

WEED CONTROL IN UPLAND RICE UNDER VARYING SOIL MOISTURE REGIMES SIMULATED THROUGH LINE SOURCE SYSTEM

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By

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Certificate

This is to certify that the thesis entitled "WEED CONTROL IN UPLAND RICE UNDER VARYING SOIL MOISTURE REGIMES SIMULATED THROUGH LINE SOURCE SYSTEM" submitted in part fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY IN AGRONOMY to the Tamil Nadu Agricultural University, Coimbatore is a record of *bona fide* research work carried out by Mr. V. B. BHANUMURTHY under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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In Fond Memory of my Mother

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ABSTRACT

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WEED CONTROL IN UPLAND RICE UNDER VARYING SOIL MOISTURE
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Field experiments were conducted during kharif, 1985, as well as summer and kharif, 1986 to evaluate the efficiency of different herbicides under varying soil moisture levels created through line source system and to study the growth and yield of upland rice.

Herbicides thiobencarb (1.5 kg/ha) and arrosolo, a preparatory mix of molinate and propanil (each 1.44 kg/ha), applied 8 DAS were compared with hand weeding and unweeded check during kharif, 1985. Pre-sowing 2,4-D (2.0 kg/ha) in the form of ethyl ester was tested during summer, 1986; in addition, thiobencarb, arrosolo and the combination of arrosolo and 2,4-D were super imposed following a hand weeding. During kharif, 1986, the combination treatment was dropped and the herbicides (pre-sowing 2,4-D at 1.5 kg/ha applied 8 DAS and thiobencarb and arrosolo applied 8 DAS) were

compared with hand weeded check. Line source system was adopted throughout the crop period after a common irrigation at sowing.

All the herbicides were effective on the major weed Echinochloa colona (L.) Link. Thiobencarb was effective when the soil moisture was above field capacity in the top 15 cm at spraying, and maintained for 2-3 days after spraying. Armosolo was more effective even when the soil moisture was at 50 per cent ASM. Pre-sowing 2,4-D controlled the major weed effectively upto the level of 75 per cent ASM, which could be created by applying 15 mm of water to a dry soil. Pre-sowing 2,4-D was not effective at reduced dose of 1.5 kg/ha. Studies with GLC showed that the degradation of 2,4-D EE followed the first order kinetics and residue degraded to below 0.22 ppm both in dry and moist soil, but the degradation was slow in dry soil. Weeds in dry soil or with lower moisture level failed to absorb the herbicide and were not controlled.

The weed weight was low at higher levels of moisture (more than the evaporation) added through high frequency irrigation, leading to anaerobic conditions on clay soil and reduced availability of soil N and K.

Upland rice required lower levels of moisture during early stages and responded to moisture from 60 DAS onwards.

The growth characters like plant height, tiller number, LAI and shoot weight; the yield attributes viz., number of productive tillers, panicle length, panicle weight, number of filled grains per panicle and 1000-grain weight; days to flowering, grain yield, straw yield, harvest index, AWUE and N-uptake by the crop were adversely affected due to moisture stress. The chlorophyll content, particularly chlorophyll-b increased due to stress at grand growth period while sterility percentage was very high due to stress at reproductive stage. Leaf elongation and panicle exertion rates were affected by moisture levels. The RWC of flag leaves decreased with age while, the canopy-air temperature differential was found to be a good indicator of plant water status.

The weed weight showed negative relationship with yield while, the expression gram day competition (GDC) appeared to predict the yield losses more precisely. The cost of chemical weeding was cheaper compared to hand weeding. The weed control treatments did not influence most of the growth and yield attributes. Thiobencarb caused tiller mortality during application and pre-sowing 2,4-D delayed the sprouting by 6 days. However, the crop recovered rapidly in both the cases. Arrosolo and 2,4-D combination caused antagonistic effects. The best weed control treatments

resulted in higher yields with adequate moisture. When the moisture regimes were low, the yield levels dropped and weed control became insignificant. The water requirement was above 670 mm during favourable situations while, it was high, around 1400 mm during summer and around 1200 mm due to improper weed control as a result of shift in weed flora from annual grass E. colona to perennial sedge C. rotundus.

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INTRODUCTION

INTRODUCTION

In Asia, rice, the staple food, is predominantly cultivated under low land conditions, flooding the field for most of the growth period; yet 11 million hectares are grown under upland conditions. This together with the 2 million hectares in Africa and 6 million hectares in Latin America adds upto 19 million hectares representing one eighth of the total rice area of the globe. In India, where rice is the principal food crop, one third of rice area is grown under upland conditions (Maurya and Vaish, 1984).

Upland rice yields are low, they account for only 5 per cent of world production. Even so, upland rice is important because upland rice growers are mostly subsistence farmers, among the poorest of the poor, and for them with few alternate sources of food, rice constitutes a significant part of their diet.

In the last 15 years, low land rice yields have improved substantially while those of upland rice have remained stagnant. Upland rice has more diverse production problems although not necessarily more difficult ones.

Upland rice is defined as "rice grown in rainfed, naturally well-drained soils, without surface water accumulation, normally without phreatic water supply and normally not banded" (IRRI, 1984).

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The rice plant which is physiologically, morphologically and anatomically adapted to water logged, anaerobic soils, must adjust itself to a diametrically opposite environment - dry, aerobic soils under upland conditions, which is not easy. In low land rice, the standing water benefits rice by eliminating water stress, by controlling weeds, by regulating the micro-climate and perhaps most important, by providing a favourable chemical and microbiological environment for the rice roots (Ponnampetuna, 1975). The situations in dryland rice are totally different and thus upland rice is characterized by retarded plant growth, nutritional disorders and low yield.

Availability of water is more uncertain for upland than for lowland rice because upland fields are not banded. Because, upland rice depends entirely on rain water, both the amount and distribution of rainfall are important. The daily rainfall is actually more critical than the monthly or annual rainfall. Moisture stress can damage or even kill plants in an area which receives as much as 200 mm of precipitation in one day and then receive no rainfall for the next 20 days. A precipitation of 100 mm per month, distributed evenly, is preferable to 200 mm per month, which all falls in 2 or 3 days. In rainfed rice cultivation, periodical drought is a common problem.

The important agrophysiological problems in upland rice culture include, uncertainty of seeding, poor germination, plant mortality, opulent weed growth, leaf death, tiller death or reduced tillering, delay in heading, suppression of panicle emergence, reduction in seed setting and test weight, difficulty in fertilizer application etc.

Weeds are a major problem to upland rice farmers. Poor weed control is second only to inadequate water supply as a barrier to increasing upland rice production. Weed problems are far more complex and serious in dry seeded upland rice than in other rice production systems. A much wider range and intensity of weed problems in this culture may be because of differences in land preparation, the lack of water and the dry seeded crop emerges at the same time as the weeds. Weed growth is so heavy that if weeds are left uncontrolled, total yield loss may occur.

Several methods of weed control can be used in dry seeded rice. These include cultural, mechanical, manual, chemical and biological means. Hand weeding is the most common weeding practice in many upland rice areas. A single hand weeding requires 300-800 manhours/ha; often, several such hand weedings are necessary to keep upland rice fields free of weeds. Hand weeding may be effective, but using it as the only control method has drawbacks. Hand

weeding is slow and labour-intensive, expensive, impractical during bad weather and difficult to perform at the early vegetative stage when grassy weeds are indistinguishable from rice seedlings (Moody and Mukhopadhyay, 1982).

Interrow cultivation is also practiced as a weed control method in many areas, but its success depends greatly on climatic and edaphic conditions. It may not be feasible in heavy soil types after heavy rains and is even more difficult in broadcast seeded upland rice.

Disadvantages of hand weeding and other physical weed control methods may be minimized by using herbicides (De Datta and Ilagas, 1984). Chemical weed control in dry seeded rice is gaining importance or is being considered for use in areas where it has not previously been used. Moody (1982) suggests that a probable change in cropping system will be from transplanted to dry seeded rice, partly as an economy in labour but also as a means of greater productivity. And in such situations, chemical weed control becomes more essential.

The use of herbicides is dependent on various factors like type of weed, stage of weed growth, the most important soil factor being the soil moisture. The soil moisture status influences not only the weed emergence but also the

amount of herbicide in solution. The soil moisture content at and after herbicide application and the solubility of herbicides in water determine the efficiency of soil applied herbicides. Information on the performance of different weed control methods at different moisture levels in upland rice is limited. Hence, the present investigation was undertaken with the following objectives.

1. To know the efficiency of some promising herbicides under varying soil moisture levels.
2. To study the weed growth and changes in weed flora in relation to moisture regimes.
3. To study the growth and yield of rice under different moisture regimes and weed management practices.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Rice that is seeded under dry conditions and that depend on rainfall for moisture, has more complex problems, because it is grown under a wide range of management intensities. Weeds are a more serious problem because the crop emerges at the same time as the weeds (Moody, 1982). A brief review on the nature of weed spectrum, their competitive effects on rice, different methods of control, time and method of herbicide application, herbicidal efficiency in relation to water management is given in this chapter. Some of the effects of water management on performance of upland rice are also discussed.

2.1. Weed flora of upland rice: The most common weeds in the upland rice irrespective of edaphic differences are Echinochloa colona (L), Link, E. crus-galli (L.) Beauv, Cynodon dactylon (L) Pers, Eleusine indica (L) Gaertn., Ipomoea sp., Pimbristylis sp., Commelina benghalensis L., Phyllanthus niruri L. and Amaranthus sp., (Pande et al., 1967; Patro and Misra, 1969; Chattarjee et al., 1971; Misra and Roy, 1971; Mukhopadhyay et al., 1972; and Rath and Tiwari, 1979).

annual grasses and sedges ^{or} from 80 to 90 per cent of the total weeds while broad leaved weeds represent only

10 to 12 per cent (Misra and Roy, 1971). The relative importance of grasses in terms of population and biomass accumulation is greater than that of sedges and dicot weeds in the direct sown rice according to Mukhopadhyay et al. (1971) and Zaheruddeen and Prakasha Rao (1983). Grasses, sedges and broad leaved weeds represent 53, 35 and 12 per cent of the total population in upland rice, respectively, in Tamil Nadu (Anon., 1986).

Various weed surveys carried out in India (Misra and Roy, 1970; Chakraborty and Majumdar, 1973; Mahatim Singh et al. 1974; Sharma et al. 1977; Munroe et al. 1982 and Biswas and Thakur, 1983), show that E. colona is the most common and widely distributed weed in upland rice. More than 80 per cent of the total weed population is constituted by E. colona, according to Sahai et al. (1983) and Govindra Singh et al. (1986); and it is the predominant grass weed under Coimbatore conditions (Ali and Sankaran, 1984).

Cyperus iria (Pande et al., 1966 and Ali and Sankaran, 1984), C. rotundus and Fimbristylis littoralis (Venkatakrishnan et al., 1983) are the major sedge weeds of upland rice. Sankaran and De Datta (1985) listed out 25 most commonly mentioned weeds in the upland ^{areas} grass of different continents, wherein C. rotundus is reported to be the most noxious weed.

2.1.1. Factors influencing the weed flora: The type and number of weeds growing with preceding crops, weeding treatments; and soil moisture conditions before and after crop establishment determine the weed flora.

Tiwari and Neema (1967) report that E. colona, Eclipta prostrata (L.) Link, Commelina jacobii Fischer, Rumex dentatus L. and Ageratum conyzoides L. become predominant with decrease in soil moisture as against Ludwigia perennis L. and Ammania baccifera L. which dominate the flooded fields.

Soil type also influences the weed flora to certain extent. Dixit and Singh (1981) observed C. rotundus and Cynodon dactylon to be major weeds under sandy loam soil while Ali and Sankaran (1981) observed C. iria and Eclipta alba on clay loam soil. However in both the above situations, E. colona is the major grass weed.

Akobundu and Fagade (1978) observed the weed flora of upland rice not to vary between climatic zones, although Rottboellia exaltata L.f. may be the dominant weed in one area, while E. colona may predominate in another area of the same climatic zone.

2.2. Crop-weed competition: Weed competition largely governs the development of upland rice. Among the limiting factors,

inadequate weed control is perhaps next to poor water supply and is the most difficult constraint to increasing upland rice production (De Datta, 1972).

The rice crop and weeds use the same environmental factors for their growth needs. Competition begins as soon as a factor cannot support the normal growth needs of the crop and the weeds (Utomo, 1981). Weeds in upland rice can withstand drought better than rice because they have deeper roots and high root length density to tap moisture from deeper soil layers (Sankaran and De Datta, 1985).

2.2.1. Critical period of competition: Establishing the critical period of competition is essential to develop effective, economical weed control measures. Vega et al. (1967) find weed free condition between 20 and 40 days essential for direct sown crop of 120 days duration. Linear increase in yield is established by Panchal and Sastry (1974) with increasing the weed free period from 10 to 20 or 30 days after sowing. Maximum competition occurs according to Dubey et al. (1977) during the first three weeks and the loss gradually declines till nine weeks. First weeding at 2 to 3 weeks after germination and another at flower bud differentiation are preferred by Kawatei et al. (1966) if two weedings are to be given in upland rice. The first 15 days after rice seeding seem to be the maximum period during which weeds can be

tolerated without affecting the final crop yield (Ghosh et al., 1977; Sharma et al., 1977; Schiller and Indhaphun, 1979; Upadhyay and Choudhary, 1979; De Datta, 1980; Wells and Cabradilla, 1981; Sahai et al., 1983).

Shetty and Gill (1975) find two hand weedings, 22 and 55 DAS to be insufficient for maximum yields while Naidu and Bhan (1979) and Sahai et al. (1983) report that the crop requires weed free period for the first 45 days.

Competition begins during the first three weeks of the crop (Wells and Cabradilla, 1981). Weed growth increases exponentially during the first 60 days and the critical period of weed competition is between 2 and 7 weeks after sowing.

Early crop growth period i.e., upto 50 or 60 days after sowing seems to be the critical period for weed competition.

2.2.2. Nature and effect of competition: Weed competition to deplete soil moisture in upland rice is well established (Smith, 1970; De Datta and Beachell, 1972 and Okafor and De Datta, 1976a).

Severe weed infestation depletes 30 to 37 kg N/ha (Mukhopadhyay et al., 1971). Nitrogen content in weed species at the vegetative, flowering and post-flowering

stages is higher (Chakraborty, 1973) indicating severe competition for nitrogen throughout the upland rice growing season. A significant negative correlation between G. rotundus dry weight and rice grain yield as influenced by nitrogen application is established by De Datta, 1974. Rice crop could remove only 24 kg N/ha under unweeded conditions, according to Kakati and Mani (1977).

Purple nutsedge competition according to Okafor and De Datta (1976a) reduces the light transmission ratio. The tops of rice plants and weeds compete for light and the root zone competes for nitrogen and moisture (Utomo, 1981). In these competitions, rice plants develop less chlorophyll and contain less nitrogen, resulting in fewer panicles and spikelets per plant.

Severe weed infestation in upland rice depresses the height (Wells and Cabradilla, 1981), dry matter (Chakraborty, 1973; Sahai et al., 1983), tiller and panicle number (Okafor and De Datta, 1974; Sharma et al., 1977; Kolhe and Mitra, 1981), Leaf Area Index (Okafor and De Datta, 1974) and number of filled grains per panicle (Ali, 1978). Weed competition lowers the panicle number by 37 per cent, number of filled grains per panicle by 13 per cent and 1000 grain weight by 4 per cent (Ghobrial, 1981).

2.2.3. Yield losses due to weeds: The combination of annual weeds and C. rotundus reduces rice yield by 82 per cent (Okafor and De Datta, 1974). Such yield losses are reported to be 27 per cent (Siriwardana and Amarasingha, 1982), 69 per cent (Tosh, 1977), 40-85 per cent (Moody, 1982), 89 per cent (Markandeya Singh and Mahatim Singh, 1986) and even results in total crop loss (IRRI, 1967, 1968; Vega et al., 1967; Manna et al., 1971; Madrid et al., 1972; Mukhopadhyay et al., 1972). Season long weed free condition enhances rice grain yield 16-fold by comparison with unweeded control (Sahai et al., 1983). For every day that the crop is not weeded after the critical period of establishment, the yield is reduced by about 60 kg/ha (Anon., 1982a).

2.3. Methods of weed control: Weed control in dry seeded rice is practiced by cultural and mechanical methods and also by chemical means.

2.3.1. Cultural and mechanical control: Hand weeding is the most widely used weed control method for upland rice. For upland rice fields two manual weedings—one at 30 days and the other at 50 days after sowing are found adequate by Schiller and Indhaphun (1979) for good yields. Upadhyay and Choudhary (1979) find weeding 3 and 6 weeks after sowing upland rice to be ideal to produce maximum yield. Sharma et al. (1986) recommend three hand weedings successively

at 20, 35 and 50 days after sowing for effective weed control. Several workers in India and other countries have observed hand weeding to be efficient as compared to other weed control methods (Shetty and Gill, 1975; Ghosh et al., 1977; IRPI, 1980, 1981; Dixit and Singh, 1981).

Although hand weeding is effective, it is laborious and time consuming. A single hand weeding at 25 DAS requires 321 man hours/ha (De Datta, 1972). Ray (1973) estimated a single hand weeding need 300 to 700 man hours/ha. The cost of manual weeding is higher than other methods because of greater use of agricultural labour i.e., 44 man days/ha (Salik Ram and Parida, 1986). Several hand weedings are needed for successful upland rice production. Labour is expensive and sometimes scarce. By the time weeds are removed by hand, they have already competed for nutrients and moisture with the crop causing yield reduction.

Different inter row cultivators, hoe weeders and rototillers are used to control weeds in upland rice. Weed control by hoeing is an efficient method but it is laborious, costly, time consuming and unsuitable for large farms (Maharudrappa et al., 1974). Thakur (1968) noted hoeing to be not profitable under broadcast conditions. Not that hoeing is difficult in broadcast rice, it destroys only 40 per cent of the weeds whereas herbicides destroy

85 per cent of the weeds (Landav, 1960). However hand hoe, blade hoe and rice weeders are as effective as hand weeding and in addition they help conserve soil moisture (Singh et al., 1976). Rolling weeder for inter row cultivation is an acceptable substitute for labour intensive hand weeding (Singh et al., 1981).

It may be possible to reduce weeds in dry seeded rice by using the stale seed bed technique. Delay in sowing is, however, a disadvantage of use of this technique. The two weeks that can be gained by doing land preparation during the dry season are lost (Moody, 1982). Moreover, the earlier sowing is done after the start of the rains, the fewer are the weed problems.

2.3.2. Chemical weed control: Because of the high labour requirements for hand weeding; high wages, particularly during peak periods of farming operations; and unfavourable weather conditions at weeding times; herbicides for controlling weeds in dry-seeded rice are gaining importance in areas where they have not previously been used (Moody, 1982). Experiments at IRRI have shown the chemical weed control to be economical and effective (De Datta, 1972). Chemical weed control by pre-sowing, pre-emergence and post-emergence methods and their combinations is usually practiced and as such can be discussed under these sub heads.

2.3.2.1. Pre-sowing: Non-selective herbicides are mostly used before sowing of the rice crop. They help to create weed free conditions during crop establishment.

As early as in 1966, Appalanaidu et al., used 2,4-D sodium and ester forms for weed control. They applied very high doses of these herbicides and allowed one month time before planting. Misra and Roy (1970) found pre-sowing application of 2,4-D and MCPA at 1.12 to 2.24 kg/ha at single leaf stage of weeds to be effective in upland rice. Singh and Khan (1972) recommend the application of 2,4-D 1.0 kg/ha one week before sowing. Pre-sowing application of 2,4-D Na at 1.5 kg/ha seven days prior to sowing after final land preparation is effective in preventing the germination of weed seeds (Patro and Tosh, 1973). 2,4-D is effective when applied 10 days before sowing along with compost according to Pande et al. (1974). Allowance of sufficient time between 2,4-D application and rice sowing seems to be essential as phytotoxicity and reduced crop germination of rice is noticed when 2,4-D is applied pre-emergence (Pande et al., 1974; Tiwari et al., 1986 and Lokras et al., 1986). (N - α dimethyl benzyl) N'-P-totyl urea (K-223) for pre sowing application is recommended for control of C. rotundus by Okafor and De Datta (1976 b).

2.3.2.2. Pre-emergence: Chemical weed control through pre-emergence herbicides results in weed free conditions during critical periods of weed competition and is mostly practiced.

Herbicide butachlor is very extensively tested on upland rice. De Datta (1972) recommends the application of butachlor before the weed germination when rice is at 1 to 2 leaf stage. Butachlor at 2.0 kg/ha is recommended for pre-emergence weed control (Pillai and Rao, 1974; Gurmeh Singh and Chauhan, 1977; Pillai et al., 1977; Okafor, 1979; and Schiller and Indhapun, 1979) and at 3.6 kg/ha (Manda, 1977). Singh and Biswas (1981) and Singh and Singh (1986a) found butachlor suitable for upland rice.

Butachlor is recommended in combination with stale seed bed preparation (Castin and Moody, 1981) or hoeing and hand weeding (Singh and Chauhan, 1978; Rathi and Tiwari, 1979; and Lubigan et al., 1982) or hoeing or using weeders (Markandeya Singh and Mahatim Singh, 1986).

Butachlor when applied 4 days after sowing rice results in weed control efficiency of 83 to 89 per cent, but causes 87 to 88 per cent seedling mortality (Rao et al., 1976). Ahmed and Moody (1979) find crop injury with butachlor applied zero and 4 days after sowing but not when applied

3 days after emergence. Toah (1977) observed phytotoxicity on rice with butachlor applied 8 days after sowing. Arceo and Mercado (1981) observed drooping and yellowing of rice leaves and reduced plant height when butachlor is applied 10 days after sowing. The phytotoxicity is more pronounced when the soil moisture is at field capacity or saturation (Noriel and Mercado, 1981). Olofintoye and Mabbayard (1984) found stunting of rice seedlings whereas Pablo et al. (1982) did not notice any stand reduction in rice.

Thiobencarb has, as well been widely tested for use in dry seeded rice. Good weed control with 2.0 kg/ha of thiobencarb granules is established by Manna et al., (1971). They observed slight injury to the crop which recovered later. Thiobencarb applied at 1.5 kg/ha (IRRI, 1971) or 3.0 kg/ha (IRRI, 1979) at 3 or 6 days after sowing gives best control of grass weeds. Rao et al. (1976) obtained 69 to 78 per cent weed control efficiency with thiobencarb applied 4 days after sowing, but the seedling death ranged from 66 to 89 per cent. Pre-emergence application of thiobencarb results in good weed control when applied at 1.0 kg/ha (Singh and Singh, 1986b), at 1.5 kg/ha (Babu and Singh, 1985; Bisen and Tiwari, 1985 and Varshney, 1985); at 1.0 and 1.5 kg/ha followed by hand weeding (Bhan et al., 1984; Poonia et al., 1984 and Triwedi et al., 1986) and at 4.5 kg/ha (Richard and Street, 1984). Reduced weed weight even at the final stages

of crop growth with thiobencarb is found by Lokras et al. (1986). However Manigon et al. (1981) could not obtain adequate weed control even at higher dose of 4 kg/ha.

Pendimethalin at 1.0 to 2.0 kg/ha is effective under upland conditions (Mercado et al., 1974; Tosh, 1975 Singlachar et al., 1978 and IRRI, 1979 and 1983). At 0.75 kg/ha applied 8 days after sowing, Pendimethalin is an effective and economical weed control treatment (Ali, 1978). At IRRI (1983) 1.5 kg/ha is recommended.

Pendimethalin causes reduction in the crop stand when applied immediately after sowing (Pablico et al., 1982) or 4 days after sowing (Ahmed and Moody, 1979), but it is safe when applied 3 or 4 days after crop emergence.

Pendimethalin is recommended followed by one hand weeding (Munroe et al., 1982; Pande and Singh, 1982 and Govindra Singh et al., 1986).

Pre-emergence application of Molinate 3.0 kg/ha (Manna et al., 1971) or 3.84 kg/ha (Rameshchandrased et al., 1986) is found good for irrigated uplands. Smith (1971) reported the application of molinate at 3.0 kg/ha when weeds are at 1 to 6 leaf stage and when water remained for 7 to 12 days. Pre-sowing application at 6.0 kg/ha is found good by Dutta et al. (1977) while Moody (1984) recommends

the application either 7 days before sowing or 7 days after sowing.

Different other herbicides are also recommended for use in upland rice like Oxadiasozon (IRRI, 1974), Oxyfluorfen (IRRI, 1979; Gidnavar, 1981 and Ghosh and Singh, 1986) and Anilophos (Tosh and Misra, 1986).

2.3.2.3. Post-emergence: MCPA sodium or 2,4-D sodium at 1.12 to 2.25 kg/ha applied to 45 day old upland crop according to Misra and Roy (1971) gives partial control of Cyperus sp. but has little effect on grasses. Pande et al. (1974) established control of annual sedges alone with post emergence 2,4-D. However, it gives good control of dicot weeds (Tiwari et al., 1986).

Propanil is the most widely tested post-emergence herbicide in upland rice. Effectiveness of propanil in controlling weeds in upland rice is reported by Mukhopadhyay and Bhattacharyay (1968), Manna et al. (1971), Gurnel Singh and Chauhan (1977), Kaushik and Mani (1977), Mahatim Singh et al. (1979) and Tosh (1977). Propanil (3.0 kg/ha) at 21 and 50 days after emergence gives effective weed control equal to that of three hand weeding according to Chakraborty and Majumdar (1973). Kolhe and Mitra (1981) recommend 2.0 kg/ha of propanil at 20 days after sowing followed by

hand hoeing and weeding 20 days later. Dixit and Singh (1981) recommend 3.0 kg/ha followed by hand weeding. Propanil alone applied 15 days after sowing is equally effective to that of its combination with butachlor, thiobencarb, pendimethalin or molinate (Baker and Shreffler, 1982). However, some results show that plots treated with post-emergence propanil 3.0 kg/ha to be as weedy as untreated control 52 days after application in upland rice (IHRI, 1970). Propanil is a contact herbicide and a single application is unsatisfactory. However, sequential applications may be cost prohibitive (Tosh, 1977).

2.3.2.4. Herbicide combinations and mixtures: Results obtained with a single herbicide application have been variable. The use of herbicide combinations, whether the herbicides are applied simultaneously or sequentially generally results in improved weed control compared to single herbicide application (Moody, 1982).

Split application of propanil either 3 and 6 weeks after sowing rice (Mukhopadhyay, 1968) or 15 and 30 days after emergence (Tosh, 1977) is found effective in upland rice. Split application of thiobencarb 3 and 20 days after emergence (Anon., 1977a) is also effective.

Lubigan and Moody (1982) found that sequential application of pre-emergence butachlor, thiobencarb or pendimethalin followed by post-emergence 2,4-D is effective for weed control in upland rice. However, propanil is very widely tested for sequential application. Pre-sowing 2,4-D (Patro and Tosh, 1973), pre-sowing butachlor (Singh et al., 1977), pre-emergence nitrofen (Mukhopadhyay et al., 1971 and Sharma et al., 1986), pre-emergence butachlor (IRRI, 1983; Mahatim Singh and Srivastava, 1984) or pre-emergence thiobencarb (Smith, 1973; Singh et al., 1984 and Singh and Mami, 1986) followed by post-emergence propanil are found to provide sustained and broad-spectrum weed control. Pre-emergence butachlor or thiobencarb followed by post-emergence 2,4-D or propanil (Mukhopadhyay et al., 1971) and pre-emergence pendimethalin followed by 2,4-D (Munroe et al., 1982) are also reported to be effective. Application of 0.5 kg/ha 2,4-D 2 weeks after emergence followed by 1.0 kg/ha bentazon 4 weeks after emergence gives good control of Cyperus rotundus (IRRI, 1981).

Propanil mixed with butachlor, thiobencarb or pendimethalin (Shepard, 1981; Lubigan and Moody, 1982 and Navarez et al., 1982) for early post-emergence application gives excellent weed control. Mixture of propanil with oxadiazon or nitrofen (Smith, 1973), alachlor (Sharma et al., 1977) or thiobencarb (Ali, 1978) is also reported to give good weed control.

Excellent weed control in direct seeded rice at Sudan Gezira (Babiker, 1982) is reported through molinate-propanil combination. At IARI (1983), molinate-propanil applied 9 days after emergence gave good weed control upto 60 days after emergence. Ramachandraprasad et al. (1986) reported Arroscolo (molinate-propanil) to give comparable yields with that of hand weeding. Moderate weed control is recorded with the tank mixture of piperophos and 2,4-D (Biswas and Thakur, 1983b).

The superiority of herbicide combinations can be explained through the control of more species of weeds and the effective control lasts longer than with single herbicide treatments.

2.3.3. Rainfall distribution and weed emergence: In places where rainfall is the only source of water, moisture may have the greatest influence on weed seed germination and weed emergence. Growth of individual weed species is suppressed by soil moisture contents higher or lower than the optimum for a species. Within the range of optimum soil moisture content, competition regulates the weed population. Outside this range, soil moisture regulates the weed population (Walter, 1979). Competition for soil moisture may begin early, particularly in low rainfall areas (Sharma et al., 1977).

Garcia (1951) found that the seeds of Panicum grise-galli, Eclipta alba, Cyperus difformis, Cyperus pilosus, Cyperus iria and Fimbristylis annua do not sprout when the moisture content of the germinating medium is as low as, or lower than 30 per cent saturation. But when the moisture content is increased, there is a corresponding increase in the percentage of germination. The results show that C. difformis and F. annua fail to grow when the soil is near field capacity, while C. pilosus and E. alba do not resist standing water.

Continuous moisture is necessary to stimulate profuse germination of weeds. When the irrigation interval is extended to 6 to 12 days, germination though greater than unirrigated check is only about 1/3 that when the plots are irrigated at 3 day interval (Samiano and Motooka, 1975).

E. colona is not affected by the time of flooding or the moisture level and it can survive in both low land and upland rice fields, once it becomes established (Civico and Moody, 1979).

2.3.4. Soil moisture content and herbicide activity: Soil moisture status in upland rice influences not only weed emergence but also the amount of herbicide in soil solution.

The herbicides are dependent on soil moisture for activation (Moody, 1982). The soil moisture content at and

after herbicide application (Sahu, 1978) and the solubility of herbicides in water (Chen and Chen, 1979) determine the efficiency of soil applied herbicides.

Molinate controls E. crus-galli and Brachiaria platyphylla when water remains for 7 or 12 days in drill seeded rice field, but the weed control reduces when irrigation water is held for only 2 days (Smith, 1971).

Thiobencarb gives excellent herbicidal activity according to Jikihara and Kimura (1977) when rain occurs soon after application. Herbicidal activity decreases as rainfall is delayed following application and as soil moisture decreases.

The efficacy of butachlor applied pre-emergence is dependent on soil moisture conditions after application (Schiller and Indhaphun, 1979). When the herbicide is applied to a dry soil or dry conditions occur immediately after application or both, the effectiveness of the herbicide is markedly reduced.

Sahu (1975) established the rate of downward movement of butachlor to increase with an increase in soil moisture content, which ensures effective control of susceptible weed species to a greater soil depth. But the susceptibility

of the germinating crop seedlings to the herbicide increases (Sahu, 1978).

Severe phytotoxicity to rice is observed by Rao et al. (1976) in the case of denitrimine, piperophos + dimethametryn and butachlor, moderate toxicity with nitrofen and low toxicity with thibencarb when there is high soil moisture or when the field is flooded. Toxicity in general is low under low rainfall conditions.

The emergence of weeds like E. crus-galli is delayed when the soil remained moist during a 2 week unflooded period and no chemical treatment increased the weed control to a greater extent than the sequential application of propanil (Richard and Street, 1984). The authors also found reduced initial post-emergence activity during drought stress and ascribed the herbicidal differences to differences in solubility and leaching.

Soil moisture status determines the success of chemical weed control in upland rice (Sankaran and De Datta, 1984). The rice yields with pendimethalin and oxadiazon are similar to those of the hand weeded check at high moisture levels (811 and 691 mm). When moisture levels dropped below cumulative pan evaporation (688 mm), yields with chemical and hand weeding are similar to those in the unweeded check.

Below 525 mm, there is no grain yield although use of herbicides and hand weeding effectively controlled weeds.

Jamiya and Moody (1984) from a similar study using line source sprinkler system for creating moisture gradient observed weed control to be better with butachlor and pendimethalin at 15 days after emergence at higher moisture levels. At 30 days after emergence, the herbicidal effect of butachlor disappeared while pendimethalin controlled weeds at all moisture levels. Rice yield increased by hand weeding and pendimethalin application when the amount of water applied is above pan evaporation or the crop is able to extract water to meet the evaporative demand. At lower moisture levels, no yield increase due to weed control is obtained.

2.3.5. Economics of weed control in upland rice: Although hand weeding is effective, it is laborious and time consuming and sometimes uneconomical too. Sweep hoe has given excellent weed control and a high net return compared to conventional hand weeding (Singh et al., 1976). Although repeated weedings give effective control and increased grain yield, it results in a net loss in income compared with hoeing plus hand weeding at 3 and 6 weeks (Upadhyay and Choudhary, 1979). A pre-emergence spray of 2.0 kg/ha butachlor followed by one hand weeding (Singh and Chauhan, 1978) nets a higher

income than conventional hand weeding. Ghosh et al. (1977) reported higher net income inspite of chemical weed control (pre-emergence butachlor 2.5 kg/ha) being more expensive than mechanical weeding. Mandal (1977) observed butachlor 3.6 kg/ha to be more efficient and economical than traditional mechanical weeding. A post-emergence application of propanil (Raghavulu and Sree Ramamurthy, 1973); followed by either 2,4-D (Chakraborty and Majumdar, 1973) or one hoeing and weeding (Kolhe and Mitra, 1981) gives higher net returns than conventional hand weeding. A combination of 1.0 kg 2,4-D Na/ha and MCPA followed by one hoeing and weeding (IRRI, 1967; Misra and Roy, 1970; Singh and Khan, 1972) gives a higher net return than the weed-free check in upland rice.

Hand weeding is still the major form of weed control in upland rice. Considering the labour hours saved and the returns from herbicide use, herbicides may soon be adopted in many areas.

The versatile results as discussed could be due to the differential performance of the herbicides in upland rice; the most important factor determining the herbicidal efficacy being soil moisture. There is need to determine the initial soil moisture levels required for the herbicides to bring about effective weed control. The moisture requirement varies depending upon the type of the herbicide, its solubility,

half life etc. In view of the better weed control with herbicide mixtures, they should be evaluated in comparison with single application of residual herbicides. The information on soil moisture-herbicide relationship is very meagre and needs elucidation through research.

2.4. Upland rice and moisture: The major problems of upland rice production are inadequate water availability associated with irregular rainfall, weed competition, diseases and poor soil fertility (Greenland, 1985). The growth of upland rice, the effects of moisture on it, the plant-water relations, relationships of yield attributes and yield, are briefly reviewed below.

2.4.1. Rice growth on uplands: Plants under unflood culture make an initial vigorous start, but soon show poor tillering, depressed leaf growth, delayed flowering and foliar chlorosis (Senewiratne and Mikkelsen, 1961) and slow rate of stem elongation, stable leaf dimensions, predominantly long and thick crown and fairly deep roots (Majchoudhari and Gupta, 1981). Mambani and Lal (1983) reported higher ratio of leaf sheath to leaf blade and high energy status of water in the plant to associate with drought resistance. When rice could not be flooded, the flowering is delayed by a month associated with very high sterility resulting in lower yields (Chaudhry and Medlean, 1963). High levels of manganese found

in the plant affects the indole acetic acid oxidase mechanism and results in retarded growth and depressed grain yields (Senewiratne and Mikkelsen, 1961). Slow rice growth under upland condition is attributed to impaired iron nutrition by Ponnampetuma (1975).

Rice root proliferation is reduced under upland conditions (Yoshida, 1981). Rice root penetration and proliferation decreases sharply between 5 and 20 bars of soil strength (O'Toole, 1982). Drought tolerant varieties of rice can recover even after a prolonged drought for 36 days reaching soil moisture tension of 10 bars (Malabuyoc et al., 1985). Of the total root length density in the 75 cm profile, 70-80 per cent is found in the upper 30 cm layer and 60-70 per cent of the total water extraction occurs in this layer (IRRI, 1980). Forty five per cent of moisture is extracted from the top 15 cm soil according to Paul et al. (1974). However, from a comparison of water extraction pattern and rooting pattern, Jaggi and Bisen (1984) suggested that rooting density may not be the sole determinant of water uptake. Soil water factors (soil water potential and hydraulic conductivity) must also be considered. The root-shoot ratios are reported to be high in upland rice (Raychaudhuri and Gupta, 1981; O'Toole and Moya, 1981).

2.4.2. Effects of moisture stress: Higher leaf water potential of upland rice variety could not be explained by leaf diffusive resistance or leaf rolling (O'Toole and Cruz, 1980), though leaf rolling is a common indication of water deficit (O'Toole et al., 1979). Visual scores on the degree of leaf rolling and drought tolerance show that the water stress is more evident when water applied is less (IRRI, 1980) and the leaf water potential of upland rice is high (Aragon and De Datta, 1982). Osmotic adjustment aids in drought resistance of rice by delaying leaf rolling, thereby maintaining gas exchange and delaying leaf death (Hsiao et al., 1984). Nayak et al. (1982) observed relative water content of leaves to range from 88 to 95 per cent under saturated conditions compared to 80 to 86 per cent under moisture stress.

Dry matter production until panicle emergence is a function of water used (Puckridge and O'Toole, 1981). Moisture stress during pre-tillering and tillering stages do not reduce grain yield according to Nayak et al. (1974). The drought during entire vegetative phase of 60 days is less harmful than the soil drought during the 36 days of reproductive stage.

The most striking characteristics of the rice plant under moisture stress are reduced plant height, delayed

flowering and extremely high sterility (Yoshida, 1975). The reproductive stage in rice, about the last 55 to 60 days, is characterized by four phases when developmental processes are more sensitive—panicle initiation, meiotic development of gametes, anthesis, fertilization and grain filling (O'Toole and Chang, 1979). Water deficits during reproductive stage cause characteristic effects on the components of yield depending upon the reproductive phase affected. Stress at panicle initiation reduces the number of primordia (spikelets), at meiotic stage or anthesis increases sterility of florets, and at grain filling results in lower weight of individual grains.

The panicle exertion rate is high (4.5 to 5.5 cm/day) under well watered conditions, decreases to about 3 cm/day in the stressed plots and the incomplete panicle exertion accounts for 25-30 per cent spikelet sterility in the severely stressed plots (O'Toole and Nauco, 1983). The spikelet sterility is as high as 20, 30 and 60 per cent when stress occurs at early, maximum and late flowering stages respectively (IRRI, 1980). Water stress decreases yield per panicle by 32-40 per cent by affecting rate of grain filling but does not influence the duration of grain filling (Rahman and Yoshida, 1982). Crop stressed during the reproductive stage, shows characteristic sensitivity to water deficits in terms of decreased yield due partially to higher

panicle sterility and decreased grain weight (O'Toole and Moya, 1981). Ekanayake et al. (1985) observed significant relationship between the number of spikelets opened and the panicle water potentials. Spikelets in stressed panicles remain open for a longer period than in the well watered panicles. Unlike the rice leaves, panicles, have little plasticity to control the transpiration. The deleterious effects on spikelets opening and spikelet water loss contribute to the reduced spikelet fertility.

2.4.3. Consumptive use of water: The mean consumptive use of water by rice is 610 mm to 646 mm (Muntajabuddin and Borulkar, 1983), and the average water requirements are 960, 780, 570 and 360 mm under 1.8, 1.4, 1.0 and 0.6 IW/CPE ratios. The same authors in 1985 reported that the per day rate of evapotranspiration is influenced by growth stages. It is low in the initial stages and maximum (8.65 mm) during boot leaf stage. The ET declines after the 50 per cent flowering stage and lowest value (2.28 mm) is observed at maturity. Drought period is initiated when the ratio of actual evapotranspiration to the potential evapotranspiration (AE/PE) fall below optimum, which are 0.75, 1.0, 1.0 and 0.50 during seedling, vegetative, reproductive and maturity stages (Patel and Sastri, 1985).

2.5. Correlation studies: Grain yield has positive and significant correlation with total dry weight and leaf area index at flowering stage (Vinaya Rai et al., 1978). Satpathi and Nanda (1978) found correlation to be positive between yield and yield per plant and 1000 grain weight, but the association between yield and ear bearing tillers/plant to be not significant. Upland rice do not tend to produce more than 3-4 tillers/plant and as such, the authors stressed the importance of maintaining adequate plant population for realising reasonably good yield in dryland agriculture.

Cook and Evans (1983) reported positive correlation between rate of photosynthesis and specific leaf weight, and between leaf area ratio (leaf area relative to total plant dry weight) and relative growth rate. They also found positive relation of grain yield per panicle with spikelet number, photosynthetic rate of flagleaf expressed on a whole leaf basis and measured between 1 and 2 weeks after anthesis. Grain yield per plant is positively correlated with number of productive tillers, panicles and spikelets/plant; plant height and 1000 grain weight; and sterility percentage exhibits negative relationship with grain yield per plant (Sharma and Choubey, 1985).

The availability of moisture after land preparation or sowing will greatly influence such factors as crop performance, weed intensity, the weed flora, crop weed competition and herbicide performance. Information on the performance of different weed control methods at different moisture levels in upland rice is limited and hence the present investigation was undertaken.

Line source sprinkler system (Hanks et al., 1976) which would impose a wide range of controllable stress simultaneously, equivalent to testing under a wide range of environments, would be the appropriate tool for this purpose. Studies are made earlier using line source sprinkler system in upland rice for screening varieties with drought resistance (Puckridge and O'Toole, 1981), for nitrogen application (Aragon and De Datta, 1982) and also for recommending weed control practices (Janiya and Moody, 1984 and Sankaran and De Datta, 1984).

Hence, line source sprinkler system was chosen for this study.

MATERIALS AND METHODS

MATERIALS AND METHODS

Field experiments were conducted to investigate the performance of weed control practices across a wide range of moisture imposed through line-source sprinkler system. The studies were made during three crop seasons viz., kharif, 1985; summer, 1986 and kharif, 1986 at the Tamil Nadu Agricultural University, Coimbatore.

3.1. MATERIAL

3.1.1. Location: The experiments were carried out at O-block of wet land farm of Tamil Nadu Agricultural University, Coimbatore, located at 11°N latitude and 77°E longitude at an altitude of 427 m above mean sea level.

