CHAPTER V

DISCUSSION

Field experiments were conducted during rabi 2005-06 and rabi 2006-07 to study the interaction effects of seed rate and weed management practices in direct seeded rice under wet condition at four locations viz., Tanjore and Kanchipuram of TamilNadu, and Trichur and Alleppy of Kerala. In direct seeded rice stand establishment and maintaining the crop density are important for getting desirable yield. Since the crop and weed seeds germinate almost at the same time, weed competition is very severe in direct seeded rice and the weeds compete severely during the establishment of crop at early stages. Crop density which shall be achieved by optimum seed rate plays a key role in weed management. In direct seeded rice, popular method of weed control is through herbicide based weed management practice. By maintaining optimum crop density with suitable seed rate, the herbicide activity shall be complementary for the weed management practice.

In the present study combined approach of optimum seed rate and integrated weed management practices were employed to achieve the maximum weed control efficiency in direct seeded rice under puddled condition so as to increase the grain yield.

5.1. Season and crop (Fig.1, 2)

In general, the climatic factors which prevailed during the cropping period were favourable to the direct seeded rice in first year than in second year with relevant to the total rainfall received and the number of rainy days. The higher grain yield was recorded in second year at Tanjore and Kanchipuram. At both the locations there were two rainy days during flowering to harvest. The mean sunshine hour’s day$^{-1}$ was comparatively more in second year than in first year which favored better photosynthetic efficiency resulted in higher grain yield. At Trichur and Alleppy the higher grain yield was recorded in first year than in second year. At these two places there was no shortage of water since dewatering is the critical task which was handled on community basis called padam. The rainfall received during flowering to harvest in first year in two rainy days might have played a combined effect along with sunshine hours day$^{-1}$ and the slight reduction in minimum temperature. The positive effect of slight reduction in minimum temperature has been reported by Samui (1999).
Fig 1. Weather prevailed during cropping period at Tanjore and Kanchipuram
Fig 2. Weather prevailed during cropping period at Trichur and Alleppy.
5.2. Studies on weed and weed flora (Fig.3)

The experimental fields at different locations were infested with composite weed flora comprising of grasses, sedges and broadleaved weeds. The mixed weed flora and their absolute presence in numbers showed that the trial plots had very good weed competition necessitating to investigate the present objective. The major graminaceous weeds were *Echinochloa colonum*, *E. crusgalli* and *E. stagnina*, common cyperaceae were *Cyperus difformis* and *Fimbristylis miliacea* and five families of which *Bergia capensis* (Elatinaceae), *Monochoria vaginalis* (Pontederiaceae), *Sphaeranthus indicus* (Compositae), *Ludwigia parviflora* (Onagraceae) and *Lindernia procumbens* (Scrophulariaceae) were predominant in all the four locations. Similar spectrum of dominant weeds in direct seeded puddle rice was reported by many workers (Malik and Moorthy, 1996; Singh *et al.*, 1998).

Study on the relative density of weeds in two years at different locations revealed dominance of broad leaved weeds at Kanchipuram and Alleppy in first year and at Tanjore and Alleppy in second year. The dominance of monocots was observed at Tanjore in the first year, at Kanchipuram in second year and at Trichur in both the years. *Echinochloa sp* present at all the locations and it was *Echinochloa colonum* at Tanjore, *Echinochloa crusgalli* at Kanchipuram and Alleppy, and *Echinochloa stagnina* at Trichur. The common sedge present across the trial locations was *Cyperus difformis* indicating its dominance and distribution in puddled paddy fields. At Trichur *Fimbristylis miliacea* was also observed along with *C. difformis*. Among the broad leaved weeds *B. capensis*, *M. vaginalis* and *L.parviflora* were distributed equally in TamilNadu and Kerala trial locations. *Sphaeranthus indicus* was common in TamilNadu and was found at Tanjore and *Lindernia procumbens* which was common in Kerala found at Trichur trials.

Broad leaved weeds dominated in all the trial locations except at Trichur in second year. Bharathi (1996) reported that broadleaved weeds were predominant in wet seeded rice grown in TamilNadu. The kind of weed species associated with different rice culture was strongly affected by biotic factor and cultural practices in a given environment (Moody, 1980).
Fig 3. Relative density of weeds present at the experimental plots.
5.3. Studies on weeds (Fig.4, 5)

5.3.1. Weed density

In general, the total weed density (grasses, broadleaved and sedge weed) increased from 30 DAS upto 60 DAS. This showed the continuous dominance and growth of weeds at early stage of the crop. This was observed across all the locations in both the years. Chinnamuthu (1990) and Umapathi (1998) also opined that irrespective of the season, the weed population increased upto the critical period of crop growth.

