

**STUDIES ON BIOLOGY OF *Cyperus* BULB BORER,
Athesapeuta cyperi Marshall AND BIOSUPPRESSION
OF *Cyperus rotundus* Linnaeus**

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA

in partial fulfilment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY (AGRICULTURE)

in

AGRICULTURAL ENTOMOLOGY

by

Ghassan Ibrahim

(Reg.No. 20013)



DEPARTMENT OF AGRICULTURAL ENTOMOLOGY

POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH,
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APPROVED BY



Dr. J.R. Kadam

(Chairman and Research Guide)



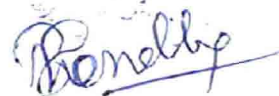
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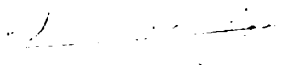
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POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA**

2003

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted by me or other person to any other University or Institute for a Degree or Diploma

Place : MPKV, Rahuri


(Ghassan Ibrahim)

Dated : / /2003.

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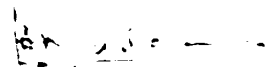
CERTIFICATE

This is to certify that the thesis entitled, "**Studies on Biology of *Cyperus* Bulb Borer, *Athesapeuta cyperi* Marshall and Biosuppression of *Cyperus rotundus* Linnaeus**", submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRICULTURAL ENTOMOLOGY**, embodies the results of a *bona fide* research carried out by **MR. GHASSAN IBRAHIM**, under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

The assistance and help received during the course of this investigation have been acknowledged.

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Maharashtra State (INDIA)

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(D.M. Sawant)

Place : MPKV, Rahuri

Dated : 10 / 03 / 2003.

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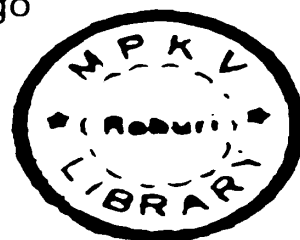
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LIST OF ABBREVIATIONS

| | | |
|--------|---|--|
| A | : | Amaranthus |
| atz | : | Atrazine |
| bb | : | <i>Cyperus</i> bulb borer, <i>Athesapeuta cyperi</i> |
| C | : | <i>Cyperus rotundus</i> |
| C.D. | : | Critical difference |
| C.R.D. | : | Completely Randomised Design |
| C.V. | : | Critical variation |
| chw | : | Care hand weeding |
| et al. | : | And others (<i>et alibi</i>) |
| Eve. | : | Evening |
| g | : | Gram |
| hw | : | Hand weeding |
| Max. | : | Maximum |
| Min. | : | Minimum |
| Mor. | : | Morning |
| MW | : | Meteorological week |
| N.S. | : | Non significant |
| O | : | Okra |
| rf | : | <i>Cyperus</i> rust fungus, <i>Puccinia romagnoliana</i> |
| S | : | Sorghum |
| S.E. | : | Standard error |
| sb | : | <i>Cyperus</i> stem borer, <i>Bactra venosana</i> |
| W | : | Wheat |

ABSTRACT

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A candidate for the degree
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Purple nutsedge or nutgrass, *Cyperus rotundus* L. is the world's worst weed in 52 crops in more than 90 countries. Investigations were undertaken to study biology of *Cyperus* bulb borer, *Athesapeuta cyperi* Marshall and biosuppression of *Cyperus rotundus* Linnaeus at Biocontrol Research Laboratory and Farm of Department of Entomology, M.P.K.V., Rahuri during 2000-2003.

Biology of *A. cyperi* : Average pre mating period was 3.5 days, while the mating period was 70 minutes. Female weevil was polyandrous, mate frequently with different males. Sex ratio of male to female was 1.13 : 1. The preoviposition, oviposition and postoviposition periods were 3-18 (av. 6.9), 22-55 (av. 31.3) and 40-137 (av. 58.6) days.

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respectively. The oviposition was restricted to the bulbs. A female laid 0 to 2 eggs/day and fecundity was 35-46 eggs (av. 42.1). Incubation period was 9.5 days with hatching percentage of 90. The grubs are internal feeders and feed only on the *Cyperus* bulbs. There were 4 grub instars. The duration of Ist, IInd, IIIrd and IVth instars was 4-6 (av. 4.6), 7-14 (av. 9.2), 8-14 (av. 10.8) and 11-17 (av. 13.8) days, respectively. As such total grub development period was 30-51 (av. 38.4) days. Prepupal and pupal stages lasted for 8-10 (av. 8.9) and 9-15 (av. 13.5) days, respectively. However, the total duration of life cycle from egg to adult emergence was 55 to 88 (av. 71.3) days.

Adults are slender, shiny black and measured 3.2 x 1.2 mm. Males are normal fliers. They possessed sharp tooth on the fore tibiae and dense hairs on the antennal club. The male weevils survived for 2 to 15 (av. 5.4), 2-16 (av. 6.5), 30-43 (av. 36.5) and 31-48 (av. 40.3) days by providing no food and no water, water only, food only and food and water, against the corresponding periods of 8-18 (av. 11.7), 10-18 (av. 12.5), 65-210 (av. 106.7) and 69-220 (109.4) days, respectively, for female weevils. There were 3 generations, wherein over 80 per cent population was in pupal stage in March, July and November. A Pteromalid, *Anisopteromalus calandrae* Howard was observed to parasitize (1.53 per cent) of the grubs of *A. cyperi*. The fecundity of *Cyperus* stem borer, *Bactra venosana* was 20-170 (av. 74.7) eggs and caterpillar period was 22-27 (av. 24.3) days.

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Host specificity test : Out of 25 crops and 12 weed species included in oviposition and feeding test, the weevils fed only on *C. iria*, *C. difformis* and *C. alternifolius* in the absence and on *C. esculentus* in the presence of *C. rotundus*. Oviposition was noticed on *C. esculentus* in the presence of *C. rotundus*. Besides, later grubs completed their development in *C. esculentus* only in laboratory experiment.

Losses : *C. rotundus* caused 65 (2.9 times) and 79.6 (4.9 times) per cent reduction in yield of sorghum and okra in pot culture, respectively. The loss was 36 per cent (1.5 times) in sorghum in field.

Seasonal incidence : The weevil infestation on *Cyperus* in field ranged from 2.6 – 15.6 per cent (av. 7.9). The peak activity of *Cyperus* bulb borer (13.9 %) and stem borer (20.3 %) were observed in August. The weevil infestation was significantly and negatively correlated with maximum air and soil temperature while the correlation was positive with morning and evening relative humidity. The multiple regression analysis showed that only 59 per cent of the weevil infestation related to weather parameters. However, 92 per cent of *Bactra* spp. infestation was related to meteorological factors.

Bioagents potential : A gravid female of *A. cyperi* caused 13 to 25 dead hearts (av. 20.9), release of 2 mated females/100 *Cyperus* plants caused 40 per cent dead hearts, 10 caterpillars of *B. venosana* damaged 23.5 per cent plants and combination of both the bioagents resulted in 62 per cent damage to the weed.

Biosuppression experiments : Pot culture experiment showed that sorghum was the most competitive crop. It significantly reduced growth of *Cyperus* plants as compared to amaranthus, wheat, gram and okra. The best treatment for the weed suppression was bulb borer (4 weevils/pot) + stem borer (2 larvae/pot) + atrazine (0.01 g/pot) + rust fungus (2×10^5 spores/ml). The treatment recorded lowest (1 : 0.3) multiplicability ratio, the most precise indicator of weed suppression, followed by the treatments with bulb borer + rust fungus and hand weeding which gave 14 and 20.3 tubers and 0.43 and 0.43 tuber multiplicability, respectively. The significantly highest income (Rs. 12985) was obtained in the treatment with bulb borer + stem borer + atrazine and rust fungus followed by the treatment with bulb borer and rust fungus (Rs. 12600). These treatments also reduced number of *Cyperus* plants, biomass, number of tubers and showed higher infestation of the bioagents. In okra crop, the best treatment was bulb borer and rust fungus which registered the lowest multiplicability ratio (1 : 1.2) and resulted in yield of 43.3 q/ha.

In sorghum field trials, the best treatments were bulb borer (10 weevils/plot) and care hand weeding, which showed highest infestation of the bioagents (22.2 to 34.6 %), lowest multiplication rate (1.01 to 3.7 times), least multiplicability ratio (0.37 to 1.3) and highest yield (17.3 to 22.3 q/ha). The trend of results of

this treatment was the same also in okra crop in field showing 18.6 per cent, 5 times, 2.4 and 25 q/ha for bioagent infestation, multiplication rate, multiplicability ratio and yield of okra, respectively.

Rust fungus : *Cyperus* rust fungus, *Puccinia romagnoliana* Maire and Sacc caused severe infection to *Cyperus* plants and reduced the multiplicability ratio by 28.9 per cent over the control.

Competitive vegetation : The smothering effect of the weed, *Hierarcium vagum* Jord resulted in 25 per cent reduction in plant number and 15.9, 22.0, 37.6 and 25.7 per cent reduction in number, weight, sprouted number and sprouting percentage of the tubers/ respectively.

Management strategy : The proposed *Cyperus* management strategy comprised of soil tillage, protecting *Cyperus* dead hearts for conserving bioagents, soil drainage, incorporating wide canopy crops in rotation, avoiding drift of chemical insecticides on weed, inoculative and inundative releases of *A. cyperi* and *B. venosana* and spray of rust fungus, *P. romagnoliana* on the weed and need based use of recommended herbicides.

INTRODUCTION

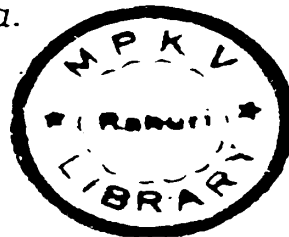
1. INTRODUCTION

Purple nutsedge or nutgrass, *Cyperus rotundus* Linnaeus (Cyperales : Cyperaceae) is called as 'Lavhala' in Marathi and 'Alsaad' in Arabic language (Plate 1a). In spite of utility of the weed tuber it is the world's worst weed in 52 crops occurring in more than 90 tropical, subtropical and temperate countries (Holm *et al.*, 1977).

