CHAPTER II

REVIEW OF LITERATURE

Rice is produced worldwide and is the primary staple for more than half of the world's population. Rice is the most important crop of India and it occupies 23.3 per cent of gross cropped area of the country. Rice contributes 43 per cent of total food grain production and 46 per cent of total cereal production, besides it account for 15 per cent annual GDP of India. It provides 43 per cent calorie requirement of more than 70 per cent of Indians. It continues to play vital role in the national food grain supply. India’s population is expected to be 1.2 billion by the year 2012 and it will have to produce a whopping 120 million tons of rice to meet the burgeoning demand. Demand for food grains in India is expected to grow and the requirement for 2025 is estimated to be a 40 per cent production increase compared with 2003-04.

Rice is grown under varying Eco-systems on a variety of soils under varying climatic and hydrological conditions ranging from waterlogged and poorly drained to well-drained situations. Rice is also cultivated under rain fed as well as irrigated conditions. The total area under irrigated rice is about 22.0 m.ha, which accounts about 49.5 per cent of the total area under rice crop in the country. Rice is grown under irrigated conditions in the states of Punjab, Haryana, Uttar Pradesh, Jammu and Kashmir, Andhra Pradesh, Tamil Nadu, Sikkim, Karnataka, Himachal Pradesh and Gujarat. In these states rice is grown under irrigated conditions with more than 50-90 per cent area.

2.1. Shift in Crop Establishment method

Transplanting is the most popular method of cultivation. Irrigated lowland, upland and flood prone are the main ecosystem of rice in India and covers 19.0 m.ha area under irrigated lowland transplanted situation which is 44 per cent of total rice area followed by others. In the near future, the possibility for expanding areas under rice-based systems will remain very limited because of the scarcity of global water resources for agriculture, the expansion of urban and industrial sectors where land is already limited and the high costs of developing
new lands that are suited for rice production. It is estimated that irrigated lowland rice receives some 34–43 per cent of the total world’s irrigation water, or 24–30 per cent of the total world’s freshwater withdrawals. The growing water shortage means there is a pressing need to devise methods of growing rice with less water, without any penalty to production. The change in rice crop establishment from transplanting to direct seeding has occurred in many Asian countries because of rapid economic growth, increasing labor costs, and shortages of water. Direct seeded rice gave more water productivity of 0.461 kg grain m$^{-3}$ of irrigation water as against 0.436 kg grain m$^{-3}$ (Gill, 2008). In addition, there is a need to reduce the costs of rice production in order to maintain profitability despite the declining market price, a trend that is expected to continue in the future.

2.2. Direct Seeded Rice

Direct seeding can refer to either wet or dry methods, depending on the manner of crop establishment. Although, transplanting is the most common method in Asia’s irrigated rice growing areas (De Datta, 1986), this practice is increasingly being replaced by direct seeding as labour becomes a demand as well as a cost factor (De Datta, 1989; Rachel and Martin, 1995; Madhu and Nanjappa, 1995; Jayadeva et al., 1998; Ito 1998). Direct seeded rice needs only 34 per cent of total labour requirement and saves 29 per cent of total cost of transplanted crop (Ho and Romli, 2000). The economic incentives for adoption of wet seeding were provided for by its labor saving feature as exemplified by 1-2 man day ha$^{-1}$ vis-à-vis 20 man day ha$^{-1}$ in the transplanting rice culture (Azmi and Baki, 2006). Wet seeding involves sowing pre-germinated seed, either broadcast or drilled, on to puddled wet soil, and then gradually flooding the land. In dry-seeding, rice is broadcast or drilled into dry soil and the seed is then covered. The most promising option for the future is to adopt direct sowing of rice in place of transplanting, reducing its dependence on labour and water, and for farmers to become familiar with the correct use of herbicides. Water use efficiency was more in direct seeded rice as the water requirement for the land preparation is less compared to transplanted rice (Bhuiyan, 1992). Sattar and Khan (1994) reported that direct wet-seeded rice required about 20 per cent less water compared with transplanted rice. Isvilanonda (2002) reported that direct seeded rice reduced 2-6 per cent production cost and increased net return by 37 per cent, in dry season. Direct seeding eliminates the need for seedbed preparation,
seedling uprooting and transplanting and the associated costs and energy. Most of the field experiments and on-farm research have proved accurate seed rate, timely seeding, efficient weed control and water management under direct seeded conditions gave as high yield as transplanted rice with comparatively lower production cost (Awan et al, 1989 and Baloch, 1994). In addition, direct seeded rice matures about 8-10 days earlier (Husain et al, 2003) by escaping from transplanting shock and injury (Sattar et al, 1996).

2.2.1. Forms of direct seeding

Direct seeding is practiced in three main forms: dry seeding, wet seeding, and water seeding.

Dry seeding where non-germinated seeds are sown beneath the soil surface. The plant stand is more consistent than in wet and water seeding as the soil is aerobic. Dry seeding is advantageous when the water supply is limited at the time of land preparation and crop establishment. The rain or irrigation water is impounded when the crop is 30-45 days and thereafter it is converted into a wetland crop when the tank gets filled with the monsoon showers (Ramiah and Muthukrishnan, 1992).

Wet seeding is a widely practiced form of direct seeding in which the land is flooded and puddled in the same way as in transplanting. Pre-germinated seeds are sown on the puddled soil surface just after drainage. The practice of wet seeding was first adopted by Malaysian farmers in the late seventies because of labour shortage and labour costs during peak demand (Wan and Daud, 1990). Wet seeded rice yields were high in both water sufficient and water stress situations (Sattar, 1992).

Water Seeding is practiced in leveled fields where the water depth at seeding time is 5-10 cm; pre-germinated seeds sown in fields under flooded conditions.