The different seed rates used influenced the competition of the weeds at different stages of the crop. At early stage on 30 DAS the grass and broadleaved weeds density were suppressed by higher seed rate of 120 kg ha\(^{-1}\) (M3) and thereby resulted in lower total weed population. But the sedge weed density was not influenced by the seed rate at 30 DAS in first year. At 45 DAS the higher seed rate of 100 kg ha\(^{-1}\) (M3) and 100 kg ha\(^{-1}\) (M2) suppressed grass weed population. But the total weed density was highly influenced by 120 kg ha\(^{-1}\) seed rate (M3) which reduced them significantly. As the crop grew, at 60 DAS, the total weed reduction was enhanced by 120 kg ha\(^{-1}\) (M3) seed rate though 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) seed rate (M3) comparably reduced the grassy weeds. But to suppress the broadleaved weeds density at 60 DAS 120 kg ha\(^{-1}\) seed rate (M3) played significant role. Overall observations showed that at all the locations total weed population at 60 DAS the use of 120 kg ha\(^{-1}\) (M3) helped to lower the weed density significantly. This may be attributed to the early crop establishment by giving less space for the weed competition. Similar result was reported by Mussari et al., 2009.

Among the weed management practices the herbicides played specific role by controlling grasses alone by cyhalofop butyl, and broadleaved weeds and sedges by bensulfuron methyl. Since there is an antagonistic effect between cyhalofop butyl and sulphphonyl urea herbicides, the two herbicides did not allow for the tank-mix application. Bensulfuron methyl gave a little suppression of grasses at early stage but that was not sufficient enough to have complete control at the rate used in the present study (60 g a.i ha\(^{-1}\)). Hence sequential application of cyhalofop butyl \(fb\) bensulfuron methyl was necessary to get total control of all the weeds. Sangeetha et al. (2008) reported lower weed density of grasses in early post application of cyhalofop butyl on 15 DAS. From the two year studies across
Fig 4. Weed population (m$^2$) as affected by seed rate and weed management practices in direct seeded rice at Tanjore and Kanchipuram
Fig 5. Weed population (m²) as affected by seed rate and weed management practices in direct seeded rice at Trichur and Alleppy
four locations, it is evident that though cyhalofop butyl alone gave a good control of different species of *Echinochloa* the level of grass control was enhanced with the sequential application of cyhalofop butyl *fb* bensulfuron methyl. This may be attributed to the additional ability of bensulfuron methyl to suppress the grasses. Chiang and Leu (1987) reported control of *E. crus-galli* upto 10 DAA. Bernasor and De Datta (1986) observed the inhibition of *E. crus-galli* by application of bensulfuron methyl at 40 g a.i ha⁻¹. Hence among the weed management practices, cyhalofop butyl *fb* bensulfuron methyl (S5) and cyhalofop butyl *fb* bensulfuron methyl *fb* hand weeding (S8) were found to be superior in controlling the grassy weeds.

The weed management practices like bensulfuron methyl (S4), cyhalofop butyl *fb* bensulfuron methyl (S5), bensulfuron methyl *fb* hand weeding (S7) and cyhalofop butyl *fb* bensulfuron methyl *fb* hand weeding (S8) significantly reduced the broadleaved weeds population. These treatments were comparable with hand weeding twice at 25 and 45 DAS (S2). The broadleaved weeds were effectively controlled by the treatments bensulfuron methyl (S4) and cyhalofop butyl *fb* bensulfuron methyl (S5) themselves though the hand weeding in bensulfuron methyl *fb* hand weeding (S7) and cyhalofop butyl *fb* bensulfuron methyl *fb* hand weeding (S8) complemented further removal of the late emerging broadleaved weeds. But bensulfuron methyl alone gave very good residual control of all the broadleaved weeds till 60 DAS of observation. Since weed flora is becoming complex and diverse in direct seeded rice and no single herbicide molecule is able to control all weeds. Therefore, a broad spectrum herbicides or a combination of herbicides, tank-mixed or sequential application along with cultural practices is needed for effective control of grass, broad leaf and sedge weeds in direct seeded rice (Singh and Kumar, 2009). At Tanjore and Kanchipuram, where the disturbance of top soil at 45 DAS by hand weeding in bensulfuron methyl *fb* hand weeding (S7) and cyhalofop butyl *fb* bensulfuron methyl *fb* hand weeding (S8) resulted in second flush of *B. capensis*. After hand weeding at 45 DAS, the germination of this weed was noticed and this may be attributed to the surface soil disturbances and exposure of the new seeds at top soil. Similar to broadleaved weeds control, bensulfuron methyl gave good control of the sedges *C. difformis* and *F. miliacea* also in the experimental fields. This is evident from the efficiency of bensulfuron methyl (S4), cyhalofop butyl *fb* bensulfuron methyl (S5), bensulfuron methyl *fb* hand weeding (S7) and cyhalofop butyl *fb*
bensulfuron methyl fb hand weeding (S8). Hand weeding as one of the component in the treatments bensulfuron methyl fb hand weeding (S7) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) had residual control of sedges, except at Alleppy where similar to B.capensis at Tanjore the fresh germination of C.diffusis was observed after hand weeding.