Purple nutsedge is an extremely difficult weed to control because of the plant's biological adaptability. It propagates by tubers formed along underground rhizomes (Plate 1b). Each tuber produces upto thirteen shoots, normally one at a time due to apical dominance (Hammertom, 1974). Once a leafy shoot has established, a dense inter connected system of shoots, rhizomes and new tubers is rapidly produced (Hauser, 1962 and Horowitz, 1972). The fact that tubers may remain dormant in the soil, further favours its survival.

The perennial weed rarely propagates by seeds (Thullen and Keeley, 1979) but mostly by rhizomes.

The sedge family, Cyperaceae represents a diverse group of plants which has been used to make paper, rain garments and mats. It has been eaten, brewed, used as medicine and grown as ornamentals. There are about 4000 species belong to this family. Out of this, 220 species (5.5 %) are identified as weeds; most of them (42 %) belong to the genus *Cyperus*. Other genera in this family are *Eleocharis*, *Scirpus*, *Fimbristylis*, *Scleria*, *Kyllinga*, *Rhynchospora*, *Bulbostylis*, *Fuirea* and *Dichromena*.



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Plate 1 : *Cyperus rotundus*



A. Cotton field infested by *C. rotundus*



B. *C. rotundus* plant with tuber and rhizome chain

Tubers are recognized as the primary dispersal unit. They are produced on rhizomes consisting of rhizomatous tissues with numerous buds, the characteristics of stem tissues (Stoller *et al.*, 1972). Basal bulbs are similar to tubers occurring in the upper 10 cm layer of soil. If the weed cultured in field without interference from other plants, it may produce 10 to 30 million tubers per hectare in a season (Horowitz, 1972). In a greenhouse experiment a single tuber produced a system of 146 tubers and basal bulbs within three and half months (Smith and Fick, 1937). A tuber found at 12 inches below the soil surface can remain dormant in the soil for more than two and half years (Smith and Mayton, 1938).

The nutgrass possesses the highly efficient C_4 dicarboxylic acid photosynthetic pathway (Chen *et al.*, 1970). Plants with this characteristic continued to convert CO_2 into carbohydrates by the C_3 Calvin cycle and this weed converts 44 to 50 per cent of its dry weight into tubers (Williams, 1982).

Purple nutsedge can reduce yield of many crops from 12 to 89 per cent (William and Warren, 1975 and Okafor and De Datta, 1976). In spite of the nutsedge competition with other crops, the leaf canopy provides a favorable environment for certain insects and diseases. It is natural host of leafhopper, *Sanctanus fasciatus* (Dabek, 1979). Certain chemicals produced by the grass can reduce the growth and vigour of several crops. Since tuber is the most vital part for the weed multiplicability, maximum efforts to destroy maximum tubers will be the best solution to suppress the weed.

Cultural and mechanical methods are viable options for inclusion in any weed management programme. Selection of the management practices depends on growth habit, value of crop, yield losses inflicted by the weed, weather and labour availability. Crop rotation with faster growing competitive crops, hamper the weed growth by shade effect upto manageable levels. Ploughing or disking at an interval of 3 weeks or less during two consecutive growing seasons reduced the weed infestation by about 80 per cent (Smith and Mayton, 1938 and 1942). Mulching has not been effective for nutsedge management because it can penetrate organic or physical mulches (William, 1976).

Historically, almost all herbicides have been tested for control of purple nutsedge. However, most of the chemicals provide only poor or temporary control. Reasons for the failure include marginal translocation of herbicides to sites of action, temporary inhibition of tuber sprouting and control of new tuber formation or inconsistent control when applied at different stages of growth and under various environmental conditions. The herbicides have localized and temporary effect on the *Cyperus* suppression.

Biological control has the advantages of minimizing adverse impacts of herbicides on the environment, biota of the area, lower cost and long term suppression effect. A total of 132 insects have been associated with purple nutsedge. Approximately, half of these insects are known to feed on crop plants. Four insect bioagents are more specific to this weed. The three Tortricid Lepidopteran stem borers attacking *Cyperus* are *Bactra verutana* Zeller in the USA, *B.*

minima Meyrick and *B. venosana* Zeller in the Indian subcontinent and a *Cyperus* bulb boring Coleopteran weevil, *Athesapeuta cyperi* Marshall in Southeast Asia (Frick, 1978). Although mass production technique for *Bactra* spp. have been developed using artificial diet (Frick *et al.*, 1978 and Visalakshy Ganga, 2002), however, the effectiveness of *Bactra* spp. is limited by the egg parasitoid, *Trichogrammatoidea bactrae*, which is considered as a key mortality factor (Visalakshy Ganga and Jayanth, 1995). The stem borers rarely attack the *Cyperus* bulb and always leave chance for regeneration of the damaged weed plant.

Numerous fungal diseases are associated with the weed viz., *Alternaria tenuissima* Clint., *Puccinia canaliculata* Lage., *P. cyperi* Arm., *P. romagnoliana* Maire and Sacc., and *Phytophthora cyperi-rotundati* Sawada. Most of these pathogens are host specific and had variable effects on *Cyperus* growth. However, the rust fungus, *P. romagnoliana* considered as a potent pathogen for controlling the weed and an axenic culture of this pathogen has been developed (Bedi and Sokhi, 1994 and Bedi *et al.*, 1995). Among other pathogens nematodes and bacteria were also observed on *Cyperus* plants, but their potential and host specificity are not studied. Ducks and Geese also reported to feed on the grass and have been used to check its growth in small area (Mayton *et al.*, 1945).

However, *Cyperus* bulb borer, *Athesapeuta cyperi* M attacking vital portion, the bulb of the weed, which stops regeneration of almost all the infested *Cyperus* plants, so it could be a highly potent bioagent to suppress the weed. Rare and only primary

efforts have been made to study biology of the bulb borer weevil, *A. cyperi*. Similarly, so far efforts to explore possibility of biointensive management of the weed are lacking. Therefore, the studies on biology of *A. cyperi* and biosuppression of the weed were carried out under the conditions of Maharashtra state, India. The investigations were undertaken with the following objectives.

1. To study biology of *Cyperus* bulb borer, *Athesapeuta cyperi* Marshall (Coleoptera : Curculionidae) under the conditions of Maharashtra state.
2. To undertake host specificity test for *A. cyperi* on pot cultured plants.
3. To study the seasonal incidence of the bioagent in relation to some environmental factors.
4. To study potential of the weevil bioagent in the integration of the biointensive methods of management.
5. To develop *Cyperus* management strategy.



**REVIEW OF
LITERATURE**

2. REVIEW OF LITERATURE

The review of literature showed that there are rare references on the selected research topic. So, related references to the aspects of investigations have been quoted as supporting literature under this chapter.

2.1 Purple nutsedge, *Cyperus rotundus* Linnaeus

2.1.1 Classification

Purple nutsedge is a perennial monocot weed (Gleason, 1963).

The taxonomic status of nutsedge

| | | |
|-----------|---|------------------|
| Kingdom | : | Plant |
| Phylum | : | Angiospermae |
| Class | : | Monocotyledoneae |
| Order | : | Cyperales |
| Family | : | Cyperaceae |
| Genus | : | <i>Cyperus</i> |
| Species | : | <i>rotundus</i> |
| Authority | : | Linnaeus |

2.1.2 Distribution

The weed appears in 52 crops in 90 tropical, subtropical and temperate countries (Holm *et al.*, 1977). It is a serious weed in rice, sugarcane, cotton, maize, sorghum, soybean, peanut, vegetables and many plantation crops in countries in all continents.

2.1.3 Description

Purple nutsedge rarely reproduces by seeds (Thullen and Keeley, 1979). It mostly propagates by white and fleshy rhizomes with scaly leaves. Later, these became ligneous or wiry; either extend upward, horizontally or downward. Upward ones swell upon reaching the soil surface to form a basal bulb. It is 0.3 to 1 cm in diameter and produces shoots, roots and other rhizomes. Those which grow horizontally or downward give rise to tubers that repeat the cycle to form other tubers in a chain or to form new shoots (Ranade and Burns, 1925; Hauser, 1962 and Holm *et al.*, 1977). The tubers vary in length from 0.75 to 3.5 cm and in width from 0.3 to 1 cm.

Leaves : These are three ranked, shiny, dark green and appear corrugated in cross section. They are 6 to 10 mm wide and 10 to 35 cm long. The rachis, which grows through the centre of the leaf bundle, is erect, simple, smooth, triangular in cross section and 10 to 60 cm long. The rachis supports a terminal inflorescence which carries red, reddish-brown or purplish brown colour florets. Individual seeds are achenes, 1.5 mm long, ovate or oblong-ovate, three angled, dull olive-gray to brown or black in colour, covered with a network of gray lines. Each achene is sessile on the spikelet and is subtended and covered by a single scale or glume (Holm *et al.*, 1977 and Wills *et al.*, 1980).

Rhizomes : The young actively growing rhizomes are white and fleshy with an outer covering of scale leaves. Old mature rhizomes are brown, wiry and appear deteriorated.

Tubers : Tuber formation occurs at the apex of the rhizome in the meristematic region directly posterior to the leaf primordial. As tubers matured, the internodes do not elongate, the leaf primordial remain dormant, and parenchyma cells increase in girth and accumulate high concentrations of starch.

Basal bulb : The basal bulb (corm) is formed from the meristematic cells of the rhizome apex in a manner similar to that described for the tuber except that the leaf primordial produced shoot growth. A short stem extends acropetally with the leaves developing from compact nodes.

Roots : Roots evolve from the endodermis of tubers and bulbs.

C₄ photosynthetic pathway : Purple nutsedge possesses the highly efficient C₄ dicarboxylic acid photosynthetic pathway (Black *et al.*, 1969). Plants with this characteristic continue to convert CO₂ into carbohydrates by the C₃ Calvin cycle which is common to all photosynthetically active plants. However, it possesses an additional characteristic of a highly efficient phosphoenolpyruvate pathway (Downton and Tregunna, 1968).

Black *et al.* (1969) noted that species which fix CO₂ at high rates under conditions of increased temperature and light intensity coupled with characteristics such as rhizomatous spreading, have the potential of being serious weed pests.