2.2.2. Direct Seeded Rice in India

In India, too, direct-seeded rice is grown in parts of several states, including Karnataka, Kerala, Tamil Nadu, Orissa, Andhra Pradesh, Chattisgarh, Bihar, West Bengal, and the hill state of Uttaranchal. It is being promoted by IRRI & IARI in Indo gangetic plains to effectively utilize the monsoon rains and to conserve the water. In Kerala direct seeding by
pre-germinated seeds is the major method of rice cultivation. In Tamilnadu it is being practiced in limited districts but off late being practiced in more areas by the farmers. The area under direct seeded rice is constantly increasing in Tamilnadu. There is an increasing trend to replace transplanting of rice by wet seeding. In effect, farmers are substituting capital in the form of seed and herbicides for labour. The results also suggest that the labour cost advantage of wet seeding more than compensates for the increase in herbicide cost, and adoption is increasing even though herbicide costs are rising (Erguiza et al. 1990). John Kutty et al., (2002) from their studies during 1996-98 in Kerala found that the labour intensive and costly method of transplanting could be substituted by direct-seeding with no sacrifice in productivity.

2.3. Climatic and weather condition affecting direct seeded rice

In India rice is grown under widely varying climatic conditions and altitude. Therefore, the rice growing seasons vary in different parts of the country, depending upon temperature, rainfall, soil types, water availability and other climatic conditions. In eastern and southern regions of the country, the mean temperature is found favourable for rice cultivation through out the year. Hence, two or three crops of rice are grown in a year in eastern and southern states. Rice being a tropical and sub-tropical plant, requires a fairly high temperature, ranging from 20° to 40°C. The optimum temperature of 30°C during day time and 20°C during night time seems to be more favourable for the development and growth of rice crop. Summer rice is called as Rabi rice. It is known as 'Boro' in Assam and West Bengal, 'Dalua'in Orissa, 'Dalwa' in Andhra Pradesh, 'Punja' in Kerala and 'Navarai' in Tamil Nadu and 'Garma' in Bihar. The sowing time of summer rice is November to February and harvesting time is March to June. The area under summer rice is only nine per cent and early maturing varieties are mostly grown in this season. Rice is grown under so diverse soil and climatic conditions that it is said that there is hardly any type of soil in which it can not be grown including alkaline and acidic soils. Rice crop has also got wide physical adaptability. Therefore, it is grown from below sea-level (Kuttanad area of Kerala) upto an elevation of 2000 metres in Jammu & Kashmir, hills of Uttaranchal, Himachal Pradesh and North-Eastern Hills (NIT!) areas. Rice is grown under varying Eco-systems with a variety of soils under varying climatic and hydrological conditions ranging from waterlogged and poorly drained to
well drained situations. Rice is also grown under rain fed as well as irrigated conditions. The coastal area is always subjected with salinity problem and these areas are situated in West Bengal, Orissa, Andhra Pradesh, Tamil Nadu and Kerala.

2.4. Production Constraints

Stand establishment is often poor under direct seeding because of poor land preparation, high temperature, weed competition and poor weed control (De Datta, 1981). This shall be minimised in direct seeding under puddled condition. Studies in rice growing countries showed that grain yields from direct seeding could be similar or even higher than the transplanted rice. Wet seeded rice producing similar or higher yield than transplanted rice was well documented by several workers in India (Ramasamy et al, 1994; Rachel and Martin, 1995). The shift in methods of rice culture from transplanting to direct seeding has magnified the weed problem.

A cardinal and perennial constraint in wet-seeded rice is weed infestation, requiring good field drainage and judicious water control for satisfactory crop establishment and weed control (Azmi and Baki, 2006). In direct seeded rice, weed competition is very severe because, the crop weed seeds germinate simultaneously and the weeds being more vigorous in growth, smother the crop (Moody and Mukhopadhyay 1982). Heavy weed infestation and competition are serious among the several constraints for higher yield in wet seeded rice (Kandasamy and Sivaperumal, 1997; Jayadeva et al, 1998). During the initial growth phase weed infestation was a major problem in wet seeded rice (Reddy et al, 1994) because of the germination of large number of all kinds of weeds (Moody and Chavez, 1995). Weed control has always been one of the major inputs in rice production (Seaman and De Datta, 1968). The weed menace associated with the direct seeding system could be overcome by application of herbicides.

2.5. Effect of Seed rate on Rice Productivity

Low plant density and the presence of gaps encourage the growth of weeds. On the other hand, too thick a stand should be avoided because it tends to increase lodging, prevents the full benefit of nitrogen application (Anon, 1986). High seeding rate can compensate partly for poor weed control. Seeding rates used in wet-seeded rice are generally high to help
control weeds (Moody, 1977a), to compensate for damage by rats and birds (Mabbayad and Obordo, 1970), to partially overcome the adverse effects of herbicides (Moody, 1984), and to compensate for poor stand establishment (Moody, 1986). Moody (1977b) reported that there was a significant decrease in weed weight as the seeding rate increased from 50 to 250 kg ha\(^{-1}\). The establishment of a crop with a more uniform and dense plant distribution will increase its ability to suppress weeds. Low plant density and the presence of gaps encourage the growth of weeds. Such a stand will, in many cultivars, result in less uniform ripening and poor grain quality. On the other hand, too thick a stand should be avoided because it tends to increase lodging, prevents the full benefit of nitrogen application (Anon, 1986).