Since the direct seeded rice is always dominated by mixed weed flora of grasses, sedges and broadleaved weeds any weed control method should advocate total weed control to overcome the weed competition during critical period. Among the weed management practices cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) exhibited good control of all the weeds comparable that with that of hand weeding twice at 25 and 45 DAS (S2). Integrated weed management including tank mixture or sequential application of herbicides substantiated with hand weeding become very essential for success of direct seeded rice (Yadhav et al., 2009). The total weed density was comparatively lesser in TamilNadu locations than at Kerala locations. This may be attributed to variations in climatic conditions which might have influenced the ecology of the environment. The weed control efficiency of cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) was significantly superior to cyhalofop butyl fb bensulfuron methyl (S5) at Kerala where continuous emergence of weeds were observed as was evident from hand weeding twice at 25 and 45 DAS (S2). At Kanchipuram, total weed control was achieved significantly by cyhalofop butyl fb bensulfuron methyl (S5). This indicated that the chemical weed control alone can give the desirable control of all the weeds.

At Tanjore the higher seed rate 120 kg ha\(^{-1}\) (M3) coupled with hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) registered lower total weed density at 60 DAS. This might be due to synergistic effect of higher plant population to enhance the weed competition in favour of crop and weed management program, targeting total weed control.
5.3.2. Dry weight of weeds

5.3.2.1. Dry weight of grasses

In general, the dry weight of grasses were influenced by the seed rates and the lowest dry weight of grasses was recorded at 100 kg ha\(^{-1}\) seed rate (M2) and 120 kg ha\(^{-1}\) (M3) was comparable during both the years of study at 45 and 60 DAS. This might be due to the optimum population of rice crop ensured by the seed rates which smothered the competition of grasses right from the early stage of the crop. More growth of grasses was observed at lower seed rates and thereby higher dry matter of grasses.

Among the weed management practices cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8), cyhalofop butyl \(fb\) bensulfuron methyl (S5) and cyhalofop butyl \(fb\) hand weeding (S6) significantly reduced the dry weight of grasses which might be attributed to the herbicidal action of cyhalofop butyl and complemented by suppression of grasses by bensulfuron methyl. Kumar et al. (2008) reported significantly lower dry weight of weeds in wet seeded rice using cyhalofop butyl \(90\) g a.i. ha\(^{-1}\). Cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) was consistent across all the locations at both 45 and 60 DAS because of the integration of hand weeding at 45 DAS which removed the fewer grasses left after the herbicidal activity. At 60 DAS, the effect of hand weeding was observed in cyhalofop butyl \(fb\) hand weeding (S6). Overall maximum dry weight of grasses observed at Trichur which might be attributed to the robust nature of \(E.\) stagnina when compared with other species found at remaining locations.

5.3.2.2. Dry weight of broadleaved weeds

The growth of broadleaved weeds were highly smothered at the higher seed rate 120 kg ha\(^{-1}\) (M3) which recorded lowest dry weight at 60 DAS in first year at all the locations. The significance of seed rate on reducing the broadleaved weeds was not consistent.

Among the weed management practices cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8), cyhalofop butyl \(fb\) bensulfuron methyl (S5), bensulfuron methyl (S4) and bensulfuron methyl \(fb\) hand weeding (S7) suppressed the broadleaved weeds growth and resulted lowest dry matter at 45 DAS. The effect of bensulfuron methyl on the control of broadleaved weeds was confirmed through these results. Further at 60 DAS, the effect of integration of hand weeding was evidenced through lowest dry matter of broadleaved weeds
recorded in hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8), bensulfuron methyl fb hand weeding (S7) and also at cyhalofop butyl fb hand weeding (S6). Though the new growth of *B. capensis* was observed after disturbance of top soil by hand weeding at Tanjore and Kanchipuram, it was not reflected in dry weight because of its reduced growth due to crop canopy smothering its growth at 60 DAS.

Significant interaction found at Trichur at 60 DAS revealed that combination of seed rate of 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3) with bensulfuron methyl fb hand weeding (S7) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) resulted in lower dry weight of broadleaved weeds. This might be attributed to the optimum crop stand and the control of broadleaved weeds by bensulfuron methyl integrated with one hand weeding. At Tanjore, the combination of hand weeding twice at 25 and 45 DAS (S2) irrespective of the three seed rates also recorded lowest dry weight of broadleaved weeds. This suggest that hand weeding effectively reduces the broadleaved weeds density thereby their dry weight also minimized.

### 5.3.2.3. Dry weight of sedges

The significant role of seed rates at 45 DAS, in minimizing the dry weight of sedges was observed at Tanjore in both the years and at Alleppy in first year showed the superiority of 120 kg ha\(^{-1}\) seed rate (M3). At 60 DAS, the superiority of the higher seed rate (120 kg ha\(^{-1}\)) was observed at Tanjore and Alleppy in both the years and at Trichur in second year. The crop stand and its early establishment due to the higher seed rate reduced the growth of sedges and their dry weight.

