10	8.30
9	4.18	10.94	2.94	8.81
27	3.99	11.73	2.12	7.59
81	3.91	8.57	2.08	7.72
LSD (0.05)	0.47	3.15	1.34	1.92
Rice spacing:				
15 x 15 cm	4.11	10.56		
15 x 10 cm	3.95	11.19	-	-
LSD (0.05)	0.10	2.09		

WAP- Weeks after planting.

Table 4.7. Tiller number of rice as affected by rice cultivar and barnyardgrass (BYG) density.

Treatment	1993/94 Wet season (Maha)		1994 Dry season (Yala)	
	4 WAP	Maturity	4 WAP	Maturity
	no. hill^{-1}			
Rice cultivar:				
BG 1611	6.35	6.20	7.74	6.40
BW 267-3	4.90	5.07	7.31	6.65
BG 350	5.97	6.92	7.09	5.71
PPL	4.40	5.50	7.38	6.20
BG 94-2	-	-	7.01	5.37
LSD (0.05)	0.49	0.69	0.47	0.70
BYG density:				
0 (no. m^{-2})	6.16	6.82	8.69	6.80
3	6.00	6.36	8.09	6.33
9	5.42	6.43	6.81	6.23
27	4.80	5.39	6.56	5.42
81	4.64	4.60	6.37	5.55
LSD (0.05)	0.68	1.10	0.47	0.61
Rice spacing:				
15 x 15 cm	5.89	6.52	-	-
15 x 10 cm	5.22	5.33		
LSD (0.05)	0.38	0.49		

WAP- Weeks after planting.

Table 4.8. Leaf area of rice as affected by rice cultivar and barnyardgrass (BYG) density.

Treatment	1993/94 Wet season (Maha)		1994 Dry season (Yala)	
	4 WAP	Maturity	4 WAP	Maturity
	cm² hill⁻¹			
Cultivar:				
BG 1611	224.23	519.97	169.60	398.80
BW 267-3	226.67	475.67	234.60	489.27
BG 350	193.33	523.45	182.93	369.20
PPL	270.97	406.43	266.87	462.33
BG 94-2	-	-	256.00	520.93
LSD (0.05)	56.61	61.17	27.53	43.98
BYG density:				
0 (no. m^{-2})	232.67	468.88	251.53	554.20
3	270.67	519.67	249.93	520.20
9	207.54	445.46	236.13	435.73
27	231.75	472.25	180.33	360.80
81	201.38	437.88	191.87	369.60
LSD (0.05)	142.36	148.74	28.15	118.39
Rice spacing:				
15 x 15 cm	254.60	496.98		
15 x 10 cm	203.00	440.67	-	-
LSD (0.05)	53.31	54.48		

WAP- Weeks after planting.

Rice yields: In general, the grain yield of cultivars of rice declined as the density of BYG increased. There were significant differences (*p=0.01*) in rice grain yield among the tested BYG densities and rice cultivars (Table 4.9). The cultivar by BYG density interaction was highly significant for rice grain yield and panicle number per plant during both growing seasons. Therefore the yield response of each rice cultivar to increase of BYG density was studied separately (Figures 4.1).

Table 4.9. Grain yield of rice as affected by rice cultivar and barnyardgrass (BYG) density.

Treatment	1993/94 Wet season (Maha)	1994 Dry season (Yala)
	——— Kg ha^{-1} ———	
Cultivar:		
BG 1611	4386.0	4461.1
BW 267-3	4229.4	4472.7
BG 350	3465.9	4349.0
PPL	2523.9	3158.3
BG 94-2	-	4267.6
LSD (0.05)	254.5	305.8
BYG density:		
0 (no. m^{-2})	5697.3	5930.8
3	5023.6	5643.8
9	3678.5	4550.2
27	2275.6	2777.1
81	1581.4	1805.7
LSD (0.05)	702.9	619.0
Rice spacing:		
15x15 cm	3540.1	-
15x10 cm	3762.5	
LSD (0.05)	306.2	

During both cultivation seasons, grain yields of cultivar BG 1611, BG 350 and BW 267-3 declined more sharply with the increase of BYG density. Cultivar BG 94-2 had an intermediate slope while the cultivar PPL had the lowest rate of yield decline

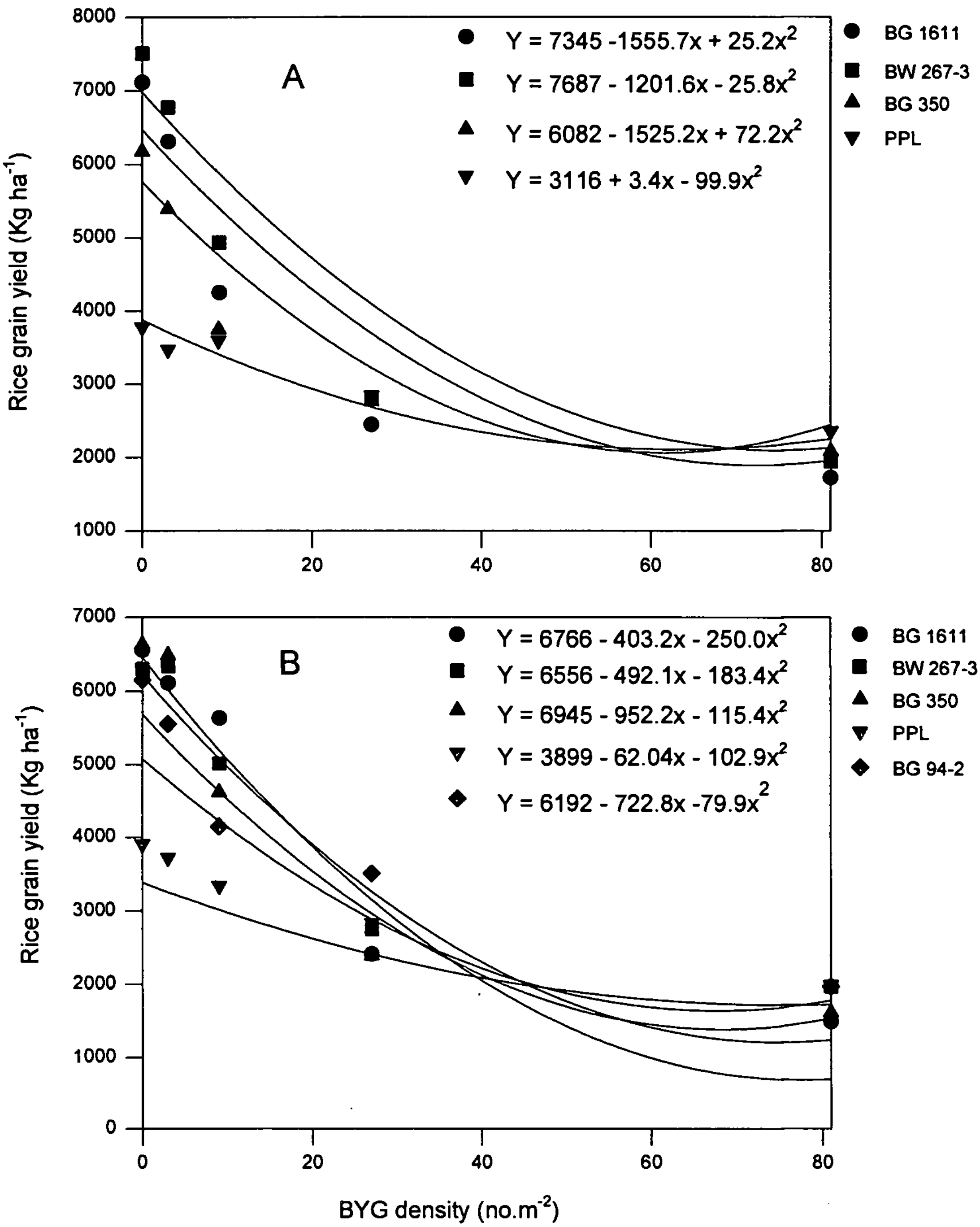

Figure 4.1. Effects of barnyardgrass (BYG) competition on grain yield of rice cultivars. (a) Maha season (b) Yala season.

with increased BYG density (Figure 4.1). This suggests the existence of some weed competitive traits in these two cultivars.

At BYG densities of 0 - 27 m^{-2}, rice yield reductions in all cultivars appeared to be linear during both seasons. During the 1993/94 Maha season, grain yields of rice fell more rapidly with increased BYG density than during the 1994 Yala season because BYG grew more vigorously and produced more dry matter during the wet weather (Table 4.6). The grain yield of the cultivar PPL was affected by lodging and neck blast disease. The cultivar BG 94-2 also had moderate susceptibility to lodging at maturity but it did not cause much crop loss.

Important morphological traits: The cultivar PPL was the tallest at the time of transplanting and during early seedling phase. The cultivar BG 94-2 was the tallest at maturity and grew taller rapidly during late vegetative phase. (Table 4.3 and Figure 4.2). Average height of rice cultivars at 4 WAP had a strong negative correlation with the BYG dry weight (Table 4.10). The relationships between rice plant heights and BYG dry weights during both years are shown graphically in Figure 4.3. This figure suggests that increased rice plant height tends to reduce BYG dry weight. BW 267-3, the high yielding rice cultivar with intermediate plant height, also was associated with relatively low weed dry weights as compared with short stature cultivars BG 350 and BG 1611, indicating the importance of the seedling plant height on weed competitive ability.

Cultivar PPL and BG 94-2 possessed long, wide, droopy leaves resulting in a high leaf area during early growth. Correlation analysis results revealed that the leaf

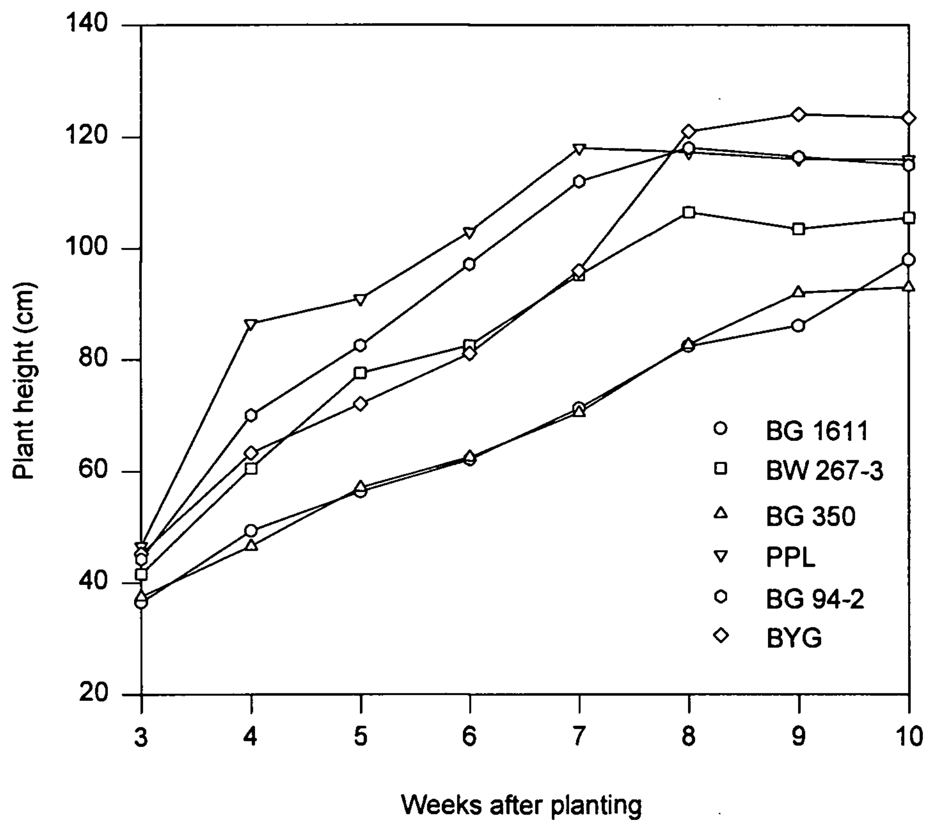

Figure 4.2. Plant height growth pattern of rice cultivars (average across weed free plots) and barnyardgrass (BYG) during 1994 Yala season.