In dry-seeded rice, a high seed rate of 125 to 162.50 kg ha\(^{-1}\) was found very effective in suppressing weeds (Supatanakul et al., 1977). One of the easiest and most consistent methods to accomplish this goal is to simply increase the crop seed rates (Mohler, 2001). Some farmers in Sri Lanka sow 200 to 300 kg seed ha\(^{-1}\) to suppress weeds during the initial growth of wet-seeded rice (Moody, 1993). For wet-seeded rice, a rate of 100 kg ha\(^{-1}\) was found to be suitable (Kanchanomai, 1981). Guyer and Quadranti (1985) noted that higher seeding rates would be beneficial if no weed control is planned or only partial weed control is expected. However, it is not necessary to use high seeding rates to suppress weeds in wet-seeded rice if a herbicide that is effective in controlling weeds is used (Castin and Moody, 1989).

In one of the seven experiments (1996-98) in which the weed population was high and no weed control was conducted throughout crop growth, a high seeding rate of 200 kg ha\(^{-1}\) was required to minimize the adverse effect of weeds. On the other hand, when weeds were controlled, a seeding rate of 100 kg ha\(^{-1}\) produced the highest yield. Cultivars with low established plant density competed poorly with weeds (Romyen et al., 2000). Seeding rate was inversely correlated to weed interference. Severe rice yield reduction (71%) caused by weeds was found at a seeding rate of 40 kg seed ha\(^{-1}\) in the wet season. Using seeding rates of 80 and 160 kg seed ha\(^{-1}\), respectively, lowered yield loss to 47 and 26 per cent in the wet season, 32 and 18 per cent in the dry season. Therefore suitable method and/or rate of seeding can significantly suppress weeds in direct-seeded lowland rice (Phuong et al., 2005). Research showed that increasing the seed rate from 40 to 100 kg ha\(^{-1}\) for direct seeded rice decreased weed weight from 52 to 188 g m\(^{-2}\) and increased rice yield from 2.78 to 3.45 t ha\(^{-1}\).
(Hooda, 2002). Diarra et al. (1985) compared seeding rates of 50, 100, and 134 kg ha\(^{-1}\) and found that 100 kg ha\(^{-1}\) optimized rice yield in 1 of 2 years. Overall, as rice seeding rate increased, culm and panicle number increased while grains per panicle decreased. Estorninos et al. (1998) reported rice grain yield increased from the 50 to 100 kg ha\(^{-1}\) seeding rate, but did not increase from 100 to 150 kg ha\(^{-1}\) seeding rate. Jones and Snyder (1987) reported the optimum seeding rate was 80 to 100 kg ha\(^{-1}\) for rice grown in monoculture in southern Florida.

Crop sown with higher seed rate always gave more number of panicles m\(^{-2}\) than under low seed rate (Reddy et al., 1994). Gill (2008) observed that the effective tillers increased significantly with the increase in seed rate and were maximum at 150 kg ha\(^{-1}\) followed by 100 kg ha\(^{-1}\) and lowest in 50 kg ha\(^{-1}\). However, Wu et al. (1998) reported tillers per plant and spikelets per panicle increased with decrease of plant density in direct seeded rice.

Crop density has a key role in weed management. Optimum crop density result in rapid shading on soil surface and prevent weed growth (Radosевич et al., 1997). However, Kevin et al. (2001) indicated that different rice densities in direct seeding have no significant effect on barnyard-grass growth. Lesnik (2003) reported that in optimum crop density, lesser herbicide will be required. Mussavi et al. (2009) concluded that it is possible that a reduced herbicide dose will be adequate for weed control while seeding rate is optimum. It seems that in density of 120 kg ha\(^{-1}\), weeds could be more controlled than other densities and a better nutritive space will be provided for rice. These conditions can be helpful for crop in competition in barnyard-grass. Ultimately, it seems that optimum seeding rate as a good crop density can decrease crop sensitivity to weed competition and herbicide use.

2.6. Weed Control in Direct Seeded Rice

Weed infestation is a major threat to yield and the further expansion of direct seeding in India. Effective weed control is one of the major requirements to ensure a successful wet-seeded rice crop. In most of the countries, insufficient attention is given to the important operation of weeding. The main weed control method in rice has until recently been manual weeding combined with water management. Labour shortage is an increasing problem in several states. Because of this the herbicide control methods gradually become the choice for the effective weed control. The major problem faced by the semi-dry rice crop is the
occurrence of weeds, which leads to a crop loss ranging from 78 to 91 per cent (Ali and Sankaran, 1984; Ravichandran, 1993). Nojima (1966) found that in direct seeding, the germination of rice seeds and the emergence of weeds take place almost at the same time and therefore weed control at the early stages of the crop growth is important. During early establishment, weeds make 20-30 per cent of their growth while the crop makes 2-3 per cent of its growth (Moody, 1990).

2.6.1. Weed Flora and Biology

Information on the weed flora of direct seeded rice describing the ecology and habitat of weeds is very much needed for planning effective weed control measures. Even though the weed flora is similar in transplanted and wet seeded rice, the weed flora has a bearing on the efficacy of the control measures adopted. (Janiya and Moody, 1989). *Echinochloa* weed species are a major constraint to rice production worldwide. Smith (1983) reported the 10 most important weed species in rice as *Echinochloa crus-galli*, *Echinochloa colonom*, *Cyperus difformis*, *Cyperus rotundus*, *Cyperus iria*, *Eleusine indica*, *Fimhrisiylis littoralis*, *Ischaemum rugosum*, *Monochoria vaginalis* and *Sphenoclea zeylonica*. These weeds are widely associated with rice and the damage they cause to the crop is permanent. Large numbers of weed species were observed in rice, because rice is grown in wide range of climatic and edaphic conditions. The frequency and abundance of these species vary according to geographical locations and growth conditions.