Among the weed management practices similar to broadleaved weeds, cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8), cyhalofop butyl fb bensulfuron methyl (S5), bensulfuron methyl (S4) and bensulfuron methyl fb hand weeding (S7) reduced the dry weight of broadleaved weeds at 45 DAS mainly due to the herbicidal activity of bensulfuron methyl. *C. difformis* and *F. miliaceae* observed in the trials were effectively controlled by bensulfuron methyl @ 60 g a.i. ha\(^{-1}\). At 60 DAS, the integration of hand weeding was visible at cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8), hand weeding twice at 25 and 45 DAS (S2), bensulfuron methyl fb hand weeding (S7) and also at cyhalofop butyl fb hand weeding (S6) where the lowest dry weight of sedges were recorded.
5.3.2.4. Dry weight of total weeds (Fig.6)

The influence of higher seed rates in reducing the dry weight of total weeds were evidenced from the trial results. At all the locations at 45 and 60 DAS, 80 kg ha\(^{-1}\) seed rate (M1) recorded high dry weight of total weeds. Thigh might be attributed to the good crop stand and its establishment ensured by the higher seed rates. Gill (2008) revealed that seed rate also influenced the weed dry matter effectively as the seed rate increased, the competition among crops increased which shows excellent smothering effect. Azoni and Mortimer, 1999 reported a seeding rate of 100 kg ha\(^{-1}\) significantly reduced sedges and broadleaved weed biomass at 60 DAS.

Among the weed management practices, at 45 DAS, cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) and cyhalofop butyl \(fb\) bensulfuron methyl (S5) played as significant role in reducing the dry weight of total weeds by the sequential application of cyhalofop butyl and bensulfuron methyl to control grasses, broadleaved weeds and sedges respectively. At 60DAS, the integration of hand weeding in lowering the dry weight of total weeds were evidenced in hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8), bensulfuron methyl \(fb\) hand weeding (S7) and also at cyhalofop butyl \(fb\) hand weeding (S6).

At 45 DAS, the combination of 120 kg ha\(^{-1}\) seed rate (M3) with cyhalofop butyl \(fb\) bensulfuron methyl (S5) and cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) at Tanjore in first year and at Alleppy in second year revealed the importance of optimum crop density and better weed management to reduce the total dry weight of weeds.

5.3.3. Weed control efficiency (Fig.7)

The smothering of weed growth by the higher seed rate 120 kg ha\(^{-1}\) (M3) resulted in high weed control efficiency. The competition for space, light and nutrient by weeds were reduced at higher seed rate and resulted in enhancing weed control efficiency.

The sequential application of cyhalofop butyl and bensulfuron methyl and the integration of hand weeding resulted in good control of all the weeds viz., grasses, and broadleaved and sedge weeds. This helped to increase the weed control efficiency and was apparent in hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8), cyhalofop butyl \(fb\) hand weeding (S6) and bensulfuron methyl
Fig 6. Total weeds dry weight at 60DAS affected by seed rate and weed management practices in direct seeded rice – Pooled mean

Fig 7. Weed control efficiency at 60 DAS as affected by seed rate and weed management practices in direct seeded rice at Tamilnadu (TN), Kerala (KL) and Pooled mean
hand weeding (S7) at 60 DAS. The control of grasses, broadleaved and sedge weeds ensured by cyhalofop butyl and bensulfuron methyl and the removal of the weeds through hand weeding at 60 DAS increased the weed control efficiency of cyhalofop butyl fb hand weeding (S6) and bensulfuron methyl fb hand weeding (S7). Singh et al. (2006) recorded maximum weed control efficacy of direct seeded rice either with sequential application of herbicides or with integrated weed control approach.

5.4. Studies on Crop

5.4.1. Plant height (Fig.8)

In general, the different seed rates used did not influence the plant height at all the stages of crop viz., seedling, tillering, flowering and maturity. However at tillering stage, significance of seed rate on plant height was observed at Alleppy, during both the years where the plant height was maximum at 120 kg ha\(^{-1}\) seed rate (M3). At flowering and maturity stage effect was comparable with 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) seed rate (M3) at Alleppy and Trichur. These may be attributed to lesser weeds at higher seed rates which might have reduced the competition for growth by the weeds. Payman and Singh (2008) reported that increasing seed rate from 40 to 60 kg ha\(^{-1}\) produced significantly higher emergence count and helped in suppressing the weed population at 30 and 60 DAS, resulting in taller plants. Similar kind of influence of seed rate was observed at Kanchipuram during maturity stage in both the years.

Among weed management practices cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) helped to reduce the weed competition at seedling and tillering stages, which increased the plant height across all the locations. Apart from these treatments cyhalofop butyl (S3) also reduced the weed competition at Tanjore alone in first year and at all locations in second year. This indicated that grasses compete with crop at early stage and suppress the plant height. The removal of weeds and thereby their competition in hand weeding twice at 25 and 45 DAS (S2) helped to produce taller plants. Also consistently maximum plant height was observed in cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) at all the locations during flowering and maturity which may be attributed due to integrated approach of sequential application of herbicides and supplemented with one hand weeding. Walia et al. (2009) reported
Fig 8. Effect of seed rate and weed management practices in direct seeded rice on plant height (cm)
significantly higher plant height recorded in sequential application of herbicides when compared with other weed control treatments. At the above stages of crop the next best treatment was use of pure chemical treatment of cyhalofop butyl fb bensulfuron methyl (S5). Plant height was shortest in untreated weedy check (S1) indicating that the plant height was severely affected by heavy infestation of weed. Begum et al., (2003) reported similar findings.