3.1.2. Soil properties: The soil is deep, clayey and categorised as vertisol. The details of the analytical data of the experimental site are furnished in Table 1. The field was irrigated by a deep bore well situated in the same block and the pH and EC of the irrigation water were 8.20 and 0.575 m mhos/cm, respectively.

3.1.3. Cropping history of the site: The field selected for experimentation was fallow during the preceding season.

3.1.4. Weather conditions: The weather condition prevailed during the cropping period is presented in tables 2, 3 and 4.

Table 1. Soil characteristics of the experimental field

A. Textural composition (Piper, 1950)

	Per cent on moisture free basis
Coarse sand	17.8
Fine sand	20.0
Silt	18.3
Clay	43.9

B. Chemical properties (Jackson, 1967)

i) Available nitrogen (Subbaiah and Asija, 1956)	275.4 kg/ha
ii) Available phosphorus (Olsen <u>et al.</u> , 1954)	21.6 kg/ha
iii) Available potassium (Stanford and English, 1949)	563.8 kg/ha
iv) pH	7.63
v) EC (mmhos/cm)	0.64
vi) Organic matter (Walkley and Black, 1934)	1.1 per cent

C. Physical characters

i) Bulk density (Dakshinamurthy and Gupta, 1968)	1.26 g/cm ³
ii) Field capacity (Dastane, 1972)	30.35 per cent
iii) Permanent wilting point (Richards, 1947)	14.72 per cent
iv) Maximum water holding capacity (Dakshinamurthy and Gupta, 1968)	47.6 per cent
v) Rate of infiltration (Dakshinamurthy and Gupta, 1968)	1.6 cm/h

TABLE 41 WEATHER DATA DURING KNARI 1957

Date and month	Stardard week	Mean solar radiation cal/cm ² /day	Mean sun shine hr/day	Mean Temp. °C		Mean R.H. %		Total rain-fall (mm)	Total rainy days	Pan Evapo-ration mm/day	Wind velo-city mph
				Max.	Min.	0722 hrs	1422 hrs				
9-15 Jul.	28	390	3.3	29.6	21.9	96	53	-	-	6.5	6.4
16-22 Jul.	29	403	2.6	29.4	21.2	95	57	5.0	1	4.9	6.2
23-29 Jul.	30	408	5.3	28.8	20.6	95	61	15.0	2	4.4	7.4
30-5 Aug.	31	418	4.8	28.9	21.7	82	57	2.0	-	7.0	15.4
6-12 Aug.	32	463	6.5	29.6	21.2	87	53	-	-	8.1	13.1
13-19 Aug.	33	477	4.2	28.9	22.4	82	54	-	-	8.5	18.2
20-26 Aug.	34	460	4.0	30.1	21.2	95	67	34.0	2	3.8	5.3
27-2 Sep.	35	517	6.8	30.6	21.2	93	62	14.2	1	5.4	6.4
3-9 Sep.	36	506	5.6	30.6	21.3	96	51	5.0	1	5.3	6.9
10-16 Sep.	37	442	8.0	29.9	21.4	88	54	-	-	6.8	11.8
17-23 Sep.	38	419	7.4	30.9	21.2	91	52	14.0	1	7.0	4.0
24-30 Sep.	39	458	5.8	30.5	21.8	95	61	79.9	6	3.7	1.5
1-7 Oct.	40	462	6.1	30.8	21.7	95	78	58.0	1	4.1	5.4
8-14 Oct.	41	496	8.4	30.8	21.1	95	52	-	-	6.3	4.2
15-21 Oct.	42	509	7.5	31.6	20.0	95	58	8.1	1	4.9	3.4
22-28 Oct.	43	435	8.4	30.7	20.6	87	50	18.0	1	4.9	2.6
29-4 Nov.	44	472	4.4	29.9	21.1	83	57	-	-	4.3	3.1
5-11 Nov.	45	322	1.3	28.3	21.5	96	85	115.2	5	1.0	2.3
12-18 Nov.	46	370	6.0	29.4	19.9	93	64	1.2	-	3.1	0.7

Date and month	Standard week	Mean solar radiation cal/cm ² /day	Mean Temp. °C		Mean Rel. %		Total rain-fall (mm)	Total rainy days	Pan evapo-ration mm/day	Wind velo-city mph
			Max.	Min.	0722 hr	1422 hr				
8-14 Jan.	2	374	28.5	18.8	85	56	-	-	3.7	3.3
15-21 Jan.	3	397	29.7	20.2	88	46	38.0	1	3.1	1.9
22-28 Jan.	4	464	29.8	18.4	86	40	-	-	3.1	1.9
29-4 Feb.	5	521	31.1	17.5	81	39	-	-	4.8	2.6
5-11 Feb.	6	464	31.0	16.5	78	34	-	-	5.5	3.9
12-18 Feb.	7	464	31.4	19.2	85	44	1.0	-	4.9	3.2
19-25 Feb.	8	506	31.2	20.3	83	43	2.2	-	5.5	3.2
26-4 Mar.	9	468	30.9	18.5	81	32	1.0	-	6.1	4.5
5-11 Mar.	10	518	32.6	17.6	80	43	-	-	6.4	5.5
12-18 Mar.	11	509	33.1	21.3	83	36	-	-	6.4	4.6
19-25 Mar.	12	494	34.1	21.1	79	26	-	-	7.5	3.7
26-1 Apr.	13	535	36.0	19.7	78	28	-	-	9.2	5.1
2-8 Apr.	14	534	35.7	21.8	79	29	-	-	7.9	3.7
9-15 Apr.	15	516	37.0	22.9	73	25	-	-	8.1	4.0
16-22 Apr.	16	537	37.3	22.2	79	31	-	-	7.9	4.6
23-29 Apr.	17	481	36.5	24.5	76	37	3.0	1	7.2	4.1
30-6 May	18	486	34.0	23.2	89	46	14.8	3	4.6	2.7
7-13 May	19	519	35.9	22.9	77	34	3.0	1	7.1	4.6
14-20 May	20	503	36.9	18.8	77	36	11.6	2	8.9	6.9
21-27 May	21	515	36.1	20.5	73	35	15.0	1	8.0	5.2
28-3 Jun.	22	475	33.5	21.9	79	46	3.0	1	5.2	3.4

Date and month	Stan- dard week	Mean solar radia- tion cal/cm ² /day	Mean sun- shine hr/day	Mean Temp. °C		Mean R.H. %		Total rain- fall (mm)	Total rainy days	Pan evapo- ration mm/day	Wind velo- city kmph
				Max.	Min.	0722 hr	1422 hr				
2-8 Jul.	27	418	7.8	32.4	22.9	82	42	-	-	6.7	11.8
9-15 Jul.	28	381	4.8	31.3	21.5	78	53	23.4	3	6.8	16.2
16-22 Jul.	29	356	6.0	30.8	24.4	61	43	-	-	10.9	25.7
23-29 Jul.	30	477	8.2	32.4	22.2	81	41	-	-	8.3	17.2
30-5 Aug.	31	598	4.1	31.4	22.2	83	53	3.5	1	5.9	10.1
6-12 Aug.	32	314	2.1	28.3	22.9	72	59	10.2	3	6.5	36.7
13-19 Aug.	33	354	8.6	31.7	21.2	85	45	-	-	7.9	18.1
20-26 Aug.	34	367	8.9	32.2	20.3	87	42	-	-	6.4	7.5
27-2 Sep.	35	459	9.2	32.8	21.4	86	41	1.0	-	7.3	8.5
3-9 Sep.	36	547	8.3	32.8	20.8	79	39	-	-	8.2	16.0
10-16 Sep.	37	438	5.8	32.1	21.0	89	50	23.0	2	5.2	8.3
17-23 Sep.	38	494	6.2	30.8	22.0	88	63	36.0	3	4.2	5.6
24-30 Sep.	39	504	6.5	31.6	22.3	90	57	64.4	2	6.3	6.0
1-7 Oct.	40	475	5.2	30.5	22.6	90	57	28.8	3	3.5	3.9
8-14 Oct.	41	384	6.5	31.8	22.8	88	50	19.4	1	3.3	3.7
15-21 Oct.	42	506	8.3	32.2	22.5	90	41	-	-	5.1	2.8
22-28 Oct.	43	467	6.3	31.4	21.4	86	49	34.2	3	4.4	4.0
29-4 Nov.	44	406	3.2	29.1	21.7	90	65	51.4	4	1.4	2.9
5-11 Nov.	45	387	3.7	28.6	21.5	91	71	69.2	4	1.8	3.2
12-18 Nov.	46	358	10.0	29.6	18.2	89	39	-	-	3.7	2.3
19-25 Nov.	47	453	8.8	29.7	19.2	84	42	-	-	5.3	4.7

The weather was favourable for the cultivation of upland rice during kharif '85 and kharif '86. During summer '86, the solar radiation and maximum temperature were high particularly during flowering and ripening periods which led to low level of productivity. Rainfall did not interfere when herbicides were applied and thus the relationship could be studied with moisture levels imposed. During kharif, 86 the wind velocity was high in the initial stages and the sprinkler system was operated during late night hours when the wind speed was low. In general, the weather was favourable for crop growth.

3.1.5. Crop variety: The rice variety selected was vaigai derived from the cross TN 1 x CO 29. It is a photo-insensitive variety with a duration of 110 days under low land conditions, with an yield potential of 5 t/ha. It is a drought resistant variety as well as responsive to water applied. It is suitable to all the seasons of cultivation.

3.2. METHODS

3.2.1. Experimental Techniques

a) Design and Layout: The experiment was laid-out in strip plot design with four replications, two on either side of the sprinkler line. The line source sprinkler system (Hanks et al., 1976) consists of a single line of

sprinklers each 6.1 m. apart which are located in the centre of the plots. Rice rows were parallel to the sprinkler line. The line source system produced a linear decrease in the amount of water applied with distance away from the water source. Each 1.6 m (8 rows of rice) was considered as a plot and hence there were 8 levels of irrigation within the wetted area. Weed control treatments were imposed randomly across the sprinkler line. The sprinklers were precalibrated to determine the amount of water delivered at a given pressure per unit of time. A uniform pressure of 3.5 kg/cm^2 was maintained during irrigation. To assure uniform distribution of irrigation water, the sprinklers were operated when the wind speed was low.

Aluminium portable alloy pipes of 75 mm size were fitted with M 322 sprinklers with $7/32 \times 1/8$ " nozzles of the Goromandel Indog Products (Pvt.) Ltd.

b. Treatments: There were four weed control treatments during each season. The treatments during kharif, 1985 were as follows:

- 1) Hand weeding - with 4 hand weedings done at 0, 40, 60 and 80 days after sowing.
- ii) Thiobencarb at 1.5 kg/ha
- iii) Arrosole (molinate + propanil) at 4 l/ha to supply 1.44 kg/ha of chemical
- iv) Unweeded check.

Unweeded check treatment was left out during the next two seasons. During summer, 1986, pre-sowing treatment with 2,4-D EE at 2.0 kg/ha was tested. This was done uniformly in the plots earmarked for chemical treatment. The three chemical treatments that imposed later were,

- i) Thiobencarb at 1.5 kg/ha
- ii) Arrosolo - 4 l/ha
- iii) Arrosolo at 4 l/ha + 2,4-D EE at 1.0 kg/ha.

These were compared with hand weeding treatment.

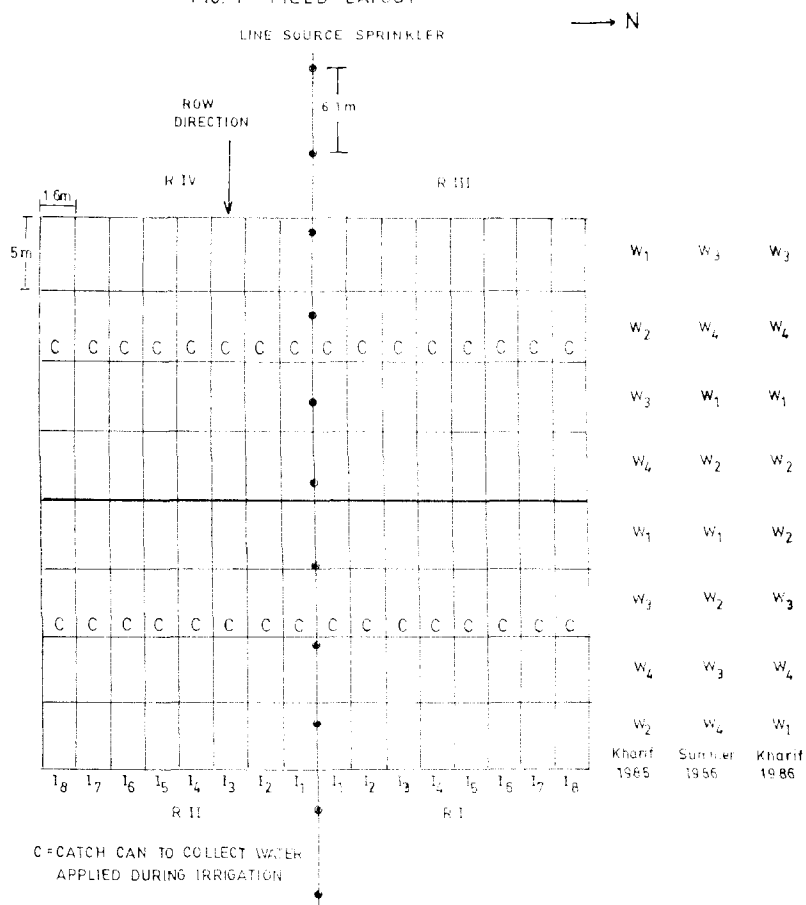
In view of some of the difficulties experienced during summer, '86, the pre-sowing treatment was restricted to one plot alone with reduced dose during kharif, 1986 and the treatment arrosolo + 2,4-D EE was left out.

The weed control treatments during kharif, 1986 were

- i) Hand weeding
- ii) Thiobencarb at 1.5 kg/ha
- iii) Arrosolo at 4 l/ha
- iv) Pre-sowing 2,4-D at 1.5 kg/ha.

The lay-out of the experiment depicting line source sprinkler system and allotment of treatments during the three seasons is shown in Fig.1.

FIG. 1 FIELD LAYOUT



	W ₁	W ₂	W ₃	W ₄
KHARIF '85	HAND WEEDING	THIOBENCARB	ARROSOLO	UNWEEDED
SUMMER '86	HAND WEEDING	PRE-2, 4-D fb THIOBENCARB	PRE-2, 4-D fb ARROSOLO	PRE-2, 4-D fb ARROSOLO + 2, 4-D
KHARIF '86	HAND WEEDING	THIOBENCARB	ARROSOLO	PRE-2, 4-D

3.2.2. Herbicide application: The herbicides were sprayed with the help of back-pak sprayer fitted with flat fan nozzle with a pressure of 0.70 kg/cm^2 . Calculated quantity of herbicides was mixed with water at the rate of 600 l/ha. The application was followed by irrigation through line source system.

The field selected had adequate weed population and as such there was no need to bombard the field with weed seeds. In case of hand weeding treatment weeds were removed by hoeing and hand weeding. Hand pulling was also done to remove the weeds in the close proximity of the crop.

3.2.3. Plot size: The gross plot was 5 m x 1.6 m and the net plot was 4 m x 0.8 m.

3.2.4. Preparation of the field: The field was ploughed with a tractor drawn mould-board plough and later was also harrowed. Then the field was levelled with a tractor drawn leveller. There were no bunds. One metre width fallow space was left between two adjacent weed control plots.

3.2.5. Seeds and sowing: The vaigai seed obtained from the central farm of the Agronomy department was having more than 95 per cent germination. A seed rate of 100 kg/ha was adopted and dry seeds were sown in rows 20 cm apart. The dates of sowing and harvesting during the three seasons were as follows:

	<u>Sowing date</u>	<u>Harvesting date</u>
Kharif, 1985	9-7-85	21-11-85
Summer, 1986	9-1-86	9-6-86
Kharif, 1986	6-7-86	27-11-86

3.2.6. Fertilizer application: A total quantity of 100 kg N, 40 kg each of P_2O_5 and K_2O per hectare was applied to the crop. The entire quantity of P_2O_5 and K_2O was applied basally in the form of single super phosphate and muriate of potash, respectively. Nitrogen was applied in the form of urea in three equal splits at 20, 40 and 80 DAS.

3.2.7. Irrigation: The field was irrigated by flooding soon after sowing. Later line source sprinkler system was used till maturity. The water was collected in catch cans placed in the centre of the plot as shown in Fig.1. and later converted into mm. The catchcans were kept at the canopy height as the crop grew, with the help of bamboo sticks. The irrigation water applied along with rainfall, if any, was termed as the total water applied (TWA). The pan evaporation during that period, termed as upland evaporation (UE) was considered to work out TWA/UE ratios.

3.2.8. Plant protection: There was no pest or disease incidence except the presence of earhead bug at milking stage and it was controlled by spraying monocrotophos 0.05 per cent thrice at weekly intervals.

3.2.9. Harvesting and threshing: The border rows were first harvested and then net area was harvested. Each net plot was threshed separately with utmost care. Grain weight was recorded after drying and cleaning and adjusted to 14 per cent moisture. Straw weight was recorded after drying.

3.3. Biometric observations: One metre row in each plot was randomly marked for recording observations on tiller number. Ten plants in this one metre row were labelled for recording observations like plant height, leaf length, leaf width, at 30, 60 and 90 days after sowing.

3.3.1. Plant height: Plant height was measured from the base of the plant to the tip of the longest leaf stretched, at 30, 60 and 90 DAS, and upto the tip of the panicle at harvest.

3.3.2. Tiller number: The total tillers in the one metre row were counted and expressed as tillers/m.

3.3.3. Shoot dry weight and dry matter partitioning: Rice plants from 0.5 m row in the sampling area were carefully uprooted from 20 cm. depth of soil. The roots were cut and separated. The shoot portion was separated into leaf, sheath and culm manually. They were dried in oven and dry weight was recorded. The dry weight was expressed as percentage to the total dry weight including leaf, sheath + culm and root. The leaf and sheath weight put together was expressed as shoot dry weight in g/m. row. Root: Shoot ratio was also worked out.

3.4. Growth analysis

3.4.1. Leaf area index (LAI): From the measurements of leaf length and leaf width, leaf area was worked out as outlined by Palanisamy and Gomez (1974) using 0.73 as the factor. The total leaf area to the ground area was expressed as leaf area index.

3.4.2. Crop growth rate (CGR): Crop growth rate was calculated as suggested by Buttery (1970) using the formula,

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \quad \text{where,}$$

W_1 and W_2 are the shoot dry weights recorded at time t_1 and t_2 , and CGR was expressed as g/m/day.

3.4.3. Relative growth rate (RGR): Relative growth rate was estimated as per Enyi (1962) from his formula,

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \quad \text{g/g/day,}$$

where W_1 , W_2 and t_1 and t_2 were the same as given for CGR.

3.4.4. Net assimilation rate (NAR): Enyi (1962) suggested the following formula for estimating NAR.

$$\text{NAR} = \frac{(W_2 - W_1) (\log_e L_2 - \log_e L_1)}{(t_2 - t_1) (L_2 - L_1)}$$

g/dm²/day, where L_1 and L_2 refer to leaf area in dm² at t_1 and t_2 .

3.4.5. Leaf elongation rate: The leaf just appeared on each of the ten plants from marked area was tagged with coloured silk thread and leaf length was measured daily and the data were used to compute leaf elongation rate.

3.4.6. Panicle exertion rate: The length of the panicle emerged was measured daily from the collar of the flag leaf to the tip of the panicle, after tagging the tillers at boot leaf stage with coloured silk thread. Panicle exertion rate was found as the panicle length (cm) exerted during each day.

3.4.7. Relative water content (RWC): It was estimated by recording the fresh weight (FW), turgid weight (TW) and dry weight (DW) of either leaves (Tomar and Ghildyal, 1973) or panicles (O'Toole *et al.*, 1984). The formula adopted was,

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

3.4.8. Specific leaf area (SLA) and specific leaf weight (SLW): The leaf area was measured for the leaves used for knowing RWC and using the data on leaf area and leaf dry weight, SLA and SLW were calculated as cm^2/g or g/cm^2 , respectively.

3.4.9. Canopy temperature (T_c) and canopy air temperature differential ($T_c - T_a$): These two parameters were measured by infrared thermometer by focussing it to the canopy during mid-day when the weather was free of clouds and wind.

3.4.10. Leaf characters measured through steady state-porometer: Leaf temperature (T_p) in $^{\circ}\text{C}$; relative humidity of leaf (RH) in percentage; photosynthetically active radiation (PAR) in $\mu\text{mol/s/m}^2$; diffusive resistance (DR) in s/cm and transpiration rate (T_r) as $\mu\text{H}_2\text{O/cm}^2/\text{sec}$ were measured simultaneously through steady state porometer for a representative single leaf in each plot. The mean of repeated observations was presented.

3.4.11. Chlorophyll estimation: Leaf sample of 0.5 g was ground with acetone (80%) and chlorophyll was extracted through filtration. The extracted sample was made upto 50 ml with acetone and centrifuged for 10 min. The colour intensity was read at optical densities (OD) 645 and 663, in spectrophotometer. The following formulae were adopted for calculations.

Total chlorophyll = $(0.0202 \times \text{OD } 645) + (0.00802 \times \text{OD } 663)$

Chlorophyll a = $(0.0127 \times \text{OD } 663) - (0.00269 \times \text{OD } 645)$

Chlorophyll b = $(0.0229 \times \text{OD } 645) - (0.00488 \times \text{OD } 663)$

From the above formulae chlorophyll content in mg/ml was known, which was later converted into percentage.

3.5. Weed characters: Adopting the methods described by Burnside and Wicks (1965), the population of weeds/m² and dry matter production of weeds were recorded at 20, 40, 60 and 80 DAS just before hand weeding and at harvest.

3.5.1. Weed population: Periodical counts of the weed species were taken in two randomly selected quadrat areas of 0.25 m² each (0.5 x 0.5 m) and were expressed as no/m². Weeds were separated into grasses, sedges and broad leaved weeds (BLW).

3.5.2. Weed dry matter: The weeds in the quadrat areas as said above were removed and the above ground portions were oven dried and weighed. Weed dry weight was expressed as g/m² separately for grasses, sedges and broad leaved weeds. In case if the sampling was not followed by hand weeding, sampling was done outside the net area, but within the gross plot.

Using the data on weed number, relative density and weed control efficiency were calculated while the data on weed dry weight was used to find out relative dry weight and weed control index.

3.5.3. Total gram days of competition: The weed weight recorded before each hand weeding was utilised to calculate weed growth rate similar to crop growth rate. Based on the weed growth rate, the weed competition on each day was estimated as grams of weed competition for a particular day. The cumulative values were taken as gram day competition, adopting the formula,

$$\text{Weed growth rate} \times \frac{n(n+1)}{2} \quad \text{where}$$

n = number of days.

Such values were found for the period between two successive hand weedings and also for the period upto harvest from the day of last weeding and totalled up, to give the gram day competition (GDC) under each treatment. In case of unweeded check, the dry weight at harvest was considered to work out weed growth rate and thus the total gram day competition.

3.6. Yield attributes and yield: The following observations were recorded using standard procedures.

1. Number of productive tillers/m
2. Per cent productive tillers
3. Number of filled grains/panicle
4. Number of unfilled grains/panicle



5. Per cent sterility
6. Panicle length
7. Panicle weight
8. 1000-grain weight
9. Grain yield
10. Straw yield
11. Harvest index
12. Days to flowering and maturity

3.6.1. Apparent water use efficiency (AWUE): The ratio of grain yield to the total water applied inclusive of rainfall, was expressed as AWUE in kg/mm of water.

3.7. Uptake of nitrogen by crop and weeds: The dry matter samples of rice and weeds were ground by Willey mill and the samples collected at various stages were used for estimating nitrogen content through microkjeldahl method (Humphries, 1956) and the uptake was expressed as kg/ha.

3.8. Estimation of 2,4-D residue in soil by GLC in a pot culture study: A pot culture study was made to find out the persistence of 2,4-D in soil with varying levels of moisture. Pots of uniform size were filled with soil from the site of the field experiment. Different quantities of water were added to the soil on weight basis to bring the soil to moisture levels of 40, 25 and 18 per cent and another was kept dry. Three different sets as above were

made of which two sets were placed in glass house under shade while one set was left in open area. Out of the two sets placed in glass house, one set was watered daily to maintain the moisture level, while the remaining sets were allowed to dry up, one inside the glass house under shade and the other, in the open area. In this way different moisture levels were created. The herbicide 2,4-D EE was added to the pots corresponding to 2 kg/ha. Soil samples were collected one day, three days, five days and seven days after the application for estimation of 2,4-D residue and also to find out soil moisture, separately. On 7th day, after the collection of samples, all the pots were uniformly watered to bring the moisture level to about 40 per cent and all were allowed to dry for another 7 days. On 14th day after herbicide application, the last sampling was done. 2,4-D in the soil was estimated by Gas liquid chromatography by following the procedure adopted by Grover et al. (1985).

To 25 ml of the soil sample collected, 50 ml of solvent mixture (80:20:2.5 by volume of acetonitrile, distilled water and glacial acetic acid) was added and the samples were kept in mechanical shaker for one hour. Later they were subjected to vacuum filtration using Buckner funnel.

The filtrate was transferred to a 250 ml separating funnel and 100 ml of sodium carbonate aqueous solution (Prepared by dissolving 50 g of sodium carbonate in one litre of water) was added, followed by 25 ml of n-hexane. After thorough shaking, the lower aqueous phase was separated and the organic phase (hexane) was collected after passing through sodium sulphate crystals in a filter paper. The process was repeated with the aqueous phase with another 25 ml of n-hexane, and the hexane portion was pooled.

The aqueous phase was acidified with 15 ml of concentrated hydrochloric acid and later 50 ml of diethyl ether was added. The ether portion was separated and collected. The process was repeated with another 50 ml portion of diethyl ether. The pooled ether was allowed to evaporate. Afterwards 5 ml of boron trifluoride-methanol mixture (140 ml of boron trifluoride was made upto one litre with methanol) was added to the beaker which was placed in water bath at 70°C for 45 minutes (Smith and Hayden, 1981). Later 25 ml of saturated sodium chloride solution was added and the contents were transferred to a 120 ml separating funnel. To this, 5 ml of n-hexane was added. After shaking, the hexane portion was separated.

The hexane portions collected (first set before acidification and the second set after methylation) were fed separately to the gas chromatograph (Chemito 3800 fitted with BCD) using OV-17 + QF -1 column maintaining the following conditions.

Column temperature	- 211°C
Injector temperature	- 229°C
Detector - DB	- 243°C
DS	- 251°C

The retention time was 110 and 370 seconds, respectively, for ethyl ester and acid.

3.9. Estimation of 2,4-D and its metabolites by thin layer chromatography:

1. Preparation of activated silica gel plates:

Silica gel slurry was prepared by mixing 40 g of silicagel and 80 ml of water. The slurry was spread over glass plate with the help of an applicator adjusted to 250 microns thickness. The plates were dried in the air and activated by keeping in an air oven for one hour at 100°C.

2. Spotting and development of the chromatoplates:

With the help of lambda pipette, 2,4-D, metabolites and the soil sample extracts were spotted on the chromatoplates.

The spotted plates were developed in a solvent system (benzene-n-hexane 20:80). The plates were air dried and sprayed with silver nitrate chromogenic agent (dissolve 0.5 g of silver nitrate in minimum quantity of water. Add 10 ml of phenoxy ethenol and make up to 200 ml with acetone. Add six drops of 30 per cent H_2O_2). The plates were dried and exposed to UV light for 5-10 minutes. 2,4-D and the metabolite spots were located as black spots in white background. The R_f value for 2,4-D was 0.20 to 0.22. The R_f values of 4-chlorophenol and 2,4-dichlorophenol were 0.30 and 0.71, respectively.

3.10. Statistical analysis: The data pertaining to crop and weed were statistically analysed as per the procedure for strip plot design by Gomez and Gomez (1984) on the suggestions of Moody (Personal communication). Data on weed count and weed weight showed high variations and as such were subjected to $\sqrt{x + 0.5}$ transformation before statistical analysis. Correlations and regression equations were worked out for some characters and the homogeneity test for regression co-efficients was carried out in case of weed weight and the procedures outlined by Gomez and Gomez (1984) were followed for the above purposes.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results of the experiments conducted during kharif 85 and 86 as well as summer 86 seasons to establish the relationship between herbicides and soil moisture and the effect of different weed control methods at varying moisture levels on upland rice are presented and discussed in this chapter, season-wise.

4.1. Kharif, 1985

4.1.1. Total water applied during different periods: After a common irrigation soon after sowing, line source sprinkler system was used to provide moisture gradient throughout. The data pertaining to the total water applied (TWA), and the ratio of TWA/US are presented in Table 5. During the initial stages i.e., upto 30 DAS TWA/US ratio was maintained slightly above 1.0 nearer the line source which fell to the level of 0.58 at the extreme end. During the next 30 days, the water applied was slightly increased. During 60-90 DAS, the TWA/US ratio was above 1.0 for all the treatments. This period coincided with panicle initiation and early flowering stages and as such higher quantity of water was applied to meet the crop demand. The total water applied for the entire crop growth period ranged from 990 mm in the wet regime (I_1) to 468 mm in dry regime (I_9) and the TWA/US ratio ranged between 1.51 and 0.71. A fairly wide range of moisture

Table 5. Total water applied (TWA) in mm. and its ratio to the upland evaporation (UE) during different periods (kharif '85)

	0-30 DAS	30-60	60-90	90-M	Total
I ₁	233 (1.23)	256 (1.37)	298 (1.96)	202 (1.59)	990 (1.51)
I ₂	223 (1.17)	242 (1.30)	244 (1.60)	186 (1.46)	937 (1.48)
I ₃	205 (1.08)	233 (1.25)	236 (1.55)	171 (1.34)	888 (1.35)
I ₄	191 (1.00)	222 (1.19)	231 (1.52)	159 (1.25)	843 (1.28)
I ₅	178 (0.94)	202 (1.08)	223 (1.47)	148 (1.16)	790 (1.20)
I ₆	158 (0.83)	177 (0.95)	210 (1.38)	125 (0.99)	701 (1.07)
I ₇	133 (0.70)	145 (0.78)	194 (1.27)	86 (0.68)	578 (0.88)
I ₈	111 (0.58)	115 (0.62)	177 (1.16)	65 (0.51)	468 (0.71)

DAS = Days after sowing

M = Maturity

TWA/UE ratios in parenthesis.

gradient created, provided conditions necessary to study the differences in the response of weed growth and crop growth under different weed control treatments. The line source sprinkler system provided a gradual decrease in the amount of water applied with increase in distance from the sprinkler line. This negative relationship of water applied to distance was observed throughout the period of study (Fig.2).

4.1.2. Weed flora of the experimental field: The weed flora of the experimental field are listed in Table 6. Among the grasses, Echinochloa colona was the only predominant weed, while the remaining species appeared sporadically. The weed population was grouped into grasses, sedges and broad leaved weeds. Because of the predominance of E. colona under grasses and Cyperus rotundus under sedges, the terms grass and sedge in the text were deemed to be referring to these weed species. The proportion of the broad leaved weeds was very small and as such all were grouped to be termed BLW in the text.

4.1.2.1. Effect of treatments on weed population 20 DAS: The herbicides were applied 8 DAS and the changes in weed population were observed 20 DAS. The grass weed population was affected by the weed control treatments (Table 7). The population was very low ($60/m^2$) in arrosolo applied

FIG. 2 AMOUNT OF WATER APPLIED AS
AFFECTED BY DISTANCE FROM
THE SPRINKLER LINE (KHARIF, 1985)

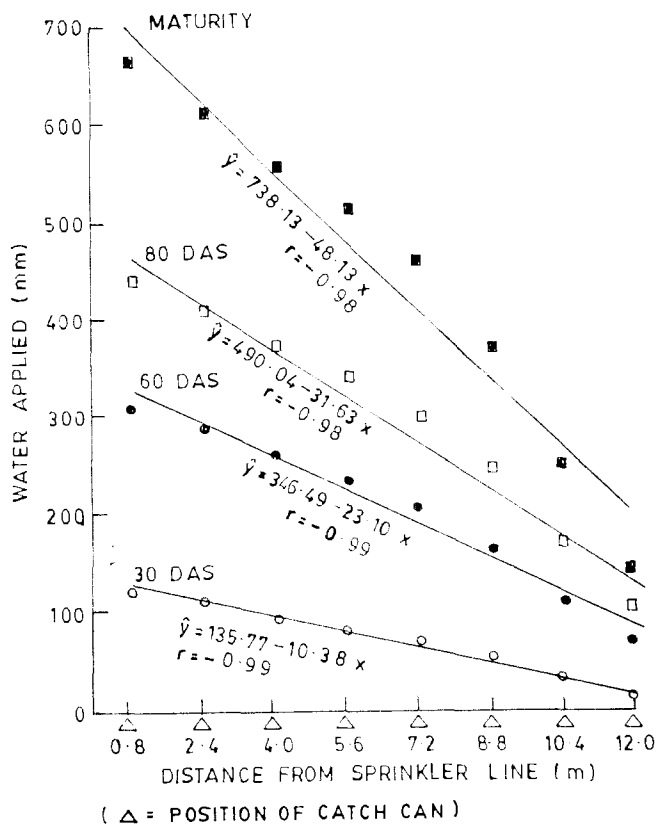


Table 6. Weed flora of the experimental field

Botanical name	Family
<u>Grasses:</u>	
<u>Echinochloa colona</u> (L.) Link	Poaceae
<u>Echinochloa crus-galli</u> (L.) Beauv.	Poaceae
<u>Paspalum distichum</u> L.	Poaceae
<u>Chloris barbata</u> Swartz	Poaceae
<u>Dinebra retroflexa</u> Jacq.	Poaceae
<u>Sedges:</u>	
<u>Cyperus rotundus</u> L.	Cyperaceae
<u>Cyperus iria</u> L.	Cyperaceae
<u>Broad leaved weeds:</u>	
<u>Alternanthera triandra</u> Lamk	Amaranthaceae
<u>Cleome chelidonii</u> L.f.	Cleomaceae
<u>Euphorbia prostrata</u> Ait.	Euphorbiaceae
<u>Chrozophora rotleri</u> Klotzsch	Euphorbiaceae
<u>Phyllanthus madaraspatensis</u>	Euphorbiaceae
<u>Eclipta alba</u> (L.) Hassk	Asteraceae
<u>Eclipta prostrata</u> (L.) L.	Asteraceae
<u>Lippia nodiflora</u> Mich	Verbinaceae
<u>Marramia emerginata</u> Halli.f.	Convolvulaceae
<u>Vigna</u> sp.	Papilionaceae
<u>Trianthema monogyna</u> L.	Aizoaceae

Table 7. Weed number/m² at 20 DAS

(Kharif '85)

	Grass	BLW	Sedge	Total
Hand weeding	262 (15.80)	24 (4.82)	2.0 (1.48)	288 (16.67)
Thiobencarb	76 (8.45)	13 (3.55)	1.5 (1.15)	90 (9.34)
Arrosoiro	60 (6.85)	8 (2.70)	3.0 (1.50)	71 (7.75)
Unweeded	338 (16.77)	20 (4.47)	1.5 (1.20)	359 (17.50)
SE _d ±	2.25	0.42	0.30	2.21
CD (P=0.05)	5.09	0.95	NS	5.00
I ₁ (121 mm)	166 (11.48)	14 (3.67)	5.2 (1.80)	185 (12.52)
I ₂ (115)	175 (11.61)	12 (3.57)	3.2 (1.56)	190 (12.41)
I ₃ (107)	179 (11.89)	16 (4.00)	1.5 (1.28)	196 (12.72)
I ₄ (98)	192 (12.25)	17 (4.07)	2.7 (1.44)	212 (13.14)
I ₅ (94)	215 (12.67)	22 (4.60)	1.2 (1.21)	238 (13.73)
I ₆ (88)	193 (12.28)	17 (3.96)	1.7 (1.29)	212 (13.06)
I ₇ (81)	174 (11.54)	16 (3.62)	0.2 (0.99)	190 (12.18)
I ₈ (75)	178 (12.04)	14 (3.60)	1.0 (1.11)	193 (12.78)
SE _d ±	0.92	0.42	0.42	0.85
CD (P=0.05)	NS	NS	NS	NS

NS = Not significant

Transformed data in parenthesis

plots, closely followed by thiobencarb treatment ($76/m^2$). In the untreated plots, the grass weed population was high. Effect of moisture regimes was not seen on the grass weed population. The common irrigation of 7 cm given at sowing for uniform germination of rice would have been sufficient for the weeds to germinate as well. The moisture gradient created later, did not influence the number of weeds already sprouted. This could be clearly seen from, more or less uniform number of grass weeds under the different moisture regimes, particularly in the untreated plots. The marginal differences in the grass weed population under different moisture regimes in the herbicide treated plots, did not reach the level of significance.

As early as in 1931, Garcia observed soil moisture level of 30 per cent of the saturation to be sufficient for the seeds of Panicum crus-galli (now Echinochloa crus-galli) to sprout. The 7 cm of initial irrigation was sufficient in the present study for uniform sprouting of weeds.

The number of broad leaved weeds (BLW) differed with the weed control treatments (Table 7). It was low ($8/m^2$) in azoxystrobin treated plots followed by thiobencarb ($13/m^2$). The BLW number was evidently higher in the untreated plots. The moisture levels did not influence the BLW population and the interaction effect was not noticed.

The sedge weed population was very low, ranging between 1.5 and 3.0/m² (Table 7). Neither the weed control treatments, nor the moisture levels influenced the sedge population and interaction was absent.

The total number of weeds was affected by weed control treatments (Table 7). It was low in herbicide applied plots and the weed population under the two herbicides, arrosolo and thiobencarb was comparable. It was high in the untreated plots. The different moisture levels and their interactive effect on total weed number was not felt. The results with total weed number were similar to the grass weed number, which was the dominant component. The mean number of grass, ELW, sedge and total weeds at 20 DAS was 184, 16, 2 and 202, respectively, grasses constituting 91 per cent of the total population.

The broad spectrum of weed control through arrosolo could be due to the combination of molinate and propanil. Molinate promotes the penetration of propanil giving more complete contact control, in addition to its effects on germinating grasses when moisture is available (Soong, 1981).

4.1.2.2. Weed number and weight at 40 DAS: After a hand weeding 20 DAS in the hand weeded check, the effect of treatments on weed number and weight was observed on 40 DAS.

The grass weed number (Table 8) and weight (Table 9a) were high in the unweeded check. Hand weeding at 20 DAS lowered the grass weed number. Both the herbicides were similar in their mean effect with regard to grass weed number while the weed weight under both the herbicides was similar to that in hand weeding. The results clearly show that the herbicides effectively checked the grass weed growth upto 40 DAS and the effect is similar to that of one hand weeding.

The grass population in unweeded check started to decline, which could be due to very high density of more than 300 weeds/m² at 20 DAS resulting in mortality. In the herbicide treated plots, the weed number increased compared to 20 DAS indicating the gradual decrease in the efficacy of herbicides over time.

The mean effect of moisture regimes was not noticed on the grass weed number, but they affected the weight of grass weeds. The weed weight was low in the first three moisture regimes (I₁ to I₃). Weed weight increased with decrease in moisture levels and it was high in the last three levels (I₆ to I₈). Higher moisture regimes on deep clayey soil resulted in anaerobic conditions, where the growth would be normally less. A root subjected to oxygen shortage has its growth or elongation decreased and the rate of transfer

Table 8: Weed number/m² at 40 DAS

(Kharif '85)

	Grass	RLW	Sedge	Total
Hand weeding	82 (8.93)	15 (3.66)	5.1 (1.79)	102 (9.97)
Thiobencarb	130 (11.29)	43 (6.39)	2.9 (1.40)	176 (13.19)
Amrosolo	127 (10.77)	22 (4.49)	6.4 (1.88)	155 (12.05)
Unweeded	231 (14.77)	25 (4.95)	3.7 (1.31)	260 (15.75)
SE _{d±}	1.00	0.75	0.30	0.88
CD (P=0.05)	2.26	1.69	NS	1.98
I ₁ (259 mm)	137 (11.21)	25 (4.85)	8.0 (1.79)	170 (12.67)
I ₂ (248)	137 (11.26)	26 (4.84)	7.2 (2.12)	170 (12.66)
I ₃ (227)	147 (11.75)	26 (4.92)	3.0 (1.42)	176 (12.94)
I ₄ (217)	136 (11.04)	29 (4.92)	5.2 (1.84)	170 (12.61)
I ₅ (195)	152 (11.83)	31 (5.40)	7.2 (1.83)	190 (13.29)
I ₆ (169)	153 (11.83)	28 (5.07)	3.0 (1.57)	184 (13.11)
I ₇ (140)	142 (11.42)	22 (4.41)	1.5 (1.13)	165 (12.40)
I ₈ (113)	136 (11.18)	22 (4.58)	1.1 (1.07)	159 (12.26)
SE _{d±}	0.52	0.46	0.54	0.47
CD (P=0.05)	NS	NS	NS	NS

NS = Not significant

Transformed data in paranthesis

Table 9a: Grass weed weight (g/m^2) at 40 DAS

(Kharif '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁	20.1 (4.46)	17.3 (4.16)	13.6 (3.69)	75.5 (8.51)	31.6 (5.21)
I ₂	16.6 (4.12)	25.2 (5.00)	19.8 (4.45)	78.9 (8.81)	35.1 (5.60)
I ₃	24.7 (4.99)	30.0 (5.41)	26.6 (5.16)	83.8 (9.15)	41.3 (6.18)
I ₄	23.6 (4.82)	31.4 (5.55)	23.7 (4.87)	121.4 (10.98)	50.0 (6.55)
I ₅	30.9 (5.58)	62.7 (7.65)	39.9 (6.09)	120.2 (10.84)	63.4 (7.54)
I ₆	37.9 (6.16)	69.9 (8.02)	49.7 (6.97)	121.3 (10.98)	69.7 (8.03)
I ₇	46.0 (6.77)	86.5 (8.84)	42.2 (6.27)	137.9 (11.72)	78.1 (8.40)
I ₈	44.1 (6.65)	70.5 (7.77)	48.1 (6.82)	182.6 (13.51)	86.3 (8.69)
Mean	30.5 (5.45)	49.2 (6.55)	32.9 (5.54)	115.2 (10.56)	
		I	W	W at I	I at W
SE _d ±		0.50	0.73	1.08	0.89
CD (P=0.05)		1.04	1.66	NS	NS

NS = Not significant

Transformed data in parenthesis

of water and nutrients from the soil to the xylem tissue is also decreased (Russell, 1973). This could be the probable reason for decreased weed growth at higher moisture levels. Janiya and Moody (1984) reported positive relationship between weed growth and water applied, where the soil was loamy in nature. Even in their study, weed weight remained more or less unchanged between the moisture levels of 111 to 298 mm under unweeded conditions.

