INTEGRATED MANAGEMENT OF PURPLE NUTSEDGE (*Cyperus rotundus* L.)

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DECLARATION

I hereby declare that this thesis entitled "**Integrated Management of Purple nutsedge (*Cyperus rotundus* L.)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Integrated Management of Purple nutsedge (*Cyperus rotundus* L.)"** is a record of research work done independently by Mrs. Ameena. M. (99-21-03) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

%	–	per cent
@	–	at the rate of
ai	–	active ingredient
BCR	–	Benefit Cost Ratio
^{0}C	–	degree Celsius
cm	–	centimetre
DAS	–	Days after sowing
Fig.	–	Figure
FYM	–	Farm yard manure
g	–	Gram
ha	–	Hectare
HW	–	Hand weeding
kg	–	Kilogram
K	–	Potassium
LAI	–	Leaf Area Index
m	–	Meter
mg	–	Milligram
mg plant^{-1}	–	Milligram per plant
N	–	Nitrogen
NS	–	Non-significant
P	–	Phosphorus
S	–	Soluble liquid
SE	–	Soil exposure
SSB	–	Stale seed bed
t	–	Tonnes
WAH	–	Weeks after harvest
WASP	–	Weeks after spraying
WP	–	Wettable powder
2,4-D	–	2,4-dichlorophenoxy acetic acid

Introduction

1. INTRODUCTION

As weed scientists move into a transition period, research efforts must focus towards understanding the basic biology of weeds which will guide our decisions about the right timing of the integration of various weed control strategies. This type of approach is really warranted for managing the world's most noxious weed purple nutsedge (*Cyperus rotundus* L.).

Purple nutsedge, a native of India is a pernicious perennial weed in 52 crops in more than 90 tropical and subtropical countries (Bendixen and Nandihalli, 1987) and is ranked as one of world's worst weeds (Holm *et al.*, 1977). It propagates mainly by tubers, which have several buds that can sprout repeatedly which make cultural or manual methods ineffective. The longevity of tubers, the ability of tubers to sprout several times, and the lack of herbicides that can kill dormant tubers have made purple nutsedge control difficult. Research workers from time to time have suggested various cultural, mechanical, chemical and biological control measures, yet this weed continue to infect vast productive land and still remain as the tropical scourge in cultivated crop.

As the production of food evolves towards greater sustainability, weed management systems will be subjected to many internal and external constraints. These may sharply limit the available range of weed control methods. Thus research must develop an environmentally safe management strategy integrating chemical, physical and cultural methods for controlling perennial weed species like purple nutsedge.

Interest in soil solarisation arises since it is a method based on abundantly available natural resource, solar radiation. Solarisation has two different and complementary effects *viz.*, foliar scorching of plants emerged under plastic cover and decreased weed emergence after removing the plastic sheets. Effectiveness of solarisation for the control of *Cyperus rotundus* has been reported by Patterson (1998).

Knowledge of successful cultural practices need to be expanded and used to supplement mechanical and chemical control practices. Past studies indicated that several cultural practices like smother cropping can shift the competitive advantage of nutsedge to crops. The lack of aggressiveness of nutsedges in crops that quickly form a shade canopy suggest that additional knowledge of crop management practices should be developed to take advantage of the sensitive nature of nutsedge to shade. Thakur *et al.* (1989) reported similar control of nutsedge by cover cropping and raising intercrops. Other eco-friendly weed management technique like hand weeding at critical growth stages necessitate a more thorough understanding of nutsedge free period requirement for crops for more economical nutsedge control (Reddy *et al.*, 1998). Plant residue mulch like eucalyptus leaves play a prominent role in weed control by acting as a physical barrier and by virtue of secretion of allelochemicals (Babu and Kandasamy, 1997).

Glyphosate is found more promising in effecting the control of purple nutsedge since it translocate rapidly to the tubers. Success of glyphosate against purple nutsedge has been exploited by many workers with lowest regeneration (Bhatia *et al.*, 2001). However, herbicide application alone could not completely eradicate the weed because of the failure of it to control or desiccate the dormant tubers. Also, lack of information regarding the stage of application warrants location specific studies.

Finally our research efforts must focus on economic analysis of weed management systems if we have to make decision on optimizing farm inputs for sustainable agriculture. Logically the most economical control will be achieved when we supply only the control that the crop cannot supply itself.

The allelopathic potentiality of nutsedge was reported first by Beiber (1967). Nutsedge asserts allelopathic effects on crop plants through inhibition of germination, growth or metabolism (Del Moral and

Cates, 1971). Evidence of allelopathy has accumulated in the literature over many years and many kinds of allelochemicals have been identified (Leela, 1995). Under field conditions, the deleterious effect may be facilitated by exudates, leachates from decomposing residues and residues incorporated to the growing medium (Garcia and Anderson, 1984). The effect of nutsedge root exudates on seedling growth of five important group of crops were studied which would determine the productivity of crops. Though the information on the allelopathic effects of many weed species is available, relatively less information is available regarding the effect of purple nutsedge on other weed plants and its root exudates on crop plants.

In the light of the above facts, the present investigation was conducted to develop an economically viable and environmentally safe integrated weed management strategy for nutsedge with the following objectives.

1. To study the biology of purple nutsedge in different seasons and to assess the stage of tuberisation
2. To study the effect of integrated management practices for purple nutsedge control in okra (*Abelmoschus esculentus* L. Moench.)
3. To study the effect of control measures on death and regeneration of purple nutsedge in non-cropped area.
4. To evaluate the economics of different weed management techniques.
5. To study the allelopathic effect of purple nutsedge root exudates and extracts on crop and weeds.
6. To identify the chemical nature of allelochemicals in purple nutsedge.

Review of Literature

2. REVIEW OF LITERATURE

Purple nutsedge (*Cyperus rotundus* L.) is one of the most noxious perennial weeds of the world which causes 30 – 80 per cent reduction in crop yield. The nomenclature *Cyperus rotundus* originated from the Latin word 'rotundus' meaning circular or round. The growth habit and mode of propagation of the weed pose tremendous problems in its control. So, knowledge of the weed biology is highly essential for evolving an economically viable and environmentally acceptable weed management strategy. Traditional methods of hand weeding and cultivation are not effective for the control of this weed due to the underground production of the propagating units. This particular nature of the weed makes it difficult to control by adopting a single control measure. An integrated approach comprising of both chemical and cultural methods can be effective in controlling this abnoxious weed. As presence of many kinds of allelochemicals have been reported from nutsedge, the study also aimed to identify the allelochemicals and to investigate the allelopathic influence of the weed on other weed and crop plants. In this chapter, an attempt has been made to review the available literature on the biology, control and allelopathic effect of this noxious weed.

2.1 BIOLOGY OF PURPLE NUTSEDGE (*Cyperus rotundus* L.)

Purple nutsedge (*Cyperus rotundus* L.) has been cited as one of the world's worst weeds in major crops (Holm, 1969). It propagates mainly by tubers, which has several buds that can sprout repeatedly. The longevity of tubers, the ability of tubers to sprout several times, and the lack of herbicides that can kill dormant tubers have made the control of purple nutsedge difficult.

First record of purple nutsedge acting possibly as a weed was by Gunther (1934). The probable origin of nutsedge assumed by Bach (1964) is Eurasia, but it is very commonly found on the tropical or

subtropical areas of Asia, Africa, South and North America. The plant is adaptable to a wide variety of soils and environmental conditions in tropical and subtropical regions. Holm *et al.* (1977) observed that *C. rotundus* is distributed throughout the world. Thakur (1977) reported that nutgrass is widely distributed as an agricultural weed in almost all parts of the country upto an elevation of 2500 m. Shelke (1981) opined that nutsedge is native to India and is widely known in the world under the common names nutgrass, nutsedge and purple nutsedge.

An ecological study was carried out by Kuntohartono (1991) to determine the difference in growth characteristics of nutsedge in different parts of Indonesia and the study revealed that there are distinct ecotypes which reacted differently to environmental conditions. Wills (1998) collected purple nutsedge from 21 different locations to compare their reproduction and morphological characteristics. Differences were found with respect to flowering, length of culms supporting the inflorescence and number, the number of shoots produced from a single tuber, number of leaves per shoot and the length and width of leaves.

Ray (1975) reported that the tubers of purple nutsedge grow in chains that develop in all directions from the mother plant. The leaves are bright green in colour, linear and have a deep furrow in the middle lengthwise. Veerabhadriah (1977) reported that the tubers are white and succulent when young and turn reddish brown and finally black with age. The tubers have nodes, internodes, scaly leaves and axillary buds. The buds develop into rhizomes and in turn end in tubers. The rhizomes are thin, dark and have vascular tissue in them. The developed tubers are very hardy and are capable of withstanding severe unfavourable environmental conditions. The rhizomes may grow upwards and form the aerial shoots. At the juncture of the rhizome and the leaves, below the ground level a tuberous enlargement is formed which is referred to as basal bulb. Shelke (1981) described *C. rotundus* as an erect, persistent, glabrous, perennial

herb with an unjointed, triangular, solid stem and leaves in three ranks with closed sheaths and without ligules.

Rhizomes are the organs by which the plant spreads in all directions and it is through them that the food moves to the tubers. Pandey (1984) opined that when an isolated tuber germinates, it sends out a rhizome that grows to the surface and terminate in an aerial shoot. A tuberous enlargement called basal bulb develops at the junction of the rhizome and leaves. Basal bulb like tubers contains food and produce rhizome from buds at nodes. Wills (1987) proposed that nutsedge extensively reproduces by rhizomes which initially are white and fleshy with scale leaves, later becoming ligneous or wiry. Rhizome either extend upward, horizontally or downward. Those which extend upward upon reaching the surface form basal bulb or corm and produce shoots, roots and other rhizomes. Those which extend horizontally or downward give rise to tubers that repeat the cycle to form other tubers in a chain or to form new shoots. Thus, a nutsedge plant is composed of aerial shoots, basal bulbs, a chain of tubers and their associated rhizomes and developing tubers.

2.1.1 Flowering

Okafor (1973) reported that flowering in *C. rotundus* can occur within 21 days after emergence under field conditions. In the tropics flowering occurs almost round the year (Mercado, 1979). Jha and Sen (1981) have recorded two seasons of its flowering i.e, during September-October and January-April in India.

As per the reports of Wills (1987) in purple nutsedge the rachis supports a terminal inflorescence which is simple or slightly compound, loose umbel. Each inflorescence is subtended by two or more involucral leaves or leaf like bracts that are as long or longer than the flower bearing rays. The rays are formed from three to nine slender, spreading, three sided peduncles of unequal length. Near the ends are clusters of narrow spikelets,

0.8 to 2.5 cm long and 2 mm wide, 10 to 40 flowers, acute and compressed with a red, reddish brown or purplish brown colour.

2.1.2 Tuber development

Tuber, an underground vegetative organ of *C. rotundus* is rich in stored food material and is responsible for propagation. It occurs upto a depth of 30 to 40 cm. Several buds remain on tubers which sprout repeatedly until the food reserves in the tuber are exhausted or until all buds develop (Bendixen, 1973). The first tubers produced in a chain by an individual plant tend to form shoots but subsequent tubers tend to be dormant. Rhizomes are not reported to give rise to new growth except through tubers (Ray, 1975). Rhizomes are tubers which are white and fleshy when young and some become firmly packed with starch. On ageing they darken, harden and most of the tissues exterior to the endodermis of the rhizomes sloughs off to give a wiry structure which is resistant to desiccation and decay (Shelke, 1981). According to Pandey (1984) these torredo shaped tubers are seldom larger than 1.25 cm. The terminal bud on a tuber may send out a new rhizome, which in turn terminate in second tuber and so on until a chain of several interconnected tubers are formed.

2.1.2.1 Tuber sprouting

Andrews (1960) reported that at least 30 per cent of field moisture capacity was needed for adequate germination. However, with the moisture content below 16 per cent, the tubers generally died within five weeks. Dormant tubers sprouted at 68^0F and a temperature of 80 to 97^0F was ideal for subsequent growth.

Smith and Fick (1937) observed that terminal buds on a tuber sprout first. Ray (1975) opined that first tuber in a chain inhibited the sprouting of the lower tubers. Also, in a single tuber, the apical sprouts first and suppresses the lateral buds from sprouting.

Jangaard *et al.* (1971) reported that tuber sprouting is regulated someway by the growing plant as well as by the photoperiod, temperature

and moisture. Upon the death of foliage, inhibition of tuber sprouting is relieved and one or more tubers on the rhizome chain may sprout. Pandey (1984) observed that tuber did not sprout in humid tropical climate during December when minimum and maximum temperature varied between 8.7^{0}C to 23.4^{0}C. Sprouting started towards the third week of January with rise in temperature and plants continued to grow vigorously till October end.

Kim *et al.* (1994) studied the sprouting characteristics of purple nutsedge and found that sprouting and initial growth of tubers were increased with a 35/25^{0}C day / night temperature. Also tubers that were cut lattitudinally had similar growth to intact tubers. Fischer *et al.* (1995) showed that the organic nitrogen reserves and their mobilization during sprouting of purple nutsedge tubers and found that some net protein degradation occurred after 2-4 weeks of sprouting in the presence or absence of exogenous nitrogen. Amino acids decreased much faster especially during the first two weeks. The major amino acids were arginine and asparagine which together accounted for 70 per cent of total amino acids at day zero and which had almost disappeared after four weeks of sprouting.

Miles *et al.* (1996) conducted experiments to determine the response of purple nutsedge tuber sprouting to diurnally alternating temperature. Tuber sprouting was more rapid and complete with alternating temperature than with constant temperatures. Increasing temperature fluctuation from 0 to 6^{0}C for 12 hours daily linearly increased total tuber sprouting.

Bhowmik (1997) reported that sprouting percentage is higher and shoot emergence is faster from tubers located closest to the soil surface. Sprouting can occur at different times during the growing season. Chase *et al.* (1999) found that sprouting and growth of nutsedge tubers were faster at 40^{0}C than at room temperature and multiple sprouts arose from some tubers so that there was more than one shoot per tuber.

2.1.2.2 Tuber initiation / tuberisation

Tubers store food and are also a very effective means of propagation. Various factors influence tuberisation of nutsedge species. Tuberisation is the result of a response of nutsedge plants to excess carbohydrate, regulated by growth substances, and to interactions of photoperiod and temperature. Low nitrogen levels combined with high temperature promoted tuberisation (Bhowmik, 1997).

New tubers are produced within three weeks after germination of an individual tuber and tuber formation is completed within 10 or 15 days after germination (Andrews, 1960). Hauser (1962) found no evidence of tuber formation in the first four weeks after the plant had emerged, but the number of basal bulbs had increased five times. At six weeks there were still no tubers and after seven weeks the first tuber initiated. There were no tubers on plant that had already flowered and there were no chains and only single tuber was formed. A four tuber chain was found 3 to 5 months after the original tubers were planted and at 4 to 5 months, longer chains were seen.

Devendra *et al.* (1996) conducted experiments under field and pot culture conditions and found that by the 30th day, planted tuber reserves were completely depleted and the bulk of photosynthates was diverted to shoot and root development. During the 60 –120 days after sowing, tuber biomass, constituted 40 – 73 per cent of the total biomass, suggesting that 40 DAS photosynthates was used for tuber development. Bhowmik (1997) observed that under suitable conditions, a shoot emerged from a tuber 4 to 7 days after planting. Tuber formation began from 4 to 6 weeks after seedling emergence.

2.1.2.3 Tuber multiplication

Tumbleson and Kommedahl (1961) reported that a single tuber could produce about 1900 plants and nearly 8900 tubers within a year on an area of about 34 sq.ft on a silt loam soil. If only 1280 tubers were distributed uniformly over an acre, 2.5 million plants and one tonne of tubers could be produced within a year. Hauser (1962) observed that during the first season tubers planted at one feet intervals produced approximately three million plants and 66 million tubers and bulbs in one acre of land. These results emphasise the capacity of nutsedge to infest or reinfest cultivated lands.

Smith and Fick (1937) found that a single nutsedge tuber produced a system of 46 tubers and basal bulbs in 3 – 5 months in the green house. Hauser (1962) also reported that tuber planted on sterile soil 0.3 and 0.9 meter apart produced an average 760 and 526 plants m^{-2} respectively after ten weeks. Bharadwaj and Verma (1968) reported that a single nutgrass growing free of competition could develop as many as 103 tubers in four months. Misra (1969) calculated an amount of 2400 tubers m^{-2} down to a depth of 30 cm and this was seven times the number of shoots present on that area.

Horowitz (1972) reported that a plant which started from a single tuber had spread over an area of 56.7 m^2 at the end of second season's growth. Siriwardana and Nishimoto (1987) studied the distribution of propagules of purple nutsedge in soil and found that upper 30 cm of soil in a field infested with purple nutsedge contained 4900 to 5700 corms and tuber m^{-2} six weeks after soil rotovation and irrigation. Kim *et al.* (1994) conducted pot experiments under green house conditions and harvested nearly 1000 tubers from ten tubers that had been planted for three months. Suwunnamek (1996) reported that under field conditions, a single tuber produced about four times the number of original counts *ie.*, from 120 tubers 0.25 m^{-2} and 20 cm deep in a year. There are many reports that tuber production is much higher than these figures.

Neeser *et al.* (1997) studied the effect of age on tuber survival and found that an exponential decay function accurately described the age dependent decline on tuber survival. Inderdev *et al.* (1998) studied the growth pattern and biology of purple nutsedge under subtropical-semi arid region for two consecutive years and noticed substantial increase in *C. rotundus* infestation during the second year. Tuber density ranged from 140 to 242 m^{-2} during first year and 176 to 634 m^{-2} during second year.

Chase *et al.* (1999) found that there is inverse linear relationship between *C. rotundus* density and tuber depth. By the fourth week, *C. rotundus* densities had increased one order of magnitude to 203, 183 and 155 plants m^{-2} with 5, 10 and 15 cm depths respectively.

2.1.2.4 Dormant tuber production

The tuber which does not produce shoot is known as dormant or chain tuber. The ability of purple nutsedge tubers to remain dormant during adverse environmental conditions results in a reservoir of propagative material in the soil that can respond rapidly to favourable conditions. The ability of tubers to remain viable in soil as long as two years contributes to this weed's survival mechanism. Breaking of tuber dormancy should be a major tactic in any purple nutsedge management strategy.

Terry (1974) has reported that as many as 85 per cent of these tubers remain dormant in land which was not tilled. He observed that this dormancy of nutsedge could be removed if it was broken from the chain and germination could be induced.

Apical dominance exist in nutsedge tubers in which the first tuber in a chain inhibited the sprouting of the lower tubers. In a single tuber, the apical bud sprouts first and suppresses lateral buds from sprouting. The dormancy of single tubers separated from the chain is broken (Ray, 1975) and for this reason, cultivation enhances rather than limits infestation of the weed. Apical dominance was found to exist in purple nutsedge on both the tuber and the system as a whole (Ruchburg *et al.*, 1993).

Tumbleson and Kommedahl (1963) observed that tubers passed through a period of dormancy and low winter temperature broke the dormancy as shown by the increased germination of fall harvested tubers at 3^0C.

Jangaard *et al.* (1971) studied the role of phenolics and abscissic acid in nutsedge tuber dormancy and identified the presence of high concentrations of eugenol and salicylic acid that inhibited the sprouting of nutsedge tubers. The lack of activity at lower concentrations argues against a major role for these compounds in maintaining nutsedge tuber dormancy. Exogenous abscissic acid inhibited nutsedge tuber sprouting and may be a natural dormancy factor in nutsedge.

Neeser et al. (1997) conducted field experiments to study the survival and dormancy of purple nutsedge and found that tuber dormancy increased with age. He has reported that tubers were able to enter a state of secondary dormancy after sprouting. Sunwenhao *et al.* (1997) conducted experiments under glass house conditions for dormancy release of purple nutsedge tuber buds by a single thermal pulse and found that a single 30 minute temperature pulse from 20 to 30^0C caused 80 per cent bud break while tubers without the thermal pulse had only 25 per cent bud break.

Purple nutsedge does not show any seasonal dormancy as tubers collected all year round from plants of various ages sprouted under favourable temperature and moisture conditions. Newly formed tubers of purple nutsedge sprouted readily showing no seasonal dormancy. This type of information on seasonal dormancy could be important on integrating approaches that may direct weed management priorities on depleting or inhibiting specific tubers through interfering with dormancy.

2.1.2.5 Tuber viability

Drying tubers from their natural state of more than 85 per cent water to about 15 per cent moisture will kill them and intermediate moisture contents resulted in reduced viability (Rao and Nagarajan, 1962). Extreme

temperature can kill both yellow and purple nutsedge tubers (Thomas and Henson, 1968). In a laboratory study, 50 per cent of purple and yellow nutsedge tubers were killed at –2 and –7^{0}C, respectively. However, in the field, some yellow nutsedge tubers tolerated –20^{0}C during winter (Stoller, 1973). Hejazi *et al.* (1980) reported that tarping the soil with clear polyethylene reduced the tuber viability of *C. rotundus* by 26 per cent after six weeks. Further, they observed tuber mortality by 100 per cent at 60^{0}C for six days and a temperature of 50^{0}C only reduced viability by 60 per cent after 32 days of treatment.

Gill *et al.* (1982) studied the viability of *C. rotundus* and observed that the tubers brought to surface during hot weather cultivations were rendered non viable within 24 hours. Loss of viability was due to the high temperature injury and to a threshold moisture loss. Rubin and Benjamin (1984) found that temperature of 70^{0}C for 30 minutes was required to significantly reduce tuber viability in soil. Kumar *et al.* (1993) reported reduction in tuber viability by 90 per cent however, the populaton emerging from tubers increased in mulched plots compared to unmulched plots.

Ruchburg *et al.* (1993) reported that tubers were killed readily by drying. Isolated tubers were killed by four days exposure to direct sunlight. Temperature of 60^{0}C and above killed tuber in one hour. Exposure to temperature of -3.8^{0}C for eight hours did not kill tubers. Kuva *et al.* (1995) studied the effect of soil solarisation on nutsedge tuber viability and a decrease of 20 per cent in viability was observed. Under these conditions, tuber sprouting was inhibited and the dry weight of all parts of the plant was decreased.

2.1.2.6 Influence of weather parameters on tuber growth

Growth and tuber production of nutsedge is greatly influenced by the prevailing weather particularly rainfall, temperature, photoperiod and relative humidity.

2.1.2.6.1 Rainfall

The infestation of nutgrass is severe during rainy season (July to October) in upland crops including vegetables because of a congenial temperature (26-30^{0}C), relative humidity (70-90 %) and ample moisture in the soil. Bharadwaj and Verma (1968) reported that the most favourable period for nutgrass development under the conditions prevailing in Delhi was the rainy season (July and October) when the mean monthly temperature ranged from 26 to 31^{0}C and the available moisture in the top 15 cm soil layer was 75 per cent. Williams (1976) studied life cycle of nutsedge in Brazil and observed that when irrigated it grows throughout the year, and is especially competitive at the onset of rainy season (November – December). Stoller (1976) reported that tubers remain dormant during the dry seasons of tropical region, whereas in temperate climate dormancy is during the winter months. Shelke (1981) opined that the total tuber production per pit in the humid zone (1250 to 2500 mm of rain) exceeded that in the subhumid (less than 2500 mm) zones by size and fourteen fold respectively. Jha (1982) while studying ecophysiology of *C. rotundus* recorded that tuber sprouting in Indian arid zone took place in July after receiving first showers of rain.

Raju and Reddy (1998) made phyto-sociological studies of rainy season weeds and found that *C. rotundus* had a high degree of sociability and formed large colonies under arable soil conditions.

2.1.2.6.2 Temperature

Bharadwaj and Verma (1968) reported that the most favourable temperature range for nutgrass development is 26 to 31^{0}C. Horowitz (1972) observed that on warm season, plant growth and tuber formation rate closely followed air temperature and tubers were formed within one month from planting.

Ghume (1976) carried out an experiment in glass house and inferred that the optimum temperature for the sprouting of *C. rotundus* was 30 to

35^{0}C. Minimum and maximum temperature limits of sprouting were 15^0 and 40^{0}C respectively. Shamsi *et al.* (1978) reported that minimum temperature for sprouting is 30°C and maximum temperature is 44 or 45^{0}C. Pandey (1984) observed that tuber did not sprout in humid tropical climate for a month in December when minimum and maximum temperature varied between 8.7^{0}C and 23.4^{0}C. Sprouting started towards the third week of January with rise in temperature and plants continued to grow vigorously till October end.

Erasmo *et al.* (1994) studied the effect of temperature, light quality and CO_2 concentration on sprouting of purple nutsedge and found that exposure to greater than 70^{0}C for more than 30 minutes decreased rate of sprouting, percentage sprouting and number of shoots per tuber and temperature of 90^{0}C for more than 60 minutes killed the tubers.

Inderdev *et al.* (1998) conducted field studies in Delhi to study the growth pattern and biology of purple nutsedge in subtropical semiarid regions and found that increase in growth parameters upto 60 days after emergence was closely related to temperature and the availability of moisture. A decrease in the autumn temperature and low moisture availability resulted in the cessation of shoot formation.

Chase *et al.* (1999) conducted studies to determine lethal temperatures for *Cyperus rotundus* tubers and found that growth of nutsedge was faster at 40^{0}C than at constant temperature of 26^{0}C. Tuber mortality was 100 per cent with the 50 and 55^{0}C temperature regimes.

2.1.2.6.3 Photoperiod

Misra (1969) reported that plants produced many more tubers at short photoperiods of 6 to 10 hours of day light than at 12 hours or even longer. Jansen (1971) studied the photoperiodic response of nutsedge and found that the differentiation of rhizome tips into basal bulbs was maximum at 16 hours and into tubers take place at 8 – 12 hours.

Horowitz (1972) found no apparent effect of a natural photoperiod of 10 to 14 hours on tuberisation in purple nutsedge. Mean day length during growth was a major factor influencing growth and developments, but mean temperature appeared to be important in determining new tuber size and shoot number appeared to be a reliable guide to rhizome and tuber production (Hammerton, 1975).

There is a general agreement that the plant is stimulated to flower on short photoperiod of 6 to 8 hours, whereas the period from emergence to flowering varies from 3 to 8 weeks (Holm *et al.*, 1977). Studies conducted at ICRISAT (1980) showed that there was marked reduction in both shoot and tuber dry weights and in number of new shoots and tuber when light intensity was reduced. This is because *C. rotundus* is highly shade sensitive. Shading significantly reduced dry matter accumulation, leaf area production and total tuber production (Patterson, 1981). Nemato *et al.* (1994) reported that shading reduced chlorophyll a and b levels and this was maximum at 50 per cent shading. Erasmo *et al.* (1994) conducted experiments to evaluate the effect of light quality on sprouting of purple nutsedge and found that red light decreased the number of sprouts per tuber and shoot length compared to other wavelength and white light.

However, Bhowmik (1997) reported that day length does not influence tuber formation in purple nutsedge as much as in yellow nutsedge.

2.2 CROP WEED COMPETITION

Nutsedge is very often a serious pest in vegetable crops and in nursery stocks. *Cyperus rotundus* and *Cynodon dactylon* were the major weeds in the okra fields of Madhya Pradesh (Bhalla and Parmar, 1982). Kalia *et al.* (1982) reported the dominance of *Cyperus rotundus* in tomato fields of Solan.

Tewari (1995) opined that the infestation of nutsedge is tremendously enhanced during summer/spring crops such as urd bean, mung bean, sunflower, vegetables and onion due to high temperature and frequent

irrigations. Suwunnamek (1996) observed that infestation of *C. rotundus* mostly occurs in cultivated fields especially where herbicides are used repeatedly or routinely.

Subrahmaniyan and Arulmozhi (1998) reported that nutgrass is a very persistent perennial sedge in groundnut causing 32 per cent reduction in yield. Similar studies were conducted at Coimbatore to assess the yield loss in groundnut due to weeds and found that the major weed flora infesting groundnut were *Cyperus rotundus* and *Cynodon dactylon* (Rajendran and Lourduraj, 1999). Soguy *et al.* (1999) found that *Cyperus rotundus* was one of the most widespread species causing yield reduction and is commonly found in highly fertile soils and in sugarcane, cotton and soybean crops. Oksar and Uygur (2000) studied the distribution of weeds in different crops and reported that the cover and frequency of *C. rotundus* in field margins and vegetable crops were 15.30 per cent and 43.47 per cent respectively.

From the above literature, it is clear that *Cyperus rotundus* is a major weed in almost all the upland crops like vegetables, soybean, sugarcane, cotton, corn etc.

2.2.1 Critical period of crop-weed competition

Critical period of weed competition is that part in the life cycle of a crop plant wherein weeding results in highest economic returns. The critical competitive period of nutsedge infestation depends upon crops and cultivars and other environmental conditions.

William and Warren (1975) studied the critical period of competition and reported that critical period was between three to thirteen weeks for garlic, three and seven weeks for okra and three to five weeks for cabbage, cucumber and green bean. Competition was more for light in slow growing non-competitive crops and for nutrients in all other crops.

Maintaining weed free environment has resulted in maximum yields in okra (Singh *et al.*, 1982, radish (Gambhir *et al.*, 1983) and summer squash (Ponchio JA-de *et al.*, 1984). However,

assessing the critical stages of weed competition and containing the weeds during this period was proved to be effective and economical (Singh *et al.*, 1982) it has also been reported that the critical period was 15-30 days for okra, while it ranged from 30-45 days for chilli.

In a field study made under arid zone at Jodhpur during 1982, results indicated 31.73 per cent yield loss when removal of nutgrass was done 15 days after sowing and 53.14 per cent yield loss was recorded where weeding was not done which indicated that critical competition occurred within 15 days of crop and weed emergence (Tewari, 1995).

From the above literature it can be concluded that in general, the crop-nutsedge competition mostly occurs during the initial one-third period of crop duration.

2.2.1.1 Competition for nutrients

Although of relatively short stature, nutsedges can reduce yields of many crops. Black *et al.* (1969) characterized nutsedges as having high photosynthetic efficiency and fix CO_2 at high rates which enhances its potential as high yielding crop or serious weed.

Nutsedges interfere by competing with crops for nutrients. It grows satisfactorily at nitrogen levels as low as 2.5 ppm (Nyahoza, 1973). Also, purple nutsedge grew and reproduced reasonably well when deficiencies in calcium, magnesium, iron and microelements occurred (Nel *et al.*, 1976).

Okafor and De Dutta (1976) reported that application of nitrogen benefited *Cyperus rotundus* more than rice. The weed's growth, development and competitive ability increased with increasing levels enabling it to compete more vigorously for water and further reduced light transmission to the crop. Shamsi and Ali-Ali (1983) reported that although dry matter production of nutsedge was reduced by decreasing levels of nutrients, root-shoot ratios increased as nutrient levels decreased. Also, high nitrogen levels suppressed tuberisation but promoted production of shoots and rhizomes of purple nutsedge.

When nutsedge grow in association with other crops, they reduced the nutrient content of the latter. It reduced the N and K content of cotton shoots and accumulated twice the amount of these elements as cotton without a marked effect on P (Guantase and Mercado, 1975). Volz (1977) suggested that nutsedge roots decrease the nitrogen availability of crop roots during the growing season by enhancing the activity of those bacteria which denitrify NO_3 to N_2.

A study was undertaken at Varanasi in Uttar Pradesh in 1988 in a field with inceptisol soil, which was heavily infested with *Cyperus rotundus*. The field was dug to a depth of 40 cm and the stolons, rhizomes and bulbs of this weed and any other weeds present were removed. The field was levelled and any *Cyperus rotundus* which subsequently emerged again was removed. It was estimated that there was 1.99×10^6 stolons ha^{-1} which weighed 2040 kg ha^{-1}. Also it was estimated to remove 36.5 kg ha^{-1} N, 3.88 kg ha^{-1} P and 43.45 kg ha^{-1} K from the soil (Sanoria *et al.*, 1989). Field trials at Jabalpur revealed that nutrient depletions by weeds were substantially lower under stale seed bed (3.82, 6.48 and 8.23 kg ha^{-1} NPK respectively) as compared to normal seed bed conditions (6.22, 0.72 and 12.16 kg N, P and K) in wheat and conversely NPK utilization by the crop was increased (Yadav *et al.*, 1994).

Singh *et al.* (1996) studied the potassium drain through weeds under pigeon pea-sesame intercropping system and reported that *C. rotundus* depleted 16.7 kg K ha^{-1} from the weedy control plot. When pigeon peas were grown as the sole crop and were unweeded, K loss was 93.2 kg ha^{-1} and pigeon pea yields were 0.55 t ha^{-1}. Pandey and Thakur (1998) opined that presence of weeds predominantly nutsedges removed 35 kg N, 4.3 kg P and 8.2 kg K ha^{-1} 40 days after planting rice variety.

Renu *et al.* (2000) reported that stale seed bed with paraquat spray favoured better uptake of N and P followed by stale seed bed with light hoeing and the results suggested that wherever the competition from weeds was less, the nutrient uptake by the crop was higher.

2.2.1.2 Competition for moisture

Studies with cotton in California indicated that dense populations of nutsedge depleted soil moisture resulting in reduced crop stands (Chapman, 1966). William (1973) reported an 81 per cent crop loss due to nutsedge competition when bean was irrigated only once during the dry season. William and Warren (1975) opined that competition for water was negligible in vegetable crop as vegetables are irrigated regularly. Reports indicated that purple nutsedge can severely limit the availability of soil moisture to sugarcane (Keeley and Thullen, 1975). Okafor and De Dutta (1976) found that competition by purple nutsedge for soil moisture contributed to poor yields of rice, especially as nitrogen rates increased.

Andrews (1960) reported that at least 30 per cent field moisture capacity was needed for adequate germination. However, at the moisture content below 16 per cent the tuber generally died within 5 weeks. Tubers have no specialized moisture retention mechanism as do after fresh organs like potato and onion bulbs (Day and Russel, 1955).

2.2.2 Yield loss

Cyperus rotundus causes considerable loss in crop yield as it offers severe competition for nutrients, moisture and light. Singh *et al.* (1982) reported that crop production losses may not be distinct at once but within few years the problem could become acute because of its multiplication rates. William (1973) found much higher yield reduction to the extent of 81 per cent on bean when irrigated once.