The combination of 120 kg ha\(^{-1}\) seed rate (M3) with cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) resulting in higher seedling height at Tanjore in first year might be attributed to the weed free situation created by the treatment combination. During tillering stage, the plant height was maximum when cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) was combined with 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) seed rate (M3), and cyhalofop butyl fb bensulfuron methyl (S5) combined with 120 kg ha\(^{-1}\) seed rate (M3) at Alleppy. The importance of seed rate combined with good weed management practice on plant height during flowering and maturity was revealed by the combination of hand weeding twice at 25 and 45 DAS (S2) with 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) seed rate (M3), and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) with 120 kg ha\(^{-1}\) seed rate (M3) at Alleppy.

5.4.2. Tillers production (Fig.9)

The tiller production at tillering and flowering stage was lesser at 80 kg ha\(^{-1}\) seed rate (M1) due to lesser plant density causing wide space between plants which encouraged higher weed growth. The higher seed rates of 100 kg ha\(^{-1}\) seed rate (M2) and 120 kg ha\(^{-1}\) seed rate (M3) increased the tiller production at tillering stage. The maximum tiller production recorded at flowering stage was mainly due to highest seed rate of 120 kg ha\(^{-1}\) (M3) though 100 kg ha\(^{-1}\) seed rate (M2) was also comparable at Kanchipuram and Trichur in second year. Walia et al. (2009) reported significantly more number of effective tillers with higher seed rates.

During tillering and flowering stage the maximum tiller production was recorded by weed management practices of hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8).
Fig 9. Influence of seed rate and weed management practices in direct seeded rice on tillering at flowering stage.
This might be attributed to good control of weeds either manually or by herbicides at early stage of the crop growth reducing the weed competition. Application of herbicides followed by hand weeding recorded significantly higher productive tillers with significantly lower weed count and weed dry weight at early stage (Sanjay et al., 2008). Tiller production was reduced significantly in untreated weedy check (S1) due to severe competition of weeds as reported by Srinivasan and Palaniappan (1994) and higher tiller mortality (Caton et al., 1997).

Combination of optimum seed rate coupled with good weed management practices helped in better crop stand and higher tiller production due to lesser weed competition. This was evident from higher tiller production in the combination of 100 kg ha\(^{-1}\) seed rate (M2) and 120 kg ha\(^{-1}\) seed rate (M3) with hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl \(fb\) bensulfuron methyl (S5) and cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) at Kanchipuram and Trichur at first and second year, respectively at tillering stage. The above combination produced more tillers at flowering stage at Alleppy in first year and Kanchipuram in second year.

5.4.3. Dry matter production

In general the higher seed rates of 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3) influenced favorably the dry matter production at seeding, tillering, flowering and maturity stages. The lower seed rate of 80 kg ha\(^{-1}\) (M1) recorded lowest dry matter production of rice at all the stages of the crop. Good crop stand causing lesser space for the weed growth in the optimum seed rates might have helped to overcome the competition for nutrient by the weeds and thereby increased the dry matter accumulation of the rice crop.

At seedling and tillering stages, the weed management practices of cyhalofop butyl \(fb\) bensulfuron methyl (S5) and cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) influenced the crop growth and recorded maximum dry matter production of rice. This might be attributed to lesser weed control by herbicides in the early stages and their extended duration. Combined use of herbicides followed by manual weeding resulted in more quantity of dry matter production of rice (Subramanaian et al., 2002).
Apart from these treatments hand weeding twice at 25 and 45 DAS (S2) also resulted in higher dry matter production at Tanjore in seeding stage and at Trichur in tillering stage. At later stage of the crop i.e., at flowering and maturity the dry matter production was maximum in hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl f.b. bensulfuron methyl (S5) and cyhalofop butyl f.b. bensulfuron methyl f.b. hand weeding (S8). It was evident from the results that the second hand weeding at 45 DAS in S2 enhanced the dry matter production of rice at flowering to maturity stage. The experimental results also revealed that at 20-45 DAS which is the critical weed competition period for direct seeded rice. The required lesser weed competition was achieved by manual hand weeding twice at 25 and 45 DAS (S2) or by chemical weed control methods (cyhalofop butyl f.b. bensulfuron methyl (S5) and cyhalofop butyl f.b. bensulfuron methyl f.b. hand weeding (S8)).

The significant interaction between seed rate and weed management practices at Tanjore in first year during seedling stage and at Alleppy in second year during maturity stage revealed that higher dry matter production of rice was achieved in with the combination of higher seed rates of 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3) with hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl f.b. bensulfuron methyl (S5) and cyhalofop butyl f.b. bensulfuron methyl f.b. hand weeding (S8). The synergism of lower space for weeds and better weed control methods resulted in increased dry matter accumulation by overcoming the weed competition with rice crop.

5.4.4. Crop growth rate

Significant influence of seed rate on CGR was observed only at flowering to maturity stage. Restricted weed growth and their competition at early stage might be one of the prime reasons for improved crop growth observed at flowering to maturity stage. The higher seed rate 120 kg ha\(^{-1}\) (M3) resulted in maximum CGR at flowering to maturity followed by 100 kg ha\(^{-1}\) (M2).