The effect of weed control treatments on grass weed number and weight remained the same across the moisture levels tested and hence the interaction effect was not significant.

The number (Table 8) and weight (Table 9b) of BLW was high in thiobencarb treated plots indicating that this herbicide is not effective on BLW. It was similar to unweeded check with regard to the weight of BLW. The mean effect of arrosolo was similar to hand weeding in controlling the growth of BLW. The BLW number and dry weight was not affected by the different moisture regimes. However, the effect of weed control treatments on BLW weight varied due to moisture levels. The weed weight in thiobencarb plots was high upto the level of I_5 compared to other weed control treatments. At lower regimes, it was similar to the weed weight

Table 9b. RLW weight (g/m^2) at 40 DAS

(Kharif '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁	3.1 (1.82)	18.6 (4.33)	5.3 (2.37)	11.6 (3.38)	9.6 (2.98)
I ₂	6.4 (2.10)	21.2 (4.52)	5.4 (2.43)	9.9 (3.05)	10.7 (3.02)
I ₃	3.9 (2.01)	26.4 (5.02)	11.7 (3.41)	13.8 (3.50)	13.9 (3.49)
I ₄	4.1 (2.08)	44.7 (6.57)	11.0 (3.23)	8.9 (3.03)	17.2 (3.72)
I ₅	5.9 (2.53)	38.2 (6.11)	13.9 (3.77)	18.3 (4.04)	19.1 (4.11)
I ₆	8.5 (2.93)	23.3 (4.83)	13.8 (3.49)	21.8 (4.66)	16.8 (3.98)
I ₇	7.1 (2.71)	15.0 (3.60)	8.3 (2.21)	18.8 (4.28)	12.3 (3.20)
I ₈	7.5 (2.69)	16.9 (4.07)	5.3 (2.14)	18.4 (4.15)	12.0 (3.26)
Mean	5.8 (2.36)	25.5 (4.89)	9.3 (2.88)	15.2 (3.75)	
		I	W	W at I	I at W
SE _d ±		0.41	0.50	0.80	0.71
CD (P=0.05)		NS	1.12	1.68	1.44

NS = Not significant

Transformed data in parenthesis

in hand weeding and arrosolo treated plots. The BLW weight in hand weeding, arrosolo and unweeded control plots remained similar across the moisture levels tested.

The sedge weed number (Table 8) and weight (Table 9e) were very low and not affected by any of the treatments.

Hand weeding was effective in lowering the total weed number (Table 8). Among the herbicides tested, arrosolo was more effective in reducing the total weed weight (Table 9d) and the mean effect was similar to hand weeding. The mean weed weight in thiobencarb plots was more compared to hand weeding or arrosolo. The mean effect of moisture regimes was not significant on the total weed number, probably because the weeds germinated with the sowing irrigation and the subsequent moisture regimes, even at the farthest point (I_8) from the sprinkler line, were sufficient to sustain the weeds. However, the weed weight was more when the water applied upto 40 DAS was 195 mm or less. With higher moisture levels upto I_3 (227 mm), weed weight was low.

The dry weight of weeds in thiobencarb and arrosolo treated plots was similar to hand weeded check upto the moisture level of I_3 . The soil moisture (0-15 cm) in I_3 at the time of spraying was 30.8 per cent (Table 9e) and an irrigation of 35 mm was given within 3 days after spraying in

Table 9c. Sedge weed weight (g/m^2) at 40 DAS

(kharif '85)

	Hand weeding	Thio-bencarb	Arrosolo	Unweeded	Mean
I ₁	1.3 (1.00)	0.0 (0.71)	8.4 (2.29)	0.0 (0.71)	2.4 (1.18)
I ₂	3.5 (1.63)	6.0 (1.99)	3.3 (1.63)	1.0 (1.06)	3.4 (1.58)
I ₃	1.3 (1.18)	3.3 (1.52)	0.3 (0.87)	2.0 (1.26)	1.7 (1.21)
I ₄	3.8 (1.87)	0.7 (1.00)	3.3 (1.69)	0.0 (0.71)	1.9 (1.31)
I ₅	0.7 (0.99)	1.3 (1.14)	2.1 (1.43)	6.3 (1.89)	2.6 (1.36)
I ₆	0.9 (1.11)	1.0 (1.14)	0.4 (0.89)	0.8 (1.01)	0.8 (1.04)
I ₇	0.7 (1.00)	0.0 (0.71)	0.2 (0.83)	0.3 (0.88)	0.3 (0.85)
I ₈	1.0 (1.07)	0.1 (0.77)	0.4 (0.89)	0.0 (0.71)	0.4 (0.86)
Mean	1.6 (1.23)	1.5 (1.12)	2.3 (1.31)	1.3 (1.03)	
		I	W	W at I	I at W
SE _{d±}		2.09	1.57	4.39	4.34
CD (P=0.05)		NS	NS	NS	NS

NS = Not significant

Transformed data in parenthesis

Table 9d. Total weed weight (g/m^2) at 40 DAS

(kharif '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁	24.5 (4.90)	35.9 (6.00)	27.3 (5.17)	87.1 (9.25)	43.6 (6.33)
I ₂	26.5 (5.14)	52.4 (7.23)	28.5 (5.34)	89.8 (9.46)	49.2 (6.79)
I ₃	29.9 (5.49)	59.7 (7.70)	38.6 (6.23)	99.6 (10.00)	56.9 (7.36)
I ₄	31.5 (5.63)	76.8 (8.74)	38.0 (6.10)	130.3 (11.39)	69.1 (7.97)
I ₅	37.5 (4.90)	102.2 (10.03)	55.9 (7.33)	144.8 (11.98)	85.1 (8.56)
I ₆	47.3 (6.91)	94.2 (9.50)	63.9 (7.97)	145.9 (11.56)	87.3 (9.08)
I ₇	53.8 (7.36)	101.5 (9.84)	50.7 (6.75)	157.0 (12.51)	90.7 (9.11)
I ₈	52.6 (7.27)	87.5 (9.01)	53.8 (7.19)	201.0 (14.16)	98.7 (9.41)
Mean	37.9 (5.95)	76.2 (8.51)	44.5 (6.51)	131.7 (11.34)	
		I	W	W at I	I at W
SE _d ±		0.52	0.62	1.03	0.92
CD (P=0.05)		1.08	1.39	2.26	1.86

Transformed data in parenthesis

Table 9e. Soil moisture at spraying and water applied
in different moisture regimes

	Soil moisture (0-15 cm) at spraying (percentage)	Water applied within 3 days after sowing	Total water applied upto 40 DAS
I ₁	32.4	49.1	259.1
I ₂	31.7	43.3	248.3
I ₃	30.8	35.0	227.4
I ₄	30.1	26.6	211.6
I ₅	29.2	22.6	195.0
I ₆	28.8	16.6	169.1
I ₇	26.4	9.3	140.2
I ₈	24.6	3.7	113.0

order to maintain the above soil moisture conditions. Arrosolo was more effective upto the level of I_4 when the soil moisture was 30.1 per cent followed by 26.6 mm of water application within 3 days of spraying. 30.3 per cent is the field capacity level for the soil. Hence soil moisture of above FC could result in higher efficacy of the herbicides. Arrosolo was more effective even at lower levels of moisture.

The herbicides lowered the total weed weight compared to unweeded check even at lower moisture regimes, but the effect was not rapid.

Jikiyara and Kimura (1977); Schiller and Indhapun (1979); Sankaran and De Datta (1984) and Janiya and Moody (1984) found herbicidal efficacy to decline as soil moisture content decreased. The uptake of herbicides active through the root system is encouraged by adequate soil moisture and the roots will not be able to explore dry soil. Herbicides are adsorbed more tightly by dry soil and are less available for absorption by the weeds. Under saturated conditions, water displaces herbicide molecules into the soil solution resulting in the availability of high concentrations for plant uptake whereas when soil moisture is low, the herbicide molecules compete favourably for adsorption sites on the soil colloids resulting in lower availability to the plant.

In the present study, arrosolo was effective throughout the moisture levels tested though the effect was faster when more water was applied (Fig.3). The relationship of weed growth with total water applied upto 40 DAS was negative in all the weed control treatments. The regression coefficients were found to be different from each other. The slope was more in unweeded conditions, followed by thiobencarb, hand weeding and arrosolo. The change in weed weight due to change in water applied was low in arrosolo. In other words, the weed control through arrosolo was effective under wide range of moisture levels.

4.1.2.3. Weed control efficiency (WCE), Weed control index (WCI) and Relativity of weed occurrence at 40 DAS;

WCE and WCI were worked out from total weed number and total dry weight, respectively (Table 10). WCE and WCI were high in the case of hand weeded check, followed by arrosolo and were low in the case of thiobencarb. WCI for thiobencarb was high at I_1 level alone and decreased thereafter, lowest value being observed at I_5 . With respect to arrosolo, the WCI was always more than 50 at all the moisture levels tested. The total weed number did not differ much due to moisture regimes, whereas the total dry weight was significantly related to moisture levels and as such WCI looked more representative than WCE. The relative density of grasses was high,

FIG. 3 TOTAL DRY WEIGHT OF WEEDS (g/m^2) AS AFFECTED BY TREATMENTS AT 40 DAS (KHARIF, 1985)

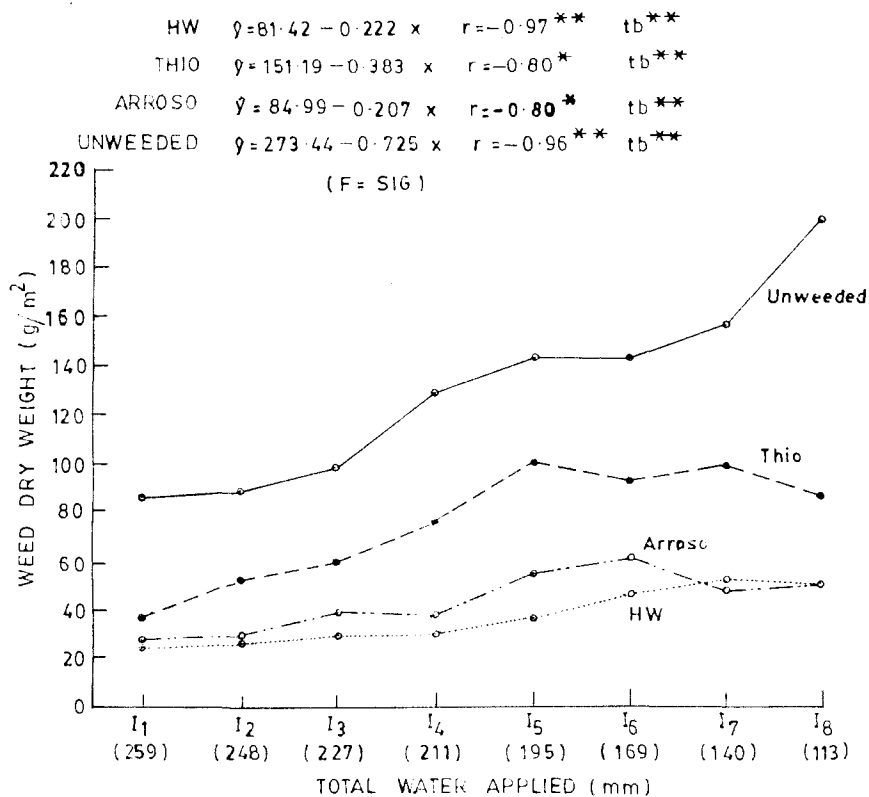


**Table 10: Weed control efficiency and weed control index
at 40 DAS (Kharif'85)**

	WCE			WCI		
	HW	Thio	Arroso	HW	Thio	Arroso
I ₁	65.4	42.3	53.8	71.9	58.8	68.7
I ₂	61.3	37.9	59.9	70.5	41.6	68.3
I ₃	63.0	36.3	42.5	70.0	40.1	61.2
I ₄	68.0	41.7	45.0	75.8	41.0	70.8
I ₅	63.6	30.4	37.4	74.1	29.4	61.4
I ₆	56.0	24.8	3.0	67.1	34.5	35.6
I ₇	50.0	4.9	45.9	65.7	35.3	67.7
I ₈	55.3	33.2	28.8	73.8	56.5	73.2
Mean	60.7	32.3	40.2	71.2	42.1	66.2

Relative Density and Relative Dry weight

	RD			RDW		
	Grass	BLW	Sedge	Grass	BLW	Sedge
Unweeded	88.9	9.6	1.5	87.5	11.5	1.0
HW	80.3	14.7	5.0	80.5	15.3	4.2
Thio	73.9	24.4	1.7	64.6	33.4	2.0
Arroso	81.7	14.2	4.1	73.9	20.9	5.2

ranging from 73.9 in thiobencarb to 88.9 in unweeded check. The RDW was also high for grasses. The proportion of BLW was high in thiobencarb as the herbicide did not control BLW. The relative proportion of sedges was very low.

4.1.2.4. Nitrogen removal by weeds at 40 DAS: The N removal by weeds was influenced by weed control treatments and moisture levels. The removal under hand weeding and arrosoir was similar and less than that in other treatments (Table 12a). The removal of N by weeds was high in the unweeded check.

The N removed by weeds in the higher moisture levels upto I₃ was low. When the water applied was lower than 195 mm, the N removed by weeds was high. The N removal by weeds behaved similar to the total weight of weeds at 40 DAS. The N content of the weeds was interesting to observe. In case of the grass weed, the per cent N content was 1.61 in hand weeded plot, 1.20 in herbicide applied plots and 0.98 in unweeded check. For BLW, the per cent N-content was 1.06, 1.70 and 1.96, respectively and it was 1.06, 0.65 and 0.98 respectively, for the sedges. In grass weeds in particular, it was high with young weeds and decreased as the growth advanced or dry matter accumulated.

4.1.2.5. Total weed growth allowed in different treatments: Four hand weedings were given in hand weeded check (20,40,60 and 80 DAS), while the herbicide applied plots were

Table 11: Total weed growth allowed (g/m^2)

(kharif, '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁	111.6 (10.48)	165.9 (12.82)	120.6 (10.85)	231.6 (15.20)	157.4 (12.34)
I ₂	131.5 (11.24)	168.5 (12.92)	155.2 (12.46)	248.4 (15.76)	175.9 (13.10)
I ₃	156.3 (12.44)	196.3 (13.87)	149.1 (12.19)	249.6 (15.73)	187.8 (13.56)
I ₄	126.0 (11.13)	212.8 (14.54)	159.1 (12.58)	248.7 (15.56)	186.6 (13.45)
I ₅	121.3 (10.96)	256.1 (15.98)	198.7 (14.08)	226.2 (14.97)	200.6 (14.00)
I ₆	145.3 (11.95)	217.6 (14.69)	198.7 (14.08)	255.9 (15.91)	204.4 (14.16)
I ₇	156.3 (12.36)	223.7 (14.88)	171.2 (13.06)	343.5 (18.12)	223.7 (14.61)
I ₈	151.9 (12.19)	213.4 (14.56)	149.1 (12.16)	213.9 (14.50)	182.1 (13.35)
Mean	137.5 (11.60)	206.8 (14.28)	162.7 (12.68)	252.2 (15.72)	
		I	W	W at I	I at W
SE _d ±		0.49	0.68	1.35	1.19
CD (P=0.05)		1.03	1.54	NS	NS

NS = Not significant

Transformed data in parenthesis

hand weeded twice (40 and 80 DAS). The weed dry matter was estimated at all these stages and also at harvest and the total weed growth was computed.

The total dry weight of weeds accumulated during the entire crop growth period was low in hand weeded check and also in arrosolo plots (Table 11). It could be said from this data, that application of arrosolo followed by two hand weedings was similar to four hand weedings in checking the weed growth. The total weed growth in thibencarb was high and was at par with unweeded check. The results clearly show that arrosolo was more effective than thibencarb.

Among the moisture regimes, the weed growth was significantly low in the first two levels (I_1 and I_2). With decrease in the water applied upto I_5 , the weed growth did not change much. In general, the weed growth increased with decreasing levels of moisture upto I_7 and with further decrease it started declining. Hence, weed growth was significantly low, when the water applied was as low as 468 mm or as high as more than 900 mm. The fluctuations in the soil moisture were minimum under high frequency irrigation and the soil was maintained near or above field capacity for a long period under high moisture levels. The moisture content in the soil below 15 cm was high and did not fluctuate much. Under such

conditions, which are different from alternate wetting and drying, crop growth and weed growth tend to be low. The effect of moisture regimes was more or less similar under all weed control treatments and hence the interaction was not significant.

4.1.2.6. Nitrogen uptake by weeds during entire crop growth:

The N uptake by weeds during the entire crop growth period was low, surprisingly in the unweeded check (Table 12a). The weed growth was profuse only upto 40 DAS and later there was little change under uncontrolled conditions. Hence after this period, the uptake by weeds was less; the N content decreased as the dry weight increased and thus the total uptake was unaltered (Table 12b). With frequent hand weedings as in the case of hand weeded check, weeds were not allowed to grow much and as such the N removal by weeds was also low. In case of the herbicide treatments, weeds were allowed to grow for considerable periods, first upto 40 DAS and later upto 80 DAS and the weed dry weight was dependent upon the weed control efficiency of the herbicide and N removal was directly related to weed dry weight. That is how, N removal by weeds was high in thiobencarb compared to arresolo.

Table 12a. Nitrogen removal by weeds (kg/ha)

	At 40 DAS	Total upto harvest
Hand weeding	5.70	17.46
Thiobencarb	10.34	24.97
Arrosoiro	5.69	19.14
Unweeded	14.39	15.30
$SE_{d\pm}$	1.16	
CD (P=0.05)	2.64	NA
I ₁	5.41	15.19
I ₂	6.01	17.22
I ₃	7.29	18.94
I ₄	8.66	19.09
I ₅	10.77	21.12
I ₆	11.06	21.01
I ₇	11.13	22.14
I ₈	11.89	19.02
$SE_{d\pm}$	1.06	
CD (P=0.05)	2.20	NA

NA = Not analysed

Table 12b. Nitrogen removal (kg/ha) by weeds under different weed control treatments (kharif '85)

	DAS				Harvest	Total uptake
	20	40	60	80		
Unweeded	1.05	14.39	-	15.26	15.30	15.30
Hand weeding	1.05	5.70	1.84	1.61	7.26	17.46
Thioben-carb	-	10.34	-	7.99	6.64	24.97
Arrosolo	-	5.69	-	7.06	6.39	19.14

N-content under unweeded conditions (percentage)

	DAS			Harvest
	20	40	80	
<u>E. colona</u>	1.91	0.98	0.62	0.58
BLW	2.10	1.96	0.89	0.81

At higher levels of moisture, the N removal by weeds was low. With decreasing levels of water applied, the N uptake by weeds increased in a similar pattern to that of weed dry weight.

4.1.3. Rice growth 30 days after sowing: The data on growth parameters of rice viz., plant height, tillers, leaf area index (LAI) and shoot dry weight are presented in Table 13.

The different weed control treatments did not affect the plant height, LAI or shoot dry weight. The tiller number was low in thiobencarb applied plots which was due to slight phytotoxic effect of the herbicide on rice seedlings. Rao et al. (1976) reported 66 to 89 per cent seedling death when thiobencarb was applied at 4 DAS. There was 15 per cent injury to rice, but crop recovered later according to Manna et al. (1971). Manigon et al. (1981) observed injury to rice due to thiobencarb. The herbicide arrosolo did not show any phytotoxic effect. Although propanil is usually applied 15 days after sowing rice, it along with molinate did not show any ill effect on rice when applied 8 days after sowing. Molinate was safe to rice when applied 7 days before or after sowing rice but was phytotoxic when applied on the day of sowing (Moody, 1984).

Table 13. Rice growth at 30 DAS (kharif '85)

Treatment	Plant height (cm)	Tillers/m	LAI	Shoot dry weight (g/m)
Handweeding	16.1	59	0.42	5.55
Thiobencarb	16.2	34	0.20	4.06
Ayrosolo	16.3	55	0.38	5.38
Unweeded	15.7	52	0.33	4.70
SE _d ±	0.35	7.7	0.08	0.65
CD (P=0.05)	NS	17.5	NS	NS
I ₁ (233.mm)	15.5	50	0.29	3.58
I ₂ (223)	16.1	46	0.31	4.74
I ₃ (205)	16.3	45	0.33	4.34
I ₄ (191)	15.3	50	0.33	4.72
I ₅ (178)	16.5	47	0.34	5.79
I ₆ (158)	16.7	52	0.35	5.77
I ₇ (133)	16.1	57	0.38	5.00
I ₈ (111)	15.6	52	0.34	5.42
SE _d ±	0.68	5.4	0.04	0.65
CD (P=0.05)	NS	NS	NS	1.36

NS = Not significant

Different moisture levels did not influence plant height, tiller production and LAI. In the different moisture regimes LAI values ranged between 0.29 (I_1) and 0.38 (I_7). In general, LAI increased with decrease in moisture levels.

The effect of moisture regimes was felt on shoot dry weight. Rice growth was low with adequate moisture, upto I_4 level, where the TW/US^A ratio was 1.0 and above (Table 5). When the water applied was below evaporation, then the rice growth was good and resulted in higher dry weight of rice shoots. Almost negative relationship was noticed between water applied and rice growth upto 30 DAS. The seedlings were pale and yellow in the higher moisture regimes while they were normal in the plots away from the sprinkler line. Moisture regimes equal to or above the evaporation from open pan were found to depress the plant growth during initial stages. The production of new roots would be more under upland conditions compared to low land conditions during the initial stages of crop growth and establishment (Reddy, 1985), which could be due to more aerobic conditions. At very high moisture content, lack of oxygen may limit plant growth. Adequate supply of oxygen to the roots is essential to efficient uptake of nutrients and water. Eventhough rice required reduced conditions,

maximum dry matter was found in soils kept under an atmosphere at 10 per cent oxygen (Sinha and Ghildyal, 1982).

The poor growth under very high moisture regimes could be due to nutritional disorders in addition to continued anaerobic conditions of the soil. Hence soil samples were collected from I_1 and I_8 plots and analysed for available N, P, K, soil pH and EC. Available N and K were low in I_1 plots (199.1 and 515.2 kg/ha, respectively) compared to I_8 (338.2 and 590.8 kg/ha respectively). The available P level in the soil was low in I_8 (17.9 kg/ha) compared to I_1 (32.2 kg/ha). There was slight increase in the pH (7.77) and EC (0.712 m.mhos/cm) in I_1 compared to I_8 (7.55 and 0.595, respectively for pH and EC). The lower availability of N and K, although still within the normal ranges, combined with adverse soil physical conditions would have reduced plant growth due to higher moisture levels.

Striking differences were observed in the distribution of dry matter among different plant parts, particularly due to moisture levels (Table 14). On an average, leaves contributed to 39.6 per cent of the total dry matter, the contribution from sheath and roots being 37.1 and 23.3 per cent, respectively. With decrease in the water applied, the percentage of root weight decreased gradually, while the

Table 14. Dry matter partitioning in rice at 30 DAS
(kharif '85)

	Percentage distribution			Root: shoot as 1: x
	Leaf	Sheath	Root	
Hand weeding	39.2	37.2	23.6	3.24
Thiobencarb	41.6	36.1	22.3	3.49
Arrosolo	40.7	36.5	22.8	3.38
Unweeded	36.8	38.5	24.7	3.05
I ₁	32.5	34.1	33.4	1.99
I ₂	34.1	35.6	30.3	2.30
I ₃	36.5	34.7	28.8	2.47
I ₄	37.2	35.2	27.6	2.62
I ₅	41.3	36.0	22.7	3.40
I ₆	44.3	37.0	18.7	4.36
I ₇	43.8	40.6	15.6	5.42
I ₈	45.1	44.0	10.9	8.20
Mean	39.6	37.1	23.3	

Contd...

Table 14 (Contd.): Dry matter partitioning in E. colona (%)
under unweeded check

	Leaf	Sheath	Root
I ₁	41.5	35.4	23.1
I ₂	45.2	32.2	22.6
I ₃	40.0	38.7	21.3
I ₄	39.1	39.5	21.4
I ₅	43.5	42.0	14.5
I ₆	42.3	40.8	16.9
I ₇	45.3	45.8	8.9
I ₈	38.2	46.5	15.3
Mean	41.7	40.8	17.5

reverse happened with leaf and sheath. The root-shoot ratio was low with higher levels of moisture and increased rapidly with every decrease in water applied. From the absolute shoot weight values (Table 13) it could be seen that shoot weight increased with decreasing moisture levels. The actual shoot weight increased and also its ratio with root. This shows that root weight did not fluctuate much due to moisture levels. The wide variations in the percentage distribution and root-shoot ratios were due to the changes in shoot growth and less due to root growth. It is evident from these results that shoot growth is much affected due to excessive moisture, more rapidly than the root growth.

During the same period, the major weed S. colona under unchecked conditions was studied for the distribution of dry matter. The mean contribution from leaf, sheath and root was 41.7, 40.8 and 17.5 per cent, respectively. The contribution from sheath was more compared to rice. This was particularly so, under I_3 conditions. This could be the reason, for its profuse growth and higher drought tolerance compared to the crop. The trends in the variation of percentage distribution of dry matter were similar to that of rice, both being from the same family.

The different leaf related parameters such as leaf temperature (Tl), relative humidity (RH), photosynthetically

active radiation (PAR), diffusive resistance (DR) and transpiration rate (T_r) can indicate the water status of the plant which in turn was influenced by the moisture regimes. Hence all the above parameters along with relative water content (RWC) of leaves were observed at 30 DAS (Table 15). The TL was slight low under excessive moisture and the PAR and DR were also low. The transpiration rate was high with higher moisture regimes. Though it decreased to a certain extent with decreasing levels of moisture, the decrease was not constant. It again increased with very low levels of water applied. However, the RWC of leaves showed drastic and significant differences. The RWC was very high in the plots with adequate moisture and decreased significantly when water applied was low. O'Toole and Cruz (1980) explained that the relative value of diffusive resistance as adaptive mechanism to impede water loss during decreasing leaf water potential could not be evaluated. They interpreted their results as an indication that rice stomata are less sensitive than some other crop species to decreasing leaf water potential. Evaluation of stomatal behaviour as an indicator of drought stress or as a tool for screening for drought resistance is problematic (O'Toole and Chang, 1979). The effects of soil moisture vary according to soil type. On the heavy clay soil in the present study, the internal moisture status of the plant as indicated through

Table 15. Leaf related parameters at 30 DAS in hand weeded check (kharif '85)

	Leaf temp- era- ture (°C)	RH of leaf (per- cen- tage)	PAR μmol/s/m ²	DR s/cm	Tr μ H ₂ O/ cm ² /sec	RWC (per- cen- tage)
I ₁	29.2	30.0	595	0.27	48.0	96.4
I ₂	29.1	29.8	575	0.31	43.3	97.0
I ₃	29.4	28.4	735	0.31	45.5	97.7
I ₄	29.4	28.2	710	0.30	46.1	94.3
I ₅	29.4	30.4	640	0.38	37.6	84.3
I ₆	29.7	29.2	690	0.42	36.7	82.5
I ₇	29.4	30.0	810	0.34	41.5	77.9
I ₈	29.7	28.0	740	0.37	41.6	52.9
<u>E. colona</u>	30.0	29.2	1010	0.41	38.3	
<u>C. rotundus</u>	30.0	30.8	670	0.32	44.2	

RWC of leaves was in accordance with the water applied, though the pattern of crop growth appeared to be totally different. Internal water status of the plant alone cannot be used as a guide to decide upon moisture requirements, but it should be related to other conditions. The relationship needs critical studies, as the behaviour of rice is different from other crops.

4.1.4. Rice growth 60 days after sowings: The growth parameters of rice viz., plant height, tillers/m row and leaf area index were recorded at 60 DAS (Table 16).

The plant height was not affected by any of the weed control treatments. It was interesting to observe plant height unaffected due to unweeded conditions even at 60 DAS. Linear growth was not a good indicator of the effects of weed competition. Ali (1978) did not notice significant differences in the plant height between unweeded check and plots kept weed free for 40 DAS, even when observed at 100 DAS. The linear growth, however, was found to be influenced by moisture levels.

Plants were taller when total water applied was 335 mm (I_6). Water levels lower than this, affected plant height, while water applied more than 335 mm did not favour linear growth. The moisture regimes upto 30 DAS did not

Table 16. Rice growth at 60 DAS (kharif '85)

Treatment	Plant height (cm)	Tillers/m	LAI	Height of E. colona in unweeded check (cm)
Hand weeding	30.0	90	2.97	-
Thiobencarb	27.7	68	2.05	-
Arrosolo	29.4	110	3.48	-
Unweeded	30.0	37	0.90	-
SE _d ±	1.2	14.1	0.60	
CD (P=0.05)	NS	32.0	1.35	
I ₁ (489 mm)	29.3	64	1.75	38.7
I ₂ (465)	29.1	63	1.83	40.1
I ₃ (439)	29.4	68	2.17	44.1
I ₄ (413)	30.5	76	2.49	52.7
I ₅ (380)	31.1	81	2.81	66.8
I ₆ (335)	31.9	89	3.19	66.4
I ₇ (273)	29.4	90	2.76	66.1
I ₈ (226)	23.5	80	1.78	48.2
SE _d ±	1.3	8.1	0.34	
CD (P=0.05)	2.6	16.9	0.70	NA

NS = Not significant

NA = Not analysed statistically

influence the plant height, whereas the growth between 30 and 60 DAS responded to moisture gradient. Upto 30 DAS, maintaining the ratio of 0.58 (TWA/UE) was ideal for proper crop growth, excess moisture, in fact, had negative effect. During the period between 30 and 60 DAS, maintaining 0.95 ratio of TWA/UE was found necessary for increased growth. Moisture levels below or above this, did not cause any appreciable change in plant height, excepting that plant height significantly reduced when 0.62 of TWA/UE was maintained. The interaction effect was not noticed on plant height.

Tiller number was influenced by weed control treatments and moisture regimes. Tillers were fewer in unweeded check. Upto 30 DAS, unweeded conditions did not affect tiller number. Later, weeds started to cover the entire ground area; they were also taller than the crop. Thus weeds completely shaded the crop, denying the benefits of solar radiation to the crop. The competition from weeds resulted in severe tiller mortality reducing the shoot population.

The tillers in arrosoir treated plots were more compared to that in thiobencarb. Though the crop in thiobencarb plots recovered from phytotoxic effects, tiller

production was less than that in arroso. Aroso with no phytotoxic effect and good weed control provided ideal conditions for plant growth and tiller production; and the effect was comparable to hand weeding.

The tiller production continued during the period from 30 DAS to 60 DAS and it was higher on 60th day. Unlike at the initial stages, moisture levels influenced the tiller production. At higher moisture levels (I_1 and I_2) the tillers were fewer than at lower moisture regimes (I_5 to I_8) and comparable with that in I_3 and I_4 . Or in other words, when water was applied more than the evaporative demand, it interfered with the tiller production. The combined effect of weed control and moisture levels was not significant.

LAI of rice at 60 DAS was affected by weed control treatments unlike at 30 DAS. It was low under unweeded conditions (0.90) which could be due to significant reduction in tiller number. It was higher in arroso and hand weeding treatments. Though the LAI in thibencarb applied plots increased considerably, compared to 30 DAS, it could not equal to that in arroso. Okafor and De Datta (1974) reported drastic reduction in LAI

from 4.9 in a weed free situation to 1.3 when annual and perennial grass weeds were present.

LAI at 60 DAS was influenced by moisture levels. It was high in I_6 level and moisture below or above this level, did not favour LAI. The moisture regime of I_6 was favourable for increased plant height, tiller number and LAI. Hence moisture level to coincide with a ratio of 0.95 TWA/UE, during the period from 30 DAS to 60 DAS provided favourable conditions for increased crop growth of upland rice. During the early stages upto 30 DAS, TWA/UE of 0.58 was optimum as higher levels of moisture did not favour crop growth.

The height of the major weed E. colona, which completely smothered the rice under unweeded conditions was conspicuous. It increased with decreasing levels of moisture upto I_5 , remained more or less constant upto I_7 and declined drastically with 226 mm of water applied in I_8 . The weed behaved similar to rice in response to moisture regimes, but was always taller than rice.

The leaf related parameters viz., T_l , RH, PAR, DR and T_r were measured at 60 DAS, to study the differential effects of moisture on rice physiology (Table 17). The leaf temperature (T_l) did not vary much except that it was slightly higher in I_3 . Compared to 30 DAS, there was a noticeable increase in the PAR indicating increased leaf activity with advancement in age. The crop was, in fact, pale and yellow at early stages, but, recovered rapidly and turned to normal green. The chlorophyll content as mentioned, gradually improved with age. With the advancement in age, rice started to respond favourably to moisture. During the active growth period after 60 days, the symptom of leaf rolling was seen, with lower moisture levels. The leaves were dark green at very low levels of moisture. The chlorophyll content was estimated in the different moisture regimes (Table 18). An increase in the chlorophyll content was observed with decreasing levels of moisture. By decreasing the moisture level from I_6 to I_3 , the increase in chlorophyll content was to an extent of 39.9 per cent in total chlorophyll, 32.9 per cent in chlorophyll 'a' and 73.9 per cent in chlorophyll 'b'. With moisture stress, the chlorophyll 'b' content increased drastically imparting dark greenish to blue

Table 17. Leaf related parameters at 60 DAS in handweeded check (kharif, '85)

Treatment	T_l	RH	PAR	DR	Tr. rate
I_1	30.5	29.6	1310	0.41	41.8
I_2	30.4	32.2	1580	0.38	41.2
I_3	30.6	34.2	2200	0.40	37.4
I_4	30.5	31.6	1985	0.31	45.6
I_5	30.6	26.6	1610	0.40	41.6
I_6	30.6	29.4	1565	0.42	39.5
I_7	30.4	29.2	1970	0.52	33.7
I_8	31.0	28.8	2130	0.41	41.7

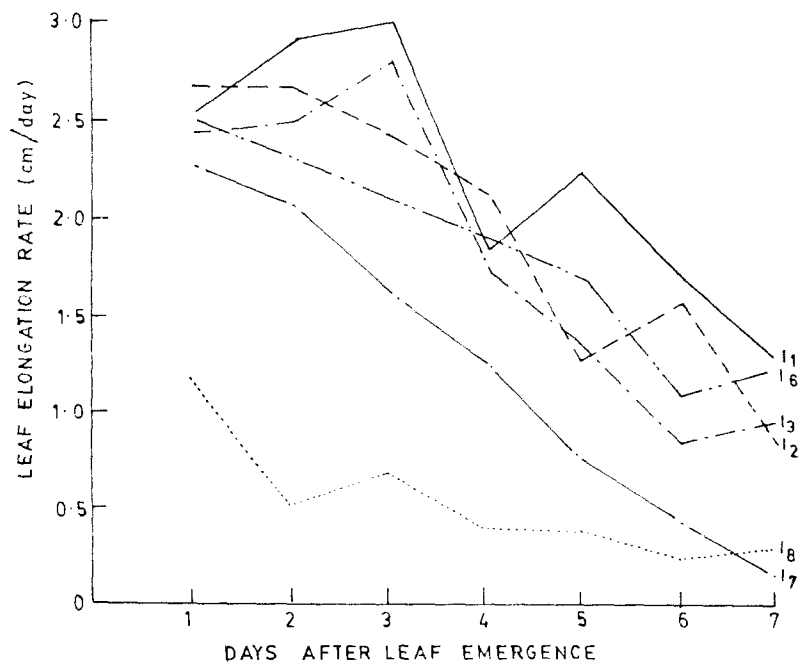
Table 18. Chlorophyll content of leaves (percentage) as influenced by moisture regimes after 60 days of crop growth

Treatment	Total chlorophyll	Chlorophyll 'a'	Chlorophyll 'b'
I_2	0.1606	0.1298	0.0287
I_4	0.1936	0.1581	0.0332
I_6	0.2015	0.1629	0.0357
I_8	0.2820	0.2165	0.0621
<u>E. colona</u>	0.2629	0.2054	0.0542
<u>E. colona</u> (Stressed)	0.2169	0.1738	0.0343

colour to the leaves. Chlorophyll 'b' does not possess any fluorescence properties unlike chlorophyll 'a' and transfers all the energy towards the process of photosynthesis (Anon., 1982b). Increase in chlorophyll 'b' seems to be the adjustment to maintain the level of photosynthesis during moisture stress.

During the active growth, the differential response to moisture was measured through the leaf elongation rate. It differed due to moisture levels (Fig.4). In general, the initiated leaves elongated faster during the first one or two days and later slowed down. With very high level of moisture (I_1), the elongation rate was always high, more than 1.5 cm/day, till the full length was attained. Though there were fluctuations from day to day in the elongation, higher moisture regimes were characterised by higher rate of elongation. In the treatment of I_7 , where 0.78 was the ratio of TWA/US during the period of observation, the leaf elongation was high initially but decreased day by day. Treatment I_3 (TWA/US ratio of 0.62) was characterised by very low rates of elongation throughout the period of leaf development. O'Toole and Baldia (1982) observed reduced leaf area expansion due to stress. It took 7 days for a leaf to attain its full length and new leaf to appear.

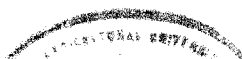
FIG. 4 LEAF ELONGATION RATE (cm/day) AT 60 DAS
AS AFFECTED BY MOISTURE REGIMES (KHARIF, 1981)



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4.1.5. Rice shoot dry weight and dry matter partitioning at

80 DAS: Shoot dry weight of rice was similar in hand weeded and arrosolo applied plots (Table 19). The crop under thiebencarb recovered from initial phytotoxic effects and as such, it was not different from the above two treatments. Unchecked weed growth resulted in very low dry weight of rice shoots. Under unweeded conditions, the weeds totally smothered the crop as explained through the height of rice and E. colona at 60 DAS and hence resulted in significantly lower dry weight of rice.

The moisture regimes influenced the shoot dry weight of rice. The shoot dry weight of rice did not differ between I_1 (684 mm) and I_4 (586 mm) and was high in I_5 (545 mm). Further decrease in water applied caused reduction in rice growth. I_8 (345 mm) resulted in lowest dry weight of rice. The TWA/UE ratio was only 0.71 upto 80 DAS under I_8 conditions. Though this ratio was sufficient for good growth during early stages upto 30 DAS, a ratio of 0.95 (I_6) and above was found good during 30-60 DAS. With advancement in age, rice crop responded to moisture. The TWA/UE ratio of less than 1.0 resulted in moisture stress conditions bringing about significant reduction in growth. Dry matter production until panicle emergence is a function of water used (Puckridge and O'Toole, 1981) even though prolonged soil drought during the entire vegetative phase is less harmful (Nayak et al., 1974).

Table 19. Rice shoot dry weight and dry matter partitioning at 80 DAS (kharif '85)

Treatment	Rice shoot dry weight g/m	Dry matter partitioning (percentage)			Root: Shoot as 1: x
		Leaf	Sheath + culm	Root	
Hand weeding	34.30	26.1	35.4	38.5	1.60
Thiobencarb	25.54	29.2	37.9	32.9	2.04
Arrosolo	34.03	27.8	37.7	34.5	1.90
Unweeded	13.67	28.6	45.7	25.7	2.89
$SE_d \pm$	4.30				
CD (P=0.05)	9.74				
I ₁ (684 mm)	24.26	28.3	40.2	31.5	2.18
I ₂ (651)	28.86	27.1	38.1	34.8	1.87
I ₃ (617)	23.99	26.5	37.7	35.8	1.79
I ₄ (586)	26.82	26.2	36.3	37.5	1.67
I ₅ (545)	36.75	27.9	37.6	34.5	1.90
I ₆ (487)	30.90	26.5	35.0	38.5	1.60
I ₇ (415)	27.27	29.2	39.5	31.3	2.20
I ₈ (345)	16.25	31.3	41.0	27.7	2.60
$SE_d \pm$	3.49				
		Mean			
CD (P=0.05)	7.27	27.9	39.2	32.9	

The partitioning of dry matter to the different plant parts viz., leaf, sheath (including culm) and root was observed. Under most weed free conditions (hand weeding) the per cent contribution of roots to total dry weight was more. A distinct decrease in the distribution of dry matter to roots was noticed in the unweeded check. Unweeded conditions not only lowered the above ground growth as seen through shoot dry weight, plant height and LAI, but also reduced the root growth. The moisture regimes caused variations in the partitioning of dry matter but not to the tune as observed at 30 DAS. The contribution through leaf sheath and culm was high both at very high and very low levels of moisture. With higher levels of moisture, the dry matter contribution through leaf was low while at lower level, the contribution through root was low. The root-shoot ratio also did not fluctuate very widely as observed at 30 DAS. The values ranged between 1.60 and 2.60 at different moisture levels. Chang and Vergara (1975) while discussing about the morpho-agronomic characteristics of upland rice, stated that the dry root weights of upland and low land varieties were similar, even though the shoot weights of upland varieties were low resulting in significantly higher root-to-shoot ratios for upland varieties.

At 80 DAS, the major weed E. colona under undisturbed conditions (unweeded check) was also sampled and the

partitioning of dry matter was studied (Table 20). E. colona flowered as early as at 30 DAS of rice and shedding of seed was observed at 80 DAS. The percentage contribution through panicle increased with decreasing levels of moisture while the contribution of roots to total dry weight decreased with decreasing levels of moisture. The sheath plus culm in rice contributed to 39.2 per cent of the total dry matter while in E. colona the sheath contributed to 51.2 per cent of the total dry matter. Unlike the leaf or root, the fluctuations in the sheath weight were less and this could be the prime reason for higher adaptation of this weed to fluctuating moisture levels. The root-to-shoot ratio was wide for this weed compared to rice.

4.1.6. Rice growth at 90 DAS: The growth of rice was observed at 90 DAS in the form of plant height, tiller number and LAI (Table 21). The plants were taller in hand weeding, thiobencarb and arrosoir treatments, while unweeded conditions lowered the plant height.