Keeley and Thullen (1975) reported that loss in yield due to nutsedge infestation varied with time of infestation, reduction being 34 per cent when nutsedge competed for entire season, only 20 per cent for six and eight weeks competition and normal for four weeks competition after planting in cotton. Okafor and De Dutta (1976) reported that grain yield of drilled and broadcast upland rice dwindled 43 and 41 per cent due to competition of *Cyperus rotundus* L.

William and Warren (1975) from their studies conducted in Brazil on the competition of various nutsedges with various vegetable crops observed 62 per cent yield reduction in okra, 89 per cent reduction in garlic, 53 per cent reduction in tomato, 40 per cent reduction in cucumber and 81 per cent reduction on beans.

Singh *et al.* (1993) reviewed that the losses due to weeds in vegetable crops ranged from 6 to 82 per cent. In okra, the loss of yield due to weed infestation is estimated to be between 50 and 90 per cent whereas in tomato, it ranged from 42-71 per cent.

Experiments conducted at Kanpur under All India Coordinated Research Programme on Weed Control during 1986-89 showed that season long competition with nutgrass registered 15.3 per cent, 12.6 per cent, 26.7 per cent and 14.9 percent decrease in grain yield of rice, maize, pigeon pea and sesamum respectively. The grain yield of summer sown mung bean declined by 23.4 per cent due to purple nutsedge infestation (Tewari, 1995)

Singh and Singh (2001) reported that competition with *C. rotundus* caused 52.5 per cent reduction in rice grain yield while competition with all the weeds growing with the crop caused 86 per cent reduction in grain yield.

From the above literature, it is clear that full season competition from nutsedge reduced the growth of almost all crops and caused moderate to severe crop losses.

2.2.3 Growth of okra (*Abelmoschus esculentus* L. Moench) as influenced by nutsedge infestation

Okra is an important vegetable widely grown in our country. One of the major problems encountered in cultivation of okra during rainy season is heavy infestation of weeds owing to wider spacing, initial slow growth, frequent irrigation or rains, liberal use of manures and fertilizers coupled with congenial weather conditions.

Okra is a tall growing plant that produces a dense canopy, but develops slowly during the first six to nine weeks. Full season nutsedge competition reduced okra yield by 62 per cent. So first weeding should be conducted within three weeks after field preparation and if the weeding is delayed, significant crop losses will occur (William and Warren, 1975).

Keeley (1987) observed that okra required more weedings when planted in early spring rather than summer. The critical purple nutsedge competitive period was ten weeks for spring planted okra but was only five weeks for the summer planted crop.

Uncontrolled weed growth has been reported to reduce tender fruit yield by 80 per cent and seed yield by 55-67.3 per cent (Singh *et al.*, 1991).

In Ludhiana, Saimbhi *et al.* (1994) had reported that the control of *Cyperus rotundus* resulted in higher yields of okra. In vegetable crops, thresholds rarely work because even low number of weeds can reduce marketable yield. However, a crop does not need to be weed free from sowing until harvest to prevent yield losses caused by weeds.

2.3 STRATEGIES OF WEED MANAGEMENT

2.3.1 Cultural control

Cultural practices form an important management strategy for weed control.

2.3.1.1 Stale seed bed technique

Gupta and Lamba (1978) reported that the main advantage of stale seed bed was that crops germinate in a weed free environment and if selectively stimulated, they might close in before subsequent flush of weeds appear. Burnside *et al.* (1980) opined that crops grown in shallow tilled seed beds or treated with a non-selective herbicide had fewer weeds and greater yields than those grown in no-till cropping system.

Ali *et al.* (1979) and Sumner *et al.* (1981) observed that stale seed bed practice prior to planting reduced weed population. However in a stale

seed bed programme, planting usually occur in some emerged vegetation, which necessitates the timely use of herbicide for weed control (Stougaard *et al.*, 1984; Elmore and Heatherly, 1988; Buchler and Werling, 1989; Bruff and Shaw, 1992).

According to Heatherly and Elmore (1988) successful form of reduced tillage was stale seed bed system which use some degree of tillage and thus controlled weeds. Gunsolus (1990) noted that rotary hoeing of stale seed beds in soybean and corn (*Zea mays*) after weed seed germination, but immediately prior to emergence, reduced the number of weed seeds in the plow layer. According to Hosmani and Meti (1993) stale seed bed encouraged a flush of new weed seedling, which could be controlled very easily prior to planting and reduced the crop weed competition in succeeding crops. Johnson and Mullinix (1995) reported that shallow tillage of stale seed bed reduced numbers of certain weeds and improved weed control in peanut (*Arachis hypogea* L.) replacing the need for post emergence herbicides.

The advantage of stale seed bed practice in weed control was emphasized by Hosmani and Chittapur (1996) and Krishnarajan and Meyyazhagan (1996). Ca roll and Benjamin (1998) reported that shallow tillage of stale seed bed before planting improves weed control in cucumber. Although weed species response varied among stale seed bed management systems, florida parsley and yellow nutsedge densities were among the lowest in plots with stale seed bed. It was also reported that stale seed beds integrated with a basic weed management programme eliminated the need for additional herbicides in cucumber production.

Renjan (1999) reported that adoption of stale seed bed technique enhanced the yield attributes and grain yield of rice significantly and the weed index was significantly reduced.

Renu *et al.* (2000) reported that stale seed bed with paraquat showed reduced weed incidence than stale seed bed with hoeing in rice and also in terms of grain yield, straw yield and uptake of nutrients, the stale seed bed

treatments were superior to normal sowing. Singh *et al.* (2000) showed that stale seed bed integrated with pre-plant fluchloralin at 1.0 kg ha^{-1} achieved excellent control of all major weeds in mustard and recorded the highest seed yield and net return.

Caldwell and Mohler (2001) studied the effect of several stale seed bed procedures on weed density and biomass and reported that glyphosate-stale seed bed techniques significantly reduced density and biomass of principal weeds and this could be incorporated into integrated weed management programme to improve control and reduce the need for herbicides. John and Mathew (2001) evaluated the effectiveness of stale seed bed to achieve total weed control on direct seeded lowland rice and reported that direct sowing under the stale seed bed system produced the highest yield equivalent to that of an almost totally weed free crop environment. The results showed the significant yield advantage of the stale seed bed system over hand weeding at no additional cost.

2.3.1.2 Soil exposure as a measure for controlling weeds

The infestation of nutgrass could be effectively managed through exposing the propagating parts to the sun during summer by repeated deep ploughing. These tubers and rhizomes come up at the surface and are desiccated by solar heat resulting in moisture depletion below, critical limit and result in the death of tubers.

Standifer *et al.* (1984) studied the effect of soil solarisation on soil weed seed population and reported that seeds of *Cyperus* sedges and barnyard grass were killed only in the upper 3 to 4 cm. Enhanced tomato yield followed by solarisation for six weeks, prior to planting of tomato was reported by Ismaileh (1991) in Jordan. Birader et al. (1993) reported that yield response by solarisation in groundnut was statistically similar to the pod yield obtained under weed free conditions.

Birader *et al.* (1993) reported that yield response by solarisation in groundnut was statistically similar to the pod yield obtained under weed

free conditions. He also reported 95 and 99 per cent reduction of *Cyperus rotundus* by solarisation for 2 and 3 months respectively. Tewari (1995) in an AICRP trial revealed that the exposure of tuber to sun through deep ploughing after digging of potato and maize reduced the aerial shoots by 65.42 per cent and tuber by 70.08 per cent of nutgrass. As a result of considerable reduction in nutgrass infestation, the yield of maize and potato increased by 13 and 5 per cent respectively.

However, survival of *Cyperus rotundus* tubers in the soil even after solarisation has been reported by several workers (Horowitz *et al.*, 1983). It has been attributed to the heat resistance of tubers. Another reason for escape for *Cyperus rotundus* may be attributed to the tuber formation in deeper layers. Hauser (1962) reported that irrespective of soil texture, most of the tubers were found in 10-15 cm depth followed by 6-10 cm depth of soil. Enhanced germination of *Cyperus rotundus* after solarization was reported by Egley (1983).

2.3.1.3 Mulching as a weed control measure

Covering or mulching the soil surface can prevent weed seed germination or physically suppress seedling emergence. A mulch may take many forms: a living plant ground cover, loose particles of organic or inorganic matter spread over the soil or sheets of artificial or natural materials laid on the soil surface.

2.3.1.3.1 Polythene mulching

Hejazi *et al.* (1980) reported that tarping the soil with clear polyethylene reduced the tuber viability of *Cyperus rotundus* by 26 per cent after six weeks. An experiment conducted in Puerto Rico revealed that the highest marketable yield (64.5 t ha^{-1}) of tomato and net income were obtained from plastic mulching in combination with hand weeding (Liu *et al.*, 1987). Gonzalez *et al.* (1992) observed that although solarization alone failed to control *Cyperus rotundus*, it weakened the propagules making them susceptible to a low dose of glyphosate. It was found that

solarisation for 2.5 months followed by 0.22 kg glyphosate ha^{-1} led to a sharp decline in *Cyperus rotundus* populations.

Gutal *et al.* (1992) observed that polythene mulch film increased soil temperature by 5-7^{0}C, and checked weed growth. Results of a three years study with 25μ black LDPE film as mulch indicated that tomato yield could be increased by 55 per cent and weed growth was reduced by 90 per cent and soil moisture conserved was 28 per cent more than that without mulch. Kumar *et al.* (1993) reported reduction in germination by 90 per cent however the population emerging from tubers increased on mulched plots compared to unmulched plots.

Kuva *et al.* (1995) analysed the effect of polythene mulching on purple nutsedge tuber viability and a decrease of 20 per cent in tuber viability was observed. The rate of tuber multiplication was decreased from 1.11 to 1.40 when the plant was covered at the vegetative stage. Bhaskar (1996) reported that polyethylene mulching followed by one hand weeding controlled *Cyperus rotundus* by 98 per cent in Ber nursery. Mashingaidze *et al.* (1996) noticed that, the harvesting period of tomato was extended by black polythene mulching and subsequently the total yield. The enhanced growth and yield was attributed to the changed temperature and light micro environment around the plants.

Peak soil temperature of 62^{0}C and 59^{0}C in the solarised soil at 5 and 10 cm depth, respectively was observed by Vilasini (1996) at Kerala Agricultural University, Vellanikkara, when the atmospheric temperature of the experimental area ranged from 23^{0}C to 39.4^{0}C. Yadav *et al.* (1996) based on experiments conducted in Ber nursery reported that black polythene mulching after one hand weeding at 70 DAS provided more than 98 per cent control of *Cyperus rotundus* while hand weeding alone could provide only 60 per cent control of this weed. Bhaskar and Nanjappa (1997) observed highest temperature of 50.1^{0}C and 42.8^{0}C at 5 and 10 cm depths respectively compared to 43.6 and 39.8^{0}C in the uncovered plots in Bangalore.

Saikia *et al.* (1997) obtained the maximum weed control efficiency of 96.5 per cent in okra by mulching with black polythene. Patterson (1998) reported that in green house experiments translucent mulches reduced purple nutsedge shoot biomass, tuber and rhizome number and tuber biomass by 85-90 per cent while in field experiment, translucent mulches reduced emergence and growth of purple nutsedge by 70-88 per cent. Number of viable tubers in the soil were reduced by 65-76 per cent.

Dwivedi *et al.* (1999) reported that black polyethylene mulch kept the plots totally weed free throughout the crop season and produced the highest fruit yield and gross income per hectare in pointed gourd. Ricci *et al.* (1999) tested the effectiveness of polythene cover sheets for the control of *Cyperus rotundus* weed infestation in Brazil and found that solarisation gave highly significant reduction of the weed population and increased carrot yield. In the solarised plots, no weeding was needed during the vegetable crops cycle whereas the untreated plots required hand weeding within the first month from sowing. Chakrabarti (2000) reported that black polythene mulching integrated with fluchloralin and one hand weeding recorded the highest fruit yield of brinjal next to completely weed free condition.

Gutal *et al.* (1992) observed that a 20 per cent saving in weeding cost could be achieved by the use of black LDPE film mulching in brinjal. Saikia *et al.* (1997) reported that mulching with black LDPE promoted okra growth and resulted in yields of 223 q ha^{-1} compared with 31.1 q ha^{-1} for control and highest cost benefit ratio of 1:3.1.

2.3 1.3.2 Eucalyptus leaf mulching

Eucalyptus is a common tree grown in agro forestry systems which produce enormous quantities of litter and is reported to have allelopathic properties.

Del Moral and Muller (1970) reported that eucalyptus sp. produced both terpenes and phenolics which were important phytotoxins that

inhibited the growth of grasses and other susceptible vegetation under its canopy. Phenolic acids were found to act strongly in accumulated litter of eucalyptus. Spurr and Barrens (1973) opined that release of these phytotoxins from eucalyptus canopy was regular and continuous in all seasons due to rain drift in monsoon and volatilization during summer. Babu and Kandasamy (1997) studied the allelopathic potential of *Eucalyptus globulus* fresh and dried leaf leachates on purple nutsedge and Bermuda grass and found that aqueous leachates of fresh leaves of eucalyptus significantly suppressed the establishment of vegetative propagules of the weeds.

Natarajan *et al.* (2001) studied the dynamics of weeds as influenced by allelopathic crop residues and found that soil mulching of eucalyptus leaf litter @ 2 t ha^{-1} significantly reduced the total weed dry matter production. Mulching of eucalyptus leaf litter and sweet potato fresh vines residues gave comparable growth suppression of *Cyperus rotundus*.

2.3.1.4 Smother cropping and weed growth

Raising plants that grow fast and develop high leaf area is found to adversely affect many weeds especially *Cyperus rotundus* which follows C_4 pathway for CO_2 fixation.

Patterson (1982) pointed out that the weed competition especially of nutsedge was maximum during first 20 days after sowing of crops, due to its early germination and vigorous growth. Later on it tends to decline, since nutsedge was highly sensitive to shading.

Cowpea is a very suitable smother crop. Growing cowpea, green gram and soybean as intercrops in maize, could exert suppressing effect on weeds. Reduction in weed growth by raising cowpea, in the coconut banana cropping system was reported by Savithri (1990). Bhan and Sushilkumar (1998) reported that growing cowpea as an intercrop in banana resulted in development of a dense canopy covering entire ground area and suppressed weed growth completely for a period of 70 days.

Intercropping of sorghum with cowpea smothered weeds and reduced hand-weeding cost without affecting sorghum yield (Rao and Shetty, 1981). Thakur *et al.* (1989) concluded that cropping systems including smother crops and or intercropping with cover crops greatly reduced the growth of *Cyperus rotundus* and other species seen on the sandy loam soils of Dholi in Bihar. Smother crop can also improve soil fertility by adding organic matter and preventing soil erosion. Moreover it is an eco-friendly method of weed control. Cultivating smother crop like cowpea which grew most rapidly form a very valuable measure in any weed control programme, since they filled the inter row space with canopy faster than the weeds (Rao, 2000).

Above literature shows the superiority of cowpea as a smother crop and success of smother crops for effective weed control.

2.3.2 Physical methods of Weed control

2.3.2.1 Handweeding at critical growth stages

Hand weeding is the most common practice of weed control in vegetablesin the country (Gupta and Lamba, 1978). Despite its high cost, it is sometimes favoured because of its high cash returns from these crops. Leela (1989) studied the weed control efficacy of several herbicides applied immediately after planting in comparison with manual weeding and observed that manual weeding was effective but costly. According to Yadav *et al.* (1994) hand weeding at 30 DAS stage proved as the most effective measure for controlling weeds and increased seed yield in cluster bean.

Reddy *et al.* (1998) based on their study in soybean opined that applying herbicides followed by hand weeding at 30 DAS increased the level of weed control compared to that obtained with herbicides alone. Basha and Reddy (2001) studied the effect of integrated weed management in summer irrigated okra and found that the chemical treatments in combination with hand weeding significantly controlled the weeds

predominantly *Cyperus rotundus* and improved the growth and yield of okra. Reddy *et al.* (2001) conducted field experiments to study the effect of integrated weed management in okra and found that hand weeding at 25 and 45 DAS recorded lower weed dry matter and the highest WCE of 94-95 per cent. Significantly higher yields were obtained with lower herbicide rates and hand weeding at 25 DAS.

2.3.2.2 Digging

Digging is a kind of mechanical weed management which can be done by any unskilled labour and relatively safe to the operators. Mc Cue and Sweet (1982) tested various tillage programmes, combined with the use of herbicide to control foliage in fields infested with nutsedge. The number of newly formed tubers decreased by 40 per cent with late cultivation and by 98 per cent with season long foliage control. Old tubers were unaffected. Tuber numbers decreased with increasing number of cultivation, three cultivations at monthly intervals gave a reduction equal to that obtained with season long foliage control. Sanoria *et al.* (1989) also proved the effectiveness of repeated ploughing for long lasting results.

Combination of cultural and chemical weed control methods were used against *Cyperus rotundus* in a potato and maize cropping system in sandy loam at Kanpur in 1987-89 by Tewari and Singh (1991). Exposure of underground tubers of the weed to the soil surface by deep ploughing twice in April and May gave the best *Cyperus rotundus* control (65.39, 70.08 and 69.00 per cent reduction in aerial shoots, tubers and rhizomes respectively). Control of *Cyperus rotundus* by summer ploughing increased the grain yield of maize and the tuber yields of potatoes by 13.75 and 3.40 per cent respectively.

Eslaquit *et al.* (1999) evaluated the effect of digging in dry season for controlling purple nutsedge in horticultural production systems and found that digging every two and three weeks reduced *Cyperus rotundus* population by 72 per cent and 58 per cent respectively. In the control when

no digging was done, the population was reduced by 14 per cent indicating that lack of moisture and high temperature during dry seasons kills *Cyperus rotundus*.

The potential advantage of summer ploughing for weed control comes from the prolonged exposure of propagating structures to desiccation in the dry season. It was observed that the decline in tuber germination was ten fold when the tubers were exposed 72 hours to bright sunshine (Raju and Reddy, 1999).

2.3.3 Chemical Weed Control

Several herbicides are in use to control this noxious weed in different parts of the world. In earlier days, dalapon, paraquat and MSMA were claimed to be effective in nutgrass control. Paraquat, a non-selective and contact herbicide caused mortality by its contact action but regeneration took place after sometime (Tewari, 1995). So the use of systemic herbicides was considered a better option.

2.3.3.1 Glyphosate

Glyphosate is a non-selective translocated post emergence herbicide capable of controlling the perennial weeds, with complex underground vegetative system. Andino *et al.* (1989) reported the success of glyphosate against *Cyperus rotundus* in the tomato fields of Costa-Rica. Satisfactory control of nutgrass with glyphosate has been reported by Ahiya and Yaduraju (1995) under non-crop situations in India.

Manickam and Gnanamoorthy (1992) noticed significant reduction of nutgrass biomass through spraying of 1.0 per cent glyphosate with 0.5 per cent 2,4-D salt or one per cent ammonium sulphate. Sandhu and Bhatia (1992) found that split application of glyphosate twice @ 1 kg ha^{-1} of commercial product was effective for nutsedge control. Liu and Twu

(1993) reported that glyphosate at 1.64-2.46 kg ha^{-1} resulted in 100 per cent mortality of *Cyperus rotundus* tubers.

The results of trials undertaken in Mauritius showed that glyphosate was very quickly absorbed by *Cyperus rotundus* and that a dry period as short as one hour after spraying was sufficient for adequate weed control. Although satisfactory control was obtained, when spraying was followed by tillage 24 hours later, better results were achieved when the interval between spraying and tillage was lengthened to one week; longer intervals did not substantially increase the level of weed control (Mc Intyre and Barbe, 1995). Satao *et al.* (1995) reported that post emergent application of glyphosate at 2.76 kg ai ha^{-1} + a second spraying 20 days after sowing + a third spraying 20 DAS resulted in the least population density of this weed.

Desai *et al.* (1996) based on their study conducted at Raichur reported that higher drying percentage of 97.5 per cent was recorded with glyphosate at 4 kg ai ha^{-1}. Inderdev *et al.* (1996) estimated efficacy of glyphosate in reducing tuber viability of *Cyperus rotundus* by cutting of treated shoots and observing their regeneration and found that addition of adjuvants like urea, 2,4-D and $(NH_4)_2SO_4$ reduced regeneration of tubers substantially. Regeneration was lower with five-year application of herbicide as compared to single year application. The response of purple nutsedge population to glyphosate application was studied by Zaenudin *et al.* (1996) and they observed that post emergence application of 0.72 kg glyphosate ha^{-1} at 4-8 weeks after weed emergence resulted in good control of the weed.

Charles (1997) evaluated a range of herbicides for controlling nutgrass and found that multiple applications of glyphosate reduced tuber density by upto 96 per cent over two seasons. This was improved with successive application of glyphosate. Freitas *et al.* (1997) reported that double application of glyphosate resulted in 90.8 per cent reduction in the number of plants. The number of tubers was reduced by 76.3 per cent. Muniyappa *et al.* (1998) studied the effectiveness of different herbicides for

nutgrass control and recorded lowest tuber dry weight and tuber number with glyphosate @ 2.0 and 2.5 kg ha^{-1}. Ameena (1999) reported that glyphosate at 1.5 kg ai ha-^{1} was sufficient for complete kill of nutsedge in experimental area and there was no re-growth upto 6 weeks after spraying.

Sukhadia *et al.* (2000) studied the efficiency of herbicides on *Cyperus rotundus* control under non crop situations and found that glyphosate at 2.45 kg ha^{-1} controlled *Cyperus rotundus* effectively and economically compared to other treatments with no residual toxicity. Field and pot experiments were conducted for two years to study the effect of glyphosate on regeneration potential of *Cyperus rotundus* and results revealed that resprouting from bulbs of killed shoots was observed in all treatments. The maximum reduction in regeneration potential was obtained with glyphosate applied in three splits (Bhatia *et al.*, 2001).

Darkwa *et al.* (2001) reported that tuber populations of *Cyperus rotundus* could be reduced by 95 per cent after glyphosate at 1.8 kg ai ha^{-1} was applied at the beginning of the season. Jadhao *et al.* (2001) studied the effect of pre-emergent herbicide application combined with post emergent glyphosate application at 1 kg ha^{-1} as a spray 30 DAS and found it as the most effective measure against weeds and none of the herbicides alone or in combination caused phytotoxic symptoms on crop.

Rao and Reddy (2001) conducted green house experiments during spring and summer to evaluate the effectiveness of glyphosate over other herbicides and results indicated that glyphosate alone at 1120 g ha^{-1} gave 87 per cent control of three months old purple nutsedge.

Wangchengyuh (2001) studied the effect of glyphosate on aromatic amino acids metabolism in purple nutsedge (*Cyperus rotundus*) sprouted tubers and shoots and reported that glyphosate caused inhibition of bud elongation, increased total free amino acids concentration and caused rapid accumulation of Shikimic acid in sprouted tubers.

Nadanarsahabady *et al.* (2002) evaluated the effect of various herbicides with hand weeding on cotton and associated weeds mainly

Cyperus rotundus and found that lowest weed density was recorded for 1.025 kg glyphosate ha^{-1} with hand weeding. Oster *et al.* (2002) compared the efficacy of glyphosate and other herbicides (1350 g ha^{-1}) against *Cyperus rotundus* tuber viability and reported that glyphosate was most effective among the herbicides with 37 per cent tuber mortality after eight months and 38 per cent after 20 months. The above literature clearly indicate the suitability and effectiveness of glyphosate for purple nutsedge control.

2.3.3.2 2,4-D sodium salt

Efficiency of control of *Cyperus rotundus* with 2,4-D varies greatly with its formulations. Roa *et al.* (1973) reported sodium salt of 2,4-D more effective as compared to ester formulation.

The study by Bharadwaj (1981) revealed that application of 2,4-D at 4.4 kg ha^{-1} soon after cultivation on bare soil caused more than 80 per cent reduction in the initial stand of nutsedge in a single season. Complete control of nutsedge was achieved by repeating the treatment for one more season. The effect of 2,4-D on sprouting and growth of tubers of *Cyperus rotundus* was studied by Gill *et al.* (1986) and they observed that 2,4-D did not prevent tuber sprouting, but inhibited bud growth and the sprouted buds rotted at higher 2,4-D concentration.

Bhargavi and Reddy (1992) conducted field trials to evaluate different herbicides for nutsedge control and found that 2,4-D ethyl ester reduced the shoot population of the weed by 77.5 per cent and dry weight of nutsedge at different growth stages of the crop compared with the unweeded control. They also found that the emergence rate of *Cyperus rotundus* was 1.94 shoots m^{-2} day^{-1} in unweeded control plots and less than one in most of the herbicide treated plots.

Hawton *et al.* (1992) compared the efficacy of different herbicides like glyphosate, 2,4-D, bromacil, EPTC etc for nutsedge control and found that the greatest effect of most treatments was on the shallowest tubers

(0-10 cm) except for 2,4-D which affected tuber uniformly over the 0-10, 10-20 and 20-30 cm depth ranges studied.

Liu and Twu (1993) reported that the sodium salt of 2,4-D at 3.2 kg reduced *Cyperus rotundus* growth by 42 per cent and it did not affect germination of tubers. Gupta (1998) opined that nutsedge tuber desiccation can be greatly improved by supplementary tillage with 2,4-D @ 2-4 kg ha^{-1} at the last cultivation before the onset of monsoon.

2.4 ALLELOPATHY OF NUTSEDGE (*Cyperus rotundus* L.)

Plants produce a large number of compounds that have no obvious role in primary metabolism. One possible function of such secondary metabolites may be as protective agents in the plant. Molisch (1937) coined the term allelopathy to refer to the biochemical interaction between all type of plants including microorganism. Rice (1974) has used the term allelopathy to refer to the deleterious effect that one plant has on another through the production of chemical retardants that escape into the environment. A wide variety of secondary plant metabolites can inhibit the growth of crop and weed species (Rice, 1979).

The allelopathic potentiality of nutsedge was reported first by Beiber (1967) who recorded the inhibition of germination and seedling development of crown vetch by aqueous extract of *Cyperus rotundus* shoots. The increase of allelopathic phenolic and terpenoid compounds under environment stress has been well documented by Tang *et al.* (1995) and work on purple nutsedge showed that water stress enhanced phytotoxic secondary metabolites in both plant tissue and in the rhizosphere.

2.4.1 Nutsedge Interference with Other Weeds

Allelopathy is the interference plants impose upon one another through the release of chemicals. It has been implicated most frequently with aggressive weeds on their interference with crops and less frequently with weeds against weeds. Narwal (1994) observed that in the near future, allelopathy mediated weed control technology may be available which will

be free from environmental pollution and suitable for future sustainability of agriculture.

Shettil and Balke (1983) evaluated the effect of phenolic acids on weed growth and found that p-hydroxybenzoic acid caused greatest reduction in growth of pigweed while it did not reduce the growth of velvet leaf or wild proso millet. Arunachalam (2000) reported that allelochemicals such as phenolic compounds, alkaloids and tannins are useful to reduce germination of weed such as purslane and *Amaranthus* sp. under laboratory conditions.

2.4.2 Nature of Allelochemicals in *Cyperus rotundus*

Allelochemicals refer to the secondary metabolites produced by plants and are byproducts of primary metabolic process. Allelochemicals are produced in above or below ground plant parts or in both. Out of thousands of such compounds only limited number of them have been identified as toxins involved in allelopathy. Plant parts known to contain allelochemicals include leaves, stem, roots, flowers, fruits and seeds.

Tames *et al.* (1973) found that tubers of *Cyperus rotundus* contained inhibitory compounds like p-hydroxy benzoic, vanillic, syringic, ferulic, p-coumaric acids plus other unidentified ones, which inhibited the germination of sugar beet, peas, lettuce and tomato. Komai and Ueki (1975) analysed the polyphenolic substances in purple nutsedge tubers at both dormant and non-dormant stage. The polyphenols isolated were primarily catechol, tannin of leucocyanidin and leucocyamedin glucoside. Phenolic acids detected in the hydrolysis of the phenols with HCl or NaOH were p-coumaric acid and protocatechuic acid. These allelopathic substances are released into the soil during decomposition of crop residues (Patterson, 1981).

Williams and Hoagland (1982) opined that potential allelochemicals which are able to produce inhibitory effect on seed germination are identified as phenolic acids. Einhellig (1987) reported that allelopathic

inhibition of germination and plant growth typically occurred from the joint action of several allelochemicals. Additive or synergistic effects have been shown in bioassays with combination of monoterpenes, organic acids and several classes of phenolic acids.

Hosmani (1995) suggested that the inhibitory substances on purple nutsedge were phenolics identified as cyperone, p-selinine, cypernone and 2-cypernone. Leela (1995) recorded the presence of phenolic acids *viz.*, p-hydroxybenzoic acid, caffeic acid, o-coumaric acid and ferulic acid in tubers of purple nutsedge.

El-Bassiouny and Messeha (1999) conducted chromatographic fractionations and bioassays of growth regulating substances in *Cyperus rotundus* extract leading to the isolation of mainly phenolic components. Quayyum *et al.* (2000) studied the growth inhibitory effects of nutgrass (*Cyperus rotundus*) on rice and tentatively identified nineteen compounds from the aqueous extracts of leaves and tubers by ethyl acetate extraction followed by gas chromatography-mass spectroscopy and dicarboxylic, phenolic and fatty acids were identified as the major compounds.

2.4.3 Effect of Phenolics on Plant Growth

Many different secondary metabolites like phenolics, terpenoids, alkaloids, steroids etc can act as allelochemical. Phenolics have been implicated as having a role in allelopathic interactions among different group of plants. Vansumere *et al.* (1972) reported that phenolic compounds inhibit germination by interfering with energy metabolism and biosynthetic processes in seed embryos. According to Lucaena (1974) biologically active substances produced by the underground parts of *Cyperus rotundus* acted on the hormonal processes that regulate plant growth, and the response depended on the concentration in the media where the plants germinate and grow.

Some phenolics can either inhibit or stimulate hormone synthesis and also modify their actions. Caffeic acid and ferulic acids suppress

Indole Acetic Acid (IAA) and may reverse ABA inhibition (Ray *et al.*, 1980). Patterson (1981) found that phenolic acids at concentrations of 1mμ reduced growth and physiological process, including photosynthesis in soybean.

Hsofreng-Yuan (1982) reported that vanillic acid inhibited biosynthesis of hemicellulose while ferulic, vanillic and o-hydroxy phenyl acetic acids suppressed cellulose biosynthesis and protein synthesis. Shettel and Balke (1983) analysed plant growth response to several allelopathic chemicals and found that at 1.12 kg ha^{-1} p-hydroxy benzoic acid, salicylic acid, caffeine, hydroquinone and umbelliferone inhibited the weed species more than the crop species.

Phenolics can modify biosynthesis of major plant constituents and carbon flow into different cellular pools and can possibly affect cell growth and development (Einhellig, 1986). Cinnamic acids are among the most active compounds in blocking plant nutrient uptake. The uptake of phosphorus in sorghum and soybean and potassium and magnesium in sorghum were reduced by ferulic acid (Einhellig, 1987).

Moreland and Novotsky (1987) suggested that phenolics inhibited CO_2 dependent O_2 evolution in chloroplasts by altering the ATP-generating pathway at low concentrations and by inhibiting electron transport at high concentration. Blum and Rebbeck (1989) reported influence of ferulic acid on uptake of P, K and water relations by cucumber seedlings. Seigler (1996) proposed that phenolic acids like vanillic, ferulic and p-coumaric acids reduce chlorophyll content in soybean.

Sasikumar *et al.* (2002) studied the allelopathic effect of eucalyptus leachates on blackgram and reported the presence of coumaric, gallic, gentisic, hydroxy benzoic, syringic and vanillic acids. Germination was unaffected by coumaric acid while gallic acid, syringic acid and hydroxy benzoic acids significantly inhibited germination. All the phenolic acids except coumaric acid significantly decreased the vigour index while coumaric acid stimulated the vigour index of black gram.

2.4.4 Effect of Root Exudates on Crop Plants

Allelochemicals or allelopathins are released by the donor plants from living leaves as volatiles or leachates or from roots through exudation or sloughing off of dead tissues or decaying plant litter or leaching from leaf litter on the soil surface (Putnam, 1983). Of these, exudation of chemicals by the plant is a common phenomenon. Root exudates are substances released into the surrounding medium by healthy and intact plant roots. The term 'root exudates' refer to organic substances which are exuded from the roots by any mechanism (Young, 1984).

Collection and identification of allelopathic compounds from undisturbed root system of Bigalta Limpograss (*Hemarthria altissima*) was done by Tang and Young (1982). The plant was established in sand culture and extracellular hydrophobic metabolites were adsorbed using XAD-4 resin. Bioassays of trapped root exudates using lettuce seed combined with paper and thin layer chromatography showed that the inhibitors were mainly phenolic compounds.

Effects of asparagus root exudates on the growth and nutrient uptake of the seedlings of the same species in vermiculite culture was investigated by Young (1984). The phytotoxicity of collected root exudates of asparagus was tested by asparagus seed bioassay and found that growth of asparagus radicle and shoot was inhibited by the root exudates collected from a resin trapping system. These data suggested that asparagus is an auto inhibited species in which root exudates inhibit its own growth.

Valliappan and Towers (1988) employed a novel system called continuous root exudates trapping system to investigate the allelopathic potential of the hazardous weed *Parthenium hysterophorus*. Bioassay of root exudates tested showed that all the growth characters were significantly inhibited with radicle length inhibited more than the plumule growth.

Valliappan (1989) conducted green house experiments with a potted staircase set up comprising 2 tiers. *Cyperus rotundus* was grown in the

upper tier and leachates were allowed to drain naturally to the lower tier containing rice plants. It was revealed that rice germination, growth and yield were significantly reduced by leachates from *Cyperus rotundus* and that the inhibition may have been due to the presence of allelopathins. Tang *et al.* (1995) showed that drought stress increased the inhibitory activity of tissue extracts and root exudates of purple nutsedge.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Integrated management of purple nutsedge (*Cyperus rotundus* L.)" is primarily aimed at formulating an integrated management strategy for the control of nutsedge. Separate experiments were undertaken at laboratory, pot and field situations for accomplishing the objective of the study. Pot experiment was designed to study the biology of nutsedge. Field experiments were envisaged with the objective of investigating the effect of various management strategies for the control of nutsedge in cropped and uncropped situations. Laboratory experiments were conducted to study the allelopathic effect of nutsedge on various crops and weeds. The allelochemicals in nutsedge tubers were identified by employing HPLC (High Performance Liquid Chromatography) technique. The materials used and the methods adopted in the experiments are detailed here under.