2.1.4 Ecotypes

Many workers have reported ecotypic differences in purple nutsedge (Stoller and Weber, 1974 and Boldt *et al.*, 1976) on the basis of physical characteristics, type of flowering and length of the rachises supporting flowers.

2.2 Losses inflicted by *C. rotundus*

2.2.1 Direct losses in crop yields

Purple nutsedge can reduce yield of many crops. The reported losses in Horticultural crops due to this weed competition during the entire cropping season were (i) garlic 89 per cent, (ii) okra 62 per cent, (iii) tomato 53 per cent, (iv) carrot 45 per cent, (v) cucumber 43 per cent, (vi) green bean 41 per cent and (vii) cabbage 35 per cent (William and Warren, 1975). In case of Agronomical crops the estimated losses were (i) soybean 87 per cent, (ii) corn 79 per cent, (iii) rice 59 per cent, (iv) sugar cane 45 per cent (v) cotton 41 per cent, (vi) groundnut 32 per cent, (vii) cowpea 16 per cent and (viii) sorghum 12 per cent (Okafor and De Datta, 1976).

2.2.2 Allelopathic effects

Friedman and Horowitz (1970) conducted a preliminary experiment and demonstrated phytotoxicity in aqueous extracts from soil incubated with dead subterranean tissues of *C. rotundus*. Singh *et al.* (1970) showed that purple nutsedge tubers produced allelopathic substance which inhibited the growth of other plants in immediate area. Friedman and Horowitz (1971) found that the growth of barley (*Hordeum distichum* L.) seedling growing in vial was reduced by addition of ethanolic extract of *C. rotundus*. The germination of

barley, mustard and cotton was reduced in soil which had been infested previously with purple nutsedge. Chromatographic studies indicated that the inhibitors are phenolic substances. Horowitz and Friedman (1971) observed that the germination and growth of barley was inhibited when barley was sown in soil contained three months decayed subterranean parts of *C. rotundus*. Elmore (1985) reported that live, growing purple nutsedge produced substances which were toxic to radish. Jeong *et al.* (2000) indicated that rotundines A, B and C (three novel sesquiterpene alkaloids with an unprecedented carbon skeleton) were isolated from the rhizomes of *C. rotundus*. The structure of these substances elucidated by spectral and chemical methods.

2.3 Methods of management

2.3.1 Mechanical methods

Purple nutsedge tubers and basal bulbs are the vital parts of the weed by which the weed reproduces and spreads. The tubers are apparently carried to new localities with nursery stock, sweet potato and other plants, and even in potato tubers. Tillage implements separate the tubers and distribute them in other part of the field or other fields and consequently, entire farm may rapidly become infested. Decontaminating plants, tubers and farm implements from *Cyperus* bulbs and tubers helps to reduce the spread. Ranade and Burns (1925) found that an average of 1.5 per cent of the seeds produced was viable. Seed yield may be high with viability less than 5 per cent (Justice and Whitehead, 1946), so destruction of *Cyperus* flower had no significance in suppression of

the weed. Rao and Kanodia (1962) concluded that digging to soil depth and removing the tubers proved to be the best method to control *C. rotundus*.

2.3.2 Cultural practices

Crop rotation : It can have a beneficial effects on weed control.

Crop selection : Fast growing competitive crops which form a wide canopy quickly, reduce the growth and reproductive potential of the weed by shade effect (Hauser *et al.*, 1974; Teasdale and Frank, 1983 and William and Chiang, 1980).

In most crops, the first four to eight weeks are the most critical period of weed competition. A longer duration of weed control is necessary for maximum yields of non-competitive dwarf crops such as garlic or okra (William, 1976). Increased yield, less tillage and reduced herbicides use are benefits derived from using narrow rows and/or high seeding rates (Burnside and Colville, 1964; Peters *et al.*, 1965 and Walker and Buchanan, 1982).

Polythene mulch : Mulching has not been effective for nutsedge control (William, 1976) because nutsedge will penetrate organic or physical mulches. However, 1000 gauge black polythene film has been found useful in holding back nutsedge. The translucent mulches reduced *Cyperus* shoot biomass, tuber and rhizome number, and tuber biomass, 85-99 per cent (Patterson, 1998) in a green house experiments.

Killing tubers by desiccation : Nutsedge tubers survive almost indefinitely in dry soils if their feeding roots are in contact with moist soil, but if feeding roots are cut, the tubers dry out and when their

moisture content drops around 15 per cent, as contrasted to the normal moisture content, around 50 per cent, they die (Andrews, 1940). Tubers exposed on dry soil surface may be killed in as less as 4 days (Smith and Fick, 1937) in direct sunlight and low humidity. Tubers buried 2 to 4 inches below soil surface required 8 to 16 days for drying under dry condition (Ranade and Burns, 1925 and Smith and Fick, 1937). According to Andrews (1940) tubers survived for five weeks at a soil moisture of 16 per cent and 3 weeks at 11 per cent. But in humid regions, soil gets dry enough very rarely to permit the effective use of cultivations. On such soils tillage must be continued at frequent intervals unless the tuber reserves are exhausted. Mudaliar and Ayyer (1945) found that, it is possible to eradicate nutgrass by keeping the land fallow for seasons and cultivating it periodically.

Tillage : Pre plant tillage can be beneficial in stimulating tuber sprouting of nutsedge. Soil disturbance also tends to move tubers closer to the surface where desiccation and cold temperature are more prevalent (Wax, 1975 and Stoller, 1981). The maximum benefits in nutsedge control are observed if tillage is delayed until substantial tuber sprouting has occurred (William and Chiang, 1980 and Stoller, 1981). Purple nutsedge can be reduced to manageable levels by ploughing or disking at intervals of 3 weeks or less for 2 years and by planting a winter grain or hay crop in October to be harvested by June (Smith and Mayton, 1938 and 1942). But minimum tillage should be practiced to reduce erosion and conserve fossil fuels.

Thakur (1955) found that the weed reaches its lowest level of reserved starch in storage organs after 18 days from

sprouting and suggested synchronization of this time for controlling the weed.

Effect of mowing : Summerlin *et al.* (2000) conducted field studies to determine the response of *C. rotundus* to mowing regimes. The treatment included mowing at 1.3 and 3.3 cm with mowing frequencies of three times per week and once a week, respectively. Reduction in *C. rotundus* shoot number were observed beginning from 6th week after the initial treatment in first year and 9th week in second year for the 1.3 cm mowing regime. The 3.8 cm mowing regime did not reduce shoot number until the final evaluation of each year.

2.3.3 Chemical control

Historically, many herbicides have been evaluated for the control of *C. rotundus*, although most of the chemicals provided only poor or temporary control due to marginal translocation of herbicides to sites of action, temporary inhibition of tuber sprouting and control of new tuber formation or inconsistent control when applied at different stages of growth and under various environmental conditions. Brief summary of herbicides evaluated given below :

| Sr. No. | Group/mode of action | Herbicide | | |
|---------|--|-----------------------|---|--|
| | | Common Name | Results | Reference |
| 1. | Growth regulator | 2, 4-D | Erratic results | Cowart and Ryker, (1950) Loustalot <i>et al.</i> (1954) |
| | | | Repeated applications are needed | Bhan (1966) Standifer (1974) |
| | | | Killed shoots | Harrison (1946) |
| | | | Inhibited growth of lateral rhizomes and tubers | Bhan <i>et al.</i> (1970) Burr and Warren (1972) |
| | | | 9 sprays gave good control | Hauser (1963) |
| | | | Weed sprouted within a month of treatment | Loustalot <i>et al.</i> (1954) |
| | | | | |
| 2. | Photosynthetic inhibitors | Atrazine | Gave consistent control by split pre and directed post emergence | Parochetti (1974) Wax (1975) Pawar <i>et al.</i> (2000) |
| | | Bromacil and Terbacil | Effective control by pre emergence spray | Keeley and Thullen (1974) Yang (1978) |
| | | Linuron | Marginal control | Burr and Warren (1972) |
| 3. | Pigment synthesis inhibitors | Amitrol | Excellent control at 4 th week No control at 6 th week | Hauser (1963) |
| 4. | Cell membrane destroyers | Paraquat | Inconsistent control | Hammerton (1974) Standifer (1974) |
| | | | Desiccate leaves and stop tuber growth | Mc Cue and Sweet (1981) |
| | | | Effect temporary and new sprout emerged | Teo <i>et al.</i> (1973) |
| 5. | Sprouted shoot inhibitors | EPTC | More effective than other thiocarbamate herbicides | Bell <i>et al.</i> (1962) Baker <i>et al.</i> (1970) Yip and Sweet (1978) Warren and Coble (1999) |
| 6. | Root and shoot inhibitors of seedlings | Metolachlor | 80 per cent tuber mortality | Dixon and Stoller (1982) Wilcut <i>et al.</i> (1994) |
| | | Dichlobenil | Incorporation with soil gave better control | William <i>et al.</i> (1984) |

Table contd.....

| Sr. No. | Group/mode of action | Common Name | Herbicide | Reference |
|---------|----------------------------------|-------------------------------------|---|---|
| 7. | Disturbing amino acid metabolism | Glyphosate | Suppress the resprouted tubers | Zandstra and Nishimoto (1977) Appleby and Paller (1978) Keeley et al., (1986) Bryson et al. (1994) |
| | | | Low doses controlled younger plants | Stoller <i>et al.</i> (1975) Hunt and Linscott (1983) Satao <i>et al.</i> (1998) Nadanassababady and Kandaswamy (2000) |
| 8. | Soil fumigant | Methyl bromide chlorobromopropen | Eradication of patches of nutsedge | Leonard and Harris (1950) Day (1953) |
| 9. | Oil carriers/ adjuvant | 2, 4-D Linuron Atrazine | Oils (Diesel, Pentox-2 and Rich field) increased effectiveness | Burr and Warren (1972) Nishimoto (1981) Colby (1967) Nishimoto <i>et al.</i> (1978) Stoller <i>et al.</i> (1975) |
| | | Bentazon | // | |
| | | Paraquat | Nitrogenous carriers increased toxicity | Thangaraj and Rao (1973) |
| | | Glyphosate | Applying ammonium sulfate enhanced glyphosate activity | Suwannamek and Parker (1975) |

Interaction between cultural and chemical control methods

Marcelli (1957) and Meadly (1957) suggested the control of nutsedge by first disturbing the underground system and spraying the chemicals when tubers sprouted. Contrary to this, Burts (1958) obtained the best kill of nutgrass by first spraying 2, 4-D at the rate of 2 to 4 lb a.e. per acre and then disking repeatedly at 10 to 20 days interval. However, Bhan (1966) conducted a field trial to study the relative efficiency of three formulations of 2, 4-D (sodium, amine and ester), used at three concentrations (1.5, 2 and 2.5 lb a.e. per acre) with three times of application and three levels of cultivation in Agra. He found that all the formulations of 2, 4-D were able to control nutsedge successfully. Repeated application of herbicides has significantly reduced the stand of nutgrass and increased the per cent kill. Increased number of soil tillage increased the stand of nutgrass.