Reduction in the plant height was observed under moisture stress conditions (I_7 and I_8). Unlike in the early stages, plant height responded to moisture. With increase in the level of moisture, plant height increased, though the differences did not reach the level of significance,

Table 20. Dry matter partitioning in E. colona at 80 DAS
under unweeded conditions (kharif '85)

Treatment	Dry matter partitioning (percentage)				Root : shoot as 1: x
	Leaf	Sheath	Panicle	Root	
I ₁	15.9	52.0	8.8	23.3	3.29
I ₂	20.8	46.1	8.1	25.0	3.00
I ₃	14.9	47.0	9.2	28.9	2.46
I ₄	18.7	50.9	10.7	19.7	4.09
I ₅	18.4	52.0	15.0	14.6	5.86
I ₆	15.9	56.5	11.8	15.8	5.35
I ₇	12.7	46.5	19.1	21.7	3.63
I ₈	16.2	58.7	15.6	9.5	9.45
Mean	16.7	51.2	12.3	19.8	

Table 21. Rice growth at 90 DAS (kharif '85)

Treatment	Plant height (cm)	Tillers/m	LAI
Hand weeding	59.3	106	5.77
Thiobencarb	57.2	77	4.22
Apresolo	58.5	89	4.87
Unweeded	39.2	26	0.67
SE _d ±	2.1	7.1	1.52
CD (P = 0.05)	4.8	16.1	3.45
I ₁ (787 mm)	56.7	73	3.58
I ₂ (709)	60.3	73	3.63
I ₃ (675)	57.8	70	3.69
I ₄ (644)	56.4	68	3.55
I ₅ (603)	54.8	70	4.00
I ₆ (545)	53.3	78	4.33
I ₇ (473)	47.7	78	4.42
I ₈ (403)	41.6	85	3.85
SE _d ±	3.5	4.6	2.50
CD (P=0.05)	7.2	NS	NS

NS = Not significant.

between I_6 and I_1 . In fact, the plants were taller at I_6 level at 60 DAS while the maximum height was observed with I_2 level, at 90 DAS. The response to water appeared to be more positive between 60 and 90 days after sowing of rice. The interaction effect was not significant.

The number of tillers was affected by weed control treatments. Under unweeded conditions, there was tiller mortality and the tiller number got reduced to minimum. The crop in thiobencarb and arrosole applied plots did not differ in tiller number, thus showing complete recovery of crop in thiobencarb applied plots from the initial phytotoxic effects. The tiller number was high in hand weeding treatment, which received four hand weedings by that time. Tiller multiplication was rapid during the period between 60 and 90 DAS and responded to moisture levels, unlike at 60 DAS. The shoot population in higher moisture regimes increased and thus the differences in tiller number at different moisture levels were not significant.

The LAI values were higher in all the weed management treatments as compared to that in unweeded check. The differences in LAI due to moisture levels were not significant. The interaction effect was also not noticed. There was considerable increase in the LAI between 60 and 90 DAS.

Very wide differences were observed in the days to flowering (Table 22). Under unweeded conditions, tillering was affected. Only primary tillers survived which were also very weak and aborted the panicles causing early flowering. Flowering started 78 DAS. But once weeds were controlled, the days to flowering were more related to weed free conditions. Crop under hand weeding was the first to flower (88 days), where the crop was relatively weed free. The crop in arrosolo and thiobencarb applied plots took 89 and 90 days, respectively, to flower.

The differences in the days to flowering were more pronounced in different moisture levels. Flowering started early (85 days) in the high moisture regime (1.52 TWA/US). With gradual decrease in moisture, the crop took relatively more days to flower. Under L_7 (TWA/US of 0.92) the crop started to flower 94 DAS and when the moisture level declined further (I_9), the crop failed to flower.

The crop duration is longer under upland conditions. Chang and Vergara (1975) found that most upland varieties flowered 1 to 15 days later under upland conditions, and IR-5 matured 37 days later than when planted as a drill-flooded crop. A more positive relation was observed between days to flowering and the hydrology of the drill sown rice.

Table 22. Flag leaf characters, canopy temperature, at
90 DAS and days to flowering (kharif '85)

Treatment	RWC *	SLM 10^{-3} g/cm ²	SLA cm ² /g	Tc	Tc-Ta	Days to flower- ing
I ₁	81.6	541	185.0	27.2	-3.6	85
I ₂	83.4	517	193.3	27.7	-3.5	86
I ₃	83.7	541	185.2	27.2	-4.0	86
I ₄	86.9	529	190.2	27.7	-3.9	87
I ₅	87.5	541	185.3	28.4	-2.9	88
I ₆	91.7	455	220.3	29.0	-2.2	92
I ₇	76.1	467	214.3	30.8	-0.5	94
I ₈	67.5	505	198.6	32.0	+0.3	-
Hand weeding						88
Thiobencarb						90
Arrosoiro						89
Unweeded						78

* Fully unfurled leaves in I₆, I₇ and I₈

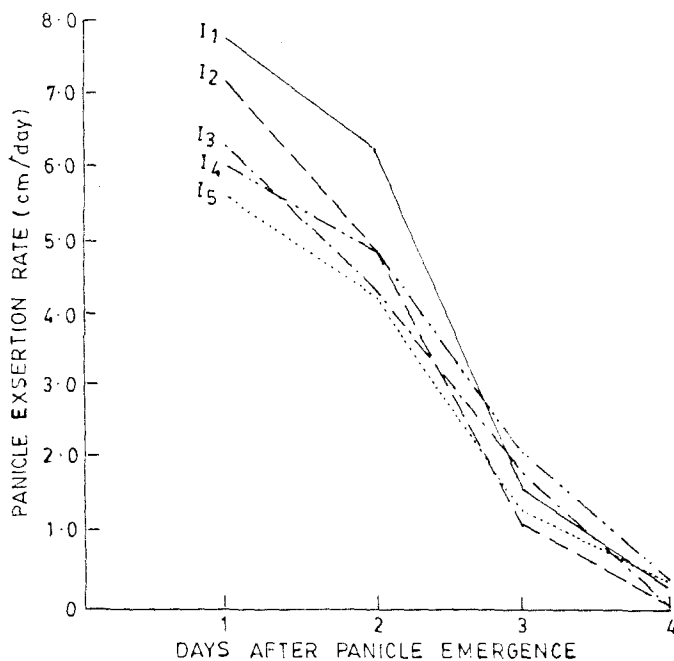
The effect of moisture levels on leaf characters was observed at 90 DAS through relative water content (RWC), specific leaf weight (SLW) and specific leaf area (SLA). The canopy temperature and canopy-air temperature differentials were measured through infrared thermometer. The RWC of the flag leaves (upto I_5) was low in higher moisture regimes and increased gradually with decreasing levels (Table 22). The flag leaf emerged earlier in higher levels of moisture due to early flowering. Thus, RWC of flag leaves seemed to be more related to the age of the leaf which in turn was the function of moisture availability. In the remaining levels (I_6 to I_8), the RWC of fully unfurled leaves had strong positive relation with soil moisture content. Rice crop showed osmotic adjustments and the plants previously conditioned or stressed maintained higher turgidity than the unstressed plants (Cutler *et al.*, 1980). However, the results would be different under continuous stress.

The SLW was high for the flag leaves (I_1 to I_5) while the SLA was more for the fully unfurled leaves (I_6 to I_8). Higher SLW values show that flag leaves were more thicker than the other leaves. O'Toole (1982) considered thick leaves as an adaptation to moisture stress. The SLA of the fully unfurled leaves (I_6 to I_8) decreased with increasing stress. Nobel (1980) stated that greater mesophyll surface area per unit leaf area results in higher photosynthetic rate.

The canopy temperature (T_c) did not vary much upto I_4 level, but gradually increased thereafter with decrease in water availability (Table 22). The increase in canopy temperature was a good indication of reduced transpiration. The T_c-T_a values also did not fluctuate much upto I_4 and increased gradually with decreasing moisture levels. It was interesting to find negative values of T_c-T_a even upto I_7 level and the T_c-T_a was positive only with I_8 , where the leaves were totally rolled during mid day. T_c-T_a values of -3.0 or above, looked to be appropriate for upland rice crop to keep the crop unstressed. These observations show the possibility of using infra-red thermometer in upland rice for developing stress indices. However, the chances of such studies are remote as upland rice is mostly rainfed.

The panicle exertion rate was recorded during flowering. Panicles emerge from the flag leaf sheath mainly by the elongation of the internode, which pushes the panicle out of the flag leaf sheath. Moisture stress interferes with the internodal elongation and complete exertion of the panicles. The daily rate of panicle exertion was measured under different moisture treatments and presented in Fig.5. It was high during first day and decreased gradually. The exertion was rapid and almost complete in 4 days in the moisture regimes upto I_5 , while it was slow and erratic with no definite trend in the very low levels of moisture.

FIG. 5 PANICLE EXSERTION RATE (cm/day)
AS AFFECTED BY MOISTURE REGIMES
(KHARIF 1985)



On the first day, the exertion was upto 8 cm in I_1 , while it was about 5.5 cm in I_5 . On the second day also, the exertion was more in the higher moisture regimes. By second day itself, major portion of the panicle was exerted. The rate of panicle exertion rapidly, decreased in I_3 and I_2 , while the decrease was gradual in I_4 and I_5 with the result that the rate of exertion in these moisture levels was more compared to I_1 and I_2 on 3rd and 4th day. O'Toole and Namuco (1983) found the panicle exertion rate to decrease linearly with decreasing mean daily leaf water potential and concluded that decreased panicle exertion was a causal factor of spikelet sterility in moisture stressed rice.

4.1.7. Growth analysis: The growth during the season was analysed by computing crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR).

The CGR was low during the initial periods (Table 23) and increased with advancement in age. Fast growth was observed between 80 DAS and maturity. Upland rice is characterised by slow crop growth rates primarily due to low moisture and higher mechanical impedence. Under unweeded conditions, the CGR was low upto 80 DAS and thereafter there was no growth practically. Among the different moisture

Table 23: Crop growth rate (g/m/day), Relative growth rate (g/g/day) and Net assimilation rate (10^{-5} g/dm²/day) under different treatments (kharif '85)

	Crop growth rate			Relative growth rate			Net assimilation rate		
	DAS			DAS			DAS		
	0-30	30-80	80-M	0-30	30-80	80-M	0-30	30-80	30-80
Hand weeding	0.18	0.57	2.59	0.034	0.040	0.032	51.6	17.0	
Thiobencarb	0.13	0.43	1.92	0.022	0.037	0.031	48.0	19.5	
Arrosoir	0.18	0.57	1.99	0.032	0.037	0.028	52.5	20.4	
Unweeded	0.16	0.18	0.00	0.026	0.021	Nil	48.5	19.4	
I ₁	0.11	0.41	3.13	0.018	0.037	0.039	39.0	19.2	
I ₂	0.16	0.48	2.75	0.028	0.036	0.034	48.5	22.7	
I ₃	0.14	0.39	3.00	0.025	0.034	0.038	44.7	19.5	
I ₄	0.16	0.44	2.63	0.028	0.033	0.035	48.7	19.5	
I ₅	0.19	0.62	2.11	0.035	0.045	0.026	59.0	26.0	
I ₆	0.19	0.50	1.71	0.035	0.032	0.025	58.5	18.5	
I ₇	0.16	0.44	1.03	0.029	0.032	0.019	47.0	16.5	
I ₈	0.18	0.21	0.98	0.032	0.022	0.027	55.7	10.5	

M = Maturity.

regimes, OGR was high in I_5 upto 80 DAS. However, after 80 days, a positive relationship with moisture was observed. The RGR did not differ much between different periods of observation (Table 23). Similar to OGR, the RGR was nil in unweeded check beyond 80 DAS. NAR was high during the initial period compared to the period between 30-80 DAS. The variations in NAR due to treatments appeared to be negligible.

4.1.8. Plant height at harvest: Plant height recorded at harvest was influenced by weed control treatments, moisture regimes and their combined effect (Table 24).

The plants were taller in all the weed control treatments as compared to the unweeded check. Plant height upto 60 DAS was not affected by weed control treatments and since then the effect of weeding was reflected through plant height. The common hand weeding at 40 and 80 DAS should have facilitated the crop to attain the linear growth in other treatments. Depressed plant height in upland rice due to severe weed infestation was reported by Wells and Cabradilla (1981).

Plant height decreased gradually with decreasing levels of moisture, but the differences in the first 3 levels (990 to 888 mm) were not significant. The plants were dwarf

Table 24. Plant height (cm) at harvest (kharif '85)

	Hand weeding	Thioben- carb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	74.4	72.3	72.0	46.7	66.3
I ₂ (937)	72.4	69.7	69.7	45.9	64.4
I ₃ (888)	70.0	68.5	68.6	47.3	63.6
I ₄ (843)	67.6	67.2	66.5	45.0	61.6
I ₅ (790)	65.5	64.2	64.5	44.4	59.6
I ₆ (701)	61.2	61.7	58.9	46.6	57.1
I ₇ (578)	56.2	55.1	56.8	39.6	51.9
I ₈ (468)	47.9	49.6	47.6	33.8	44.7
Mean	64.4	63.5	63.1	43.7	-
	I	W	W at I	I at W	
SE _d ±	1.4	1.5	2.7	2.5	
CD (P=0.05)	3.0	3.3	5.6	5.1	

with very low moisture (468 mm). Plant height did not respond to levels of moisture upto 30 DAS while positive response was noticed from 60 days onwards. The effect of moisture was more pronounced under relatively weed free conditions. Under unweeded check, plant height was not influenced by moisture levels excepting at I_7 and I_8 . Severe weed competition coupled with severe moisture stress resulted in shortest plants (33.8 cm).

4.1.9. Total tillers: The total shoot population was influenced by weed control treatments (Table 25). It was low in unweeded check. Severe weed competition resulted in tiller death and this trend was observed from 60th day onwards. Among the other treatments, though the shoot population in thiobencarb plots was similar to that in arrosolo plots, it was low compared to hand weeding. Hand weeding and arrosolo showed similar effect.

The number of total tillers was not influenced by different moisture regimes. The interaction effect was not noticed. In a particular range of available moisture where severe stress conditions are not encountered, shoot population tends to remain constant or unaffected. Water deficits at vegetative phase even if decrease the tiller number, appear to be least detrimental to yield (O'Toole and Chang, 1979). On the other hand, decreased tiller number due to

Table 25. Total tillers/m at harvest (kharif '85)

	Hand weeding	Thioben- carb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	119	92	105	20	84
I ₂ (937)	118	93	93	28	83
I ₃ (888)	125	91	83	19	80
I ₄ (843)	118	91	90	27	81
I ₅ (790)	120	92	108	16	84
I ₆ (701)	115	112	118	22	92
I ₇ (578)	116	96	116	29	89
I ₈ (468)	127	100	122	25	94
Mean	120	96	105	23	-
	I	W	W at I	I at W	
SE _d ±	6.1	5.3	10.8	10.6	
CD (P=0.05)	NS	11.9	NS	NS	

NS = Not significant.

severe weed infestation was reported by Okafor and De Datta (1974) and Sharma *et al.* (1977).

4.1.10. Yield attributes and yield

4.1.10.1. Productive tillers: Weed control treatments influenced the number of productive tillers in a similar way to that of total tillers (Table 26). The number of productive tillers was high in hand weeding and low in unweeded check. The effect of thiobencarb and arrosolo was similar. The conversion of total tillers into productive tillers was more or less uniform due to the common hand weeding at 80 DAS. The productive tillers number was the resultant of the total tiller number which was decided earlier by the degree of weed competition.

In spite of the uniform shoot population, number of productive tillers varied due to moisture regimes. There was a gradual decrease in the number of productive tillers with decrease in the soil moisture, though the differences did not reach the level of significance upto I_6 . Productive tillers were low in I_7 . With 468 mm (I_8), maintaining TWA/UE ratio of 0.71 for the total period, the crop failed to flower. During the active vegetative growth period, the crop suffered for want of moisture. Leaf rolling during mid-day was observed for long periods. While stating that water deficit

Table 26: Productive tillers/m at harvest (kharif '85)

	Hand weeding	Thio- benoarb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	103	93	95	15	74
I ₂ (937)	100	84	83	15	71
I ₃ (888)	109	82	77	10	70
I ₄ (843)	96	79	80	12	67
I ₅ (790)	100	77	90	10	69
I ₆ (701)	81	83	83	12	65
I ₇ (578)	50	58	52	16	44
I ₈ (468)	-	-	-	-	-
Mean	91	78	80	13	
	I	W	W at I	I at W	
SE _d ±	6.6	3.3	8.3	9.7	
CD (P=0.05)	13.8	7.6	16.9	19.8	

at vegetative stage appeared to be least detrimental to yield, O'Toole and Chang (1979) revealed that the same at reproductive stage in rice, about the last 55 to 60 days, caused irreparable loss of potential yield. Because of the use of continuous variable irrigation throughout the study, the crop in I_3 was under continuous stress. This could be the reason for non-flowering of rice in this treatment. At higher moisture level (I_4) the effect of hand weeding and arrosalo was similar while thiobencarb was significantly different from hand weeding. With decreased levels of moisture at I_6 and I_7 , the effect of all these weed control treatments was same. Under unweeded conditions, moisture levels did not influence the productive tiller number.

4.1.10.2. Per cent productive tillers: In thiobencarb treatment, 82 per cent of the total tillers were productive, and it was better than hand weeding (Table 27). But hand weeding was better, with regard to the actual number of total and productive tillers. The response of a crop to favourable environment would be more when the crop was subjected to some sort of stress during early stages than when grows under continued ideal conditions.

In thiobencarb treatment, the crop suffered due to phytotoxicity and also due to weed competition. When ideal

Table 27. Per cent productive tillers (kharif '85)

	Hand weeding	Thio- bencarb	Arrosoiro	Unweeded	Mean
I ₁ (990 mm)	86.5	90.6	89.6	73.9	85.2
I ₂ (937)	84.6	90.9	89.7	52.6	79.5
I ₃ (888)	87.0	89.8	92.7	56.0	81.4
I ₄ (843)	82.8	85.6	89.3	44.5	75.5
I ₅ (790)	82.8	82.7	83.0	60.2	77.2
I ₆ (701)	70.3	74.9	70.2	58.1	68.4
I ₇ (578)	43.9	59.4	45.7	57.2	51.6
I ₈ (468)	-	-	-	-	-
Mean	76.8	82.0	80.0	57.5	-
	I	W	W at I	I at W	
SE _d ±	4.4	1.6	5.9	6.9	
CD (P=0.05)	9.1	3.6	11.9	14.0	

conditions were provided later due to common hand weeding, the crop response would have been rapid. This could be the reason for higher percentage of productive tillers in thiobencarb. However, the actual number would influence the grain yield.

The percentage productive tillers decreased gradually with decreasing levels of moisture. Significant reduction was observed with very lower levels of moisture in I_6 and I_7 . It was interesting to observe that the percentage of productive tillers in unweeded check was equal to or better than other treatments at I_7 . These results showed that at lower moisture regimes, higher level of productivity cannot be achieved, even with effective weed control.

4.1.10.3. Panicle length: The panicle length due to the three weed control treatments viz., hand weeding, thiobencarb and arrosolo did not differ much, but was low in unweeded check (Table 28).

With lower moisture regimes, the panicle length decreased gradually. It was low in I_7 . The interaction effect was not significant. With decrease in the moisture level, the panicle exertion rate was low (Fig.5), resulting in incomplete exertion of the panicles. Hence the panicle length was affected.

Table 28: Panicle length (cm) (Kharif '85)

	Hand weeding	Thio- bencarb	Arrosoiro	Unweeded	Mean
I ₁ (990 mm)	19.0	17.9	18.1	8.3	15.8
I ₂ (937)	18.4	18.1	18.6	9.0	16.0
I ₃ (888)	18.2	18.4	17.9	8.3	15.7
I ₄ (843)	17.5	17.9	18.2	8.8	15.6
I ₅ (790)	18.1	17.4	17.3	8.6	15.3
I ₆ (701)	17.7	17.4	16.1	8.9	15.0
I ₇ (578)	15.0	15.8	14.5	8.0	13.3
I ₈ (468)	-	-	-	-	-
Mean	17.7	17.6	17.2	8.6	-
	I	W	W at I	I at W	
SE _d ±	0.4	0.6	0.9	0.7	
CD (P=0.05)	0.8	1.4	NS	NS	

NS = Not significant.

4.1.10.4. Panicle weight: In a similar way to that of panicle length, panicle weight was low in unweeded check (Table 29). It was high in the weed management treatments which were comparable between themselves.

The panicle weight decreased gradually with decrease in the level of moisture and it was low in L_7 . Under unweeded conditions, the panicle weight was very low and the different moisture regimes showed no effect. In other treatments, it decreased with lower levels of moisture. The number of spikelets per panicle, the per cent chaff and the weight of filled grains, together, influence the panicle weight. The decrease in weight could be due to any one of the above factors or due to their combined effect.

4.1.10.5. Number of filled grains per panicle: The number of filled grains was low in unweeded check (Table 30). The differences among the rest of the weed control treatments were not significant. Ali (1978) did not observe significant differences in grain number due to butachlor, thiobencarb and hand weeding treatments.

The effect of moisture regimes was more pronounced. The differences in the first 4 levels were not significant. Thereafter, the number of filled grains decreased with further decline in moisture level. The rate of decrease was more

Table 29: Panicle weight (g) (kharif '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	1.64	1.50	1.60	0.10	1.21
I ₂ (937)	1.44	1.61	1.62	0.13	1.20
I ₃ (888)	1.51	1.54	1.52	0.08	1.16
I ₄ (843)	1.40	1.46	1.57	0.11	1.14
I ₅ (790)	1.60	1.45	1.39	0.11	1.14
I ₆ (701)	1.37	1.31	1.16	0.11	0.99
I ₇ (578)	0.73	0.93	0.70	0.08	0.62
I ₈ (468)	-	-	-	-	-
Mean	1.39	1.40	1.37	0.10	-
	I	W	W at I	I at W	
SE _d ±	0.09	0.08	0.14	0.14	
CD (P=0.05)	0.18	0.18	0.29	0.28	

Table 30: Number of filled grains/panicle (kharif '85)

	Hand weeding	Thio- ben carb	Aerrosolo	Unweeded	Mean
I ₁ (990 mm)	73.8	67.9	75.2	8.1	56.2
I ₂ (937)	66.5	69.3	67.0	4.6	51.8
I ₃ (888)	69.9	69.0	65.0	4.3	52.0
I ₄ (843)	63.3	68.5	71.3	6.0	52.3
I ₅ (790)	61.7	66.4	65.7	3.7	49.4
I ₆ (701)	56.2	58.2	53.4	6.5	43.6
I ₇ (578)	39.8	49.3	41.9	8.4	34.8
I ₈ (468)	-	-	-	-	-
Mean	61.6	64.1	62.8	5.9	
	I	W	W at I	I at W	
SE _d ±	2.7	2.9	5.0	4.6	
CD (P=0.05)	5.6	6.6	10.4	9.4	

rapid in hand weeding, compared to thibencarb. Once the stress due to weeds was relieved in thibencarb plots, the response to moisture appeared to be more due to adaptive mechanisms of the crop. The effect of moisture was not felt under unweeded conditions as the filled grain number remained unchanged across the moisture levels tested.

O'Toole and Moya (1981) reported reduced number of grains per panicle due to moisture stress.

4.1.10.6. Number of chaffy grains per panicle: The differences in the number of chaffy grains due to weed control treatments were not significant (Table 31). The number of filled grains per panicle was negligible (5.9) in unweeded check compared to other treatments (more than 60). Hence the actual number of unfilled grains did not give the true picture.

With very low levels of moisture at I_6 and I_7 the chaffy grain number was high. The stress at meiotic stage or at anthesis results in sterility of florets (O'Toole and Chang, 1979).

The sterility percentage would be more meaningful than the data on the actual number of chaffy grains.

4.1.10.7. Sterility percentage: The percentage spikelet sterility was high in the unweeded check compared to other

Table 31: Number of chaffy grains/panicle (kharif, '85)

	Hand weeding	Thio- bencarb	Arrosoiro	Unweeded	Mean
I ₁ (990 mm)	4.6	4.4	4.2	2.9	4.0
I ₂ (937)	6.3	5.4	5.0	3.4	5.0
I ₃ (888)	5.5	4.7	5.0	2.5	4.4
I ₄ (843)	6.2	4.2	6.5	3.6	5.1
I ₅ (790)	6.7	5.6	5.3	4.6	5.5
I ₆ (701)	8.2	6.5	9.3	4.2	7.0
I ₇ (578)	16.0	10.8	15.5	7.6	12.5
I ₈ (468)	-	-	-	-	-
Mean	7.6	5.9	7.3	4.1	-
	I	W	W at I	I at W	
SE _d ±	1.2	1.4	2.0	1.8	
CD (P=0.05)	2.5	NS	NS	NS	

NS = Not significant.

treatments (Table 32). The unchecked weed growth smothered rice crop. The tops of rice plant and weeds compete for light and root zone competes for nutrition and severe competition causes fewer panicles and spikelets per plant (Utomo, 1981).

The sterility percentage was low in I_1 (990 mm). In general, sterility percentage increased with decreasing levels of moisture in all weed control treatments except that no definite pattern was seen in unweeded check which could be due to very low number of spikelets (Fig.6). When averaged over weed control treatments, the sterility percentage was high in the moisture regime of I_7 . Chaudhry and McClean (1963) reported higher percentage of sterility under moisture regime of near field capacity compared to submergence in low land rice. Jones (1981) and O'Toole and Moya (1981) noted higher percentage of spikelet sterility and reduced number of grains per panicle due to moisture stress. From their studies using line source sprinkler system, Janiye and Moody (1984) stated that spikelet sterility was not affected by different weed control treatments; but it increased significantly with decrease in the amount of water applied in all weeding treatments. Cruz and O'Toole (1984) reported that the dominant yield component influencing grain yield was spikelet sterility.

Table 32: Sterility percentage (kharif, '85)

	Hand weeding	Thio- ben carb	Arrosolo	Unseeded	Mean
I ₁ (990 mm)	5.9	6.2	5.5	27.9	11.3
I ₂ (937)	8.3	7.3	7.1	45.7	17.1
I ₃ (888)	7.1	6.1	7.2	38.4	14.7
I ₄ (843)	8.6	5.7	8.3	40.8	15.9
I ₅ (790)	9.7	7.3	7.5	57.2	20.5
I ₆ (701)	12.6	10.2	14.3	42.8	20.1
I ₇ (578)	30.3	17.9	26.8	54.3	32.3
I ₈ (468)	-	-	-	-	-
Mean	11.8	8.7	11.0	43.9	
	I	W	W at I	I at W	
SE _d ±	2.6	4.0	6.2	5.1	
CD (P=0.05)	5.4	9.0	NS	NS	

NS = Not significant

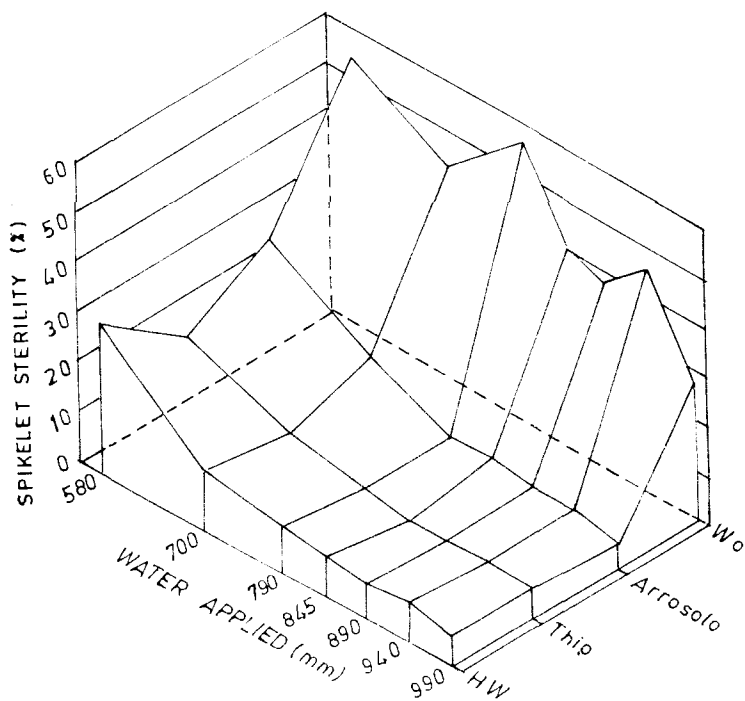
FIG.6 SPIKELET STERILITY AS AFFECTED BY MOISTURE REGIMES UNDER DIFFERENT WEED CONTROL TREATMENTS (KHARIF, 1985)

$$HW \quad \hat{y} = 54.33 - 0.052 x \quad r = -0.8774^{**}$$

$$Thio \quad \hat{y} = 29.96 - 0.026 x \quad r = -0.8685^{*}$$

$$Arroso \quad \hat{y} = 51.07 - 0.049 x \quad r = -0.9145^{**}$$

$$W_0 \quad \hat{y} = 82.32 - 0.047 x \quad r = -0.6807 \text{ NS}$$



4.1.10.8. 1000-grain weight: The weight of 1000 grains was low in the unweeded check, while it was similar with rest of the weed control treatments (Table 33). The weed competition will not influence the grain weight, unless it continued upto maturity. Ali (1978) found the test weight to be low in unweeded control while different herbicidal treatments did not influence it. 1000-grain weight was not affected by different weed control treatments in the study by Janiys and Moody (1984).

The 1000-grain weight was similar in the moisture regimes of I_1 to I_4 , but decreased thereafter with further decrease in the moisture level. The test weight was low in I_7 . The effect of weed control treatments was similar at all moisture regimes except at I_4 where arrosolo was better than thiobencarb and at I_6 thiobencarb was better than the rest. The 1000-grain weight under unweeded check remained unaffected due to moisture levels.

The moisture stress during grain filling period i.e., about 21 days post-anthesis would result in lower 1000 grain weight (O'Tools and Chang, 1979), through reduced current photosynthesis, though partially compensated by translocation of reserve starch from the culm and leaf sheath (IRRI, 1983).

Table 33: 1000-grain weight (g) (kharif, '85)

	Hand weeding	Thio- ben carb	Arrosoiro	Unweeded	Mean
I ₁ (990 mm)	23.6	22.9	25.7	13.6	21.4
I ₂ (937)	22.4	22.6	22.3	13.9	20.3
I ₃ (888)	23.0	22.5	22.8	14.6	20.7
I ₄ (843)	22.3	23.5	23.8	14.9	21.1
I ₅ (790)	20.4	22.6	21.6	14.4	19.7
I ₆ (701)	18.8	22.0	18.8	13.5	18.3
I ₇ (578)	17.9	17.6	17.2	13.0	16.4
I ₈ (468)	-	-	-	-	-
Mean	21.2	21.9	21.8	14.0	-
	I	W	W at I	I at W	
SE _d ±	0.7	0.8	1.2	1.1	
CD (P=0.05)	1.5	1.8	2.6	2.3	

4.1.10.9. Grain yield: Grain yield was influenced by weed control treatments (Table 34). It was high in hand weeding treatment. The treatments arrosolo and thibencarb did not differ much between themselves with regard to grain yield. Under unweeded conditions the grain yield was very low and practically negligible. In case of hand weeding, the total weed growth allowed during the entire period of study was low. Because of relatively greater weed free conditions during the critical period of competition, the crop enjoyed the greatest benefits of the favourable environment resulting in higher number of total tillers and productive tillers. The LAI during reproductive period was also more. The higher number of panicles could be the chief factor contributing to higher grain yield, as the differences in grain number and grain weight were very little compared to herbicide treatments.

In spite of the better weed control with arrosolo, than with thibencarb, the increase in grain yield was not perceptible. This could be due to uniform hand weeding at 40 and 80 DAS. These two treatments did not differ much in influencing the yield attributes like number of productive tillers, number of filled grains per panicle and test weight.

Table 34: Grain yield (kg/ha) (Kharif, '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	4541	3507	4034	58	3035
I ₂ (937)	4562	3232	3545	40	2845
I ₃ (888)	5029	3001	3875	29	2984
I ₄ (843)	4231	2791	3485	20	2632
I ₅ (790)	4042	2613	2951	23	2408
I ₆ (701)	2731	2410	1847	42	1758
I ₇ (578)	777	703	1052	78	653
I ₈ (468)	-	-	-	-	-
Mean	3702	2608	2970	41	-
	I	W	W at I	I at W	
SE _d ±	226	222	433	415	
CD (P=0.05)	470	502	896	839	

Due to unweeding, tiller number was the first factor of growth to be affected, followed by LAI. Later the plant height also got affected due to continued weed growth. The weed growth reached its peak by 80 DAS and rice was completely smothered. All the yield attributes were severely affected resulting in practically no yield. Complete failure of crop can occur due to uncontrolled weed growth (Vega *et al.*, 1967; Manna *et al.*, 1971; Madrid *et al.*, 1972; Mukhopadhyay *et al.*, 1972). On the other hand, several workers have confirmed the efficiency of hand weeding as compared to other weed control methods (Ghosh *et al.*, 1977; Dixit and Singh, 1981). Manna *et al.* (1971) reported good weed control with thibencarb, where slight injury to the crop was observed which recovered later. Good weed control with thibencarb was reported when followed by one hand weeding (Bhan *et al.*, 1984; Poonia *et al.*, 1984 and Trivedi *et al.*, 1986). Molinate-propanil combination gave excellent weed control in Sudan Gazira (Babiker, 1982), at IRRI (1983) and in India (Ramachandra Prasad *et al.*, 1986) where yields were comparable with that of hand weeding.

Grain yield was lowered due to decrease in the moisture regimes. Highest yield was observed with the wettest regime (I_1) but the differences were not significant upto the level of I_4 . The yield reduction was significant at

the levels of I_6 (42.1 per cent) and I_7 (78.8 per cent). With 468 mm of water applied (I_8), there was no yield. The crop response to moisture was remarkable from 60 days onwards. Higher moisture regimes resulted in increased plant height, higher per cent of productive tillers, more number of filled grains per panicle, lower sterility percentage and higher 1000-grain weight. However, the differences between the first 4 levels (I_1 to I_4) were not significant in most of the above characters. The water applied in these treatments varied between 843 and 990 mm and the TWA/UE for the total crop period ranged between 1.28 and 1.51. The average water requirement was 960 and 780 mm under 1.8 and 1.4 IW/CPE ratios when studied under the conditions of Parbhani (Mumtazbuddin and Borulkar, 1983). In the present study, when the total water applied fell short of the total upland evaporation as in I_7 , there ^{was} striking decrease in the yield and no yield could be obtained at 0.71 TWA/UE ratio. The results show that upland rice can yield only when the rainfall for the crop duration is above the total evaporation. Sankaran and De Datta (1984) could get no grain yield when water applied was below 925 mm at IRRI, Manila.

The interaction between weed control treatments and moisture regimes was significant. Hand weeding was better than thiobencarb upto the moisture level of I_5 . The grain

yield under arrosolo and hand weeding was similar at moisture levels of I_1 and I_4 . The yield in arrosolo applied plots did not differ from that in thiobenearb plots significantly, except at I_3 . At I_7 , where the moisture level dropped below evaporation, the grain yield under chemical and hand weeding treatments was similar. No response to moisture was noticed under unweeded check, where the yield was practically nil.

Sankaran and De Datta (1984) reported that the grain yields under pendimethalin and oxadiazon were similar to those of the hand weeded check at high moisture levels and when moisture levels dropped below cumulative pan evaporation, yields with chemical and hand weeding were similar to those in unweeded check. Janiya and Moody (1984) recorded increased grain yields by hand weeding and pendimethalin application when the amount of water applied was above pan evaporation, or when the crop was able to extract water to meet evaporative demand, but no yield increase due to weed control was obtained at lower moisture levels.

4.1.10.10. Straw yield: The straw yield under unweeded check was low (Table 35). A significant increase in the straw yield was observed under hand weeding. The differences in the herbicide treatments were not significant.

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Table 38: Straw yield (kg/ha) (kharif, '85)

	Hand weeding	Thio- bencarb	Arrosoiro	Unweeded	Mean
I ₁ (990 mm)	7699	5605	6244	610	5039
I ₂ (937)	7172	5311	5455	490	4607
I ₃ (888)	7638	5083	5750	453	4731
I ₄ (843)	6844	5000	5572	402	4454
I ₅ (790)	5877	4561	5600	462	4125
I ₆ (701)	5163	4633	4255	545	3649
I ₇ (578)	4586	3628	3949	719	3220
I ₈ (468)	4225	3540	3765	527	3014
Mean	6150	4670	5074	526	-
	I	W	W at I	I at W	
SE _d ±	218	493	640	437	
CD (P=0.05)	454	1114	1380	882	

Straw yield decreased with decrease in the moisture level. The differences in the first 3 levels were not significant. The decrease in straw yield was not to a similar magnitude as to that of grain yield. The straw yield in the treatments of I_7 and I_8 was similar, despite the fact that there was no grain yield in I_8 .

Upto the moisture level of I_3 (888 mm), hand weeding was significantly superior to the chemical treatments. When the water applied was 843 mm (I_4), the straw yields under hand weeding and arrosolo treatments were similar. With further decrease in moisture level, straw yields under both the herbicides were similar to hand weeding. Under unweeded conditions, it did not vary with moisture levels.

4.1.11. Harvest Index (HI): Significant differences existed in the HI of the crop due to weed control and moisture regimes (Table 36). The differences due to hand weeding and herbicides were not significant. HI was low in the unweeded check.

Among the moisture regimes, the changes in the HI upto the level of I_5 were not significant. Thereafter, it decreased with successive decrease in water applied. This was due to the drastic reduction in grain yield compared to the fall in straw yield.

Table 36: Harvest Index (kharif, '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	0.37	0.38	0.40	0.08	0.31
I ₂ (937)	0.38	0.38	0.40	0.07	0.31
I ₃ (898)	0.40	0.37	0.40	0.06	0.31
I ₄ (843)	0.38	0.36	0.38	0.05	0.29
I ₅ (790)	0.40	0.36	0.34	0.04	0.29
I ₆ (701)	0.34	0.33	0.30	0.07	0.26
I ₇ (578)	0.14	0.16	0.21	0.09	0.15
I ₈ (468)	-	-	-	-	-
Mean	0.35	0.33	0.35	0.07	
	I	W	W at I	I at W	
SE _d ±	0.01	0.02	0.03	0.02	
CD (P=0.05)	0.03	0.05	0.07	0.05	

The changes in the HI under unweeded check due to the different moisture treatments were not significant, while in other weed control treatments, it was low at lower moisture regimes. It was interesting to note that hand weeding did not differ from unweeded check at the lowest moisture regime of I_7 .

4.1.12. Apparent water use efficiency (AWUE): AWUE in the hand weeding was high compared to other weed control treatments (Table 37). The changes due to herbicides were not significant. It was negligible under unweeded check.

AWUE was not affected upto the moisture regime of I_3 , although highest value was obtained at I_3 . This shows that the decrease in grain yield was proportional to the decrease in water applied upto this level. With further decrease in the level of water applied, AWUE decreased drastically.

The AWUE under hand weeding and herbicides remained similar under very high moisture regime (I_1) and also under lower levels. The differences were more pronounced at I_3 , where hand weeding, arrosolo and thiobencarb were in the decreasing order. The differential effects of moisture were not noticed on the AWUE under unweeded check.

4.1.13. Nitrogen uptake by the crop: The different weed control and moisture regimes influenced the uptake of nitrogen by the crop (Table 38). The crop could remove just 3.2 kg N/ha

Table 37: Apparent water use efficiency (kg/mm) (kharif '85)

	Hand weeded	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	4.59	3.54	4.07	0.06	3.06
I ₂ (937)	4.87	3.45	3.78	0.04	3.03
I ₃ (888)	5.66	3.37	4.36	0.03	3.35
I ₄ (843)	5.01	3.31	4.13	0.02	3.12
I ₅ (790)	5.11	3.30	3.73	0.03	3.04
I ₆ (701)	3.89	3.44	2.68	0.05	2.51
I ₇ (578)	1.34	1.21	1.82	0.13	1.13
I ₈ (468)	-	-	-	-	-
Mean	4.35	3.09	3.50	0.05	-
	I	W	W at I	I at W	
SC _d ±	0.28	0.28	0.53	0.50	
CD (P=0.05)	0.59	0.64	1.09	1.02	

Table 38: Total nitrogen uptake by crop (kg/ha) (Kharif '85)

	Hand weeding	Thio- bencarb	Arrosolo	Unweeded	Mean
I ₁ (990 mm)	90.6	68.1	77.3	3.9	60.0
I ₂ (937)	88.0	63.6	67.7	3.1	55.6
I ₃ (888)	95.5	59.9	72.9	2.7	57.8
I ₄ (843)	82.6	57.1	67.7	2.4	52.5
I ₅ (790)	75.4	52.8	62.1	2.7	48.3
I ₆ (701)	57.4	51.0	42.9	3.4	38.7
I ₇ (578)	33.1	27.2	32.7	4.7	24.4
I ₈ (468)	22.8	19.1	20.3	2.8	16.3
Mean	68.2	49.9	55.4	3.2	-
	I	W	W at I	I at W	
SE _d ±	3.3	4.3	7.1	6.2	
CD (P=0.05)	6.9	9.8	15.0	12.6	

under unweeded conditions, while it was as high as 68.2 kg/ha in hand weeding. The effect of arrosolo and thiebencarb was similar on the N uptake.

The changes in the N uptake due to moisture levels were distinct. It was unaffected upto the level of I_3 . With lower levels of water applied, the N uptake decreased drastically.

Upto the level of I_4 , the uptake was high under hand weeding. At lower levels of moisture, the N removed by the crop under hand weeding and herbicides was similar.

The N uptake by the crop was recorded at 30 and 80 DAS in addition to the total uptake at harvest (Table 39). Unweeded conditions upto 30 DAS, did not affect the N removal by crop. The value was less at harvest compared to 80 DAS, due to tiller mortality. The uptake increased rapidly between 80 DAS and maturity which coincided with the rapid crop growth rate during this period. The changes in the uptake by the crop due to moisture regimes were little upto 80 DAS, because the crop growth rate was low and the response to moisture during this period of vegetative growth was not marked.