3.1 EXPERIMENTAL SITE – FIELD EXPERIMENT

The investigation was undertaken in block IV of the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The Farm is located at $8^0$30'N latitude, $76^0$9' E longitude and at an altitude of 29 m above MSL.

3.2 CLIMATE AND SEASON

Field experiments were conducted during December 2000 to May 2002 in both cropped and uncropped situations. Typical humid tropical climate is experienced by the area. The mean annual rainfall was 28 26 mm. The mean annual maximum and minimum temperatures were 31.44 and 22.04^{0}C respectively and the relative humidity was 77.81 per cent. The data on various weather parameters *viz.*, weekly rainfall, maximum temperature, minimum temperature and relative humidity obtained from the meteorological observatory, College of Agriculture, Vellayani are given in Appendix I and II and graphically represented in Fig. 1a and 1b.

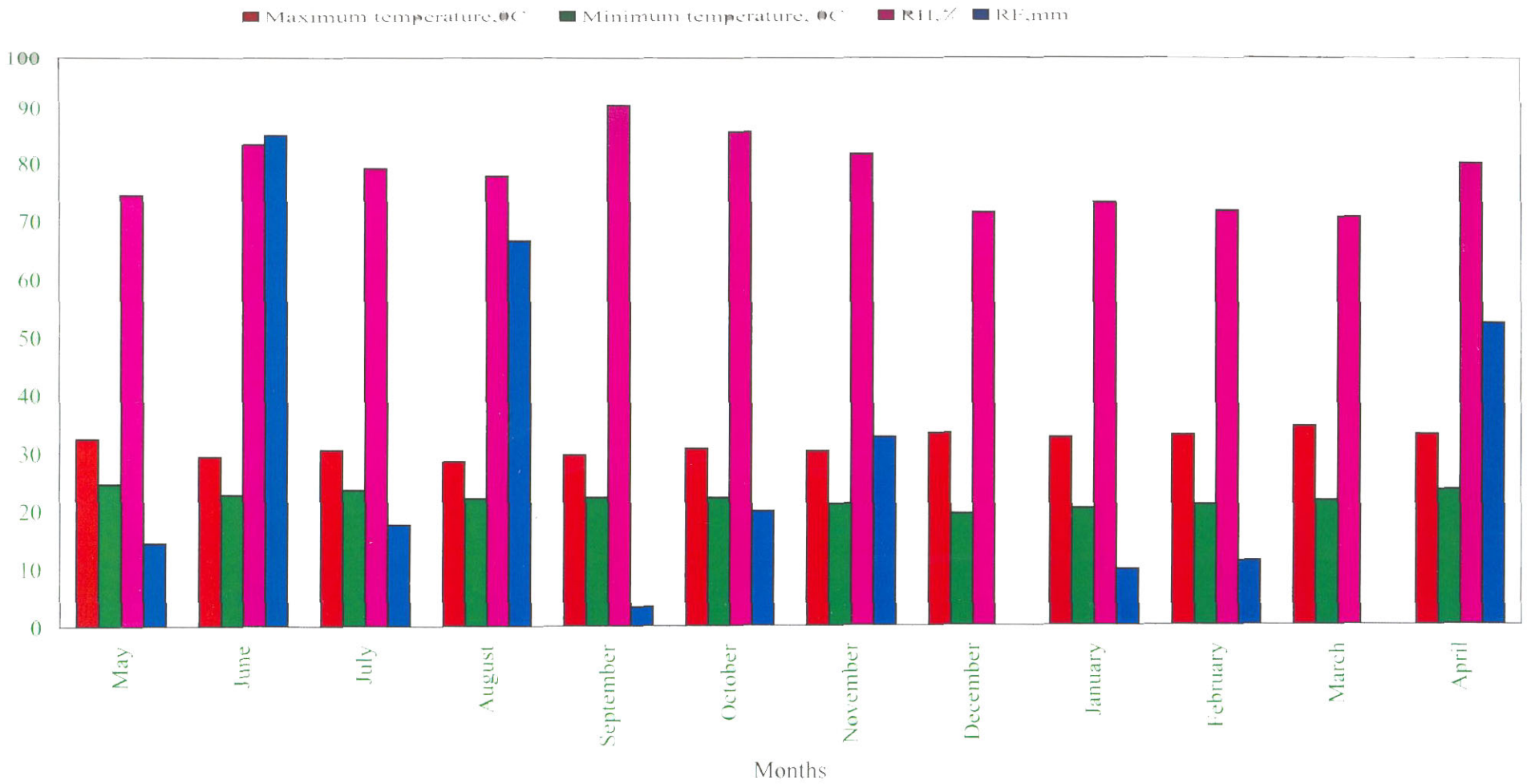


Fig. 1a Weather parameters during the crop growth period of experiment I

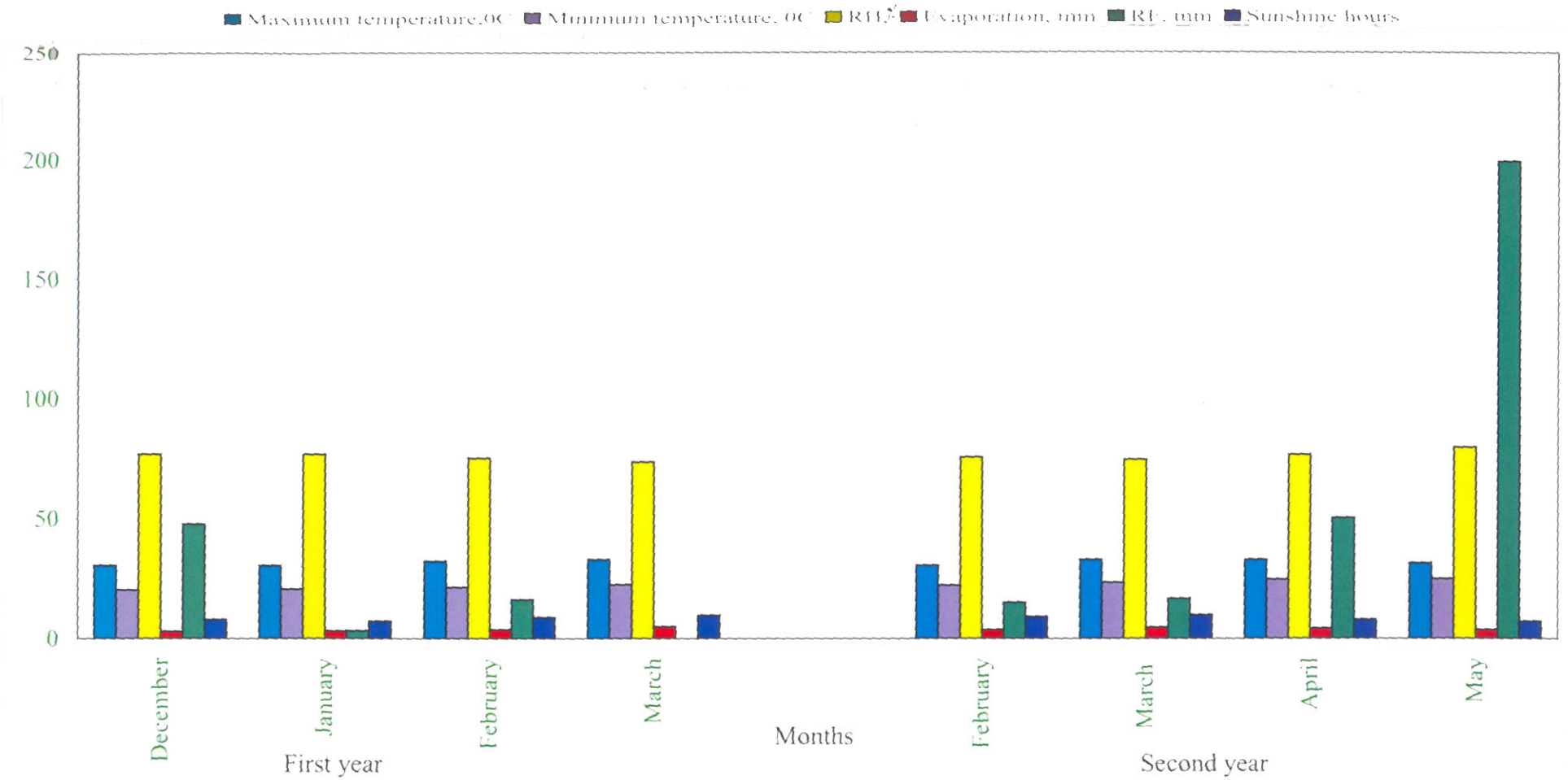


Fig. 1b. Weather parameters during the crop growth period of experiment II (I and II year)

3.3 SOIL

Composite samples of the soil were drawn from a depth of 0 – 15 cm prior to the investigation and were analysed for physico-chemical properties and the data are presented in Table 1. The soil of the experimental site belonged to the taxonomical class, loamy kaolinitic isohyperthermic rhodic haplustox. Soil analysed low in available nitrogen, medium in available phosphorus and potassium and registered a pH value of 5.2.

Table 1. Soil physio-chemical properties of the experimental site

Parameters	Mean value	Method used
I. Physical properties		
1. Mechanical composition		
Coarse sand (per cent)	36.35	
Fine sand (per cent)	15.00	Bouyoucos Hydrometer Method
Silt (per cent)	17.50	(Bouyoucos, 1962)
Clay (per cent)	30.00	
2. Bulk density (gcc^{-1})	1.375	Gupta and Dakshinamoorty (1980)
3. Water holding capacity (per cent)	21.50	Gupta and Dakshinamoorty (1980)
4. Porosity (per cent)	32.00	Gupta and Dakshinamoorty (1980)
II. Chemical properties		
1. Soil reaction (pH)	5.20	pH meter with glass electrode (Jackson, 1973)
2. Available N ($kg\ ha^{-1}$)	288.51	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
3. Available P_2O_5 ($kg\ ha^{-1}$)	11.35	Bray colourimetric Method (Jackson, 1973)
4. Available K_2O ($kg\ ha^{-1}$)	57.75	Flame Photometric Method (Jackson, 1973)

3.4 CROPPING HISTORY OF THE FIELD

The experimental site was lying fallow and was completely infested with nutsedge.

Experiment I

3.5 STUDIES ON THE BIOLOGY OF NUTSEDGE AND STAGE OF TUBERISATION

Tubers of uniform size were collected from the field and were planted in pots. Tubers sprouted on the same day were selected for studying the biology. The study was conducted for one year to assess the seasonal influence on the growth and development of the weed. The observations made are furnished below.

3.5.1 Days to Sprouting

Number of days taken for emergence of sprout was recorded.

3.5.2 Sprouts Tuber^{-1}

Number of sprouts per tuber was counted and averaged out.

3.5.3 Tuber number plant^{-1}

On complete drying up of the aerial shoots the plant was uprooted after each season and the tubers were counted and recorded.

3.5.4 Shoot Dry Weight

Nutsedge plant was uprooted at random at the end of the season and the dry weight of shoot was recorded and expressed as g plant^{-1}.

3.5.5 Tuber Dry Weight

Nutsedge plant was uprooted at random at the end of the season, tubers were separated, cleaned and dry weights of tubers were recorded and expressed as grams plant^{-1}.

3.5.6 Days to Flowering

Number of days required for emergence of inflorescence of 50 per cent of plant population was recorded.

3.5.7 Days to tuberisation

Number of days required for the initiation of a new tuber from the parent tuber was recorded.

Experiment No. II

3.6 EFFECT OF CONTROL MEASURES ON DEATH AND REGENERATION OF NUTSEDGE IN CROPPED AREA

The study consisted of two field experiments taken up in summer seasons of 2001 and 2002 in a nutsedge infested area. Crop selected was okra (*Abelmoschus esculentus* L. Moench) being a widely spaced upland crop.

3.7 MATERIALS

3.7.1 Crop Variety

The bhindi variety Varsha Uphar released from Hisar Agricultural University was the test crop. The variety was developed from the cross between Lam selection and Parbhani Kranti. The variety exhibited an average yield of 9.8 t ha^{-1}. Fruits are of dark green colour and the variety is reported to be resistant to yellow vein mosaic disease.

3.7.1.1 Source of the seed material

The bhindi seeds for the experiment were obtained from the Instructional Farm, Vellayani.

3.7.2 Manures and Fertilizers

FYM (0.4, 0.3, 0.2 % of N, P_2O_5, K_2O respectively) was used as the organic manure source for the experiment. Urea (46 % N), Mussoriephos

Plate 1. General field view of experiment II

(20 % P_2O_5) and MOP (60 % K_2O) were used as sources of nitrogen, phosphorus and potassium respectively.

3.7.3 Herbicide

The herbicide glyphosate was applied according to the treatments.

3.7.4 Smother crop (cowpea)

C-152 variety of cowpea seed obtained from crop museum was used as the smother crop.

3.7.5 Mulching materials

Black polythene sheets of 300 gauge thickness was used as the mulching material.

3.7.6 Eucalyptus leaf

The fallen dry leaves of eucalyptus collected from College garden after analyzing the nutrient status was used as the mulch material. On chemical analysis the litter recorded an NPK status of 0.910, 0.086 and 0.680 per cent of nitrogen, phosphorus and potassium.

3.8 METHODS

3.8.1 Field Culture

The experimental site was ploughed, clods broken, stubbles removed and the field was laid out into blocks and plots. The plots were separated by bunds of 30 cm width and the blocks by 50 cm bunds. All the cultural practices except weed management were carried out as per the Package of Practices Recommendations –Crops (KAU, 2003).

3.8.2 Application of Manures and Fertilizers

FYM @ 5 t ha^{-1} was applied at the time of land preparation and mixed well with the soil. N, P_2O_5 and K_2O were applied in the form of urea, mussoriephos and MOP respectively. The recommended nutrient dose was 50:8:25 kg ha^{-1} of NPK (KAU, 2003).

Entire dose of phosphorus and potassium and half of the recommended dose of nitrogen were applied at the time of sowing and the remaining doses of nutrients were applied one month after sowing.

3.8.3 Gap Filling

Gap filling was done with healthy seedlings, wherever necessary.

3.8.4 Irrigation

Crop was irrigated daily till establishment and further at two days interval.

3.8.5 Plant Protection

Fruit borer infestation and incidence of yellow vein mosaic was noticed in all the treatments. Ekalux @ 0.2 per cent was applied four times at interval of seven days to control the pest attack.

3.8.6 Harvest

First harvest was taken 45 days after sowing and subsequent harvests were taken at 3 – 5 days interval.

Technical Programme

Design and layout

The layout of the experiment is given in figure.2

Design	: Randomised Block Design (RBD)
No. of treatments	: 11
Replications	; 3
Gross plot size	: 3 x 3 m^2
Total No. of plots	: 33

Two rows of plants were left as border on all the sides and the observations were taken from the net plot area.

Treatments

Treatment details are furnished below

T_1 – Stale seed bed with glyphosate @1.5 kg ai ha^{-1} (PP) + hand weeding at critical growth stages

T_2 – Stale seed bed with glyphosate @1.5 kg ai ha^{-1} (PP) + black polythene mulching

T_3 - Stale seed bed with glyphosate @1.5 kg ai ha^{-1} (PP) + eucalyptus leaf mulching

T_4 - Stale seed bed with glyphosate @1.5 kg ai ha^{-1} (PP) + cowpea (smother crop)

T_5 - Stale seed bed with glyphosate @ 1.5 kg ai ha^{-1} (PP) + post emergent direct spraying in between rows and hand weeding between plants

T_6 – Soil exposure for 72 hours + hand weeding at critical growth stages

T_7 - Soil exposure for 72 hours + black polythene mulching

T_8 - Soil exposure for 72 hours + eucalyptus leaf mulching

T_9 - Soil exposure for 72 hours + cowpea (smother crop)

T_{10} – Weedy check

T_{11} – Completely weed free

(PP – pre-plant application with respect to crop)

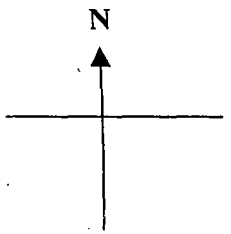
3.9 WEED MANAGEMENT

3.9.1 Stale seed bed

The stale seed bed plots were prepared by digging the field so as to expose and break the nutsedge tuber chains. This is followed by irrigation so as to stimulate sprouting of dormant tubers.

3.9.2 Herbicide application

Herbicidal spray solution was prepared as per the treatment and was sprayed uniformly after one month as pre plant spraying. Post emergent direct spraying was given between rows of plants at one month after sowing.



First year

T_5	T_2	T_7	T_8	T_1	T_6	T_3	T_{10}	T_{11}	T_9	T_4	R-I
T_9	T_3	T_{10}	T_2	T_8	T_{11}	T_4	T_6	T_1	T_7	T_5	R-II
T_{11}	T_7	T_4	T_1	T_9	T_6	T_{10}	T_2	T_8	T_5	T_3	R-III

Second year

T_7	T_2	T_5	T_{11}	T_{10}	T_3	T_9	T_4	T_6	T_1	T_8	R-I
T_9	T_5	T_{10}	T_8	T_3	T_1	T_6	T_4	T_2	T_7	T_{11}	R-II
T_5	T_{11}	T_1	T_7	T_4	T_9	T_3	T_6	T_8	T_{10}	T_2	R-III

Fig. 2. Layout of the experimental plots in cropped area

Plate 2. Various treatment combinations for purple nutsedge control

3.9.3 Hand weeding

Hand weedings were done at the critical stages of 15, 30 and 45 days after sowing and in T_5 hand weeding was done at 30 days after sowing between plants.

3.9.4 Black polythene mulching

After preparing the plot, the land was thoroughly leveled. Holes of 12 cm diameter were made on polythene sheet at 30 cm distance and the sheet was spread on the whole plot.

3.9.5 Eucalyptus leaf mulching

After sowing bhindi seeds, plot was mulched with eucalyptus leaves.

3.9.6 Smother crop

Three rows of cowpea were raised on the ridges at a spacing of 10 cm and is mulched at 25 days after sowing.

3.9.7 Weedy check

In weedy check plot, no weed control operation was taken up.

3.9.8 Weed free check

By removing the weeds as and when they appeared, weed free check was maintained throughout the experiment.

3.9.9 Observations on crop characteristics

Five plants were selected at random from the net plot area of each plot and tagged. The following observations were recorded from these sample plants and the mean values were worked out.

3.9.9.1 Days to flowering

Number of days taken for 50 per cent flowering was noted and recorded.

3.9.9.2 No. of fruits per plant

Number of fruits per plant was counted and mean values were worked out.

3.9.9.3 LAI at flowering and at harvest

The leaf samples were collected at respective time and area was measured using graphical method. The leaf area per plant was divided by land area and expressed as LAI.

3.9.9.4 Fruit yield per ha

The weight of fruits from the net plot area was recorded from each harvest, the total was worked out and expressed in t ha^{-1}.

3.9.9.5 Dry matter production at harvest

Sample plants were collected at random and oven dried at 70 ± 5^0C to a constant weight. The final dry weight was averaged and expressed in t ha^{-1}.

3.9.9.6 Number of economic harvest

It was calculated based on the existing wage rate of labourer and the yield from each treatment.

3.9.9.7 Economics

The economics of cultivation was worked out based on the cost of cultivation and prevailing price of crop produce.

Net income (Rs ha^{-1}) = Gross income – Total expenditure

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.9.10 Observations on weed characteristics

3.9.10.1 Initial and final plant population

Before and after each season, nutsedge population was recorded with a 33 x 33 cm quadrat placed at random in three areas in each plot. The

number of aerial shoots was counted and average was calculated. The count was expressed as number m^{-2}.

3.9.10.2Initial shoot and tuber dry weight

After counting the aerial shoots of nutsedge, shoots and tuber from one quadrat was uprooted, washed and dried at 70^0C to a constant weight and expressed as g m^{-2}.

3.9.10.3 Final shoot and tuber dry weight

After each season, shoots and tuber from anyone of the quadrats was uprooted and dried to a constant weight and expressed as g m^{-2}.

3.9.10.4 Percentage reduction in shoot dry weight

This was calculated using the formula

$$\text{Percentage reduction} = \frac{\text{Initial shoot dry weight} - \text{Final shoot dry weight}}{\text{Initial shoot dry weight}} \text{ X } 100$$

3.9.10.5 Percentage reduction in tuber dry weight

This was calculated as in the case of percentage reduction in shoot dry weight.

3.9.10.6 Percentage reduction in plant population

This was calculated as in the case of shoot dry weight.

3.9.10.7 Regeneration count

In each plot, 0.1m^2 area was marked and kept undisturbed after imposing the treatments. New sprouts appeared were recorded at weekly interval.

3.9.10.8 Weed Control Efficiency (WCE)

Weed control efficiency was calculated by using the formula suggested by Mani *et al.* (1973).

$$\text{WCE} = \frac{\text{WDWC} - \text{WDWT}}{\text{WDWC}} \text{ X } 100$$

WCE = Weed Control Efficiency

WDWC = Weed Dry Weight in unweeded (Control plot)

WDWT = Weed Dry Weight in Treated plot

3.9.10.9 Weed Index (WI)

WI was calculated using the formula suggested by Gill and Vijayakumar (1969).

$$WI = \frac{X - Y}{X} \times 100$$

Where,

X – Yield from weed free plot or treatment which recorded minimum number of weeds.

Y – Yield from plot for which WI is to be worked out.

3.9.10.10 Tuber viability

After the application of treatments, ten tubers were collected at random from each plot, detached and the individual tubers were kept in petri dishes for testing viability. Number of tubers germinated were counted two and three weeks after sowing and expressed as percentage.

3.9.10.11 Nutrient uptake by the weed

The N, P and K uptake by the weeds were worked out as the product of content of these nutrients and the dry weight of weeds expressed in kg ha^{-1}.

Experiment III

3.10 INVESTIGATIONS ON NUTSEDGE CONTROL IN NON-CROPPED AREA

Field experiments were conducted for three reasons from June 2002 to April 2003 in a nutsedge infested area. The entire plot was dug and the treatments were imposed on the regenerated shoots at the corresponding stages.

Design and layout (First two seasons)

Design	: Randomised Block Design (RBD)
No. of treatments	: 5
Replications	: 4
Total number of plots	: 20
Gross plot size	: 10 x 4 m

Treatments (first two seasons)

T_1 – 2,4- D @ 1.5 kg ai ha^{-1} before tuber initiation

T_2 – 2,4 –D @ 1.5 kg ai ha^{-1} before dormant tuber production

T_3 – Glyphosate@ 1.5 ai ha^{-1} before tuber initiation

T_4 – Glyphosate@ 1.5 ai ha^{-1} before dormant tuber production

T_5 – Weedy check

Third season

Design	: Split plot design
No. of treatments	: 20
Main plot factor	: 5 treatments
Sub plot factor	: 4 treatments
Replications	: 4
Total no. of plots	: 80
Gross plot size	: 2.5 x 1m

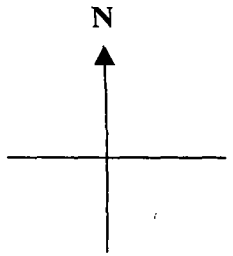
Stages of tuber initiation and dormant tuber production were identified from the first experiment. During the third season, experiment was conducted in split plot design with four subplot treatments and five main plot treatments. Treatments tried during the first two seasons served as the main plot treatments and indicated as M_1, M_2, M_3, M_4 and M_5 during third season. Subplot treatments were

S_1 – Stale seed bed with irrigation + chemical weeding with best herbicide identified from the first experiment

S_2–Stale seed bed with ethrel application (300 ppm) + chemical weeding with best herbicide identified from the first experiment.

First two seasons

T_3	T_1	T_4	T_2	T_5	R-I
T_4	T_2	T_5	T_1	T_3	R-II
T_2	T_5	T_3	T_4	T_1	R-III
T_4	T_1	T_5	T_3	T_2	R-IV



Third season

m_3s_3	m_3s_1	m_1s_3	m_1s_1	m_4s_3	m_4s_4	m_2s_2	m_2s_1	m_5s_4	m_5s_1	R-I
m_3s_2	m_3s_4	m_1s_2	m_1s_4	m_4s_2	m_4s_1	m_2s_4	m_2s_3	m_5s_2	m_5s_3	
m_4s_1	m_4s_3	m_2s_3	m_2s_1	m_5s_2	m_5s_3	m_1s_2	m_1s_1	m_3s_4	m_3s_3	R-II
m_4s_2	m_4s_4	m_2s_4	m_2s_2	m_5s_1	m_5s_4	m_1s_3	m_1s_4	m_3s_2	m_3s_1	
m_2s_2	m_2s_4	m_5s_4	m_5s_2	m_3s_3	m_3s_2	m_4s_3	m_4s_2	m_1s_2	m_1s_3	R-III
m_2s_3	m_2s_1	m_5s_3	m_5s_1	m_3s_1	m_3s_4	m_4s_4	m_4s_1	m_{1s1}	m_1s_4	
m_4s_3	m_4s_2	m_1s_2	m_1s_1	m_5s_2	m_5s_3	m_3s_3	m_3s_1	m_2s_3	m_2s_4	R-IV
m_4s_1	m_4s_4	m_1s_4	m_1s_3	m_5s_1	m_5s_4	m_3s_4	m_3s_2	m_2s_2	m_2s_1	

Fig. 3. Layout of the experimental plots in uncropped area

S_3–Digging once

S_4 –Weedy check

3.10.1 Stale seed bed with irrigation

The plots were prepared thoroughly and irrigated to stimulate germination of nutsedge tubers.

3.10.2 Stale seed bed with ethrel application

The plots were prepared thoroughly and sprayed with ethrel at 300 ppm to break dormancy of tubers.

3.10.3 Digging once

The soil was dug well to expose the deep tubers to the surface.

3.10.4 Weedy check

In weedy check plot, no weed control operation was taken up.

3.10.5 Herbicides

The herbicides glyphosate and 2,4-D sodium salt were applied according to the treatments.

a. Glyphosate	: N- (Phosphonomethyl) glycine
Formulation	:41 per cent SL
Trade name	: Round up
Produced by	: Monsanto chemicals, USA
Price	: Rs.480 $litre^{-1}$
b. 2,4-D sodium salt	: 2,4-dichlorophenoxy acetic acid
Formulation	: 80 per cent WP
Trade name	: Fernoxone
Produced by	: Imperial Chemical Industries, U.K.
Price	: Rs. 120 kg^{-1}

c. Ethrel : 2-chloro ethyl phosphoric acid

Trade name : Ethephon 10 per cent SL

Produced by : Tropical Agrosystem (India) Ltd.

Price : Rs.400 litre^{-1}

3.10.6 Observations on Weed Parameters

3.10.6.1 Initial and final plant population

Plant population was recorded as in 3.9.10.1.

3.10.6.2 Initial shoot and tuber dry weight

Shoot and tuber dry weights were recorded as in 3.9.10.2.

3.10.6.3 Final shoot and tuber dry weight

Final shoot and tuber dry weights were recorded as in 3.9.10.3.

3.10.6.4 Percentage reduction in shoot dry weight

This was calculated same as in 3.9.10.4

3.10.6.5 Percentage reduction in tuber dry weight

This was calculated same as in the 3.9.10.5.

3.10.6.6 Percentage reduction in plant population

This was calculated same as in the 3.9.10.6.

3.10.6.7 Regeneration count

This was taken same as in the 3.9.10.7.

3.10.6.8 Weed control efficiency

This was calculated same as in the 3.9.10.8

Experiment IV

3.11 ALLELOPATHIC STUDIES

3.11.1 Allelopathic influence of root exudates

Root exudates of the weed plant was collected at various stages of the weed by fabricating a device as designed by Tang and Young (1982).

3.11.1.1 Details of the apparatus

The system for trapping root exudates was fabricated as designed by Tang and Young (1982). The system consisted of a stainless steel vessel which was connected to a glass tube with the help of a rubber stopper. The glass tube was filled with one per cent (100 : 1) sand charcoal mixture. Nutrient solution leached through the soil and adsorbent column was cycled to the soil and column with the help of a rubber tube and air pump. The bottom end of the side arm was inserted into the glass column and the top end was let to stand over the mouth of the container. This system ensured a steady and constant circulation of the flow from the container through the sand-charcoal mixture.

3.11.1.2 Test crops

Rice, cowpea, sesamum, bhindi, brinjal

Technical programme

Design	: Completely Randomised Block Design (CRD)
Treatments	: 5
Replications	: 4
Medium	: Filter paper circle in petri plate

Treatments

T_1 – Roots exudates collected at sprouting stage

T_2 – Root exudates collected at tuberisation stage

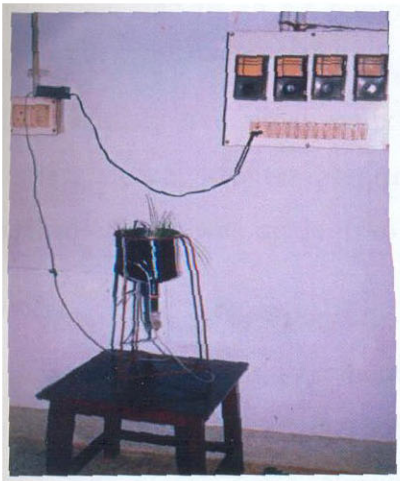
T_3 - Root exudates collected at flowering stage

T_4 - Root exudates collected at dormant tuber formation stage

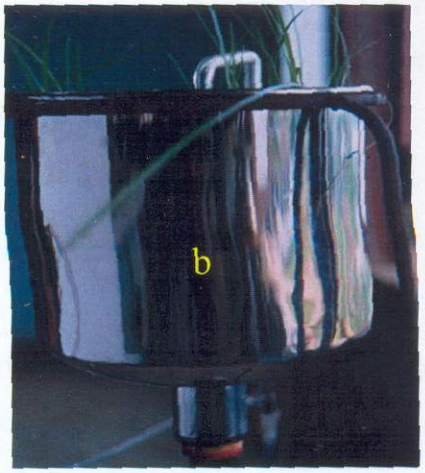
T_5 – Control (distilled water)

3.11.1.3 Collection of the exudates

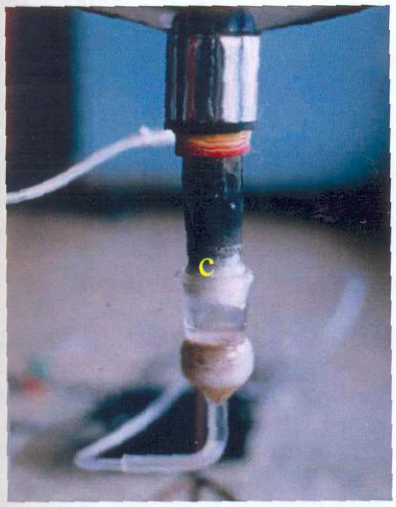
The stainless steel vessel was filled with 1.75 kg white sand which is washed thoroughly and sterilized at a temperature of 100°C for two days. Twenty tubers of nutsedge were sown in the container and irrigated. Once the weed reached the growth stage as indicated in treatments 1 to 4, the



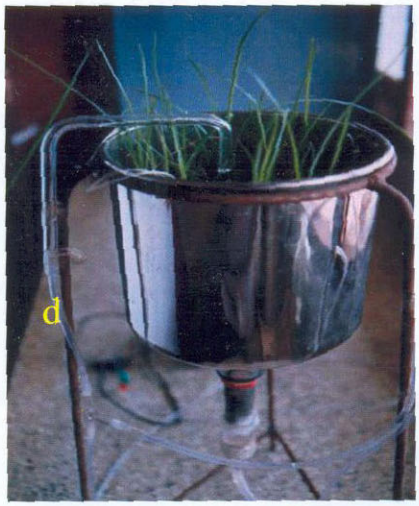
a. Apparatus



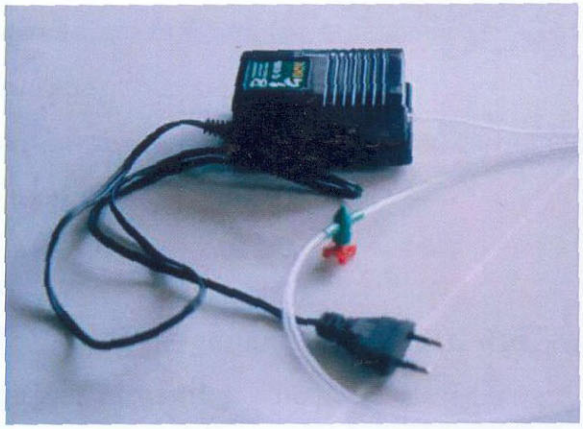
b. Stainless steel vessel



c. Glass tube with adsorbent



d. Recirculating glass tube



e.Air pump

Plate 3. Apparatus for root exudate collection

attachment of glass column was filled with the adsorbent (50 g). The system was then connected to an air pump. After the solution had been recirculated through the system for 72 hours, each loaded column was detached and eluted sequentially five times with 50 ml of methanol each time. The eluate was concentrated at low temperature using a rotary vacuum flash evaporator and the final volume was made upto 25 ml.

3.11.1.4 Methodology of bioassay

Glass petri dishes (9 cm diameter) were sterilized at an atmospheric pressure of 15 lb $inch^{-2}$ for one hour and later dried in hot air oven at 120^0C. Seeds of test plants were sterilised by dipping in 0.1 per cent Hg Cl_2 (mercuric chloride) solution for five minutes followed by repeated washing with distilled water to remove residues of Hg Cl_2 and dried in folds of ordinary filter paper. In each petri plate a filter paper was kept at bottom and thereafter 2 ml of the exudate was poured on the filter paper so as to impregnate it with the chemical in the exudates. After impregnating the filter paper 50 seeds each of the test crop was arranged in circles on the top of the filter paper. Then 5 ml of distilled water was added on each petri plate. Thereafter 2 ml of distilled water was added uniformly as and when required till the end of the trial.The data on germination and seedling growth were recorded and analysed statistically.