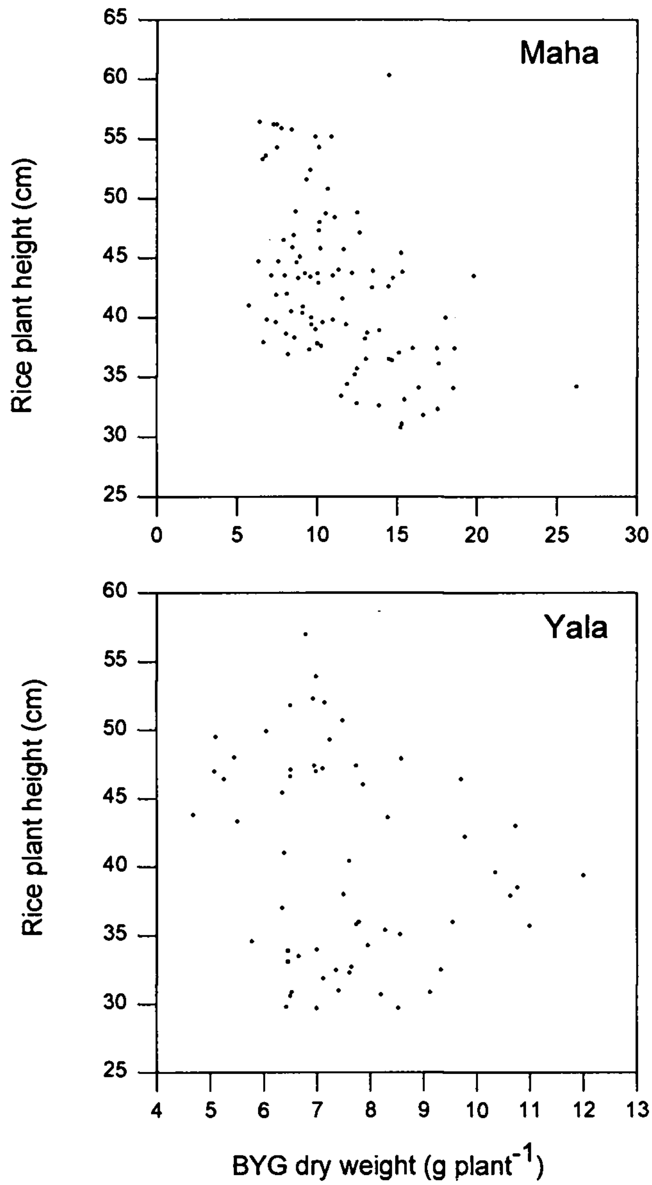

Figure 4.3. Observed relationship between rice plant height at 4 weeks after planting (WAP) and barnyardgrass (BYG) plant dry weight at maturity during Maha and Yala seasons.

areas at 4 WAP also have a high negative correlation with final dry weight of BYG (Table 4.10). High values of leaf area were observed in cultivars PPL, BG 94-2 and also in BW 267-3 at the 4 WAP sampling (Table 4.8). These cultivars also had relatively less grain yield losses than BG 350 and BG 1611. Therefore in addition to the relatively great seedling height, these high values of seedling leaf area also may have contributed to their better performances under weed competition. Leaf area at maturity was not significantly correlated with weed dry weight (Table 4.10). However, the blast disease in the cultivar PPL reduced leaf area during the reproductive growth period and may have changed the real effects.

Calculated values of RGR_{LA} during the first month after transplanting (seedling stage) was highest in cultivar PPL. Cultivars BG 94-2 and BW 267-3 ranked second and third while the cultivar BG 350 had the slowest RGR_{LA}. This trend was similar during both cultivation seasons (Table 4.11). During late growing season other cultivars had faster leaf area increases than cultivar PPL.

Calculated LAI values for rice cultivars (for 15x10 cm plant density) were highest in the cultivar PPL throughout the growing period during Maha season. During Yala season the cultivar PPL had the highest LAI during seedling stage but the cultivar BG 94-2 had the highest LAI at maturity (Table 4.12). Light intensity in the monoculture rice canopy at 4 WAP was also lowest in the cultivar PPL during both cultivation seasons (Table 4.13). This information suggests cultivar PPL has reduced light availability in the canopy at early stages of growth giving it a competitive advantage over weed seedlings.

Table 4.10. Correlation coefficients (r) for final dry weight of barnyardgrass (BYG) and some rice plant characters under different BYG densities.

Season	BYG density	Plant dry weight		Plant height		Tiller number		Leaf area	
		4 WAP	Maturity	4 WAP	Maturity	4 WAP	Maturity	4 WAP	Maturity
	- no. m^{-2} -	Correlation coefficient (r)							
93/94	3	.17	-.08	-.39	-.13	-.04	-.04	-.47*	-.34
Maha	9	-.15	-.11	-.44*	-.34	-.06	-.81*	-.58*	-.40*
(n=24)	27	-.78**	-.22	-.47*	-.37	-.04	-.22	-.62**	-.22
	81	-.78**	-.18	-.54*	-.39*	-.41	-.01	-.58*	-.29
94 Yala	3	-.16	-.17	-.27	-.39*	-.19	-.15	-.43*	-.31
(n=15)	9	-.40*	-.52*	-.36*	-.61**	-.35*	-.36	-.39	-.38
	27	-.41*	-.27	-.59**	-.50**	-.26	-.41	-.41*	-.42
	81	-.47*	-.42	-.49**	-.26	-.10	-.25	-.47*	-.39

WAP- Weeks after planting.
*, ** - Statistically significant at 5% and 1% probability level respectively.

Table 4.11. Relative growth rate of leaf area of rice cultivars during seedling and mature stages under each barnyardgrass (BYG) density.

Season	Cultivar	BYG density (no.m^{-2})									
		0		3		9		27		81	
		0-4 WAP	4-8 WAP	0-4 WAP	4-8 WAP	0-4 WAP	4-8 WAP	0-4 WAP	4-8 WAP	0-4 WAP	4-8 WAP
		g day^{-1}									
Maha	BG 1611	.051b	-.002b	.041a	.008b	.016c	.023a	.032b	.017a	.035ab	.012a
	BW 267-3	.058a	.021b	.038a	.017a	.045a	-.005c	.035b	.002c	.003c	.001b
	BG 350	.044bc	.009a	.004b	.006b	.040b	.004b	.033b	.009c	.038a	-.001b
	PPL	.058a	-.002b	.042a	.017a	.056a	.003b	.051a	.012b	.041a	.012a
Yala	BG 1611	.036b	.015ab	.036b	.018a	.034b	.017a	.019b	.020a	.020b	.026a
	BW 267-3	.037a	-.018a	.036b	-.019a	.031c	-.008b	.027a	-.002c	.031a	-.015bc
	BG 350	.035b	.015ab	.041ab	.006b	.039a	.007b	.030a	.021a	.031a	.003b
	PPL	.043a	-.011b	.043a	-.002b	.041a	.008b	.027a	.010b	.027a	.019a
	BG 94-2	.039a	-.011b	.036b	-.01ab	.034b	.003c	.028a	-.008c	.031a	.000c

WAP- weeks after planting.
In a column data followed by the same letter in each season are not significantly different at the 5% probability level of the Duncan's multiple range test.

Table 4.12. Leaf area index (LAI) of rice cultivars at different stages of growth under each barnyardgrass (BYG) density.

Season	Cultivar	BYG density (no. m^{-2})																			
		0				3				9				27				81			
		0 WAP	4 WAP	8 WAP	10 WAP	0 WAP	4 WAP	8 WAP	10 WAP	0 WAP	4 WAP	8 WAP	10 WAP	0 WAP	4 WAP	8 WAP	10 WAP	0 WAp	4 WAP	8 WAP	10 WAP
		LAI																			
Maha	BG 1611	.51	2.6	2.5	3.3	.51	1.7	2.7	3.6	.51	2.5	2.8	3.6	.51	2.1	2.9	3.8	.51	1.8	2.4	3.2
	BW 267-3	.59	2.5	2.6	3.5	.59	2.0	2.6	3.4	.59	1.0	1.8	2.7	.59	1.7	2.6	3.5	.59	1.7	2.4	3.1
	BG 350	.57	2.9	1.9	4.7	.57	1.8	2.9	3.8	.57	2.1	1.8	2.6	.57	1.7	1.9	2.8	.57	1.5	1.9	2.7
	PPL	.76	2.7	3.4	3.3	.76	2.7	3.0	3.8	.76	2.4	2.7	3.5	.76	2.2	2.6	3.4	.76	2.3	2.3	3.1
Yala	BG 1611	.49	1.3	2.0	3.1	.49	1.3	2.4	2.9	.49	1.3	2.1	2.6	.49	.83	1.5	2.2	.49	.89	2.0	2.5
	BW 267-3	.54	1.8	1.3	3.9	.54	1.8	1.9	4.1	.54	1.9	2.5	3.2	.54	1.1	1.5	2.6	.54	1.2	2.1	2.4
	BG 350	.45	1.2	1.8	3.2	.45	1.4	1.7	3.1	.45	1.3	1.6	2.3	.45	1.0	1.9	1.8	.45	1.1	1.2	1.9
	PPL	.71	2.0	1.2	3.8	.71	2.0	1.2	3.4	.71	1.7	1.3	2.9	.71	1.5	1.4	2.6	.71	1.7	1.1	2.8
	BG 94-2	.66	2.0	1.5	4.4	.66	1.8	1.3	3.8	.66	1.7	1.9	3.5	.66	1.5	1.3	2.9	.66	1.6	1.6	2.8

WAP- weeks after planting.

Table 4.13. Light intensity (% of ambient) measurements at 4 and 8 weeks after planting (WAP) taken at different heights within the canopy of rice monocultures.

Season	Distance from soil surface	Cultivar									
		BG 1611		BW 267-3		BG 350		PPL		BG 94-2	
		4 WAP	8 WAP	4 WAP	8 WAP	4 WAP	8 WAP	4 WAP	8 WAP	4 WAP	8 WAP
	– cm –	Percent									
Maha	25	58 a	45 ab	54 a	35 b	62 a	51 a	52 a	26 c	-	-
	50	81 a	65 a	78 a	65 a	84 a	65 a	76 a	43 b	-	-
	75	87 a	95 a	87 a	80 ab	86 a	100 b	88 a	70 b	-	-
	100	90 a	100 a	90 a	100 a	91 a	100 b	92 a	94 a	-	-
Yala	25	58 a	58 a	58 a	45 b	65 a	45 b	44 b	25 c	60 a	25 c
	50	86 a	82 a	82 a	50 b	89 a	60 b	58 b	38 c	66 b	52 b
	75	89 a	94 a	94 a	74 b	91 a	100 a	80 b	84 b	100 a	73 b
	100	100 a	100 a	100 a	100 a	100 a	100 a	100 a	91 a	100 a	100 a

WAP- weeks after planting.
In a row, values with same letter in a same sampling date are not significantly different at the 5% probability level of Duncan's multiple range test.

Other rice plant traits related to competition with BYG during early growth: Correlation analysis results showed that rice plant dry weight at 4 WAP is correlated with reduced BYG plant weight (Table 4.10). Light intensity measurements recorded 4 WAP inside the monoculture canopy were lowest in cultivar PPL among the tested rice cultivars (Table 4.13). This suggests that tall stature, fast seedling growth and leaf morphology of this cultivar had resulted in low light availability in the canopy, thereby reducing the potential growth of weeds. Similar observations of low light intensity were made in the cultivar BG 94-2 at 8 WAP (Table 4.13). This may be due to canopy cover by its rapid leaf growth during late vegetative phase. With the high variability in light intensity measurements from rice-BYG mixtures it was not possible to use these data for interpretation of results. Probably this may be due to the low accuracy of the single probe light meter used for these measurements.

Tillering capacity of rice was high in cultivars BG 1611 and BG 350 (Table 4.7), but in general these cultivars suffered more from BYG competition than the other cultivars of rice. There were only small negative correlations between rice tiller number and BYG dry weights in tested rice cultivars during both seasons in most of the competitive situations (Table 4.10). Therefore tillering capacity of rice was not important for weed competitive ability in this experiment.

Interestingly, grain yields from the rice under high weed densities were positively correlated with the rice plant height in this experiment. But in low weed densities it was negatively correlated (Table 4.14). This clearly suggests that under situations of high weed pressure the morphological trait plant height had significantly

Table 4.14. Correlation coefficients (r) between grain yield and some morphological traits of rice under different barnyardgrass (BYG) densities.

Season	BYG density	Character							
		Plant dry weight		Plant height		Tiller number		Leaf area	
		4 WAP	Maturity	4 WAP	Maturity	4 WAP	Maturity	4 WAP	Maturity
	– no.m^{-2} –	Correlation coefficient (r)							
93/94	0	.28	-.16	-.38*	-.42	.29	.31	-.19	-.01
Maha	3	-.32	-.42	-.64**	-.38	.38	.00	-.37	-.20
(n=24)	9	-.16	-.44**	-.13*	-.14	.08	.02	-.38	-.12
	27	-.06	-.14	-.17*	-.30	-.03	-.22	-.21	.25
	81	.30*	.28	.32	.27	-.45**	-.26	.48*	.27
94 Yala	0	-.18	-.62	-.51*	-.08	-.41	.23	-.50*	.10
(n=15)	3	-.27	-.38	-.62**	-.22	-.35	-.08	-.62**	.03
	9	-.67	-.45	-.56*	-.29	-.27	.02	-.08	-.02
	27	-.27	-.41	-.33	-.23	-.14	-.21	.65**	.55
	81	.48	.30	.60**	.80	.44	.05	.48	-.03

WAP- weeks after planting.
*, ** - Statistically significant at 5% and 1% probability level respectively.

increased the rice grain yield, probably by increasing weed competitive ability. In the absence of weed pressure crop plant height is not correlated with yield. Under high weed densities similar trends were observed in other traits such as leaf area and dry weight of rice seedlings (Table 4.14). Therefore this information suggests that under high weed infestations rice plant height is the most important morphological trait determining weed competitive ability but other morphological traits such as high leaf area and growth rate of seedlings also have strong relationships with increased weed competitive ability.

According to the results of the root growth study, cultivar BG 94-2 had the highest average root dry weight at 4 WAP. The cultivar BW 267-3 ranked second while other three cultivars had much similar values (Table 4.15). Even though the cultivar PPL did not produce as good a root system as the cultivar BG 94-2 it had a higher weed competitive ability than BG 94-2. This suggests that if a cultivar possesses a plant morphology that decreases light penetration through the canopy during seedling stage, it can become a good competitor even though it has poor competitive ability for obtaining mineral nutrients.