4.1.14. Relationship of grain yield with total weed growth or total grain day competition: In most of the weed control studies, the results are interpreted based on the weed number, weed weight or the period of competition. Extrapolation

Table 39: Nitrogen uptake by crop (kg/ha) at different stages (kharif '85)

	30 DAS	80 DAS	Matu- rity
Hand weeding	5.7	27.8	68.2
Thiobencarb	4.2	20.7	49.8
Arrosoir	5.5	27.6	55.4
Unweeded	4.8	11.1	3.2
I ₁	3.7	19.6	60.0
I ₂	4.9	23.4	55.6
I ₃	4.5	19.4	57.7
I ₄	4.9	21.7	52.4
I ₅	6.0	29.7	48.2
I ₆	5.9	25.0	38.7
I ₇	5.1	22.1	24.4
I ₈	5.6	13.1	16.2

of these results to similar situations becomes difficult, since all the above parameters may not re-occur in the same proportions. Weed number may increase; yet the weed weight may remain unchanged or may be the same at different periods of weed competition. In such situations, the prediction of the experimental results becomes limited. Few attempted to develop mathematical models for predicting yield losses. Dew (1972) and Schweitzer (1975) developed linear models based on the weed densities to predict yield losses in sugarbeet; wheat and barley. But the weed number is a relatively poor measure of competition. Weed weight can be a better parameter, since it more precisely measures the quantities of growth factors captured by the weed and thus made unavailable to the crop (Aldrich, 1984).

The total amount of weed growth may not be the sole factor in deciding the grain yield, as the duration of competition may also need consideration. However these two parameters are measured in different units; the period of competition in the form of days and the amount of competition in the form of dry weight.

In the present investigation, an attempt was made to combine the amount and duration of weed competition by working out the expression "gram day competition" (GDC) and relate it to the grain yield. Since the weed competition period varied

with weed management in this study, the expression GDC became broadbased.

When the total weed growth allowed was considered (Table 11) and related to grain yield, the relationship was negative as the grain yield decreased with increase in the total weed weight. Linear equation was fitted for the complete data (Fig.7). Kean perusal of the data on total weed weight shows little differences between some plots of thiobencarb and unweeded check. In spite of the uniform weed weight, wide differences were observed in the grain yield. This could be due to the duration of competition. Thiobencarb was followed by two hand weedings while weed competition occurred till maturity in unweeded check. Hence, the expression "gram day competition" was worked out. This showed wide variations in the weed control treatments, the values being very high for unweeded check (Table 40).

Relationship of "gram day competition" with grain yield was linear, similar to that with total weed weight (Fig.7). The linear relationship of gram day competition with grain yield was more closer as compared to that with the total weed weight. The estimated grain yields from GDC are closer to the observed values, in view of the striking differences in the intercept values of the equations. To illustrate the differences, consider the weed weight under I_5

FIG.7 GRAIN YIELD AS INFLUENCED BY TOTAL WEED
GROWTH AND GRAM DAY COMPETITION
(KHARIF, 1985)

$$\hat{y} = 6290.36 - 22.39 x \quad (x = \text{WEED WEIGHT})$$

$$r = 0.66^{**}$$

$$\hat{y} = 3417.97 - 0.209 x \quad (x = \text{GRAM DAY COMPETITION})$$

$$r = 0.68^{**}$$

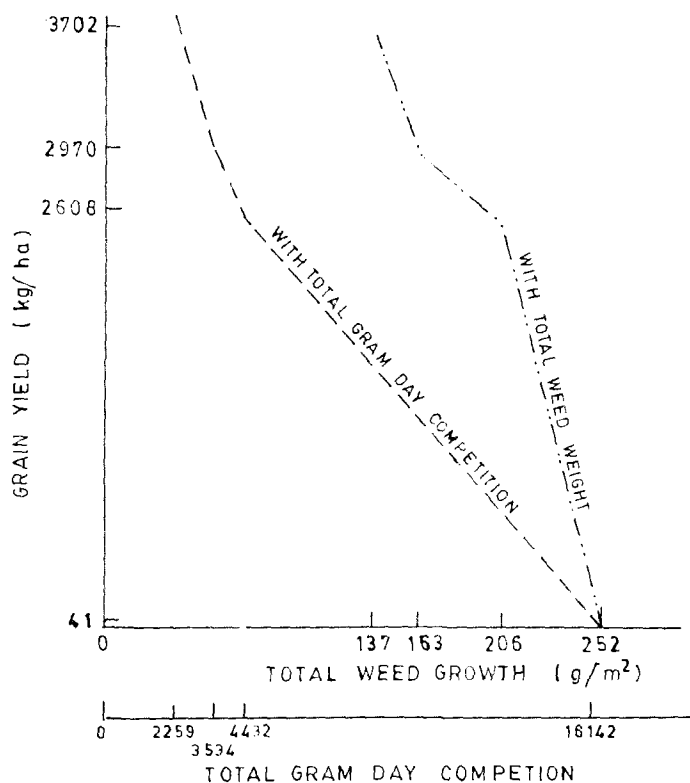


Table 40: Gram dry competition under different treatments

	Hand weeding	Thiobencarb	Arrosolo	Unweeded
I ₁	1750	3594	2596	14822
I ₂	2233	3590	3381	15898
I ₃	2839	4213	3214	15974
I ₄	2071	4546	3485	15917
I ₅	1882	5472	4298	14477
I ₆	2326	4631	4290	16371
I ₇	2522	4784	3749	21984
I ₈	2450	4624	3260	13690
Mean	2259	4432	3534	16142

(Not analysed statistically)

in thibencarb and I_6 under unweeded check which is similar (256 g/m^2) for both. The expected yield would be 558 kg/ha with the equation developed from total weed weight data. But the actual yields were 2613 kg/ha and 42 kg/ha under thibencarb and unweeded check, respectively. For the same data, the predicted yields would be 2274 kg/ha and 'nil' by using the equation developed from the gram-day competition. Hence this expression seems to be more appropriate and a distinct improvement over the conventional ways.

When the weed weight is known along with the period of competition, the gram day competition can be used to predict the yield losses more precisely than any of the parameters such as weed number, weed weight or period of competition alone. This concept, however, needs to be tested on a wide range of situations.

4.1.15. Correlation studies: The grain yield was correlated with different yield attributes and the correlation values were also estimated between the attributes. Grain yield significantly correlated with the total tiller number, per cent productive tillers, number of filled grains per panicle, 1000 grain weight, LAI at 90 DAS and final plant height (Table 41). A significant negative correlation was found between sterility percentage and grain yield. The different attributes put together could explain the variations in grain

Table 41: Correlation values (r)

	Total tillers	Per cent produc- tive tillers	Number of filled grains	Sterility percen- tage	1000- grain weight	LAI at 90 DAS	Plant height at harvest
Grain yield	0.7694	0.8570	0.9080	-0.8732	0.9162	0.7229	0.9482
Total tillers	-	0.4752*	0.8738	-0.8114	0.7674	0.9773	0.8078
% Productive tillers	-	-	0.8019	-0.8219	0.8416	0.3955*	0.8390
No. of filled grains	-	-	-	-0.9544	0.9631	0.8152	0.9624
Sterility %	-	-	-	-	-0.9220	-0.7426	-0.9393
1000-grain weight	-	-	-	-	-	0.6956	0.9637
LAI at 90 DAS	-	-	-	-	-	-	0.7396

n = 2=26 * = Significant at 5% level. Remaining values were significant at 1% level

(Contd..)

Table 41: (Contd..) Multiple linear regression equation
for grain yield

	b-value	S.E.	T. test
Total tillers	9.170	13.32	NS
% productive tillers	71.197	13.83	**
No. of filled grains	-61.006	22.50	*
Sterility %	28.807	16.77	NS
1000-grain weight	176.655	101.08	NS
LAI - 90 DAS	386.872	188.86	*
Plant height at harvest	105.751	34.16	**

Intercept = -12703.482

$R^2 = 0.96^{**}$

NS = Not significant

* = Significant at 5% level

** = Significant at 1% level

yield to an extent of 96 per cent ($R^2=0.96$) as compared through multiple linear regression equation. Per cent productive tillers, number of filled grains per panicle, LAI at 90 DAS and plant height contributed significantly to the variations in grain yield. Despite the significant correlation, the parameters, total number of tillers, sterility percentage and 1000-grain weight did not show significant influence on grain yield.

4.1.16. Water requirements of upland rice: From the observations on crop growth at different periods, it was seen that higher moisture is not required by the crop during early growth. Upto 30 DAS, the shoot dry weight was more in lower moisture regimes and treatments I_6 to I_8 could be considered suitable (111 to 158 mm upto 30 DAS).

The growth upto 60 DAS was highest in I_6 and as such for the period between 30 and 60 DAS, 177 mm would be sufficient. The shoot dry weight was highest in I_5 at 80 DAS and plants were taller with higher quantities of water as observed at 90 DAS. Hence for the period between 60 and 90 DAS, the moisture regimes ranging between I_5 and I_2 (223 to 244 mm) could be regarded as suitable. Based on the yield, I_1 to I_4 (202 mm to 159 mm) for the period from 90 DAS to maturity seemed to be essential. These split up values put together

ranged between 670 mm and 780 mm. Hence, reasonably good yields of upland rice can be expected if the total water applied (or) rainfall for the crop period ranged above 670 mm, when the evaporation from open pan was 655 mm. The crop water requirement for upland rice was low upto 60 DAS (TWA/UE ratios of 0.58 to 0.83 for the first 30 days and 0.95 for the remaining 30 days), increased considerably thereafter upto maturity (1.47 to 1.60 TWA/UE ratio upto 90 DAS and 1.25 to 1.59 thereafter).

Studies on crop water requirements of upland rice are limited as the crop is totally rainfed. However, few researchers showed that the mean consumptive use of water by rice was 610 to 646 mm (Muntajabuddin and Borulkar, 1985). Forest and Kalms (1984) showed that upland rice has two distinct growth stages with relatively high water requirement; during tiller multiplication (45 to 65 DAS) and at panicle initiation and heading (80 to 120 DAS), when water needs exceeded 4 mm/day (Kc of 1.30). They also stated that total rainfall during growth cycle partly caused high yield variability, but distribution in each phenological stage appeared to determine yield. Patel and Sastri (1985) stated that drought period was initiated when the ratio of actual evaporation to the potential evapotranspiration (AE:PE) fell below

optimum, which were 0.75, 1.0, 1.0 and 0.50 during seedling, vegetative, reproductive and maturity stages, respectively.

4.1.17. Economics and net returns under different weed management treatments: The initial hand weeding was difficult because of the similar appearance of the grass weed and rice. It required 480 manhours/ha costing Rs.720/ha. The herbicides were cheaper and the total cost of weeding was low under herbicide treatments (Table 42). The total cost of cultivation was high in hand weeded check because of higher weeding costs. Considering the mean grain and straw yields, the net returns were higher in hand weeded check followed by the herbicide treatment of arroso. The gross returns per rupee invested were also in the same order. The returns would be still higher in the plots of adequate moisture, where the yields were higher. Considering the total cost of cultivation, profit can result only when the grain yield level is more than 2 t/ha. In the very low moisture levels as in I₆ and I₇, there would be net loss.

The higher net returns and returns per rupee invested in hand weeding could be because of higher yields resulted due to weed free conditions during the entire vegetative growth phase. However, considering the total cost of weeding, herbicides appeared to be cheaper. The initial hand weeding

Table 42:

Economics of cultivation under different weed control treatments (kharif '85)

	Cost of weeding			Total cost of weeding	Cost of cultivation excluding weeding cost	Total cost of cultivation	Grain yield kg/ha t/ha	Straw Gross returns	Net Returns	Returns per rupee invested		
	Initial upto 20 DAS	Weeding at 40 DAS	At 60 DAS								At 80 DAS	
Hand weeding	720.00	540.00	540.00	540.00	2340.00	2250.00	3702	6.15	8381.80	4291.80	1.93	
	(480 man hrs/ha)		(360 man hrs/ha)									
Thiobencarb	386.00	540.00	-	600.00 (400 man hrs/day)	1526.00	2250.00	3776.00	2608	4.67	6307.70	2531.70	1.67
Arrosolo	450.00	540.00	-	600.00	1590.00	2250.00	3840.00	2970	5.07	7146.60	3306.60	1.86
Labour charges for hand weeding = Rs.12 per 8 hours										Cost of produce		
Thiobencarb = Rs.84 per litre										Grain = Rs.2.15 per kg		
Arrosolo = Rs.100 per litre										Straw = Rs.150 per tonne		

can be dispensed with, by the use of herbicides, as it was difficult as well as costly requiring higher manhours (480 per hectare).

4.2. Summer 1986

During the summer season the treatment unweeded check was dropped, as, it did not result in any yield during the previous season. The sprouting of weeds was observed along with rice and use of pre-sowing herbicides appeared to work well under these conditions. Hence 2,4-D in the form of ethylester was tested for pre-sowing conditions. Eight days before sowing, the field was wetted through line source sprinkler system and 2,4-D at 2 kg/ha was applied in all the three plots earmarked for chemical weed control. Pre-sowing irrigation causes sprouting of weeds before rice sowing and it would be difficult to control them 8 DAS as they cross susceptible stage by the time moisture gradient is created. Hence 2,4-D was applied in all the plots and imposition of other treatments was deferred to a later date. The effect of 2,4-D EE was observed till 20 DAS. Then the entire field was uniformly hand weeded. Twelve days after hand weeding, the treatments thibencarb, arroso and arroso + 2,4-D were super imposed over the plots previously studied under pre-sowing 2,4-D. This was done, to separate the effects of pre-sowing 2,4-D from the main weed control treatments. The objective was to study the herbicide-moisture interaction for effective weed control.

4.2.1. Total water applied during different periods: During the first 30 days, the TWA/UE values varied between 1.41 and 0.87 (Table 43). During the next 30 days, very low ratios of TWA/UE (1.12 to 0.30) were maintained, during which period the herbicides were applied and the interaction with moisture levels was studied. Thereafter, the water applied was increased. Because of the severity of summer, the water requirement of the crop was very high. The total water applied in I_1 was as high as 1441 mm. Even in the farthest plot from the water source (I_8), 500 mm was applied. The line source system provided fairly wide range of gradient and a gradual decrease in the amount of water applied was noticed with increase in the distance from the sprinkler line (Fig.8).

4.2.2. Effect of pre-sowing 2,4-D: 2,4-D showed some deleterious effects on crop emergence, even after 8 days gap, between application and sowing. Sprouting of the rice seedlings was observed 10 to 11 DAS as against 6 days in the unsprayed plots. The number of germinants was also low (91/m.) compared to unsprayed plots^(130/m). Inspite of the delayed and reduced germination (430/m) the rice growth loss was not significant as observed later, while the weed control was excellent.

Table 43: Total water applied (mm) and TWA/UE during different periods (Summer, '86)

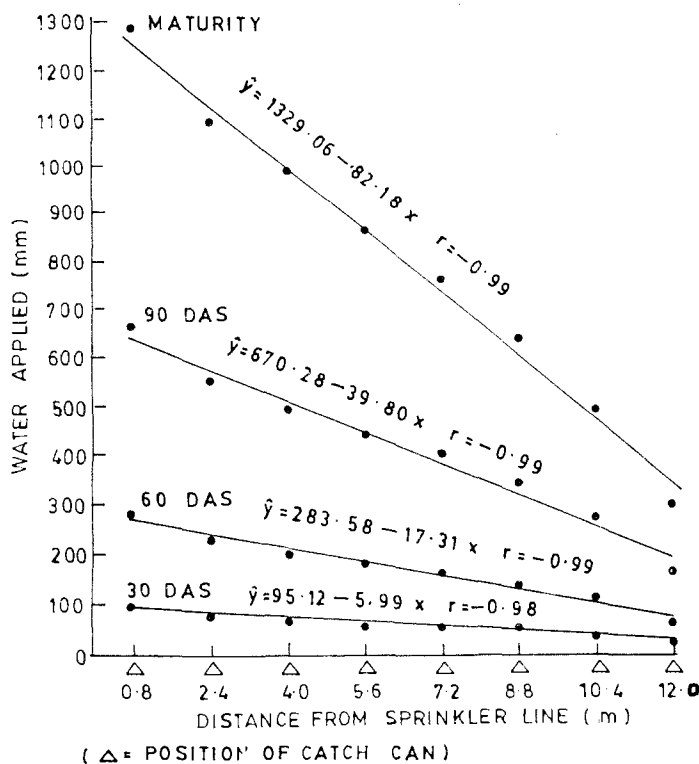
	DAS				Total
	0-30	30-60	60-90	90 - M	
I ₁	202 (1.41)	193 (1.12)	381 (1.67)	665 (2.38)	1441 (1.75)
I ₂	184 (1.29)	164 (0.94)	324 (1.42)	572 (2.04)	1243 (1.51)
I ₃	175 (1.23)	144 (0.83)	285 (1.25)	517 (1.85)	1122 (1.36)
I ₄	170 (1.19)	129 (0.74)	254 (1.11)	552 (1.55)	1105 (1.23)
I ₅	164 (1.15)	117 (0.67)	230 (1.01)	590 (1.45)	1101 (1.16)
I ₆	156 (1.09)	103 (0.59)	201 (0.88)	412 (1.01)	872 (0.92)
I ₇	143 (1.00)	83 (0.48)	164 (0.72)	321 (0.79)	711 (0.75)
I ₈	125 (0.87)	53 (0.30)	103 (0.45)	220 (0.54)	500 (0.53)

DAS = Days after sowing

M = Maturity

TWA/UE in parenthesis

FIG. 8 AMOUNT OF WATER APPLIED AS AFFECTED BY DISTANCE FROM THE SPRINKLER LINE
(SUMMER, 1986)



4.2.2.1. Weed number and weed weight at 20 DAS: The grass weed number (Table 44a) was low in the first 3 moisture regimes, where the total water applied was more than 106 mm, upto 20 DAS. Similar trend was noticed both under treated and untreated conditions. The herbicide 2,4-D effectively checked the grass weed number in the higher moisture regimes. In the treated plots, the grass weed number was low upto I_3 level and gradually increased, upto the level of I_5 . When the moisture level was further lowered (less than 98 mm), the herbicide was not effective as observed from the higher weed number. Similar trend was noticed with grass weed weight (Table 44b). The weed weight was markedly low in 2,4-D treated plots upto the level of I_5 . The herbicide 2,4-D, lowered the grass weed weight by 89 per cent at moisture level I_1 and the efficacy decreased gradually upto I_5 , where the reduction in weed weight was 69 per cent. Beyond the level of I_5 , the herbicide was not effective. The changes in the total weed number (Table 45a) or total weed weight (Table 45b) were similar to grass weed number or weight, as the latter constituted 92.7 per cent of the total weed population and contributed to 87 per cent of the total weed weight.

The soil moisture in I_5 level was 26.7 per cent at spraying (Table 45c) which would be 75 per cent of ASM. Hence, the herbicide was highly effective with soil moisture near FC

Table 44a: Gross weed number/m² at 20 DAS (Summer '86)

	Control	2,4-D	Mean	
I ₁	352 (17.41)	140 (11.79)	246 (14.60)	
I ₂	389 (18.26)	200 (13.97)	294 (16.11)	
I ₃	423 (19.36)	219 (14.64)	321 (17.00)	
I ₄	624 (22.63)	263 (16.11)	443 (19.37)	
I ₅	607 (22.36)	327 (17.83)	467 (20.09)	
I ₆	485 (20.88)	604 (24.36)	544 (22.62)	
I ₇	550 (22.42)	738 (27.02)	644 (24.72)	
I ₈	574 (23.40)	664 (25.75)	619 (24.57)	
Mean	500 (20.84)	394 (18.93)	-	
	I	W	W at I	I at W
SE _d ±	0.80	5.27	5.61	1.65
CD (P=0.05)	1.65	NS	17.13	3.45

NS = Not significant

Transformed data in paranthesis

Table 44b: Grass weed weight (g/m^2) at 20 DAS (Summer '86)

	Control	2,4-D	Mean
I ₁	15.8 (3.87)	1.7 (1.48)	8.7 (2.67)
I ₂	18.8 (4.23)	3.1 (1.88)	10.9 (3.06)
I ₃	22.9 (4.55)	4.5 (2.19)	13.7 (3.37)
I ₄	25.1 (4.81)	5.4 (2.38)	15.2 (3.60)
I ₅	21.8 (4.48)	6.7 (2.63)	14.2 (3.56)
I ₆	24.9 (4.80)	16.9 (4.05)	20.9 (4.42)
I ₇	20.0 (4.41)	22.0 (4.68)	21.0 (4.54)
I ₈	21.0 (4.53)	11.4 (3.43)	16.2 (3.98)
Mean	21.3 (4.46)	9.0 (2.84)	

	I	W	W at I	I at W
SE _d ±	0.21	0.89	1.02	0.44
GD (P=0.05)	0.45	NS	2.98	0.91

NS = Not significant

Transformed data in paranthesis

and continued to be effective upto the level of 75 per cent ASM. 2,4-D was not effective when the soil moisture fell below 75 per cent ASM or when the water applied was less than 15 mm during pre-spraying period.

The weed weight showed negative relationship with water applied under 2,4-D treatment while the relationship was not significant under the check plot (Fig.3). The homogeneity test for regression coefficients showed that they were significantly different from each other. The 70 mm of water applied at sowing did not bring about any change in the performance of the herbicide, indicating short life span or half life of the herbicide.

Pesticide degradation in soils is mainly due to the combined action of chemical, biological and photochemical processes and the rate of degradation depends on the nature and quantity of the chemicals applied, the soil type, moisture content, temperature, organic matter content etc. Of all the contributing factors the moisture present in the soil and the soil/atmospheric temperature play a vital role in the effectiveness of herbicides applied to dryland agriculture.

The effectiveness of esters of 2,4-D in controlling various weeds is considerably higher than that of its salts and various other derivatives. Thus phenoxy herbicides are

Table 45a: Total weed number/m² at 20 DAS (Summer '86)

	Control	2,4-D	Mean	
I ₁	375 (18.19)	177 (13.33)	276 (15.76)	
I ₂	435 (19.62)	226 (14.96)	330 (17.29)	
I ₃	473 (20.67)	251 (15.76)	362 (18.21)	
I ₄	654 (23.47)	307 (17.49)	480 (20.48)	
I ₅	642 (23.31)	350 (18.47)	496 (20.89)	
I ₆	523 (21.98)	630 (24.87)	576 (23.43)	
I ₇	590 (23.36)	771 (27.63)	680 (25.49)	
I ₈	631 (24.70)	690 (26.24)	660 (25.47)	
Mean	540 (21.91)	425 (19.84)	-	
	I	W	W at I	I at W
SE _d ±	0.82	4.84	5.17	1.61
CD (P=0.05)	1.70	NS	15.74	3.36

NS = Not significant

Transformed data in paranthesis

Table 45 b: Total weed weight (g/m^2) at 20 DAS (Summer '86)

	Control	2,4-D	Mean
I ₁	17.2 (4.05)	4.9 (2.23)	11.0 (3.14)
I ₂	22.3 (4.61)	5.6 (2.44)	13.9 (3.53)
I ₃	27.8 (5.04)	6.5 (2.75)	17.1 (3.90)
I ₄	26.1 (4.93)	9.2 (3.03)	17.6 (3.98)
I ₅	23.8 (4.70)	7.7 (2.81)	15.7 (3.75)
I ₆	27.2 (5.09)	18.0 (4.21)	22.6 (4.65)
I ₇	23.6 (4.75)	23.6 (4.86)	23.6 (4.80)
I ₈	23.6 (4.81)	12.1 (3.51)	17.8 (4.16)
Mean	23.9 (4.75)	10.9 (3.23)	-

	I	W	Wet I	I at W
SE _{at}	0.27	0.73	0.91	0.49
GD (P=0.05)	0.57	NS	2.54	1.01

NS = Not significant

Transformed data in paranthesis

45c: Data on soil moisture at spraying and water applied
in different treatments (Summer '86)

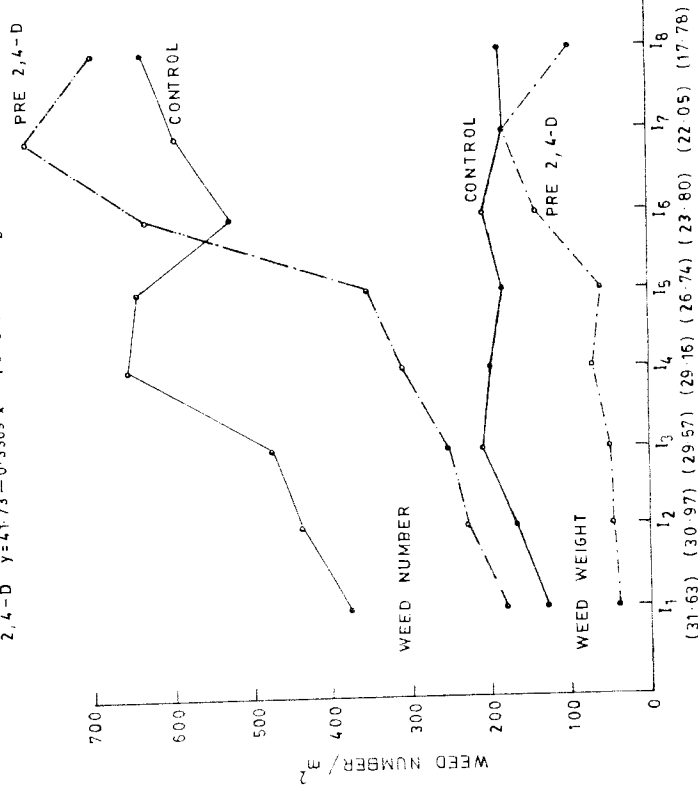
	Soil moisture (0 - 15 cm) at spraying (percentage)	Total water applied	
		Pre- sowing	Upto 20 DAS
I ₁	31.6	21.2	121.2
I ₂	31.0	19.5	110.5
I ₃	29.6	18.8	106.4
I ₄	29.2	16.2	102.4
I ₅	26.7	12.9	97.8
I ₆	23.8	10.5	92.6
I ₇	22.0	6.8	86.7
I ₈	17.8	2.0	77.3

BY TREATMENTS AT 20 DAS (SUMMER, 1986)

WEED WEIGHT AND WATER APPLIED

CONTROL $\hat{y} = 33.51 - 0.1046x$ $r = -0.43$ NS $t_b = NS$

2,4-D $\hat{y} = 41.73 - 0.3369x$ $r = -0.71$ * $t_b = SIG$



frequently applied as esters which have substantially different properties than the acid. The rate of ester hydrolysis is important in determining the behaviour of the herbicides in the soil. Smith (1972) reported that after 24 hours of application to loam, sandy loam and heavy clay soils at their wilting point moisture levels, no iso-propyl or n-butyl ester residues of 2,4-D could be detected in any of the soils, indicating rapid hydrolysis of the ester to the acid. In another study (Smith, 1978), he observed that although only 30 per cent of the applied 2,4-D was recoverable in moist soil after an incubation period, the degradation on air dried soil (15 per cent of FC) was negligible with over 85 per cent of the applied herbicides being recovered. This showed that the hydrolysis of the ester form to the acid and the subsequent degradation from the acid to other derivatives/degradation products with the decreasing bio-efficacy might be expected with the level of moisture present in the soil and the prevailing temperature conditions.

4.2.2.2. 2,4-D residues in soil in pot culture study: In the present investigation, an attempt was made to study the effect of different levels of moisture on the degradation and persistence of 2,4-D ethyl ester in a black soil. The results of the pot culture study showed that the degradation of 2,4-D ethyl ester was rapid in the black soil (pH 8.3,

O.M content 1.1, Clay 42 per cent) with below 0.24 ppm remaining 14 days after application at varying moisture levels. When the quantities of 2,4-D were plotted against the elapsed days, the relationship was found to be exponential and when the log values of the same were plotted, the relationship turned to be a straight line function, characteristic of the first order kinetics. This indicated that the rate of degradation of 2,4-D in the soil was independent of magnitude of the initial deposit under similar conditions as evidenced from their $t^{1/2}$ values. This confirmed the findings of Norris (1981) who observed that the per cent recovery of 2,4-D applied at two rates was the same and followed the first order kinetics. The degradation of 2,4-D was rapid in all soils with approximately 0.1 mg/kg remaining 20 days after application. Burecar *et al.* (1966) reported that complete disappearance of the iso-octyl ester 2,4-D in the Colorado soil occurred in 14 days after aerial application.

It is interesting to note that the quantity of 2,4-D remaining in soil one day after treatment was found increasing from the higher moisture regime to the lower moisture status. The soils which were maintained dry and at 21 per cent moisture had recorded higher residues (1.76 and 1.87 ppm) than the soils which were maintained at 28 per cent (1.63 ppm) and

42 per cent (1.51 ppm). Evidently the higher moisture in the soils had accelerated the ester hydrolysis and degradation of 2,4-D ester. Several earlier workers (Brown and Mitchell, 1948; Kris, 1947 and Hernandez and Warren, 1950) observed that 2,4-D degraded faster in moist soils. Smith (1978) opined that the 2,4-D breakdown in all his experimental soils was rapid and the average half-life was less than 7 days in moist soil.

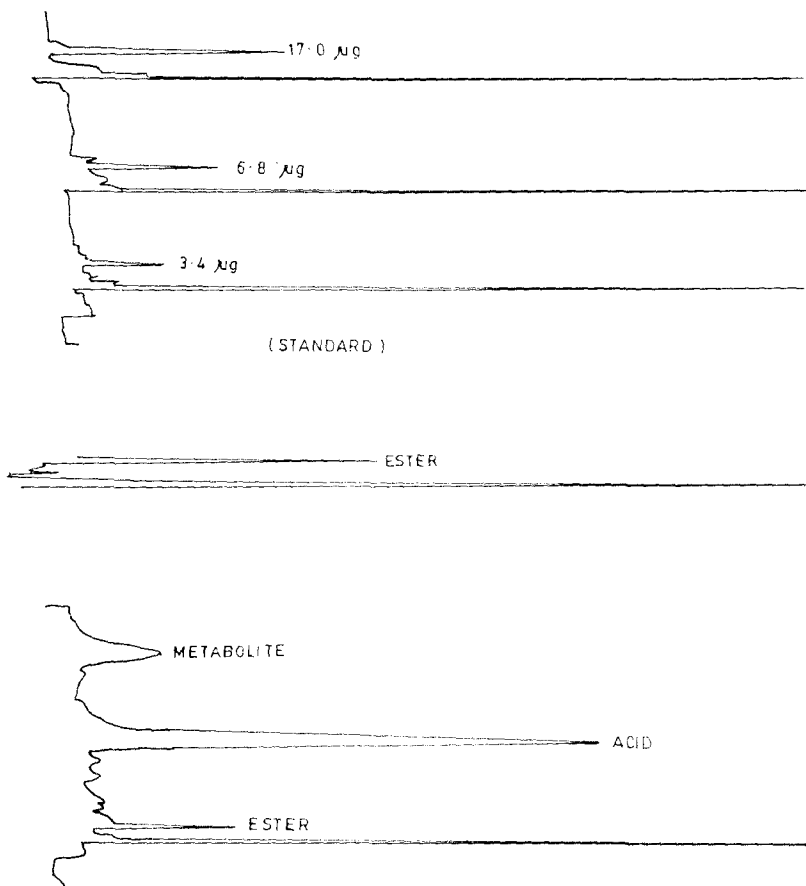
The results further indicate that the rate of degradation or the disappearance of 2,4-D from soils after the treatment depended on the level of moisture. The disappearance was greater in soils with higher moisture than the lower moisture status (Table 46). However the dry soils had substantially a higher residue upto 7 days period and only when the soils were flooded, the residue declined to low levels almost equivalent to that of other soils which had different levels of moisture. This clearly indicates that moisture had substantial effect on the degradation of 2,4-D in soils. This might be due to the ester hydrolysis due to the soil moisture to 2,4-D acid and further dissipation of the molecule to other degradation products as evidenced from the GLC and TLC determination. The results show that 2,4-D ester was rapidly converted to 2,4-D acid (Fig.10) and the

Table 46. 2,4-D residue (acid + ester) in ppm during different periods under pot culture study

Moisture range	Days after treatment					t ¹ in days	Degradation constant (K)
	1	3	5	7	14		
High	1.51 (42.7)	0.67 (32.1)	0.41 (29.5)	0.15 (21.7)	0.06 (43.1)	2.8	0.2436
	1.51 (42.7)	0.41 (43.9)	0.20 (43.5)	0.11 (40.1)	0.04 (33.4)	2.7	0.2573
	1.51 (42.7)	0.90 (8.6)	0.62 (6.2)	0.30 (4.8)	0.10 (12.6)	3.3	0.2088
Medium	1.63 (27.8)	0.87 (21.6)	0.57 (15.5)	0.26 (14.9)	0.10 (39.2)	3.3	0.2123
	1.63 (27.8)	0.53 (26.3)	0.35 (25.3)	0.20 (20.8)	0.08 (34.1)	3.2	0.2130
	1.63 (27.8)	1.10 (7.1)	0.56 (7.0)	0.28 (4.9)	0.12 (13.6)	3.4	0.2038
Low	1.76 (21.8)	0.93 (18.9)	0.62 (15.3)	0.33 (13.0)	0.14 (40.6)	3.6	0.1897
	1.76 (21.8)	0.89 (22.1)	0.75 (21.6)	0.35 (17.6)	0.11 (34.2)	3.3	0.2089
	1.76 (21.8)	1.12 (8.3)	0.89 (4.8)	0.47 (3.9)	0.16 (13.9)	3.7	0.1846
Dry	1.87 (15.0)	1.62 (7.4)	1.05 (6.8)	0.85 (4. 7)	0.20 (38.8)	3.9	0.1766
	1.87 (15.0)	1.06 (6.3)	1.16 (4.7)	0.98 (2.3)	0.22 (14.1)	4.1	0.1693

Soil moisture percentage in parenthesis.

FIG. 10 GAS LIQUID CHROMATOGRAMS OF 2,4-D ETHYL ESTER,
2,4-D ACID AND ITS METABOLITE



residue values represent both 2,4-D ester and the acid (Table 46). As the days advanced the ester values had declined and the acid values increased; and the residues on 7th and 14th day represent mostly 2,4-D acid. This is in confirmity with the findings of Smith (1972 and 1978) who observed that 90 to 100 per cent of the hydrolysis of isopropyl; n-butyl and iso-octyl esters of 2,4-D secured in 24 to 48 hours. He further indicated that even at wilting point moisture level, only less than 15 per cent of the applied iso-propyl or n-butyl ester could be recovered and after 24 h, no isopropyl or n-butyl ester could be detected in any of the soils and indicated the faster conversion of 2,4-D ester to acid form.

The GLC analysis indicated that apart from 2,4-D ester and acid, there was another peak which could not be identified for want of pure standard. This extra peak found in all the extracts of the soils which were flooded might be one of the degradation products. When the same extract was screened through TLC, two compounds were detected and identified as 2,4-dichlorophenol and 4-chlorophenol. Further there were also few spots which could not be identified for want of standards. The results of the GLC and TLC analysis of the soil samples indicated that 2,4-D ester was converted to 2,4-D acid and this was further broken down to dechlorinated phenolic inactive products. Aly and Faust (1964) demonstrated that the butyl ester of 2,4-D was biologically degraded by

microbes to 2,4-D and butyl alcohol within 9 days. Crosby (1970) observed that butyl ester of 2,4-D decomposed rapidly under UV to 2,4-dichlorophenol and Crosby and Tuttle (1966) demonstrated that major reaction in this change was the cleavage of the ether bond to produce 2,4-dichlorophenol which was then dehalogenated to 4-chlorocatechol, and 1,2,4-benzene triol. Results with sunlight were essentially identical to those with UV-light. Evans and Smith (1964) with soil cultures of *Pseudomonas* grown on 2,4-D, reported the formation of a phenolic acid derivative possibly the 6-hydroxy-2,4-dichlorophenoxy acetic acid. Loos (1969) observed the conversion of 2,4-D to 3,5-dichlorocatechol via 2,4-dichlorophenol rather than via 6-hydroxy-2,4-dichlorophenoxy acetic acid. All these studies suggest that 2,4-D acid may be converted to 2,4-dichlorophenol or 3,5-dichlorocatechol via hydroxy acids. In the present investigation 2,4-dichlorophenol and 4-chlorophenols were observed as metabolites when the soils were flooded and since these were dechlorinated products, there must have been anaerobic dechlorination possibly mediated by microbes. This confirmed the work of Miksell and Boyd (1985) who observed the formation of 4-chlorophenol in 7 days and this compound disappeared in another 49 days.

It was found that the dissipation of 2,4-D in dry soils was slower than the moist soils. The GLC analysis indicated that residue values in dry soils represent mostly the 2,4-D ester. Evidently the moisture available in the

soils would have been insufficient to cause ester hydrolysis. However there was a gradual decline in 2,4-D residues from 1 to 7 days. In the absence of the ester hydrolysis, the reduction of residue could be attributed only to the vapour loss at the prevailing higher temperatures (36.1°C max. temp. 20.5°C min. temp.). Hernandez and Warren (1950) found that 2,4-D applied to soil was still toxic to cabbage seeds 8 weeks after application when the soil temperature was 4.4°C while toxicity symptoms disappeared in 4 weeks when the temperature was 15°C. Grover *et al.* (1985) observed that the loss of 2,4-D ester as vapour from dry soils increased following several rainfall events. This indicated that vaporisation of 2,4-D ester would be increased when there is little moisture in the soil. Obviously, the greater loss of 2,4-D ester in the soils which contained different levels of moisture might be due to the vaporisation in addition to ester hydrolysis. When the dry soil was flooded, the higher residues in them were lost in another 7 days and the residues on 14th day were almost similar to that of other soils. This indicated the rapid loss of residues due to ester hydrolysis coupled with vapour loss due to added moisture. Thus the vaporisation of the ester from the soil and its hydrolysis to the acid metabolite and the subsequent degradation of the acid metabolite in the soil were all dependent on the available soil moisture. In spite of longer persistence in dry moisture range,

the herbicide could not control the weeds. The uptake of herbicide by weeds was limited due to insufficient soil moisture.

4.2.3. Effect of treatments on crop growth at 30 DAS: The effect of pre-sowing 2,4-D and moisture levels on crop growth was observed at 30 DAS.

Application of 2,4-D reduced plant height. It decreased from 12.3 cm to 9.9 cm (Table 47a). Plant height decreased due to decreased levels of water applied. The plants were shorter in the treatments of I_7 and I_8 . The growth was low compared to kharif 1985. However response to moisture was greater which could be due to high temperatures and severity of summer. Tiller number and LAI decreased by 36 per cent and 63 per cent, respectively due to 2,4-D application. The variations in the tiller number due to moisture levels were little. The results were found to be significant probably because of lower number at I_4 level, which cannot be attributed to the treatmental effect. The LAI in I_4 level was low because of lower tiller number. Significant reduction in LAI was found with lower levels of moisture at I_7 and I_8 .

The mean dry weight of rice shoots was very low in 2,4-D treated plots compared to control, even though statistical significance was not seen (Table 47b). At

Table 47a: Crop Growth at 30 DAS (Summer '86)

	Plant height (cm)	Tillers/m	LAI	Root : shoot as 1:x
Control	12.3	107	0.51	2.01
2,4-D	9.9	68	0.19	1.52
SE _d ±	0.2	19	0.12	NA
CD (P=0.05)	0.8	NS	NS	
I ₁ (202 mm)	12.6	103	0.51	1.84
I ₂ (184)	12.0	101	0.42	1.66
I ₃ (175)	11.9	92	0.41	1.83
I ₄ (170)	10.7	63	0.26	1.73
I ₅ (164)	10.9	88	0.36	1.69
I ₆ (156)	11.4	92	0.37	1.91
I ₇ (143)	9.8	83	0.25	1.83
I ₈ (125)	9.4	80	0.21	2.90
SE _d ±	0.7	11	0.07	
CD (P=0.05)	1.5	24	0.16	

NS = Not significant

NA = Not analysed

Table 47b: Shoot dry weight of rice (g/m) at 30 DAS
(Summer '86)

	Control	2,4-D	Mean
I ₁	6.58	3.04	4.81
I ₂	9.88	4.36	7.12
I ₃	8.71	3.78	6.25
I ₄	8.36	2.86	5.61
I ₅	5.30	2.12	3.71
I ₆	6.43	1.68	4.06
I ₇	5.16	3.26	4.21
I ₈	4.28	2.52	3.40
Mean	6.84	2.95	-

	I	W	W at I	I at W
SE _d ±	0.95	1.41	1.64	1.14
CD (P=0.05)	1.98	NS	4.76	2.38

NS = Not significant.

higher moisture levels (I_2 to I_4) where 2,4-D was more effective, caused significant reduction in the rice shoot dry weight. It was low in moisture regimes of I_5 to I_8 where the differences due to weed control treatments were not significant.

The root:shoot ratio was lowered due to 2,4-D application (Table 47a). It was due to lowered shoot weight. The differences in the root : shoot ratios were not marked due to moisture levels, excepting that the ratio was slightly high at I_3 . The lower values of shoot weight, in general, resulted in lower root : shoot ratios.

4.2.4. Imposition of main weed control treatments: Combination of Arrosolo and 2,4-D was tested in addition to the individual application of arrosolo and thiobencarb.

Herbicides were applied following hand weeding in order to separate their effects from pre-sowing 2,4-D. The results of herbicide-moisture interaction can be adopted to a normal situation.

However, the hand weeding done was not very effective, as most weeds were cut and not uprooted fully. The cut weeds resprouted and their control became difficult. Hence the effect of the treatments was studied for a short period and

data were collected at 40 DAS before giving another uniform hand weeding.

4.2.4.1. Weed number and weed weight at 40 DAS: The number of grass weeds as well as the total weed number (Table 48) was not affected by weed control treatments, but the dry weight of these weeds (Tables 49a and 49d) was low in the herbicide treated plots and the mean effect of herbicides was similar. The number (Table 48) and dry weight (Table 49b and 49e) of BLW and sedges was not affected by weed control treatments.

The number and dry weight of grasses and sedges was influenced by moisture regimes. The grass weed number (Table 48) and weight (Table 49a) increased with decreasing levels of moisture. The grass population was high in the last 3 moisture regimes, while the grass weight increased upto the level of I_7 (123 mm) and further decrease in moisture did not favour the buildup of grass weed weight. The sedge weed number (Table 48) as well as the dry weight (Table 49c) was high in the first 3 moisture levels and decreased gradually with reduced moisture regimes.