3.11.1.5 Observations

3.11.1.5.1 Germination percentage

The number of seeds that germinated was counted and expressed as percentage of the total seeds.

3.11.1.5.2 Plumule length

On the day of final germination count, the shoot length of all sprouted seedlings was measured. The mean shoot length was arrived at and expressed in cm.

3.11.1.5.3 Radicle length

On the day of final germination count, the root length of all the sprouted seedlings was measured. The mean root length was arrived at and expressed in cm.

3.11.1.5.4 Dry weight

All sprouted seedlings were oven dried at 70±5°C to constant weight, weighed and the dry weight was expressed in mg plant^{-1}.

3.11.1.5.5 Vigour index (VI)

Seedling vigour index was calculated by adopting the formula suggested by Abdul baki and Anderson (1973) and expressed as a number.

VI = Germination percentage x (Root length + shoot length)

3.11.2 Allelopathic influence of nutsedge extracts on weed plants

Laboratory experiments were undertaken separately to examine the allelopathic influence of nutsedge extracts on some of the important seed propagated weeds. The experiments were carried out in the laboratory under room temperature (27^{0}C).

3.11.2.1. Test plants

Weeds

Eupatorium – *Chromolaena odorata* (L.)

Venalpacha – *Synedrella nodiflora*

Neervadamalli – *Gomphrena decumbens*

Technical programme

Design	: Completely Randomised Block Design (CRD)
No. of treatments	: 6
No. of replications	: 4
Medium	: Filter paper circle in petri plate

Treatments

T 1– Aqueous extract of dry whole plant at flowering

T 2 - Aqueous extract of dry whole plant after flowering

T 3– Ethanol extract of dry whole plant at flowering

T4 -Ethanol extract of dry whole plant after flowering

T5 – Control (distilled water)

T6 – Control (Ethanol)

3.11.2.2 Preparation of aqueous extract

Purple nutsedge (*Cyperus rotundus* L.) plant samples were collected from infested fields at the respective growth stage. The plants were then cleaned off dirt and soil. It was then shade dried for one week. One hundred gram shade dried plant samples were immersed in 200 ml distilled water separately and kept at room temperature for 48 h. There after, it was stirred manually for few minutes and filtered through whatman no.1 filter paper. It was considered as leachate of 50 per cent concentration and was further diluted with distilled water to 10 per cent concentration. Ethanol extract was prepared in the same way with ethanol as the extractant.

3.11.2.3 Methodology of bioassay

Glass petri dishes (9 cm diameter) were sterilized in auto clave at an atmospheric pressure of 15 lb $inch^{-2}$ for one hour and later dried in hot air oven at 120^0C. Seeds of test plants were sterilized by dipping in 0.1 per cent Hg Cl_2 solution for five minutes followed by repeated washing under tap water to remove residues of Hg Cl_2 and dried on in folds of ordinary filter paper. In each petri plate a Whatman No.1 filter paper was kept at bottom and there after 50 seeds each of test crop were arranged in circles on the top of the filter paper. Then 3 ml of the aqueous extract and ethanol extract or distilled water was added in each petri plate as per the treatments. Thereafter 2 ml solution of extract or distilled water were added uniformly as and when required till the end of the trial. The data on germination and seedling growth were recorded and the data were analysed statistically.

3.11.2.4 Observations

3.11.2.4.1 Germination percentage

Recorded as in the case of root exudates experiment.

3.11.2.4.2 Shoot length

Recorded as in the case of root exudates experiment.

3.11.2.4.3 Root length

Recorded as in the case of root exudates experiment.

3.11.2.4.4 Dry weight

Recorded as in the case of root exudates experiment

3.11.3 Identification of Allelochemicals

Nutsedge extract was prepared as per the procedure suggested by Leela (1995) and the allelochemicals present in the tubers were identified by High Performance Liquid Chromatography (HPLC).

3.11.3.1 Extraction of inhibitory compounds

One hundred and seventy five gram dried tubers of nutsedge were finely ground in a blender and soaked in 500 ml of methanol for 30 minutes. Then it was filtered through a muslin cloth. The final volume was made to 1000 ml. The filtrate was concentrated on a vacuum flash evaporator. The residue (10 ml) was diluted in 50 ml water to which 2.5 g of NaCl is also added. This is extracted thrice with 25 ml ethyl acetate each time. The ethyl acetate extracts combined, concentrated and the residue was hydrolysed with 2N NaOH. Then the pH was adjusted to 2.0 using 2N HCl. This was again extracted with ethyl acetate three times and evaporated to dryness. The dried residue was treated with 0.1 N $NaHCO_3$ solution and the pH was adjusted to 2.0. This was re-extracted with ethyl acetate three times and washed with distilled water to remove last traces of HCl. This was evaporated to dryness. The residue was dissolved in 25 ml ethyl acetate and phenols present were analysed with High Performance Liquid Chromatography (HPLC).

3.12 STATISTICAL ANALYSIS

The data recorded were subjected to analysis of variance technique as applied to Randomised Block Design and split plot design (Cochran and Cox, 1965) and the significance was tested by F test. Those treatments showing abnormally high or low values due to the nature of treatment were not included in the statistical analysis and remaining treatments were compared. Pooled analysis was conducted for important parameters of both the crop and the weed.

Results

4. RESULTS

Field and laboratory experiments were conducted at the College of Agriculture, Vellayani to workout an effective management practice for nutsedge control. The data recorded were analysed statistically and the results are presented below:

4.1 BIOLOGY OF PURPLE NUTSEDGE (*Cyperus rotundus* L.)

Purple nutsedge or *Cyperus rotundus* L. belonging to Cyperaceae family is a noxious weed. Information on the biology of the weed is basic to adopt effective control measures and the plant characteristics observed are presented in Table 2.

4.1.1 Days to Sprouting

The number of days required to sprout varied significantly at different seasons and between plant parts. Shoot tuber or bulb took only lesser time to sprout while chain tuber or tuber took more time to sprout than bulbs. The minimum time required to sprout was five days for tuber and four days for bulbs. The most favourable season to sprout was August for chain tuber and March-May for bulbs and the least favourable time was May-August when it took nearly 26 days to sprout for tuber and seven days for bulbs.

4.1.2 Number of Sprouts Tuber^{-1}

The number of sprouts produced tuber^{-1} varied significantly among seasons with the highest number of sprouts (2.85) produced during August-November which was on par with November-March (2.0). Sprouts produced was lesser in May-August (1.70) which was on par with March-May (1.90).

4.1.3 Tuber Number after each Season Plant^{-1}

Seasonal influence on tuber production was found significant. Maximum number of tubers were produced during May-August and

Table 2. Growth characteristics of purple nutsedge as influenced by different seasons

Seasons	Days to sprouting		Sprouts tuber^{-1}	Tuber No. plant^{-1}	Dry weight		Days to flowering	Days to tuberisation
	Chain tuber	Shoot tuber			Shoot, g plant^{-1}	Tuber, g plant^{-1}		
May-Aug	26.40	7.45	1.70	14.40	0.76	4.28	36.24	57.75
Aug-Nov	5.35	5.68	2.85	9.20	1.17	4.52	44.50	24.50
Nov-Mar	17.00	5.35	2.00	8.23	1.22	6.05	56.25	50.75
Mar-May	7.70	3.60	1.90	13.37	1.00	6.24	39.75	39.00
SE	1.13	0.15	0.17	0.89	0.11	0.64	0.39	0.97
CD	3.48	0.48	0.53	2.76	NS	NS	1.22	2.76

NS-non significant

Plate 4. Stages of tuber initiation of purple nutsedge

March-May and the least number during November-March and August-November. There was wide variation in the number of tubers produced by the plant at maturity. The range was 8-14 with a maximum of 14 and 13 during May-August and March-August respectively.

4.1.4 Shoot Dry Weight (g plant^{-1})

Shoot growth did not show any response with respect to the seasons.

4.1.5 Tuber Dry Weight (g plant^{-1})

Though the number of tuber produced after each season varied among seasons, the tuber fresh and dry weights did not vary significantly among seasons.

4.1.6 Days to flowering

The number of days taken for flowering was found to range between 36 to 56 days. Inflorescence emergence was noticed from 36 days after planting in May planted tuber while it took nearly 56 days for November planted tubers.

4.1.7 Days to Tuberisation

The number of days required for tuber initiation varied significantly among seasons. It was found to range between 24.50 to 57.75 days. Early tuberisation was observed in August (24.50) planted tubers followed by March (39) planted tubers. May planted tuber took the maximum time (57.75) for tuberisation.

4.2.2 Observation on Okra (*Abelmoschus esculentus* L. Moench)

4.2.2.1 Days to 50 per cent flowering

Data on days to 50 per cent flowering for two years are presented in Table 3.

The number of days taken to 50 per cent flowering was significantly influenced by the weed management practices during both

Table 3. Effect of weed management practices on growth characters of okra (*Abelmoschus esculentus* L. Moench) during first and second year

Treatments	Days to 50 % flowering		LAI				DMP at harvest, t ha^{-1}		
			At flowering		At harvest				
	I year	II year	I year	II year	I year	II year	I year	II year	Pooled
T1- SSB + Gly + HW	35.33	37.00	1.83	1.85	0.176	0.133	6.13	3.27	4.70
T_2- SSB + Gly + Polythene	29.66	34.66	1.84	2.17	0.560	0.380	6.09	3.61	4.85
T_3- SSB + Gly + Eucalyptus	27.66	34.66	2.33	1.84	0.503	0.577	12.70	3.28	7.99
T_4- SSB + Gly + Cowpea	34.66	42.66	0.52	0.45	0.143	0.143	3.76	1.64	2.70
T_5- SSB+Gly+Gly (pre & post)	35.66	39.00	1.16	1.10	0.196	0.143	5.11	2.20	3.65
T_6-SE + HW	35.00	38.00	1.86	1.91	0.376	0.330	3.89	2.42	3.15
T_7-SE+ Polythene	27.33	34.66	1.76	1.84	0.473	0.190	8.27	2.24	5.25
T_8-SE + Eucalyptus	29.00	36.33	1.82	1.76	0.420	0.447	8.48	2.54	5.51
T_9-SE+Cowpea	36.00	40.66	0.71	0.45	0.163	0.117	8.09	1.32	4.68
T_{10}-Weedy Check	39.66	41.33	0.22	0.17	0.136	0.140	3.64	1.29	2.47
T_{11}-Weed Free	30.00	37.66	1.87	1.79	0.436	0.403	10.74	4.48	7.61
SE	2.13	1.50	0.05	0.05	0.029	0.02	1.42	0.51	1.58
CD	6.30	4.42	0.15	0.14	0.084	0.049	4.21	1.52	4.49

SSB-Stale seed bed SE-Soil exposure HW-Hand weeding Gly-Glyphosate

the years. The number of days required for flowering ranged from 27 to 40 days during first year and 34 to 43 days during second year. During first year, flowering was early in T_7 (27.33) and T_3 (27.66) and they were on par with T_8 (29.00), T_2 (29.66) and T_{11} (30.00). Maximum number of days were taken for flowering in weedy check plot (39.66) and it was on par with T_5 (35.66), T_6 (35.00) and T_9 (36.00). T_7 (soil exposure + polythene film mulching) flowered about 12 days earlier than weedy check plot. In general, a difference of about three days was observed between the mean values of stale seed bed treatment and soil exposure treatments.

During second year, the number of days required for flowering increased in general for all the treatments with T_4 (SSB + cowpea) recording the highest (42.66) and was on par with weedy check plot (41.33) the treatment which took maximum time for flowering during the first year. Flowering was early in T_2, T_3 and T_7 (34.66) and they were on par with all the treatments except T_9 (40.66), T_{10} (41.33) and T_4 (42.66). During both the years, polythene mulched plots showed superiority over rest of the treatments and flowered a week earlier than weedy check plot.

4.2.2.2 Leaf area index at flowering and harvest

Leaf area index of bhindi plants at flowering was significantly influenced by the weed management practices. The highest LAI (at flowering) of 2.33 was recorded by stale seed bed with eucalyptus leaf mulching which was significantly superior to rest of the treatments during first year. During second year, the highest LAI of 2.17 was recorded by stale seed bed with polythene mulching and it was significantly superior to rest of them. The lowest leaf area indices of 0.22 and 0.17 were recorded by weedy check plots during both the years.

At harvest during first year, T_2 and during second year, T_3 recorded maximum leaf area indices of 0.560 and 0.577 respectively. T_2 was on par with T_3, T_7 and T_8. At harvest also, weedy check recorded lowest values of LAI.

4.2.2.3 Dry matter production at harvest (t ha^{-1})

Data on dry matter production at harvest are presented in Table 3. The results revealed that weed management practices have significant influence on dry matter production of okra. Dry matter production was maximum in T_3 (12.7 t ha^{-1}) during first year while it was maximum in T_{11} (4.48 t ha^{-1}) during second year. During first year, lowest dry matter production was recorded (3.64 t ha^{-1}) in T_{10} (weedy check) and it was on par with other treatments like T_4 (SSB + cowpea), T_6 (SE + HW) and T_5 (SSB + glyphosate-pre and post).

During second year, highest dry matter production was recorded by T_{11} (4.48 t ha^{-1}) which was on par with T_2 (3.61 t ha^{-1}), T_3 (3.28 t ha^{-1}) and T_1 (3.27 t ha^{-1}). In general, stale seed bed treatments showed superiority over soil exposure treatment except T_4 (1.64) and T_5 (2.20). Lowest dry matter production was recorded by T_{10} (1.29) followed by T_9 (1.32) and T_4 (1.64 t ha^{-1}).

During both the years, stale seed bed treatments with hand weeding, polythene mulching and eucalyptus mulching along with completely weed free treatments showed superiority over rest of the treatments.

The data on pooled analysis indicated that there is no seasonal influence on dry matter production of okra. Also, the weed management practices had significant influence on drymatter production of okra.

4.2.2.4 Number of fruits $plant^{-1}$

The data on number of fruits $plant^{-1}$ presented in Table 4, revealed that the weed management practices exerted significant influence on this yield attribute during both the years. During first year, the highest number of fruits $plant^{-1}$ (32.66) was recorded by T_3 (SSB + eucalyptus leaf mulching) and was significantly superior to other treatments. This was followed by T_2 (30.66) (SSB + polythene mulching), T_1 (29.66) (SSB + HW) and T_{11} (26.00) (Completely weed free). Lowest number of fruits

plant^{-1} (10.66) was recorded by T_4 (SSB + cowpea) and was comparable with weedy check (11.66). In general, a difference of five fruits plant^{-1} was observed between the mean values of SSB treatment and soil exposure treatments. All the treatments except cowpea treatments (T_4 and T_9) and glyphosate pre and post (T_5) were superior in performance and was on par with completely weed free plots.

During second year, highest number of fruit plant^{-1} (36.66) was recorded by T_7 (soil exposure + polythene mulching) and was on par with T_1 (SSB + hand weeding) (29.00). A difference of about 24 fruits plant^{-1} was observed between the best treatment 36.66 (soil exposure + polythene mulching) and weedy check (12.66). Here also, treatments with cowpea (T_4 and T_9) and pre and post glyphosate (T_5) performed poorly and was on par with weedy check.

4.2.2.5 Fruit yield per hectare (t ha^{-1})

The data on yield of okra are presented in Table 4.

Various weed management practices resulted in significant increase in yield of okra, in both years. Among them, stale seed bed with eucalyptus leaf mulching was the superior one (4.95 t ha^{-1}) in first year followed by soil exposure with polythene mulching (4.35 t ha^{-1}) and completely weed free (4.19 t ha^{-1}). In second year, stale seed bed with polythene mulching was the best (7.30 t ha^{-1}) followed by SSB with HW (6.23 t ha^{-1}) and soil exposure with polythene mulching (6.06 t ha^{-1}).

During first year, the effect of weed management practices on fruit yield per hectare was in line with the effect on number of fruits plant^{-1}. The highest fruit yield of 4.95 t ha^{-1} was recorded under T_3 (SSB + eucalyptus leaf mulching) while there was drastic yield reduction in unweeded control (1.42 t ha^{-1}) with a difference of nearly 3.5 t ha^{-1}. The lowest yield was recorded by weedy check (1.42 t ha^{-1}) and was on par with SSB + cowpea (T_4), SE + HW (T_6), SSB + glyphosate (pre and post) (T_5) and SSB with HW and polythene mulching (T_1 and T_2).

Table 4. Effect of weed management practices on yield attributes of okra (*Abelmoschus esculentus* L. Moench) during first and second year

Treatments	Fruit plant^{-1}		Fruit yield, t ha^{-1}			No. of economic harvest	
	I year	II year	I year	II year	Pooled	I year	II year
T_1- SSB + Gly + HW	29.66	29.00	2.39	6.23	4.31	6.00	4.00
T_2- SSB + Gly + Polythene	30.66	33.00	2.33	7.30	4.81	6.00	4.00
T_3- SSB + Gly + Eucalyptus	32.66	26.00	4.95	5.53	5.24	6.00	5.00
T_4- SSB + Gly + Cowpea	10.66	19.33	1.47	3.76	2.62	5.00	2.00
T_5- SSB + Gly + Gly (pre & post)	21.66	20.00	1.99	4.33	3.16	4.00	4.00
T_6-SE + HW	23.33	25.33	1.72	5.56	3.64	6.00	5.00
T_7-SE+ Polythene	24.66	36.66	4.35	6.06	5.21	5.00	4.00
T_8-SE + Eucalyptus	21.66	20.33	3.31	4.16	3.74	5.00	4.00
T_9-SE+Cowpea	13.33	14.66	3.14	3.90	3.52	4.00	3.00
T_{10}-Weedy Check	11.66	12.66	1.42	2.43	1.93	2.00	1.00
T_{11}-Weed Free	26.00	23.00	4.19	5.23	4.71	5.00	4.00
SE	3.85	3.14	0.42	0.82	0.95	0.49	0.39
CD	11.36	9.25	1.25	2.41	2.70	1.44	1.15

During second year, polythene mulched plots (T_2 and T_7) performed well with the highest yields of 7.30 and 6.06 t ha^{-1} and (T_2) was on par with SSB + HW (6.23 t ha^{-1}), SE + polythene mulching (6.06 t ha^{-1}), T_6 (SE + HW) (5.56 t ha^{-1}) and T_3 (SSB + eucalyptus mulching) (5.53 t ha^{-1}) and completely weed free (T_{11}) plot (5.23 t ha^{-1}). The productivity was lowest in weedy check plots (2.43 t ha^{-1}) and was on par with cowpea as smother crop (T_4) and pre and post emergent glyphosate applied plots. In general, polythene laid plots showed superiority in weed control and stimulatory for okra growth.

The data on pooled analysis revealed significant difference in fruit yield with treatments and seasons. Highest fruit yield (5.24 t ha^{-1}) was recorded in T_3 which was on par with T_7 (5.21 t ha^{-1}), T_2 (4.81 t ha^{-1}), T_{11} (4.71 t ha^{-1}) and T_1 (4.31 t ha^{-1}). Weedy check recorded the minimum productivity of 1.93 t ha^{-1} and it was on par with treatments where cowpea was raised as smother crop.

4.2.2.6 Number of economic harvest

Data on number of economic harvest are presented in Table 4.

The results indicated that weed management practices could significantly influence the number of economic harvests during both the years. During first year, the treatments T_2 (SSB + Polythene mulching), T_3 (SSB + eucalyptus leaf mulching), T_1 (SSB + HW) and T_6 (SE + HW) recorded the highest number of economic harvests (6.0). When weed free situation recorded an economic harvest of 5.0 weedy check recorded only 2.0. Except weedy check, all the treatments recorded good harvests and comparable among themselves when compared with unweeded control.

During second year, T_3 (SSB + eucalyptus mulching) and T_6 (SE + HW) recorded the highest number of economic harvest of 5.0 and the lowest number was recorded by weedy check (1.0) and was on par with SSB + cowpea (2.0).

Table 5. Effect of weed management practices on quality attributes of okra (*Abelmoschus esculentus* L. Moench)

Treatments	Vitamin C, mg 100 g^{-1}	Keeping quality, days	Fruit protein, %	Fruit fibre, %
T_1	18.75	4.66	15.88	36.51
T_2	14.58	4.66	14.81	37.02
T_3	16.66	5.00	14.58	36.27
T_4	16.66	4.33	15.51	36.74
T_5	14.58	4.66	14.46	36.88
T_6	12.50	4.66	14.46	36.32
T_7	14.58	4.66	16.56	36.54
T_8	18.75	4.33	17.73	36.96
T_9	14.58	4.66	16.80	36.46
T_{10}	16.66	4.66	15.63	36.67
T_{11}	14.58	4.66	15.75	36.33
SE	1.85	0.32	0.50	0.40
CD	NS	NS	NS	NS

NS-Non significant

4.2.2.7 Quality parameters of okra

The data on quality attributes of okra as affected by different weed management practices are presented in Table 5.

None of the treatments recorded any effect on quality parameters of fruits like vitamin C, keeping quality, fruit protein percentage and fruit fibre percentage. No deleterious effect was observed in quality parameters even in herbicide applied plots.

4.2.2.8 Effect of treatments on soil nutrient status

The data on nutrient status of the soil after the experiment are presented in Table 6.

The content of nitrogen, phosphorus and potassium in soil after the experiment was found significantly influenced by various weed management practices.

During first year, the nitrogen content of soil was the highest under weed free check (257.35 kg ha^{-1}) and was on par with SSB with eucalyptus mulching (257.14 kg ha^{-1}). The lowest nitrogen content of 141.84 kg ha^{-1} was estimated with weedy check. During second year, the nitrogen content of soil was the highest under SSB with polythene mulching (180.31 kg ha^{-1}) and it was on par with rest of the treatments except weedy check (123.68 kg ha^{-1}).

The highest phosphorus content of 17.51 kg ha^{-1} was estimated with T_7 which was comparable with T_4 while T_3 recorded the lowest phosphorus content of 9.26 kg ha^{-1} during first year. During second year, highest phosphorus was recorded in cowpea (29.26) plots which was on par with T_{11}, T_6 and T_8.

In the case of potassium, during first year the content was highest under T_7 (47.78 kg ha^{-1}) and this was on par with T_2 (45.92 kg ha^{-1}), T_4 (44.80 kg ha^{-1}) and T_{11} (44.42 kg ha^{-1}). On the other hand lowest potassium content of 23.52 kg ha^{-1} was registered in weedy check. In second year, potassium content was highest under T_4 (37.14 kg ha^{-1}) which

Table 6. Effect of weed management practices on soil nutrient status during first and second year, kg ha^{-1}

Treatments	Available N		Available P		Available K	
	I year	II year	I year	II year	I year	II year
T_1	166.93	159.13	9.78	20.43	30.61	33.82
T_2	219.57	172.14	11.85	27.01	45.92	24.82
T_3	257.14	180.31	9.26	22.66	38.82	36.24
T_4	193.37	174.56	16.49	26.47	44.80	37.14
T_5	172.98	174.04	10.81	23.21	25.01	30.23
T_6	184.28	174.04	10.30	28.67	43.86	33.85
T_7	206.66	171.25	17.51	23.48	47.78	25.83
T_8	232.06	165.15	10.81	27.73	39.94	26.43
T_9	235.40	176.65	10.81	29.26	35.46	24.97
T_{10}	141.84	123.68	16.22	18.17	23.52	31.06
T_{11}	257.35	165.48	16.31	28.40	44.42	23.55
SE	2.45	6.26	0.36	0.72	1.56	1.36
CD	7.24	18.46	1.08	2.14	4.62	4.01

Table 7. Effect of weed management practices on nutrient uptake of okra during first and second year, kg ha^{-1}

Treatments	Nitrogen		Phosphorus		Potassium	
	I year	II year	I year	II year	I year	II year
T_1	58.01	28.19	8.33	3.46	72.31	30.14
T_2	66.58	49.08	9.86	2.96	82.01	32.00
T_3	98.61	33.86	15.76	3.59	129.62	27.82
T_4	40.21	15.73	8.10	3.09	49.44	16.09
T_5	37.02	26.60	7.87	3.08	47.75	17.38
T_6	40.09	21.12	5.79	3.05	52.46	26.77
T_7	88.57	15.73	13.19	4.45	89.16	32.21
T_8	81.93	24.85	12.90	2.88	86.32	25.10
T_9	51.15	12.44	7.99	2.42	44.43	14.35
T_{10}	40.97	12.14	5.46	1.29	40.04	14.10
T_{11}	94.91	47.01	14.69	4.33	125.88	48.48
SE	4.83	2.83	1.00	0.31	4.99	2.29
CD	14.25	8.34	2.96	0.92	14.72	6.78

was on par with T_3 (36.24 kg ha^{-1}), T_6 (33.85 kg ha^{-1}) and T_1 (33.82 kg ha^{-1}). Lowest potassium content of 23.55 kg ha^{-1} was recorded under completely weed free conditions.

4.2.2.9 Nutrient removal by okra

The data on uptake of nitrogen, phosphorus and potassium by okra during first and second year are presented in Table 7.

a. Nitrogen

Okra crop in SSB + eucalyptus leaf mulched plots had maximum uptake of N (98.61 kg ha^{-1}) in first year while SSB + polythene mulched plots had maximum uptake of N (49.08 kg ha^{-1}) during second year. This was followed by completely weed free plots in both the years. Raising cowpea and post emergent glyphosate application were on par with weedy check (40.97 and 12.14 kg ha^{-1}) during both the years. Polythene and eucalyptus mulched treatments had maximum uptake of N during both the years and was on par with completely weed free condition (94.91 and 47.01 kg ha^{-1}).

b. Phosphorus

Among the treatments, SSB + eucalyptus leaf mulching treatments had maximum uptake of P (15.76 kg ha^{-1}) followed by completely weed free condition (14.69 kg ha^{-1}) during first year. This was on par with soil exposure combined with polythene mulching (13.19 kg ha^{-1}) and eucalyptus mulched plots (12.90 kg ha^{-1}). However, during second year maximum uptake of P was recorded by soil exposure combined with polythene mulching (4.45 kg ha^{-1}) followed by completely weed free plots (4.33). Though lower, the uptake in cowpea and post emergent glyphosate applied plots were higher than weedy check (5.46 and 1.29 kg ha^{-1}) during both the years.

c. Potassium

Completely weed free condition was the most successful treatment which permitted maximum uptake of K by okra during both the years (125.88 and 48.48 kg ha^{-1}). SSB + eucalyptus leaf mulching (129.62 kg ha^{-1}) recorded highest uptake value than completely weed free condition during first year. Here also cowpea as smother crop treatments and post emergent glyphosate application recorded lower values of K uptake during both the years, but higher values compared to unweeded control (40.04 and 14.10 kg ha^{-1}).

4.2.2.10 Regeneration of nutsedge on cropped area

In okra crop, regeneration of nutsedge was observed after the harvest (Table 8). During first year lowest regeneration (4.66 and 8.00) was recorded in pre and post emergent glyphosate applied plots (T_5). During one week after harvest T_5 was the best in controlling regeneration of nutsedge and was statistically superior to rest of the treatments. However, at three weeks after harvest, both T_5 and T_2 (8 and 9) were found superior in reducing regeneration of nutsedge and they were on par among themselves.

During second year also, the results are in line with that of first year with T_5, T_2 and T_7 recording the lowest regeneration values of 6, 7 and 9.33.

4.2.2.11 Tuber viability

Viability of nutsedge tubers were significantly influenced by the weed management practices (Table 9). Both weedy check (66.66) and completely weed free plots (63.66) recorded higher viability percentage of nutsedge tubers and they were statistically superior to rest of the treatments, during first year. The lowest tuber viability was recorded by pre and post emergent glyphosate applied plots (T_5) with a viability percentage of 23.33 and it was on par with T_2 (30.00).

Table 8. Effect of weed management practices on regeneration count of nutsedge in cropped area during first and second year, 0.1 m^{-2}

Treatments	Regeneration – I year		Regeneration – II year	
	I WAH	3 WAH	I WAH	3 WAH
T_1	11.33	15.66	9.33	12.66
T_2	8.66	9.00	3.33	7.00
T_3	13.66	20.00	16.00	16.00
T_4	19.00	23.33	16.00	20.30
T_5	4.66	8.00	4.33	6.00
T_6	17.00	20.00	14.00	16.66
T_7	8.66	12.33	6.33	9.33
T_8	20.66	24.00	20.00	20.33
T_9	25.88	23.66	16.33	20.66
T_{10}	-	-	-	-
T_{11}	10.66	13.66	9.33	10.33
SE	0.03	1.40	1.06	1.05
CD	1.19	3.98	3.03	2.99

WAH-Weeks after harvest

Table 9. Tuber viability of nutsedge as affected by weed management practices during first and second year

Treatments	Tuber viability, %	
	I year	II year
T_1	33.33	43.33
T_2	30.00	26.66
T_3	36.66	63.33
T_4	40.00	46.66
T_5	23.33	20.00
T_6	43.33	46.66
T_7	33.33	26.66
T_8	33.33	46.66
T_9	36.66	53.33
T_{10}	63.33	83.33
T_{11}	66.66	80.00
SE	3.11	3.46
CD	8.85	9.85

During second year, the results were in line with that of first year. Here also, the lowest tuber viability (20.00) was recorded by T_5 and it was on par with T_2 (26.66) and T_7 (26.66). Highest viability percentage was recorded by T_{10} (83.33) followed by T_{11} (80.00).

4.2.3 Nutsedge Growth

4.2.3.1 Nutsedge population (0.1 m^{-2})

The data on initial, final and percentage reduction of population for two years are presented in Table 10.

The results revealed that all the weed control treatments had significant influence on controlling nutsedge population. However, data on initial plant population did not show any significant difference during both the years.

During first year, lowest initial population (27.77) was recorded by T_5 (SSB + pre and post glyphosate) and it also recorded the lowest final population (9.66) with a reduction percentage of 65.91 per cent. Regarding final plant population, lowest values are recorded by T_5 (SSB + glyphosate pre and post), T_7 (SE + polythene film mulching) and T_2 (SSB + polythene mulching) and they were on par among themselves while weedy check recorded a significantly higher population than initial.

Solarisation with polythene mulching was most successful in bringing down the nutsedge population in both the years (71.17 (T_7) and 82.60 % (T_2)) except completely weed free condition (100 %). These treatments were statistically on par with the pre and post emergent glyphosate applied plots during both years of study.

The data on pooled analysis indicated that there is no seasonal influences on nutsedge population as affected by weed management practices. However, on pooling there is significant difference between treatments and SSB with polythene mulching emerged as the best treatment with the highest reduction percentage of 75.07 per cent followed by SE with polythene mulching (71.93 %).

Table 10. Effect of weed management practices on nutsedge population during first and second year, 0.1 m^{-2}

Treatments	Initial population		Final population		Percentage reduction		
	I year	II year	I year	II year	I year	II year	Pooled
T1- SSB + Gly + HW	32.54	29.33	21.60	20.33	32.64	31.52	32.08
T_2- SSB + Gly + Polythene	38.11	29.33	11.98	5.00	67.54	82.60	75.07
T_3- SSB + Gly + Eucalyptus	31.55	27.00	14.88	19.33	52.15	29.39	40.77
T_4- SSB + Gly + Cowpea	34.55	31.33	24.53	23.33	26.95	26.53	26.74
T_5- SSB + Gly + Gly (pre & post)	27.77	38.00	9.66	13.00	65.91	64.77	65.34
T_6-SE + HW	28.11	34.33	19.66	19.33	30.21	40.19	35.20
T_7-SE+ Polythene	35.44	30.00	10.10	8.33	71.17	72.68	71.93
T_8-SE + Eucalyptus	30.33	32.00	25.66	20.66	15.25	36.75	26.00
T_9-SE+Cowpea	31.77	31.33	18.66	24.66	41.65	22.12	31.88
T_{10}-Weedy Check	30.88	34.33	39.30	43.66	-13.89	-27.17	-20.53
T_{11}-Weed Free	32.10	30.00	0.00	0.00	100.00	100.00	100.00
SE	8.17	2.66	1.98	2.51	7.47	7.03	3.42
CD	NS	NS	5.95	7.46	22.42	21.10	8.76

NS-Non significant

4.2.3.2 Nutsedge shoot dry weight

The data on initial, final and percentage reduction in nutsedge shoot dry weight for both the years are presented in Table 11.

The data revealed that there is significant difference in shoot dry weights before the treatment during first year. However, none of the treatments showed significant difference in shoot dry weight after its implication. Though the treatments resulted in a reduction percentage ranging from 30.49 and 57.64 per cent excluding weedy check, the effect was not prominent to cause a significant difference among the treatments.

During the second year, solarisation with polythene mulching was the most successful treatment in bringing down the nutsedge shoot production (70.65 and 67.73 %). The next best treatment was pre and post emergent glyphosate application with a reduction percentage of 59.28 per cent.

The data on pooled analysis indicated no significant difference between the treatments tried and between seasons..

4.2.3.3 Nutsedge tuber dry weight

The data on initial, final and percentage reduction in nutsedge tuber dry weights are presented in Table 12.

During both the years, the results indicated that the different weed control measures had significant influence on final tuber dry weight though the initial tuber dry weights did not differ significantly among the plots. Stale seed bed combined with polythene mulching was the most effective treatment in controlling nutsedge tuber production (74.08 and 72.55 %) in both the years. This was followed by stale seed bed with pre and post emergent glyphosate application (67.58 and 62.27 %). Stale seed bed combined with cowpea as smother crop was found less effective in controlling tuber dry weight with a reduction percentage of 18.62 and 15.87 per cent and was superior to unweeded control (-151.73, 92.64) during both the years.