Kanadasamy and Palaniappan (1990) recorded that dominant species in direct seeded rice cultivation were from Ongraceae, Marsileacea and Asteraceae families. Verma and Kanke (1987) found that grassy weeds constituted more than 75 per cent of weed flora with *Echinochloa crus-galli* (57 per cent). But Tomar (1991) observed a proportion of 70 per cent grasses. Ramakrishan *et al.* (1992) noticed more than 45 weed species in wet seeded rice in Tamilnadu. Huh and Lim (1996) reported that *Lindernia procumbens*, *Cyperus difformis*, *Cardamine flexuosa* and *Cyperus serotinus* were the major weed species in direct seeded rice. The major weeds associated with dry-seeded rice in National Research Centre for Weed Science (NRCWS), Jabalpur during rainy seasons of 2006 and 2007 were: *Echinochloa colona* (31.5 per cent), *Phyllanthus* spp (26.5 per cent), *Commelina communis* (17.8 per cent), *Cyperus iria* (9.9 per cent), *Alternanthera sessilis* (5.9 per cent), *Dinebra retroflexa*
(5.1 per cent), *Physalis minima* (1.8 per cent) and *Caesalia axillaris* (1.2 per cent) which was reported by Mishra and Singh (2008).

In direct seeded rice under puddled conditions the predominant weeds were *Echinochloa crusgalli* in grasses, *Cyperus difformis* in sedges, *Ammania baccifera*, *Eclipta alba*, *Marsilea quadrifoliata* in broad leaf weeds (Ali and Sankaran, 1981). Singh *et al* (1998) reported that *Echinochloa crusgalli*, *E.colona*, *Cyperus iria*, *Ipomea sp.*, *Sphenoclea zeylonica*, *Ludwigia parviflora* and *Panicum repens* were the major weed flora found in wet seeded rice fields. The predominant weeds found in the experimental field at Faizabad during 1986-87 were, *Cynodon dactylon*, *Echinochloa colonum*, *Digitaria adscendens*, *Cyperus rotundus*, *Ammania baccifera*, *Corchorus oacutanglus*, *Eclipta alba*, *Phyllanthus niruri*, *Phyllanthus simplex* and *Lindernia* spp (Vaishya *et al*, 1992). Venkatraman *et al*, 2000 reported that in wet season in Aduthurai *Echinochloa colona*, *Cyperus difformis*, *Eclipta alba* and *Ludwigia parviflora* were the dominant weeds. Musthafa and Potty (2001) from their experimental trials at Trichur, Kerala observed the weed flora viz., *Dactyloctenium aegyptium* (L.) P. Beauv., *Echinochloa colonum* (L.) Link, *Eleusine indica* Gaertn., *Digitaria ciliaris* (Retz.) Koeler, *Panicum repens* L. and *Saccolepis interrupta* Stapf, sedges viz., *Cyperus rotundus* L. and broad-leaf weeds viz., *Melochia corchorifolia* L., *Cleome viscosea* L., *Celosia argentea* L., *Euphorbia hirla* L., *Abutilon indicum* G. Don., *Phyllanthus niruri* Auct. etc. In CRR1, Cuttack the major weed flora found during the crop growing season (2006) were *Echinochloa colona* (9.6 per cent), *Cyperus difformis* (21.9 per cent), *Fimbristylis miliacea* (19.2 per cent), *Sphenochlea zeylanica* (23.3 per cent), and *Ludwigia parviflora* (26.0 per cent) (Saha, 2005). In Punjab during 2000-05, the major weed species noticed in the rice field were *Echinochloa crusgalli*, *E.colonum*, *Cyperus iria*, *Fimbristylis tenera* and *Ammania baccifera* (Gill, 2008). It was also found that the weed count of all the five species were more under direct seeded rice than under transplanted rice.

### 2.6.2. Crop Weed Competition

Rice weed competition was minimum under transplanting and intermediate in direct sowing under puddled condition and higher in direct seeding under dry conditions (Singh and Sharma, 1984). The degree of rice weed competition depends upon rainfall, rice variety, crop duration, soil type, weed density, weed growth and crop age at which the weeds started to
compete for nutrient, space, light and CO₂ (De Datta, 1995). Weed competition is greatest in wet seeded rice than in transplanted rice due to similarities of age and morphological characteristics of grass weeds and rice seedlings (Castin and Moody, 1989; Moody, 1993; Hill et al, 1990; De Datta and Baltazar, 1996). The loss in grain yield of direct sown rice caused by unchecked weed growth ranged from 18.2 to 59.2 per cent in different years from 1991-94 (Sharma, 1997). Rice crop is likely to experience yield reduction unless it is kept weeds free during the critical period of its growth duration, the phenomenon otherwise referred to as the critical period of weed competition (Azmi and Baki, 2006).

2.6.3. Critical Period of Crop Weed Competition

In the crop growth period, there exists a critical period during which the crop is very sensitive to weed competition. The presence of weeds beyond a certain density at that time will cause significant yield reduction. The most critical period of competition between rice and weeds in rice is vegetative phase and yield components of the rice plants are being differentiated (Kim and Moody, 1989; Bayer, 1991). If weeding is delayed until the initiation of panicle primordia, the rice yield will be greatly reduced. In direct seeded rice, weed emergence is almost at the same time as the rice plants emerge and therefore, the competition is severe at early stages of rice crop (Balyan et al, 1986 and Reddy et al, 1994). Prusty et al (1990) reported best weed control (85%) from broadcast sown rice that was manually weeded at 25 and 40 days after crop emergence. Fischer et al. (1993) noticed that weeds emerging with crop were the most damaging ones and also they stated that rice yield increased with longer weed free upto 70 DAS. Weed competition was greater in wet seeded rice than in transplanted one due to the similarities in age and morphological characteristics of grass weed and rice seedlings (Moody, 1993). Weed free period of 30 days during the initial crop growth stage was found to be favourable to prevent yield losses caused by weeds (Broar et al, 1994). Most of the research findings showed that competition period from 15 to 45 DAS had the most impact on yield of wet seeded rice (Ampong - Nyarko and De Datta, 1991; Moody, 1993; Madhu and Nanjappa, 1995; Sathyamoorthy and Kandasamy, 1998). Radosevich et al (1997) also reported that weeds should be controlled during the critical period to prevent yield losses.
2.7. Weed Management Approaches