Seeds of E. colona required more aerobic conditions for higher germination as the moisture applied was sufficient to induce sprouting. The sprouting was low, when anaerobic conditions prevailed due to continuous irrigations with

Table 48: Number of weeds/m² at 40 DAS

(Summer '86)

	Grass	BLW	Sedge	Total
Hand weeding	108 (9.97)	14 (3.66)	18 (3.54)	140 (11.50)
Thiobencarb	62 (7.76)	10 (3.07)	14 (3.05)	86 (9.20)
Arrosolo	84 (9.09)	7 (2.59)	22 (3.61)	113 (10.64)
Arrosolo + 2,4-D	90 (9.30)	6 (2.48)	23 (3.89)	119 (10.83)
SE _d ±	1.27	0.76	0.54	0.85
CD (P = 0.05)	NS	NS	NS	NS
I ₁ (222 mm)	51 (7.02)	7 (2.72)	41 (5.55)	99 (9.74)
I ₂ (192)	62 (7.65)	8 (2.64)	33 (4.97)	103 (9.89)
I ₃ (176)	70 (8.17)	8 (2.66)	25 (4.26)	103 (9.92)
I ₄ (166)	81 (8.88)	8 (2.75)	16 (3.47)	106 (10.17)
I ₅ (156)	90 (9.31)	10 (3.06)	14 (3.29)	114 (10.56)
T ₆ (144)	106 (10.10)	10 (3.07)	11 (2.70)	127 (11.17)
T ₇ (123)	121 (10.80)	12 (3.34)	8 (2.34)	141 (11.78)
T ₈ (93)	110 (10.32)	12 (3.37)	4 (1.60)	126 (11.11)
SE _d ±	0.47	0.36	0.77	0.73
CD (P=0.05)	0.97	NS	1.59	NS

NS = Not significant

Transformed data in paranthesis.

Table 49a: Grass weed weight (g/m^2) at 40 DAS

(Summer '86)

	Hand weeding	Thio- benarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	13.9 (3.75)	8.9 (2.98)	13.1 (3.56)	8.7 (3.03)	11.1 (3.33)
I ₂	22.2 (4.67)	11.2 (3.38)	17.5 (4.16)	10.9 (3.37)	15.4 (3.90)
I ₃	30.7 (5.44)	15.8 (4.02)	18.8 (4.32)	13.2 (3.68)	19.6 (4.37)
I ₄	47.2 (6.88)	18.1 (4.30)	18.3 (4.28)	17.6 (4.25)	25.3 (4.93)
I ₅	56.9 (7.52)	20.3 (4.55)	22.3 (4.72)	26.2 (5.15)	31.4 (5.48)
T ₆	80.8 (8.89)	34.7 (5.90)	26.0 (5.10)	50.9 (7.03)	48.1 (6.73)
I ₇	66.9 (8.19)	44.5 (6.67)	37.8 (5.94)	55.4 (7.26)	51.1 (7.02)
I ₈	51.7 (7.15)	28.2 (5.35)	22.0 (4.68)	25.7 (4.87)	31.9 (5.51)
Mean	46.3 (6.56)	22.7 (4.64)	22.0 (4.60)	26.1 (4.83)	-
		I	W	W at I	I at W
SE _d ±		0.32	0.54	0.72	0.54
CD (P = 0.05)		0.67	1.23	1.54	1.10

Transformed data in paranthesis.

Table 49b: BLW weight (g/m^2) at 40 DAS

(Summer '86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	1.5 (1.35)	0.8 (1.11)	2.0 (1.49)	0.6 (1.01)	1.2 (1.24)
I ₂	2.5 (1.65)	1.4 (1.37)	3.4 (1.77)	0.8 (1.13)	2.0 (1.48)
I ₃	3.2 (1.86)	0.9 (1.17)	2.8 (1.68)	1.0 (1.20)	2.0 (1.48)
I ₄	3.5 (2.00)	1.7 (1.38)	0.4 (0.95)	0.6 (1.00)	1.5 (1.34)
I ₅	5.7 (2.49)	1.7 (1.48)	1.8 (1.38)	2.3 (1.54)	2.9 (1.72)
I ₆	6.5 (2.60)	2.3 (1.59)	0.8 (1.12)	1.5 (1.40)	2.8 (1.60)
I ₇	3.6 (2.01)	2.9 (1.80)	0.7 (1.11)	2.4 (1.61)	2.4 (1.63)
I ₈	2.0 (1.53)	3.8 (2.03)	0.4 (0.90)	3.2 (1.75)	2.3 (1.55)
Mean	3.6 (1.94)	1.9 (1.49)	1.6 (1.30)	1.5 (1.33)	
		I	W	W at I	I at W
SE _d		2.93	2.05	5.86	5.87
CD (P=0.05)		NS	NS	NS	NS

NS = Not significant

Transformed data in paranthesis

Table 49c: Sedge weed weight (g/m^2) at 40 DAS

(Summer '86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	10.7 (2.69)	3.7 (2.03)	7.0 (2.29)	5.9 (2.31)	6.8 (2.33)
I ₂	6.2 (2.22)	3.4 (1.86)	3.6 (1.76)	5.5 (2.16)	4.7 (2.00)
I ₃	2.1 (1.54)	3.3 (1.80)	5.1 (2.04)	3.4 (1.74)	3.5 (1.78)
I ₄	4.8 (1.93)	1.4 (1.25)	2.6 (1.55)	2.3 (1.62)	2.8 (1.59)
I ₅	2.9 (1.77)	0.7 (1.01)	3.5 (1.81)	4.1 (1.91)	2.8 (1.62)
I ₆	0.5 (0.96)	4.2 (1.76)	3.8 (1.75)	1.9 (1.46)	2.6 (1.48)
I ₇	1.1 (1.17)	1.4 (1.23)	0.7 (1.01)	1.3 (1.23)	1.1 (1.16)
I ₈	1.3 (1.29)	0.0 (0.71)	0.8 (1.02)	0.2 (0.85)	0.6 (0.97)
Mean	3.7 (1.70)	2.3 (1.46)	3.4 (1.65)	3.1 (1.66)	-
		I	W	W at I	I at W
SE _d $\pm$		0.31	0.18	0.50	0.53
CD (P=0.05)		0.66	NS	NS	NS

NS = Not significant

Transformed data in paranthesis

Table 49d: Total weed weight (g/m^2) at 40 DAS

(Summer '86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	26.1 (5.04)	13.4 (3.67)	22.2 (4.73)	15.2 (3.92)	19.2 (4.34)
I ₂	30.9 (5.47)	16.0 (4.01)	24.5 (4.99)	17.2 (4.16)	22.1 (4.66)
I ₃	36.0 (5.93)	20.1 (4.50)	26.8 (5.21)	17.6 (4.24)	25.1 (4.97)
I ₄	55.6 (7.48)	21.3 (4.64)	21.3 (4.65)	20.6 (4.57)	29.7 (5.33)
I ₅	65.2 (8.09)	22.8 (4.81)	27.7 (5.30)	32.6 (5.71)	37.1 (5.98)
I ₆	87.8 (9.27)	41.3 (6.42)	30.7 (5.58)	54.2 (7.29)	53.5 (7.14)
I ₇	71.7 (8.47)	48.8 (6.99)	59.2 (6.09)	59.2 (7.56)	54.7 (7.28)
I ₈	55.1 (7.40)	32.1 (5.70)	23.2 (4.80)	29.2 (5.23)	34.9 (5.78)
Mean	53.6 (7.14)	26.9 (5.09)	27.0 (5.17)	30.7 (5.33)	-
		I	W	W at I	I at W
SE _d ±		0.43	0.45	0.66	0.62
CD (P=0.05)		0.89	1.03	1.41	1.26

Transformed data in paranthesis

Table 49e: Data on soil moisture at spraying and water applied in different treatments (Summer '86)

	Soil moisture (0-15 cm) at spraying (percentage)	Total water applied		
		20-40 DAS	30-40 DAS	Upto 40 DAS
I ₁	30.8	128.2	64.6	220.2
I ₂	30.2	108.9	54.2	191.9
I ₃	29.7	96.6	47.0	176.2
I ₄	28.2	87.8	41.9	166.0
I ₅	27.8	79.2	38.1	156.1
I ₆	26.7	69.5	33.6	143.6
I ₇	22.5	51.6	26.4	123.5
I ₈	19.7	26.2	14.9	93.5

higher amounts of water. On the contrary, the rhizomes of *C. rotundus* required higher levels of moisture to put forth new vegetative growth. Once sprouted, this weed was not affected either by higher or lower levels of moisture.

C. rotundus can germinate even when the soil moisture content of the tubers is 12 per cent (Sakharam Rao and Nagarajan, 1963) and standing water of 60 cm for 3 days did not affect *C. rotundus* stand (Singh *et al.*, 1983). The distinctly different features of *E. colona* and *C. rotundus* caused the above variations as discussed earlier. The sedge weed got more ideal conditions in the higher moisture levels due to less sprouting of the major weed, *E. colona*.

The weight of BLW was not influenced by moisture regimes, while the total weight increased when the moisture levels were low.

In the first 3 moisture regimes where the weight of grass weeds and the total weed weight were low, the differences due to weed control treatments were not perceptible. At the moisture levels of I_4 and I_5 all the herbicides lowered the grass weight and the total weed weight compared to control. The grass weed weight increased beyond the level of I_5 in control; beyond I_4 in thiofenocarb and arrosolo + 2,4-D and beyond I_5 in arrosolo treated plots. The total weed weight was low upto the level of I_6 in arrosolo treated plots.

Thiobencarb was more effective at higher moisture levels while arrosolo was effective over a wider range. The efficacy of arrosolo was greater upto the level of I_4 , where soil moisture was 28.2 per cent (86 per cent ASM) and 42 mm of water was applied within 10 days of spraying (Table 49a). Arrosolo was effective even when applied at 26.7 per cent soil moisture (76 per cent ASM). Thiobencarb alone showed significant relationship with water applied, while the relationship was not significant in the case of other treatments (Fig.11). The lower values of regression coefficients for arrosolo indicate less change in weed weight due to moisture variations. Homogeneity test for regression coefficients showed that they were significantly different from each other.

4.2.4.2. Relative density (RD) and relative dry weight (RDW) of weeds at 40 DAS: The mean RD of grasses, BLW and sedges was 74.8, 8.2 and 17.0 per cent, respectively (Table 50). The weed control treatments did not alter the relative proportion of these weeds. The RD and RDW of grasses increased with decreasing levels of moisture, while that of sedges was more at higher moisture regimes and decreased with lower levels of water applied. The BLW proportion was not altered due to moisture levels. Compared to kharif, 1985 the relative proportion of sedges increased considerably, more so in higher

FIG.11 TOTAL WEED DRY WEIGHT AT 40 DAS AS AFFECTED
BY DIFFERENT TREATMENTS (SUMMER, 1986)

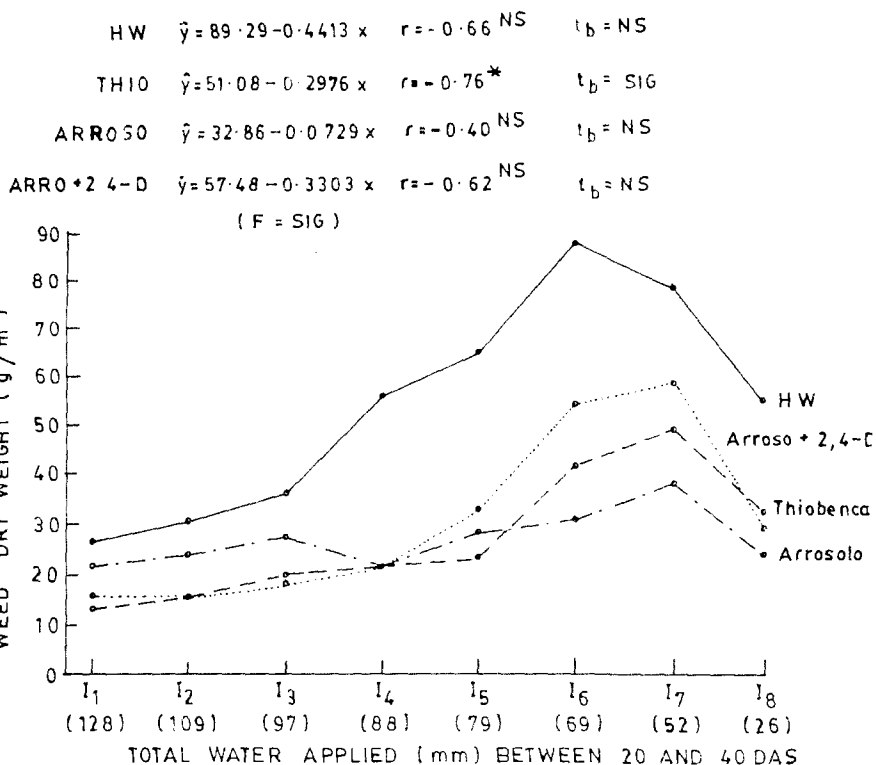


Table 50: Relative Density and Relative dry weight of
weeds at 40 DAS

	RD			RDW		
	Grass	ELW	Sedge	Grass	ELW	Sedge
Hand weeding	77.1	10.0	12.9	86.4	6.7	6.9
Thiobencarb	72.1	11.6	16.3	84.4	7.1	8.5
Arrosolo	74.3	6.2	19.5	81.5	5.9	12.6
Arrosolo + 2,4-D	75.6	5.0	19.4	85.0	4.9	10.1
I ₁	51.5	7.1	41.4	58.1	6.3	35.6
I ₂	60.2	7.8	32.0	69.7	9.0	21.3
I ₃	68.0	7.7	24.3	78.1	8.0	13.9
I ₄	77.1	7.6	15.3	85.5	5.1	9.4
I ₅	78.9	8.8	12.3	84.6	7.8	7.6
I ₆	83.5	7.9	8.6	89.9	5.2	4.9
I ₇	85.8	8.5	5.7	93.6	4.4	2.0
I ₈	87.3	9.5	3.2	91.7	6.6	1.7
Mean	74.8	8.2	17.0	84.3	6.1	9.6

moisture regimes. The sedge weed, *C. rotundus* was not controlled by any of the weed control treatments. The overall efficiency of herbicides was low compared to previous season because of the increase in the proportion of this weed.

4.2.4.3. Nitrogen removal by weeds at 40 DAS: The weeds in the herbicide treated plots removed lower quantity of N compared to hand weeding treatment (Table 51). Among the moisture regimes, the N removed by weeds was low upto the level of I_4 and increased thereafter. It was very high in the moisture levels of I_6 and I_7 . The N removal was low upto I_3 in case of control, upto I_4 in arrosolo + 2,4-D and upto I_5 in thiobencarb treated plots. In case of arrosolo it did not differ much across the moisture levels.

4.2.5.1. Total weed growth allowed: The total weed growth allowed upto maturity was estimated. It was similar under different weed control treatments (Table 52a). The differences observed with moisture levels were significant. Total weed growth was low in the higher moisture levels. Weed weight was low in thiobencarb plots upto the moisture level of I_3 ; upto I_4 in arrosolo + 2,4-D and upto I_5 in arrosolo plots. These differences were noticed at 40 DAS and the results remained unchanged because of uniform hand weeding thereafter.

Table 51: Nitrogen removal (kg/ha) by weeds at 40 DAS

(Summer '86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	4.20	2.16	3.58	2.44	3.09
I ₂	4.98	2.58	3.97	2.77	3.58
I ₃	5.81	3.22	4.33	2.84	4.05
I ₄	8.94	3.42	3.42	3.30	4.77
I ₅	10.58	3.66	4.46	5.21	5.98
I ₆	14.13	6.64	4.92	8.70	8.60
I ₇	11.52	7.86	6.29	9.50	8.79
I ₈	8.85	5.19	3.71	4.71	5.62
Mean	8.63	4.34	4.33	4.93	-
		I	W	W at I	I at W
SE _d ±		0.86	1.00	1.46	1.31
CD (P = 0.05)		1.79	2.27	3.11	2.67

Table 52a: Total weed growth allowed (g/m^2)

(Summer '86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	174.3 (12.85)	154.3 (12.34)	178.4 (13.37)	182.1 (13.48)	172.3 (13.01)
I ₂	198.0 (13.89)	180.1 (13.35)	189.2 (13.76)	203.7 (14.26)	192.7 (13.81)
I ₃	231.9 (15.04)	205.3 (14.33)	210.3 (14.47)	216.0 (14.70)	215.9 (14.64)
I ₄	293.9 (17.04)	225.8 (14.97)	209.3 (14.40)	229.3 (15.14)	239.6 (15.39)
I ₅	305.2 (17.37)	271.1 (16.41)	238.9 (15.38)	299.9 (17.29)	278.8 (16.62)
I ₆	351.0 (18.63)	333.9 (18.19)	265.4 (16.14)	328.5 (18.04)	319.7 (17.75)
I ₇	325.0 (17.97)	361.8 (18.92)	339.3 (18.08)	326.4 (17.99)	338.1 (18.24)
I ₈	257.5 (15.98)	203.4 (13.99)	190.1 (13.58)	217.1 (14.61)	217.0 (14.54)
Mean	267.1 (16.10)	242.0 (15.31)	227.6 (14.90)	250.4 (15.63)	-
		I	W	W at I	I at W
SE _d ±		0.89	1.19	1.28	0.99
CD (P=0.05)		1.85	NS	2.86	2.05

NS = Not significant

Transformed values in paranthesis

4.2.5.2. Nitrogen removed by weeds upto harvest: The total N removed under hand weeding, thiobencarb, arrosolo and arrosolo + 2,4-D was 35.1, 29.5, 28.0 and 30.3 kg/ha, respectively (Table 52b). It was low in arrosolo treatment due to better weed control. Weeds removed 21.2 kg/ha of nitrogen in the wettest moisture regime. The uptake by weeds increased gradually upto I_7 (41.9 kg/ha). In I_3 , weeds removed 26.9 kg N/ha.

4.2.6. Observations on crop growth

4.2.6.1. Chlorophyll estimation at 45 DAS: The rice leaves were pale green with higher levels of moisture. Chlorophyll content was more with lower moisture regimes. With decrease in the moisture from I_1 to I_7 , the total chlorophyll increased by 126 per cent while the increase was by 87 per cent in chlorophyll 'a' and 288 per cent in chlorophyll 'b' (Table 53). The increase in chlorophyll 'b' was very high which seemed to be related to drought or moisture stress.

4.2.6.2. Crop growth at 60 DAS: Plant height, tiller number, LAI and shoot weight were recorded 60 DAS (Table 54). All these characters were affected by herbicide treatments. The lower values in these treatments could be due to the initial effect of pre-sowing 2,4-D. Due to the decreasing levels of moisture, the values were lowered in all these characters. The

Table 52b: Total removal of nitrogen by weeds (kg/ha)
(Summer '86)

Hand weeding	35.1
Thiobencarb	29.5
Arrosolo	28.0
Arrosolo + 2,4 - D	30.3
I ₁	21.2
I ₂	23.7
I ₃	27.2
I ₄	30.1
I ₅	34.4
I ₆	40.4
I ₇	41.9
I ₈	26.9

Table 53: Chlorophyll content at 45 DAS in some
moisture regimes
(Summer '86)

	Chlorophyll content percentage		
	Total	Chlorophyll 'a'	Chlorophyll 'b'
I ₁	0.0985	0.0782	0.0190
I ₂	0.0832	0.0607	0.0214
I ₄	0.1334	0.0962	0.0355
I ₇	0.2229	0.1467	0.0737

Table 54: Crop growth at 60 DAS

(Summer '86)

	Plant height (cm)	Tillers/m	LAI	Shoot dry weight (g/m)	Root: shoot as 1:x
Hand weeding	20.5	84	0.93	24.6	2.86
Thiobencarb	18.2	51	0.46	10.0	2.73
Arrosolo	18.6	46	0.46	9.7	2.44
Arrosolo + 2,4-D	16.1	38	0.32	9.2	2.73
SE _d ±	0.9	15.9	0.21	1.8	NA
CD (P=0.05)	2.0	35.3	0.47	4.3	
I ₁ (395 mm)	21.8	70	0.84	16.8	2.60
I ₂ (347)	20.3	67	0.72	18.1	2.58
I ₃ (319)	19.2	60	0.62	14.3	2.56
I ₄ (299)	19.5	53	0.57	13.9	2.30
I ₅ (281)	19.4	56	0.61	13.3	2.51
I ₆ (259)	17.6	45	0.40	12.8	3.02
I ₇ (226)	15.9	44	0.35	11.0	3.83
I ₈ (177)	13.3	42	0.22	6.7	8.64
SE _d ±	1.4	8.5	0.14	1.6	NA
CD (P=0.05)	2.9	17.7	0.28	3.4	

NS = Not significant

NA = Not analysed

decrease in plant height, tiller number and LAI were not significant upto the level of I_5 , while the shoot weight was not affected upto I_4 . When the water applied was below 280 mm upto 60 DAS, significant reduction was noticed in all the characters. During this season, the evaporation was high due to higher temperatures and low relative humidity thereby resulting in moisture stress with lower levels of water applied. The root:shoot ratio of rice did not change due to weed control treatments, but it was high at moisture stress treatment of I_3 .

4.2.6.3.1. Crop growth at 90 DAS: Though the differences due to weed control treatments were not significant with regard to plant height, tiller number and LAI, the values were low in arroso + 2,4-D applied plots (Table 55). Generally, contact and systemic herbicide combinations showed antagonistic response (Rao, 1983). Contact herbicide rapidly destroys the leaf tissue and as a result the uptake and movement of systemic herbicide is prevented. Addition of 2,4-D to arroso might have had antagonistic effect, thereby decreasing the overall weed control efficiency. In addition, this treatment caused loss in plant growth as observed through plant height, tiller number and LAI.

The plant height decreased with decreasing levels of moisture, indicating the effects of moisture stress.



Table 55: Crop growth at 90 DAS

(Summer '86)

	Plant height (cm)	Tillers/m	LAI	Root : shoot as 1:x
Hand weeding	33.8	114	2.83	3.83
Thiobencarb	34.5	90	2.34	4.47
Aprosolo	34.9	83	2.13	5.40
Arrosolo + 2,4-D	30.5	59	1.27	3.43
SE _d ±	1.8	16.4	0.55	NA
CD (P=0.05)	NS	NS	NS	
I ₁ (776 mm)	42.4	102	2.64	4.24
I ₂ (671)	38.6	90	2.26	4.78
I ₃ (605)	34.9	94	2.25	3.60
I ₄ (553)	33.9	83	2.14	3.87
I ₅ (511)	33.7	82	2.30	3.66
I ₆ (460)	31.7	83	2.28	3.75
I ₇ (390)	29.7	81	1.97	3.81
I ₈ (280)	22.5	78	1.31	4.84
SE _d ±	2.4	13.4	0.42	NA
CD (P=0.05)	5.1	NS	NS	

NS = Not significant

NA = Not analysed

Yoshida (1975) reported that effects of moisture stress can very much be felt on plant height. The tiller number increased in general after 60th day and the differences due to moisture levels were not significant. Similar trend was observed with LAI. The roots:shoot ratio improved considerably compared to 60 DAS and the differences were not much either due to weed control or moisture treatments.

4.2.6.3.2. Shoot dry weight at 90 DAS: The shoot dry weight was low in the herbicide treatments (Table 56). It was very low in arrosolo + 2,4-D treatment, which could be due to the antagonism of these herbicides resulting in poor crop growth in addition to poor weed control.

It was high at moisture level I_2 and decreased with lower levels of moisture. At higher moisture levels the shoot dry weight in hand weeding was higher than that in herbicides. But when moisture stress occurred as in I_7 and I_8 the shoot dry weight of rice was not influenced by weed control treatments and hand weeding was similar to herbicides. During the previous season, crop growth at 90 DAS did not respond to higher water application above 545 mm, while response was found upto 670 mm during summer. In spite of higher response to moisture, the crop growth was low during summer.

Table 56: Shoot dry weight of rice (g/m) at 90 DAS
(Summer, 1986)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁	84.45	46.49	69.59	25.35	56.47
I ₂	110.00	78.15	46.15	47.33	70.41
I ₃	80.13	44.04	30.99	30.07	46.31
I ₄	60.17	26.95	31.37	37.32	38.35
I ₅	57.77	21.60	21.32	11.86	28.14
I ₆	49.69	35.33	29.22	9.40	30.91
I ₇	31.64	14.97	20.93	18.00	21.38
I ₈	16.08	9.02	9.85	4.93	9.97
Mean	61.24	34.57	32.43	23.03	-
		I	W	W at I	I at W
SE _d ±		2.88	4.05	8.97	7.96
CD (P = 0.05)		6.19	9.92	18.89	16.18

4.2.6.3.3. Leaf characters and canopy temperature after 90 DAS:

Flag leaves from I_1 to I_3 and fully unfurled leaves from rest of the treatments were collected to know RWC, SLA and SLW (Table 57). The RWC of the flag leaves decreased with age as it was high (90.4 per cent) in I_3 . In the other plots, the RWC of fully unfurled leaves was less than 90 per cent. The SLA was low for flag leaves and they had higher SLW, and thick leaves were signs of adaptation to moisture stress. During the same period, the canopy temperature increased gradually with the imposition of moisture stress. $T_c - T_a$ values were more negative at higher levels of moisture while they were on positive side at stressed plots (I_6 to I_9). Canopy-air temperature differentials ($T_c - T_a$) indicated the plant water status more precisely than the other parameter.

4.2.6.4. Days to flowering and days to maturity:

Striking differences were observed in the days to flowering. Flowering was delayed by 4-5 days under herbicides. The crop took 93 days to flower in the wettest moisture level, where the water applied was 776 mm upto 90 DAS (Table 58). When the total water applied was low, flowering was delayed. Under the most stressed plot (280 mm of water applied upto 90 DAS) the flowering was delayed by another 25 days. The crop took 37 days from flowering to maturity under higher level of moisture while it took 30 days to complete flowering, grain

Table 57: Leaf characters and canopy temperature after
90 days, in different moisture regimes
(Summer '86)

	SPC *	SLA	SLW	Tc	Tc - Ta
I ₁	78.0	157.2	0.00636	34.3	-0.80
I ₂	89.1	152.9	0.00654	34.8	-0.45
I ₃	90.4	166.7	0.00600	34.2	-0.45
I ₄	84.1	157.6	0.00634	35.0	-0.35
I ₅	83.6	174.1	0.00574	35.9	-0.10
I ₆	86.2	203.5	0.00491	35.3	+0.40
I ₇	89.9	195.9	0.00510	36.0	+0.65
I ₈	89.7	188.9	0.00529	35.3	+0.65

* I₁ to I₃ - Flag leaves and rest fully
unfurled leaves.

Table 58: Days to flowering and days to maturity under different moisture regimes (Summer, 86)

	Days to flowering	Days to maturity
I ₁	93	130
I ₂	95	130
I ₃	98	130
I ₄	105	140
I ₅	112	148
I ₆	114	148
I ₇	117	148
I ₈	118	148

Table 59: RWC of flag leaf and panicle and observations with steady state porometer at 120 DAS (Summer '86)

	R.W.C.*		TL	PAR	DR	Tr.rate
	Flag leaf	Panicle				
I ₁	77.9	70.1	34.4	2040	1.45	13.64
I ₂	78.9	71.5	35.1	2035	1.77	12.95
I ₃	82.0	75.6	35.3	1995	1.93	10.91
I ₄	82.8	79.6	35.5	1960	2.11	10.63
I ₅	83.3	70.8	35.6	1950	2.31	9.94
I ₆	85.2	74.3	35.7	1920	2.36	10.47
I ₇	79.7	-	36.1	1905	2.47	11.36
I ₈	79.9	-	36.2	1700	2.60	11.40

*Fully unfurled leaves in I₇ and I₈

filling and ripening phases in lower levels. The crop duration in stressed plots was 148 days against 110 days of this variety under low land conditions.

4.2.6.5. RWC of flag leaves and panicles at 120 DAS: The RWC of flag leaves was found to increase with the decreasing moisture levels where the flag leaves were relatively young. RWC of flag leaves was more associated with their age (Table 59). It was high during active flowering and as the panicle emerged, the flag leaves gradually lost control over transpiration and resulted in lower RWC. However the RWC of panicles did not vary much either due to water applied or due to age. Panicles of rice lack active mechanism to reduce water loss and transpire at potential rates (Reddy, 1985). The leaf related parameters like TL , PAR , DR and Tr rate of flag leaves were measured. TL and DR increased due to stress. Tomar and Ghildyal (1975) found that resistance to water transport in the non-flooded plants was nearly twice as that in flooded plants. The Tr rate was high with higher levels as well as at stressed plots. The higher Tr rate in stressed plots could be because leaf rolling was not seen at that stage. Parker (1968) stated that leaf rolling reduces transpiration, but rolling do not occur until the water content is reduced to lethal levels.

4.2.7. Growth analysis: The CGR, RGR and HAR were calculated during this season (Table 60).

The CGR was low during the first 30 days and increased with advancement in age upto 90 days. In the herbicide treatments, the CGR was low compared to hand weeding upto 90 DAS, but it continued to increase upto maturity. On the other hand, it remained low in hand weeding beyond 90 DAS. The loss of early growth could be made up during later stages, when the conditions were made ideal similar to hand weeding. The differences in the CGR were more pronounced from 30 days onwards due to moisture levels. The moisture stress as in I_6 to I_8 , reduced the CGR to a greater extent.

RGR indicated that rice crop made a higher beginning in case of hand weeding and decreased at late stages. In case of herbicide treatments, it was low initially and increased at later stages thereby compensating the early loss. Among the moisture regimes, RGR was high in higher levels upto 90 DAS. It was very low in drought stressed plots and did not increase at any stage. The results show that the depression in the crop growth at initial stages due to herbicides could be made up later, but continued drought resulted in poor growth throughout.

Table 60: Crop growth rate (g/m/day), Relative growth rate (g/g/day) and Net assimilation rate (10^{-3} g/dm²/day) under different treatments (Summer '86)

	Crop growth rate				Relative growth rate				Net assimilation rate			
	DAS				DAS				DAS			
	0-30	30-60	60-90	90-M	0-30	30-60	60-90	90-M	0-30	30-60	60-90	
Hand weeding	0.23	0.59	1.22	0.56	0.038	0.043	0.027	0.008	51.7	44.0	34.2	
Thiobencarb	0.10	0.23	0.82	0.92	0.012	0.041	0.036	0.017	33.4	45.1	33.4	
Artesolo	0.10	0.23	0.76	1.00	0.012	0.037	0.041	0.019	33.4	36.4	32.7	
Artesolo+2,4-D	0.10	0.21	0.47	0.80	0.012	0.037	0.026	0.021	33.4	41.9	31.5	
I ₁	0.16	0.43	1.32	1.62	0.027	0.047	0.041	0.021	35.5	35.5	41.5	
I ₂	0.23	0.41	1.74	0.92	0.040	0.037	0.047	0.012	57.5	38.0	65.7	
I ₃	0.21	0.31	1.06	1.33	0.030	0.036	0.038	0.021	51.5	39.7	42.0	
I ₄	0.19	0.32	0.83	0.99	0.030	0.041	0.035	0.017	50.5	52.5	39.2	
I ₅	0.13	0.34	0.49	0.69	0.017	0.047	0.025	0.018	32.0	41.5	32.2	
I ₆	0.13	0.33	0.67	0.36	0.020	0.052	0.033	0.009	34.5	55.0	31.7	
I ₇	0.14	0.24	0.29	0.40	0.023	0.034	0.019	0.015	43.5	43.2	15.2	
I ₈	0.11	0.13	0.11	0.24	0.016	0.021	0.017	0.015	35.5	29.2	8.7	

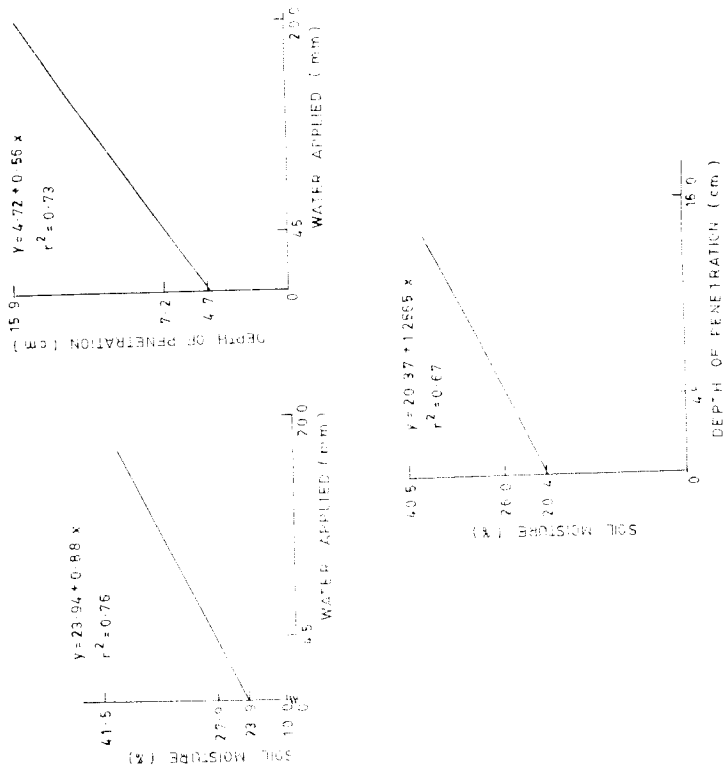
M = Maturity.

The NAR was high during the first 30 days under most ideal conditions. It improved after 30 days in herbicides applied plots, while decreased with prolonged moisture stress, as observed at I_3 level.

4.2.8. Soil mechanical resistance: The relationship between the amount of water applied, soil moisture percentage and soil mechanical resistance was observed during the active growth period. The soil resistance was measured through the depth of penetration of a 0.5 mm graduated steel rod with a constant weight of 2 kg on it. The pressure applied was constant and depth of penetration varied due to soil moisture status.

Positive relationship was noticed between soil moisture percentage and amount of water applied and the linear equation could predict 76 per cent of the variations. Similarly the depth of penetration increased with the increase in the water applied or increase in the soil moisture percentage (Fig.12). Davidson (1965) reported increased soil strength with decreased moisture contents. Lower moisture levels accompanied by higher soil resistance hinder the root proliferation and depth of root penetration thereby affecting the uptake of nutrients and water by plants.

FIG. 12 RELATIONSHIP BETWEEN WATER APPLIED, SOIL MOISTURE AND
DEPTH OF PENETRATION (SUMMER, 1986)



4.2.9. Leaf elongation rate at 80 DAS: The leaf elongation rate was measured during the active growth period (Fig.13). The elongation was rapid on the first day and slowed down on the second day. The fluctuations in the higher moisture levels were minimum. The elongation was low with lower levels of moisture, and fluctuations were more. In general, it took 7 days for leaves to attain their full length. In addition to lower rates of elongation due to stress, it took more days for a new leaf to emerge. Under higher moisture levels, new leaf appeared 5 days after the production of previous leaf while it took 7 days in the stressed plots. Thus production of new leaves was more affected than the leaf elongation rate. Yoshida (1981) stated that a leaf emerges about every 4-5 days before the initiation of panicle primordia, afterwards about every 7-8 days.

4.2.10. Panicle exertion rate: The panicle exertion was rapid on the first day and decreased gradually with time and also with low levels of water applied (Fig.14). However under extremely low levels of moisture, where the days to flowering was inordinately delayed, the exertion was slow on the first day, but increased rapidly and was spread over 4 days against 3 days in plots of adequate moisture. The rapid panicle exertion or heading during this season could be due to higher temperatures.

FIG. 13 LEAF ELONGATION RATE (cm/day) AT
80 DAS AS AFFECTED BY MOISTURE
REGIMES (SUMMER, 1986)

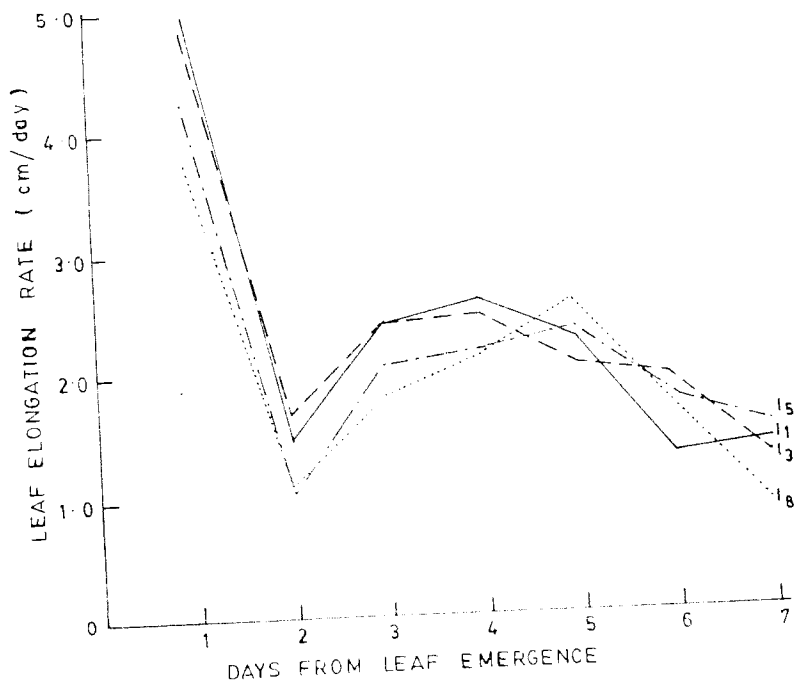
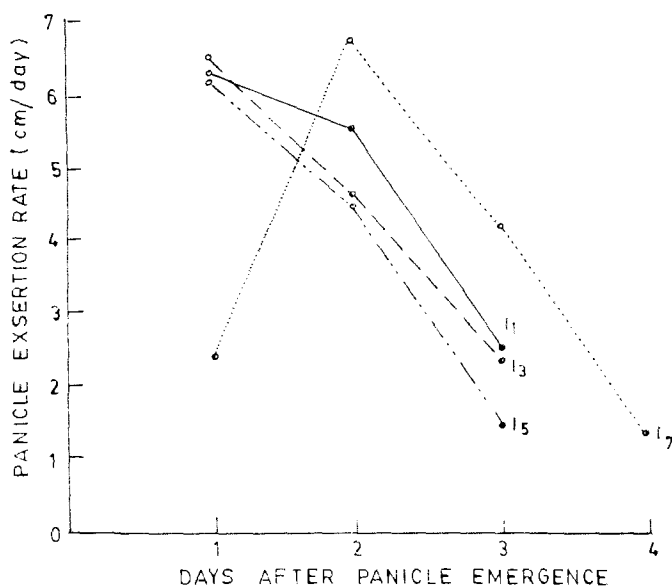


FIG. 14 PANICLE EXSERTION RATE (cm/day)
AS AFFECTED BY MOISTURE REGIMES
(SUMMER, 1986)



4.2.11. Data recorded at harvest

4.2.11.1. Plant height, number of total tillers and productive tillers: The differences in the plant height were not significant due to weed control treatments (Table 61). But the number of total tillers, as well as productive tillers was low in the treatment of arrosolo + 2,4-D. Addition of 2,4-D to arrosolo showed antagonistic effects and affected the shoot population soon after application and the recovery, was low resulting in lower tiller number at harvest.

The effect of moisture levels was more pronounced on these characters. Plant height and tiller number decreased due to moisture stress. More than 90 per cent of the total tillers were productive when the total water applied was 1440 mm. The percentage of productive tillers decreased when the water applied was less than 1100 mm. With 550 mm of water, only 31.3 per cent of the tillers could bear panicles. The effect of weed control treatments was the same across the moisture regimes.

4.2.11.2. Panicle characters, sterility and 1000 grain weight:

The length and weight of the panicles were low in the hand weeding treatment, while the herbicide treatments did not differ between themselves (Table 62). The number of unfilled grains, mean sterility percentage and 1000-grain weight were

Table 61: Data on plant height and tillers at harvest

(Summer '86)

	Plant height (cm)	Total tillers/ m	Productive tillers/m	Per cent productive tillers
Hand weeding	60.0	69	53	75.1
Thiobencarb	62.8	68	49	70.5
Arrosolo	61.1	65	55	77.5
Arrosolo + 2,4-D	62.9	46	37	76.2
SE _d ±	1.2	5.9	5.1	2.7
CD (P=0.05)	NS	13.3	11.6	6.2
I ₁ (1441 mm)	67.5	74	67	90.5
I ₂ (1243)	65.7	67	59	88.9
I ₃ (1122)	64.7	67	57	84.4
I ₄ (1105)	63.4	61	52	84.7
I ₅ (1101)	62.2	60	50	82.0
I ₆ (872)	59.8	62	47	77.1
I ₇ (711)	57.7	55	33	59.8
I ₈ (500)	53.1	51	24	31.3
SE _d ±	1.8	4.0	4.9	5.2
CD (P=0.05)	3.8	8.3	10.4	10.9

NS =Not significant.

Table 62: Data on panicle characters, sterility and 1000-grain weight

(Summer '86)

	Panicle length (cm)	Panicle weight (g)	Unfilled grains/ panicle	Sterility percen- tage	1000-grain weight (g)
Hand weeding	16.0	0.77	9.9	22.5	17.9
Thiobencarb	17.1	0.93	14.2	25.2	18.5
Arrosolo	16.9	0.96	12.7	23.2	18.1
Arrosolo + 2,4-D	17.0	0.91	14.6	27.0	18.0
SE _d ±	0.27	0.05	1.4	2.8	0.43
CD (P=0.05)	0.60	0.11	NS	NS	NS
I ₁ (1441 mm)	16.4	1.25	5.8	9.2	20.8
I ₂ (1243)	16.5	1.16	7.5	12.6	19.6
I ₃ (1122)	16.7	1.08	8.8	15.2	19.1
I ₄ (1105)	17.2	0.99	10.0	17.8	18.5
I ₅ (1101)	17.1	0.91	11.3	21.0	18.0
I ₆ (872)	17.3	0.75	11.3	21.7	17.2
I ₇ (711)	16.8	0.57	17.6	37.9	16.3
I ₈ (500)	16.2	0.42	30.3	60.4	15.4
SE _d ±	0.47	0.05	2.0	4.0	0.27
CD (P=0.05)	NS	0.10	4.2	8.4	0.57

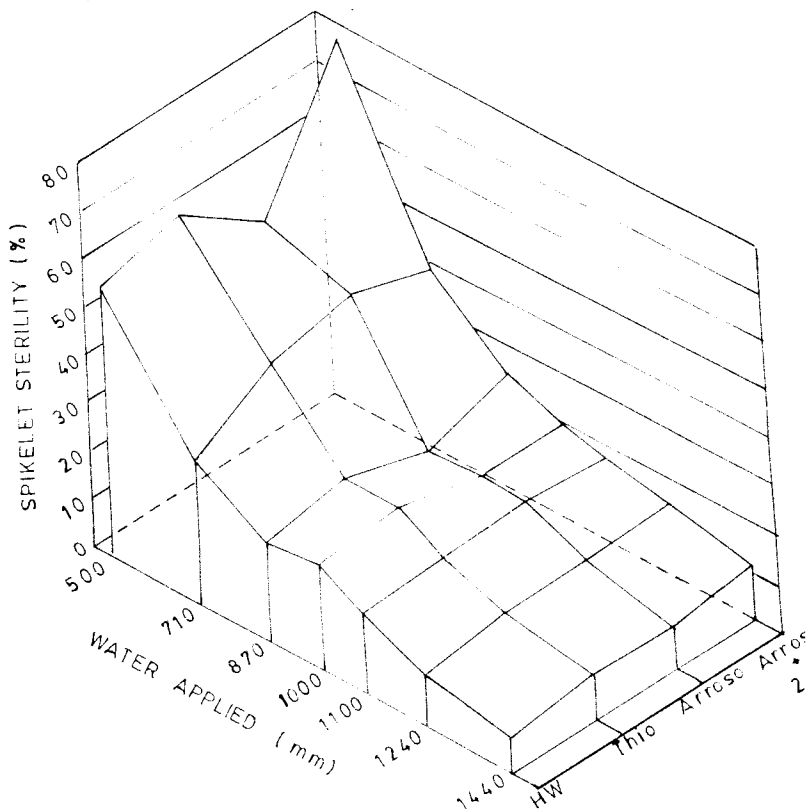
NS = Not significant

not affected by weed control treatments. In spite of delayed heading and lower rate of panicle exertion with stress, the panicle length was not influenced by moisture levels. However, the effects of moisture were markedly seenⁿ with panicle weight and other characters. Panicle weight decreased when water applied was low. The decrease was remarkable when the water applied was less than 1100 mm. The panicle weight decreased by 66 per cent with 500 mm of total water applied compared to 1440 mm. Similarly the weight of 1000 grains was lowered by 26 per cent.