2.3.4 Biological control

Biological control of weeds with insects has been popular in India for long. With the launching of "All India Coordinated Research Project on Biological Control of Crop Pests and Weeds" in 1977, the subject gathered momentum. So far, more than 30 insects have been imported into India from the country of origin of many exotic weeds that are considered to be serious in the country (Anonymous, 1989).

Observations on the effects of living organisms on weeds dated from 1795 when cochineal mealy bug, *Dactylopius ceylonicus* Green (Hemiptera : Dactylopiidae) was introduced from Brazil for

suppression of prickly pear, *Opuntia vulgaris* Miller (Tyron, 1910, Goeden, 1978 and Julien, 1982). Since that time, biological control of weeds employed mainly the classical strategy of introducing natural enemies from areas of coevolution.

The strategy of augmenting an indigenous natural enemy to kill or suppress the weed host by applying high inoculum pressure at an appropriate time has been termed bioherbicide tactic (Templeton and Smith, 1977) or inundative biological control (Wapshere, 1979).

Self perpetuation and dissemination of the introduced enemies was essential to suppress successfully the weed below economic level (Andres *et al.*, 1976 and Andres, 1982). This classical tactic is suited particularly for weeds that are distributed widely in less intensively cropped or non cropped areas (Goeden, 1978). Guideline to introduced foreign organisms for biological control of weeds has been established (Klingman and Coulson, 1982).

2.3.4.1 Higher animal

Mayton *et al.* (1945) attempted eradication of *Cyperus* with white leghorn chickens and geese and found that the former were effective only in small enclosed areas while the latter proved effective only in enclosed $\frac{1}{2}$ acre cropped areas.

2.3.4.2 Insects

Julien (1982) listed 225 organisms including 178 insect and 6 mite species against 111 weed species. Out of these many gave successful control and several failed to establish or suppress the

target weeds. Phatak *et al.* (1987) listed a total of 77 insect species associated with purple nutsedge. Major species are given below

| Species | Order and Family |
|--------------------------------------|----------------------------|
| <i>Chaetocnema pulicaria</i> | Coleoptera : Chrysomelidae |
| <i>Athesapeuta cyperi</i> | Coleoptera : Curculionidae |
| <i>Sphenophorus cariosus</i> | Coleoptera : Curculionidae |
| <i>Aleurocybotus</i> spp | Hemiptera : Aleurodidae |
| <i>Schizaphis siniscirpi</i> | Hemiptera : Aphididae |
| <i>Deltocephalus sonorou</i> | Hemiptera : Brachypteridae |
| <i>Macrosteles fasciifrons</i> | Hemiptera : Cicadellidae |
| <i>Peregrinus maidis</i> | Hemiptera : Delphacidae |
| <i>Chorizococcus rostellum</i> | Hemiptera : Pseudococcidae |
| <i>Ferrisia virgata</i> | Hemiptera : Pseudococcidae |
| <i>Phenacoccus solani</i> | Hemiptera : Pseudococcidae |
| <i>Amsacta moorei</i> | Lepidoptera : Arctiidae |
| <i>Heliothis virescens</i> | Lepidoptera : Noctuidae |
| <i>Spodoptera exempta</i> | Lepidoptera : Noctuidae |
| <i>Marasmia trapezalis</i> | Lepidoptera : Pyralidae |
| <i>Nymphula depunctalis</i> | Lepidoptera : Pyralidae |
| <i>Bactra</i> spp | Lepidoptera : Tortricidae |
| <i>Cydia perfricta</i> | Lepidoptera : Tortricidae |
| <i>Matsumuratettix biroglyphicus</i> | Lepidoptera : Tortricidae |

However, many of these insects known to feed on crop plants. In India, some insects have been reported to feed on nutgrass (Singh, 1997).

| Species | Order and Family |
|--|----------------------------|
| <i>Chaetocnema basalis</i> | Coleoptera : Chrysomelidae |
| <i>Athesapeuta cyperi</i> | Coleoptera : Curculionidae |
| <i>Echinocnemus</i> spp | Coleoptera : Curculionidae |
| <i>Myloccerus cardoni</i> and <i>M. dorsatus</i> | Coleoptera : Curculionidae |
| <i>Xanthochelus faunus</i> | Coleoptera : Curculionidae |
| <i>Trogophloeus indicus</i> | Coleoptera : Staphylinidae |
| <i>Euproctis virguncula</i> | Lepidoptera : Lymantriidae |
| <i>Laelia lilacina</i> | Lepidoptera : Lymantriidae |
| <i>Mocis frugalis</i> | Lepidoptera : Noctuidae |
| <i>Sesamia inferens</i> | Lepidoptera : Noctuidae |
| <i>Spodoptera mauritia</i> | Lepidoptera : Noctuidae |
| <i>Calamotropha unicolorellus</i> | Lepidoptera : Pyralidae |
| <i>Chilo</i> spp | Lepidoptera : Pyralidae |
| <i>Crambus atkinosoni</i> | Lepidoptera : Pyralidae |
| <i>Bactra minima</i> and <i>B. venosana</i> | Lepidoptera : Tortricidae |

Four insects were adequately host plant specific, three Tortricid moths, *Bactra verutana* Zeller in USA, *B. minima* Meyrick and *B. venosana* Zeller in the Indian subcontinent and one weevil, *Athesapeuta cyperi* Marshall in Southeast Asia (Frick, 1978).

i. *Athesapeuta cyperi* Marshall

The *Cyperus* bulb borer, *A. cyperi* was first recorded from the Philippines from where it was imported and released in Hawaii for the control of *C. rotundus* in 1925 (Swezey, 1926 and Williams,

1931). Later, Marshall (1928) described the weevil from specimens from both the Philippines and Hawaii.

Poinar (1964) reported that the egg incubation period was 4 to 5 days. The grubs fed and pupated in bulbs. The pupal stage lasted for 10 to 11 days. The preoviposition period was about two months. No parasitoids were observed. Sankaran and Srinath (1966) found that *A. cyperi* attacked *C. rotundus* around Bangalore, India and it was active throughout the year and caused 16.5 per cent infestation to nutsedge plants in sorghum and maize fields. Schroder (1970) proposed to import *A. cyperi* and *Bactra* spp. from India into West Africa for the biological suppression of *C. rotundus*. Khan (1971) observed that *A. cyperi* completed its development on *C. rotundus* and one grub completely destroyed one potted plant and no regeneration occurred. Sankaran and Rao (1972) opined that *A. cyperi* has the merit consideration as biological agent for the control of *C. rotundus*.

Habib (1976a) found that *A. cyperi* is widely distributed on *C. rotundus* in Pakistan and was found to occur upto an altitude of 1850 m. The only other host of the weevil in nature was *C. bulbosus*. The weevil over winter in diapause from February to March. The highest per cent infestation recorded was in April to May (7 to 8 %) and October (6 %). Oviposition commenced on 18th day after the mating took place, eggs were deposited in bulbs and incubation period was 8 to 9 days. The total larval duration was 40 to 64 days. The pupal period was 12 to 16 days. Some adults lived for about one year. Fecundity was 27 to 29 eggs. Two parasitoids were recorded (i)

an unidentified Braconid parasitoid during May to August and (ii) *Anisopteromalus calandrae* Howard (Hymenoptera : Pteromalidae) during April to August. It was concluded that *A. cyperi* once established might prove to be a good biocontrol agent of *C. rotundus*. Gupta (1977) reported that *A. cyperi*, *B. minima* and *B. venosana* were appeared to keep the weed under biotic pressure, however suspected that whether these insects were harmful to any cultivated plant was not known.

ii. The Genus *Bactra*

Fourteen species of this cosmopolitan genus attack plants in three Monocotyledonous families, Cyperaceae, Typhaceae and Juncaceae (Diakonoff, 1964; Forbes, 1923; Heinrich, 1926 and Poinar, 1964).

According to the available literature, the genus *Bactra* seemed to be restricted to the family Cyperaceae. Some *Bactra* spp. have been recorded from *Scirpus* spp (Diakonoff, 1956), *B. venosana* is also known from *Kyllinga* spp. (Poinar, 1964) while most other species are from the genus *Cyperus*. Habib (1976b) stated that *Bactra* spp. showed a phylogenetically stable host pattern where the insect and the host plant (*Cyperus* spp.) seemed to have co-evolved with almost no host transference over long periods and the Gramineous plants (sorghum, rice, oats, etc.) were not preferred by the *Bactra* spp.

Frick and Garcia (1975) stated that the life cycle of *Bactra* was about 30 days. So, 6 generations were needed for *Bactra* to achieve a high degree of infestation, which only came at the end of the growing season.

Garcia and Frick (1975) concluded that large scale releases of *Bactra* would be needed early in the growing season to suppress the weed growth and therefore they developed an artificial diet and rear it for 35 consecutive generations, each of which averaged 28 days. The use of first instar larvae generally gave consistent results. In the green house, an infestation of shoots with a single application of 2 to 5 larvae/shoot (Frick and Garcia, 1975) or with 3 larvae/shoot (Frick and Quimby, 1977) caused significant damage to purple nutsedge.