Although the effect was not statistically significant, the cultivar BW 267-3 was a better competitor against BYG than cultivars BG 1611 and BG 350 in terms of grain yield production under weedy situations (Figure 4.1 and 4.2). This performance may be a cumulative effect of relatively tall seedlings, high leaf area and good root growth in this cultivar.

Table 4.15. Root dry weight of rice cultivars (collected from the observation study).

Cultivar	Barnyardgrass density							
	0		1		2		4	
	4 WAP	8 WAP	4 WAP	8 WAP	4 WAP	8 WAP	4 WAP	8 WAP
	g plant^{-1}							
BG 1611	1.08	2.15	1.75	2.50	0.93	1.80	0.90	-
BW 277-3	1.37	3.46	1.41	3.51	1.09	1.92	1.12	2.04
BG 350	1.20	2.05	1.23	2.05	1.61	2.40	0.91	1.52
PPL	1.12	1.95	1.21	2.16	1.08	1.86	-	1.62
BG 94-2	1.58	3.81	1.62	2.60	1.50	2.80	1.25	2.45

- Data not available. WAP= weeks after planting.

Both of the tall cultivars PPL and BG 94-2,were susceptible to lodging. Therefore in the process of screening of rice cultivars for competitive ability, the use of plant height trait has limitations. Cultivars with tall seedlings and a slow late height growth, leading to an intermediate plant height at maturity, is desirable. For weed competitive ability it is also important to have a good combination of other competitive traits such as high seedling leaf area, rapid seedling growth and a good root growth. The high yielding cultivar BW 267-3 possesses these characters to a certain extent.

Information gathered in these experiments revealed that the morphological traits and other related rate-parameters which were highly sensitive in determining crop yield in the INTERCOM simulation model are important for weed competitive ability of rice. It also suggests the possibility of using crop-weed competition simulation models to predict the weed competitive ability of rice cultivars. Since screening of new rice cultivars is done under weed free conditions these simulation models can be used to test cultivar performances under "on-farm" conditions where the crop has weed competition. Therefore the use of crop-weed competition models could be a useful tool to analyze weed competitive ability and yield loss of new cultivars developed by rice breeders.

CHAPTER V

EFFECTS OF TIMING FERTILIZER APPLICATION ON RICE (*Oryza sativa* L.) - BARNYARDGRASS (*Echinochloa crus-galli* (L.) Beauv.) COMPETITION.[1]

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1. ABSTRACT

Field experiments were conducted in the low country dry zone of Sri Lanka to study the effect of delaying starter fertilizer application on rice-barnyardgrass (BYG) competition. Rice cultivar BG 350 was transplanted with a moderate density (10 plants of BYG m^{-2}) or no BYG competition and with the starter fertilizer application delayed for 0, 7 or 14 days after planting. Delay of fertilizer application reduced the yield in rice monocultures, but in rice-BYG mixtures the delay of fertilizer application increased the grain yield. The interaction effect of starter fertilizer application time and BYG had significant effects on rice plant dry weight, tiller number, plant height, leaf area, panicle number and grain yield. With normal planting densities of rice, the delay of starter fertilizer application for 14 days reduced the crop loss by BYG

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competition by 6.64 and 22.99% during the Maha and Yala seasons, respectively.

Nomenclature: Barnyardgrass, *Echinochloa crus-galli* (L.) Beauv. #[3] ECHCG.

Additional index words: Starter fertilizer, weed density.

2. INTRODUCTION

Numerous weed species have infested rice (*Oryza sativa* L.) cultivation throughout the world. According to De Datta (1981) the average annual crop loss due to weeds in rice is about 9.5% of the potential production. Under lowland irrigated conditions usually weeds compete with rice to obtain mineral nutrients and for light. The intensity of rice yield loss by weed competition varies with the soil fertility, time of weed infestation, planting method, the weed flora and the rice variety used (De Datta et al., 1969).

Usually weeds absorb large amounts of mineral nutrients at a faster rate than crops, as they have well developed root systems that derive a greater benefit from applied fertilizer (Zimdahl, 1980). Many studies have proved the importance of below ground competition between crops and weeds for mineral nutrient absorption (Perera et al. 1992; Johri et al., 1991; Exley and Snaydon, 1992). In a study of wheat (*Triticum aestivum* L.) and blackgrass (*Alopecurus myosuroides* Huds.) competition, Exley and Snaydon (1992) concluded that root competition for nutrient absorption was higher than the above ground competition for light. In another study on rice-barnyard

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci., suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

grass competition, Perera et al., (1992) recorded below ground competition for nutrients was more important than the above ground competition for light.

Most of the presently growing improved cultivars of rice have slow initial growth, while weeds in rice have a rapid initial growth resulting in their absorption of much of the nutrients applied at the time of planting or seeding of rice. In addition, transplanted rice seedlings usually take 3-5 days to recover from the transplanting shock. Therefore usually during early seedling stages, rice seedlings have less competitive ability than weeds to acquire mineral nutrients.

Effects of mineral nutrition on plant growth and yield are usually explained in terms of the functions of nutrient elements in plant metabolism (Marschner 1986). However these mineral nutrients may also have indirect relationships on plant growth and yield by changing responses of other components like weeds associated with crops. Many researchers have recorded stimulation of weed growth with application of inorganic fertilizers just before seeding or planting a rice crop (Bleasdade, 1960; Adiar et al., 1962; Kleinnig and Noble 1968; Smith 1983). This stimulation of weed growth is an additive effect of relatively low competition effects of the rice seedlings and high rate of nutrient absorption by weeds. Under high nitrogen and phosphorous fertilizer levels the growth of rice was much more affected by weeds than those growing with low levels of nitrogen and phosphorous (Ampong-Nyarko and De Datta, 1992 ; Kleing and Nobel, 1968). Therefore the level of soil nutrient availability at early growth stages is an important factor determining the outcome of rice-weed competition.

In many rice growing situations availability of fertilizer is limited or a costly input and therefore the maximization of fertilizer use efficiency by rice is important. In most growing situations nitrogen is the first growth limiting nutrient for rice. The efficiency of absorption or percentage of nitrogen recovery varies to a great extent depending on soil properties, timing and method of application and crop management practices (Yoshida, 1983). In the tropics recovery of applied nitrogen varies from 30-50 percent. (Prasad and De Datta, 1979). The percent of applied nitrogen recovery tends to be high with split applications and also when the nitrogen is top dressed at later stages of growth (Prasad and De Datta, 1979). Therefore delaying starter fertilizer application until roots of transplanted or direct seeded rice get established in the soil may increase the fertilizer use efficiency and it may increase the competitive ability of rice by reducing the stimulation of the growth of weeds. This would be a useful agronomic practice with poor weed control, if the net yield of rice under delayed fertilizer application is higher than for a rice crop that received fertilizer at the time of planting.

The objective of this study was to evaluate the effects of delayed starter fertilizer application on rice plant growth and yield under moderate weedy situations.

3. MATERIALS AND METHODS

This field experiment was conducted during 1993/94 Maha (wet) and 1994 Yala (dry) cultivation seasons at the Regional Agricultural Research Center, Aralaganwila, Sri Lanka under lowland, irrigated conditions. The soil type at the experimental site was sandy old alluvial (p^H 6.5 and organic matter 1.8% , nitrogen 163 ppm, phosphorous 52 ppm, potassium 180 ppm).

Land preparation for the experimental site consisted of two plowings, one harrowing and a final puddling operation. Plot size used was 4 x 3 m, each separated by a 30 cm bund (dike). Rice (cultivar BG 350; 3.5-month age class) seedlings which were raised in a wet bed nursery were transplanted manually with either 10 x 10 cm (high density) or 15 x 15 cm (normal density) spacing with 3 seedlings per hill. Barnyardgrass (*Echinochloa crus-galli* (L) Beauv.) a troublesome weed in rice was used as the weed in this experiment. Seedlings of barnyard grass (BYG) were raised in a separate nursery and transplanted uniformly in relevant plots just after planting of rice with a density of 10 plants m^{-2}, keeping one seedling per hill. This density of barnyard grass resembles a moderate level of weed infestation (Smith 1983) which is similar to the weed pressure in many rice farms. Water level in plots was maintained at 5-10 cm throughout the growing period.

The experimental design used was a split-split plot with four replications, with the planting density of rice as main plots, barnyard grass density (0 or 10 plants m^{-2}) in sub plots and the starter fertilizer application time (0, 7 or 14 days after planting) in sub-sub plots. All weeds other than planted barnyard grass were removed by manual weeding at 2-week intervals during the first two months after planting. All plots received the recommended level of rice fertilizer mixture for the low country dry zone (Department of Agriculture, Sri Lanka, 1991). The total amount of fertilizer (N 100, P_2O_5 25, K_2O 25 Kg ha^{-1}) is recommended to be applied with N 25, P_2O_5 25 and K_2O 25 Kg ha^{-1} as starter fertilizer (at planting) and 25 and 50 N Kg ha^{-1} as top dressings at 3 and 7 weeks after planting. In this study the starter fertilizer application time was delayed 0, 7 or 14 days as needed for relevant treatments.

Soil samples were taken just before starter fertilizer application to determine N and P levels in each plot. Leaf samples of rice and barnyard grass were also taken just before starter fertilizer application and one week after to determine plant N and P contents. Plant height measurements, tiller number, plant dry weight and panicle number were measured at 3, 5, 7, 9 and 11 weeks after planting (WAP) in both rice and barnyard grass. Leaf area measurements of rice and barnyard grass were taken at 5 and 8 WAP using a leaf area meter (Delta-T area measuring device, Model AM 82, Cambridge, England). Relative growth rate (RGR) of rice and BYG were calculated from the collected plant dry weight data using the following equation (Hunt, 1982).

$$RGR = (\ln W_2 - \ln W_1) / (T_2 - T_1)$$

Where, W_1 and W_2 - The dry weight at beginning and at end of each harvest interval.

T_1 and T_2 - Time of harvest (days).

Therefore this equation calculates the weight increase of each species relative to the size already attained (W_1).

Rice grain yields were obtained from a 6 m^2 harvesting area and measured at 14% moisture level. Analysis of variance was performed using the general linear models procedure (SAS Institute Inc., 1991) to study the effects of treatments on rice and BYG performances.

4. RESULTS AND DISCUSSION

Effects of treatments on rice and BYG growth: Retarded plant growth was observed in rice monocultures when the starter fertilizer application was delayed. But in the presence of barnyardgrass, delayed fertilizer application increased the growth of rice plants compared to the growth of rice plants in the rice-BYG mixture fertilized at the time of planting. Statistical analysis of the collected data on rice plant growth revealed that the interaction of basal fertilizer application time and BYG had significantly affected the rice plant dry weight, tiller number, plant height, leaf area, panicle number and grain yield in both cultivation seasons (Tables 5.1 and 5.2). The planting density of rice also had significantly affected plant dry weight, tiller number and leaf area of rice and the plant dry weight, tiller number and panicle number of BYG (Table 5.3 and 5.4).

In general, calculated values of relative growth rate (RGR) of rice were higher in normal rice density than the high density rice (Figure 5.1 and 5.2). This effect was highly significant. Though a reduced growth of rice was observed with the early application of starter fertilizer in the rice-BYG mixture, no statistically significant differences in RGR values were recorded in rice among fertilizer application times (Figures 5.2 a, b, c and d). But the delay of starter fertilizer application had significantly reduced the RGR of barnyardgrass throughout the growing period in the Maha season and during the early growth phase in the Yala season. RGR values of BYG exhibited a high degree of variability, making the interpretation of results difficult.

Table 5.1. Effect of the delay of starter fertilizer application on rice plant growth and yield (1993/94 Maha season).

Treatment	Height at maturity	Tiller number at maturity	Plant dry weight at maturity	Leaf area (8 WAP)	Panicle number	Grain yield
	— cm —	– no. plant^{-1} –	– g plant^{-1} –	— cm^2 —	– no. plant^{-1} –	– Kg ha^{-1} –
S1W0B1	87.63 a	13.00 b	16.31 a	300.25 b	6.35 a	6200 a
S1W0B2	85.55 a	11.00 ab	14.72 a	391.25 b	5.33 ab	6145 a
S1W0B3	86.06 a	11.00 ab	13.66 b	401.75 b	6.20 a	6111 a
S1W1B1	91.00 ab	9.25 ab	11.34 b	438.25 b	5.25 b	4713 b
S1W1B2	91.63 ab	9.75 ab	13.01 b	356.50 b	5.63 ab	4715 b
S1W1B3	93.44 b	10.13 ab	13.28 b	530.00 a	5.90 ab	5049 b
S2W0B1	87.48 a	9.38 bd	8.86 bc	301.00 b	3.30 bc	6523 a
S2W0B2	84.75 a	7.70 a	8.41 bc	275.50 bc	3.23 c	6308 a
S2W0B3	87.06 a	7.74 a	8.08 bc	302.50 bc	4.00 b	6154 a
S2W1B1	83.45 a	7.10 a	9.23 bc	279.25 bc	3.35 bc	5279 b
S2W1B2	82.50 b	8.13 a	7.64 c	272.75 bc	3.30 bc	5562 b
S2W1B3	85.44 a	8.76 a	8.32 bc	269.50 c	3.68 bc	5923 a

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W0 and W1 - weed free and 10 barnyardgrass m^{-2}. B1, B2 and B3- starter fertilizer application at 0, 7 and 14 days after planting. WAP - weeks after planting. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

Table 5.2. Effect of the delay of starter fertilizer application on rice plant growth and yield (1994 Yala season).