Table 11. Effect of weed management practices on nutsedge shoot dry weight (g $0.1m^{-2}$) during first and second year

Treatments	Initial shoot dry weight		Final shoot dry weight		Percentage reduction		
	I year	II year	I year	II year	I year	II year	Pooled
T1- SSB + Gly + HW	43.26	49.43	17.56	32.42	49.02	33.72	41.37
T_2- SSB + Gly + Polythene	34.66	42.41	16.05	13.18	50.58	67.73	59.15
T_3- SSB + Gly + Eucalyptus	39.23	47.77	21.63	29.55	41.57	38.29	39.93
T_4- SSB + Gly + Cowpea	37.44	47.94	23.70	38.81	35.46	20.54	28.01
T_5- SSB + Gly + Gly (pre & post)	37.69	51.85	18.52	20.62	51.74	59.28	55.51
T_6-SE + HW	35.61	32.20	22.91	18.51	30.49	39.54	35.02
T_7-SE+ Polythene	43.81	33.49	19.40	9.67	54.67	70.65	62.66
T_8-SE + Eucalyptus	39.07	26.90	23.12	20.26	34.29	23.37	28.83
T_9-SE+Cowpea	50.01	29.87	15.78	22.91	57.64	23.32	40.49
T_{10}-Weedy Check	47.38	28.51	53.45	44.82	-59.84	-57.20	-58.52
T_{11}-Weed Free	47.33	29.18	0.00	0.00	100.00	100.00	100.00
SE	9.77	5.08	4.37	3.60	14.88	4.34	14.89
CD	28.83	15.01	NS	10.71	NS	13.02	NS

Table 12. Effect of weed management practices on nutsedge tuber dry weight (g 0.1 m^{-2}) during first and second year

Treatments	Initial tuber dry weight		Final tuber dry weight		Percentage reduction		
	I year	II year	I year	II year	I year	II year	Pooled
T1- SSB + Gly + HW	64.40	88.45	32.32	55.43	50.66	37.55	44.11
T_2- SSB + Gly + Polythene	90.23	91.25	24.46	25.14	74.08	72.55	73.32
T_3- SSB + Gly + Eucalyptus	107.08	83.08	58.05	44.81	45.79	45.44	45.62
T_4- SSB + Gly + Cowpea	75.78	82.88	61.73	68.53	18.62	15.87	17.25
T_5- SSB + Gly + Gly (pre & post)	69.75	110.05	23.41	41.21	67.58	62.27	64.93
T_6-SE + HW	79.52	87.22	37.03	50.66	53.09	40.95	47.03
T_7-SE+ Polythene	72.87	75.36	36.64	25.55	49.31	64.88	57.09
T_8-SE + Eucalyptus	93.60	83.95	71.55	47.61	23.23	42.84	33.04
T_9-SE+Cowpea	68.24	81.40	34.24	62.90	46.74	21.08	33.92
T_{10}-Weedy Check	69.84	80.18	172.24	150.54	-151.73	-92.64	-122.18
T_{11}-Weed Free	83.89	90.55	0.00	0.00	100.00	100.00	100.00
SE	14.91	12.39	9.93	7.20	7.94	3.61	8.98
CD	NS	NS	29.79	21.61	23.82	10.84	NS

Pooled analysis of data on tuber dry weight revealed the significance among treatments that SSB with polythene mulching was the best treatment (73.32) in controlling tuber production of nutsedge. The next best treatment was SSB with pre and post emergent glyphosate application (64.93). However no significant influence on tuber dry weight was observed between the seasons.

4.2.3.4 Weed Control Efficiency(WCE)

The data on WCE during first and second year are presented in Table 13.

The data revealed that during first year weed control efficiency was not significantly influenced by the different weed management practices. At all stages WCE of weedy check was taken as zero and that of weed free check as 100. Highest values of WCE were recorded by solarisation with polythene mulching treatments (83.33) followed by SSB with pre and post emergent herbicide application (83.01).

During second year, all the treatment combinations involving polyethylene mulching in okra crop resulted in higher weed control efficiency (81.86 and 80.35). The results were in line with that of first year.

4.2.3.5 Weed Index (WI)

Generally, all weed control treatments showed a lower weed index value compared to control during both years indicating the superiority of these treatments (Table 13). However, SSB with eucalyptus mulching was the best treatment (-20.12) during first year followed by soil exposure with polythene mulching (-2.87).

During second year, it was polythene mulching (-37.52 and -17.69) which resulted in very low WI values. This was followed by SSB with hand weeding (-19.93 and -7.41) and eucalyptus mulching (-6.81).

Table 13. Effect of weed management practices on weed control efficiency (WCE) and weed index (WI) during first and second year

Treatments	WCE		WI		
	I year	II year	I year	II year	Pooled
T_1	80.02	54.74	42.77	-19.93	11.42
T_2	83.33	80.35	44.17	-37.52	3.32
T_3	66.75	61.43	-20.12	-6.81	-13.47
T_4	64.80	45.05	65.17	26.66	45.91
T_5	83.01	68.03	52.19	17.01	34.60
T_6	75.32	64.73	58.80	-7.41	25.70
T_7	76.91	81.86	-2.87	-17.69	-10.28
T_8	61.02	65.04	20.68	20.71	20.70
T_9	49.15	56.13	23.66	25.32	24.49
T_{10}	0.00	0.00	66.30	52.67	59.49
T_{11}	100.00	100.00	0.00	0.00	0.00
SE	5.46	5.14	11.04	15.82	20.07
CD	-	15.43	32.82	47.14	57.04

Table 14. Effect of weed management practices on nutrient uptake by weeds during first and second year, kg ha^{-1}

Treatments	Nitrogen		Phosphorus		Potassium	
	I year	II year	I year	II year	I year	II year
T_1	24.88	54.29	15.75	42.90	26.58	74.40
T_2	20.06	28.35	13.84	16.96	29.97	23.50
T_3	58.76	40.85	45.93	36.17	46.82	57.89
T_4	72.09	63.58	36.53	63.67	53.44	108.26
T_5	40.54	26.47	17.22	41.96	38.80	46.10
T_6	63.89	40.61	32.96	34.49	43.62	54.77
T_7	61.56	14.05	32.98	18.90	43.54	26.94
T_8	29.82	24.77	27.02	33.93	29.38	55.88
T_9	135.83	46.11	43.59	37.47	82.07	77.05
T_{10}	279.94	140.12	120.64	88.36	280.46	222.11
T_{11}	0.00	0.00	0.00	0.00	0.00	0.00
SE	8.70	2.80	3.24	4.07	3.65	2.86
CD	26.09	8.41	9.72	12.10	10.97	8.58

The data on pooled values clearly indicated the significance among treatments and the superiority of polythene mulching with soil exposure + polythene mulching better than SSB with polythene mulching.

4.2.3.6 Nutrient removal by weeds

The data on uptake of nitrogen, phosphorus and potassium by weeds during first and second year are presented in Table 14.

a. Nitrogen

During first year, stale seed bed combined with polythene mulching recorded minimum N removal (20.06 kg ha^{-1}) while soil exposure combined with polythene mulching recorded minimum N removal (14.05 kg ha^{-1}) in second year. Cowpea raised plots recorded higher uptake values (72.09, 63.58 kg ha^{-1}) during first and second year which was significantly higher than rest of the weed control treatments. In general, polythene mulched plots resulted in lower N uptake during both the years (29.82 and 24.77 kg ha^{-1}).

b. Phosphorus

Stale seed bed combined with polythene mulching recorded minimum P uptake by weeds (13.84 and 16.96 kg ha^{-1}) during both the years. This was followed by SSB combined with hand weeding (15.75 kg ha^{-1}) and post emergent glyphosate application (17.22 kg ha^{-1}) during first year and soil exposure combined with polythene mulching (18.90 kg ha^{-1}) during second year. All the treatments had lower P removal than the unweeded control (120.64 and 88.36 kg ha^{-1}) during both the years. Among the weed control methods, in okra crop, the superiority achieved by SSB + hand weeding was lost during second year where hand weeding had higher P uptake than most of the treatments except cowpea raised plots.

c. Potassium

Among the treatments, all the treatments except weedy check significantly reduced K removal by weeds and stale seed bed with hand weeding had the lowest uptake (26.58 kg ha^{-1}) during first year. This was followed by SE with eucalyptus mulching (29.38 kg ha^{-1}) and SSB with polythene mulching (29.97 kg ha^{-1}) which were on par among themselves.

During second year, SSB with polythene mulching was the best treatment with the lowest P uptake of 23.50 kg ha^{-1} and this was followed by soil exposure with polythene mulching (26.94 kg ha^{-1}). However, other treatments were superior to weedy check (222.11 kg ha^{-1}) in reducing K removal.

4.2.3.6 Economics

The data on the economics of different weed control treatments given to okra are given in Table 15.

In okra, the economics was found influenced by the different weed management practices. The highest net income (Rs.18,270/-) was recorded by stale seed bed with eucalyptus mulching (T_3) which was closely followed by completely weed free plots (T_{11}) (Rs.10,970/-). Soil exposure treatments were more economical than stale seed bed treatments. The B:C ratio ranged from 0.89 to 2.01 with stale seed bed + eucalyptus mulching recording the highest B:C ratio. The weedy check plot undoubtedly recorded the lowest B:C ratio.

4.3 EFFECT OF CONTROL MEASURES ON DEATH AND REGENERATION OF NUTSEDGE IN UNCROPPED AREA

The experiment was conducted for three reasons. During first two seasons experiment was conducted in RBD, and during the third season the design adopted was split plot.

Table 15. Economics of weed control treatments in okra (*Abelmoschus esculentus* L. Moench)

Treatments	Normal cost of cultivation ($Rs.ha^{-1}$) excluding weeding	Additional cost for weed control operations ,$Rs.\ ha^{-1}$	Total cost, $Rs.ha^{-1}$	Gross income, $Rs.\ ha^{-1}$	Net income, $Rs.ha^{-1}$	B:C ratio
SSB+HW	15,000	6710	21710	30170	8460	1.38
SSB+PE	15,000	13410	28410	33705	5295	1.19
SSB+Eucaly	15,000	3410	18410	36680	18270	2.01
SSB+Cowpea	15,000	4110	19110	19350	195	1.01
SSB+Glyph	15,000	5070	20070	22120	2050	1.10
SE + HW	15,000	5250	20250	25480	5230	1.25
SE + PE	15,000	11750	26750	36435	9685	1.36
SE + Eucaly	15,000	1750	16750	26145	9395	1.56
SE +Cowpea	15,000	2450	17450	24640	7190	1.41
Weedy check	15,000	00.00	15000	13475	-1525	0.89
Weed free	15,000	7000	22000	32970	10970	1.50

Cost of glyphosate – Rs.480 l^{-1}
Cost of black polythene mulch – Rs. 40 per m^2
Wage rate of ordinary labourer – Rs. 100 day^{-1}
Rent of sprayer – Rs.4 $hour^{-1}$
Cost of FYM – Rs. 295 per ton
Cost of urea – Rs. 3.5 kg^{-1}
Cost of mussoriephos – Rs.4.0 kg^{-1}
Cost of MOP – Rs. 5.0 kg^{-1}

4.3.1 Observations on nutsedge

4.3.1.1 Nutsedge population (0.1 m^{-2})

The data on initial, final and percentage reduction in nutsedge population during first and second year are presented in Table 16.

All the treatments resulted in better weed control during both years of study. During first season, the treatment glyphosate@ 1.5 kg ai ha^{-1} applied before tuber initiation resulted in the least population of nutsedge (6.58) closely followed by 2,4-D @ 1.5 kg ai ha^{-1} (9.83) applied before dormant tuber production. Weedy check plots showed increase in nutsedge count during successive seasons. In terms of percentage reduction brought about by the treatment, all performed well with statistically on par values except T_5 and better than control.

4.3.1.2 Nutsedge shoot dry weight

In general, only glyphosate treatments showed consistent and significant reduction in nutsedge shoot dry weight (Table 17). All the treatments resulted in good control except unweeded check. Maximum reduction in growth during first season was achieved by glyphosate @1.5 kg ai ha^{-1} applied before tuber initiation (86.90 %) closely followed by glyphosate @ 1.5 kg ai ha^{-1} applied before dormant tuber production (85.84) and all except T_1 were statistically on par. The effect was non-significant during second season.

4.3.1.3 Nutsedge tuber dry weight

Control achieved in terms of reduction in nutsedge tuber production after first season was found to range from 30 to 55 per cent (Table 18). Glyphosate @ 1.5 kg ai ha^{-1} sprayed before tuber initiation resulted in maximum reduction of 55.56 per cent closely followed by glyphosate @ 1.5 kg ai ha^{-1} sprayed before dormant tuber production.

Table 16. Effect of weed management practices on nutsedge population (0.1 m^{-2}) during first and second season in uncropped area

Treatments	Initial population		Final population		Percentage reduction	
	I season	II season	I season	II season	I season	II season
T_1	38.50	21.75	7.57	11.37	79.38	47.15
T_2	50.25	21.87	9.83	11.63	80.28	46.38
T_3	44.25	18.37	6.58	9.13	84.94	50.15
T_4	42.50	19.12	8.58	9.87	79.55	48.32
T_5	32.50	31.00	40.62	40.00	-25.90	-30.27
SE	3.41	2.23	0.56	0.66	2.66	3.65
CD	10.52	6.87	1.80	2.12	8.20	NS

NS-Non significant

Table 17. Effect of weed management practices on nutsedge shoot dry weight (g 0.1 m^{-2}) during I and II season in uncropped area

Treatments	Initial shoot dry weight		Final shoot dry weight		Percentage reduction	
	I season	II season	I season	II season	I season	II season
T_1	19.80	16.43	6.37	5.55	66.22	66.15
T_2	25.85	16.77	5.03	5.69	80.43	65.75
T_3	27.29	13.81	3.51	4.35	86.90	68.00
T_4	32.93	14.68	4.42	4.79	85.84	67.10
T_5	25.13	23.22	24.03	34.37	0.58	-50.10
SE	2.92	1.79	0.37	0.30	7.09	2.16
CD	NS	5.52	1.18	0.97	21.86	NS

NS-Non significant

Table 18. Effect of weed management practices on nutsedge tuber dry weight (g 0.1 m^{-2}) during I and II season in uncropped area

Treatments	Initial tuber dry weight		Final tuber dry weight		Percentage reduction	
	I season	II season	I season	II season	I season	II season
T_1	84.50	81.58	51.35	41.53	37.92	48.33
T_2	112.26	79.90	77.27	38.63	30.88	51.54
T_3	96.26	63.83	42.43	31.31	55.56	50.99
T_4	94.66	66.52	51.79	34.13	43.34	48.29
T_5	71.35	99.57	173.92	138.15	-147.73	-39.02
SE	7.42	6.71	3.60	2.79	7.34	3.49
CD	22.86	20.69	11.53	NS	22.64	NS

NS-Non significant

Table 19. Effect of weed management practices on weed parameters during first and second season in uncropped area

Treatments	Total weed dry weight, g 0.1m^{-2}		WCE, %	
	I season	II season	I season	II season
T_1	52.72	47.08	70.59	70.61
T_2	82.30	44.32	58.06	72.44
T_3	45.94	35.67	76.82	78.61
T_4	56.21	38.92	71.40	76.33
T_5	197.95	172.52	0.00	0.00
SE	3.64	3.03	2.06	2.14
CD	10.34	NS	5.87	NS

NS-Non significant

Table 20. Effect of weed management practices on regeneration of nutsedge in uncropped area

Treatments	No. of shoots regenerated $0.1m^{-2}$							
	5 WASP		6 WASP		7 WASP		8 WASP	
	I season	II season	I season	II season	I season	II season	I season	II season
T_1	10.50	4.75	14.50	6.75	18.75	8.25	26.00	10.75
T_2	14.00	6.50	18.00	9.50	23.00	10.75	21.75	12.25
T_3	8.00	5.50	10.75	7.75	15.25	8.75	20.50	9.75
T_4	7.25	4.25	11.50	6.50	14.00	9.50	18.00	11.25
T_5	-	-	-	-	-	-	-	-
SE	0.89	0.70	1.06	0.64	1.26	0.68	1.05	0.66
CD	2.55	NS	3.03	1.82	3.59	NS	2.99	NS

NS-Non significant

WASP – Weeks after spraying

4.3.1.4 Weed parameters

The data revealed that the weed management practices exerted significant influence on total weed dry weight and WCE during first season (Table 19). Among the treatments, glyphosate applied before tuber initiation recorded the lowest weed dry weight (45.94 and 35.67 g) and it was on par with T_1 (52.72) and T_4 (56.21). The glyphosate treatments (T_3 and T_4) recorded the highest WCE values of 76.82 and 71.40 and they were on par among themselves and significantly different from 2,4-D application.

During second season, both WCE and total weed dry weight were found not significant.

4.3.1.5 Regeneration of nutsedge during first and second seasons

Different weed management practices had significant influence on the regeneration ability of nutsedge shoots after its implications (Table 20). Glyphosate treatments showed its superiority over 2,4-D treatments with its lower rate of regeneration during five to eight weeks of spraying. Glyphosate treatments were on par among themselves and was statistically superior in suppressing weed growth to 2,4-D treatments during 6, 7 and 8 weeks after spraying.

During second season, regeneration was significant only at 6 weeks after spraying. Here also, glyphosate treatments recorded lower rate of regeneration and it was on par with 2,4-D @ 1.5 kg ai ha^{-1} before, tuber initiation.

4.3.2 Third season observations

4.3.2.1 Nutsedge population

During summer seasons, the nutsedge population was much lesser in all the treated plots compared to weedy check (Table 21a and 21b). Among the main plot treatments, glyphosate treated plots recorded the lowest initial (7.84 and 7.43) and final (1.22 and 1.33) counts with the highest percentage reductions of 74.95 and 70.45 per cent. This was

Table 21a. Effect of weed management practices on nutsedge population (0.1 m^{-2}) during the third season in uncropped area

Treatments	Initial population	Final population	Percentage reduction
Main plots			
M_1	9.31	2.01	52.17
M_2	10.09	1.57	69.91
M_3	7.84	1.22	74.95
M_4	7.43	1.33	70.45
M_5	24.31	13.31	45.78
SE	0.43	0.07	3.17
CD	1.34	0.22	9.78
Subplots			
S_1	11.77	1.12	86.77
S_2	12.30	1.39	80.39
S_3	11.57	2.15	58.37
S_4	11.55	2.89	25.09
SE	0.33	0.09	2.87
CD	NS	0.26	8.18

NS-Non significant

Table 21b. Interaction effect of weed management practices on nutsedge population (0.1 m^{-2}) during the third season in uncropped area

Interaction effects	Initial population	Final population	Percentage reduction
m_1s_1	9.63	1.29	81.64
m_1s_2	8.50	1.69	65.22
m_1s_3	9.63	2.17	50.37
m_1s_4	9.50	2.89	11.45
m_2s_1	9.75	1.11	86.74
m_2s_2	11.13	0.95	88.91
m_2s_3	10.00	1.83	65.08
m_2s_4	9.50	2.38	38.89
m_3s_1	7.50	0.43	94.78
m_3s_2	5.88	0.68	89.61
m_3s_3	8.88	1.56	71.25
m_3s_4	9.13	2.21	44.19
m_4s_1	7.75	0.86	87.14
$m_{4s}s_2$	6.13	0.85	84.58
m_4s_3	7.75	1.36	75.47
m_4s_4	8.13	2.27	34.62
m_5s_1	24.25	1.93	83.52
m_5s_2	29.88	2.78	73.63
m_5s_3	21.63	3.82	29.68
m_5s_4	21.50	4.69	-3.71
SE	0.74	0.21	6.42
CD	2.13	NS	NS

followed by 2,4-D @1.5 kg ai ha^{-1} at before dormant tuber production (69.91) and they were on par among themselves and significantly different from unweeded control.

Among the treatments, the most effective treatment was stale seed bed with irrigation followed by glyphosate spraying which resulted in the highest reduction percentage of 86.77. The next best treatment was stale seed bed with ethrel spraying followed by glyphosate application which resulted in a reduction percentage of 80.39. They were on par among themselves and significantly different from unweeded control. The interaction between main plot and subplots were found not significant.

4.3.2.2 Nutsedge shoot dry weight

The data revealed that, all the summer season weed management practices had significant influence in bringing down the shoot growth of nutsedge (Table 22a and 22b). All the treatments had significantly lowered shoot growth compared to unweeded control before and after the treatment. Glyphosate treatments resulted in maximum reduction (74.41 % and 72.40 %) and they were superior to 2,4-D application.

Among the subplot treatments, all the treatments performed well except unweeded control. The best treatment was stale seed bed with ethrel application followed by glyphosate spraying with a reduction percentage of 80.85 followed by stale seed bed with irrigation followed by glyphosate spraying (70.36) and digging once (60.43). These treatments were on par among themselves and significantly different from unweeded control. The interaction between main plots and subplots were found not significant. Interaction effects were not significant.

4.3.2.3 Nutsedge tuber dry weight

Data on the effect of main plot and subplot treatments on the count of underground propagating structures of *C. rotundus* are presented in Table 23a and 23b.

Table 22a. Effect of weed management practices on nutsedge shoot dry weight (g 0.1 m^{-2}) during the third season in uncropped area

Treatments	Initial shoot dry weight	Final shoot dry weight	Percentage reduction
Main plots			
M_1	5.11	1.76	36.65
M_2	5.82	1.23	66.34
M_3	5.02	0.96	74.41
M_4	4.91	1.06	72.40
M_5	14.52	2.38	48.56
SE	0.46	0.14	9.64
CD	1.43	0.43	NS
Sub plots			
S_1	6.54	0.86	70.36
S_2	7.33	0.99	80.85
S_3	7.49	1.63	60.43
S_4	6.93	2.44	27.05
SE	0.45	0.14	7.96
CD	NS	0.42	22.68

NS-Non significant

Table 22b. Interaction effect of weed management practices on nutsedge shoot dry weight (g 0.1 m^{-2}) during the third season in uncropped area

Treatments	Initial shoot dry weight	Final shoot dry weight	Percentage reduction
m_1s_1	5.12	0.95	81.24
m_1s_2	4.64	1.25	64.77
m_1s_3	5.41	1.56	52.94
m_1s_4	5.26	3.27	-151.55
m_2s_1	4.42	0.86	74.30
m_2s_2	6.96	0.76	87.58
m_2s_3	6.24	1.48	63.64
m_2s_4	5.67	1.82	39.85
m_3s_1	4.28	0.33	94.93
m_3s_2	3.65	0.58	87.45
m_3s_3	6.54	1.20	75.17
m_3s_4	5.62	1.73	40.09
m_4s_1	5.05	0.71	87.01
m_4s_2	3.67	0.68	83.03
m_4s_3	5.42	1.06	78.36
m_4s_4	5.52	1.79	41.19
m_5s_1	13.84	1.44	83.10
m_5s_2	17.83	1.67	81.41
m_5s_3	13.84	2.84	32.02
m_5s_4	12.59	3.56	-2.28
SE	1.01	0.33	38.34
CD	NS	NS	NS

Table 23a. Effect of weed management practices on tuber dry weight (g 0.1 m^{-2}), during the third season uncropped area

Treatments	Initial tuber dry weight	Final tuber dry weight	Percentage reduction
Main plots			
M_1	35.16	16.08	36.78
M_2	31.15	9.68	50.25
M_3	19.14	8.88	41.63
M_4	17.95	7.49	44.12
M_5	72.22	43.96	28.81
SE	2.43	1.70	4.42
CD	7.51	5.25	13.64
Sub plots			
S_1	34.60	9.05	53.15
S_2	39.15	12.08	53.98
S_3	32.34	17.02	41.38
S_4	34.41	30.73	12.76
SE	1.73	1.27	3.94
CD	NS	3.63	11.24

NS-Non significant

Table 23b. Interaction effect of weed management practices on nutsedge tuber dry weight (g 0.1 m^{-2}) during the third season in uncropped area

Treatments	Initial tuber dry weight	Final tuber dry weight	Percentage reduction
m_1s_1	33.68	7.89	72.54
m_1s_2	38.66	11.37	68.92
m_1s_3	34.17	15.63	54.11
m_1s_4	34.12	29.45	14.89
m_2s_1	30.33	6.05	79.61
m_2s_2	40.64	7.08	82.51
m_2s_3	27.25	9.92	63.15
m_2s_4	26.39	15.66	39.32
m_3s_1	19.92	6.08	68.96
m_3s_2	14.50	2.61	81.61
m_3s_3	21.43	8.71	57.25
m_3s_4	20.70	18.15	12.17
m_4s_1	19.23	5.56	70.95
m_4s_2	15.95	4.84	68.25
m_4s_3	16.04	7.17	56.34
m_4s_4	20.58	12.41	39.73
m_5s_1	69.82	19.68	71.50
m_5s_2	86.00	34.54	60.19
m_5s_3	62.81	43.66	26.73
m_5s_4	70.27	77.97	-10.69
SE	3.86	2.85	6.56
CD	NS	8.12	18.69

2,4-D application @ 1.5 kg ai ha^{-1} after tuber initiation stage was the most successful in bringing down the underground propagating structures of *Cyperus rotundus* (50.25). This was statistically on par with glyphosate treatments (44.12 and 41.63).

Among subplot treatments, stale seed bed with irrigation or ethrel fared equally well (53 %). Eventhough digging significantly reduced the count of propagating structures, it was not as efficient as other treatments. The interaction between main plots and subplots were found significant. Among the interactions, combination of glyphosate sprayed before tuber initiation combined with SSB and ethrel application recorded the lowest final tuber dry weight (2.61) followed by glyphosate sprayed after tuber initiation coupled with SSB and ethrel application. Regarding percentage reduction 2,4-D sprayed after tuber initiation coupled with ethrel application (m_2s_2) recorded the highest control (82.51) followed by glyphosate and ethrel application (m_3s_2-81.61) which were on par. Percentage reduction was found very low in plots where no weed control treatments were enforced during the third season.

4.3.2.4 Weed parameters

a. Total weed dry weight (Table 24a and 24b)

Among the main plot treatments, glyphosate treatments and 2,4-D after tuber initiation recorded lower values of weed dry weight and were on par among themselves. Among subplot treatments, SSB with irrigation or ethrel application fared equally well while M_5 and S_4 recorded higher values. Glyphosate sprayed before tuber initiation coupled with SSB with irrigation (m_3s_2) recorded the lowest weed dry weight followed by m_4s_2, m_4s_1, m_3s_1, m_2s_1, m_2s_2, m_1s_1 and m_4s_3.

b. WCE

Among the main plot treatments, the effect was not significant. SSB with irrigation followed by glyphosate spraying recorded the highest WCE (70.43) among subplot treatments and it was on par with SSB with ethrel

Table 24a.Effect of weed management practices on weed characters of nutsedge during the third season in uncropped area

Treatments	Total weed dry weight, g 0.1 m^{-2}	WCE, %	Regeneration count, No.of shoots 0.1m^{-2}
Main plots			
M_1	21.16	63.48	3.33
M_2	11.49	49.24	4.41
M_3	10.19	69.06	2.50
M_4	8.91	56.66	2.66
M_5	50.52	58.54	-
SE	2.15	8.03	0.32
CD	6.11	NS	0.92
Sub plots			
S_1	10.01	70.43	3.70
S_2	13.41	64.93	5.25
S_3	20.12	42.82	6.85
S_4	38.28	0.00	-
SE	1.86	3.76	0.72
CD	5.30	10.69	2.05

NS-Non significant

Table 24b.Interaction effect of weed management practices on weed characters of nutsedge during the third season in uncropped area

Treatments	Total weed dry weight, g 0.1 m^{-2}	WCE, %	Regeneration count, No.of shoots 0.1m^{-2}
m_1s_1	8.84	83.73	2.25
m_1s_2	12.94	61.28	3.00
m_1s_3	18.11	45.44	4.75
m_1s_4	44.77	0.00	-
m_2s_1	6.82	61.37	3.25
m_2s_2	7.88	53.73	4.00
m_2s_3	12.23	32.63	6.00
m_2s_4	19.01	0.00	-
m_3s_1	6.30	71.01	1.50
m_3s_2	3.07	85.52	2.50
m_3s_3	10.17	50.64	3.50
m_3s_4	21.22	0.00	-
m_4s_1	6.25	59.69	2.00
m_4s_2	5.47	65.22	3.00
m_4s_3	8.24	45.07	3.00
m_4s_4	15.67	0.00	-
m_5s_1	21.86	76.38	9.50
m_5s_2	37.67	58.93	13.75
m_5s_3	51.83	40.31	17.00
m_5s_4	90.74	0.00	-
SE	4.17	8.41	0.66
CD	11.86	NS	1.88

(64.93) application. Digging was inferior to these treatments. Interaction effects were not significant.

c. Regeneration count

Glyphosate treatments recorded lower regeneration values of 2.50 and 2.66 and it was statistically on par with 2,4-D sprayed before tuber initiation (3.33). Among the subplot treatments, SSB treatments (S_1 and S_2) recorded lower regeneration values and were on par among themselves. Among the interactions, glyphosate sprayed before tuber initiation coupled with SSB and irrigation (m_3s_1) recorded the lowest regeneration (1.50) followed by m_4s_1, m_1s_1, m_3s_2, m_1s_2, m_4s_2, m_4s_3, m_2s_1 and m_1s_3.

4.4 ALLELOPATHIC INFLUENCE OF NUTSEDGE ROOT EXUDATES ON CROP PLANTS

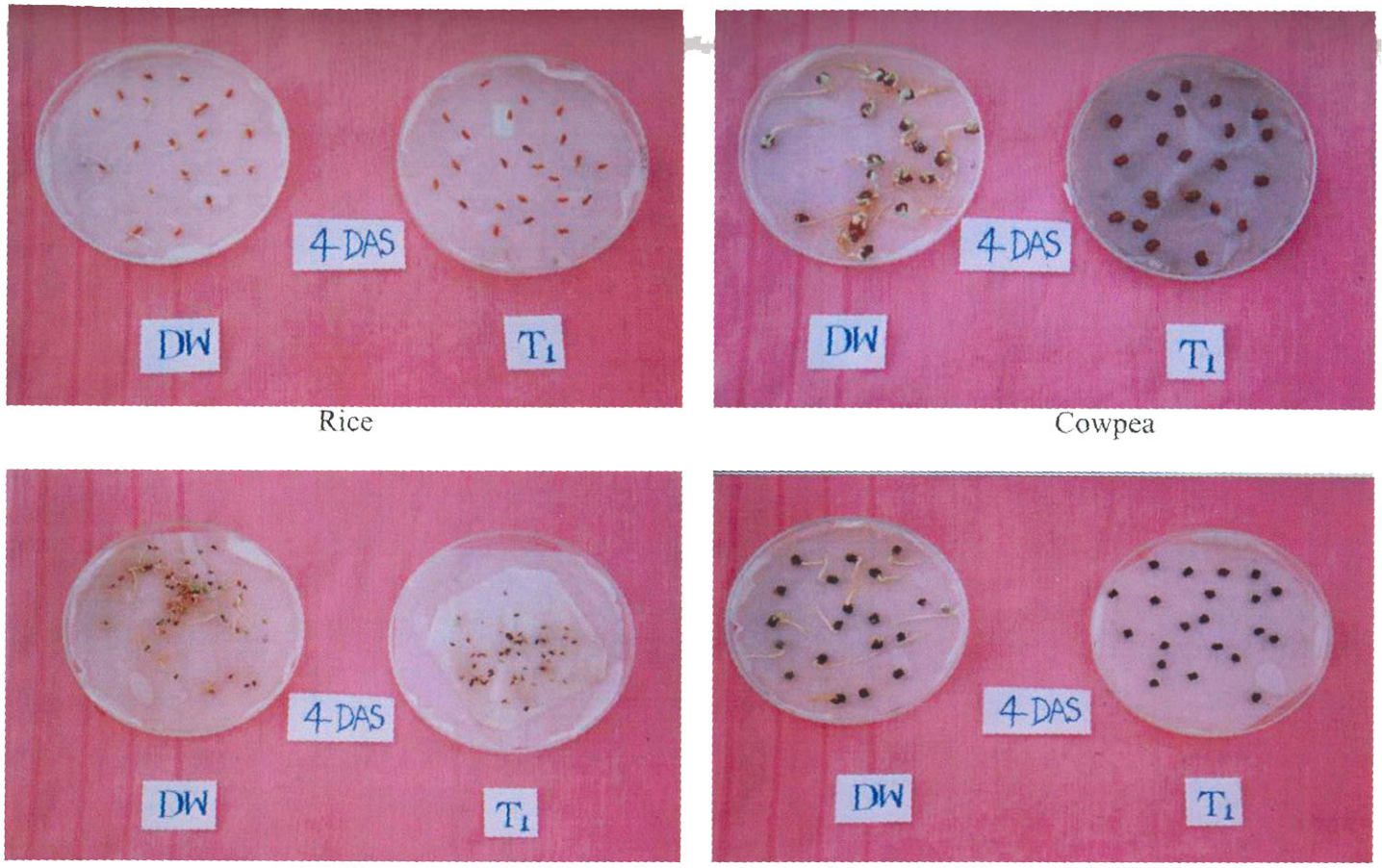
The allelopathic influence of nutsedge root exudates on germination and seedling growth of five field crops *viz.*, Rice (*Oryza sativa* L.), Cowpea (*Vigna unguiculata* (L.) Walp), Sesamum (*Sesamum indicum* L.), Bhindi (*Abelmoschus esculentus* L. Moench) and Brinjal (*Solanum melongena*) were studied under laboratory conditions.

4.4.1 Allelopathic influence of nutsedge root exudates on rice (*Oryza sativa* L.)

The results revealed that nutsedge root exudates collected at sprouting stage completely inhibited the growth and development of rice seeds, while distilled water treatment recorded cent per cent germination, T_1 recorded zero germination percentage (Table 25). However, rest of the treatments showed no inhibitory influence on any of the growth parameters tested.

4.4.2 Allelopathic influence of nutsedge root exudates on cowpea (*Vigna unguiculata* L. Walp)

Root exudates collected at sprouting stage caused complete inhibition of germination and growth of cowpea seeds (Table 26).



Rice Cowpea

Sesamum Okra

Plate 5. Allelopathic influence of purple nutsedge root exudates on germination and growth of crop seeds

Table 25. Allelopathic influence of nutsedge root exudates on germination and early growth of rice (*Oryza sativa* L.)