According to Frick (1978), wherever purple nutsedge is a problem, biological control with insects probably will involve manipulating the local or introduced population of a native species of *Bactra*. This manipulation should consist of an early season inundative release so, the larvae can attack the plants early in the growth cycle before the crop is established. Frick and Chandler (1978) reduced above ground growth of purple nutsedge by 30 to 60 per cent within 4 to 7 weeks after last release. Yield of seed cotton following purple nutsedge control with 3 to 5 releases of *B. verutana* was equivalent to yield from crops not infested with the weed. Trematerra and Ciampolini (1989) reported five species of *Bactra* viz., *B. furfurana*, *B. lanceulana*, *B. robustana*, *B. bactrana* and *B. venosana* infesting nutsedge.

Visalakshy Ganga (2002) reported the development of an artificial diet for mass rearing of *B. venosana*. The ingredients of the artificial diet were, wheat gem (32 g), sucrose (32 g), ascorbic acid (1 g), alphacel (4.7 g), streptomycin (0.03 g), multivitamin capsules (0.3

g), yeast capsules (0.9 g), agar (22 g), distilled water (850 ml) and *C. rotundus* leaf powder (33 g). Developmental duration, pupal weight, fecundity and per cent egg hatched of *B. venosana* maintained on natural hosts and on artificial diet up to five generations was on par.

Factors limiting the effectiveness of *Bactra*

Several reasons for the over all ineffectiveness have been advanced. These factors include (1) Poor temporal synchronization for adequate multiplicability for suppression of *Cyperus* in early to mid growth period since moth population increase in late season (Keeley *et al.*, 1970), (2) Survival of rarely more than 1 larva/shoot, even though more number of eggs may be laid on the leaves of a shoot (Sankaran and Srinath, 1966), (3) Larvae generally not feeding or with limited feeding on the basal bulb, leading to continued production of new aerial shoots and tubers (Cashmore and Compbell, 1946) and (4) Parasitism of the moth egg by *Trichogramma* spp in Hawaii (Poinar, 1964), *T. australiacum* in India (Sankaran and Srinath, 1966) and parasitism of larvae by some Braconid or Ichneumonid wasps.

2.3.4.3 Other bioagents

The possibility of using snails in biological control of weeds has been demonstrated by some workers. Gohbara and Yamaguchi (1994) reported that the snails (*Lymnaea* spp and *Physa* spp) have an effect on nutgrass, barnyard grass and broadleaf weeds in paddy fields. Shibayama (1994) also used snails for control of weeds in paddy fields. In Taiwan, the snail, *Pomacea canaliculata* was introduced from South America in 1970 and within a few years it

established in rivers, ponds ditches and paddy fields. Snails fed on algae and many kinds of higher plants including rice seedlings. However, the snails were controlled with pesticides at the time of planting or transplanting to prevent any damage to rice seedlings. After the seedling stage, the snails were allowed to feed on dicots and sedges (Chiang, 1994).

2.3.4.4 Biocontrol with plant pathogens

The idea of controlling weeds with plant pathogens dated from 1893 in New Jersey when Experimental Station Bulletin reported a list of fungi injurious to weed seedlings (Halsted, 1893 and 1894). Numerous fungal diseases are associated with purple nutsedge viz., *Alternaria tenuissima* (Betria, 1973), *Cintractia limitata* (Ling, 1950), *Puccinia canaliculata* (Standley, 1916 and Phatak, 1984), *P. cyperi* (Weiss, 1950), *P. philippinensis* (Yen, 1974), *P. romagnoliana* (Purohit *et al.*, 1979 and Bedi and Sokhi, 1994), *Phytophthora cyperi-rotundati* (Sawada, 1927), *Dactylaria higginsii* (Barreto and Evans, 1995 and Kadir *et al.*, 2000a) and *Cercospora caricis* (Barreto and Evans, 1995). Other organisms known to attack the weed are (i) ring nematode, *Crisonemoides onoensis* (Hogger and Bird, 1976 and Hollis, 1977), cyst nematode, *Heterodera mothi* (Husain *et al.*, 1978), (ii) Bacterium, *Xanthomonas oryzae* (Chattopadhyay and Mukherjee, 1968) and (iii) Lucerne dwarf virus (Freitag, 1951).

Among these pathogens, *Puccinia canaliculata*, *P. romagnoliana* and *Dactylaria higginsii* have shown promising results in controlling *C. rotundus*. Extensive work on the biological control potential of the rust fungus, *P. canaliculata* has been done especially

in the USA (Phatak *et al.*, 1983 and Bruckart *et al.*, 1985). This potent fungus was registered as an augmentative bioherbicide by the US Environmental Protection Agency in 1988 (Phatak *et al.*, 1995). The product, namely Dr. Biosedge (containing non formulated spores) has not attracted much interest because of laboriousness of collection and stringent conditions required for storage.

The work done at the Punjab Agricultural University on the rust fungus, *P. romagnoliana* has yielded good results. When 3 weeks old plants were inoculated with suspension of the rust urediniospores, 100 per cent leaves were diseased. The total leaf area covered by the rust was 15.08 and 30.40 per cent, in pot and field trials, respectively. Plant mortality was 11.58 per cent in pots and 34.16 per cent in the field (Bedi and Sokhi, 1994). A hormone supplemented Murashige – Skoog medium was tried for culturing *P. romagnoliana* and leaves of *C. rotundus* with chlamydospores resulted in the appearance of yellow necrotic spots after 15-20 days which later became dark brown and necrotic (Bedi *et al.*, 1995).

Dactylaria higginsii is another promising fungal bioagent for controlling *C. rotundus*. Barreto and Evans (1995) reported that the fungus sporulated readily in culture. Evans (1995) concluded that the fungus could be evaluated for mycoherbicidal potential. The potential of this fungus as a bioherbicides was field tested in natural population of *C. rotundus* (Kadir *et al.*, 2000a). The results showed that three applications of 10^6 conidia/ml provided more than 90 per cent nutsedge control. The authors suggested *D. higginsii*, as an effective bioherbicides candidate and it deserve further development



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for commercial use. In another experiment, Kadir *et al.* (2000b) showed that the fungus required a minimum dew period of 12 hours and a six leaf stage of *Cyperus* plants inoculated with 10^6 conidia/1 ml. Under these conditions, 75 per cent leaf area damaged and excellent weed control was achieved. The authors suggested that the limitation of need for a long dew period for infection and disease development may be overcome by using inoculum amended with moisture retaining gels.

2.3.4.5 Integration of biocontrol in weed management system

Little efforts have been directed toward integration of biological control with more conventional weed control practices.

Quimby and Frick (1980) used a novel approach to extend the effectiveness of *B. verutana* by first coating the larvae with glyphosate and releasing them to attack and to carry the glyphosate into *Cyperus*. However, this approach may not be practical because of the ineffectiveness of the insect larvae. Phatak (1984) demonstrated that the rust fungus, *P. canaliculata* and paraquat combination provided 99 per cent control of nutsedge compared with 60 per cent control with rust and 10 per cent with paraquat alone. Callaway *et al.* (1985) reported significant interactions when sequential applications of rust (*P. canaliculata*) followed by imazaquin, bentazon and metribuzin. Most rust and herbicide combinations reduced number of live plants, total number and weight of tubers.

2.3.4.6 Effect of other plants on *C. rotundus*

a. Sweet potato (*Ipomoea batatas*)

Peterson and Harrison (1995) reported that due to allelopathic influence of sweet potato cultivar 'Regal' on *Cyperus*, shoot dry weight, total shoot length and tubers number were significantly lowered than the control (47, 36 and 19 per cent inhibition, respectively). The active material were heat stable, had a molecular weight of 250 ± 100 a.m.u. and possibly contained protocatechuic and linoleic acid.

b. Eucalyptus leaf leachates and oil

Babu *et al.* (1966) showed that 20 per cent of leaf leachate applied five times decreased shoot height, root length and chlorophyll content but not the weed biomass. While, application of eucalyptus oil @ 1 per cent significantly reduced all the growth characters and biomass of purple nutsedge.

**MATERIAL AND
METHODS**

3. MATERIAL AND METHODS

Laboratory and field "Studies on Biology of *Cyperus* bulb borer, *Athesapeuta cyperi* Marshall and biosuppression of *Cyperus rotundus* Linnaeus" were undertaken during 2000-2003 at the Central Campus of Mahatma Phule Krishi Vidyapeeth, Rahuri. The details of material and methods used in the experimentation are described in this chapter.

3.1 Material

3.1.1 The weed, purple nutsedge

| | | |
|----------------|---|----------------------------------|
| Class | : | Angiospermae |
| Subclass | : | Monocotyledoneae |
| Order | : | Cyperales |
| Family | : | Cyperaceae |
| Botanical name | : | <i>Cyperus rotundus</i> Linnaeus |

3.1.2 Test bioagents

3.1.2.1 *Cyperus* bulb borer

| | | |
|-----------------|---|------------------------------------|
| Class | : | Insecta |
| Order | : | Coleoptera |
| Family | : | Curculionidae |
| Subfamily | : | Baridinae |
| Scientific name | : | <i>Athesapeuta cyperi</i> Marshall |

The taxonomic identity of the weevil along with *Bactra venosana* was confirmed by Dr. V.V. Ramamurthy, Division of

Entomology, IARI, New Delhi and it was registered under RRS No. 532-545-2001.

3.1.2.2 **Cyperus stem borer**

| | | |
|-----------------|---|-------------------------------|
| Class | : | Insecta |
| Order | : | Lepidoptera |
| Family | : | Tortricidae |
| Scientific name | : | <i>Bactra venosana</i> Zeller |

3.1.2.3 **Cyperus rust fungus**

| | | |
|-----------------|---|---|
| Division | : | Eumycota |
| Subdivision | : | Basidiomycotina |
| Class | : | Teliomycetes |
| Order | : | Uredinales |
| Scientific name | : | <i>Puccinia romagnoliana</i> Maire and Sacc |

The rust fungus infected leaves were sent to Mycologist, Agharkar Research Institute, Pune for identification. The fungus identity was confirmed by Dr. (Mrs.) Alaka Pande, Scientist E-2 and In-charge, Department of Mycology and Plant Pathology, Division of Plant Science, Agharkar Research Institute, Pune.