Treatment	Height at maturity	Tiller number at maturity	Plant dry weight at maturity	Leaf area (8 WAP)	Panicle number	Grain yield
	– cm –	– no.plant^{-1} –	– g plant^{-1} –	– cm^2 –	– no.plant^{-1} –	– Kg ha^{-1} –
S1W0B1	89.31 a	10.56 a	22.25 a	366.25 a	8.40 a	7960 b
S1W0B2	81.06 b	8.44 b	20.19 a	296.50 a	7.30 b	6885 b
S1W0B3	83.13 bc	8.06 b	16.48 b	265.50 a	7.97 b	6300 bc
S1W1B1	83.06 b	7.13 b	13.23 b	295.25 a	7.10 b	4740 d
S1W1B2	85.56 a	7.11 b	13.81 b	327.50 a	7.45 b	5110 c
S2W1B3	90.56 a	9.03 b	17.10 b	380.75 a	8.45 a	5200 c
S2W0B1	87.13 ac	6.63 bc	10.85 b	272.25 a	7.78 b	8905 a
S2W0B2	84.75 ac	5.69 bc	9.17 bc	190.50 bc	5.05 bc	7127 b
S2W0B3	80.25 bc	5.06 bc	8.11 bc	176.50 bc	5.13 bc	7960 b
S2W1B1	76.06 b	4.06 c	8.05 c	149.25 c	4.65 c	5860 bc
S2W1B2	76.13 b	4.88 c	8.70 bc	149.00 c	4.95 c	6298 c
S2W1B3	79.38 b	6.25 bc	10.50 b	230.75 b	5.30 bc	6580 bc

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W0 and W1 - weed free and 10 barnyardgrass m^{-2}. B1, B2 and B3 - starter fertilizer application at 0, 7 and 14 days after planting. WAP - weeks after planting. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

Table 5.3. Effect of the delay of starter fertilizer application on barnyard grass growth (Maha season 1993/94).

Treatment	Height at maturity	Tiller number at maturity	Plant dry weight at maturity	Leaf area (8 WAP)	Panicle number
	— cm —	- no.plant^{-1} -	- g plant^{-1} -	— cm^2 —	- no.plant^{-1} -
S1W1B1	124.81 a	9.55 a	53.63 a	147.50 a	4.93 a
S1W1B2	130.75 a	8.06 a	48.60 b	188.50 a	3.91 b
S1W1B3	115.56 ab	7.63 a	38.05 bc	162.75 a	3.23 b
S2W1B1	119.44 a	7.19 b	42.15 b	201.75 a	3.78 b
S2W1B2	113.31 ab	7.06 b	39.45 bc	186.75 a	3.26 b
S2W1B3	108.88 b	6.38 b	37.35 c	146.00 a	3.69 b

Table 5.4. Effect of the delay of starter fertilizer application on barnyard grass growth (1994 Yala season).

Treatment	Height at maturity	Tiller number at maturity	Plant dry weight at maturity	Leaf area (8 WAP)	Panicle number
	— cm —	— no.plant^{-1} —	- g plant^{-1} -	— cm^2 —	— no.plant^{-1} —
S1W1B1	112.94 a	4.25 a	28.73 a	231.75a	5.13 a
S1W1B2	102.19 bc	3.94 a	24.95 a	162.75b	4.96 b
S1W1B3	101.47 bc	3.66 a	20.03 b	114.75bc	4.24 bc
S2W1B1	104.18 b	3.88 a	22.63 b	118.50bc	3.94 cd
S2W1B2	94.50 c	2.94 ab	17.10 bc	99.75bc	3.29 cd
S2W1B3	96.25 bc	2.38 b	15.25 c	80.25c	3.00 d

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W1 - weed free and 10 barnyardgrass m^{-2}. B1, B2 and B3 - starter fertilizer application at 0, 7 and 14 days after planting. WAP - weeks after planting. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

A covariate analysis was done for soil and plant analysis data since these were measured in different growth stages. Soil analysis for total N revealed a reduced availability of N with the delay of starter fertilizer application. Similarly, leaf N analysis of samples collected at the time of fertilizer application revealed that both rice and barnyardgrass had lower N content than normal when the starter fertilizer was delayed (Tables 5.5 and 5.6). Generally this effect was more pronounced the greater the delay. Leaf N analysis of rice plant samples taken at one week after starter fertilizer application were not statistically significantly different from samples collected from the plots which were fertilized at the time of planting, but

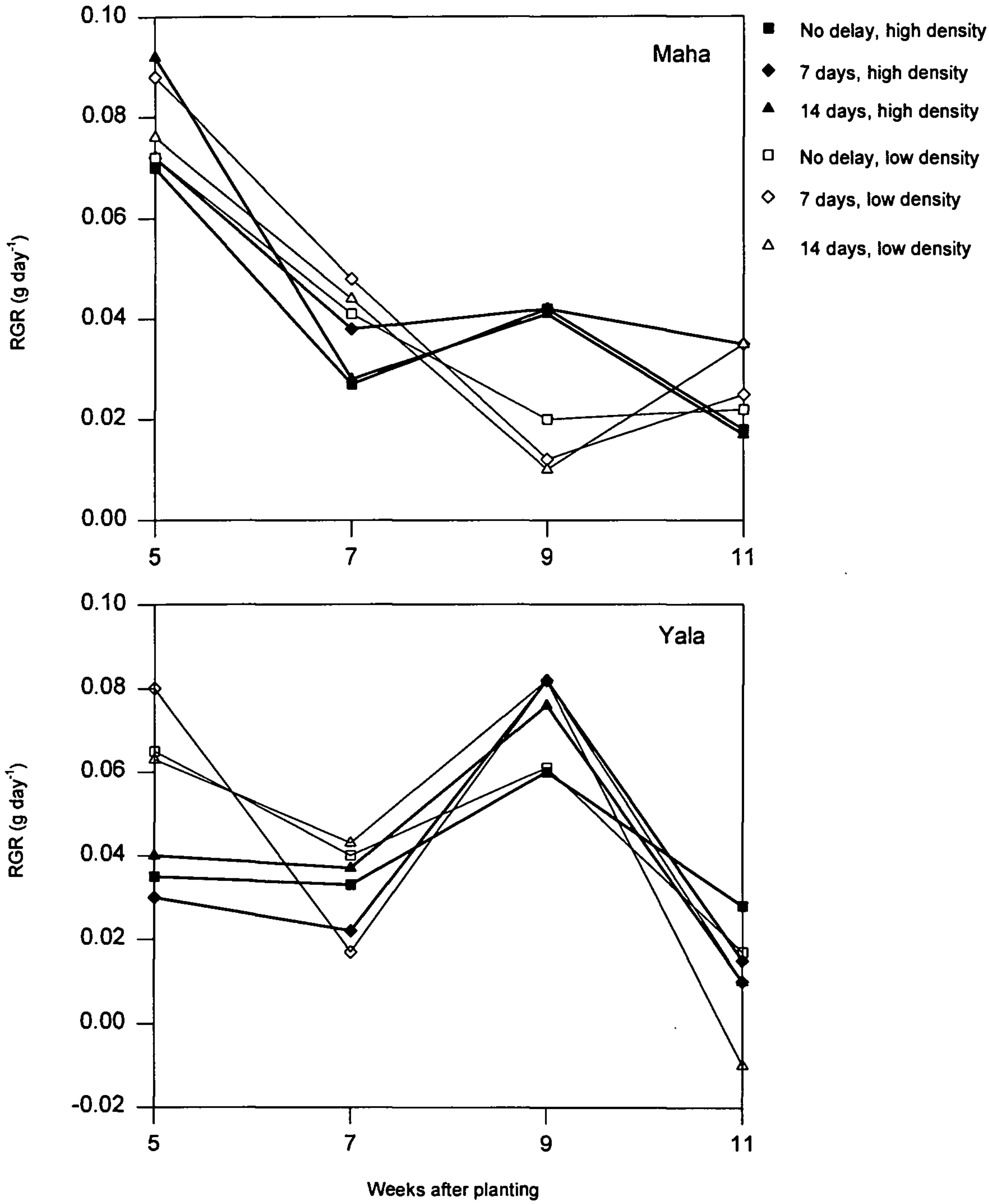


Figure 5.1. Relative growth rate (RGR) of rice monoculture as affected by the delay of starter fertilizer and rice density during Maha and Yala seasons.

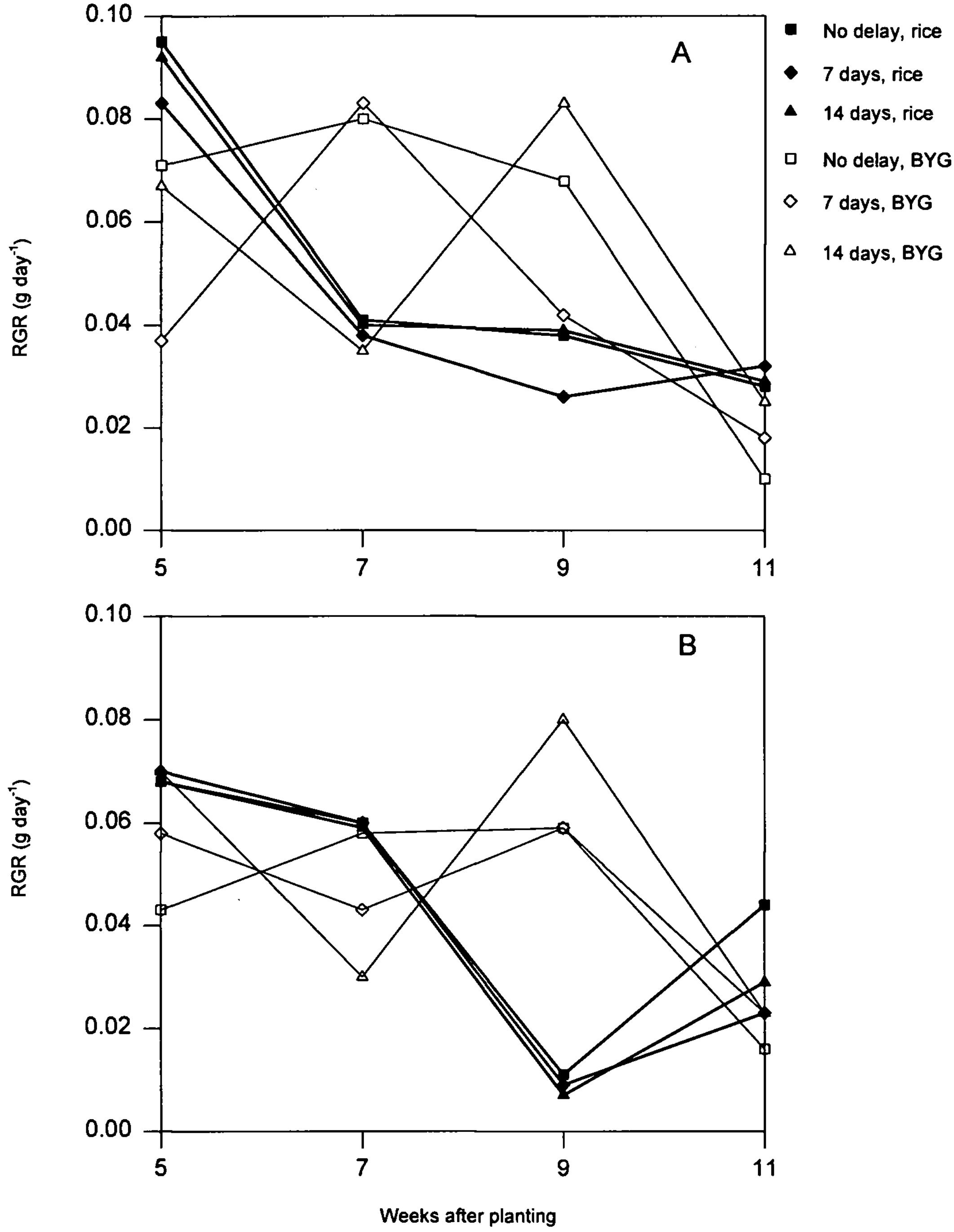
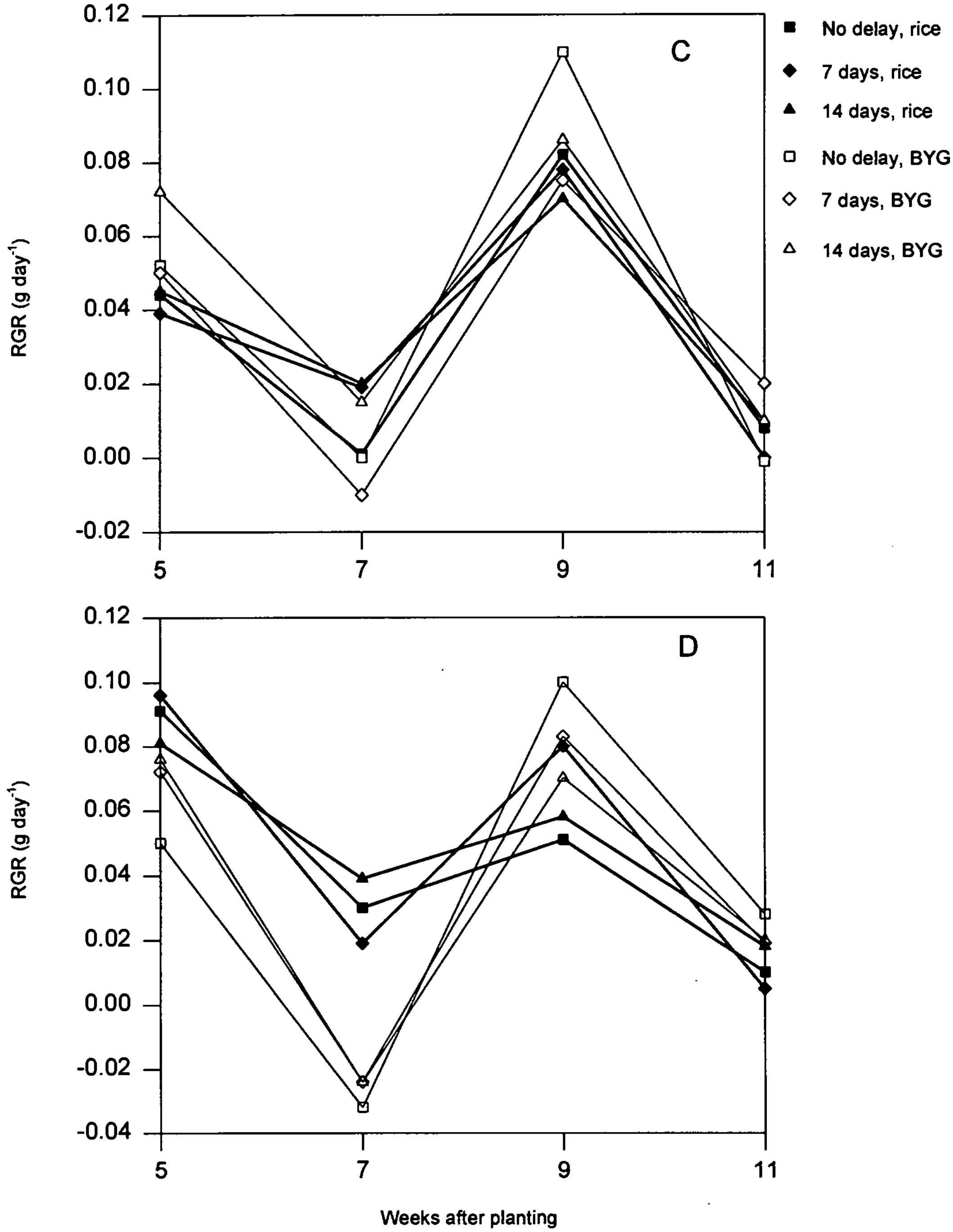