In general, among the weed management practices hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl f.b. bensulfuron methyl (S5) and cyhalofop butyl f.b. bensulfuron methyl f.b. hand weeding (S8) resulted in higher CGR at all the stages. This might be attributed to restricted weed competition due to better control of weeds by these
treatments and effective utilization of space and nutrient by the rice crop. Also, cyhalofop butyl fb hand weeding (S6) and bensulfuron methyl fb hand weeding (S7) contributed to higher CGR at flowering to maturity stage. Here in these treatments the hand weeding at 45 DAS helped to overcome the weed competition which might have enhanced the dry matter production. The CGR at untreated weedy check (S1) was lesser across the locations due to the effect of severe weed competition.

Interaction between seed rate and weed management practices at Tanjore in first year resulted in maximum CGR at flowering to maturity stage in the combinations of 100 kg ha$^{-1}$ seed rate (M2) with hand weeding twice at 25 and 45 DAS (S2) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8).

5.5. Yield parameters.
5.5.1. Panicles m$^{-2}$ (Fig.10)

In general, the seed rates of 100 kg ha$^{-1}$ (M2) and 120 kg ha$^{-1}$ (M3) resulted in higher panicles m$^{-2}$ across all the locations during both years of study. Both the seed rates were found to be effective in suppressing the weeds and helped in establishing good crop stand with maximum tillers and accumulation of dry matter of crop at different stages and thereby contributed to the maximum panicles m$^{-2}$.

Among the weed management practices, cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) recorded maximum panicles m$^{-2}$ in all the locations during both years. Cyhalofop butyl fb bensulfuron methyl (S5) and hand weeding twice at 25 and 45 DAS (S2) were also comparable with above treatments. This might be due to weed free condition that prevailed during critical period of crop growth and higher growth parameters of rice such as tiller number and dry matter production which increased the sink capacity of the crop. Similar findings were reported by Solaiappan and Veerabadran (1997) and Joseph (1998). Herbicide applications also helped in maintaining weed free condition and thereby gave more number of panicles m$^{-2}$ (Hayat et al., 2003 and Bhat et al., 2008).

The lowest number of panicles m$^{-2}$ was observed in the untreated weedy check (S1) during both the years. This was due to severe competition exerted by weeds for
Fig 10. Influence of seed rate and weed management practices in direct seeded rice on panicles m$^2$. 
space, light and nutrients throughout the crop growth period. Unweeded check recorded significantly less panicles m$^{-2}$ than other weed management practices as reported by Vaishya et al. (1992).

The combinations of 100 kg ha$^{-1}$ (M2) and 120 kg ha$^{-1}$ seed rate (M3) with weed management practices of hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) resulted in maximum panicles m$^{-2}$ at Kanchipuram and Trichur in both the years. These combinations provided better suppression of weeds due to good crop establishment there by converted the initial tiller production and dry matter accumulation of the crops to productive tillers bearing panicles. Similar findings were reported by Moorthy and Saha (2002) and Madhavi and Reddy (2002).

In the first year the combinations of hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) with 100 kg ha$^{-1}$ seed rate (M2) at Tanjore and with 120 kg ha$^{-1}$ seed rate (M3) at Alleppey recorded maximum panicles m$^{-2}$.

5.5.2. 1000 grain weight

Thousand grain weight was not significantly affected by the different seed rates used in the present study. This parameter is mainly governed by the genetic make up of the plant and not easily influenced by management factors like seed rates, except in cases of severe biotic and abiotic stresses.

Among the weed management practices the lowest 1000 grain weight recorded in untreated weedy check (S1) was significantly inferior to other weed management practices which were all comparable at all the locations except in Tanjore in first year Begum et al. (2003) reported lowest 1000 grain weight in untreated control. No significant influence of weed management practices was observed at Tanjore in both years of study.

During the second year of study, at Kanchipuram, Trichur and Alleppey the weed management practices of hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb
bensulfuron methyl (S5) and cyhalofop butyl \( fb \) bensulfuron methyl \( fb \) hand weeding (S8) resulted in higher 1000 grain weight than other weed management practices. The herbicide application to control weeds produced heavier grains than weedy check (Awan et al., 2001 and Hayat et al., 2003)

5.5.3. Panicle length

Significant influence of seed rate on the panicle length was observed only at Kanchipuram and Trichur in first year. Here the 100 kg ha\(^{-1}\) seed rate (M2) recorded maximum panicle length. But during second year no significant influence of seed rates on this parameter was observed.

The panicle length was maximum in hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl \( fb \) bensulfuron methyl (S5) and cyhalofop butyl \( fb \) bensulfuron methyl \( fb \) hand weeding (S8). These weed management treatments facilitated the crop free from stress caused by weed competition and there by helped in expression of the potential crop vigour. Apart from these, cyhalofop butyl (S3) and cyhalofop butyl \( fb \) hand weeding (S6) also provided grass weed free situation which resulted in lengthier panicles. Significant increase in panicles length in chemical weed control over untreated check was reported by Vivela et al. (2008) and Singh et al. (2008).