3.1.3 **Other material**

Earthen pots of 35 cm diameter and 40 cm height, plastic containers of various sizes, thermometer, hygrometer, blades, forceps, muslin cloth, rubber bands, soft hair brushes, plastic tray, flask, alcohol, hand gloves, blotting papers, ocular and stage micrometer, haemocytometer, microscope etc., were made available at Biocontrol

Research Laboratory of Department of Entomology, PGI, M.P.K.V., Rahuri.

Seeds of horticultural and agronomic crops used in host specificity test were obtained from the Senior Vegetable Breeder, Department of Horticulture and from Seed Cell, Department of Botany, sorghum seeds were supplied by AICRP on Sorghum, M.P.K.V., Rahuri.

3.2 Methodology

3.2.1 Stock cultures

3.2.1.1 *Cyperus* plants

Pot culture

Tubers of purple nutsedge collected from field were washed and dipped in water in a container and floated ones were discarded. Tubers filled in containers and kept wet for further use by intermittent sprinkling of water. Small and medium sized tubers were used for rearing of the grub. Fifteen tubers each of 1 g were sown in each earthen pot duly filled with light soil. The weed plants in pots were maintained at the Biocontrol Research Laboratory and watered frequently and uniformly.

Plot culture

Four hundred tubers were dibbled in 3 x 3 m sized plot at spacing of 15 x 15 cm for maintaining permanent culture of nutsedge plants to breed *A. cyperi*, *B. venosana* and rust fungus, *P. romagnoliana*. Such 6 plots were sown at the interval of a month and irrigated regularly.

3.2.1.2 ***Cyperus* bulb borer, *A. cyperi***

The stock of the weevil culture was initiated by collection of grubs and pupae from field. Infested nutsedge plants were collected from field. The upper portion of each plant was cut at 3 cm above the basal bulb and all roots and rhizomes were removed. Then, each basal bulb was opened carefully with the help of forceps to collect grubs and pupae of the weevil. The grubs were reared upto adult stage using *Cyperus* tubers as food. The pupae were kept in plastic containers at ambient temperature with 60 per cent R.H.

The emerged weevils were kept in 5 liters capacity plastic jar filled with soil upto 10 cm height. *Cyperus* tubers were already sown in soil. The top of the container was covered with muslin cloth and held tightly with rubber bands. Adequate quantity of water was added intermittently to keep the soil moist. In each container 20 weevils were released. Behaviour of the adult weevils, mating and egg laying was critically observed.

3.2.1.3 ***Cyperus* stem borer, *B. venosana***

Larvae of the stem borer were collected from the field and reared upto adult stage on *Cyperus* plants grown in soil in plastic jar and used for the study. Pupae were also collected and held in plastic containers. The adults were provided with honey solution for feeding.

3.2.1.4 ***Cyperus* rust fungus, *P. romagnoliana***

P. romagnoliana infected *Cyperus* plants were maintained in earthen pots at the Biocontrol Research Laboratory.

3.2.2 Biology of *A. cyperi*

3.2.2.1 Egg characters and incubation

The eggs laid on duly provided *Cyperus* bulbs were incubated at ambient temperature of 19°C in November, 2001 and 21 C in August 2002 with 80 per cent R.H. Morphological and biometrical characters were recorded with the help of ocular and stage micrometer fitted in microscope. Incubation period and hatching percentage was also noted.

3.2.2.2 Grub characters and rearing

Morphological and biometrical characters of newly hatched grubs were recorded under microscope. Being the grub an internal feeder and to facilitate monitoring of grub instars, new techniques developed for their rearing are described below.

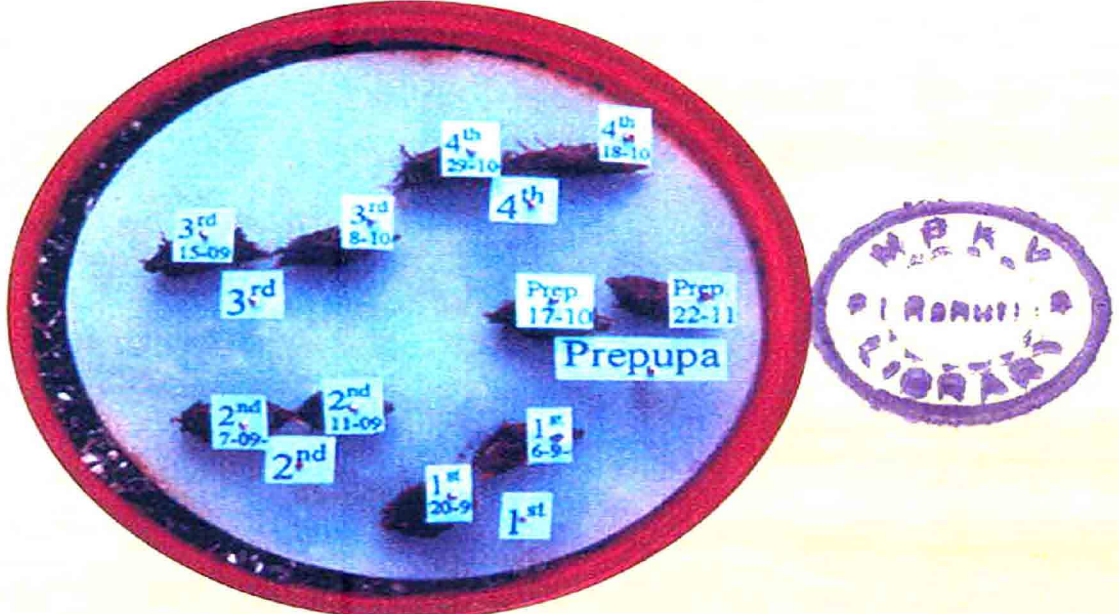
i. *Cyperus* tuber slit method to study grub instars

The *Cyperus* tubers of various sizes and ages were used for the purpose. A tuber was cut into two halves. A pit equal to grub size was made at one side of a half portion. Respective grub was placed gently in the pit and concealed by placing another half portion of the tuber maintaining natural form of the tuber. The two halves were secured as such tightly by pinning ensuring safety to inner stages of the bioagent (Plate 2). The pinned tubers were labelled mentioning date, grub instar and serial number. The labelled tubers were placed on moist sand in plastic dishes which kept in another container at 60 to 70 per cent R.H. The grubs in the tubers were examined daily under microscope by removing the pin for presence of exuviae and shed head capsule, change in colour and feeding

Plate 2 : Tuber slit method for grub rearing



A. Preparation of tubers for grub rearing



B. Tubers concealing growing grubs



capacity. Presence of the shed head capsule and exuviae was considered as an indication of starting of new instar. The label of new instar was changed (continuing the same serial number) while repinning of the tuber and placed in the container. The damaged tubers were changed. Newly formed tubers were used for rearing of the first instar grub. For studying the number and duration of the grub instar, a set of 100 of such tubers was kept under daily observation.

ii. ***Cyperus* tuber top beheaded method to study total duration of grub**

Another new method was developed in the present study for rearing the grub upto adult stage. Tubers were cut horizontally at one tip and tunneled with the help of sharp narrow forceps. Grub was inserted in the tunnel and closed with little quantity of the frass of the tuber and kept in container at 60 per cent R.H. After approximate grub period, the tubers were opened daily upto pupal stage. The pupae were collected and grubs were provided with fresh tunnelled tubers.

3.2.2.2.1 Grub instars

Hundred grubs were reared individually using *Cyperus* tuber slit method 3.2.2.2 (i) and observed daily to note change in instar and duration of preceding instar on the basis of presence of shed head capsule and exuviae.

3.2.2.3 Prepupal stage

The last instar grubs were further observed daily at 8, 15 and 23 hrs to find out prepupal period. The period from ceasing of feeding by last instar grub to formation of pupa was recorded as

prepupal period. Morphological and biometrical characters of the prepupa were recorded. Observations were also recorded on the aspect under field conditions.

3.2.2.4 Pupal stage

After shedding the skin of the prepupa, the period from formation to eclosion of pupa was counted as the pupal period. Observations on length, breadth and morphological features of pupa were recorded. Gradual changes in the pupa upto adult formation were noted critically.

3.2.2.5 Adult weevil

3.2.2.5.1 Morphological and biometrical characters

Morphological characters of different body regions, distinctive features of female and male weevils, appendages and chaetotaxy were recorded.

3.2.2.5.2 Sex ratio

To determine the sex ratio, 300 adults were examined during August 2001 to December 2002. The males were differentiated on the basis of the presence of the tooth on the front tibiae (Plate 6a) as described by Marshall (1928).

3.2.2.5.3 Mating

A pair of newly emerged male and female adults was released on *Cyperus* plants grown in small container of ½ litre capacity to study mating behaviour. The top of the container was covered with muslin cloth and secured firmly in position with rubber band. Such 25 sets were prepared for the purpose. Observations on premating, mating, coital periods and mode of mating were recorded.

In another set of 5 containers, in each, one female was released with five males to observe the polyandrous phenomenon. At each mating the concerned male was removed from the container. As such the number of males mated with the same female was recorded.

3.2.2.5.4 Oviposition and fecundity

A newly emerged female with two males were released on a *Cyperus* plant in 500 ml sized plastic container. It was duly filled with fine sand to facilitate easy planting and uprooting of the *Cyperus* plants. Fifty of such containers were observed daily. The period before oviposition considered as preoviposition period. The site of oviposition was located by careful examination of whole plant under microscope. The period from first to the last egg laid was considered as oviposition period. During the period, the fecundity was also recorded. The female survival period after last egg laid was considered as postoviposition period.

3.2.2.5.5 Longevity of weevil

The survival of the weevils was studied by providing (i) only food, (ii) only water (iii) both food and water and (iv) no food and no water from June to December, 2001. In each set 10 pairs (male-female) of the weevil were released. In case of providing food and water, the weevils were released in the containers described under sub-section 3.2.1.2 and water was provided by fully soaked cotton swab. In second set only water soaked cotton swab was provided in the containers. Only sprouted tubers were kept in third set at alternative days. In fourth set of no water and no food only the weevils were released in empty containers. All containers were held

at ambient temperature and 80 per cent R.H. Adult behaviour and survival periods were recorded.

3.2.2.6 Duration of life cycle

Based on the observed duration of egg, grub, prepupal and pupal stages and adult death, the total period required for completion of a life cycle was worked out.