Figure 5.2. Relative growth rate (RGR) of rice (in mixture) and barnyardgrass (BYG) as affected by the delay of starter fertilizer application (a) Maha, low density (b) Maha, high density (c) Yala, low density (d) Yala, high density.


C
No delay, rice
7 days, rice
14 days, rice
No delay, BYG
7 days, BYG
14 days, BYG
RGR (g day^{-1})
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
5
7
9
11
D
RGR (g day^{-1})
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
5
7
9
11
Weeks after planting

barnyardgrass leaves had significantly lower N when the starter fertilizer was delayed. Therefore this information suggests that at low nitrogen availability, rice is less affected than barnyardgrass in the competition process for nitrogen. As cited by Marschner (1990), Klemm (1966) had found increased root growth in cereals with low nitrogen supply during early growth. Therefore the increased root growth of rice due to the delay of fertilizer application may have increased the ability of rice to absorb late applications of nitrogen.

Plant analysis data for phosphorous did not show statistically significant effects from the delayed fertilizer application. Soil phosphorous contents at the time of starter fertilizer application time also were not different from the initial levels.

Effects of treatments on rice grain yield: The planting density of rice had significant effects on rice grain yield during the Maha season but during the Yala season it was not significant. When the starter fertilizer application was delayed for 14 days both densities of rice monocultures showed significant yield reductions during the Maha season. Though a similar trend was observed in the Yala season it was not significantly different (Table 5.7).

Interestingly, an increase in rice plant growth and grain yield was observed in the rice-BYG mixture with the delay of starter fertilizer application. There were increases in the yield of rice in rice-BYG mixtures in both of the tested rice densities, but only the high density planting of rice recorded statistically significant effects. The increased rice grain yield with a 14-day delay was 12.20 % and 12.29% in the Maha and Yala seasons, respectively (Table 5.7).

Table 5.5. Available nitrogen and phosphorous levels at planting, at the time of starter fertilizer application and a week after fertilizer application (1993/94 Maha season).

Treatment	Average nutrient level at fertilizer application						Average nutrient level one week after fertilizer application			
	Soil		Rice		Barnyard grass		Rice		Barnyardgrass	
	N	P	N	P	N	P	N	P	N	P
	— ppm —		— % —							
S1W0B1	160c	52a	2.98e	0.38a	-	-	3.10b	0.26a	-	-
S1W0B2	120bc	49a	2.56d	0.42a	-	-	3.15b	0.31b	-	-
S1W0B3	80a	61b	1.48a	0.46b	-	-	2.98ab	0.29ab	-	-
S1W1B1	200d	53a	2.98e	0.38a	2.85b	0.31c	2.57a	0.21a	2.48b	0.28a
S1W1B2	150c	41a	1.48a	0.44a	2.18a	0.32c	3.12b	0.33b	2.30a	0.31a
S1W1B3	60a	38a	1.86bc	0.43a	2.08a	0.23b	2.78a	0.28ab	2.31a	0.29a
S2W0B1	180cd	42a	2.98e	0.38a	-	-	3.05b	0.30b	-	-
S2W0B2	80a	51a	1.73b	0.41a	-	-	2.68a	0.29ab	-	-
S2W0B3	50a	51a	1.64b	0.50b	-	-	2.92ab	0.34b	-	-
S2W1B1	130bc	60b	2.98e	0.38a	2.85b	0.31c	2.94ab	0.23a	2.41a	0.28a
S2W1B2	120bc	42a	1.97c	0.41a	2.38ab	0.19a	3.10b	0.31b	2.38a	0.31a
S2W1B3	100b	40a	2.35d	0.29c	2.11a	0.25b	2.78a	0.35b	2.41a	0.23a

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W0 and W1 - weed free and 10 barnyardgrass m^{-2}. B1, B2 and B3 starter fertilizer application time 0, 7 and 14 days after planting respectively. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

Table 5.6. Available nitrogen and phosphorous levels at planting, at the time of starter fertilizer application and a week after fertilizer application (1994 Yala season).

Treatment	Average nutrient level at fertilizer application						Average nutrient level one week after fertilizer application			
	Soil		Rice		Barnyardgrass		Rice		Barnyardgrass	
	N	P	N	P	N	P	N	P	N	P
	—— ppm ——		——————		————— %		—————		——————	
S1W0B1	172cd	67cd	3.23cd	0.29a	-	-	3.28b	0.32a	-	-
S1W0B2	165cd	71d	3.14c	0.32a	-	-	3.35b	0.27a	-	-
S1W0B3	120b	71d	2.14a	0.35a	-	-	3.19ab	0.30a	-	-
S1W1B1	176d	65c	3.23cd	0.29a	3.21c	0.38a	3.05a	0.31a	3.16b	0.31a
S1W1B2	164c	54ab	2.46ab	0.42b	2.68b	0.33a	3.16ab	0.33a	2.67a	0.28a
S1W1B3	148c	51a	2.18a	0.32a	2.21a	0.38a	3.18ab	0.26a	2.42a	0.30a
S2W0B1	94ab	47a	3.23cd	0.29a	-	-	3.98d	0.33a	-	-
S2W0B2	157c	62bc	2.17a	0.37a	-	-	3.68c	0.31a	-	-
S2W0B3	94ab	53a	2.45ab	0.40b	-	-	2.92a	0.24a	-	-
S2W1B1	67a	64c	3.23cd	0.29a	3.21c	0.38a	3.22ab	0.32a	3.24bc	0.35a
S2W1B2	125b	57b	2.41ab	0.31a	3.14c	0.27b	3.22ab	0.29a	3.52c	0.34a
S2W1B3	125b	58b	2.82b	0.36a	2.32a	0.34a	3.17ab	0.33a	2.75a	0.22a

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W0 and W1 - weed free and 10 barnyardgrass m^{-2}. B1, B2 and B3 starter fertilizer application time 0, 7 and 14 days after planting respectively. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

Table 5.7. Effect of the delay of starter fertilizer application on rice grain yield.

Starter fertilizer application time	S1W0		S1W1		S2W0		S2W1	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
— DAP —	Kg ha^{-1}							
0	6200 a	7960 a	4713 a	4740 a	6523 a	8905 a	5279 a	5860 a
7	6145 a (-0.90)	6885 a (-13.5)	4715 a (0.04)	5100 a (7.59)	6308 a (-3.30)	7128 b (-19.96)	5562 ab (5.37)	6298 ab (7.47)
14	6111 a (-1.44)	6300 b (-20.9)	5049 a (7.14)	5200 a (9.70)	6154 a (-5.50)	7960 b (-10.61)	5923 b (12.2)	6580 b (12.29)

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W0 and W1 - weed free and 10 barnyardgrass m^{-2}. DAP - days after planting. Rice yield loss/gain by the delay of fertilizer application as a percent of its "no delay" treatment is given in the parenthesis. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

The percent rice yield loss by barnyard grass competition at each fertilizer application time was calculated from the yield difference between the rice crop grown under weed free and weedy conditions for each fertilizer application time (Table 5.8). These values clearly showed that the delay of starter fertilizer application had reduced the magnitude of rice yield loss by competition from barnyardgrass. Generally, the percent yield loss in the high density planting of rice was relatively less than that in the normal planting density of rice. The reduction of competitive effects of BYG with the delay of starter fertilizer application had improved the performance of rice, resulting in increased growth and yield.

Table 5.8. Percent yield loss of rice by barnyardgrass competition at each fertilizer application time.

Basal fertilizer application time	S1W1		S2W1	
	Maha	Yala	Maha	Yala
— DAP —	— Percent —			
0	24.00 ab	40.45 b	19.07 c	34.19 b
7	33.00 b	25.93 a	11.82 b	11.64 a
14	17.36 a	17.46 a	3.76 a	17.34 a

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively).
W1 - 10 barnyardgrass m^{-2}. DAP - days after planting. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

Application of the starter fertilizer at planting under weedy situations seems to stimulate the growth of BYG and its resulting increased competition with rice to acquire resources, ultimately reducing rice yield. When fertilizer application was delayed both rice and BYG had reduced nutrient availability (Table 5.5 and 5.6). Under this low fertility condition the relative competitive ability of BYG seems to be reduced, resulting in a reduced effect on rice plant growth. Similarly, delayed application of starter fertilizer may increase the fertilizer use efficiency of rice as the roots of rice can be better established in the soil by the time of fertilizer application. Similar growth responses of rice and BYG were recorded by Kleinig and Noble (1968) in an experiment on the effect of different levels of nitrogen and phosphorus on BYG competition with rice. Under conditions of high N and high P, BYG competition reduced rice grain yield more than under low N and low P conditions. The intensity of yield reduction by BYG was greater for additions of nitrogen than for the addition of P fertilizer in that experiment.

Delaying fertilizer application for 2 weeks resulted in more yield reduction than a delay of one week (Table 5.7), but the 2-week delay had less yield loss from weed competition (Table 5.8). When considering the total yield loss in Table 5.9, the 2-week delay resulted in the least total yield loss as compared to a delay of 0 or 7 days. The net reduction in percent yield loss by the delay of starter fertilizer application by two weeks ranged from 0 - 13.29%. Therefore delaying the starter fertilizer application for two-weeks seems to be a good alternative agronomic practice to reduce the magnitude of rice yield reduction by weed competition.

Table 5.9. Total yield loss by the delay of fertilizer and barnyardgrass competition at each fertilizer application time.

Basal fertilizer application time	S1W1		S2W1	
	Maha	Yala	Maha	Yala
– DAP –	Percent			
0	24.00 a	40.45 c	19.07 b	34.19 c
7	33.04 b	33.52 b	17.19 ab	19.11 b
14	24.50 a	27.16 a	15.96 a	29.63 a

S1 and S2- Planting density of rice (15 x 15 and 10 x 10 cm respectively). W1 - 10 barnyardgrass m^{-2}. DAP - days after planting. In a column, means followed by the same letter are not significantly different at the 5% probability level of Duncan's multiple range test.

CHAPTER VI

SIMULATION OF THE EFFECTS OF PLANT TYPE AND NITROGEN FERTILIZER TIMING ON RICE (*Oryza sativa* L.) BARNYARDGRASS (*Ecinochloa crus-galli* (L.) Beavu.) COMPETITION[1]

Lakshman L. Ranasinghe and Garvin D. Crabtree[2]

1. ABSTRACT

The rice-barnyardgrass (BYG) competition simulation model, INTERCOM was used to identify the important morphological traits and growth differences of rice cultivars for weed competitive ability. Initial sensitivity analysis revealed the relative growth rate of leaf area, leaf area of seedlings, seedling height, plant height at maturity, leaf area at maturity and the plant density at maturity as important parameters in determining the weed competitive ability. Five cultivars of rice which possess different levels of the above characteristics were evaluated in field experiments for their competitive ability against BYG to validate the above predictions. Simulated yield losses of rice cultivars followed the same trends as yields observed in field experiments. However the model simulations were always higher than the observed values. Simulated grain yields of the traditional, highly competitive but low yielding cultivar PPL was overestimated by the model since it does not take into account the cultivar yield potential. Another simulation run was done to test the

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[1]Received for publication ...,...,1995 and in revised form .....,...,1995.