Combination 100 kg ha\(^{-1}\) seed rate (M2) and 120 kg ha\(^{-1}\) (M3) with hand weeding twice at 25 and 45 DAS (S2) and cyhalofop butyl \( fb \) bensulfuron methyl \( fb \) hand weeding (S8), and combination of 100 kg ha\(^{-1}\) (M2) and cyhalofop butyl \( fb \) bensulfuron methyl (S5) resulted in maximum panicle length at Trichur in first year.

5.6. Grain yield (Fig.11, 12)

The higher grain yield was achieved by 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) seed rate (M3). Both the seed rates resulted in optimum crop density which lessened the crop sensitivity to other environmental and agronomic factors including weed competition and herbicide use (Mussavi et al., 2009). The lower seed rate of 80 kg ha\(^{-1}\) (M1) resulted in significantly lesser grain yield due to higher competition of weeds resulting in poor growth and yield attributes. Walia et al. (2009) reported increasing seed rate resulted in significant increase grain yield and decrease in weed biomass.
Fig 11. Influence of seed rate and weed management practices in direct seeded rice on grain yield
Among the weed management practices hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) resulted in recording highest grain yield in all the locations except at Trichur. This maximum grain yield was possible because of the weed free or less weed competition provided by the above treatments. Begum et al. (2008) reported 80 per cent increase in grain yield under good weed management practices compared to untreated weedy check (SI). Similar findings were reported by Choubey et al. (1998) and Salim (2002). At Trichur, the weed management practices cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) and hand weeding twice at 25 and 45 DAS (S2) were superior to cyhalofop butyl fb bensulfuron methyl (S5) and exhibited higher grain yield. All these treatments gave good weed control by controlling all the grasses, broadleaved weeds and sedges equally. The only difference in cyhalofop butyl fb bensulfuron methyl (S5) was that there was no hand weeding at 45 DAS. This hand weeding might have helped in better aeration and stimulation of the roots for effective uptake of the available nutrients in the rice field. The integration of hand weeding in weed control approach and their ability to increase the grain yield was reported by Mishra and Singh (2008), Ranjit and Swanketnikom (2005). Application of cyhalofop butyl effectively controlled grasses and bensulfuron methyl controlled broadleaved weeds and sedges. The sequential application of these two herbicides in cyhalofop butyl fb bensulfuron methyl (85) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) reduced weed density and dry matter production of weeds thereby increased weed control efficiency up to 60 DAS. Such weed free environment by these efficient weed management practices significantly influenced the yield contributing characters such as production of effective tillers, panicle length and 1000 grain weight which contributed to the increased grain yield. This was similar to the findings reported by Begum et al. (2003). The untreated weedy check (SI) resulted in lower grain yield across all the locations. The reduction in grain yield in untreated weedy check (SI) over the best weed management practices were 47-48 per cent in Tanjore, 45-50 per cent in Kanchipuram, 52-55 per cent in Trichur and 51-60 per cent in Alleppy. Similar results were reported by Mishra and Singh (2008).

The yield potential of rice is determined by weed parameters and yield components. This was reflected in the present investigation. Whenever weed parameters such as total weed density, total weed dry matter were more there was significant negative influence on
Fig 12. Main effects and interaction effect of seed rate and weed management practices in direct seeded rice on grain yield (kg ha\textsuperscript{-1})
grain yield. On the other hand effective weed management practices enhanced the rice dry matter production and yield parameters such as panicles m\(^{-2}\), panicle length and 1000 grain weight which had the beneficial influence on grain yield. The results are in agreement with the findings of Gracy Mathew et al. (1991).

Apart from independent actions of seed rates and weed management practices the interaction with each other on weed growth as well as growth and yield of direct seeded rice was evidenced by the presence of interaction at Trichur and Alleppy in first year (rabi 2005-06) and Tanjore and Trichur in second year (rabi 2006-07). The seed rates of 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3) coupled with weed management practices of hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl \(fb\) bensulfuron methyl (S5) and cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) recorded higher grain yield. This was due to lesser weed population, weeds dry matter and increased weed control efficiency, which might have significantly influenced the crop dry matter production, yield parameters and grain yield. Similar findings were earlier reported by Bayan (2000). Effective weed control and improved grain yield with use of herbicides was reported by Saini and Angiras (2002) in direct seeded rice.

5.7. Straw yield

Among the seed rates 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3) had a pronounced effect on straw yield. Both had recorded comparable higher straw yield across all the locations in both the years. The good crop stand and early crop establishment with enhanced dry matter accumulation of rice from initial stage itself would have helped to achieve higher biomass yield.