Treatments	Germination percentage		Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
	5 DAS	14 DAS				
T_1	00.00	00.00	00.00	00.00	00.00	00.00
T_2	90.00	98.75	6.55	0.90	2.25	738.25
T_3	90.00	98.75	6.23	0.85	2.70	698.50
T_4	88.75	97.50	6.13	0.93	2.40	670.75
T_5	92.50	100.00	6.75	1.12	2.78	787.50
SE	1.57	1.17	0.18	0.09	0.15	27.70
CD	NS	NS	NS	NS	NS	NS

NS- Non significant

Table 26. Allelopathic influence of nutsedge root exudates on germination and early growth of cowpea (*Vigna unguiculata*)

Treatments	Germination percentage		Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
	5 DAS	8 DAS				
T_1	00.00	00.00	00.00	00.00	00.00	00.00
T_2	93.75	100.00	20.73	14.35	60.38	3507.5
T_3	95.00	100.00	26.45	16.47	55.51	42.92.50
T_4	97.50	100.00	23.73	12.50	52.13	3612.50
T_5	91.25	100.00	26.05	13.60	63.98	3967.50
SE	1.25	0.00	0.99	1.54	1.77	227.88
CD	3.55	NS	2.82	NS	5.05	NS

NS- Non significant

Table 27. Allelopathic influence of nutsedge root exudates on germination and early growth of sesamum (*Sesamum indicum*)

Treatments	Germination percentage		Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
	3 DAS	6 DAS				
T_1	00.00	00.00	00.00	00.00	00.00	00.00
T_2	83.75	75.00	4.98	4.10	3.11	862.50
T_3	88.75	97.50	4.00	3.83	3.19	763.25
T_4	87.50	97.50	4.03	3.83	2.72	765.75
T_5	85.00	96.25	5.58	5.63	2.98	1077.75
SE	2.04	1.33	0.16	0.19	0.12	23.87
CD(0.05)	NS	NS	0.45	0.55	NS	67.85

NS- Non significant

However at 5 DAS, rest of the treatments (T_2, T_3 and T_4) showed stimulatory effect on germination of cowpea compared to distilled water treatment. At 8 DAS, the effect was non significant with all the treatments recording cent per cent germination except T_1.

The plumule growth was suppressed significantly by nutsedge root exudates collected at sprouting and tuberisation stage. The plumule lengths under these treatments were 0.00 and 20.73 cm while control (T_5) recorded a plumule length of 26.05 cm.

Inhibitory influence of the treatments on growth of radicle was found not significant except for T_1.

Inhibitory influence on dry weight was significant for the treatments T_1, T_4 and T_3. These treatments recorded dry weights of 00.00, 52.13 and 55.57 grams plant^{-1}. The effect of other treatments on dry weight of seedlings was not significant.

Influence of the treatments on vigour index was found to be non-significant except for T_1.

4.4.3 Allelopathic influence of nutsedge root exudates on sesamum

Nutsedge root exudates collected at sprouting stage completely inhibited the germination and growth of sesamum seeds (Table 27). Rest of the treatments has no significant inhibitory influence on germination of sesamum seeds.

To some extent the plumule length of sesamum seedlings was also found influenced by nutsedge extracts. While the root exudates at sprouting stage completely inhibited plumule growth, rest of the treatments caused some inhibitions compared to control.

Radicle growth was suppressed significantly by all the treatments with T_3 and T_4 recording 3.83 cm while control recorded 5.63 cm.

Dry weight of seedlings was found comparable in all treatments except T_1 indicating that rest of the treatments had no significant influence on those characters.

A drastic reduction in vigour index was noticed for all treatments except distilled water. The vigour indices recorded by these treatments were 0.00, 862.50, 763.25 and 765.75 respectively while that of control was 1077.75.

4.4.4 Allelopathic influence of nutsedge root exudates on bhindi (*Abelmoschus esculentus* L. Moench).

The results revealed that nutsedge root exudates had no inhibitory influence on the germination of bhindi seeds at both 4 and 21 days (Table 28).

In terms of length of plumule, the effect of nutsedge root exudates were significant. Root exudates collected at sprouting stage recorded zero values since there was zero germination. T_4 recorded a plumule length of 14.9 cm, while that of control was 17.83 cm.

Radicle length of bhindi seedlings was significantly inhibited by the exudates of nutsedge plants. Maximum inhibition was caused by T_1 with a suppression rate as high as 100 per cent.

Inhibitory influence on dry weight was significant for the treatment T_1, T_4 and T_3. These treatments recorded dry weights of 0.00, 27.38 and 27.92 mg plant^{-1} respectively, while that of control was 35.19 mg plant^{-1}. The effect of T_2 on dry weight of seedling was not significant.

Vigour index was drastically reduced in all the nutsedge treatments except distilled water treatment. The index values recorded by root exudates collected at tuberisation (T_2), at flowering (T_3) and at dormant tuber formation stage (T_4) were 1952, 1830 and 1839 respectively while that of control was 2207.50.

4.4.5 Allelopathic influence of nutsedge root exudates on brinjal (*Solanum melongena* L.)

The results revealed that nutsedge root exudates had no significant inhibitory influence on germination of brinjal on both 7 and 14 DAS (Table 29).

Table 28. Allelopathic influence of nutsedge root exudates on germination and early growth of bhindi (*Abelmoschus esculentus* L. Moench)

Treatments	Germination percentage		Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
	4 DAS	21 DAS				
T_1	00.00	00.00	00.00	00.00	00.00	00.00
T_2	78.75	93.75	15.98	4.85	31.61	1952.00
T_3	77.50	93.75	14.98	4.53	27.92	1830.25
T_4	82.50	95.00	14.90	4.45	27.38	1839.00
T_5	81.25	95.00	17.83	5.40	35.19	2207.50
SE	2.50	2.08	0.24	0.18	1.72	47.77
CD	NS	NS	0.68	0.50	4.89	135.81

NS- Non significant

Table 29. Allelopathic influence of nutsedge root exudates on germination and early growth of brinjal (*Solanum melongena* L.).

Treatments	Germination percentage		Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
	7 DAS	14 DAS				
T_1	00.00	00.00	00.00	00.00	00.00	00.00
T_2	68.75	85.00	6.45	3.95	15.11	887.00
T_3	71.25	85.00	5.83	4.00	12.61	835.00
T_4	70.00	87.50	5.75	3.57	12.48	821.25
T_5	68.75	86.25	6.85	4.33	22.73	949.25
SE	2.64	2.50	0.22	0.18	0.52	43.28
CD	NS	NS	0.62	NS	1.49	NS

NS- Non significant

Some of the treatments were found to suppress the growth of plumule. Significant suppression over control was recorded by T_1 (100 %) followed by T_4 (15 %) and T_3 (14 %). The effect of exudates collected at tuberisation stage was more or less similar to that of control.

Influence of nutsedge root exudates on radicle length of brinjal seedlings was found to be not significant.

Growth suppression in terms of reduction in dry weight was found to be significantly influenced by the exudates. Suppression in weight was more pronounced for exudates collected at sprouting stage (T_1) and dormant tuber production stage (T_4) which recorded dry weights of 00.00 and 12.48 mg plant^{-1} respectively while that of control was 22.73 mg plant^{-1}.

4.5 ALLELOPATHIC INFLUENCE OF NUTSEDGE EXTRACTS ON WEED SEEDS

The allelopathic influence of nutsedge extracts on germiation and seedling growth of three weed plants viz., *Synedrella nodiflora* (Venalpacha), *Gomphrena decumbens* (Neervadamalli) and *Chromolaena odorata* (Communist pacha) were studied under laboratory conditions.

4.5.1 Allelopathic influence on *Chromolaena odorata*

The data revealed that nutsedge extracts had no significant inhibitory influence on the germination of seeds of *Chromolaena odorata*. Germination of the seed lots was poor in all the treatments including control (Table 30).

Though germination was not affected, plumule length was significantly inhibited by nutsedge extracts. Nutsedge extracts taken after flowering (T_2) caused greatest inhibition with a plumule length of 0.23 cm followed by T_1 with a length of 0.55 cm while control plants recorded a length of 1.58 cm.

Table 30. Allelopathic influence of purple nutsedge extracts on germination and growth of *Chromolaena odorata*

Treatments	Germination percentage	Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
T_1	27.50 (31.53)	0.55	0.10	0.18	17.87 (4.20)
T_2	20.00 (26.18)	0.23	0.10	0.08	6.47 (2.51)
T_3	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)
T_4	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)
T_5	47.50 (44.28)	1.57	0.75	0.20	112.75 (10.25)
T_6	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)
SE	5.66	0.04	0.04	0.02	0.95
CD	NS	0.14	0.12	0.07	3.05

Figure in parenthesis indicate angular and square root transformed values

Table 31. Allelopathic influence of purple nutsedge extracts on germination and growth of *Synedrella nodiflora*

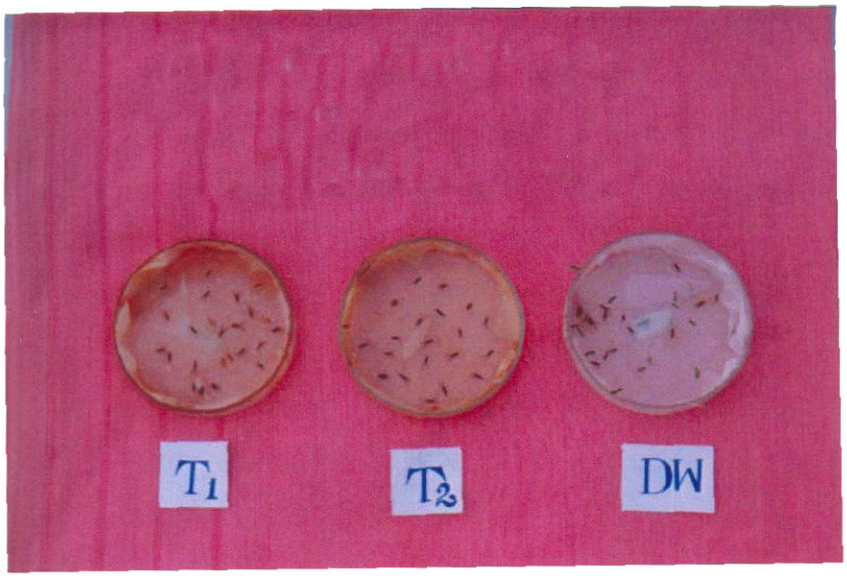
Treatments	Germination percentage 10 DAS	Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
T_1	52.50 (50.30)	1.05	0.13	0.18	58.87 (7.49)
T_2	47.50 (48.71)	1.25	0.16	0.14	68.50 (7.70)
T_3	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)
T_4	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)
T_5	80.00 (70.43)	3.93	0.31	0.20	344.42(18.27)
T_6	0.00 (0.00)	0.00	0.00	0.00	0.00 (0.00)
SE	13.54	0.16	2.21	2.73	1.57
CD	NS	0.52	7.08	NS	5.03

Figure in parenthesis indicate angular and square root transformed values
NS- Non significant

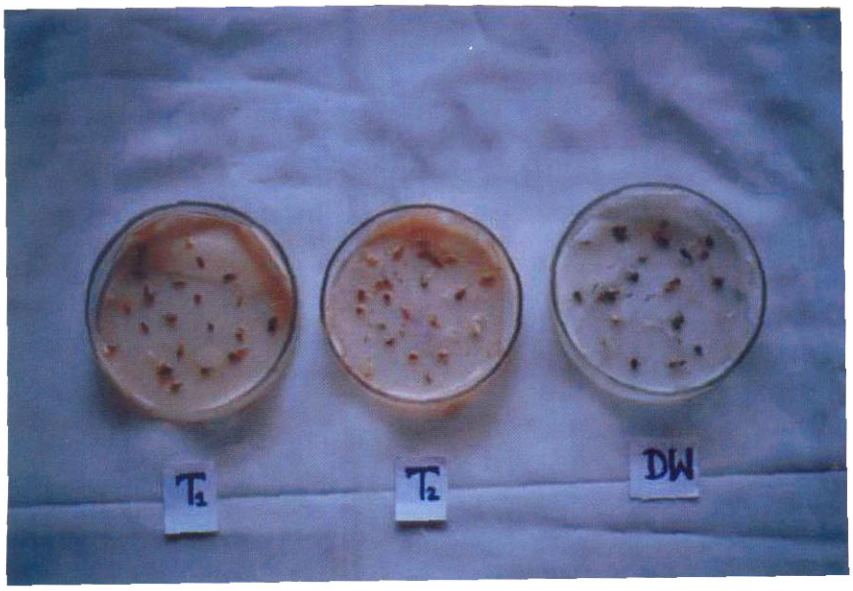
Table 32. Allelopathic influence of purple nutsedge extracts on germination and growth of *Gomphrena decumbense*

Treatments	Germination percentage 7 DAS	Plumule length, cm	Radicle length, cm	Dry weight, mg plant^{-1}	Vigour index
T_1	45.00 (42.03)	1.37	0.23(0.47)	0.25	72.75 (8.43)
T_2	27.50 (31.01)	1.15	0.28(0.51)	0.49	39.75 (6.12)
T_3	0.00 (0.00)	0.00	0.00(0.00)	0.00	0.00 (0.00)
T_4	0.00 (0.00)	0.00	0.00(0.00)	0.00	0.00 (0.00)
T_5	85.00 (70.05)	2.35	1.03(1.00)	0.54	289.00(16.93)
T_6	0.00 (0.00)	0.00	0.00(0.00)	0.00	0.00 (0.00)
SE	5.09	0.07	0.06	0.04	0.83
CD	16.31	0.22	0.20	0.13	2.65

Figure in parenthesis indicate angular and square root transformed values



Synedrella nodiflora



Gomphrena decumbense

Plate 6. Allelopathic influence of purple nutsedge extracts on germination and growth of weed seeds

Radicle growth was suppressed significantly by aqueous extracts of nutsedge and they recorded radicle length of 0.1 cm each while that of control was 0.75 cm.

Growth suppression in terms of reduction in dry weight was greatest for aqueous extract of nutsedge plants taken after flowering (T_2) with a dry weight of 0.08 mg plant^{-1} and this was significantly different from T_1 (0.18 mg plant^{-1}) and control (0.20 mg plant^{-1}).

From the results it was evident that the vigour index of *Chromolaena odorata* was greatly inhibited by aqueous extracts of nutsedge. Greatest inhibition over control (94 %) was recorded by T_2 followed by T_1 with an inhibition rate of 84 per cent. These treatments resulted in vigour index values of 6.47 and 17.87 while control recorded an index of 112.75.

4.5.2 Allelopathic influence on *Synedrella nodiflora*

At 10 DAS, the germination count was not considerably influenced by the aqueous extracts of nutsedge. Treatments involving ethanol extracts of nutsedge (T_3, T_4 and T_6) completely inhibited the germination and growth of weed seeds (Table 31).

In terms of length of shoot, the effect of aqueous extracts of nutsedge was significant. Nutsedge extract before flowering (T_1) recorded a plumule length of 1.05 cm while that of control was 3.93 cm. This was followed by nutsedge extract after flowering (T_2) which recorded a shoot length of 1.25 cm and they were on par.

Radicle length of *Synedrella* seedlings was significantly inhibited by the extracts of nutsedge. Maximum inhibition was caused by nutsedge extract before flowering (T_1) with a suppression rate as high as 58 per cent. This was followed by nutsedge extract after flowering (T_2) with a suppression rate of 48 per cent and they were on par with control.

Influence of nutsedge extracts on dry weight of weed seedlings was found to be not significant.

Analysis of vigour index revealed that aqueous extract of dry whole plant before flowering (T_1) and after flowering (T_2) could cause drastic reduction in seedling vigour index of *Synedrella nodiflora* and they suppressed the seedling vigour to a level of 83 per cent and 80 per cent respectively.

4.5.3 Allelopathic influence on *Gomphrena decumbens*

The results indicated that nutsedge extracts had significant inhibitory influence on germination and growth of seeds of *Gomphrena decumbens* (Table 32). Aqueous extracts caused some inhibition compared to control. However, ethanol extracts completely killed the seeds. Aqueous extract of nutsedge plants taken after flowering (T_2) recorded the highest inhibition of 68 per cent followed by nutsedge plants taken before flowering (T_1) which recorded an inhibition percentage of 47 per cent.

The plumule growth was suppressed significantly by nutsedge extracts. Drastic reduction in plumule length was recorded by extract of nutsedge plant taken after flowering (T_2) and nutsedge taken before flowering (T_1) which were on par among themselves and significantly different from control (T_5). The plumule length of the seedlings under these treatments were 1.15, 1.37 and 2.35 cm respectively.

The growth suppression was much pronounced in terms of radicle length also. Significant reduction of radicle growth was recorded by aqueous extracts (T_1 and T_2) of nutsedge. Aqueous extract of nutsedge plants taken before flowering (T_1) recorded the highest inhibition with a radicle length of 0.23 cm followed by T_2 with a radicle length of 0.28 cm while control plants (T_5) have a radicle length of 1.03 cm.

Inhibitory influence on dry weight was significant for the treatments T_1 and T_2 with T_1 recording the lowest dry weight (0.25 mg plant^{-1}) while control (T_5) plants recorded a dry weight of 0.54 mg plant^{-1}.

Vigour index was drastically less in all nutsedge treatments. The index values recorded by T_2 and T_1 were 39.75 and 72.75 while that of control was 289.00.

4.6 EXTRACTION AND IDENTIFICATION OF INHIBITORY COMPOUNDS

Allelochemicals in the tuber extract of nutsedge was identified by High Performance Liquid Chromatography (HPLC). The standards (reference compounds) and the sample extracts were analysed on HPLC (Schimadzu Japan) under the following conditions.

Column : Inertisol ODS-80A 5µm
150 x 406 mm ID
Cat No. : 5020-01601
Eluent : Acetonitrile (CH_3CN)/0.1%H_3PO_4-15/85 (HPLC grade)
Flow rate : 1ml/min
Detector : UV 254 nm
Col. Temp. :40^{0}C

A solvent system which can elute various standards of phenols was used for analysis of the sample. The standards were injected through a valve injection port with the solvent mobile phase mentioned above and the peaks obtained from the detector were observed. Accordingly the retention time for the various phenolic standards were estimated under the above conditions. A crude extract of the tubers obtained as per the procedure suggested by Leela (1995) was injected under similar conditions and eluted @ 1 ml min^{-1} and the retention time of major peaks obtained under the same conditions were compared with the chromatograms of standards. The qualitative characterization of the components of the nutsedge sample was done from this data.

The retention time of peaks obtained in the chromatograms of the sample (Fig. 14) revealed two major peaks at retention times 4.4 and 7.88. In addition, some minor peaks were also observed at rt values 6.79, 8.71, 13.31 and 14.61. A comparison of the retention times of the peaks

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Table 33. Identification of allelochemicals in the tuber extract of purple nutsedge (*Cyperus rotundus* L.)

Sl. No.	Reference compounds	Retention time, min	Retention of peaks in sample, min
1	Gallic acid	1.98	
2.	3,4-dihydoxy phenyl acetic acid	3.08	
3.	p-hydroxy benzoic acid	4.40	4.40
4.	Caffeic acid	4.84	
5.	Vanillic acid	5.28	
6.	Gentisic acid	5.73	5.88,6.07,6.79,7.88
7.	p-coumaric acid	8.58	8.71
8.	Ferulic acid	11.45	
9	m-coumaric acid	13.43	13.31,14.61
10.	o-coumaric acid	20.69	
11.	Salicylic acid	27.96	

obtained in sample and standards revealed that the peaks correspond to that of p-hydroxybenzoic acid and p-coumaric acid. The identification of minor peaks from these standards could be done only difficultly and they can be presumably that of m-coumaric acid, gentisic acid and caffeic acid.

Discussion

5. DISCUSSION

The results of the investigations conducted under laboratory and field conditions to evolve management strategy for purple nutsedge control is discussed hereunder.

5.1 SEASONAL INFLUENCE ON WEED BIOLOGY AND INFESTATION

Weed biology relates to plant attributes such as morphology, flowering behaviour and growth and development of tubers. A clear understanding of biology of the weed has great potential for formulating effective weed management strategies.

This study focused on the sprouting nature of chain and shoot tubers (bulb). Basal bulbs and tubers function both as the storage and reproductive organs for nutsedge. They differ primarily by their position in relation to the mother plant. Basal bulbs are directly connected to an aerial shoot. As rhizomes elongate, tubers are produced on rhizomes. They consist of rhizomatous tissues with numerous buds. These buds have the potential to sprout and initiate rhizomatous growths that develop into plants. In the present study, chain tuber took more time compared to shoot tuber for sprouting. Shoot tuber took 3-7 days to sprout while chain tuber took 7-26 days. Bulbs or shoot tuber sprout faster because it is already in the active stage. Chain tuber took more time and this may be due to the dormant nature of tubers in chains. Sprouting of chain tuber is regulated by apical dominance as suggested by Smith and Fick (1937). Ruchberg *et al.* (1993) reported that apical dominance exist in purple nutsedge on both tuber and the system as a whole. On the contrary, Horowitz (1972) recorded no significant difference between shoot tubers and chain tubers regarding their sprouting capacity. The data also indicate that purple nutsedge does not show any seasonal dormancy. This type of information on seasonal dormancy could be important in integrating

approaches that may direct weed management priorities on depleting or inhibiting specific tubers through interfering with dormancy.

The time required to sprout varied with seasons in the case of chain tuber. August and March planted tubers took lesser time to sprout because of favourable climatic conditions like temperature and rainfall (Fig. 4). August planted tubers received good rainfall (77.6 mm), which hastened their germination while March planted tubers experienced wide temperature fluctuations of 34.2^0C and 21.4^0C which helped to break dormancy. This is in line with the findings of Miles *et al.* (1996) who reported that sprouting stimulation in purple nutsedge is strongly regulated by the presence of high temperature fluctuations.

August and November planting produced more sprouts compared to March and May planting. On the contrary, an inverse relationship was observed between the sprouts per tuber and tuber per plant. This may be due to the dry matter partitioning between source and sink. But this difference in the number of sprouts and tuber is not reflected in the dry matter production, which meant that the photosynthetic efficiency of the plant was not much influenced by weather parameters. But a significant influence was observed in flowering and tuberisation (Misra, 1969; Horowitz, 1972 and Inderdev *et al.*, 1998).

March and May planting recorded more tuber production compared to August and November planting (Fig. 5). This may be due to the favourable climatic condition prevailed at that time of the year. The number of tubers produced clearly followed seasonal temperature variations. Intensive tuber production started in March, when mean temperature reached a maximum of 27.8^0C approximately. Tuber number increased rapidly throughout summer and decreased again in August-November and November-March. These results are in line with the findings of Horowitz (1972) where he reported that the effect of photoperiod was masked by temperature and temperature constituted the critical development factor for tuberisation. Bharadwaj and Verma (1968)

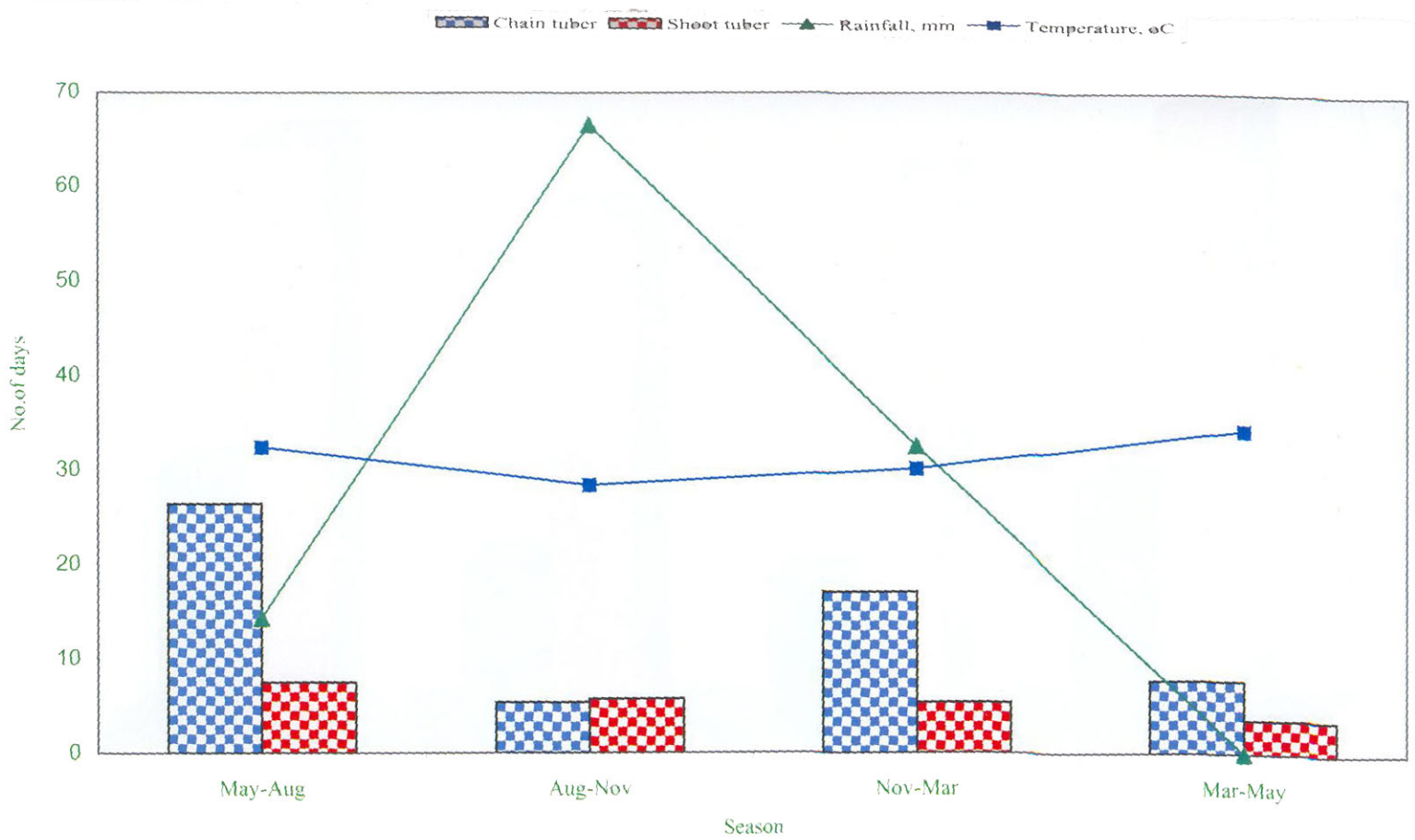


Fig. 4. Effect of weather parameters on days to sprouting for chain and shoot tuber

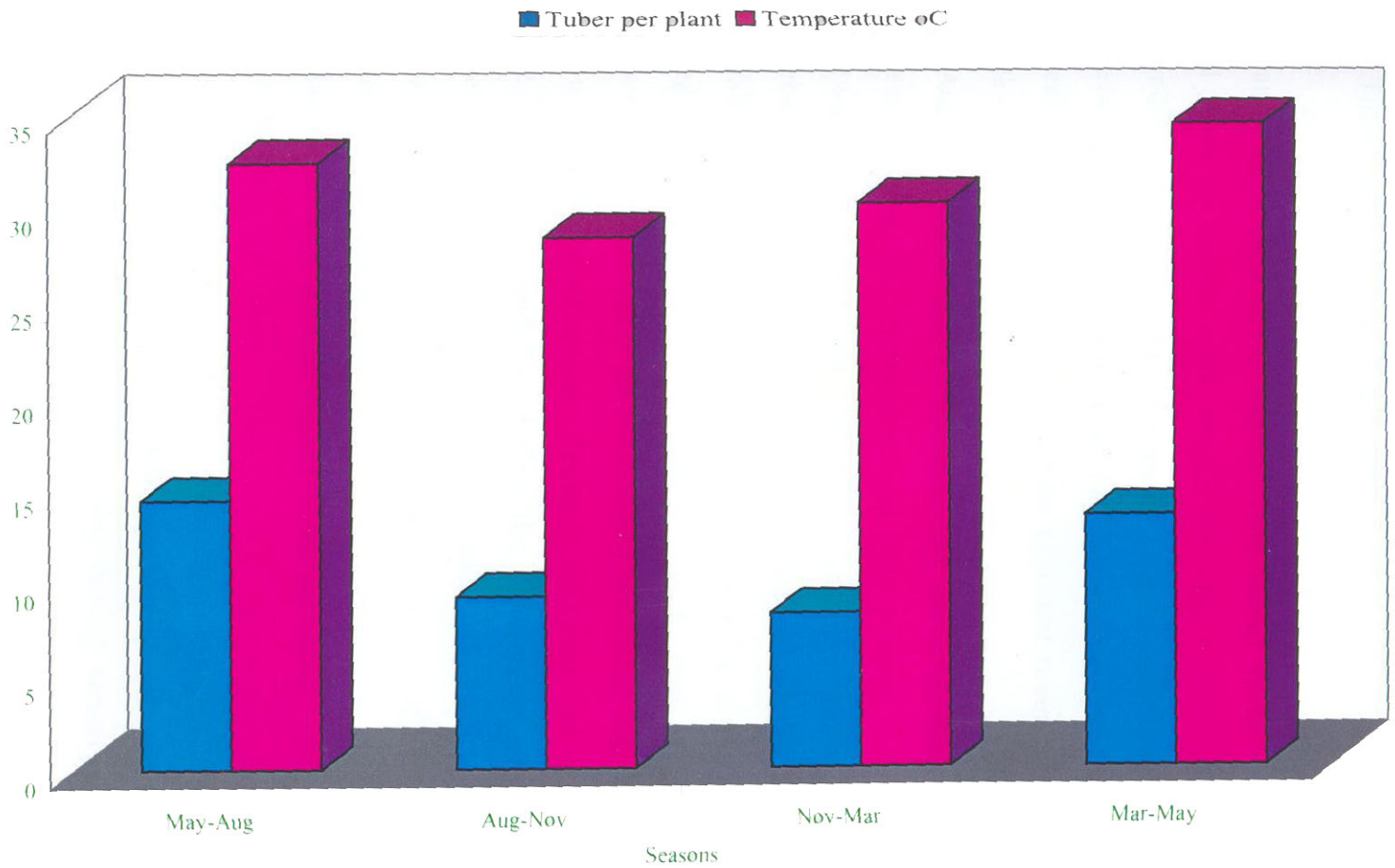


Fig. 5. Tuber production of nutsedge as influenced by different seasons and temperature

likewise reported that in Delhi tuber production was most intensive between July and October when mean temperature ranged from 26 to 31^{0}C and declined when temperature were below 20^{0}C.

Tuberisation is the result of response of nutsedge plant to varied weather parameters. The interval between planting a tuber and the appearance of a new tuber varied from about three weeks for August planted tuber to nearly eight weeks for May-August plants. This is in conformity with the results of Hauser (1962) who reported tuberisation after seven weeks, Devendra *et al.* (1996) who reported tuberisation after four weeks, and Bhowmik (1997) who reported tuberisation from four to six weeks.

August planted tubers recorded very early tuberisation compared to other seasons (Fig. 6). November and May planted tubers took more or less double the time for tuberisation compared to August planted tubers. Early tuberisation on August planted tubers could be due to the high level of rainfall (66.4 mm) received and the time of planting which hastened sprouting and early growth. This coupled with short photoperiods during the growing season (August to November) produced a favourable climatic condition for early tuberisation. Jansen (1971) studied the photoperiodic response of nutsedge and found that the differentiation of rhizome tips into tubers took place at 8-12 hours. Contrary to this, Horowitz (1972) found no apparent effect of a natural photoperiod of 10 to 14 hours on tuberisation in purple nutsedge.

March and May planted tubers flowered earlier compared to August and November planted tubers. This could be due to the response of plants towards day length prevailed at that time which is 9.6 hours during March and 9.08 hours during May. This is in conformity with the findings of Jha and Sen (1981) who recorded flowering during January-April in India. Also, Holm *et al.* (1977) reported that the plant is stimulated to flower on short photoperiods.

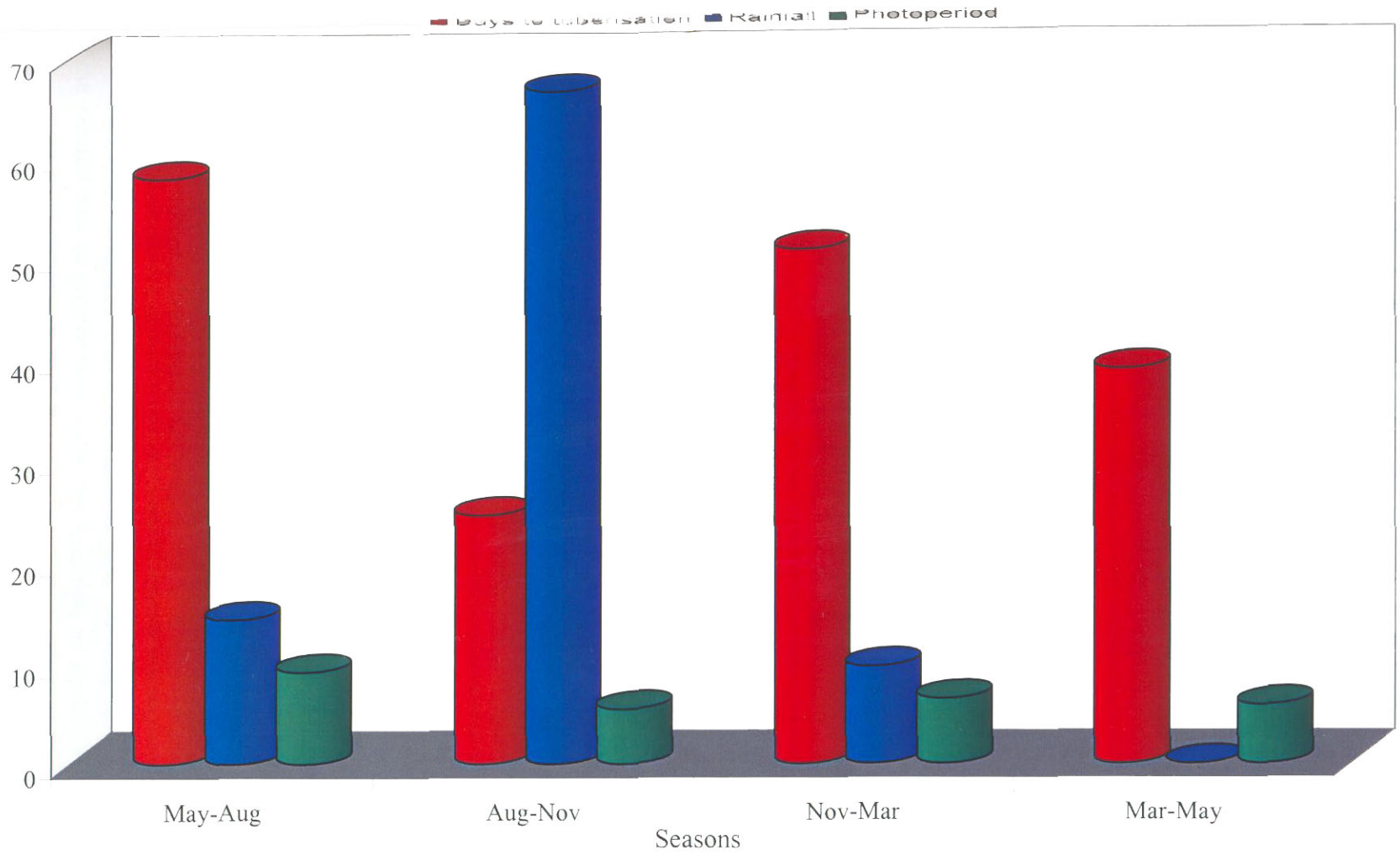


Fig. 6. Effect of weather parameters on days to tuberisation of purple nutsedge (*Cyperus rotundus* l.)