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effect of delaying starter fertilizer application on weed competition. However simulated values were not comparable with observed values in this study.

Nomenclature: Barnyardgrass, *Echinochloa crus-galli* (L.)Beauv. #[3] ECHCG.

Additional index words. Simulation, weed competition.

2. INTRODUCTION

Most current cultivars of rice with high yield potential are morphologically different from those grown earlier and require high nitrogen rates for optimum yields (De Datta, 1981). But this "improved" plant type and the high nitrogen demand of these cultivars have indirect stimulating effects on weed growth, resulting in a reduced rice yield (De Datta, 1981; Moody, 1979). Usually traditional cultivars of rice have less crop damage by weeds since these cultivars have characteristics such as tall stature, rapid seedling growth and long-droopy leaves which reduce the light penetration through the canopy (Moody, 1979; Ghosh and Sakar, 1975). Application of starter fertilizer at the time of planting or sowing tends to stimulate the weed growth in rice (Smith et al., 1959; Klenig and Nobel, 1968). Therefore yield losses and the cost and time spent for weed control are high in modern rice farming.

Improvement of the weed competitive ability of rice and development of better fertilizer application practices are important research needs in rice. Some information is available on weed competitive traits of rice, but much of this is conflicting. In

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[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci., Suppl. 2. Available from WSSA, 309 W. Clark St., Champaign, IL 61820.

addition, all these research results are based on crop-weed competition studies conducted as additive, replacement, neighborhood or addition series experiments. In all these approaches of studying crop-weed competition, the outcome of competition is described for a given moment of time with no explanation of the competition process. These studies can only account for the effect of a small number of factors that influence the competition process and are often expensive and labor intensive.

It is well recognized that the actual mechanisms of competition for resource capture are complicated as many mechanisms contribute to the outcome of overall competition. Ecophysiological simulation models may offer more accurate and economic alternatives to better understand the mechanism of competition since they have an ability to test different hypotheses and strategies within a short time and to simulate competitive situations in which many variables are considered.

The model for interplant competition (INTERCOM) by Kropff and Van Laar (1992) simulates the morphological development, dry matter allocation and accumulation of rice and barnyardgrass (BYG) under conditions of competition for capture of light, water and nutrients. This simulation is done by integrating the parameters that define the physiological and morphological characteristics of rice and BYG in the competition process. This model can also account for the influence of environmental factors, plant density, date of emergence and species characteristics on interplant competition. Therefore it can be used to analyze the impact of different morphological characteristics and agronomic practices on the competitive strength of rice cultivars.

Objectives of this study were to capture the contribution of morphological traits of rice on weed competitive ability and to evaluate the effects of delayed starter fertilizer application on weed competition and rice yield.

3. MATERIALS AND METHODS

The rice-barnyardgrass competition simulation model INTERCOM (Kropff and Van Laar, 1992) was used for simulation of interplant competition in this study. This model was written in Fortran 77 programming language and the basic structure of the model is given in the figure 6.1. Data collected from two field experiments conducted during the 1993/94 Maha (wet) and the 1994 Yala (dry) cultivation seasons at the Regional Agricultural Research Center, Aralaganwila, Sri Lanka were used for model simulations. In the first set of experiments, rice cultivar BG 350 was planted with 10 BYG m^{-2} and without BYG competition in 4x3 m plots and the application of starter fertilizer was delayed 0, 7 or 14 days after planting. The objective of this experiment was to test the effect of delaying starter fertilizer application on weed competition in rice. In the other experiment cultivars of rice with different morphological characteristics were evaluated for weed competitive ability under different BYG densities. Before starting this latter experiment, weed competitive morphological traits of rice were identified by a sensitivity analysis using the INTERCOM model (Table 6.1). The cultivars of rice possessing these traits in different quantities (Table 6.2) were then evaluated in field experiments for their competitive abilities with BYG at densities of 0, 3, 9, 27 and 81 plants m^{-2} under lowland irrigated conditions.

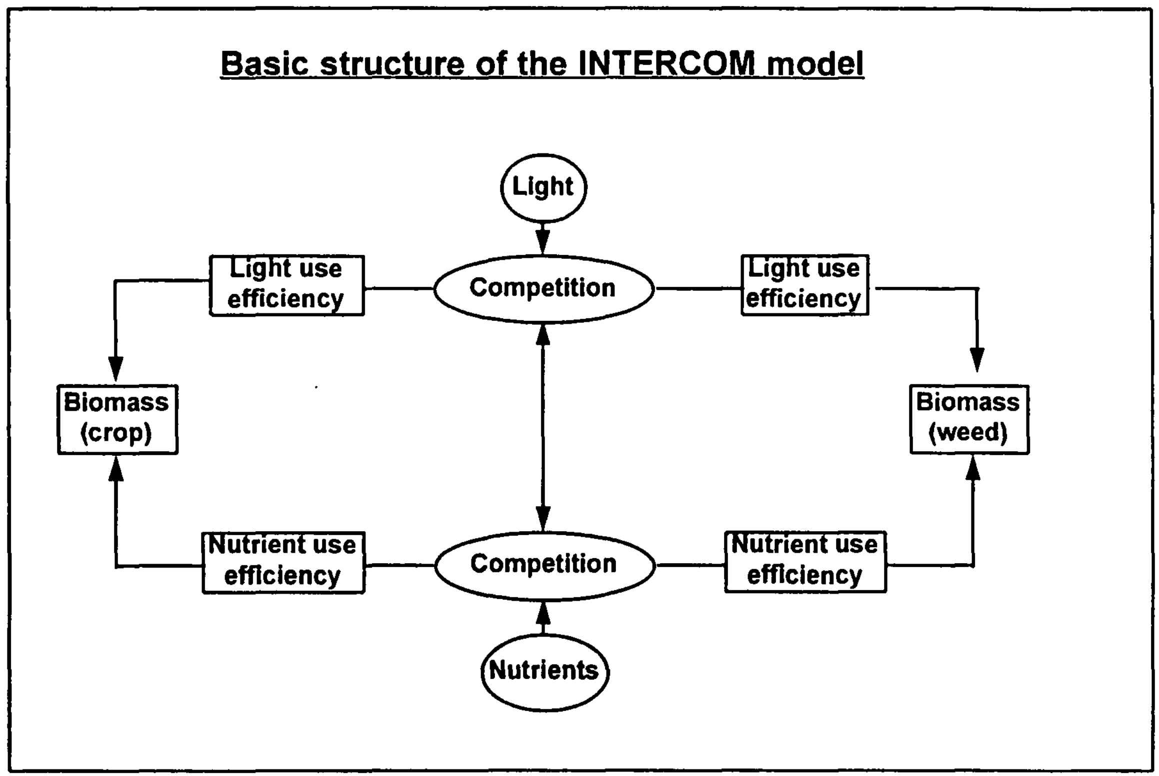

Figure 6.1. Basic structure of the INTERCOM competition simulation model.

Data collected from the above field experiments were used to simulate the interplant competition by changing the values of input data files: plant 1.dat (rice data), plant 2.dat (BYG data) and timer.dat (defining the simulation run). Separate model simulations were done for each treatment combination to evaluate the competitive responses and to compare the simulated results with the results of field experiments. Parameters and rate variables changed in the model to simulate competition were leaf area at planting, height at planting, maximum height, relative growth rate of seedling leaf area, leaf area index, and leaf nitrogen content (only for the starter fertilizer timing experiment). Crop losses caused by BYG competition were calculated from the simulated yield under each weed density and fertilizer practice.

Since there was not sufficient weather data available to change the whole weather file in the model, planting date of experiments were adjusted to the most similar weather period during the year in the INTERCOM weather data file (data from the International Rice Research Institute, Philippines), considering the rainfall pattern and daily temperature.

Table 6.1. Sensitivity of rice yield loss to a 20% increase in the value of each morphological parameter.

Parameter	Sensitivity value
Seedling height	2.83
Leaf area of seedlings	4.05
Relative growth rate of leaf area	6.69
plant height at maturity	2.85
Leaf area at maturity	2.73
Tiller number at maturity/ plant density	4.06
Initial root dry weight	0.001

4. RESULTS AND DISCUSSION

Effects of cultivar differences on grain yield: Simulated grain yields of rice cultivars were reduced as the BYG density increased (Table 6.3), but the model simulated values were much higher than the observed yields in most of the situations (Table 6.4). The traditional cultivar PPL which has low yield potential had a particularly high simulated yield. Although this cultivar possesses good weed competitive ability, it has a low potential yield. Since the INTERCOM model does not account for the potential yield of cultivars in calculating the yield, it may have overestimated the yield of this cultivar by considering its possession of weed competitive traits. Similar trends of overestimation were observed in model simulations for the grain yield of other cultivars. However the trend of simulated percent yield losses was similar to the observed trend of yield loss among all cultivars (Tables 6.5 and 6.6).

Table 6.2. Morphological characteristics of the tested rice cultivars collected from variety catalog records and an observation experiment (1993/94 Maha season).

Cultivar	Plant height		Tillers	Leaf characteristics*				Grain yield
	3 WAP	Maturity		3 WAP		Maturity		
				length	width	length	width	
	cm	cm	no./plant	cm	cm	cm	cm	
BG 1611	38.5	104.8	11.3	24.7	0.59	40.8	1.3	High
BW267-3	39.2	114.1	16.9	25.4	0.64	45.3	1.2	High
BG 350	34.3	85.1	12.0	21.2	0.68	31.6	1.3	High
PPL	51.3	124.3	11.6	28.9	0.68	47.1	1.0	Low
BG 94-2	41.1	118.6	10.2	26.2	0.62	46.2	1.2	High

* Average of 10 leaves/ plant. WAP = Weeks after planting.

Cultivars with high initial plant height, height growth rate and high leaf area growth rate during seedling stages showed less simulated yield losses (Table 6.6). These results were similar to those from the sensitivity analysis and field experiments (Table 6.1 and Table 6.5). Therefore these simulations confirm the importance of high leaf area, height growth and dry weight of seedlings for weed competitive ability. Also this information demonstrates the utility of the INTERCOM model for predicting the weed competitive ability of rice cultivars.

Simulated height growth patterns of rice cultivars and BYG (Figures 6.2 and 6.3) were similar to the observed pattern. However the model simulations of leaf area index values for rice cultivars (Figures 6.4 and 6.5) seem to be higher than the observed values (Table 6.7), but since only four leaf area measurements were taken in each experiment, it is not possible to make a firm conclusion. Simulated LAI values for BYG (Figure 6.6) were much closer to the observed values.

As one of the important weed competitive traits, plant height is associated with susceptibility to lodging and therefore the use of this trait has limitations. Similarly high leaf area index (LAI) may cause mutual shading and increase pest and disease problems, which ultimately reduce grain yield. Therefore this model can be used to optimize competitive traits in order for a rice cultivar to have the same level of competitive ability as traditional cultivars, but with an acceptable yield. This information would provide valuable insight on the nature of weed competitive ability and would be useful for the development of rice breeding programs.

Table 6.3 Simulated yield in rice cultivars to barnyardgrass (BYG) competition.

BYG density	BG 1611		BW 267-3		BG 350		PPL		BG 94-2	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
- no m^{-2} -	Kg ha^{-1}									
0	6626	6592	6593	6536	6564	6579	6519	6546	-	6608
3	6424	6474	6441	6547	5857	6404	6497	6519	-	6575
9	6106	6287	6443	6389	5666	6131	6389	6421	-	6529
27	5490	5220	6178	5979	4629	5091	6431	6374	-	6306
81	3575	2248	3881	4446	819	2342	4329	5339	-	5677

Table 6.4. Observed grain yield of rice cultivars under different barnyardgrass (BYG) densities.

BYG density	BG 1611		BW 267-3		BG 350		PPL		BG 94-2	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
- no m^{-2} -	Kg ha^{-1}									
0	7116	6556	6579	6300	5919	6633	3175	3909	-	6156
3	6305	6111	5948	6338	5019	3724	2823	3724	-	5556
9	4245	5633	4370	5011	3137	4620	2961	3337	-	4150
27	2537	2411	2444	2745	2014	2386	2108	2834	-	3509
81	1726	1489	1807	1969	1240	1617	1552	1987	-	1967

Table 6.5. Observed percent yield loss in rice cultivars to barnyardgrass (BYG) competition.

BYG density	BG 1611		BW 267-3		BG 350		PPL		BG 94-2	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
- no m^{-2} -	Percent									
3	11.4	8.2	9.6	-0.6	15.2	4.7	11.1	4.7	-	9.73
9	40.4	15.4	33.6	20.5	47.0	30.7	6.7	14.6	-	32.6
27	64.4	63.8	62.9	56.4	66.0	64.2	33.6	27.5	-	47.9
81	75.7	77.6	72.5	68.7	79.1	75.7	51.1	49.2	-	68.1

Table 6.6. Simulated percent yield loss in rice cultivars to barnyardgrass (BYG) competition.