The number of unfilled grains as well as the percentage sterility were high under lower moisture levels. With 500 mm of water, more than 60 per cent of the grains were sterile as against 9.2 per cent with 1440 mm of water (Fig. 15). The stress imposed through line source system was continuous and as such all the four phases of reproductive stage viz., panicle initiation, meiotic development of gametes, anthesis-fertilisation and grain filling were affected very much, resulting in reduced grain weight in addition to very high sterility percentage. During this season the per cent sterility was high and 1000-grain weight was low. This could be because of the higher temperatures. The mean maximum temperature was more than 35°C for a continuous period of about 5 weeks during flowering. According to Yoshida (1975)

FIG.15 SPIKELET STERILITY AS AFFECTED BY MOISTURE REGIMES UNDER DIFFERENT WEED CONTROL TREATMENTS (SUMMER, 1986)

$$\begin{aligned} \text{HW} \quad \hat{y} &= 69.35 - 0.047x & r &= -0.923 \\ \text{Thio} \quad \hat{y} &= 78.95 - 0.054x & r &= -0.936 \\ \text{Arroso} \quad \hat{y} &= 68.45 - 0.045x & r &= -0.914 \\ \text{Arroso + 2,4-D} \quad \hat{y} &= 90.45 - 0.063x & r &= -0.887 \end{aligned}$$



the critical low and high temperatures are normally below 20°C and above 30°C and the optimum temperature appears to shift from high to low as growth advances from the vegetative to the reproductive stages. It was also stated that though increased solar radiation increases plant growth under flooded conditions, it may even adversely affect plant growth under moisture stress conditions.

4.2.11.3. Number of filled grains per panicle: The mean number of filled grains per panicle was low in hand weeding. Different herbicide treatments had similar effect on grain number (Table 63). The grain number was more with higher moisture regimes and decreased when the water applied was low. With less than 1100 mm, the differences between herbicides treated plots and hand weeding were not significant.

4.2.11.4. Grain yield: The grain yield under different weed control treatments was similar (Table 64).

The mean effect of moisture was more pronounced. The total water applied of 1400 mm resulted in higher grain yield. The grain yields were high in the first 3 moisture levels, where the crop matured in 130 days. The total water applied in the treatments of I_3 , I_4 and I_5 was more or less same, because of the variations in the crop duration. The TWA/UE ratios, however varied with the same quantity of water applied,

Table 63: Number of filled grains per panicle

(Summer '86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁ (1441 mm)	45.8	58.2	63.9	58.5	56.6
I ₂ (1243)	44.2	57.1	55.5	54.5	52.8
I ₃ (1122)	39.5	52.7	52.4	54.0	49.6
I ₄ (1105)	38.6	51.0	49.3	48.0	46.7
I ₅ (1101)	33.1	47.2	44.8	44.7	42.4
I ₆ (872)	36.8	42.2	39.6	39.1	39.4
I ₇ (711)	29.3	26.4	27.2	35.8	29.7
I ₈ (500)	18.8	21.2	26.9	14.8	20.4
Mean	35.8	44.5	44.9	43.7	-
		I	W	W at I	I at W
SE _d $\pm$		2.7	2.5	4.2	4.1
CD (P = 0.05)		5.7	5.8	8.7	8.4

Table 64: Grain yield (kg/ha)

(Summer, 86)

	Hand weeding	Thio- bencarb	Arrosolo	Arrosolo + 2,4-D	Mean
I ₁ (1441 mm)	1679	1592	1433	1058	1440
I ₂ (1243)	1508	1333	1217	962	1255
I ₃ (1122)	1254	1200	1158	842	1113
I ₄ (1105)	987	1021	1091	796	974
I ₅ (1101)	667	821	879	687	763
I ₆ (872)	525	683	592	421	555
I ₇ (711)	408	433	437	225	376
I ₈ (500)	208	67	287	98	165
Mean	904	894	887	636	-
		I	W	W at I	I at W
SE _d ±		84	138	165	120
OD (P=0.05)		177	NS	361	246

NS = Not significant.

the yield varied significantly thereby indicating the importance of distribution of water. In I_5 , the TWA/US ratio was 1.16 while it was 1.36 in I_3 with the same quantity of water. With low levels of water, the reproductive stage of rice was prolonged and because of lower growth rate, delayed heading and higher sterility, the grain yields were low. Even with TWA/US ratio of 0.53 which was obtained with 500 mm of water, the rice crop could flower. Nevertheless the yield was negligible.

In the wettest moisture regimes, the grain yields under hand weeding were similar to the herbicide treatments of thibencarb and arrosolo. In these levels, the yields under arrosolo + 2,4-D were low, which could be due to ineffective weed control coupled with decreased tiller number. Under lower moisture regimes I_4 to I_9 , moisture availability was critical and was the deciding factor irrespective of weed management practices. The yield levels were very low.

4.2.11.5. Straw yield: The mean effect of weed control treatments on straw yield was the same (Table 65). Straw yield was more under wettest moisture regime and decreased when the water applied was low. The decrease in grain yield was more rapid while the decrease in straw yield was gradual.

Table 65: Straw yield, harvest index, AWUE and nitrogen uptake by crop

(Summer '86)

	Straw yield kg/ha	Harvest Index	AWUE - kg/mm	N-uptake by crop (kg/ha)
Hand weeding	3380	0.20	0.83	24.1
Thiobencarb	2891	0.22	0.81	21.6
Arrosolo	2974	0.22	0.84	22.0
Arrosolo + 2,4-D	2315	0.20	0.38	16.6
SE _d ±	444	0.01	0.13	3.2
CD (P = 0.05)	NS	NS	NS	NS
I ₁ (1441 mm)	4541	0.24	1.00	34.2
I ₂ (1245)	4062	0.23	1.01	30.3
I ₃ (1122)	3791	0.23	0.99	27.9
I ₄ (1105)	3354	0.23	0.88	24.6
I ₅ (1101)	2552	0.23	0.76	18.9
I ₆ (872)	2104	0.21	0.63	14.9
I ₇ (711)	1719	0.17	0.53	11.6
I ₈ (500)	989	0.13	0.33	6.2
SE _d ±	351	0.01	0.10	2.5
CD (P = 0.05)	730	0.03	0.21	5.2

NS = Not significant.

The combined effect of weed control treatments and moisture levels was not significant.

4.2.12. Harvest Index (HI): The HI in general was low. This was because of lower level of grain yield. During dry season, the higher atmospheric temperatures cause abnormal increase in soil temperature thereby hindering root growth, nutrient uptake and finally the crop growth. The effects would be totally different on low land rice where the standing water influences the microclimate favourably. The different weed control treatments did not influence the HI, while it was low in the moisture regimes of I_7 and I_8 where the decrease in grain yield was more rapid compared to the decrease in straw yield (Table 65).

4.2.13. Apparent Water Use Efficiency (AWUE): The AWUE was very low which again was the seasonal influence. The higher temperature and solar radiation were not favourable for upland rice cultivation. The water was applied at more than double the evaporation from open pan in certain moisture regimes during reproductive phase. In spite of this the grain yield was low. As such the AWUE was low. The effect of weed control treatments was similar on AWUE (Table 65). A maximum of 1 kg grain was produced with 1 mm of water applied in the best moisture regimes. The AWUE was low or negligible (0.33 kg/mm) when the total water applied was 500 mm.

4.2.14. Total uptake of nitrogen by crop: In addition to the seasonal effect on crop growth, the weed problem was also more during this season, because of the increase in the proportion of *C. rotundus*. When weeds removed 30.7 kg/ha of N, the mean uptake by crop was only 21.1 kg/ha. The N uptake by crop was not influenced by weed control treatments (Table 65). Under the best moisture regime the crop removed 34.2 kg N/ha while it was just 6.2 kg/ha under the stress treatment (I_8). These results show that the crop could not respond to nitrogen when it was subjected to moisture stress. Under stress, crop did not respond to weed control treatments also. Hence soil moisture levels characterise upland rice production more than any other input.

4.2.15. Correlation studies: Grain yield was significantly correlated with total number of tillers; per cent productive tillers, number of filled grains per panicle, 1000-grain weight, LAI at 90 DAS and plant height at harvest (Table 66). A significant negative correlation was found between sterility percentage and grain yield. The different attributes put together could explain the variations in grain yield to an extent of 93 per cent ($R^2=0.93$). 1000-grain weight alone contributed significantly to the variations in grain yield, while the influence of other parameters was not significant.

Table 66: Correlation values (r)

	Total tillers	Per cent productive tillers	Number of filled grains	Sterility percent- age	1000 grain weight	LAI at 90 DAS	Plant height at harvest
Grain yield	0.6650	0.7666	0.8126	-0.8361	0.9405	0.5207	0.8314
Total tillers	-	0.4027*	0.3887*	-0.5219	0.5499	0.7396	0.3569 ^{NS}
% Productive tillers	-	-	0.8336	-0.9243	0.8048	0.3910*	0.8705
Number of filled grains	-	-	-	-0.8773	0.9056	0.2579 ^{NS}	0.9386
Sterility %	-	-	-	-	-0.8438	-0.5068	-0.8581
1000 grain weight	-	-	-	-	-	0.4000*	0.9221
LAI at 90 DAS	-	-	-	-	-	-	0.2831 ^{NS}

n-2 = 26

NS = Not significant

* = Significant at 5% level

Remaining values were significant at 1% level.

Contd...

Table 66 (Contd..) : Multiple linear regression equation
for grain yield

	b-value	SE	't'-test
Total tillers	5.302	3.68	NS
% Productive tillers	-1.825	3.82	NS
Number of filled grains	-10.288	7.31	NS
Sterility percentage	-7.805	5.59	NS
1000-grain weight	234.459	51.64	**
LAI - 90 DAS	-3.690	58.42	NS
Plant height at harvest	4.264	22.66	NS

Intercept = -3233.58

$R^2 = 0.93^{**}$

NS = Not significant

** = Significant at 1% level.

4.2.16. Water requirements: During this season, the water requirement was very high. The present study made with the objective of finding herbicide moisture relationships and summer was ideal because of non-interference from rain. However, these summer conditions can be compared to the upland rice season at Africa which has higher temperatures coupled with higher rainfall. Upland rice areas in Africa are decided on the basis of a 200 mm minimum monthly rainfall requirement for the crop during the growing season. The areas with about 1400 mm of rainfall during the season are said to be best suited to upland rice where the average yields never go beyond 2 t/ha (IRRI, 1984). Brown (1969) reported that 1000 mm of rainfall with 200 mm monthly rainfall during the growth season is a minimum requirement for upland rice cultivation.

4.3. Kharif, 1986:

During summer, the herbicides were applied following a hand weeding and ineffective hand weeding led to reduced efficiency of the herbicides, although the relationship with moisture could be established. During this season, pre-sowing treatment with 2,4-D was done in one plot alone leaving one plot each for thiobencarb, arrosolo and hand weeding. The combination treatment of arrosolo and 2,4-D was dropped because of the unfavourable results during previous season.

The dose of 2,4-D was reduced from 2.0 kg/ha to 1.5 kg/ha in view of the phytotoxic effects seen on rice during the previous season.

4.3.1. Total water applied during the season: In the first 30 days, the TWA/UE values ranged between 1.13 and 0.37 (Table 67) with 280 and 93 mm of water, respectively. From 60 days onwards, the total water applied was always more than the evaporation, in all the moisture regimes. This was partly because of the higher rainfall (364.7 mm) during the crop growth period and also due to increased rates of water application. The total water applied for the entire crop growth period varied between 1299 and 512 mm. Fairly wide range of gradient was created due to line source system during different periods of crop growth and linear decrease in the amount of water applied was noticed with increase in the distance from the sprinkler line (Fig.16).

4.3.2. Weed number and weight at 20 DAS: Pre-sowing treatment with 2,4-D was done 8 DBS, while thiobencarb and arrosolo were applied 8 DAS. The data were recorded 20 DAS.

The mean effect of weed control treatments was not significant with regard to grass and sedge weed number (Table 68). BW were controlled by arrosolo, as observed by the lower number compared to hand weeding and pre-sowing

Table 67: Total water applied and TWA/US at different periods

(Kharif '86)

	DAS				Total
	0-30	30-60	60-90	90-M	
I ₁	280 (1.13)	295 (1.33)	346 (2.22)	378 (2.10)	1299 (1.61)
I ₂	253 (1.02)	258 (1.17)	316 (2.03)	349 (1.94)	1176 (1.46)
I ₃	227 (0.91)	226 (1.02)	291 (1.87)	324 (1.80)	1068 (1.33)
I ₄	209 (0.84)	202 (0.91)	270 (1.74)	304 (1.69)	984 (1.22)
I ₅	177 (0.71)	174 (0.79)	246 (1.58)	283 (1.57)	880 (1.09)
I ₆	146 (0.59)	137 (0.62)	229 (1.47)	261 (1.45)	774 (0.96)
I ₇	111 (0.45)	96 (0.44)	202 (1.30)	238 (1.32)	648 (0.80)
I ₈	93 (0.37)	49 (0.22)	164 (1.05)	206 (1.14)	512 (0.64)

DAS = Days after sowing

M = Maturity

TWA/US in paranthesis

FIG.16 AMOUNT OF WATER APPLIED AS
AFFECTED BY DISTANCE FROM THE
SPRINKLER LINE (KHARIF, 1986)

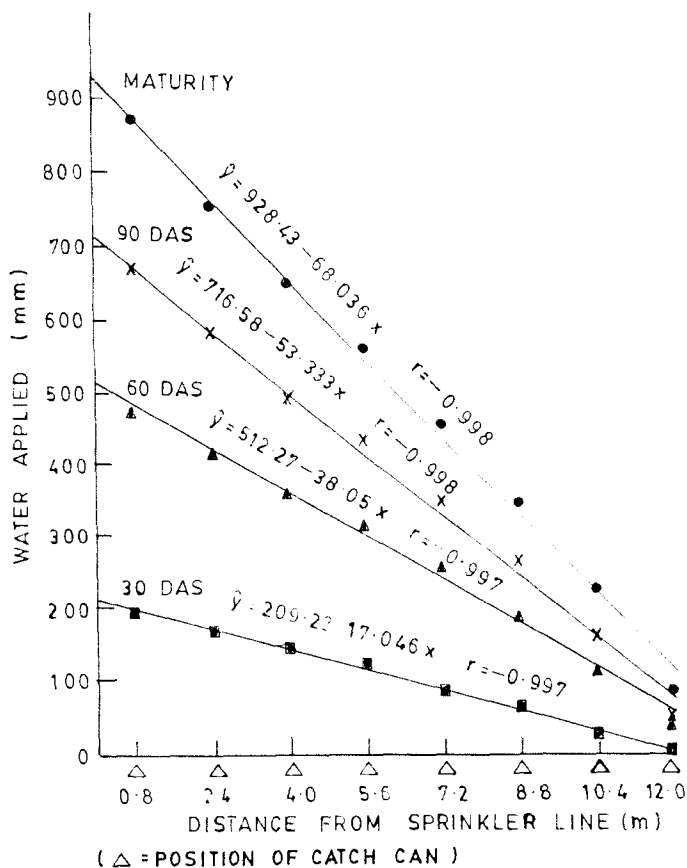


Table 68: Weed number/m² at 20 DAS

(Kharif '86)

	Grass	BLW	Sedge	Total
Hand weeding	122 (10.94)	23 (4.41)	52 (6.23)	197 (13.39)
Thiobencarb	90 (9.32)	11 (3.07)	39 (5.73)	140 (11.70)
Arrosolo	71 (8.34)	4 (1.81)	42 (5.70)	117 (10.68)
2,4-D	95 (9.37)	22 (4.13)	64 (6.75)	181 (13.43)
SE _d ±	1.40	0.68	1.08	0.88
CD (P=0.05)	NS	1.53	NS	1.90
I ₁ (184 mm)	68 (8.06)	12 (2.90)	101 (9.68)	181 (13.34)
I ₂ (167)	74 (8.41)	12 (3.25)	81 (8.65)	167 (12.86)
I ₃ (152)	82 (8.92)	13 (3.16)	67 (7.81)	162 (12.69)
I ₄ (140)	89 (9.28)	12 (3.07)	51 (6.49)	152 (12.19)
I ₅ (116)	96 (9.70)	13 (3.23)	39 (5.64)	148 (12.12)
I ₆ (95)	107 (10.22)	16 (3.54)	28 (4.70)	151 (12.24)
I ₇ (72)	114 (10.49)	19 (3.78)	19 (3.57)	152 (12.16)
I ₈ (63)	125 (10.88)	21 (3.89)	8 (2.26)	154 (12.05)
SE _d ±	0.36	0.32	0.42	0.43
CD (P = 0.05)	0.75	NS	0.88	NS

NS = Not significant

Transformed data in paranthesis

2,4-D. Pre-sowing 2,4-D was not effective unlike in the previous season, probably because of reduction in dosage.

The effect of moisture was noticed on the emergence of grass weeds. The grass weed number was low in the higher moisture regimes, probably because of more anaerobic conditions for long periods and increased gradually with decrease in the moisture levels. The behaviour of sedges was different. When grass weed number was on the rise the sedge population started to decline. As such the total population remained unaltered. The sedge weed proportion increased from 3.1 per cent during kharif, 1985 to 31 per cent during this season. The mean sedge weight was 35.4 per cent of the total weed dry weight and it was as high as 63.8 per cent in the higher moisture regime (Table 69d). It was low when the moisture levels were decreased.

The BW number (Table 68) and weight (Table 69c) were low and not influenced by moisture regimes.

The weight of grass weeds was similar in the weed control treatments in the higher levels of moisture upto I_3 (Table 69a). At the moisture levels of I_4 and I_5 , the herbicides azoxosolo and thiobencarb were similar in checking the weed weight while the weed dry weight was high in 2,4-D and control plots. With further decrease in moisture, thiobencarb was not effective while the effect of azoxosolo

Table 69a: Grass weight (g/m²) at 20 DAS

(Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁	13.2 (3.68)	12.7 (3.51)	9.4 (3.07)	15.0 (3.70)	12.6 (3.49)
I ₂	16.6 (4.12)	13.6 (3.64)	10.5 (3.24)	19.0 (4.11)	14.9 (3.78)
I ₃	18.1 (4.29)	15.2 (3.84)	11.8 (3.45)	22.5 (4.44)	16.9 (4.01)
I ₄	24.8 (4.98)	18.0 (4.16)	12.8 (3.59)	31.9 (5.16)	21.9 (4.47)
I ₅	28.6 (5.31)	20.0 (4.37)	14.0 (3.75)	40.2 (5.81)	25.7 (4.81)
I ₆	29.5 (5.40)	21.9 (4.59)	13.7 (3.66)	35.7 (5.62)	25.2 (4.81)
I ₇	30.4 (5.52)	20.0 (4.38)	9.7 (3.07)	25.6 (4.89)	21.4 (4.46)
I ₈	31.0 (5.59)	23.0 (4.63)	6.1 (2.50)	17.3 (4.13)	19.3 (4.21)
Mean	24.0 (4.86)	18.0 (4.14)	11.0 (3.29)	25.9 (4.73)	
		I	W	W at I	I at W
SE _d [±]		0.21	0.84	0.44	0.94
CD (P=0.05)		0.44	NS	0.88	2.08

NS = Not significant

Transformed data in parenthesis

Table 69b: Data on soil moisture at spraying and water applied in different treatments

	Pre-sowing treatment		Soil moisture at spraying other herbicides (Percentage)	Water applied upto 20 DAS (mm)	Water applied upto 40 DAS (mm)
	Soil moisture (0-15 cm) at spraying (percentage)	Water applied (mm)			
I ₁	30.9	24.2	33.7	183.6	313.1
I ₂	29.3	21.8	32.7	167.4	286.5
I ₃	27.6	19.2	31.9	152.3	260.2
I ₄	25.5	17.1	30.2	140.0	241.9
I ₅	23.3	15.6	29.0	116.2	210.0
I ₆	22.2	13.0	28.3	95.1	179.6
I ₇	19.2	10.9	26.7	72.4	144.5
I ₈	18.1	7.8	26.5	63.3	126.3

Table 69c: BLW weight (g/m^2) at 20 DAS

(Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁	1.7 (1.26)	0.7 (1.04)	0.3 (0.88)	0.2 (0.85)	0.7 (1.01)
I ₂	1.4 (1.27)	1.1 (1.22)	0.4 (0.93)	0.7 (1.08)	0.9 (1.12)
I ₃	1.2 (1.25)	0.6 (1.00)	0.1 (0.74)	0.6 (1.04)	0.6 (1.01)
I ₄	0.3 (0.87)	0.7 (1.04)	0.3 (0.90)	0.7 (1.03)	0.5 (0.96)
I ₅	0.3 (0.89)	0.8 (1.15)	0.4 (0.95)	1.1 (1.22)	0.6 (1.05)
I ₆	0.5 (0.99)	0.6 (1.03)	0.5 (1.00)	1.2 (1.25)	0.7 (1.07)
I ₇	1.3 (1.24)	0.4 (0.96)	0.1 (0.75)	1.3 (1.25)	0.8 (1.05)
I ₈	1.3 (1.28)	0.4 (0.93)	0.1 (0.77)	1.2 (1.18)	0.7 (1.04)
Mean	1.0 (1.13)	0.7 (1.05)	0.3 (0.87)	0.9 (1.11)	
		I	W	W at I	I at W
SE _d [±]		0.08	0.13	0.20	0.24
CD (P=0.05)		NS	NS	NS	NS

NS = Not significant

Transformed data in parenthesis

Table 69d: Sedge weed weight (g/m^2) at 20 DAS

(Kharif '86)

	Hand weeding	Thio-bencarb	Arrosolo	2,4-D	Mean
I ₁	30.9 (5.48)	15.7 (3.95)	19.0 (4.35)	28.3 (4.84)	23.5 (4.65)
I ₂	15.5 (3.87)	14.4 (3.79)	15.1 (3.89)	25.3 (4.56)	17.6 (4.03)
I ₃	14.2 (3.65)	12.8 (3.60)	11.0 (3.33)	21.7 (4.13)	14.9 (3.68)
I ₄	11.8 (3.11)	10.7 (3.31)	7.2 (2.45)	18.2 (3.69)	12.0 (3.14)
I ₅	9.9 (2.82)	8.9 (3.03)	6.1 (2.39)	12.7 (3.09)	9.4 (2.83)
I ₆	6.3 (2.40)	6.9 (2.65)	4.7 (1.96)	8.2 (2.45)	6.5 (2.36)
I ₇	3.1 (1.73)	4.8 (2.05)	3.9 (1.75)	5.6 (2.60)	4.3 (1.91)
I ₈	1.5 (1.28)	2.1 (1.41)	1.5 (1.29)	1.9 (1.39)	1.7 (1.34)
Mean	11.6 (3.04)	9.5 (2.98)	8.6 (2.68)	15.2 (3.27)	-
		I	W	W at I	I at W
SE _d ±		0.23	0.55	0.45	0.69
CD (P=0.05)		0.48	NS	NS	NS

NS = Not significant

Transformed data in paranthesis

Table 69: Total weed weight (g/m^2) at 20 DAS (kharif '86)

	Hand weeding	Thio-bencarb	Arrosoiro	2,4-D	Mean
I ₁	45.8 (6.75)	29.1 (5.33)	28.8 (5.39)	43.6 (6.56)	36.8 (6.01)
I ₂	33.6 (5.80)	29.2 (5.35)	25.9 (5.13)	45.0 (6.69)	33.4 (5.74)
I ₃	33.5 (5.77)	28.7 (5.30)	22.9 (4.82)	44.8 (6.68)	32.4 (5.64)
I ₄	36.9 (5.99)	29.5 (5.37)	20.4 (4.52)	50.8 (7.03)	34.4 (5.73)
I ₅	38.8 (6.09)	29.8 (5.38)	20.6 (4.54)	54.1 (7.18)	35.7 (5.80)
I ₆	36.4 (5.97)	29.4 (5.37)	19.0 (4.31)	45.0 (6.58)	32.4 (5.56)
I ₇	34.9 (5.92)	25.2 (4.92)	13.6 (3.68)	32.5 (5.62)	26.5 (5.03)
I ₈	33.9 (5.83)	25.5 (4.89)	7.7 (2.73)	20.4 (4.53)	21.7 (4.51)
Mean	36.6 (6.01)	28.2 (5.24)	19.9 (4.39)	42.0 (6.36)	
		I	W	W at I	I at W
SD _d ±		0.17	0.40	0.46	0.61
CD (P = 0.05)		0.36	0.90	0.92	1.28

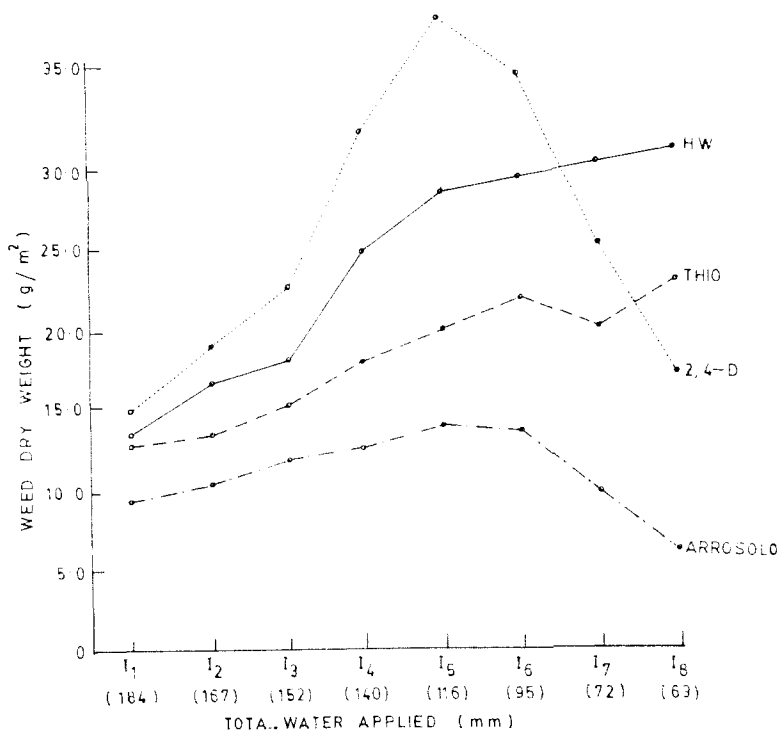
Transformed data in paranthesis

continued upto the level of I_8 . The herbicides were not effective in the higher moisture levels because of the differences in weed growth. The weeds were sprouted in these plots before sowing rice because of the pre-sowing irrigation given while applying 2,4-D. Upto the level of I_3 , about 20 mm of water was applied during pre-sowing irrigation followed by light showers. Hence weeds had higher initial start, compared to rice. By the time the herbicides were applied weeds in these plots crossed the 2-leaf stage and thus were not controlled. The herbicide thiobencarb was effective upto I_5 level, where the soil moisture was 29 per cent (91 per cent ASM) at spraying (Table 69 b). Arrosolo was effective even when the soil moisture was 26.5 per cent (75 per cent ASM). The weed dry weight in thiobencarb and 2,4-D plots at this moisture level was low compared to control indicating they were also effective, but not as effective as arrosolo (Fig.17). The herbicide 2,4-D was not effective probably because of reduced dose. Slight effect was noticed at lower levels which could be due to slow rate of degradation affecting few weeds when moisture was made available. However, the results with 2,4-D were not conspicuous.

The total weed weight was low in arrosolo applied plots followed by thiobencarb, however the latter did not

FIG. 17 DRY WEIGHT OF GRASS WEEDS (g/m^2) AT 20 DAS
AS AFFECTED BY DIFFERENT TREATMENTS
(KHARIF, 1986)

HW	$\hat{y} = 42.49 - 0.1495x$	$r = -0.94^{**}$	$t_b = \text{SIG}$
THIO	$\hat{y} = 28.15 - 0.0816x$	$r = -0.94^{**}$	$t_b = \text{SIG}$
ARROSO	$\hat{y} = 9.22 + 0.0144x$	$r = +0.24 \text{ NS}$	$t_b = \text{NS}$
2, 4-D	$\hat{y} = 33.17 - 0.0587x$	$r = -0.28 \text{ NS}$	$t_b = \text{NS}$
(F = NS)			



differ from control. The results with total weed weight did not differ from grass weed weight because of its higher relative proportion (62.3 per cent).

4.3.3. Data on weeds at 40 DAS: One hand weeding was given to the control plot at 20 DAS while the herbicide applied plots were not disturbed upto 40 DAS.

4.3.3.1. Weed number and weight at 40 DAS: The grass weed number was low in the hand weeding treatment at higher moisture regimes (I_4 and I_2) while the herbicide treatments were similar in their effect (Table 70a). However, the grass weed weight was low uniformly under all weed control treatments at these moisture levels (Table 70 b). At I_3 and I_4 , the grass weed number in arroso and thiobencarb was similar to hand weeding and low compared to 2,4-D. With decrease in the moisture levels, the weed number in thiobencarb plots increased gradually, while it decreased in hand weeding and also at a slower rate in arroso. The mean grass weight was high and did not differ when the total water applied varied between 242 and 144 mm. Anaerobic conditions caused reduction in growth at higher moisture levels, while the moisture below 144 mm was not sufficient to promote weed growth. In case of thiobencarb and 2,4-D, the grass weed weight had significant negative relationship with moisture while the relationship was not significant in case of hand weeding and arroso (Fig.18).

Table 70a. Grass weed (No./m²) at 40 DAS

(Kharif '86)

	Hand weeding	Phio- bencarb	Arrosolo	2,4-D	Mean
I ₁	38 (6.01)	64 (7.77)	65 (8.03)	93 (9.18)	65 (7.75)
I ₂	52 (7.22)	80 (8.68)	75 (8.62)	118 (10.45)	81 (8.75)
I ₃	70 (8.41)	85 (8.96)	83 (9.01)	125 (10.87)	91 (9.31)
I ₄	85 (9.21)	85 (9.10)	94 (9.60)	130 (11.12)	98 (9.76)
I ₅	84 (9.17)	109 (10.30)	115 (10.65)	141 (11.58)	112 (10.42)
I ₆	76 (8.72)	114 (10.54)	102 (9.93)	172 (12.94)	116 (10.53)
I ₇	58 (7.63)	115 (10.66)	97 (9.56)	191 (13.82)	115 (10.42)
I ₈	54 (7.40)	140 (11.80)	91 (9.02)	193 (13.81)	119 (10.51)
Mean	65 (7.97)	99 (9.73)	90 (9.30)	145 (11.72)	
		I	W	W at I	I at W
SE _d ±		0.31	1.34	0.68	1.49
CD (P=0.05)		0.65	NS	1.37	3.31

NS = Not significant

Transformed data in paranthesis

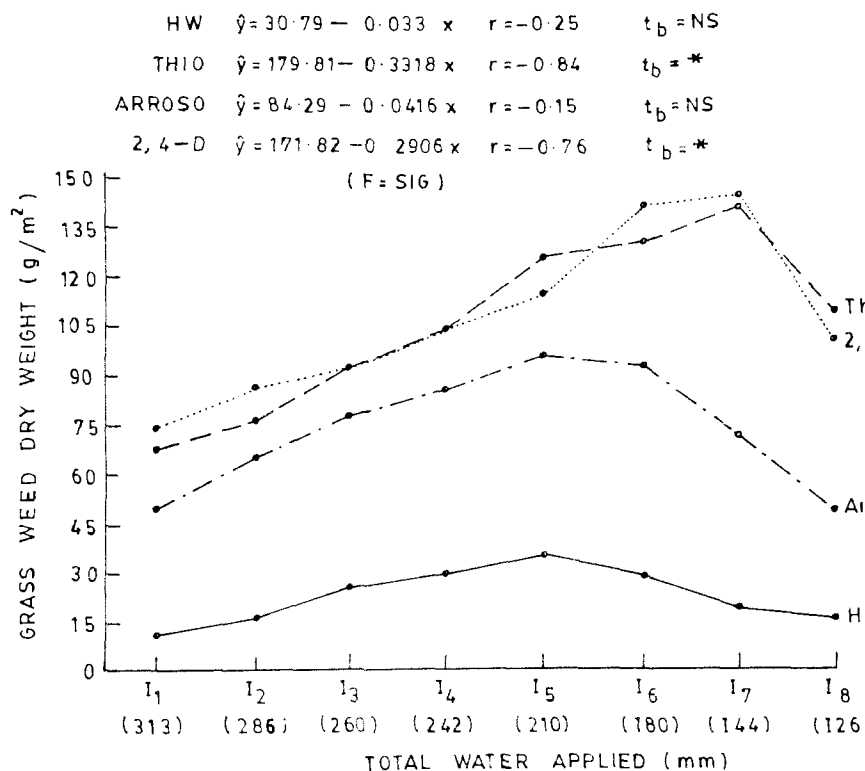
Table 70b: Grass weed weight (g/m^2) at 40 DAS (Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁	10.8 (3.33)	68.7 (8.06)	49.7 (7.01)	73.4 (8.18)	50.6 (6.65)
I ₂	16.0 (4.05)	76.7 (8.57)	66.2 (8.05)	87.1 (8.99)	61.5 (7.42)
I ₃	25.0 (5.04)	93.1 (9.47)	79.3 (8.81)	92.2 (9.26)	72.4 (8.15)
I ₄	30.5 (5.55)	104.3 (10.11)	86.8 (9.20)	103.6 (9.76)	81.3 (8.65)
I ₅	36.7 (6.05)	126.6 (11.17)	97.5 (9.72)	116.1 (10.50)	94.2 (9.36)
I ₆	30.8 (5.55)	130.9 (11.36)	95.3 (9.70)	142.5 (11.73)	99.9 (9.59)
I ₇	20.8 (4.58)	143.1 (11.76)	75.3 (8.62)	145.9 (12.07)	96.3 (9.26)
I ₈	16.8 (4.09)	110.7 (10.21)	51.0 (6.95)	102.2 (10.07)	70.2 (7.83)
Mean	23.4 (4.78)	106.8 (10.09)	75.1 (8.59)	107.9 (10.07)	
		I	W	W at I	I at W
SE _{d±}		0.45	1.12	0.85	1.36
CD (P=0.05)		0.94	2.53	NS	NS

NS = Not significant

Transformed data in paranthesis

FIG. 18 DRY WEIGHT OF GRASS WEED (g/m^2) AT 40 DAS
AS AFFECTED BY DIFFERENT TREATMENTS
(KHARIF 1986)



These results show that arrosolo was more effective than thiobencarb and effective over a wide range of moisture.

The BLW number (Table 71a) and weight (Table 71b) were low in arrosolo applied plots compared to that under thiobencarb and 2,4-D. The BLW number was low in arrosolo plots at all moisture regimes. At higher moisture levels, the effect of thiobencarb was similar to arrosolo. When moisture regimes were low, thiobencarb was less effective, but the effect was similar to hand weeding. The mean BLW weight was low (4.9 per cent of the total weight), and was not influenced by moisture levels and no interaction was observed.

The sedge weed number (Table 72a) and weight (Table 72b) were high in the wettest moisture regimes. When moisture levels decreased, they caused reduction in sedge weed number and weight. None of the weed control treatments, including hand weeding were effective against C. rotundus. It could not be uprooted under the local practice of hand weeding and the cut ends of weeds regenerate immediately. Arrosolo caused slight reduction in the weight of sedge at moisture levels of I_4 and I_5 . However, the weight decreased uniformly under all weed control treatments, when moisture levels were low.

Table 71a. BLW (No/m²) at 40 DAS

(Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁	9 (2.52)	17 (4.11)	7 (2.47)	13 (3.67)	11 (3.19)
I ₂	16 (3.73)	13 (3.55)	6 (2.58)	29 (4.91)	16 (3.69)
I ₃	12 (3.40)	11 (3.14)	6 (2.20)	18 (3.91)	12 (3.16)
I ₄	6 (2.53)	13 (3.38)	8 (2.59)	35 (5.88)	15 (3.52)
I ₅	10 (3.19)	19 (4.01)	7 (2.52)	23 (4.58)	15 (3.57)
I ₆	15 (3.66)	17 (3.94)	6 (2.31)	16 (4.05)	13 (3.49)
I ₇	18 (4.11)	18 (4.12)	5 (2.26)	49 (6.68)	22 (4.29)
I ₈	30 (5.32)	18 (4.20)	2 (1.39)	46 (6.78)	24 (4.42)
Mean	14 (3.55)	16 (3.81)	6 (2.29)	29 (5.02)	
		I	W	W at I	I at W
SE _d ±		0.41	0.33	0.72	0.72
CD (P = 0.05)		NS	0.76	1.46	1.49

NS = Not significant

Transformed data in parenthesis

Table 71b: BLW weight (g/m^2) at 40 DAS (Kharif '86)

	Hand weeding	Thio-bencarb	Arrosolo	2,4-D	Mean
I ₁	0.9 (1.10)	12.8 (3.26)	3.2 (1.72)	3.8 (1.97)	5.2 (2.02)
I ₂	2.4 (1.49)	5.2 (2.22)	1.7 (1.43)	9.5 (2.80)	4.7 (1.99)
I ₃	1.7 (1.36)	4.5 (2.01)	4.7 (1.84)	7.3 (2.53)	4.5 (1.94)
I ₄	0.8 (1.10)	13.6 (3.31)	2.5 (1.52)	13.1 (3.30)	7.5 (2.31)
I ₅	1.7 (1.45)	9.1 (2.59)	1.2 (1.24)	11.5 (3.02)	5.9 (2.07)
I ₆	4.9 (1.95)	7.9 (2.55)	0.9 (1.10)	11.4 (2.93)	6.3 (2.11)
I ₇	6.4 (2.42)	12.6 (3.23)	0.7 (1.05)	13.7 (3.20)	8.3 (2.47)
I ₈	4.5 (2.06)	4.3 (2.08)	0.2 (0.83)	8.1 (2.78)	4.3 (1.94)
Mean	2.9 (1.60)	8.7 (2.66)	1.9 (1.34)	9.8 (2.82)	
		I	W	W at I	I at W
SE _d ±		0.36	0.43	0.58	0.65
OD (P=0.05)		NS	0.97	NS	NS

NS = Not significant

Transformed data in parenthesis

Table 72a. Sedge weed (No/m²) at 40 DAS (Kharif '86)

	Hand weeding	Thio-bencarb	Arrosoiro	2,4-D	Mean
I ₁	173 (13.15)	196 (13.96)	193 (13.83)	202 (13.75)	191 (13.67)
I ₂	153 (12.35)	168 (12.75)	152 (11.92)	163 (12.12)	159 (12.29)
I ₃	123 (10.99)	146 (11.89)	125 (10.73)	143 (10.61)	134 (11.85)
I ₄	100 (9.59)	128 (11.16)	90 (7.73)	126 (9.87)	111 (9.59)
I ₅	82 (8.72)	101 (9.80)	72 (7.41)	89 (7.94)	86 (8.47)
I ₆	67 (7.84)	76 (8.63)	44 (5.08)	56 (6.04)	61 (6.90)
I ₇	40 (5.76)	38 (6.18)	35 (4.54)	42 (4.91)	39 (5.35)
I ₈	18 (3.14)	12 (3.35)	18 (3.50)	17 (3.27)	16 (3.31)
Mean	94 (8.94)	108 (9.71)	91 (8.09)	105 (8.56)	
		I	W	W at I	I at W
SE _d ±		0.76	1.31	1.16	1.62
CD (P=0.05)		1.58	NS	NS	NS

NS = Not significant

Transformed data in paranthesis

Table 72b: Sedge weed weight (g/m^2) at 40 DAS

(Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁	53.5 (7.23)	74.2 (8.52)	72.0 (8.38)	96.8 (9.20)	73.9 (8.33)
I ₂	43.4 (6.35)	61.1 (7.58)	49.0 (6.61)	81.9 (8.24)	58.8 (7.20)
I ₃	34.4 (5.54)	54.9 (7.09)	34.4 (5.45)	68.4 (7.16)	48.0 (6.31)
I ₄	27.6 (4.81)	45.5 (6.47)	18.8 (3.70)	61.5 (6.60)	38.3 (5.40)
I ₅	19.8 (4.18)	31.0 (5.43)	14.4 (3.16)	46.8 (5.75)	28.0 (4.63)
I ₆	15.4 (3.69)	24.7 (4.83)	8.5 (2.43)	31.8 (4.42)	20.1 (3.84)
I ₇	11.1 (3.04)	7.6 (2.83)	6.9 (2.22)	15.7 (3.05)	10.3 (2.78)
I ₈	3.1 (1.50)	1.9 (1.51)	4.3 (1.85)	3.9 (1.80)	3.3 (1.66)
Mean	26.0 (4.54)	37.6 (5.53)	26.0 (4.23)	50.7 (5.78)	
		I	W	W at I	I at W
SE _d ±		0.57	0.96	0.76	1.12
CD (P = 0.05)		1.18	NS	1.56	2.47

NS = Not significant

Transformed data in parenthesis.