Results of the study on weed biology indicated that the seasonal growth variations of *Cyperus rotundus* observed in the experiment was closely related to temperature changes. Aerial and subterranean growth was very rapid in the warm season. The life cycle of *Cyperus rotundus* is very short and more than four successive generations can be produced within a year. There is a need to adopt proper control measures especially during the month of August and May, the period of rapid multiplication for getting a perennial control of nutsedge. Tuberisation stage was also identified which forms great relevance in herbicide scheduling for the effective control of nutsedge.

5.2 PERFORMANCE OF OKRA (*Abelmoschus esculentus* L. Moench) AS INFLUENCED BY DIFFERENT WEED MANAGEMENT PRACTICES

Results of the study indicated that the growth characters of okra were significantly influenced by the weed management practices.

The number of days taken to 50 per cent flowering varied significantly by the management practices during both the years. Flowering was early by about 7-10 days in mulched plots under both stale seed bed and soil exposure treatments compared to weedy check plots which took maximum days for flowering. Polythene was found the best mulching material compared to eucalyptus litter.

Stale seed bed coupled with mulching registered maximum leaf area index (LAI) during both the years. Mulching along with soil exposure treatment recorded significantly lower LAI. Dry matter production of okra was the highest under stale seed bed with eucalyptus mulched plots in first year while it was maximum in completely weed free plots during second year. Polythene and eucalyptus mulched plots showed superiority because it suppressed nutsedge growth with a WCE of 83.33 and 80.35 and at the same time soil moisture was retained preserving soil structure. These results are in conformity with the findings of Saikia *et al.* (1997) in okra and Chakrabarty (2000) in brinjal. Stale seed bed showed superiority

over soil exposure treatments because it will bring dormant tubers of nutsedge also under its area of control. This coupled with glyphosate spraying will have an added advantage of better nutsedge control along with suppression by mulch on the regenerated shoots of nutsedge. Polythene mulching integrated with soil exposure treatment performed better than stale seed bed because the efficiency of polythene mulching was enhanced when integrated with soil exposure in controlling purple nutsedge while that much efficiency was not realised when integrated with stale seed bed and glyphosate application (Fig. 7a and 7b). According to Hosmani and Meti (1993) stale seed bed encouraged a flush of new weed seedling, which could be controlled very easily prior to planting. The lowest values recorded by weedy check plots is indicative of the fact that nutsedge had significant negative influence on crop growth characters especially LAI and dry matter production. The result is in conformity with the observations of Rao (2000) that for every unit of weed growth, there will be one unit less of crop growth.

When yield attributing characters are considered, all the weed control treatments except treatments where cowpea was raised as smother crop resulted in significantly more fruits per plant and fruit yield ha^{-1}. Stale seed bed technique coupled with eucalyptus mulching recorded maximum mean yield of 5.24 t ha^{-1} which was closely followed by soil exposure treatment combined with polythene mulching (5.21 t ha^{-1}). Polythene mulching along with stale seed bed technique registered next best yield of 4.81 t ha^{-1} and all these three treatments were found better than soil exposure combined with hand weeding, herbicide applied and treatments were cowpea was raised as smother crop. Higher yield in these treatments were attributed mainly to significant improvement in yield attributes. The better performance of the mulched plots may be due to the higher photosynthetic area registered in these plots (Fig. 8). Reduction in nutsedge competition is brought about by stale seed bed treatments. This coupled with improved moisture status and nutrient conservation brought

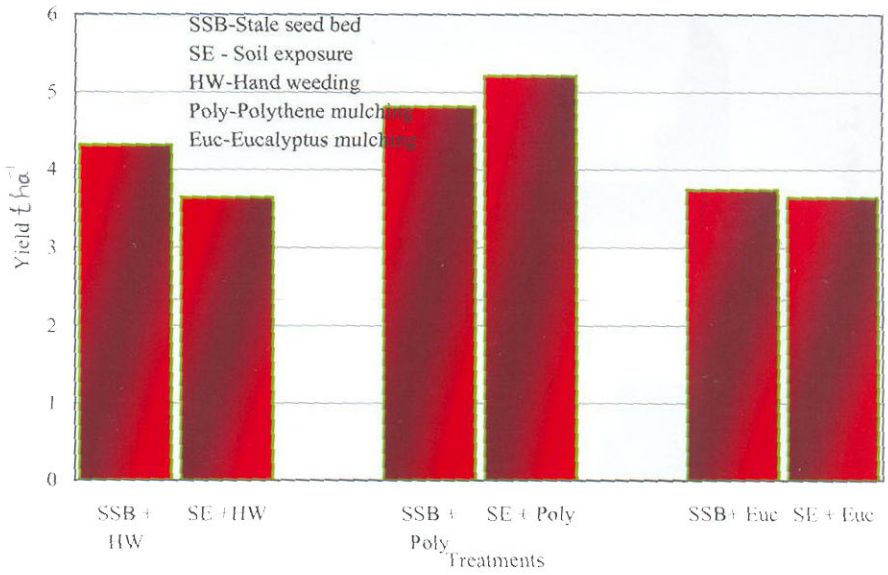


Fig. 7a. Comparison of stale seed bed and soil exposure treatments in combination with major treatments

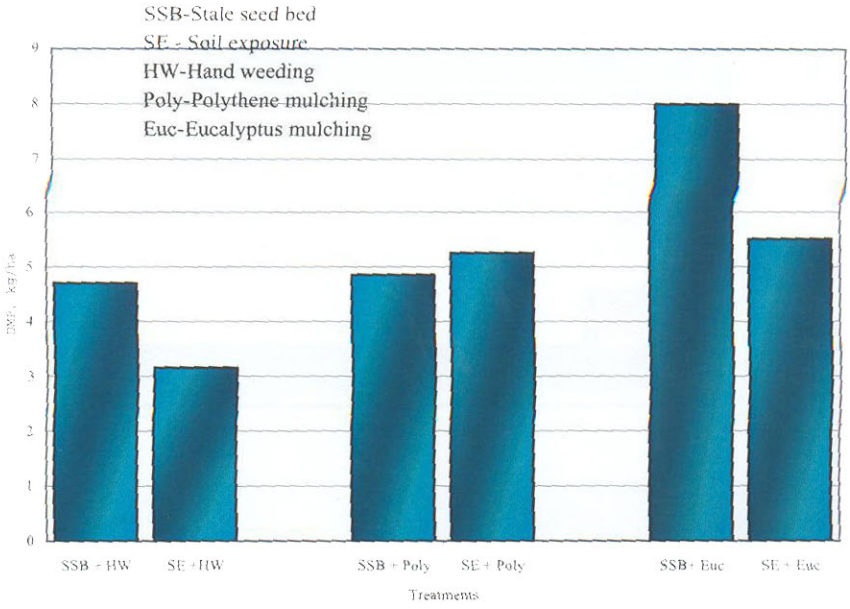


Fig. 7b. Comparsion of stale seed bed and soil exposure treatments in combination with major treatments

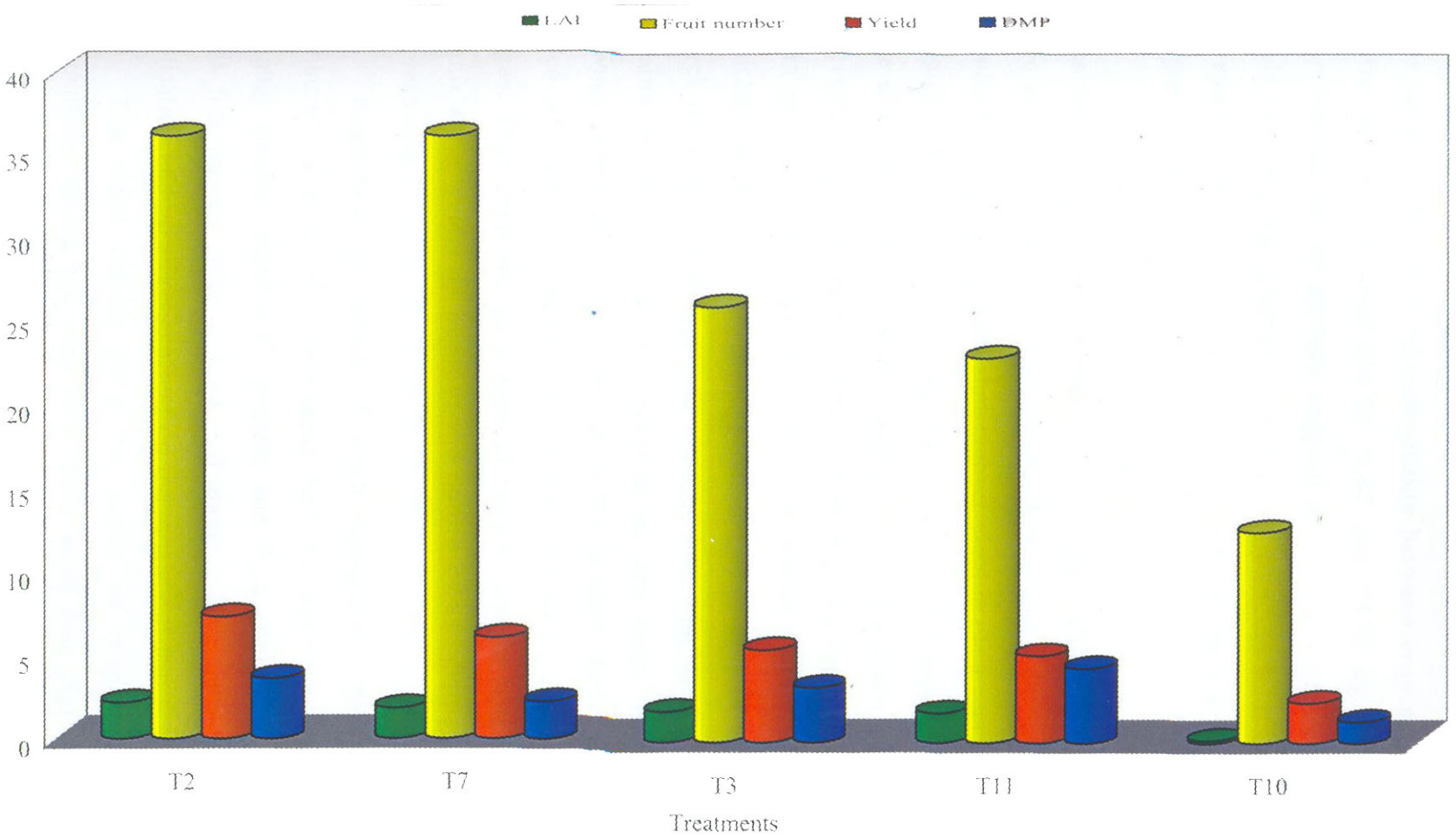


Fig. 8. Performance of the best three treatments on growth characters of okra (*Abelmoschus esculentus* L. Moench) compared with control

about by mulching contributed to increased fruit per plant and fruit yield per hectare. The reduced competition between crop and weed resulted in better nutrient removal (66.23, 9.67 and 78.72 kg ha^{-1} NPK) and this improved uptake of nutrient coupled with better LAI resulted in the higher yield contributing character as evident from the better fruit production. Greater dry matter production in these treatments is a cumulative effect of higher values of LAI and fruits per plant.

Enhancement in yield of okra through integrated approaches has also been reported by Saimbhi *et al.* (1994). Completely weed free plots also recorded higher yield levels which is in line with the studies of Singh *et al.* (1982) who reported that highest yield in okra was recorded by weed free plot and it gave 90.6 per cent more yield compared to weedy check. The direct influence of weed competition on yield characters and yield of vegetables has been reported by several workers like Singh *et al.* (1982) in okra and Singh *et al.* (1993) in tomato. Saikia *et al.* (1997) reported that mulching with black polythene promoted okra growth and yield. Weedy check recorded the lowest fruit yield of 1.93 t ha^{-1} and it was on par with treatments where cowpea is raised as smother crop. The performance of cowpea raised plots was poor as in the present study, the smother crop failed to smother nutsedge and instead smothered the crop in its initial stages. Thus expected advantage of raising cowpea crop was not realised in this study evidently because the nature of associated crop determined the response.

Regarding the effect of weed management practices on quality attributes of okra, the treatments had no significant influence on the keeping quality, vitamin C, protein and fibre content of the fruits. The shelf life ranged from 4.3 to 5.0 days. This implies that herbicide application had no adverse effect on the quality of fruits.

The weed indices gave the extent of crop loss due to weed competition, taking the crop yield from weed free plot as the reference. The yield loss was maximum under unweeded control plot while T_3 (SSB

+ eucalyptus mulching) had the minimum loss followed by polythene mulching treatments. Such response indicated the direct correlations between intensity of weed competition and crop loss.

Maximum uptake of N, P and K was recorded by the weed free treatment, while weedy check registered the minimum uptake values for all the major nutrients. The next best treatment in terms of nutrient uptake was stale seed bed with eucalyptus mulched plots. The enhanced growth characters in weed free situation contributed to high dry matter production and nutrient uptake being a product of dry matter production and nutrient content, was enhanced under such situations. It was evident that with minimum weeds to compete with and share resources, the uptake of nutrients by the crop was facilitated, resulting in more vigorous crop growth and better yield. As there was not much variation in the content of nutrients in okra due to different treatments, the uptake of nutrients followed almost the same trend of dry matter production of crop.

5.3 EFFECT OF WEED CONTROL MEASURES ON SOIL FERTILITY STATUS

The influence of weed control measures on the fertility status of soil was assessed by analyzing the soil before and after the experiment. The nutrient status of the soil after the experiment registered a marginal decrease in nitrogen content over the initial status. Nitrogen depletion in cowpea raised plots was lowest due to exhaustive removal of nitrogen by cowpea as evident from its luxuriant growth. Also it is applied only as mulch and no proper time was available for decomposition of cowpea. Though recycled, sufficient time was not available for proper mineralisation. Minimum depletion of nutrient occurred in completely weed free and mulched plots. The effectiveness of eucalyptus leaves as mulch for preventing weed growth and at the same time adding nutrients to soil by its decomposition must have contributed to higher N_2 status on these plots. Similar effects of eucalyptus has been reported by Natarajan

et al. (2001). Higher nutrient status in polythene mulched plots could be due to better WCE values (83.33 and 80.35).

However, phosphorus and potassium status of the soil was highest in stale seed bed with cowpea raised plots followed by completely weed free plots. This could be due to lower P and K removal of okra (3.09 and 16.09) in cowpea raised plots which resulted in greater P and K values in soil after the experiment. The N, P and K of the soil under completely weed free condition was indicative of the fact that effective weed control could have such positive effect on soil nutrients. Similar effects have been reported by Rao (2000).

The final nutrient status of the soil was determined by nutrient removal rather than mineralisation potential. Maximum depletion of nutrient was observed in weedy check plot which highlight the competitive nature of weeds. Therefore for sustaining productivity and maintaining nutrient status of the soil, mulching was found to be the best practice which top seeded other treatments.

5.4 EFFECT OF WEED MANAGEMENT PRACTICES ON NUTSEDGE CONTROL IN OKRA

In the present study, growth and tuber production of nutsedge was found adversely affected by the weed management practices. The data on nutsedge population, shoot dry weight and tuber dry weight revealed that nutsedge multiplication could be effectively checked by some of the treatments included in the study (Fig. 9). It was evident that stale seed bed with polythene mulching or pre and post emergent glyphosate application were the best in getting the highest level of control in all growth parameters of nutsedge. By stale seed bed technique, the dormant underground tubers are stimulated to sprout and the sprouted shoots are killed by glyphosate spraying which will reduce the weed seed bank or dormant tuber reserve on soil. The effectiveness of stale seed bed to achieve weed control in rice has been reported by John and

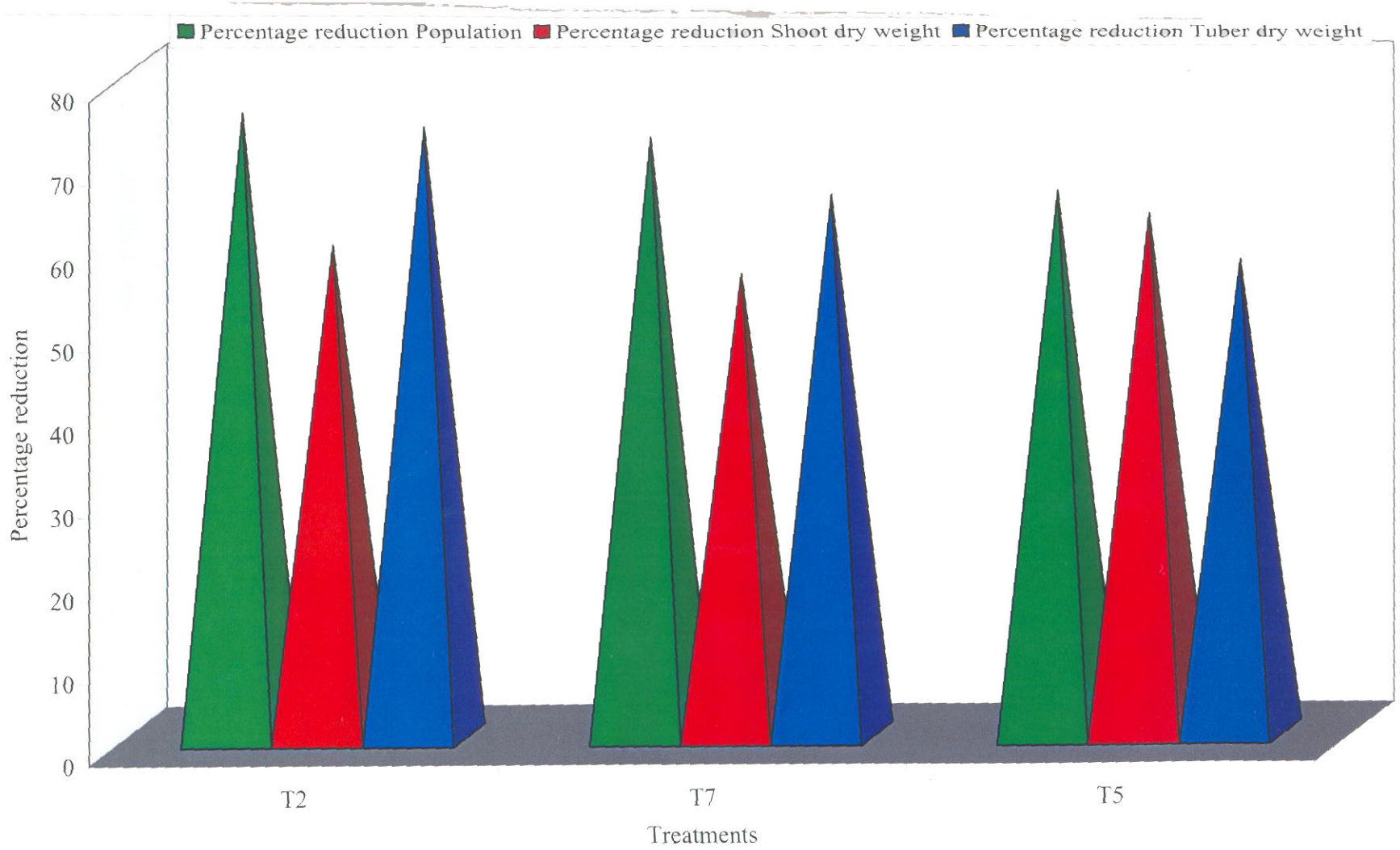


Fig. 9. Effect of weed management practices on nutsedge control in okra (*Abelmoschus esculentus* L. Moench)

Mathew (2001). Polythene mulching was very effective in suppressing nutsedge growth though some nutsedge shoots penetrated even the polythene sheets. Because of the higher temperature developed in soil under black polythene mulch, many of the tubers were made non-viable reducing further growth and regeneration. The effectiveness of black polythene mulch in reducing nutsedge growth has been reported by many workers like Hejazi *et al.* (1980), Kuva *et al.* (1995) etc. Yadav *et al.* (1996) reported that black polythene mulching after one hand weeding at 70 DAS of crop provided more than 98 per cent control of *Cyperus rotundus* while hand weeding could provide only 60 per cent control of this weed.

Post-emergent glyphosate application after stale seed bed have found to show spectacular inhibitory effect on nutsedge multiplication and spread and this treatment recorded the highest percentage reduction of nutsedge population, shoot and tuber. The effectiveness of glyphosate against nutgrass - a perennial sedge with deep ground vegetative propagules, has been reported by Grubben (1974) and Sandhu and Bhatia (1992). Better control with higher concentrations of glyphosate was earlier reported by Singh *et al.* (1993). Glyphosate being a systemic herbicide will be translocated to the underground vegetative propagules and can kill the whole plant. The effectiveness of glyphosate @ 1.5 kg ai ha^{-1} in controlling nutsedge without regeneration for a period of six weeks has been reported earlier by Ameena (1999). Wangchengyuh (2001) studied the effect of glyphosate on aromatic amino acids metabolism in purple nutsedge and reported that the herbicide caused inhibition of bud elongation, increased total free amino acids concentrations and caused rapid accumulation of shikimic acid in sprouted tubers.

Stale seed bed with cowpea emerged as the least effective treatment in controlling nutsedge because it could not smother weed effectively as evident from the low WCE values (Table 13). Stale seed bed provided a weed free environment for both cowpea and okra to establish. So, there

was competition between cowpea and okra initially, and in turn cowpea smothered okra till its incorporation. After incorporation, cowpea would not smother nutsedge growth effectively and this coupled with nitrogen deficiency after incorporation adversely affected okra growth. Patterson (1982) pointed out that the nutsedge competition was maximum during first 20 days after sowing of crops due to its early germination and vigorous growth. However, fast growing and good canopy forming qualities of cowpea and broad spectrum suppression of weeds by cowpea growing in coconut-banana cropping system was reported by Savithri (1990).

The data on weed control efficiency also followed the same pattern as dry matter production of weeds. Treatment combinations involving polyethylene mulching were the best treatments in reducing weed dry matter production in both years. The higher level of weed control obtained by solarisation in the current study can be attributed to the increased soil- temperature below the polythene sheets. According to Muzik (1970), thermo death of most plant tissues happens due to coagulation of protoplasm, between 45-50^{0}C. Higher soil temperature by solarisation has been reported by Katan (1981), Horowitz *et al.* (1983) and Ragone and Wilson (1988). Saikia *et al.* (1997) also reported 96.5 per cent WCE by black polythene mulching in okra. As stated by Birader *et al.* (1993), the supremacy of transparent polythene in raising soil temperature to higher magnitudes could be due to the maximum transmittance of the incoming short wave radiations.

5.5 ECONOMICS

The results of the present study revealed that adoption of weed management practices have significant positive influence on improving the net returns. Stale seed bed with glyphosate application integrated with eucalyptus mulching (T_3) recorded the highest net returns of Rs.18,270 ha^{-1} and B:C ratio of 2.01 and was found to be the most remunerative weed

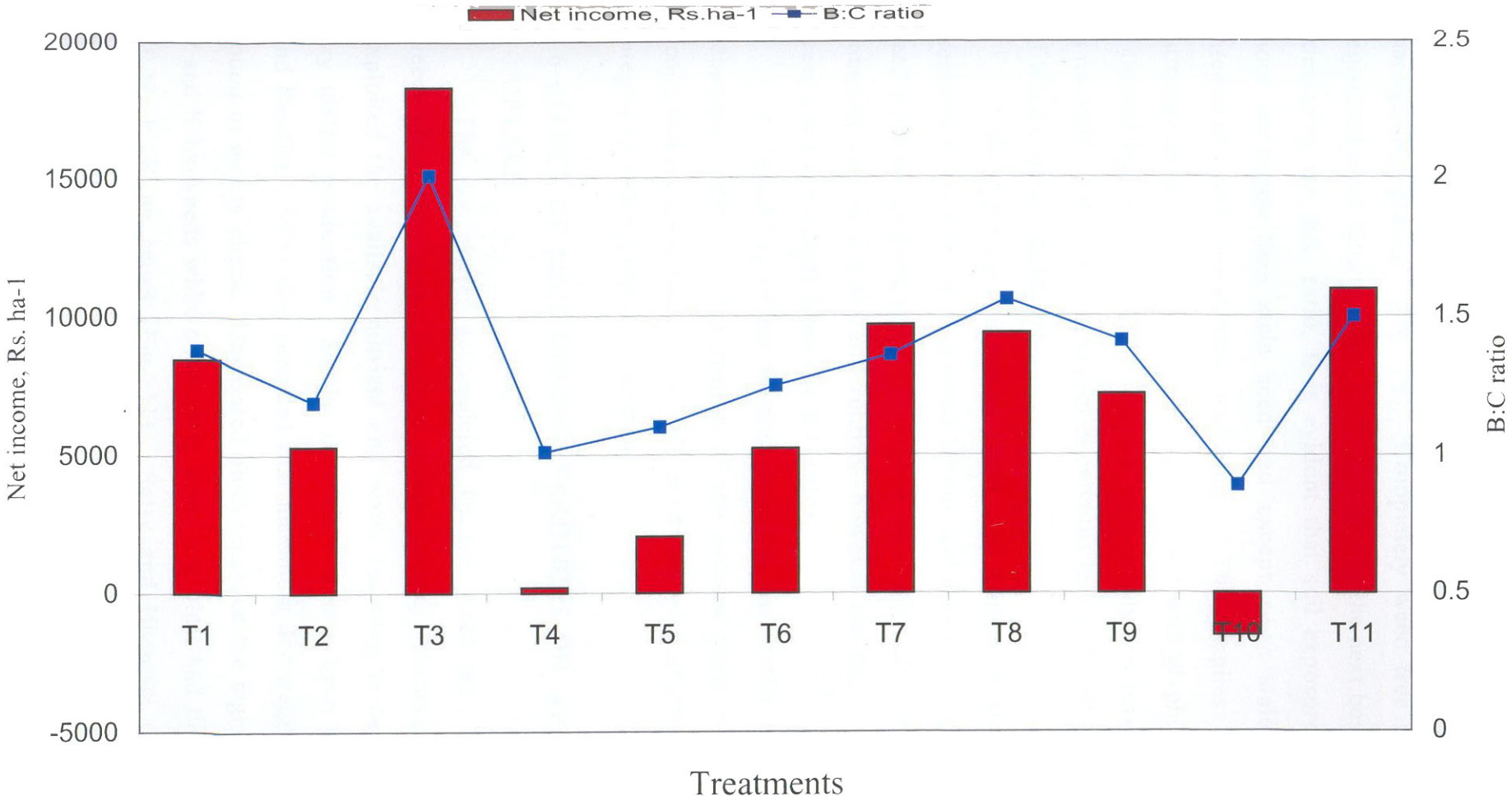


Fig. 10. Economics of weed control treatments in okra (*Abelmoschus esculentus* L. Moench)

management practice (Fig. 10). Completely weed free treatments (T_{11}) registered a net return of Rs. 10,970/- and was the next best treatment. On comparing the B:C ratio, it is evident that soil exposure treatments are more economic than stale seed bed except when stale seed bed was integrated with eucalyptus mulching. This implies controlling the nutsedge propagules initially by stale seed bed with glyphosate application followed by season long suppression with eucalyptus leaves. Since there is no additional cost incurred for eucalyptus leaves, it reduce the total cost of weed control operations.

Soil exposure treatments fared well compared to stale seed bed treatments because of additional labour and input cost involved in stale seed bed than soil exposure. Polythene mulching under both the treatment combinations recorded good returns, however the higher expenditure on weed control brought down the B:C ratio.

Acceptability of any farming practices essentially depends upon its economic viability. The results of the present study revealed that the economics favoured the use of stale seed bed with glyphosate application integrated with eucalyptus mulching.

5.6 EFFECT OF MANAGEMENT PRACTICES ON WEED NUTRIENT UPTAKE

The dry matter accumulated by the weed was maximum under weedy check throughout the crop growth period. Unchecked weed growth exploited the available nutrient and water resulting in better growth and dry matter production. Similar observations have been made by Nandal and Pandita (1988) who reported that maximum dry weight of weeds was found in weedy check. Unweeded plots recorded the highest uptake of N, P and K by weeds while completely weed free plots had the highest uptake of N, P, K by crops (Fig. 11). Setty and Hosmani (1977) observed negative correlations coefficient between crops and weeds regarding nutrient uptake. Among the treatments, stale seed bed with polythene

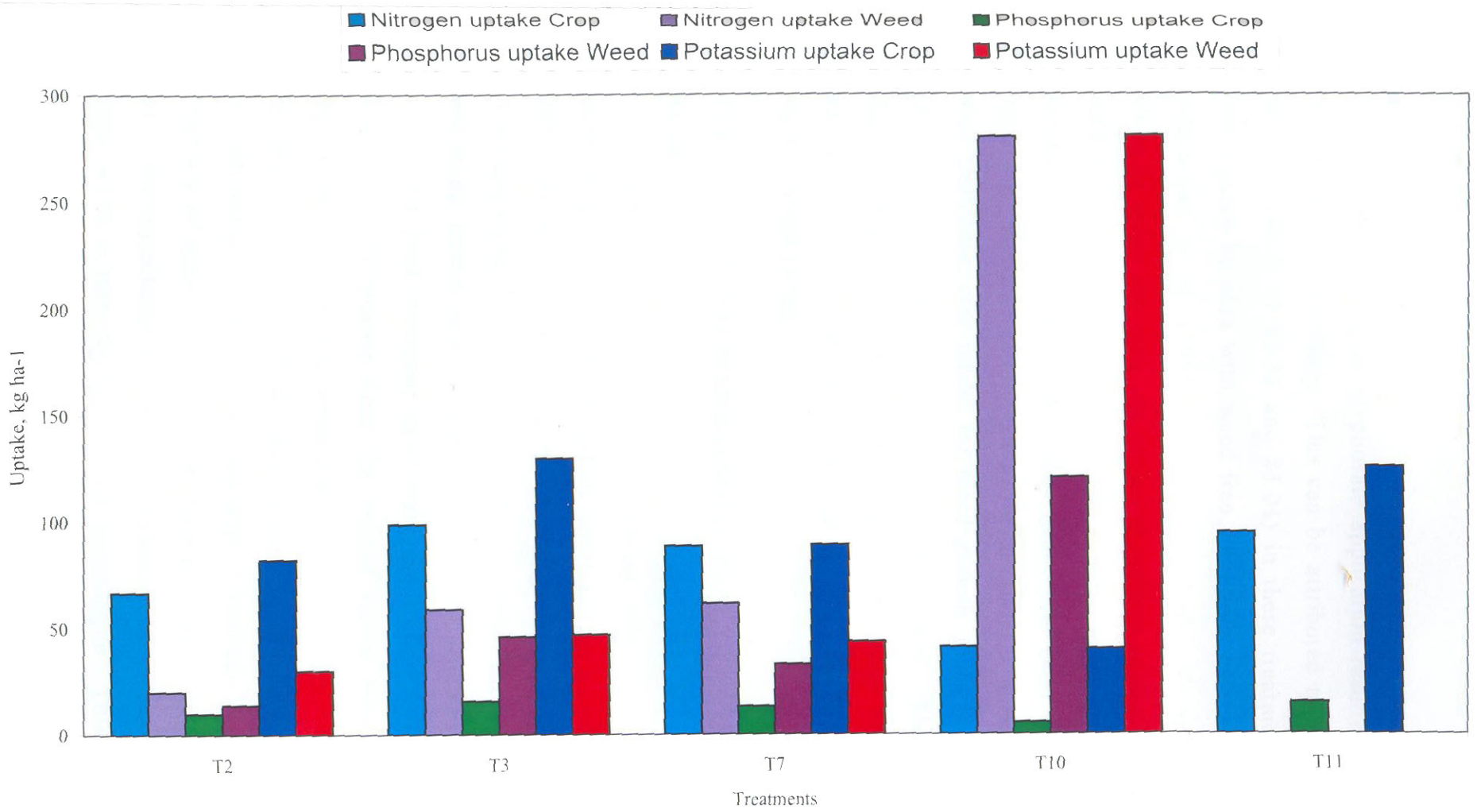


Fig. 11. Effect of weed management practices on crop and weed nutrient uptake

mulching or post emergent glyphosate application resulted in the lowest nutrient uptake by nutsedge. This can be attributed to the lowest weed competition (WCE of 83.33 and 83.01) in these treatments. Increased nutrient uptake by okra with weed free conditions have been reported by Soundararajan *et al.* (1981). Stale seed bed with either eucalyptus mulching or polythene mulching enhanced nutrient uptake by the crop and reduced nutrient uptake by nutsedge. This might be due to slow degradation of eucalyptus leaves and hence leaf litter may prevent the emergence of nutsedge shoots. Also the addition of phenolic compounds released from litter may inhibit for weed growth. This is in line with the findings of Sasikumar *et al.* (2002) in blackgram. Minimum nutrient uptake by the crop was observed in the weedy check plots, due to the increased competition between crop and nutsedge as earlier reported by Kumar and Singh (1992).