BYG density	BG 1611		BW 267-3		BG 350		PPL		BG 94-2	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
- no m^{-2} -	Percent									
3	3.1	1.8	2.3	-0.2	10.7	2.7	0.3	0.4	-	0.5
9	7.9	4.6	2.3	2.3	13.7	6.8	2.0	1.9	-	1.2
27	17.1	20.8	6.3	8.5	29.5	22.6	1.4	7.2	-	4.6
81	46.0	65.9	41.1	32.0	87.5	64.4	33.6	18.5	-	14.1

Table 6.7. Leaf area index (LAI) of rice cultivars at different stages of growth under each barnyardgrass (BYG) density.

Season	Cultivar	BYG density (no. m^{-2}) 0				3				9				27				81			
		0 WAP	4 WAP	8 WAP	10 WAP	0 WAP	4 WAP	8 WAP	10 WAP	0 WAP	4 WAP	8 WAP	10 WAP	0 WAP	4 WAP	8 WAP	10 WAP	0 WAp	4 WAP	8 WAP	10 WAP
		LAI																			
Maha	BG 1611	.51	2.6	2.5	3.3	.51	1.7	2.7	3.6	.51	2.5	2.8	3.6	.51	2.1	2.9	3.8	.51	1.8	2.4	3.2
	BW 267-3	.59	2.5	2.6	3.5	.59	2.0	2.6	3.4	.59	1.0	1.8	2.7	.59	1.7	2.6	3.5	.59	1.7	2.4	3.1
	BG 350	.57	2.9	1.9	4.7	.57	1.8	2.9	3.8	.57	2.1	1.8	2.6	.57	1.7	1.9	2.8	.57	1.5	1.9	2.7
	PPL	.76	2.7	3.4	3.3	.76	2.7	3.0	3.8	.76	2.4	2.7	3.5	.76	2.2	2.6	3.4	.76	2.3	2.3	3.1
Yala	BG 1611	.49	1.3	2.0	3.1	.49	1.3	2.4	2.9	.49	1.3	2.1	2.6	.49	.83	1.5	2.2	.49	.89	2.0	2.5
	BW 267-3	.54	1.8	1.3	3.9	.54	1.8	1.9	4.1	.54	1.9	2.5	3.2	.54	1.1	1.5	2.6	.54	1.2	2.1	2.4
	BG 350	.45	1.2	1.8	3.2	.45	1.4	1.7	3.1	.45	1.3	1.6	2.3	.45	1.0	1.9	1.8	.45	1.1	1.2	1.9
	PPL	.71	2.0	1.2	3.8	.71	2.0	1.2	3.4	.71	1.7	1.3	2.9	.71	1.5	1.4	2.6	.71	1.7	1.1	2.8
	BG 94-2	.66	2.0	1.5	4.4	.66	1.8	1.3	3.8	.66	1.7	1.9	3.5	.66	1.5	1.3	2.9	.66	1.6	1.6	2.8

WAP- weeks after planting.

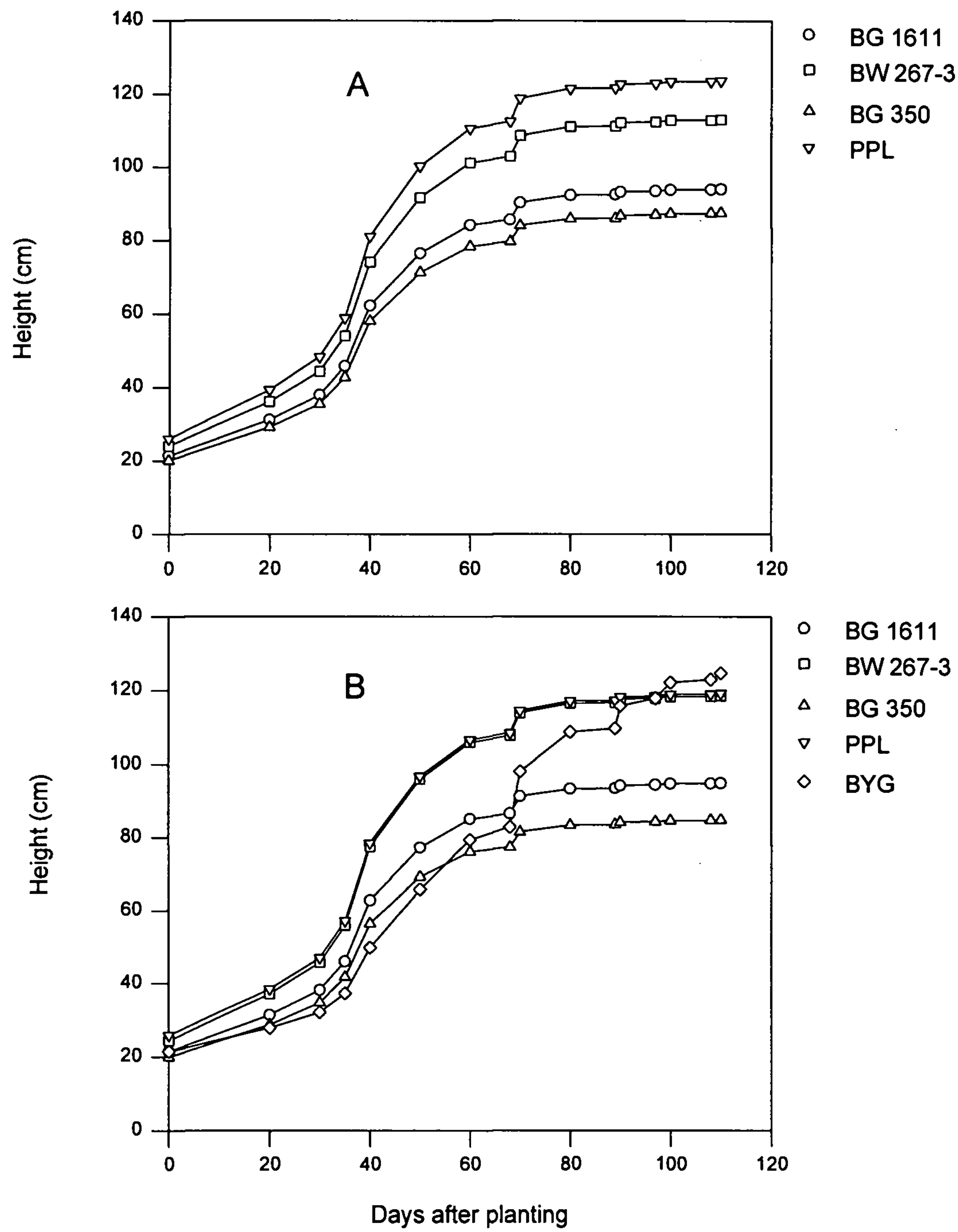

Figure 6.2. Simulated height growth (a) Rice (four cultivars) monoculture and (b) Rice-barnyardgrass mixture (27 plants m^{-2}) during Maha season.

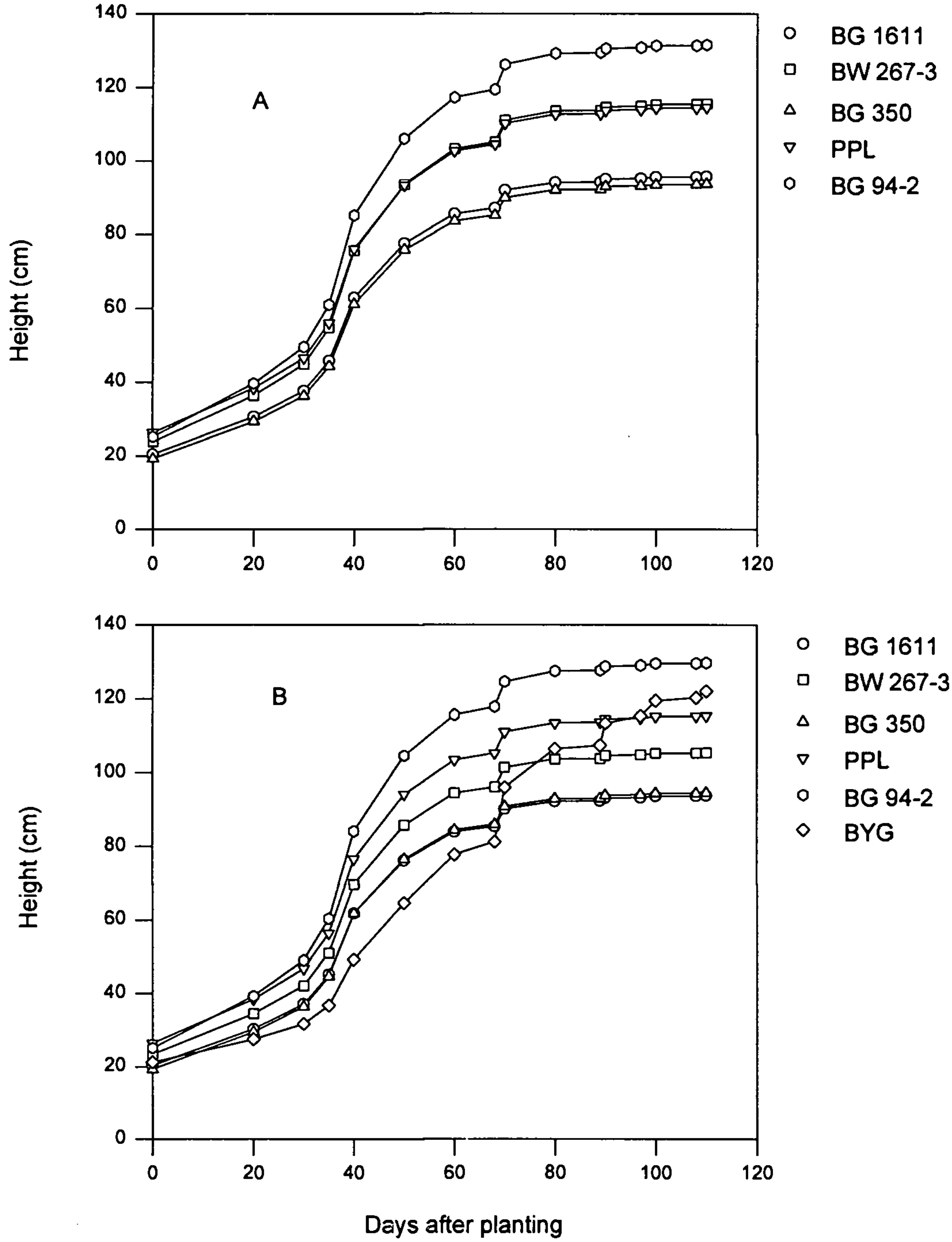

Figure 6.3. Simulated height growth (a) Rice (five cultivars) monoculture and (b) Rice-barnyardgrass mixture (27 plants m^{-2}) during Yala season.

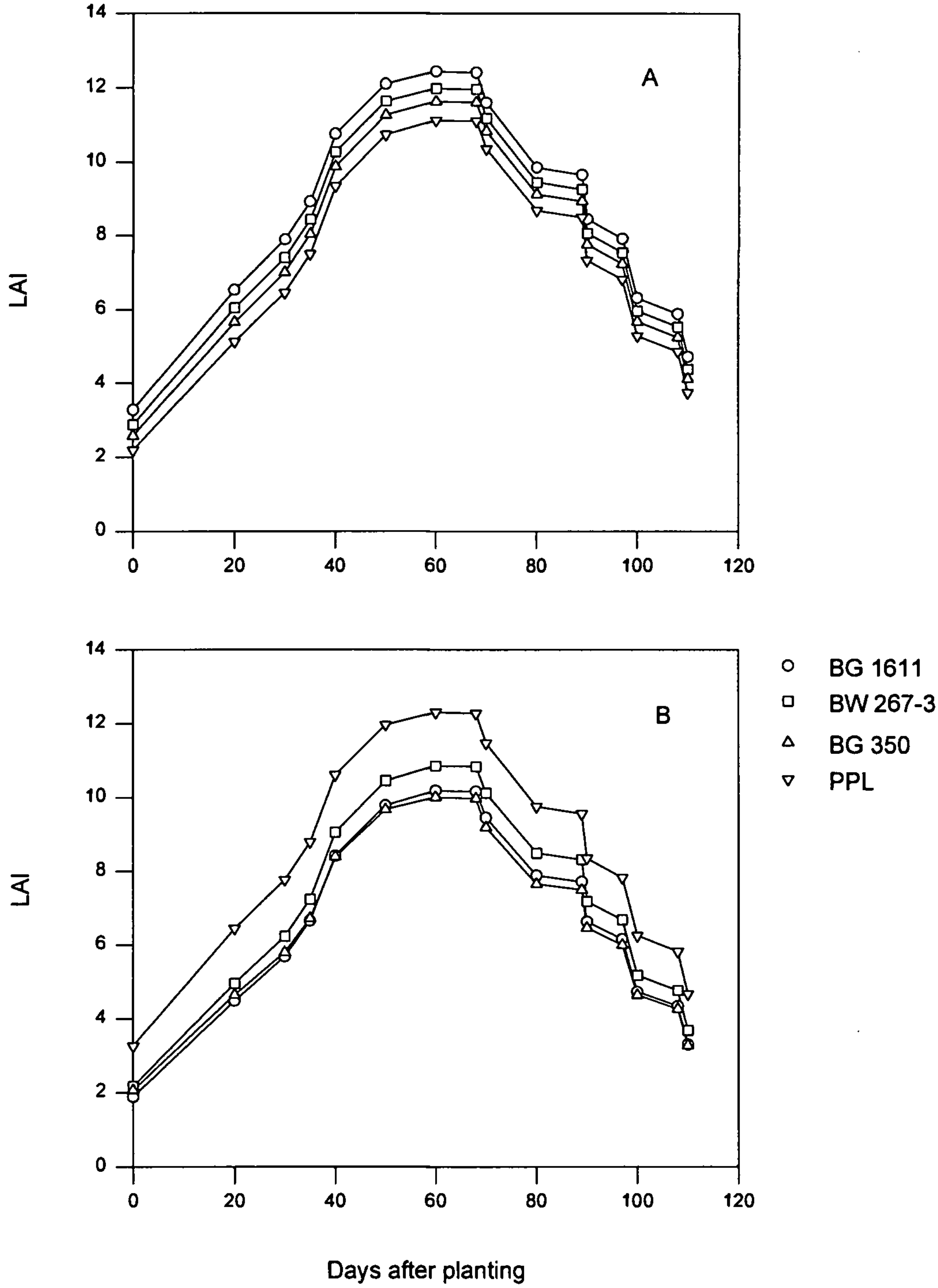

Figure 6.4. Simulated leaf area index (LAI) growth (a) Rice (four cultivars) monoculture and (b) Rice-barnyardgrass mixture (27 plants m^{-2}) during Maha season.