3.2.3 Method of mass rearing of the weevil, *A. cyperi*

Plastic containers each of 200 ml sized were filled with soil and watered. One tuber was sown in each container. Thirty containers were kept in a small tray (40 x 40 x 5 cm) and watered regularly. Such trays were covered by mosquito net cloth to avoid migration of weevils. After 15 days of sprouting of tubers, 5 pairs of weevils were released in each tray. Weekly observations of the weevil infestation were recorded by noticing the dead hearts. The infested plants were taken out of the plastic container and planted in earthen pots and labeled indicating the date of infestation. The pots were watered frequently. Ensuring completion of grub period by dissecting few sample plants, the basal bulbs of the infested plants were collected and placed in another container at 60 per cent R.H. for daily observations on adult emergence. The emerged weevils were collected and kept in the container described under subsection 3.2.1.2.

3.2.4 Host specificity test for *A. cyperi*

Twenty five crops and twelve weed species tested in this experiment from September to December, 2001 are given below:

Crops included in host specificity test.

| Sr. No. | Crop | Cultivar | Botanical nomenclature | Family |
|---------|--------------|-------------------------|--------------------------------|----------------|
| 1. | Amaranthus | RVAS-92-6-2 | <i>Amaranthus tricolor</i> | Amaranthaceae |
| 2. | Niger | IGP-76 | <i>Guizotia abyssinica</i> | Compositae |
| 3. | Sunflower | M-2, M-3, M-4 | <i>Helianthus annuus</i> | Compositae |
| 4. | Sweet potato | Local | <i>Ipomoea batatas</i> | Convolvulaceae |
| 5. | Bottle gourd | Samrat | <i>Lagenaria siceraria</i> | Cucurbitaceae |
| 6. | Bitter gourd | Phule green gold | <i>Momordica charantia</i> | Cucurbitaceae |
| 7. | Cucumber | Hemangi | <i>Cucumis sativus</i> | Cucurbitaceae |
| 8. | Ridge gourd | Phule Sucheta | <i>Luffa acutangula</i> | Cucurbitaceae |
| 9. | Rice | Kajjat-4 | <i>Oryza sativa</i> | Gramineae |
| 10. | Sorghum | Swati, M-35-1 and CSH-9 | <i>Sorghum bicolor</i> | Gramineae |
| 11. | Barley | Ambar (K-71) | <i>Hordeum vulgare</i> | Gramineae |
| 12. | Maize | Deccan 101 | <i>Zea mays</i> | Gramineae |
| 13. | Pearl millet | RHRBI-138 | <i>Pennisetum typhoides</i> | Gramineae |
| 14. | Wheat | NIAW-34 | <i>Triticum aestivum</i> | Gramineae |
| 15. | Cowpea | Pusa komal | <i>Vigna sinensis</i> | Leguminosae |
| 16. | Gram | PG-12, PG-5 and Vishal | <i>Cicer arietinum</i> | Leguminosae |
| 17. | Groundnut | TG-26 and JL-220 | <i>Arachis hypogaea</i> | Leguminosae |
| 18. | Pigeonpea | BSMR-736 | <i>Cajanus cajan</i> | Leguminosae |
| 19. | Soybean | JS-335 | <i>Glycine max</i> | Leguminosae |
| 20. | Onion | N-2-4-1 | <i>Allium cepa</i> | Liliaceae |
| 21. | Cotton | Desi | <i>Gossypium arboreum</i> | Malvaceae |
| 22. | Okra | Arka Anamika | <i>Abelmoschus esculentus</i> | Malvaceae |
| 23. | Chilli | Phule Joty | <i>Capsicum annuum</i> | Solanaceae |
| 24. | Potato | Kufri Jyoti | <i>Solanum tuberosum</i> | Solanaceae |
| 25. | Tomato | Pragati | <i>Lycopersicon esculentum</i> | Solanaceae |

Weeds included in host specificity test

| Sr. No. | Botanical nomenclature | Common name | Family |
|---------|-------------------------------|-----------------------------|------------|
| 1. | <i>Bromus sterilis</i> | Field brome | Gramineae |
| 2. | <i>Cynodon dactylon</i> | Bermuda grass | Gramineae |
| 3. | <i>Digitaria sanguinalis</i> | Large crabgrass | Gramineae |
| 4. | <i>Echinocoloa colona</i> | Jungle rice | Gramineae |
| 5. | <i>Elusine indica</i> | Goose grass | Gramineae |
| 6. | <i>Cyperus alternifolius</i> | Umbrella grass | Cyperaceae |
| 7. | <i>C. difformis</i> | Small flower umbrella plant | Cyperaceae |
| 8. | <i>C. esculentus</i> | Yellow nutsedge | Cyperaceae |
| 9. | <i>C. iria</i> | Rice flat sedge | Cyperaceae |
| 10. | <i>Fimbristylis feruginea</i> | Fimbristylis | Cyperaceae |
| 11. | <i>Scirpus maritins</i> | Bulrush | Cyperaceae |
| 12. | <i>Typha latifolia</i> | Common cattail | Typhaceae |

Seeds of the test crops and weeds were wrapped in moist blotting papers and kept wet upto germination by sprinkling water frequently. After germination, ten seedlings of each of the crop and weed species were sown in plastic containers duly filled with sand and kept at ambient temperature. Two pairs of predated and 48 hours starved weevils were released on each genotype. Also a pair of newly emerged weevils was released on test plants in separate container. The observations on weevil behaviour, feeding and egg laying were recorded. Further, five neonate grubs were released on and inside the stems or tubers of the test plant species in another set. Observations on feeding and mortality of the grubs were recorded.

3.2.5 Seasonal incidence of *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae*

Fortnightly observations on the percentage of infestation of the *Cyperus* bulb borer (*A. cyperi*) and stem borer (*B. venosana*) were recorded at M.P.K.V., Rahuri farm from September, 2000 to August, 2002. Three selected patches each of 1 m² in *Cyperus* infested field were used for such observations. The patches were not disturbed by any cultural practices. Total number of plants and plants with dead hearts in each 1 m² patch were counted. At the initiation of shoot drooping the infested plants were dissected to find out presence of grub or larva to ensure damage by the weevil or moth in the bulb or at the base of stem. The average percentage of infestation for each bioagent was worked out. The grubs in infested *Cyperus* plants were examined for the presence of any parasitoid and average percentage of parasitism was worked out. The reared parasitoid adults were identified as *Anisopteromalus calandrae*. Infestation was studied in relation to abiotic (Temperature, R.H. % and rainfall) factors and correlation and multiple regression coefficients were worked out.

3.2.6 Biosuppression of *C. rotundus*

3.2.6.1 Damage potential of an individual weevil

Pot culture experiment was carried out in 5 earthen pots. For this 100 tubers of *Cyperus* were sown in each pot. One gravid female and two males were released on two weeks old *Cyperus* seedlings. The pots were concealed with muslin cloth sleeve. *Cyperus* dead hearts were counted upto 2 months age of the potted weed.

3.2.6.2 Pot cultural experiments

3.2.6.2.1 Influence of cropping pattern and integrated measures on suppression of *C. rotundus* in pot culture

A pot culture trial with 22 treatments designed in C.R.D. with 3 replications was conducted from January to May, 2002 to study impact of interactions of some crops with integration of methods of management on suppression of *C. rotundus*.

Details of treatments

| Sr. No. | Treatments* | Abbreviated form |
|---------|--|---------------------|
| 1. | <i>Cyperus</i> and gram | C + G |
| 2. | <i>Cyperus</i> and amaranthus | C + A |
| 3. | <i>Cyperus</i> and wheat | C + W |
| 4. | <i>Cyperus</i> and sorghum | C + S |
| 5. | <i>Cyperus</i> , sorghum and gram | C + S + G |
| 6. | <i>Cyperus</i> , sorghum and amaranthus | C + S + A |
| 7. | <i>Cyperus</i> , sorghum and bulb borer | C + S + bb |
| 8. | <i>Cyperus</i> , sorghum, gram and bulb borer | C + S + G + bb |
| 9. | <i>Cyperus</i> , sorghum, amaranthus and bulb borer | C + S + A + bb |
| 10. | <i>Cyperus</i> , sorghum, bulb borer and rust fungus | C + S + bb + rf |
| 11. | <i>Cyperus</i> , sorghum, gram, bulb borer and rust fungus | C + S + G + bb + rf |
| 12. | <i>Cyperus</i> , sorghum, amaranthus, bulb borer and rust fungus | C + S + A + bb + rf |
| 13. | <i>Cyperus</i> , sorghum and stem borer | C + S + sb |
| 14. | <i>Cyperus</i> , sorghum and atrazine | C + S + atz |

Table contd....

| Sr. No. | Treatments | Abbreviated form |
|---------|--|-------------------------------|
| 15. | <i>Cyperus</i> , sorghum, bulb borer and stem borer | C + S + bb + sb |
| 16. | <i>Cyperus</i> , sorghum, bulb borer and atrazine | C + S + bb + atz |
| 17. | <i>Cyperus</i> , sorghum, stem borer and rust fungus | C + S + sb + rf |
| 18. | <i>Cyperus</i> , sorghum, bulb borer, stem borer and atrazine | C + S + bb + sb + atz |
| 19. | <i>Cyperus</i> , sorghum, bulb borer, stem borer, atrazine and rust fungus | C + S + bb + sb + atz + rf |
| 20. | <i>Cyperus</i> , sorghum and hand weeding | C + S + hw |
| 21. | Only <i>Cyperus</i> | C only |
| 22. | Only Sorghum | S only |

* Number of plants/pot and doses are mentioned below.

Considering soil surface area of pot (0.1 m²) and recommended spacing, the number of crop plants/pot was 5, 4, 3 and 5 in case of wheat, gram, amaranthus and sorghum, respectively.