5.7 EFFECT OF WEED MANAGEMENT PRACTICES ON NUTSEDGE REGENERATION

Nutsedge re-growth or regeneration after the implication of management practices is an important constraint in its effective control. Regeneration or re-growth of purple nutsedge is due to dormant tubers which escape management practices and sprout after the treatment. In the present study, lowest rate of regeneration was recorded by stale seed bed with pre and post emergent glyphosate application. This is because glyphosate is translocated from the treated leaves into tubers thereby killing the underground and aerial portions of the plant. Glyphosate is a translocated herbicide which moves to underground organs and appears to inhibit the aromatic amino acid biosynthetic pathway (Jawarski, 1972). The viability of tubers collected from these plots also recorded the lowest values. Photosynthates to rhizomes resulted in reduced food in the rhizomes which in turn resulted in poor germination. This is in line with the findings of Desai *et al.* (1996).

Black polythene mulch was also found superior in reducing regeneration of nutsedge. This could be due to the higher temperature developed under black polythene sheets which made them non viable (Bhaskar and Nanjappa, 1997). Purple nutsedge store more food in tubers as exposure to sun will desiccate tubers in the shallow depths of soil more than that occur in the deeper depths. Tuber that survive desiccation due to their placement in deeper depths of soil have a better chance of producing new plants when they contain more stored food. Similar findings have been made by Patterson (1998) who observed that shoots that develop under the mulch produce no tubers.

Highest re-growth and viability percentages were recorded in completely weed free and weedy check plots with no herbicide application. This may be due to the fact that newly formed tubers of purple nutsedge sprouted readily showing no seasonal dormancy. This type of information could be important in integrating approaches that may direct weed management priorities on depleting or inhibiting the tuber reserve.

5.8 EFFECT OF INTEGRATED WEED MANAGEMENT STRATEGY FOR NUTSEDGE CONTROL IN NON-CROPPED AREA

In non-cropped area, the experiment was repeated for three seasons continuously. During the first two seasons, herbicides were applied at different growth stage of nutsedge. In summer, as there would not be active foliage of nutsedge for herbicide application, cultural methods were tried.

In the present study, it was designed to identify, the exact growth stage of nutsedge, for effective herbicide application. The results of two seasons study indicated that spraying before tuber initiation was the best for effective control of nutsedge probably. This is because of better translocation of herbicide throughout the plant at this stage. This result is in conformity with the observations of Siriwardana and Nishimoto (1987)

who reported that best purple nutsedge control with glyphosate was achieved when the greatest proportion of propagules in the soil are new tubers. So at before tuber initiation stage, the parent tuber along with corm will translocate the herbicide to the whole plant system obtaining better level of control. Zandstra and Nishimoto (1977) reported that the activity of glyphosate on *Cyperus rotundus* was considerably greater when applied three weeks after its planting than at nine weeks.

In the present study glyphosate showed superiority over 2,4-D in nutsedge control. Glyphosate (N-phosphonomethyl glycine) and 2,4-D (2,4-Dichlorophenoxy acetic acid) are systemic post emergent herbicides which give effective control of *Cyperus rotundus* foliage (Baird *et al.*, 1976). This is because 2,4-D does not translocate to the tubers attached to treated plants. (Hammerton, 1974), while glyphosate is translocated from the treated leaves into all tubers, thereby killing the underground and aerial portions of the plant (Siriwardana and Nishimoto, 1987). Gomez (1976) also reported that glyphosate at 1.0 and 2.0 kg ha^{-1} translocated to tubers upto 30 cm from the mother plant, whereas 2,4-D@ 1 kg ha^{-1} was translocated only 10 cm and 2 kg ha^{-1} to 20 cm. Good control of *Cyperus rotundus* was observed by Sandhu and Bhatia (1992) by split application of glyphosate @ 1.5-2.0 kg ha^{-1}. He observed that glyphosate effectively and permanently inhibited the sprouting of *Cyperus rotundus* tubers attached to treated plants.

The degree of inhibition exerted by glyphosate on regeneration of nutsedge tubers was higher than that of 2,4-D. This is because the systemic action of glyphosate is capable of desiccating and killing the tubers under the soil.

From the results it may be inferred that although 2,4-D can inhibit *Cyperus rotundus* growth, it fails to give long term control in the field because of poor translocation. Data on regeneration indicated that with successive application of glyphosate for two seasons, significant reduction in tuber dry weight and viability of tubers could be obtained but cent per cent

reduction in viability could not be obtained. Ability to sprout was significantly reduced but eradication was not achieved. Toth and Smith (1979) observed that 2 kg ha^{-1} or more of glyphosate applied under field conditions, reduced tuber sprouting by over 95 per cent, but the remaining 1 – 5 per cent of viable tubers were capable of reinfesting the area rapidly.

Among the summer season treatments stale seed bed with irrigation followed by glyphosate application was the best in achieving highest level of control. This is due to better sprouting of dormant tubers in these plots. Sequential application of glyphosate might have prevented nutsedge from producing tubers in the summer season. Also, stale seed bed provided ample chances for controlling dormant tubers by providing tillage and irrigation which stimulated sprouting of the dormant tubers. Glyphosate sprayed before tuber initiation along with stale seed bed with ethrel application followed by glyphosate spraying emerged as the best treatment for getting long term control of nutsedge. Jackson and James (1972) reported that ethrel significantly increased tuber sprouting and facilitated better conversion of rhizomes into shoots. But here also regrowth occurred later though to a lesser extent. Similar results have been reported by many workers like Martinez and Pulver (1975) who reported that though glyphosate kills *Cyperus rotundus* eradication from infested fields has not been obtained even with repeated applications. Terry (1974) observed excellent control of purple nutsedge for upto 24 weeks after applications of glyphosate, but failed to eradicate it.

Sequential spraying of glyphosate @ 1.5 kg ai ha^{-1} for three seasons with third application along with stale seed bed and irrigation provided the lowest regeneration values of nutsedge. This is in line with the findings of Bhatia *et al.* (2001) who obtained maximum reduction in regeneration potential with glyphosate applied in three splits. But here also, resprouting from bulbs of killed shoots were observed in all the treatments. This indicate the difficulty in attaining a complete control or

eradication of nutsedge. But this treatment could effectively bring down the population below the economic threshold level.

5.9 ALLELOPATHIC INFLUENCE OF NUTSDGE ROOT EXUDATES ON GERMINATION AND GROWTH OF CROPS

Allelopathy refers to all stimulatory and inhibitory biochemical interactions between the plants including microbes. Such influences of plants have important implications on crop production, and have been responsible to a considerable degree for the development of any agricultural practice including crop rotation, cover cropping, fertilizer application, disposition of crop residues etc (Velu *et al.*, 1992). Allelochemicals refer mostly to the secondary metabolites produced by the plants and are bye-products of primary metabolic processes. These secondary metabolites play greater role in reduction as well as enhancement of germination, establishment, growth, development and final biomass production of various species (Lal and Oudhia, 1999). The effect of allelochemicals on metabolic changes of receiver plant include effect on cell division, elongation, membrane permeability, mineral uptake, stomatal movement, pigment synthesis, enzyme activity, photosynthesis and plant water relations (Wink and Twardenski, 1992).

Exudation of chemicals by the plant is a common phenomenon. Root exudates are substances released into the surrounding medium by healthy and intact plant roots. The terms 'root exudates' is used here in a broad sense to refer to organic substances which are exuded from the roots by any mechanism (Rovira, 1969). Under normal growth conditions, exudation probably represents a major mechanism of releasing organic chemicals into the rhizosphere. The chemistry of the bioactive compounds in the rhizosphere is of fundamental importance to the understanding of interactions between the plant root systems and other living organisms.

The study was conducted on rice, cowpea, sesamum, okra and brinjal to represent the major four groups of crops *viz.*, cereals, pulses, oilseeds

and vegetables. Exudates were collected at different growth stages and their effect on germination percentage radicle length, plumule length and dry matter production were observed and the vigour index (VI) was computed to assess the effect of exudates. Results of the study revealed that germination percentage was inhibited by the exudates collected at sprouting stage on all the crop seeds tested. This would be due to the release of some inhibitory chemicals from nutsedge tubers into the medium during the process of sprouting. According to Whittakar and Feeny (1971), the known allelopathic agents are secondary plant metabolites including phenolic acids and flavanoids and other aromatics, terpenoids, steroids, alkaloids and organic cyanides. However, the exudates collected at later stages did not elicit any response on growth characters of crop seeds. This may be because of other types of chemical reactions such as oxidation, polymerization and microbial degradation which would occur to less stable compounds (Tang and Young, 1982).

Significant reduction in vigour index was observed in seasamum and okra by the exudates collected at all stages. This reduction in vigour index is due to the adverse effect on the growth and development of plumule and radicle which finally resulted in poor biomass accumulation. Such an inhibitory effect on the development of plumule and radicle was not observed in rice, cowpea and brinjal. This differential response may be due to the difference in biochemical composition of the test crops.

Results of the study indicated that purple nutsedge inhibited the growth of the associated crops like okra and sesamum not only by its competitive nature but also due to the production of inhibitory substance as root exudates. This indicate that plants exude sufficient quantities of phytotoxic substance to influence the growth and nutrient uptake of other plants (Young, 1984). There is ample chance of presence of phenolic compounds in trace amounts in the root leachates. Stimulatory effects on germination of cowpea at 5 DAS by nutsedge root exudates is in line with the earlier findings of Ameena (1999) where she reported that

nutsedge extract had some stimulatory effects on germination of cowpea and green gram seeds.

The study revealed differential toxicity of allelopathic chemicals with exudates at sprouting stage causing inhibition of germination and rest of the treatments having no effect on it. This could be due to variation in the release of allelochemicals through exudation at various growth stages. Similar variation in production of allelochemicals according to the stress experienced by the plant has been reported by Einhellig (1986). Exudates collected at dormant tuber formation stage caused greatest reduction compared to distilled water treatment. These results correspond with the fact that allelochemical production is greatest at dormant tuber formation stage.

It may be possible to use allelochemicals advantageously in crop production. Possibilities include breeding crop plants for increased production of chemicals that inhibit weed growth and producing natural herbicides from phytotoxic chemicals synthesized by plants. For an allelochemical to be used as a herbicide, it should inhibit weeds selectively. In conclusion, plant interference is very complicated in nature, and includes both allelopathy and competition. Separation of allelopathy from competition is a real challenge. It is the first step to be done toward better understanding and justification of allelopathy work.

5.10 ALLELOPATHIC INFLUENCE OF NUTSEDGE EXTRACTS ON WEED SEEDS

In the present study, laboratory experiments were carried out to investigate the allelopathic influence of nutsedge extracts on growth and development of other weed plants to assess the possibility of utilizing allelopathy for weed management. The weeds included in the study were *Chromoleana odorata*, *Gomphrena decumbense* and *Synedrella nodiflora*. As the weed seed endosperm was too little to support seedling growth in the petridishes, the period of observation was limited to 7-10 days. Of the

four treatments tried, ethanol extract at 10 per cent concentration killed all the weed seeds completely, while aqueous extracts caused inhibition of growth of some of the weed seeds tested. This may probably due to the effect of the solvent itself.

Aqueous nutsedge extracts inhibited germination and growth of *Gomphrena decumbense* while it had no significant influence on germination of *Synedrella nodiflora* and *Chromolaena odorata* (Fig. 12 and 13). Such results confirm that the inhibitory effects of allelochemical are species specific (Bhatt and Todoria, 1996) and allelochemicals exuded by different plants have different response in crops. In *Gomphrena decumbense*, an annual dicotyledenous upland weed, nutsedge extract taken after flowering caused greatest reduction percentage of 68 while nutsedge extract taken before flowering caused a reduction percentage of 47. This can be explained by the fact that production of allelochemicals is regulated by the stage of the plant and is modified by environmental stresses like temperature extreme, nutrient moisture variables, insects and diseases and radiation (Einhellig, 1995). Leela (1995) reported presence of p-hydroxy benzoic acid, caffeic acid, o-coumaric acid and ferulic acid in *Cyperus rotundus*. In this study also, the HPLC technique revealed the presence of above said chemicals (Table 33).

Suppression of plumule growth was observed in all the weed seeds tested. Nutsedge extracts taken after flowering inhibited *Gomphrena decumbense* and *Chromolaena odorata* while extract taken before flowering inhibited *Synedrella nodiflora*. This differential inhibition may be due to the selectivity in action of the allelochemicals. This inhibition obtained at post flowering stage may be due to the higher level of allelochemicals production after flowering in nutsedge (Jha and Sen, 1982).

Significant reduction in radicle growth was recorded by aqueous extract of nutsedge for all the three weed seed tested. This is in conformity with the reports of Wibowo *et al.* (1996). Leela (1995)

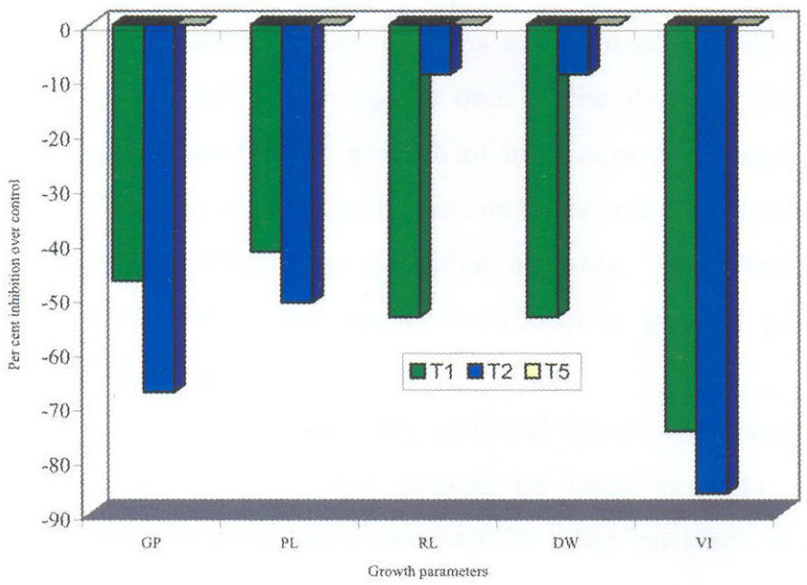


Fig. 13 Allelopathic influence of purple nutsedge extracts on germination and growth of *Gomphrena decumbense*

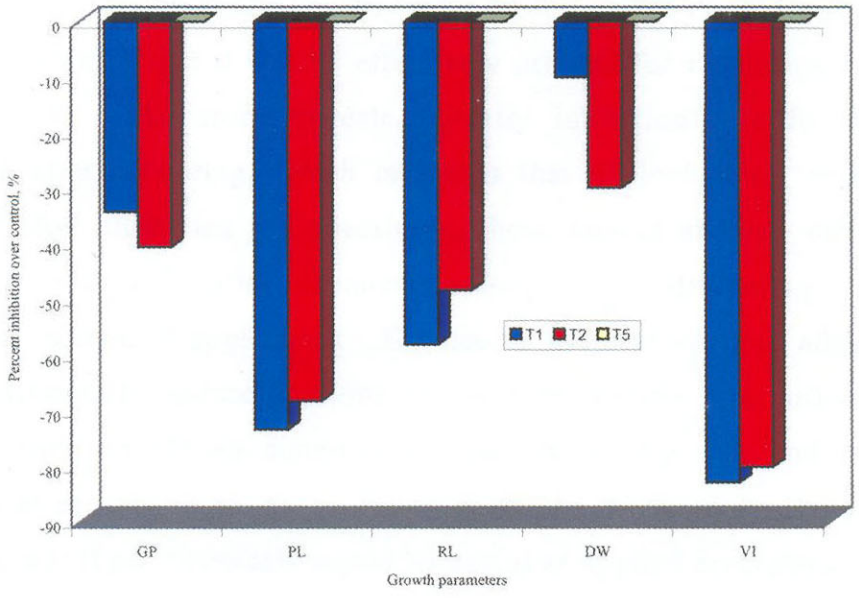


Fig. 12 Allelopathic influence of purple nutsedge extracts on germination and growth of *Synedrella nodiflora*

reported presence of coumarins in *Cyperus* extract and this could interfere with root cell elongation, water relations and photosynthesis in plant.

The dry matter production is one of the deciding factors of plant vigour and it is a function of growth of both root and shoot (Velu *et al.*, 1992). Dry weight of *Gomphrena decumbense* and *Chromolaena odorata* were significantly affected by nutsedge extracts. This reduction in dry weight is consequent to the earlier reduction in growth parameters like plumule and radicle growth.

Vigour index was drastically reduced for all the weed plants. The reduction in vigour index was caused by both extracts. Inhibition of radicle growth, which in turn resulted in poor nutrient absorption and consequent poor biomass accumulation, could be the reason for such a drastic reduction in seedling vigour.

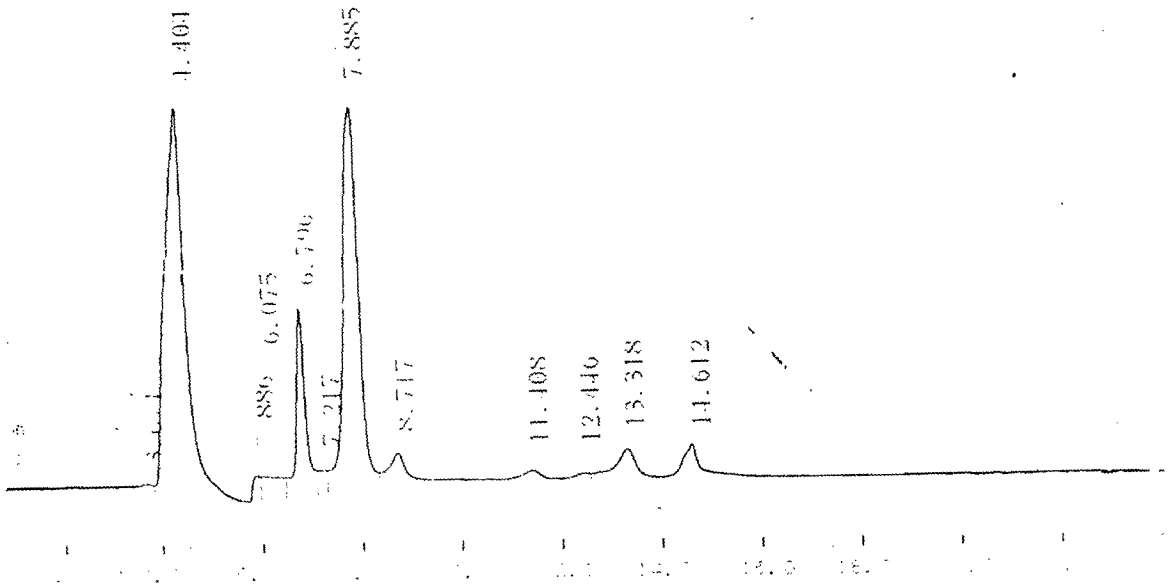
Allelopathy even though considered as an undesirable property this characters can be profitably exploited. Allelopathy generally refers to the detrimental or harmful effects. But from the results of the present study it could be inferred that it can be effectively utilized for the management of other weeds. The study revealed greater inhibition rate for extracts collected after flowering, which indicated that allelochemical production is more after flowering. Collectively, these results showed differential toxicity of the allelopathic chemicals among the sp depending upon the stage and method of application. The use of water extracts of allelopathic crops particularly nutsedge alone or in combination with other water extracts will provide an economical, environmentally safe and effective weed control technique as an alternative for herbicides. Hence it is probable that these chemicals would be useful as applied herbicides.

5.11 IDENTIFICATION OF ALLELOCHEMICALS

Chemicals that impose allelopathic influences are called allelochemicals. They may be largely classified as secondary plant metabolites which do not play a role in primary metabolic processes. Tens

SAMPLE PEARS OBTAINED FROM HPLC

CHROMATOPAC CH-2 REPORT No. 15 DATA=Q:¥CHRM2.C14 03/01/21 17:28:30



SHIMADZU 223-04230 961215

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** CALCULATION REPORT **

PEAK	TIME	AREA	HEIGHT	MK	IDNO	CONC	NAME
1	0.542	3970	110			0.0808	
	3.192	4473	303			0.091	
	3.671	31683	1429	V		0.6445	
	4.404	2053739	74233	V		41.7746	
5	5.886	55594	4855			1.1308	
6	6.075	122789	4506	V		2.4976	
7	6.796	474179	35888	V		9.6452	
8	7.217	49845	4363	V		1.0139	
9	7.885	1586058	73208	V		32.2616	
10	8.717	145788	5990	V		2.9654	
11	11.408	42490	1696			0.8643	
12	12.446	20460	1060			0.4162	
13	13.318	162407	5583	V		3.3035	
14	14.612	162764	6421	V		3.3107	
	TOTAL	4916241	219647			100	

of thousands of secondary substances are known today, but only a limited number has been implicated as allelochemicals. The chemistry of the bioactive compounds in allelopathy is of fundamental importance for the understanding of interactions between plants. However, our present knowledge remains extremely unlimited because of the difficulties in dealing with the recovery of trace organic compounds by conventional solvent extraction methods.

In the present study, the tuber extracts of nutsedge identified by HPLC technique revealed the presence of phenolic compounds. The phenolic acids identified were p-hydroxybenzoic acid and p-coumaric acid. The readily visible effects of these allelochemicals include inhibition or retardation of germination, reduced radicle or coleoptile extension, curling of the root axis, discolouration, increased number of seminal roots, reduced dry weight accumulation, and lowered reproductive capacity. These gross morphological effects may be secondary manifestations of primary events caused by a variety of more specific effects acting at the cellular or molecular levels in receiver plants (Rice, 1979).

Leela (1995) reported the presence of p-hydroxy benzoic acid, caffeic acid, o-coumaric acid and ferulic acid in tuber extracts of *Cyperus rotundus*. Reduction in germination and growth of weed seeds observed in present study corroborate the findings of Rice (1979) and Leela (1995).

Allelochemicals are present in virtually all plant tissues including leaves, flowers, fruits, stems, roots, rhizomes, seeds and pollen. They may be released from plants into the environment by means of four ecological processes *viz*., volatilization, leaching, decomposition and through root exudates. The inhibition in germination and growth of test crops observed in bioassay was marginal. This could presumably be due to the lower concentration of allelochemicals released from the tubers to the soil from which only a portion could be trapped by the adsorbent. Considering the uncontrolled growth in the field situation and a relatively high proportion of live and dormant tuber remaining in the soil coupled with the unfavourable

stress conditions to which the soil will be exposed the growth of adjacent crops can expected to be more pronounced in the field situation than the conditions prevailing in the present study.

Our work suggests that exploration of the composition of a cluster of allelochemicals, which are simple in structure, possess various biological activities and few barriers to synthesis and production, may be another alternative for developing new herbicides from individual plant allelochemicals.

Summary

6. SUMMARY

An investigation on "Integrated management of purple nutsedge (*Cyperus rotundus* L)" was carried out at College of Agriculture, Vellayani with an objective to evolve an economically viable and eco-friendly weed management schedule for nutsedge control in both cropped and non-cropped area. Biology of nutsedge was studied for a period of one year to understand the time of tuberisation at different period of the year. The study also aimed to assess the allelopathic influence of nutsedge on other weed plants and its root exudates on crop plants. An attempt has been made to identify the allelochemicals present in tubers of purple nutsedge by employing HPLC (High Performance Liquid Chromatography) technique. The salient results of the experiment are briefly summarized below.

1. Results of the study on biology revealed that shoot tuber or bulb took only lesser time (3-7 days) to sprout while chain tuber took more time (5-26 days) for sprouting during the whole season.
2. The most favourable season to sprout was August for chain tuber and March-May for bulbs and the least favourable time was May for both shoot and chain tuber.
3. The number of sprouts produced per tuber was highest (2.85) during August and least (1.70) during May.
4. Maximum number of tubers were produced during May-August and March-May and the least number during November-March and August-November.
5. The total number of tubers produced by a plant at maturity was found to range from eight to fourteen.
6. The number of days taken for flowering was found to range from 36-56 days.

7. The number of days required for tuber initiation was found to range between 24.50 to 57.75 days. Early tuberisation was observed in August (24.50) planted tubers and May planted tuber took the maximum time for (57.75) for tuberisation.
8. Results of field experiments in cropped area revealed that all growth parameters differed significantly with respect to seasons.
9. The number of days taken for 50 per cent flowering in okra was the lowest in (27 and 34 during I and II year) mulched plots along with completely weed free plots. During both the years polythene mulched plots showed superiority over rest of the treatments and flowered a week earlier than weedy check plot.
10. Polythene and eucalyptus mulched plots showed superiority in LAI values during first and second year.
11. During both the years, stale seedbed treatments with hand weeding, polythene mulching and eucalyptus mulching along with completely weed free treatments showed superiority over rest of the treatments with respect to yield attributing characters
12. The highest fruit yield per hectare (5.24 t ha^{-1}) was recorded by stale seedbed with eucalyptus mulching and it was on par with polythene mulched plots and completely weed free plots. The best economically viable treatment for effective nutsedge control was stale seed bed with glyphosate application followed by eucalyptus mulching.
13. None of the treatments recorded any effect on quality parameters of fruits like vitamin C, keeping quality, fruit protein percentage and fruit fibre percentage.
14. The nitrogen status of the soil registered a marginal decrease after the experiment and mulched plots recorded higher nutrient values compared to weedy check.
15. The phosphorus and potassium content of the soil was highest under cowpea raised plots during both the years.

16. Polythene and eucalyptus mulched plots recorded the highest uptake of N, P and K by crop during both the years and weedy check recorded the lowest uptake
17. The effect of treatment on weed parameters indicated that the lowest tuber viability percentages were recorded by pre and post emergent glyphosate applied plots (21) and polythene mulched plots (28). The treatments consequently recorded the lowest rate of regeneration.
18. Solarisation with polythene mulching was the most successful in bringing down the nutsedge population (71.70 and 82.60 %) in both the years.
19. Stale seedbed with polythene mulching was the best treatment in effecting tuber production of nutsedge (73.32) along with pre and post emergent glyphosate application (64.93). These treatments recorded the highest (83.33, 83.01) WCE values.
20. Stale seedbed with eucalyptus mulching and soil exposure with polythene mulching recorded lower weed index values compared to unweeded control.
21. The lowest uptake of nutrients (N, P and K) by weeds was recorded in stale seedbed with polythene mulched plots during both the years.
22. Investigations conducted in uncropped area, brought light the following facts. Glyphosate @ 1.5 kg ai ha^{-1} sprayed before tuber initiation recorded the highest control of nutsedge shoot dry weight (86.90) and tuber dry weight (55.56).
23. Glyphosate treatments recorded the highest WCE values of 76.82 and 71.40 and were significantly different from 2,4-D application in nutsedge control.
24. Spraying glyphosate for two consecutive seasons in uncropped area, resulted in the lowest regeneration values compared to 2,4-D.

25. Stale seedbed with irrigation followed by glyphosate spraying recorded the highest reduction percentage (87) of nutsedge population in summer season uncropped area
26. Among the main plot treatments, glyphosate spraying recorded the highest reduction. percentage of nutsedge population (74.95 and 70.45 %) and nutsedge shoot dry weight (74.41 and 72.40 %).
27. Regarding nutsedge shoot dry weight, stale seedbed with ethrel application resulted in the highest reduction (80.85) percentage followed by stale seedbed with irrigation (70.36).
28. Combinations of glyphosate sprayed before tuber initiation combined with stale seedbed and ethrel application recorded the lowest final tuber dry weight (2.61).
29. Glyphosate sprayed before tuber initiation coupled with stale seedbed with irrigation recorded the lowest weed dry weight and highest WCE.
30. Glyphosate sprayed before tuber initiation coupled with stale seedbed with irrigation recorded the lowest (1.50) rate of regeneration after three season treatments.
31. Results of lab study revealed that nutsedge root exudates collected at sprouting stage completely inhibited the growth and development of all the crops seeds tested *viz*., rice, cowpea, sesamum, okra and brinjal.
32. Nutsedge extracts had significant inhibitory influence on germination and growth of seeds of *Gomphrena decumbense*.
33. Seeds of *Chromolaena odorata* and *Synedrella nodiflora* were found unaffected by the aqueous extracts of nutsedge.
34. Treatments involving ethanol extracts of nutsedge completely inhibited the germination and growth of all the weed seeds tested.
35. Aqueous extract of dry whole plant before flowering (T_1) and after flowering (T_2) caused drastic reduction in seedling vigour index of

Synedrella nodiflora and they suppressed the seedling vigour to a level of 83 per cent and 80 per cent respectively.

36. In general, nutsedge extracts taken after flowering caused the greatest inhibition of all the growth parameters tested.
37. Allelochemical in the tuber extracts of purple nutsedge were identified by HPLC and it indicated the presence of p-hydoxy benzoic acid, p-coumaric acid, m-coumaric acid, vanillic acid, gentisic acid.

Future lines of work

1. Efforts can be made to identify the chemicals present in purple nutsedge causing tuber dormancy.
2. As the biology of purple nutsedge vary with seasons it warrants location specific management strategies.
3. Attempts can be made to formulate a bio-herbicide from purple nutsedge for weed management.
4. Allelopathic characteristics of natural mulch materials may be identified.
5. Similar studies can be carried out under various cropping systems in different situations.

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INTEGRATED MANAGEMENT OF PURPLE NUTSEDGE

(*Cyperus rotundus* L.)

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8. ABSTRACT

An investigation entitled "Integrated management of purple nutsedge (*Cyperus rotundus* L.)" was conducted during 1999-2002 at College of Agriculture, Vellayani, Thiruvananthapuram. It comprised of one pot study, two field experiments and three laboratory experiments. Pot experiment was conducted to study the biology of purple nutsedge under various seasons and stage of tuberisation. Field experiments were conducted to evolve an integrated management strategy for purple nutsedge control in cropped area and a long-term control strategy in non-cropped area. Laboratory experiments were conducted to assess the allelopathic influence of purple nutsedge root exudates on early growth of crop seeds and nutsedge extracts on weed seeds. An attempt has been made to identify the allelochemicals present in tubers of nutsedge by employing HPLC (High Performance Liquid Chromatography) technique.

In pot study, the growth and development of purple nutsedge was observed for a period of one year. Results of the study indicated that chain tuber took more time for sprouting compared to shoot tubers or bulb. The time required to sprout varied with seasons in the case of chain tuber and August and March planted tubers took lesser time for sprouting. March and May planting recorded more tuber production compared to August and November planting. August planted tubers recorded very early tuberisation and November and May planted tubers took more or less double the time for tuberisation compared to August planted tubers.

Field studies in cropped area indicated that the growth characters of okra were significantly influenced by the weed management practices. Flowering was early by about 7-10 days in mulched plots under both stale seed bed and soil exposure treatments compared to weedy check plots. Stale seed bed coupled with mulching registered maximum leaf area index during both the years. All the weed control treatments except

where cowpea was raised as smother crop resulted in significantly more fruits per plant and fruit yield per hectare. Maximum productivity of 5.24 t ha^{-1} was realised by stale seed bed with eucalyptus mulched plots which was 171.5 and 11 per cent more than weedy check and weed free plots respectively. The treatments had no significant influence on quality attributes of okra like vitamin C, keeping quality, protein and fibre content of fruits. Regarding soil fertility status, minimum depletion of nutrients occurred in completely weed free and mulched plots.

Stale seed bed with polythene mulching or pre and post emergent glyphosate application were identified as the best nutsedge control measure in cropped area. Post emergent glyphosate application after stale seed bed has found to show spectacular inhibitory effect on nutsedge multiplication and spread and this treatment recorded the highest percentage reduction values for nutsedge control. Lowest rate of regeneration was recorded by this treatment with lower viability of tubers. The most economical treatment was stale seed bed with glyphosate application integrated with eucalyptus mulching and it recorded the highest net returns (Rs.18,270/-) and B:C ratio (2.01).

In non-cropped area, results of two seasons study indicated that the effective stage for glyphosate spraying was identified as before tuber initiation. The degree of inhibition exerted by glyphosate on regeneration of nutsedge tubers was higher than that of 2,4-D. Among the summer season treatments stale seed bed with irrigation followed by glyphosate application was the best in achieving higher level of control.

In allelopathic studies, nutsedge root exudates collected at sprouting stage inhibited the germination and growth of all the crop seeds tested *viz*., rice, cowpea, sesamum, okra and brinjal. Also the nutsedge extracts collected at different stages inhibited the growth and development of *Gomphrena decumbense* and *Synedrella nodiflora*.

The allelochemicals present in tubers of purple nutsedge was identified by High Performance Liquid Chromatography (HPLC) and it indicated the presence of p-hydroxy benzoic acid, p-coumaric acid, m-coumaric acid, vanillic acid and gentisic acid.

Appendices

APPENDIX-1

Weather parameters during experiment I (May 2000 to May 2001)

Month	Maximum temperature, ^{0}C	Minimum temperature, ^{0}C	RH, %	RF,mm	Sunshine hours
May, 2000	32.4	24.60	74.46	14.26	9.08
June "	29.3	22.70	83.25	84.90	5.50
July "	30.39	23.44	78.97	17.46	7.60
August "	28.34	21.95	77.60	66.40	5.40
September "	29.48	22.12	90.47	3.30	6.80
October "	30.49	22.04	85.46	19.70	7.60
November "	30.05	20.93	81.38	32.43	6.40
December "	33.10	19.20	71.10	0.0	7.90
January, 2001	32.30	20.10	72.80	9.60	7.20
February "	32.70	20.70	71.30	11.00	8.70
March	34.20	21.40	70.20	0.0	9.60
April	32.80	23.20	79.70	51.90	6.34
May	33.20	24.20	74.90	56.50	5.79

APPENDIX-II

Weather parameters during experiment II (I and II year)

Month	Maximum temperature ^{0}C	Minimum temperature, ^{0}C	RH, %	Evapo-ration, mm	RF, mm	Sunshine hours
December	30.43	20.26	77.05	2.9	47.8	7.9
January	30.46	20.63	77.04	3.1	3.2	7.2
February	32.24	21.34	75.23	3.6	16.2	8.7
March	32.92	22.45	73.68	4.9	0	9.6
February	30.5	22.26	75.8	3.7	15	9.12
March	32.95	23.5	74.95	4.6	16.7	9.8
April	33.1	24.8	76.97	4.2	50.6	7.89
May	31.5	25	80.08	3.6	200.1	7.14