2.7.1. Manual Weeding

Many farmers do not realize that weed control is a limiting factor in crop production. Traditionally, they depend on manual labour to remove weeds. Manual hand weeding in rice should be done at early stage of crop, though it is difficult to distinguish between grassy weeds and rice seedlings. Two to three hand weeding are needed to prevent the yield losses. Vijayaraghavan et al. (1988) in irrigated direct seeded rice observed that farmer’s method of hand weeding at 20 and 40 DAS gave the highest grain yield. Subhas and Jitendra (2001) reported that hand weeding was the most effective in mitigating the weed dry matter accumulation, in rice field.

Pulling out weeds by hand is the reliable way to control weeds and in older times it was the only direct method of controlling weeds in rice (De Datta and Baltazar, 1996). Though hand weeding is very effective, it is laborious, time consuming and expensive due to high cost of labour particularly during peak period of labour requirement (Moody, 1993; Kandasamy and Raja, 1999). In an effort to reduce the hours spent on hand weeding, research has shown that, if done at the right time, the number of hand weeding that provide season-long weed control can be reduced to only one in transplanted rice, two in wet seeded rice and three in dry seeded lowland or upland rice (De Datta and Baltazar, 1996).

Under lowland conditions, it takes about 200-250 hrs ha\(^{-1}\) (25 - 31 man days ha\(^{-1}\)) to hand weed depending on the weed infestation (Parthasarathi and Negi, 1977). A single manual weeding given at 15 DAS required only 240 hrs of labour ha\(^{-1}\) (30 man days ha\(^{-1}\)) but when manual weeding was delayed until 45 DAS the labour requirement was 780 hrs ha\(^{-1}\). Manual weeding on 20 and 40 DAS reduced weed dry matter (150 kg ha\(^{-1}\)) as compared to weedy check (920 kg ha\(^{-1}\)) and also recorded the highest weed control efficiency of 77 per cent (Vaishya et al., 1992).

Weeding can only be done at a time when labour is available, but this may not coincide with the best time to do it to minimize weed competition. Small-scale farmers are particularly affected by the lack of labour for weeding which is to be effective, must take place early in the crop cycle (Anon, 1988). Removal of weeds at their critical period by traditional means may not be possible at peak period of labour demand. Hand weeding in wet-seeded rice is more time consuming and not as thorough as in transplanted rice (Moody,
1983). Due to labour scarcity and unsuitability of hand weeding in large scale farming, obviously the use of herbicides is probably the only attractive of feasible alternative for controlling weeds in direct seeded rice (Singh et al., 2006). By the time weeds are large enough to be removed by hand damage has been done and yield loss is certain and hand labour cannot undo it.

2.7.2. Chemical Weed Control

The success of direct-seeded rice is dependent upon weed control with herbicides (Day, 1974). Herbicide use should coincide with the presence of sufficient weeds to warrant treatment, and take place when weeds are most vulnerable. The optimum rate depends on such factors as cultural practices, soil type and environmental conditions. Factors which must be considered when developing a herbicide program are the herbicide itself, weed flora, application method and time, crop tolerance and cost effectiveness (Moody 1992). The use of herbicides assures effective weed control during periods of labor shortage when weeding coincides with other farm work. Herbicide-based weed management is becoming the most popular method of weed control in rice. In such situations herbicides are promising alternatives in controlling weed (Rao and Pilla, 1974; De Datta, 1980). Several workers reported the effective use of herbicides to control the weeds in direct seeded rice and to get the desirable grain yield. Some herbicides were reported to have not only controlled weeds, but also increased rice yield.

Ali et al. (1987) reported effective control of weeds when 1 kg ha\(^{-1}\) butachlor or thiobencarb were applied 18 DAS or in combination with 2 kg ha\(^{-1}\) propanil at 16DAS in lowland direct sown rice. Chandrakar et al. (1987) reported the superiority of 2.0 kg ha\(^{-1}\) of butachlor or 2.0 kg ha\(^{-1}\) of thiobencarb over 1.0 kg ha\(^{-1}\) either herbicides + hand weeding at 30 DAS, regarding grain yield.

Chon et al. (1994) applied Butachlor, pre-emergence at 3.6 kg ha\(^{-1}\) which inhibited shoot growth and development of baryardgrass (E.crusgalli) under dry conditions, while rice was unaffected. Imeokpia and Okusanya (1997) reported that dimethymetryn in mixture with either pretilachlor at 0.5 + 1.5 kg a.i.ha\(^{-1}\) or oxadiazon at 0.5 – 1.0 kg a.i. ha\(^{-1}\) combined effective weed control with high paddy rice yields similar to that of hoe-weeded control in the Nigeria Southern Guinea savanna. Islam et al. (2000) compared hand weeding with
different herbicides and found pretilachlor (500 g a.i. ha\(^{-1}\)) the most successful weedicide with higher yield and cost benefit ratio. Rana et al. (2000) revealed that application of pretilachlor 0.8 kg ha\(^{-1}\) at 7 DAS controlled weeds effectively and increased grain and straw yield significantly over weedy check and other herbicide treatments. Tamilselvan and Budhar (2001) reported highest number of productive tillers hill\(^{-1}\) was obtained with 0.3 kg anilophos ha\(^{-1}\), 0.40 kg pretilachlor ha\(^{-1}\) and 1.0 kg butanil ha\(^{-1}\) and the weed control treatments were equally effective in increasing grain yield.