The total weed number was low in arrosolo and hand weeding treatments (Table 73a) followed by thiobencarb. The moisture levels did not affect the total number in hand weeding and arrosolo plots while it was more in thiobencarb plots at lower moisture levels. However, the total weed weight was low in hand weeding followed by arrosolo plots (Table 73 b) and was not altered by different moisture levels, except that it was low when the water applied upto 40 DAS was 126 mm as in I_8 (Table 69b).

4.3.3.2. Removal of nitrogen by weeds at 40 DAS: The N-removal due to weeds was low in hand weeding followed by arrosolo (Table 74). The removal of N was high in thiobencarb and 2,4-D plots. The N-removal by weeds was not affected by moisture levels upto I_7 and it was low in I_8 .

4.3.3.3 Relative density and relative dry weight at 40 DAS: Among the weed control treatments, the RD of sedges was more in hand weeding, thiobencarb and arrosolo, but it was low in 2,4-D (Table 75). Pre-sowing 2,4-D failed to control grasses, and because of the higher number of grasses, the RD of sedges was low. The RDW of sedges was very high in hand weeding indicating its ineffectiveness over the sedge *C. rotundus*. More than 70 per cent of ^{the population was} total dry weight at *C. rotundus* and contributed to 57 per cent of total dry weight at the highest moisture level. With decrease in moisture level,

Table 73a. Total weeds (No/m²) at 40 DAS (Kharif '86)

	Hand weeding	Thio-bencarb	Arrosolo	2,4-D	Mean
I ₁	220 (14.85)	277 (16.61)	265 (16.28)	309 (17.55)	267 (16.32)
I ₂	221 (14.89)	261 (16.03)	234 (15.15)	310 (17.62)	256 (15.92)
I ₃	206 (14.34)	242 (15.40)	214 (14.55)	285 (16.84)	237 (15.29)
I ₄	192 (13.82)	227 (14.98)	193 (13.81)	291 (17.06)	224 (14.52)
I ₅	176 (13.22)	228 (15.04)	194 (13.92)	253 (15.91)	213 (14.52)
I ₆	159 (12.57)	207 (14.37)	153 (12.23)	245 (15.62)	190 (13.70)
I ₇	116 (10.70)	172 (13.07)	136 (11.50)	283 (16.85)	176 (13.03)
I ₈	102 (10.11)	170 (13.01)	111 (10.15)	256 (15.97)	159 (12.31)
Mean	173 (13.06)	223 (14.82)	187 (13.45)	279 (16.68)	
		I	W	W at I	I at W
SE _d ±		0.55	0.68	0.84	0.96
CD (P=0.05)		1.15	1.54	1.71	2.05

Transformed data in paranthesis

Table 73b: Total weed weight (g/m^2) at 40 DAS (Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁	65.2 (8.03)	155.7 (12.37)	125.0 (11.16)	173.1 (13.08)	129.7 (11.16)
I ₂	61.8 (7.78)	143.0 (11.75)	117.0 (10.79)	178.5 (13.33)	125.0 (10.91)
I ₃	61.1 (7.76)	152.5 (12.14)	118.5 (10.85)	167.9 (12.95)	124.9 (10.92)
I ₄	58.9 (7.59)	163.4 (12.72)	108.1 (10.31)	178.3 (13.31)	127.1 (10.98)
I ₅	58.2 (7.65)	166.7 (12.79)	113.1 (10.55)	174.4 (13.18)	128.1 (11.04)
I ₆	51.1 (7.16)	163.5 (12.77)	104.8 (10.20)	185.8 (13.58)	126.3 (10.93)
I ₇	38.4 (6.22)	163.3 (12.36)	83.0 (9.04)	175.4 (13.22)	114.9 (10.21)
I ₈	24.4 (4.97)	116.9 (10.55)	55.0 (7.33)	114.2 (10.64)	77.8 (8.37)
Mean	52.3 (7.14)	153.1 (12.18)	103.0 (10.03)	168.4 (12.91)	
		I	W	W at I	I at W
SE _{d±}		0.48	0.67	0.79	0.95
CD (P=0.05)		1.00	1.52	NS	NS

NS = Not significant

Transformed data in parantheses.

Table 74: Nitrogen removed by weeds at 40 DAS (kg/ha)

Hand weeding	6.86
Thiobencarb	20.85
Arrosoir	13.97
2,4-D	22.75
$SE_d \pm$	2.18
CD ($P=0.05$)	4.94
I_1	16.50
I_2	16.65
I_3	16.52
I_4	17.13
I_5	17.48
I_6	17.50
I_7	16.12
I_8	10.96
$SE_d \pm$	1.42
CD ($P=0.05$)	2.95

Table 75: Relative density and relative dry weight of weeds at 40 DAS

(Kharif '86)

	Relative density			Relative dry weight		
	Grass	Broad leaved	Sedge	Grass	Broad leaved	Sedge
Hand weeding	37.6	8.1	54.3	44.7	5.5	49.8
Thiobencarb	44.4	7.2	48.4	69.7	5.7	24.6
Arrosoiro	48.1	3.2	48.7	72.9	1.8	25.3
2,4-D	52.0	10.4	37.6	64.1	5.8	30.1
I ₁	24.3	4.1	71.6	39.0	4.0	57.0
I ₂	31.6	6.2	62.2	49.2	3.7	47.1
I ₃	38.4	5.1	56.5	58.0	3.6	38.4
I ₄	43.7	6.7	49.6	64.0	5.9	30.1
I ₅	52.6	7.0	40.4	73.5	4.6	21.9
I ₆	61.0	6.8	32.2	79.1	5.0	15.9
I ₇	65.3	12.5	22.2	83.8	7.2	9.0
I ₈	74.8	15.1	10.1	90.2	5.5	4.3
Mean	45.5	7.2	47.3	62.8	4.7	32.5

sedge weed proportion decreased while there was corresponding increase in the proportion of grasses. Even from the actual weed weight, the same trend was noticed (Fig.19), and it was interesting to note that the total weed weight did not change over a wide range of moisture.

The very high proportion of C. rotundus during this season, particularly in the higher moisture levels, did not allow proper growth of rice. Repeated hand weedings at later stage (40, 60 and 80 DAS) only helped to cut the weeds and the control was not perfect. As such the crop growth was generally poor, despite the favourable weather conditions.

4.3.4. Crop growth at 30 DAS: Plant height, LAI and shoot dry weight were more in arrosolo applied plots (Table 76). Tiller number was not affected by either weed control treatments or moisture regimes.

Plant height and LAI were more when the total water applied was between 146 and 280 mm. At moisture level I₄ (209 mm) the shoot weight was more and moisture levels above or below this, caused reduction.

4.3.5. Crop growth at 60 DAS: The plants were dwarf in 2,4-D plots among the weed control treatments while shoot dry weight was more in arrosolo plots. Tiller number and

FIG. 19 DRY WEIGHT (g/m^2) OF GRASSES, BLW, SEDGES AND TOTAL WEEDS AT 40 DAS UNDER DIFFERENT MOISTURE REGIMES (KHARIF 1986)

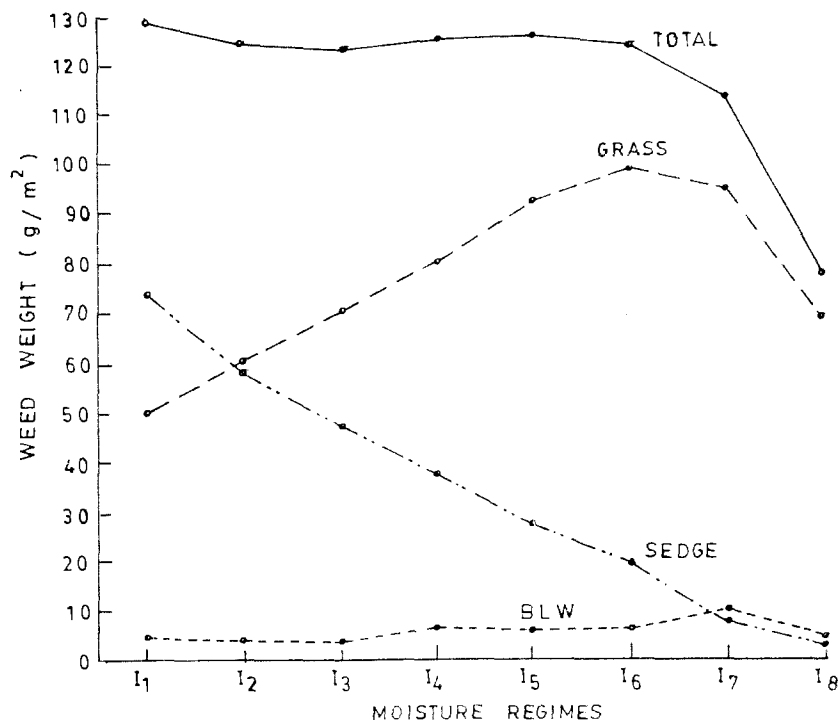


Table 76: Rice growth at 30 DAS

(Kharif '86)

	Plant height (cm)	Tillers/m	LAI	Shoot dry weight (g/m)
Hand weeding	12.4	124	0.37	4.16
Thiobencarb	12.8	128	0.39	3.46
Arrosoiro	14.4	131	0.48	5.10
2,4-D	12.9	143	0.45	4.28
$SE_d \pm$	0.52	8.1	0.03	0.26
CD (P=0.05)	1.17	NS	0.08	0.58
I ₁ (280 mm)	13.2	130	0.47	5.15
I ₂ (253)	14.3	135	0.48	4.98
I ₃ (227)	14.1	142	0.47	5.30
I ₄ (209)	14.6	137	0.49	5.94
I ₅ (177)	13.9	140	0.50	4.41
I ₆ (146)	13.1	131	0.44	3.38
I ₇ (111)	11.3	135	0.30	2.63
I ₈ (93)	10.6	105	0.23	2.24
$SE_d \pm$	0.47	10.6	0.04	0.27
CD (P=0.05)	0.99	NS	0.08	0.56

NS = Not significant.

LAI were not influenced by weed control treatments (Table 77). The differences in the tiller number and LAI due to moisture levels were not significant except at I_3 level (142 mm), where decrease was observed in both these characters. The total water applied above 511 mm or below 411 mm resulted in stunted growth. With 411 mm of water applied at 0.87 TWA/UE, the shoot dry weight of rice was more. Moisture levels above this lowered the shoot growth while the effect of decrease in water applied was very profound, causing drastic reduction in shoot weight.

Upto 60 DAS, 0.87 TWA/UE ratio appeared to be the optimum.

4.3.6. Crop growth at 90 DAS: There was considerable increase in the crop growth compared to 60 DAS because of 151.2 mm of rainfall in addition to moisture levels applied. But the influence of different treatments remained the same. Plants were dwarf in 2,4-D plots while shoot weight was more in arrosolo plots. Except the tiller number, all the other growth parameters were affected by moisture levels (Table 78).

The crop took 103 days to flower in I_7 and I_8 as against 97 days in I_1 . Weed control treatments did not influence the days to flowering.

Table 77: Crop growth at 60 DAS

(Kharif '86)

	Plant height (cm)	Tillers/m	LAI	Shoot dry weight (g/m)
Hand weeding	20.6	93	0.93	6.18
Thiobencarb	20.2	77	0.89	5.42
Arrosolo	21.7	98	1.04	7.44
2,4-D	18.3	99	0.93	6.21
SE _d ±	0.9	12.4	0.13	0.33
CD (P=0.05)	2.0	NS	NS	0.81
I ₁ (575 mm)	21.3	87	0.88	7.97
I ₂ (511)	22.9	88	1.05	7.46
I ₃ (453)	22.5	88	1.03	8.09
I ₄ (411)	22.5	108	1.18	9.07
I ₅ (351)	21.1	108	1.08	6.52
I ₆ (284)	19.7	97	1.03	4.99
I ₇ (208)	17.9	99	1.01	3.68
I ₈ (142)	13.8	60	0.31	2.74
SE _d ±	0.5	12.3	0.16	0.38
CD (P=0.05)	1.1	25.5	0.34	0.81

NS = Not significant.

Table 78: Rice growth at 90 DAS

(Kharif '86)

	Plant height (cm)	Tillers/m	LAI	Shoot dry weight (g/m)	Days to flower- ing
Hand weeding	44.3	63	1.80	27.89	
Thiobencarb	42.0	57	1.73	24.42	
Arrosolo	43.9	66	2.09	28.82	
2,4-D	39.4	57	1.57	24.25	
SE _d ±	1.7	7.5	0.21	1.45	
CD (P=0.05)	3.8	NS	NS	3.54	
I ₁ (921 mm)	44.8	67	2.25	36.11	97
I ₂ (827)	43.7	65	2.19	30.88	98
I ₃ (744)	42.0	61	1.98	25.04	98
I ₄ (681)	40.9	62	1.72	21.13	100
I ₅ (597)	39.1	60	1.58	20.01	100
I ₆ (513)	37.2	59	1.37	18.00	101
I ₇ (410)	36.6	56	1.19	15.23	103
I ₈ (306)	30.7	55	0.91	14.35	103
SE _d ±	0.9	5.4	0.06	0.67	
CD (P=0.05)	1.8	NS	0.12	1.43	

NS = Not significant.

4.3.7. Data recorded at harvest

4.3.7.1. Plant height, total tillers, productive tillers:

Plants were taller in hand weeding and arrosoiro treated plots followed by thiobencarb. Significant reduction in height was observed in 2,4-D treated plots where weeds were not controlled (Table 79). Similar effect of weed control was observed on total tiller number and also on the number of effective tillers, and the percentage of effective tillers was not altered by weed control treatments.

The total tiller number was not influenced by moisture regimes. But the number of productive tillers declined with decrease in the total water applied thereby the percentage of productive tillers as well showed similar trend. Responses in plant height due to moisture levels were significant. The plant height was less by 20 cm. when the total water applied was reduced from 1299 mm to 512 mm.

4.3.7.2. Panicle characters and 1000-grain weight:

The panicle length, panicle weight and the number of filled grains per panicle as well as 1000 grain weight were low in the 2,4-D treated plots compared to the rest of the weed management practices which were comparable between themselves (Table 80). The number of sterile grains was same in the weed control treatments, thereby, the percentage sterility

Table 79: Data on plant height and tillers at harvest

(Kharif '86)

	Plant height (cm)	Total tillers/m	Effective tillers/m	Per cent effective tillers
Hand weeding	59.8	67	41	61.4
Thiobencarb	56.1	58	34	58.5
Arrosoiro	59.0	67	41	60.8
2,4-D	52.9	56	31	56.0
SE _d ±	1.4	3.1	2.5	4.7
CD (P=0.05)	3.3	7.5	6.1	NS
I ₁ (1299 mm)	66.1	69	63	90.6
I ₂ (1176)	63.9	62	52	84.6
I ₃ (1068)	61.9	63	46	74.7
I ₄ (984)	59.3	62	41	66.3
I ₅ (880)	55.6	60	34	57.5
I ₆ (774)	52.8	57	28	48.4
I ₇ (648)	49.6	60	20	33.2
I ₈ (512)	46.2	61	11	18.1
SE _d ±	0.7	3.6	1.6	4.3
CD (P=0.05)	1.6	NS	3.5	9.3

NS = Not significant.

Table 80: Panicle characters, sterility and 1000-grain weight
(Kharif '86)

	Panicle length (cm)	Panicle weight (g)	No. of filled grains/ panicle	No. of chaffy grain/ pani- cle	Steri- lity (%)	1000- grain weight (g)
Hand weeding	15.8	0.96	43.3	13.4	25.0	18.8
Thiobencarb	15.2	0.90	40.8	13.9	26.7	18.1
Arrosolo	16.1	0.95	42.9	14.1	25.9	18.7
2,4-D	14.7	0.84	34.6	14.0	30.4	17.6
SE _d ±	0.17	0.03	2.5	1.5	3.2	0.24
CD (P=0.05)	0.42	0.08	6.8	NS	NS	0.58
I ₁ (1299 mm)	17.0	1.23	56.8	6.4	10.2	20.8
I ₂ (1176)	16.6	1.17	52.6	8.0	13.2	20.2
I ₃ (1068)	16.0	1.07	48.6	9.4	16.3	19.5
I ₄ (984)	15.6	0.96	43.8	10.9	20.2	18.8
I ₅ (880)	15.3	0.85	38.1	12.1	24.6	18.0
I ₆ (774)	14.9	0.77	34.8	14.6	30.2	17.3
I ₇ (648)	14.4	0.69	28.7	19.5	40.7	16.6
I ₈ (512)	13.7	0.57	19.8	38.1	60.6	15.1
SE _d ±	0.11	0.04	2.5	2.2	4.4	0.16
CD (P=0.05)	0.23	0.10	5.5	4.8	9.4	0.34

NS = Not significant.

was not altered except that it was slightly greater in 2,4-D plots.

In spite of the effects of moisture stress during early growth period coupled with severe competition from the weed C. rotundus, the rainfall of 151.2 mm during one to two weeks before heading followed by 175.4 mm during flowering and ripening periods helped the crop to mature, even in the farthest plot from the sprinkler line. However, significant differences persisted in these characters due to moisture regimes. The decrease in panicle length, panicle weight, number of filled grains per panicle and 1000-grain weight was significant as the total water applied was low. On the other hand, the number of chaffy grains and percentage sterility increased. The sterility percentage was more than 60 in the farthest plot (I_8) from sprinkler line.

4.3.7.3. Grain yield: The level of productivity was low during the season in spite of favourable weather, because of the shift in weed flora from grasses to sedges. However significant differences could be observed due to the treatments.

The mean grain yield was high in hand weeding and arroso plots. There was 19.1 per cent yield decrease in thibencarb plots compared to hand weeding while the decrease in yield was to the extent of 25.5 per cent in 2,4-D plots (Table 81).

Table 81: Grain yield (kg/ha)

(Kharif '86)

	Hand weeding	Thio- bencarb	Arrosolo	2,4-D	Mean
I ₁ (1288 mm)	1964	1489	1817	1378	1662
I ₂ (1176)	1478	1197	1492	1144	1328
I ₃ (1068)	1292	1006	1297	880	1119
I ₄ (964)	803	760	792	753	782
I ₅ (880)	611	505	575	481	543
I ₆ (774)	436	369	411	330	387
I ₇ (648)	292	244	281	178	248
I ₈ (512)	139	78	125	86	107
Mean	877	709	849	653	
		I	W	W at I	I at W
SE _d ±		143	47	164	99
CD (P=0.05)		307	114	347	208

Even though the crop matured in I_0 with 512 mm of water, the grain yield was very low (107 kg/ha) and negligible. About 500 kg/ha of grain could be produced when the total water applied was equal to the evaporation. The yield obtained with TWA/UE values of less than 1.0, was very poor.

With highest amount of water applied (1299 mm), grain yields under arrosolo and hand weeding were similar. With 1176 mm of water, the yield under thiobencarb was also similar to hand weeding and arrosolo. When the total water applied was 782 mm or less than that, all the weed control treatments behaved similarly. These results clearly show that, productivity cannot be raised under low levels of water applied or rainfall, inspite of effective weed control. But when more water was applied (similar to high rainfall) weed control played an important role in deciding the yield.

4.3.7.4. Straw yield, Harvest Index, AWUE and nitrogen uptake

by crop: The straw yield under arrosolo and hand weeding was comparable while it was low in 2,4-D plots (Table 82). The HI, AWUE and uptake of N by crop were low in thiobencarb and 2,4-D plots which resulted from the lower grain yields in these treatments. Straw yield decreased with decrease in the moisture regime. The straw yield decreased by 79 per cent with 512 mm of water as compared to that in

Table B2: Straw yield, Harvest index, Apparent water use efficiency and N uptake

(Kharif '86)

	Straw yield (kg/ha)	Harvest index	AWUE (kg/mm)	N-uptake by crop (kg/ha)
Hand weeding	3080	0.19	0.95	20.9
Thiobencarb	2843	0.16	0.77	18.5
Arrosolo	3066	0.18	0.92	20.6
2,4-D	2760	0.16	0.71	17.6
SE _d ±	112	0.01	0.04	0.9
CD (P=0.05)	247	0.02	0.11	2.1
I ₁ (1286 mm)	5600	0.25	1.30	35.8
I ₂ (1176)	4326	0.23	1.13	30.1
I ₃ (1068)	3756	0.22	1.05	25.8
I ₄ (984)	3104	0.18	0.79	20.2
I ₅ (880)	2569	0.16	0.62	15.9
I ₆ (774)	2090	0.14	0.50	12.5
I ₇ (648)	1500	0.13	0.38	8.7
I ₈ (512)	1153	0.08	0.21	6.0
SE _d ±	290	0.02	0.15	1.7
CD (P=0.05)	622	0.05	0.32	2.4

1299 mm, while the decrease in grain yield was 94 per cent. Hence, the decrease in grain yield was rapid, while it was gradual in straw yield, resulting in lower HI due to decreasing moisture levels. The relative decrease in grain yield was more rapid compared to water applied, thereby lowering the AWUE significantly. More than 1.0 kg grain/mm of water could result only in the first 3 moisture levels where the total water applied was more than 1000 mm. The N uptake by crop was low in 2,4-D and thiobencarb plots and it decreased when water applied was low.

4.4. General Discussion: During the three seasons of observation, the results with thiobencarb and arrosolo were more conspicuous. Thiobencarb was more effective, when soil moisture was maintained near field capacity. At lower moisture regimes, this herbicide was less effective. This can be explained by the fact that thiobencarb is adsorbed more by drier soil, with less of the herbicide left available for weeds to absorb (Anon., 1977b) . Studies on degradation of thiobencarb as reported by Yaron et al. (1985) showed that, the herbicide was readily degraded in upland soils under aerobic conditions; less readily in moist soils under anaerobic-aerobic conditions; and very slowly in flooded soils under anaerobic conditions.

Arrosolo was effective over a wide range of soil moisture condition. It was more effective with higher moisture regimes and continued to be effective even at soil moisture of 60 per cent ASM. Arrosolo is formulated by combining molinate with propanil. Molinate is stable to hydrolysis and is absorbed through plant roots (Grusdyev et al., 1983). It is a systemic herbicide and reduces the weeds without lowering the thickness of crop stand. It is a non-persistent herbicide and has very short half life (Yaron et al., 1985). On the other hand, propanil is a contact herbicide, but is translocated in the plant system (Sreeramulu, 1982). Smith (1971) reported that, on problem soils where water cannot be maintained, molinate provides residual weed control, but propanil does not. It would prevent germination and re-infestation of the grass weeds during short drained periods, or on rice fields where irrigation water is lost. Smith (1973) found that early post-emergence application of propanil with molinate controlled more weed species than a single application of either propanil or molinate. The principal advantage of residual herbicides in dry sown rice may be to eliminate the need for re-treatment with propanil when moisture availability is delayed (Richard and Street, 1984). Molinate promotes the penetration of propanil giving more complete contact control and when moisture is made available, molinate residue will control germinating grasses (Soong, 1981).

During kharif 1985, the herbicidal effect lasted till 40 DAS and arrosolo was more effective than thiobencarb. The mean weed control with arrosolo was similar to one hand weeding (Table 83). The hand weeding at 20 DAS was difficult because rice and grass weed E. colona sprouted simultaneously and were similar in appearance.

During summer, 1986, pre-sowing 2,4-D was tested at 2.0 kg/ha and excellent weed control was observed even when soil moisture was at 75 per cent ASM. However, germination of rice was delayed and shoot growth was low initially. To avoid these ill effects on rice, the dose was reduced to 1.5 kg/ha during kharif, 1986. But the result was almost poor to no weed control. This could be due to higher clay and organic matter content of the soil as they adsorb the herbicide and greatly affect the herbicide toxicity (Rao, 1983).

The pre-sowing irrigation given for 2,4-D helped the weeds in the unsprayed plots to sprout before the germination of rice. Weeds crossed the susceptible stage in the higher moisture levels, by the time the herbicides were applied. Most herbicides control grasses upto 2-leaf stage and later weeds become resistant to herbicides. Hence, weeds could not be controlled in the higher moisture ranges, where herbicides were supposed to be more effective.

In addition to the interference from pre-sowing irrigation, the increase in the proportion of C. rotundus caused

Table 83. Weed control index during different seasons

Season	Treatment	I ₁	I ₄	I ₈	Mean
Kharif, 1985	Hand weeding	71.9	75.8	73.8	91.3
	Thiobencarb	58.8	41.0	56.5	42.1
	Arrosoiro	68.7	70.8	73.2	66.2
Summer, 1986					
20 DAS	2,4-D	71.5	64.7	48.7	54.4
40 DAS	Thiobencarb	48.6	61.7	41.7	49.8
	Arrosoiro	14.9	61.7	57.9	49.6
	Arrosoiro + 2,4-D	41.7	62.9	47.0	42.7
Kharif, 1986	Thiobencarb	36.5	20.0	24.8	22.9
20 DAS	Arrosoiro	37.1	44.7	77.3	45.6
	2,4-D	4.8	Nil	39.8	Nil
40 DAS	Hand weeding	62.3	67.0	78.6	68.9
	Thiobencarb	10.0	8.3	Nil	9.1
	Arrosoiro	27.8	39.4	51.8	38.8

lower relative efficacy of herbicides. The study was made continuously for three seasons on the same plot to observe changes in weed flora. The sedge weed, which was relatively negligible during the first season, increased sharply from season to season. The increase was more in the higher moisture regimes. During kharif, 1986, the proportion of C. rotundus was more than 50 per cent in the first four moisture levels compared to less than 5 per cent during kharif, 1985 (Table 84).

C. rotundus tubers can germinate even when the moisture content in them is from 12 to 16 per cent (Sakharam Rao and Nagarajan, 1963; and Tripathy, 1969). and once germinated it cannot be controlled by any of the water management practices. Even standing water of 60 cm for 3 days did not affect C. rotundus in a dry sown rice field (Singh et al., 1983). The tuber problem can be reduced by ploughing to 30 cm depth and exposing them to sunlight (Anon., 1966) and repeated ploughings aid in bringing down their population drastically (Sinha and Thakur, 1967). In the present study, repeated ploughings could not be taken up during summer, as it was cropped to study the changes in weed flora. Otherwise, the population of C. rotundus can be lowered by cultivation. Smith (1961) stated that tillage practices during dry season decreased the prevalence of C. rotundus but increased the problems with annual grass E. colona. E. colona could be

Table 84: Change in weed flora

	RD			RDW			
	Grass	Broad leaved weed	Sedge	Grass	Broad leaved weed	Sedge	
Kharif '85	81.2	15.7	3.1	76.6	20.3	3.1	
Summer '86	74.8	8.2	17.0	84.3	6.1	9.6	
Kharif '86	45.4	7.2	47.3	62.8	4.7	32.5	
Relative proportion of sedge ($\bar{Q}$, rotundus)							
<u>RD</u>	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Kharif '85	4.7	4.1	1.7	2.9	3.7	1.6	0.6
Summer '86	41.4	32.0	24.3	15.3	12.3	8.6	5.7
Kharif '86	71.6	62.2	56.5	49.6	40.4	32.2	22.2
<u>RDW</u>							
Kharif '85	5.5	7.0	3.0	2.8	3.1	0.9	0.3
Summer '86	35.6	21.3	13.9	9.4	7.6	4.9	2.0
Kharif '86	57.0	47.1	38.4	30.1	21.9	15.9	9.0

Increase in the number or weight of $\bar{Q}$, rotundus

	Kharif '85	Summer '86	Kharif '86
No./m ²	4	19	99
Weight (g/m ²)	1.7	3.1	35.1

effectively controlled by herbicides as observed during kharif, 1985.

During the present investigation, there was considerable increase in the total weed number and weed weight from kharif, 1985 to kharif, 1986. The weed number increased from $173/\text{m}^2$ to $215/\text{m}^2$ while the increase in total weed weight was from $72.6 \text{ g}/\text{m}^2$ to $119.2 \text{ g}/\text{m}^2$. Because of the increase in total weed number and weed weight in addition to the enormous increase in the sedge weed proportion the crop growth during kharif, 1986 was poor. Hand weeding was not effective in checking C. rotundus. The severe weed competition reduced the crop growth leading to poor yields. The yield level, in fact, could be obtained due to the well distributed rainfall in addition to the moisture levels during flowering and ripening periods. The weather during both the kharif seasons was more or less similar and was favourable for rice growth (Table 85). During summer 1986, the mean maximum temperature was more than 30°C during the flowering and ripening periods. The solar radiation was also very high, above $500 \text{ cal}/\text{cm}^2/\text{day}$. The higher temperature and solar radiation though favour low land rice are highly unfavourable for upland rice (Yoshida, 1975). The unfavourable weather during summer, 1986, and competition from C. rotundus during kharif, 1986, resulted in lower yields.

Table 85. Weather during different periods

	DAS	Evapo- ration (mm/ day)	Rain- fall (mm)	Mean maxi- mum temp. (°C)	Solar radia- tion (cal/ cm ² / day)	Mean sun- shine (hours)
Kharif '85	0 -30	6.3	22.0	29.2	405.4	4.0
	30-60	6.2	53.2	29.8	480.6	5.4
	60-90	3.6	93.9	30.5	457.7	6.6
	90- M	4.6	66.0	30.1	434.4	6.0
Summer '86	0 -30	4.7	38.0	29.8	439.6	7.0
	30-60	5.8	7.2	31.1	476.0	8.3
	60-90	7.6	111	34.3	518.7	9.3
	90- M	7.0	32.4	35.7	506.1	8.4
Kharif '86	0 -30	8.3	26.9	31.5	403.3	5.8
	30-60	7.4	11.2	31.2	373.9	7.2
	60-90	5.2	151.2	31.6	492.1	6.4
	90- M	3.7	175.4	30.3	423.8	6.7

During favourable weather, when weed flora is represented mostly by annuals, efficient weed control and higher level of productivity could be obtained.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

Field experiments were conducted during kharif, 1985 as well as summer and kharif, 1986 to evaluate the efficiency of different herbicides and to study the growth and yield of upland rice under varying soil moisture levels created through line source sprinkler system.

During kharif, 1985, herbicides thiobencarb and arrosolo (molinate + propanil) were applied on 8 DAS and compared with hand weeded and unweeded checks. Echinochloa colona was the major weed and both the herbicides were effective upto 40 DAS. The herbicides were highly effective when the soil moisture was above FC in the top 15 cm. at spraying and 35 mm of water added within 3 days of spraying. The efficacy of the herbicides gradually decreased when the moisture levels were low. Arrosolo was effective even with the lower moisture levels, and it was similar to hand weeding across the moisture levels tested. The weed weight was low when the total water applied was more than 227 mm and it increased when less than 195 mm of water was applied, upto 40 DAS. The weed growth during entire crop period under arrosolo followed by two hand weedings was similar to four hand weedings in the hand weeded check.

The crop growth during the first 30 days was slow. When the water applied was more than the evaporation, the

available N and K in the soil were low, in addition to continued anaerobic conditions, and plant height, LAI and shoot dry weight of rice were low. Shoot weight was more affected due to moisture levels compared to root weight. Crop growth at early stages was good when TWA/UE ratio was around 0.58. During the period between 30 and 60 DAS, 0.95 TWA/UE ratio was found suitable as it favoured the growth factors viz., plant height, LAI and tiller number.

After 60 days, crop suffered due to moisture stress when the water applied was less than the evaporation and growth was good at higher moisture levels. The chlorophyll content increased, particularly chlorophyll b, during stress. Leaf elongation rate and panicle exertion rate were affected. Flowering started 85 DAS with adequate moisture, while it was delayed by 9 days with 0.92 TWA/UE and failed to flower when water applied was less than that. RWC of flag leaves decreased with age while canopy-air temperature differential was found to be a good indicator of plant water status. Plant height at harvest, yield attributes like number of productive tillers, panicle length, panicle weight, number of filled grains per panicle and 1000 grain weight and grain and straw yield were affected with decreasing moisture levels. Harvest index, AWUE and N uptake by crop were also affected due to lower levels of moisture. Sterility percentage increased

with stress. The different weed control treatment on the other hand did not influence most of the above characters except that all the characters were depressed due to continued weed growth under unweeded check which resulted in almost complete failure of crop. Thiobencarb lowered the tiller number initially due to phytotoxic effects. However, the crop recovered later. The grain yields under arrosoiro and hand weeding were similar at higher moisture levels and when total water applied was less than the evaporation, chemical and hand weeding treatments were similar. When 468 mm of water was applied, there was no yield. The water requirement was found to be more than 670 mm for reasonable yields under upland rice, when the weed flora was represented by annual weeds and hand weeding as well as herbicides were equally effective.

The cost of chemical weed control was cheaper; however the net returns were greater under repeated hand weeded conditions.

The total weed weight exhibited inverse relationship with grain yield, but was not accurate to predict yield losses. The expression "gram day competition" seems to be more precise in predicting yield losses due to weed competition.

During summer, 1986, pre-sowing 2,4-D was applied in the form of ethyl ester across a moisture gradient 8 DBS of rice. Bringing the soil to 75 per cent ASM level was found sufficient for the herbicide to be effective. The above condition was created with the application of 13 mm of water to a dry soil. Laboratory studies showed that the degradation of 2,4-D EE followed the first order kinetics and residue degraded to below 0.22 ppm both in the dry and moist soils. The degradation was rapid in soil with higher moisture and slowed as the moisture content decreased. The moisture in the soil accelerated the ester hydrolysis. However, the dry soil had substantially higher 2,4-D residue upto 7 days period, and only when the soil was flooded, the residue declined to lower levels, almost equivalent to that of the other soil which had different levels of moisture. 2,4-D acid was further degraded, and the products were 4-chlorophenol and 2,4-dichlorophenol which might have resulted due to anaerobic dechlorination, most probably mediated by anaerobic microbes. Weeds in dry soil or with lower moisture level, failed to absorb the herbicide, thereby they were not controlled. Pre-sowing 2,4-D delayed the sprouting of rice by 6 days, and the number of germinants was also low. But the crop recovered rapidly.

Combination of acreosolo and 2,4-D was tested during summer 1986, in addition to individual application of

arrosolo and thiebencarb, after dropping the unweeded check. These treatments were imposed following a hand weeding in order to have the results independent of the pre-sowing 2,4-D effects. Arrosolo was found to be effective even when the soil moisture was 22.5 per cent at spraying (50 per cent ASM) and 26 mm of water applied during the 8 days period of observation. Thiebencarb showed significant relationship with moisture and the weed control was noticed only at higher levels. The combination of arrosolo and 2,4-D showed antagonism resulting in poor weed control and also affected the rice shoot weight.

The response to moisture was observed from early stages during summer. All the growth characters were depressed due to stress. Lower moisture levels were found to result in higher mechanical resistance affecting poor proliferation and uptake of nutrients and water by plants. The crop took 8 days more to flower compared to kharif, 1985 even with adequate moisture. Flowering was delayed by another 25 days due to moisture stress. All the yield attributes and yield were reduced due to stress. With 1440 mm of water, grain yields under hand weeding, thiebencarb and arrosolo were similar. When water applied was about 1100 mm at lower TWA/US ratios, the yield level decreased and all the weed control treatments were at par. The AWUS was low during this season, primarily due to unfavourable weather.

During kharif, 1986, pre-sowing 2,4-D was applied at a reduced dose of 1.5 kg/ha, 8 DAS while thiobencarb and arrosolo were applied 8 DAS. 2,4-D at reduced dose was not effective. Pre-sowing irrigation helped the weeds in unsprayed plots nearer to the sprinkler line to sprout before sowing of rice. The herbicides arrosolo and thiobencarb, thus could not control the weeds in higher moisture levels, as the weeds crossed the susceptible stage by the time of application. Thiobencarb was effective when soil moisture was above 90 per cent ASM during spraying while arrosolo was effective at still lower levels. The weed control was low, partly because of the interference due to pre-sowing irrigation and partly due to the shift in weed flora to sedges. Cyperus rotundus constituted more than 70 per cent of the weed population contributing to 57 per cent of the weed dry weight at higher moisture levels. In spite of favourable weather, the level of production was low, because of higher proportion of C. rotundus, which was not controlled by any of the weed control treatments including hand weeding. The trends with grain yield were similar to the observations made during earlier seasons. Productivity could not be raised under low levels of water application in spite of effective weed control. But with high rainfall situations simulated in the study, weed control played an important role in deciding the yield.

The following conclusions are drawn from these studies.

1. Thiobencarb is effective when soil moisture is near FC during application.
2. Arrosolo is effective over a wide range of moisture upto 60 per cent ASM level
3. Inspite of effective weed control due to pre-sowing 2,4-D at 2.0 kg/ha upto 75 per cent ASM level, it causes phytotoxic effects on rice even after a gap of one week between spraying and sowing though the crop recovers subsequently. Reduced dose is not effective on deep clayey soil.
4. The expression "gram day competition" is more useful in predicting the yield losses as compared to total weed weight.
5. Weed shift occurs from annual grass E. colona to perennial sedge C. rotundus due to moisture regimes and continuous cultivation of dry seeded rice even during summer.
6. Upland rice in heavy soil requires lower levels of moisture during early stages while it is to be greater than evaporation as the growth advances.
7. Higher temperature and solar radiation do not favour upland rice cultivation.

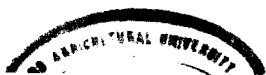
8. Weed control plays a major role in deciding the yield at adequate moisture levels and soil moisture regimes characterise upland rice production more than any other input.

After repeated summer ploughings, upland rice can be sown with early showers and either thiobencarb or arrosolo (molinate-propanil) can be used for weed control at 8 DAS depending upon moisture availability. Light showers during early stages followed by heavy rainfall during reproductive and ripening phases result in higher productivity of upland rice under heavy clay soil conditions.

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* Original not seen.

APPENDICES

APPENDIX I

Common and chemical name of herbicides referred in the review of literature

Common name	Chemical name
1. Alachlor	2-chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide
2. Anilophos	S [N (4-chloro-phenyl)-N-isopropyl-carbamoyl-methyl-] -O,O-dimethyl-dithiophosphate
3. Bentazon	3-isopropyl-1H-2,1,3-benzothiadiazin (4) 3H-one-2,2-dioxide
4. Butachlor	N-(butoxymethyl)-2 chloro-2',6'-diethylacetanilide
5. 2,4-D	(2,4-dichlorophenoxy) acetic acid
6. Dimethametryl	4 (1,2-dimethyl-n-propylamino)-2-ethylamino-6-methylthio-S-triazine
7. Dinitramine	-N ^A , N ^A -diethyl- α , α , α , trifluoro-3,5, dinitrotoluene-2,4-diamine
8. MCPA	[(4-chloro-O-tolyl) oxy] acetic acid
9. Molinate	S-ethyl hexahydro-1 H-azepine - 1 carbothioate (or) S-ethyl-N, N-hexamethylene thiocarbamate
10. Nitrofen	2,4-dichlorophenyl-p-nitrophenyl ether
11. Oxadiazon	2-tert-butyl-4-(2,4-dichloro-5-isopropoxyphenyl)-1-3-4-oxadiazolin-5-one
12. Oxyfluorfen	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene
13. Pendimethalin	N-(1-ethyl propyl)-2-6-dinitro-3,4-xylidine
14. Piperophos	1-(di-n-propoxy-phosphino-thiol-thiomethyl carbonyl)-2-methyl-piperidine
15. Propachlor	2-chloro-N-isopropylacetanilide
16. Propanil	3',4' -dichloropropionanilide
17. Thiobencarb	S-(4-chlorobenzyl)-N,N-diethylthiocarbamate

PLATES



Plate 1. Line source sprinkler system in operation and catch cans placed at right angle to the sprinkler line



Plate 2: Weed control through thiebencarb



Plate 3: Weed control through arrosolo

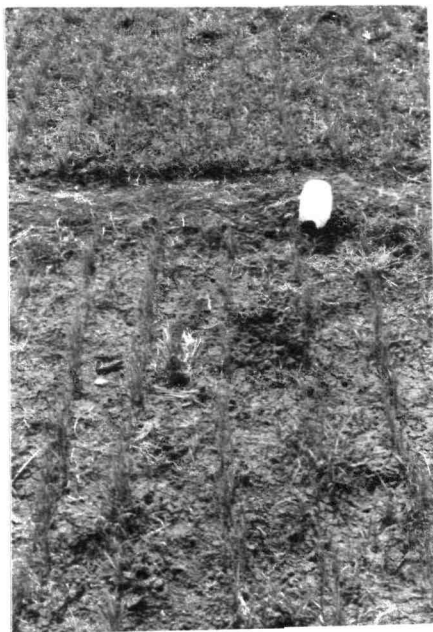


Plate 4: Effect of arrosolo as compared to untreated control

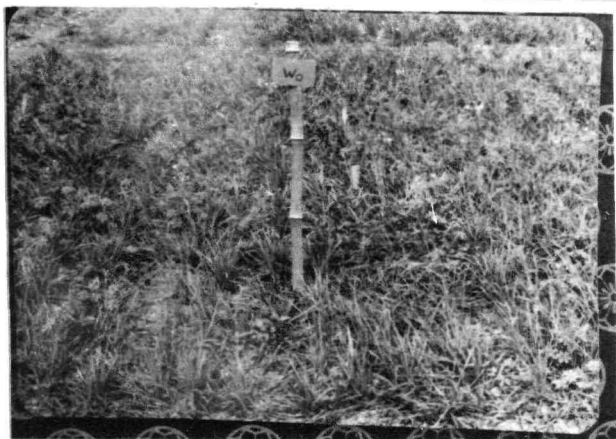


Plate 5: Untreated control



Plate 6: Crop at grand growth phase (The dried strips are the unweeded check plots)

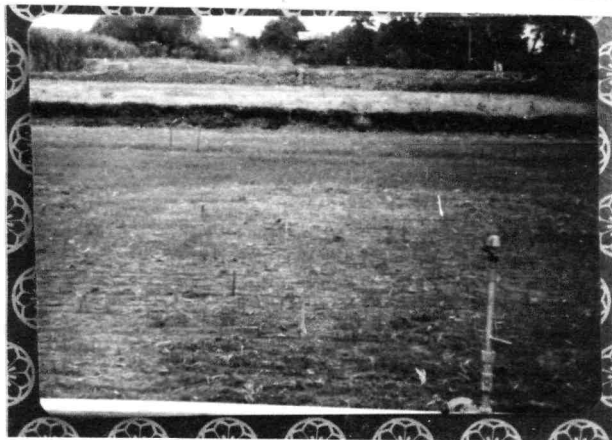


Plate 7: Effect of pre-sowing 2,4-D ED in the plots near sprinkler line (unchecked weeds in the farthest plot from sprinkler line)



Plate 8: Graduated steel rod with weight used to