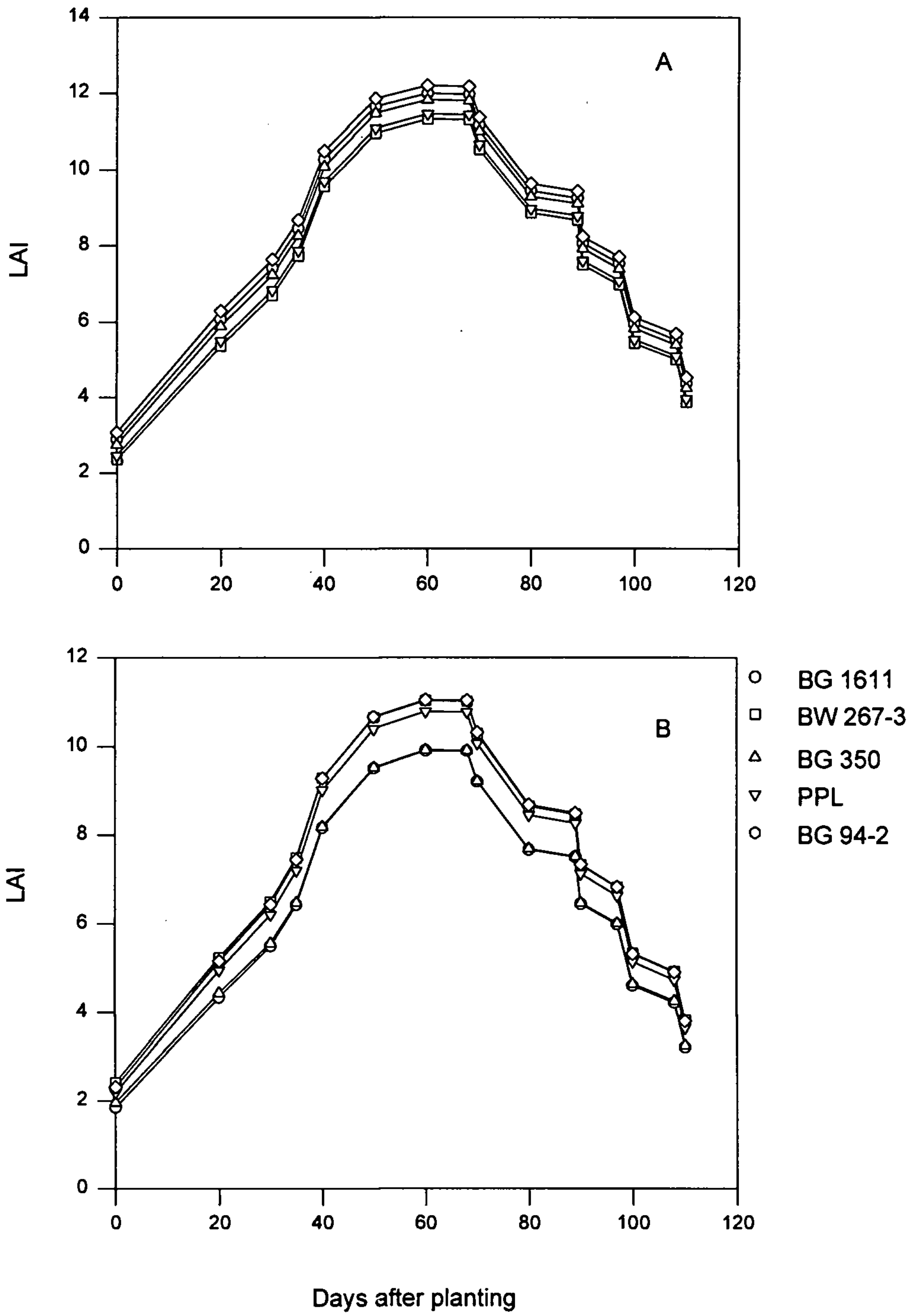

Figure 6.5. Simulated leaf area index (LAI) growth (a) Rice (five cultivars) monoculture and (b) Rice in rice-barnyardgrass mixture (27 plants m^{-2}) during Yala season.

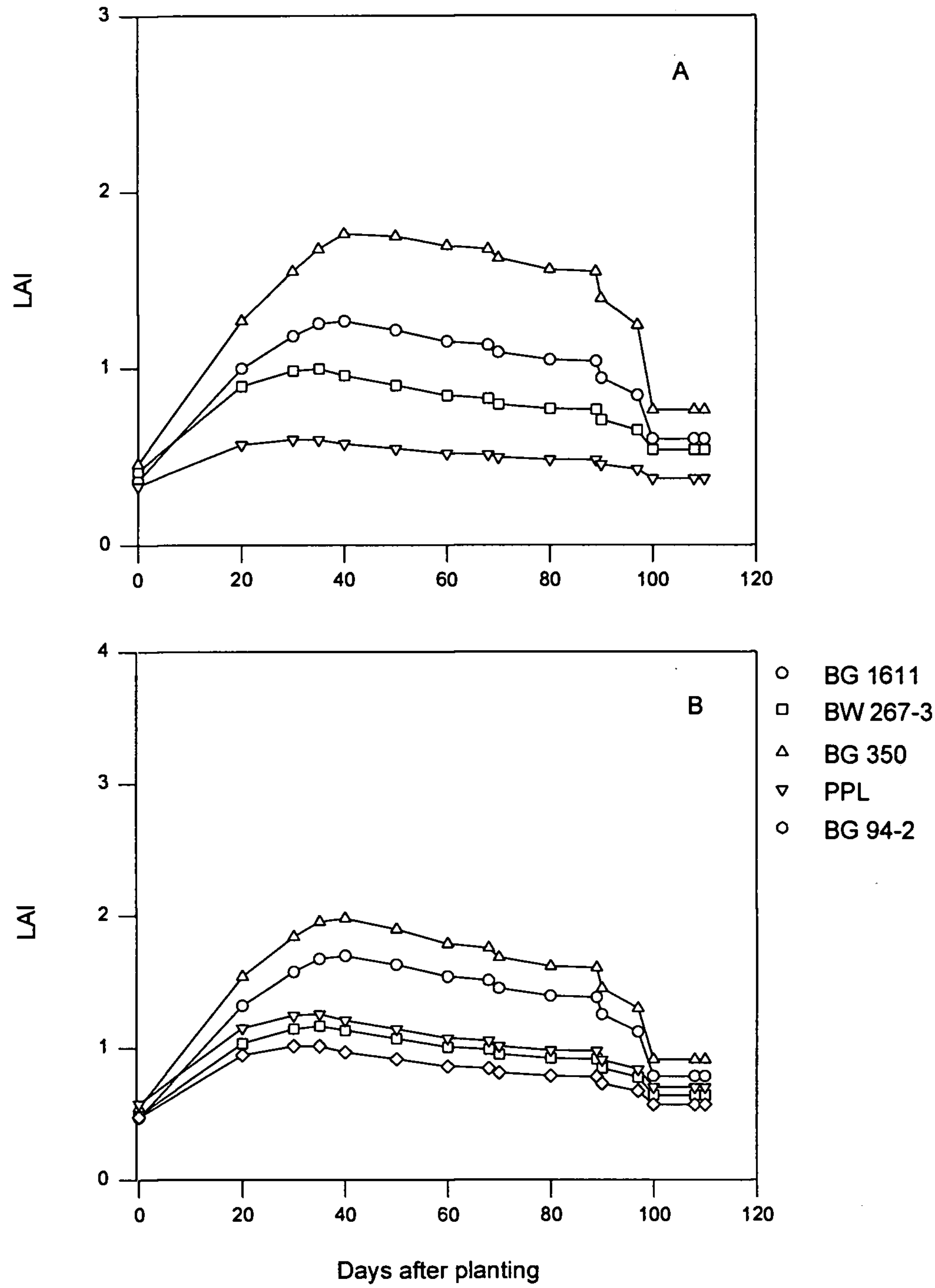

Figure 6.6. Simulated leaf area index (LAI) growth for barnyardgrass in rice-barnyardgrass mixture (27 plants m^{-2}) (a) Maha season (b) Yala season.

Effects of the delay of starter fertilizer application: Simulated rice grain yields as affected by the time of starter fertilizer application is given in Table 6.8. In these simulations the effect of the delay of starter fertilizer application, which resulted in changes in the crop and weed leaf nitrogen content, relative growth rate of leaf area and specific leaf weight, failed to show any change in the competitive ability of species. Simulated yields for all fertilizer application times were much alike (Table 6.8). These simulations were made by changing the values of the above parameters recorded at the time of planting, at the time of starter fertilizer application and one week after the fertilizer application. Therefore all of these values were taken during the first three weeks of the crop season. But the competition for absorption of nutrients continues throughout the growing period. Therefore this lack of information during the rest of the period of crop growth may be the reason for not accounting for the effect of fertilizer timing on weed competitive ability in this experiment. Another simulation run was done with reduced BYG leaf nitrogen levels while keeping the crop leaf nitrogen content in the normal range, assuming a continuation of the observed pattern of low BYG leaf nitrogen levels with the delay of starter fertilizer application. This resulted in a simulated yield much similar to the observed in field experiments with a 4.1% increase of yield over the normal fertilizer practice (5077 and 5424 kg ha^{-1} of grain yield with no delay and delay respectively). Therefore this information supports the above hypothesis.

The results of this study suggests the possibility of using the INTERCOM model for predicting weed competitive ability of rice cultivars and yield losses by weed competition under different weed management practices. However to obtain reliable results a complete set of data which describe the quantitative changes of parameters during the process of plant growth and competition is required to simulate the outcome of competition.

Table 6.8. Simulated and observed rice grain yields as affected by the time of starter fertilizer application.

Fertilizer application timing	Weed free				Rice + BYG			
	observed		simulated		observed		simulated	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
- DAP -	Kg ha^{-1}							
0	6200a	7960a	8287	8228	4713a	4740a	7497	8077
7	6145a	6885a	8176	8228	4715a	5100a	7497	8077
14	6111a	6300b	8168	8061	5049a	5200a	7496	8061

DAP- Days after planting. In a column values followed by the same letter are not significantly different at the 5% probability level of the Duncan's multiple range test.

CHAPTER VII

GENERAL CONCLUSIONS

A series of field experiments were conducted at the Regional Agricultural Research Center, Aralaganwila, Sri Lanka to investigate the possibility of enhancing weed competitive ability of lowland rice cultivars.

The nature of rice-weed competition and the crop yield loss by weed competition varied with the morphology of the rice cultivar used. The growth and yield of the semi-dwarf, erect leaved, high yielding rice cultivar BG 350 was much more affected by barnyardgrass (BYG) competition than the cultivar BG 94-2 which has a tall stature, high leaf area index and good seedling vigor. Data analysis revealed that the cultivar BG 350 suffered from interspecific competition (B_{WR}) for a longer period than the cultivar BG 94-2. This could be due to the morphological differences of these two cultivars which cause differences in obtaining limited resources under weedy situations. Under weedy situations, the dwarf plant type, slow initial growth rate of leaf area and erect leaf morphology of cultivar BG 350 may have had less access to resources than the cultivar BG 94-2, causing more interspecific competition.

In the rice cultivar testing experiment, growth and yield of rice cultivars PPL and BG 94-2 were least affected by the barnyardgrass competition while cultivars BG 1611 and BG 350 were most affected by BYG competition. Data analysis revealed that the morphological parameters such as high relative growth rate of leaf area, rapid height growth and plant dry weight increase during the seedling phase of the crop, are important for weed competitive ability. Results obtained from the INTERCOM crop-weed competition simulation model sensitivity analysis on important morphological traits were comparable with the results of field experiments.

In the fertilizer timing experiment the delay of starter fertilizer application reduced the yield in rice monocultures, but in rice-BYG mixtures the delayed fertilizer application increased the grain yield. A delay of 14 days resulted in better crop performance than application of fertilizer at the day of planting and this could be due to the increased efficiency of fertilizer use by the crop.

Simulated crop yield losses by the INTERCOM crop-weed competition simulation model followed the same pattern as observed in field experiments. Therefore this model would be useful for rice breeders to predict the weed competitive ability of new rice cultivars.

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