Yield losses as high as 46 per cent caused by weeds have been reported and consequently, farmer adoption of herbicides has increased rapidly in the last decade together with the wider use of alternative crop establishment methods (Chin and Mortimer, 2000). The comparable yield of herbicides with hand weeding, offers an option for the use of herbicides as an alternative management tool in weed control (Baloch et al., 2005). Adiun et al. (2005) concluded from their field trials that their study confirmed earlier reports by Akobundu (1981) and Imoekporia (1989) about the possibility of controlling weeds in rice with herbicides without adverse effect on the crop.

It is widely accepted that rice herbicides perform differently with different weed species and responses vary with different agro-ecological situations due to soil and climate (Okafor, 1986). Hence the selection of herbicide should depend upon the timing of application, weed species present in the field and the crop safety of the selected herbicide at the applied window.

2.7.2.1. Bensulfuron methyl

Bensulfuron methyl is a systemic sulfonylurea herbicide for the pre and post emergence control of annual and perennial broadleaved and sedge weeds in rice. It was the first rice herbicide from sulfonylurea group launched as Londax by DuPont. Sulfonylurea herbicides are very effective inhibitors of plant cell division. They inhibit acetolactate synthase (ALS) – a key enzyme in the pathway of branched chain amino acids (leucine, isoleucine and valine) in plants (Ray, 1984).

Bernasor and De Datta (1986) reported that a granular formulation of bensulfuron-methyl applied 6 or 8 days after transplanting or sowing (2- to 4-leaf stage of the weed) effectively controlled \textit{S. maritimus} and the annuals \textit{E. glabrescens}, \textit{E. crus-galli} subsp.
*hispidula* and *Monochoria vaginalis*. A study was made of the ability of Londax [bensulfuron-methyl] to control *Ammannia baccifera, A. multiflora, Rotala indica, Lindernia anagallis var. verbeneifolia, L. pyxidaria, Sagittaria trifolia, S. pygmaea, Monochoria vaginalis, Cyperus diffîrmis, Scirpus juncoides, S. planiculmis and Echinochloa crus-galli,* the main paddy weeds in Taiwan. Londax provided good control of most weeds up to 20 days after sowing at both rates, but at 0.4 kg ha\(^{-1}\), it only inhibited growth of *E. crus-galli* and *S. planiculmis*. Most weed species were controlled up to 20 days after application (DAA). However, *E. crus-galli, S. trifolia, S. juncoides* and *S. planiculmis* could only be controlled up to 10 DAA, even at 0.5 kg ha\(^{-1}\) (Chiang and Leu, 1987). Bensulfuron methyl at 20-40 g ha\(^{-1}\) effectively controlled most prevalent annual and perennial broadleaved weeds and sedges (Peudpaichit et al., 1987). Londax (bensulfuron methyl) at 20-40 g ha\(^{-1}\) effectively controlled most prevalent annual and perennial broadleaved weeds and sedges (Peudpaichit et al., 1987).

Moody (1993) earlier indicated that the use of bensulthron-methyl, bentazon, butachlor, 2,4 – D, MCPA, pretilachlor and propanil among others, resulted in effective weed control and high rice paddy yield. Wang Yi Ming (1998) reported the excellent efficacy of Bensulfuron methyl against *Scirpus planiculmis*. Kawana and Kojima (1998) reported effective control of *Sphenoclea zeylonica* by 30 kg of 0.17 per cent bensulfuron methyl per ha. Saha (2005) reported that Bensulfuron methyl (60 g ha\(^{-1}\)) applied at 20 DAS was the most effective micro-herbicide in controlling weeds (weed control efficiency, WCE 95.2 per cent) and maximizing rice grain yield (5.82 t ha\(^{-1}\)).

Begum *et al.* (2008) observed bensulfuron methyl effectively controlling *Fimbristylis miliaceae* and increased grain yield by more than 80 per cent compared to unweeded treatment and were comparable to weed free treatment.

The mode of action of bensulfuron methyl offers complete safety to mammals and animals because their target site ALS inhibitors are found only in plants. Apart from these bensulfuron methyl gives greater crop safety to rice among sulfonyleurea herbicides. Bensulfuron methyl is safe to mammals, fish and insects, and may have potential for use biological control methods (Wood, 1990). Londax in combination with BAS 514 at upto four times the recommended rates did not show any phytotoxicity symptoms at four weeks after application (Chang, 1988).
2.7.2.2. Cyhalofop butyl

The new herbicide cyhalofop-butyl (as Clincher) showed promise against Echinochloa spp (Rappapini, 2002) however, cyhalofop-butyl will need to be used in a program approach for broadleaf weed control. Cyhalofop-butyl is an aryloxyphenoxypropionate (AOPP) herbicide for postemergence use in rice to control grasses, mainly *Echinochloa* spp. Similar to other AOPP and cyclohexanedione herbicides, the site of action of CB is acetyl-coenzyme A carboxylase (ACCase), an enzyme in fatty acid biosynthesis (Ruiz-Santaella *et al.*, 2006). This was launched as Clincher by Dow.