Relatively weed free environments warranted by the weed management practices cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8), hand weeding twice at 25 and 45 DAS (S2) and cyhalofop butyl \(fb\) bensulfuron methyl (S5) resulted in higher DMP of the crop at different growth stages and net results of higher straw yield. The vigour and growth of weed were arrested at most competitive growth stages of crop which helped in better crop growth from the initial stage and upto the end of crop growth and has contributed for higher straw yield. The competition either by grasses or by broadleaved weeds and sedges at early stage of the crop impacted severely on crop biomass was evident from reduced straw yield by
cyhalofop butyl fb hand weeding (S6) and bensulfuron methyl fb hand weeding (S7). Severe competition exerted by weeds for space, nutrient and light throughout the crop in the untreated weedy check (S1) caused substantial reduction in straw yield, which ranged from 40-46 per cent at Tanjore, 48-51 per cent at Kanchipuram, 45-47 per cent at Trichur and 39-41 per cent at Alleppy over the best weed management practices. Similar finding was reported by Mukerjee and Singh (2004). The lowest straw yield was recorded in control plot might be due to heavy weed infestation and competition with crop plants and finally depressed effective tillers plant\(^{-1}\) and grain panicle\(^{-1}\) (Begum \textit{et al.}, 2003).

Interaction between seed rates 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3), and weed management practices hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl fb bensulfuron methyl (S5) and cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) resulted in higher straw yield at Tanjore and Alleppy in first and second year respectively.

5.8 Weed index

Weed index is a measure of yield loss caused by varying degree of weed competition compared to the relatively weed free situation. In this study, the maximum grain yield was recorded in cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) at Tanjore, Trichur and Alleppy. The yield loss was lesser due to weed free environment ensured by the integrated approach of chemical weed control and hand weeding. Similarly in hand weeding twice at 25 and 45 DAS (S2) at Kanchipuram the yield loss was lesser due to the weed free environment at critical weed competition period. The highest weed index was recorded in untreated weedy check (S1) which ranged from 45.96 to 60.08 per cent. This emphasis the need for the effective control of weeds to get higher grain yield in direct seeded rice. Many workers have reported yield losses of similar magnitude due to weed competition. Singh \textit{et al.} (2008) reported significantly lower weed indices were recorded in all weed control treatments over weedy check and gave higher grain yield than weedy check. Losses in growth and yield components of rice under increasing pressure of weed competition for space, light, nutrients etc., was reported by Angiras and Rana, 1998.
5.9. Economics

In general, among the different seed rates 100 kg ha\(^{-1}\) (M2) gave highest net return across all the locations. This was due to significant improvement in grain and straw yield which contributed to higher economic returns.

The details of economics worked out showed that in first year the weed management practice cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) recorded highest net return except at Kanchipuram. The next best return was obtained in cyhalofop butyl \(fb\) bensulfuron methyl (S5). In second year, at all the locations the highest net return was recorded in cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8). This was followed by hand weeding twice at 25 and 45 DAS (S2) at Tanjore and Kanchipuram, and cyhalofop butyl \(fb\) bensulfuron methyl (S5) at Trichur and Alleppy. The significant increase in grain yield was contributed to the higher B:C ratio in these treatments. The untreated weedy check (S1) recorded the least net return, which could be attributable, for severe yield losses. Highest B:C ratio was obtained with herbicide use to control weeds which significantly reduced the weed density and weed biomass during initial stages of rabi rice (Mishra et al., 2008)

The combinations of 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) (M3) with cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) and hand weeding twice at 25 and 45 DAS (S2) recorded highest net returns at Kanchipuram. However at Kanchipuram, hand weeding twice at 25 and 45 DAS (S2) combined with 100 kg ha\(^{-1}\) (M2) and 120 kg ha\(^{-1}\) seed rate (M3) obtained higher net returns. Whereas, at Trichur 120 kg ha\(^{-1}\) seed rate (M3) combined with cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) and hand weeding twice at 25 and 45 DAS (S2) recorded higher net return.

5.10. Test verification of effective treatments in large plots

The test verification trials conducted at 8 locations during rabi 2007-08 showed that all the three weed management practices viz., hand weeding twice at 25 and 45 DAS (S2), cyhalofop butyl \(fb\) bensulfuron methyl (S5) and cyhalofop butyl \(fb\) bensulfuron methyl \(fb\) hand weeding (S8) were comparable. From the mean data on studies and weeds and crop, it shall be construed that these three treatments established their consistency across all the
Plate 4: View of the test verification trial fields

A. Trichur

B. Alleppy

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locations. The weed management practices cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) and cyhalofop butyl fb bensulfuron methyl (S5) will be effectively utilized to control the weeds in direct seeded rice to maximize the yield by reducing the weed competition during critical weed competition period. By adopting these weed management practices 49-50 per cent increase in grain yield was recorded. It shall be construed that either cyhalofop butyl fb bensulfuron methyl fb hand weeding (S8) or cyhalofop butyl fb bensulfuron methyl (S5) shall be adopted to control the mixed weed flora of the direct seeded rice.

5.11. Bioassay study on residual green gram

The bioassay study on the residual green gram revealed that at the recommended use rate of 100 g a.i. ha$^{-1}$ of cyhalofop butyl and 60 g a.i. ha$^{-1}$ of bensulfuron methyl were safe to the succeeding green gram after the harvest of main crop. These two herbicides at their recommended use rates gave good control of the weeds and were also safe without any persistence to affect the succeeding fallow crops. Similar findings were reported by Balasubramanian et al. (1999)