Grassy weeds like *E. crusgalli* complex and *L. chinensis* can be controlled by selective herbicides like cyhalofop-butyl (Azmi and Baki, 2006). Cyhalofop-butyl 100 per cent EC at 1 L ha\(^{-1}\) applied at 7–10 DAS gave excellent control efficacy. Cyhalofop-butyl (300 to 600 g a.i ha\(^{-1}\)) applied at the three- to four-leaf growth stage provided 62 to 85 per cent control of early watergrass. Cyhalofop- butyl at 0.25 lb ac\(^{-1}\) provided excellent control of broadleaf signalgrass (98 per cent) and barnyard grass (96 per cent) (Buehring *et al.*, 2000). Grain qualitative characteristics (total milling yield, grain vitreosity, grain length, and grain length to width ratio) were better with cyhalofop-butyl applied EPOST in drained plots compared with propanil or molinate (Dimitros *et al.*, 2000). They also reported that barnyardgrass control with cyhalofop-butyl at 0.15 and 0.2 kg ha\(^{-1}\) applied in flooded plots was similar to or better than the control obtained with molinate. Bhagat Singh *et al.* (2008) reported that cyhalofop-butyl @ 90 g a.i ha\(^{-1}\) gave 89 per cent control of *Echinochloa* spp. Saini *et al.* (2001) investigated the effects of cyhalofop-butyl and surfactant on rice and associated weeds found that cyhalofop-butyl @ 90 g a.i ha\(^{-1}\) + 0.3 per cent surfactant recorded highest grain yield by obtaining greatest number of effective rice tillers, panicle length and number of grains per panicle. Ruiz-Santaella *et al.* (2003) observed in their study that cyhalofop-butyl gave 90 per cent control of *Echinochloa phyllopogon* S biotype. Anuruddha *et al.* (2005) found that cyhalofop-butyl 100EC at 1 L ha\(^{-1}\) applied at 7-10 DAS gave excellent control efficacy (90 per cent) of *Leptochloa chinensis*.

2.7.3. Integrated Weed Management

Weed management is a serious problem in direct seeded rice posing a threat to its yield stability. Therefore, an integrated weed management involving chemical, manual and
mechanical methods to control complex weed flora in direct seeded rice is urgently required (Bhagat Singh et al., 2008). Integrated approach based on critical period for weed management in direct seeded rice involving indirect- and direct control measures should be adopted. Sympatric weed species emerging with rice crop plants have an adverse effect on crop yields (Azmi and Baki, 2006).

Combinations of different chemicals were reported for the control of wide spectrum of weeds. Bernasar and De Datta (1986) reported that Bensulfuron-methyl and propanil + 2,4-D adequately controlled S. maritimus and the annual weeds Echinochloa glabrescens, E. crus-galli ssp. hispidula, Cyperus difformis and Monochoria vaginalis increasing rice yield significantly. Londax at 20 g ha\(^{-1}\) + BAS514H at 250 g ha\(^{-1}\) consistently controlled E. crus-galli, Sphenoclea zeylanica, Marsilea crenata, Monochoria vaginalis, Cyperus difformis and Fimbristyliis miliacea when applied on 4-10 days after sowing. Residual control lasted 45 days. No crop injury to direct-sown rice was observed and subsequent planting did not reveal any adverse effects on following crops (Peudpaichit et al., 1987). Different commercially available herbicides containing acetochlor and bensulfuron-methyl (Nongjiale, Tiancaoguang and Daocaowei) were used at different concentrations on rice of an unnamed cultivar (Tong XianMing et al., 1999). A control treatment of Daoyifeng (a different formulation of acetochlor and bensulfuron-methyl) and an untreated control were also included. The greatest yields were obtained in plots treated with 375 g ha\(^{-1}\) of 25 per cent Nongjiale and 600 g ha\(^{-1}\) of 14 per cent Daocaowei, 16.4 and 18.9 per cent higher than the treatment with Daoyifeng.

Vijayaraghavan et al. (1988) in irrigated direct seeded rice observed butachlor at 1.0 kg ha\(^{-1}\) + one hand weeding at 40 DAS recorded grain yield on par with twice hand weeding and least weed dry matter at 40DAS which was 78 per cent better than that of the control. Singh and Govindra (2001) reported that butachlor + one hand weeding recorded the highest return per rupee investment (1:1.57) and was at par with two hand weedicings and weed free treatments. Recent research into herbicide resistance management in rice in New South Wales, Australia, was reported (Taylor, 1998) which had sequential application of different herbicides. It included the following: optimal combinations with Taipan (benzoofenap) for full-spectrum weed control; comparison of a low rate sequential programme (2 litres ha\(^{-1}\) molinate followed by 2 litres Saturn [thiobencarb] + 20 g ha\(^{-1}\) Londax [bensulfuron-methyl],
followed by MCPA sodium) against the commercial standard (Saturn + Londax at 80 g) for water plantain (*Alisma plantago-aquatica*) control.

Brommer *et al.* (2000) reported the use of mixture of herbicides to control multiple weed problems. Investigations on the effects of different application dosage of Machete (butachlor) and Londax (bensulfuron methyl) mixture to control weeds in paddy fields showed that applied common could effectively control weeds to the effects exceeded 80 per cent (Xiao *et al.*, 2003). Mishra and Singh (2008) reported the lowest weed population recorded with pre-emergence application of pendimethalin / fb HW at 30 DAS. Integration of pretilachlor with HW and sequential application of pretilachlor / fb 2,4-D and fenaxaprop were equally effective in reducing the total weed density.

Cyhalofop-butyl, a known graminicide used for grass weed control as postemergence in rice. But it is antagonized by some rice herbicides when applied simultaneously. The result of this type of antagonism usually results in decreased control of grass weeds (Ottis *et al*., 2005). But this chemical shall be used effectively to control grass weeds in a sequential application with other chemical for controlling broadleaved weeds and sedges in direct seeded rice.

### 2.8. Effect on growth and yield components of rice

Weed competition has significant influence on the growth and yield characteristics of rice. Severe infestation of weeds suppressed the plant height (Senthong 1986, Begum *et al*., 2008), the number of panicles per unit area by 37 per cent and filled grains per panicle by 13 per cent (Ghobrial, 1981). Srinivasan and Palaniappan (1994) reported that dry matter of rice seedlings in unweeded plots were reduced to the tune of 66 per cent in hand weeded treatments. Azmi (1998) reported that the barnyard grass significantly reduced the number of tillers and number of panicles of rice. Zafar (1989) reported that pendimethalin and butachlor significantly enhanced tillering.

Weed competition reduced the number of panicles (Ghobrial, 1981; Moorthy, 1995) and panicle weight (Moorthy, 1995; Behera and Jena, 1997). Vaishya *et al.* (1992) reported that the weedy check recorded the least number of panicles m⁻² and grain weight panicle⁻¹; and it was 63 and 35 per cent reduction respectively over weed free check in upland direct seeded rice.
The lowest number of panicles m\(^{-2}\), filled grains panicle\(^{-1}\) and panicle weight was observed in the unweeded control plots (Bayan, 2000; Jeyasrinivas, 2003). Payman and Singh (2008) reported significant reduction in plant height, number of tillers m\(^{-2}\) at maturity and crop dry matter g m\(^{-2}\) in weedy check compared over the weed control treatments. They also reported that the weedy check caused significant loss of number of grains panicle\(^{-1}\) and reduction in panicle length.

2.9. Effect of grain yield

When weed control in rice is neglected, there is a decrease in yield because of weeds, even if other means of increasing production, including application of fertilizers, are practiced. Yield reduction due to weed competition is greater in direct-seeded than in transplanted rice. The yield loss due to weed competition ranged from 30 to 84 per cent was reported by Balyan et al. (1986). Ali and Sankaran (1984) observed 53 percent yield reduction during monsoon and summer season. Of all the constraints limiting the production of rice crop, weeds, appear to have the most deleterious effect causing between 75 and 100 per cent reduction in potential paddy rice yield (Akobundu, 1981; Imeakparice, 1989; Lavabre, 1991). Menakanit (1991) estimated the yield losses due to weeds at 37-79 per cent. Infestation of heterogeneous weed flora becomes the biggest biological constraint and yield losses even upto 90 per cent have been reported (Paradkar et al., 1997).

Azmi (1998) noticed that *E.crusgalli* reduced the yield by 41 per cent while lossed due to sedge and dicot weeds were at the rate of 10 and 28 per cent respectively. Yield reduction in upland paddy rice due to weed competition was as higher as 90 per cent (Ghosh and Sharma, 1997) and in conditions the yield reduction ranged from 10-70 per cent (Kumar and Gill, 1982). *E.crusgalli* population of 15 and 30 numbers m\(^{-2}\) reduced the grain yield by 30.4 per cent and 40 per cent respectively (Paradkar et al., 1998). Reddy and Gautam (1993) reported 50 per cent yield loss in direct seeded rice. Vaishya et al. (1992) observed 69 per cent loss of grain yield in weedy check compared to weed free check. Singh and Govindra (2001) found that the competition with all the weeds growing with the crop caused an 86.7 per cent reduction in grain yield. Awan et al. (2002) reported weed competition resulted in reduction of tillers m\(^{-2}\), panicles m\(^{-2}\) and 1000 grain weight which resulted in 50 per cent loss of grain yield in weedy check over Rifit @ 1 L ha\(^{-1}\). Begum et al. (2003) reported 33 and 35
per cent grain and straw yield respectively in control plots compared over herbicide treatments.

Bhat et al. (2008) reported 56 and 41 per cent reduction of grain and straw yield respectively in weedy check compared with weed free check in direct wet seeded rice. All the weed control treatments brought out a significant effect on yield attributes of direct wet seeded rice as compared to weedy check and most superior yield attributes were recorded in weed free plots. Payman and Singh (2008) observed 71 per cent grain yield loss in weedy check compared over two hand weeding at 30 and 45 DAS; the straw yield reduction was 61 per cent in control plot. Mishra and Singh (2008) reported 60 per cent grain yield loss in weedy check when compared to hand weeding twice at 20 and 45 DAS. Begum et al. (2008) observed 49 per cent grain yield loss in weedy check compared to weed free check whereas it was 42 per cent loss of straw yield in weedy check.

Vaishya et al. (1992) reported that the yields comparable to the yield of weed free treatment were recorded due to application of pre-emergent herbicides supplemented with two hand weedings.

2.10. Effect on economics

The choice of alternative weed control methods can be based on the relative cost of labour verses herbicides. The daily wage rate in a given area and time taken for one hand weeding determine the cost per hectare and this could be compared to the cost of herbicides to determine the economical choice (Sankaran and De Datta, 1985). Ruthenberg (1977) stated that the marginal Benefit Cost Ratio (BCR) should be at least 2:1 before adopting an innovation. Sankaran et al. (1990) reported that integrated weed control with chemical and manual weeding registered higher BCR ratio in comparison with chemical methods alone. Selection of weed control measures based on the weed flora in dry seeded rice would enable farmers to control weeds with lower cost (Riaz Mann et al., 2007). The highest net benefits observed in the plots treated with weedicide were reported by Hussain et al. (2008). Thus chemical weed control is clearly a profitable production technique in wet seeded rice.

2.11. Effect of herbicides on succeeding crops

Herbicides persistent in soil may injure succeeding residual crops. Most of the herbicides are absorbed through plant roots and underground absorptive sites besides they
undergo number of degradation processes. At the recommended dose of herbicide application
the problem may not arise and they selectively kill the weeds. Several substituted ureas,
sulphonylureas, dichlobencil and 2,3,6-TBA often pose Phytotoxic residues problem on crop
land (Sondhia, 2008). From example, injury to pea from Sulfsulfuron is noted in field
treated with Sulfsulfuron in the previous year (Sondhia and Singhai, 2007). Hence, before
recommending any herbicides its safety to the residual crops has to be studied along with its
bio-efficacy. Balasubramanian et al. (1999) reported that pre-emergence herbicides such as
thiobencarb, butachlor, pretilachlor and anilofos applied at recommended doses continuously
for four seasons in rice crop did not influence the germination and yield of urdbean grown
subsequently.