The pots were filled uniformly with thoroughly mixed soil. Fifteen *Cyperus* tubers each of about 1 gram were sown in each pot, except in treatment 22. Basal doses of fertilizer were applied at sowing time. A hand weeding was carried out for all treatments on 20 days after germination of the crop and two more hand weedings were carried out in T₂₀. However other weeds were removed frequently. Atrazine was applied as pre emergence spray @ 0.01 g/pot i.e. 1000 g/ha in respective treatments. Suspension of *Puccinia romagnoliana* (2 x 10⁵ spores/ml) was sprayed 3 times at 15 days interval as described by Narute *et al.* (2001) in concerned treatments. After 15 days of hand weeding, two females and 2 males of *Cyperus*

bulb borer were released per pot in the morning and 2 larvae of *B. venosana* were released/pot in respective treatments.

At the harvest, total number of survived plants, yield of crops per pot were recorded and the averages for each of the treatments were worked out. Number of *Cyperus* plants, number of infested plants, dry weight of above ground portion, length of leaves, fresh weight and number of tubers, length of rhizomes, number of tubers in series and size of tubers were recorded.

Viability of *Cyperus* tubers was observed by incubating them for 20 days in wet containers and multiplicability ratio was worked out by dividing the number of sprouted tubers by number of (15) sown tubers. Finally, the data were subjected to statistical analysis.

3.2.6.2.2 Influence of hand weeding and bioagents on suppression of *C. rotundus* in pot cultured okra

A pot culture trial with 7 treatments was laid out in C.R.D. with 3 replications during January to May, 2002 to study impact of okra cropping, hand weeding, weevil bioagent and rust fungus on suppression of *C. rotundus*.

The soil surface area of each earthen pot was 0.1 m². Fifteen *Cyperus* tubers were sown in each of the pots and five plants of okra were allowed to grow in each pot. Hand weeding, release of *A. cyperi* and spray of rust fungus were carried out as described in subsection 3.2.6.2.1.

Details of treatments

| Sr. No. | Treatments | Abbreviated from |
|---------|---|------------------|
| 1. | <i>Cyperus</i> and okra | C + O |
| 2. | <i>Cyperus</i> , okra and hand weeding | C + O + hw |
| 3. | <i>Cyperus</i> , okra and rust fungus | C + O + rf |
| 4. | <i>Cyperus</i> , okra and bulb borer | C + O + bb |
| 5. | <i>Cyperus</i> , okra, rust fungus and bulb borer | C + O + rf + bb |
| 6. | <i>Cyperus</i> alone | C |
| 7. | Okra alone | O |

Number of *Cyperus* plants, number of infested plants, weight of biomass of above ground portion; number, weight and viability of tubers were recorded and multiplicability ratio was worked out. Yield of green fruits of okra was also recorded. Finally, data were subjected to statistical analysis.

3.2.6.3 Field experiments

3.2.6.3.1 Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in sorghum in field

Two separate experiments were conducted in Autumn and Winter seasons of 2002-2003, to confirm the trend of results obtained in pot culture experiments. The field trials were laid out in R.B.D. with 3 replications to study the potential of the bioagents (weevil and rust fungus) and shade effect of sorghum crop on suppression of *Cyperus* multiplicability. Seeds of sorghum variety CSH-9 were sown on 26.7.2002 in Autumn (*Kharif*) and that of M 35-

1 on 10.10.2002 in Winter (*Rabi*) season. The gross and net plot sizes were 2.70 x 1.80 m and 1.80 x 1.50 m, respectively adopting the spacing of 45 x 15 cm. One meter gap was maintained between the plots.

Details of treatments for Autumn trial

| Sr. No. | Treatments* | Abbreviated form |
|---------|---|------------------|
| 1. | <i>Cyperus</i> and sorghum | C + S |
| 2. | <i>Cyperus</i> , sorghum and hand weeding | C + S + hw |
| 3. | <i>Cyperus</i> , sorghum + bulb borer and care hand weeding | C + S + bb + chw |
| 4. | <i>Cyperus</i> , sorghum and rust fungus | C + S + rf |
| 5. | <i>Cyperus</i> , sorghum and bulb borer | C + S + bb |
| 6. | <i>Cyperus</i> , sorghum, rust fungus and bulb borer | C + S + rf + bb |
| 7. | <i>Cyperus</i> only | C |

* Details of operations and doses described below

First experiment was conducted under natural infestation of the weed, while the second one was conducted in *Cyperus* free land, where 50 tubers were sown in each experimental plot, except in T₇ where only sorghum crop was grown and the treatment of normal hand weeding was skipped. General hand weeding was done in all treatments after 20 days of crop germination and thereafter 2 hand weedings were carried out in normal hand weeding treatment with an interval of 20 days for the Autumn trial. While care hand weeding treatment was done by removing all weeds avoiding the infested and small *Cyperus* plants at 20 and 40 days of release of the weevils.

Bioagent doses :

Cyperus bulb borer : 5 pairs of weevils/replication/treatment in T₃, T₅ and T₆.

Cyperus fungus : 2 x 10⁵ spore/ml suspension was sprayed 3 times at 20, 40 and 60 days after general hand weeding in T₄ and T₆.

However, other weeds were removed frequently upto 40 days of release of the weevils. Number of plants, number of infested plants, number and weight of the tubers before and after treatment were observed in 3 soil samples of 1 cubic foot/1.5 m², biomass and yield of sorghum were recorded and data was subjected to statistical analysis.

Rating for *Cyperus* rust fungus damage : The observations on rust fungus infection were recorded on the basis of 0 to 5 damage grades considering intensity of the fungus infection and its effect on the plant health.

The rust fungus, *P. romagnoliana* infection grades

| Grade | <i>Cyperus</i> area covered by rust spots (%) | Effect on <i>Cyperus</i> plant |
|-------|---|--|
| 0 | Nil | Healthy |
| 1 | < 5 % | No effect |
| 2 | 6 to 10 % | No effect |
| 3 | 11 to 20 % | Leaf tip yellowing |
| 4 | 21 to 30 % | Drying of leaf tip and yellowing of leaf |
| 5 | 31 and above | Drying of almost all leaves |

3.2.6.3.2 Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in okra in field

The field experiment laid out in R.B.D. with 3 replications in Autumn (*Khariñ*) season of 2002 to confirm the trend of results of pot culture experiment in respect of study the potential of *A. cyperi* and the rust fungus along with the shade effect of okra on the suppression of the *Cyperus* and its multiplicability. Seeds of okra (Arka Anamika) were sown on 20.7.2002. The gross and net plot sizes were 2.4 x 3.0 and 1.2 x 2.40 m size adopting the spacing of 30 x 15 cm. The gap of 1 m was maintained between plots. The doses and methods of conducting this trial were the same as described under sub-section 3.2.7.3.1 for Autumn sorghum experiment.

Details of treatments

| Sr. No. | Treatments | Abbreviated form |
|---------|---|------------------|
| 1. | <i>Cyperus</i> and Okra | C + O |
| 2. | <i>Cyperus</i> , okra and hand weeding | C + O + hw |
| 3. | <i>Cyperus</i> , okra, bulb borer and care hand weeding | C + O + bb + chw |
| 4. | <i>Cyperus</i> , okra and rust fungus | C + O + rf |
| 5. | <i>Cyperus</i> , okra and bulb borer | C + O + bb |
| 6. | <i>Cyperus</i> , okra, rust fungus and bulb borer | C + O + rf + bb |
| 7. | <i>Cyperus</i> only | C |

Observations on number of *Cyperus* plants/plot, infested plants/plot, tubers before and after treatment in 3 samples of 1 cubic

foot/plot, biomass and yield of dry fruits of okra were recorded and the data were subjected to statistical analysis.

3.2.7 Ancillary observation

3.2.7.1 Survival of different stages of *A. cyperi* in water

The study was conducted to determine the effect of flooded water (as it happens sometimes in field) on the survival of the grubs and adults. A set of 10 individuals of each of the grub instars, prepupa, pupa and adult was released in 500 ml sized beakers with 200 ml water and observed upto death of each test individual.

3.2.7.2 Life cycle and damage potential of *Cyperus* stem borer *B. venosana*

The simultaneous observations on egg, larval and pupal periods and fecundity and damage potential were recorded while rearing of the bioagent on pot cultured *Cyperus* plants in wooden cages for the purpose of *Cyperus* biosuppression experiment.

3.2.7.3 Effect of *Cyperus* rust fungus, *P. romagnoliana* on *C. rotundus*

A trial was conducted during the rainy season of 2002 (August – November) on three plots (3 x 2 m) heavily infested by one year old *Cyperus* plants. The plots were watered frequently. Three sprays of suspension of the rust fungus spores (2×10^5 /ml) at 15 days interval were conducted on two plots. Only water was sprayed on the plots on a day before and two days after each spray to create humid microclimate for the fungal infection. Number of survived plants, number of tubers before and after treatment, number of sprouted tubers and tuber sprouting per cent were recorded and finally

multiplicability ratio was calculated. The rust fungus damage was rated as per the details given under subsection 3.2.6.3.1.

3.2.7.4 Smothering effect of natural vegetation on *C. rotundus*

A feeler trial on the smothering effect of the natural vegetation was carried out during August, 2002 to January, 2003. The weed, *Hierarcium vagum* Jord. was observed to supersede the *C. rotundus*. Hence it removed from one 3 x 2 m sized plot heavily infested with *C. rotundus* and it was allowed to grow in another plot of similar size and *Cyperus* infestation for 6 months. Plots were watered frequently. After six months when *H. vagum* matured, the observations on number of *H. vagum* and *Cyperus* plants, number, weight and sprouted number of tubers were recorded to explore the possibility of using the easy to uproot and destroy weed, *H. vagum* as a source of competitive displacement to hard to kill *C. rotundus* in uncultivated lands.



**RESULTS AND
DISCUSSION**

4. RESULTS AND DISCUSSION

The results of the investigations on "Studies on Biology of *Cyperus* Bulb Borer, *Athesapeuta cyperi* Marshall and Biosuppression of *Cyperus rotundus* Linnaeus" are presented and discussed in the light of available literature.

4.1 Biology of *A. cyperi*

4.1.1 Egg

4.1.1.1 Site and process of oviposition

Field as well as laboratory observations on the site of oviposition revealed that the females oviposited exclusively in the basal bulbs of *C. rotundus* plants. Eggs were deposited in holes made by the female at the proximal portion of the basal bulbs (Plate 3b).

However, the egg laying did not interrupt the growth of the plant. The bulb length increased by 2 to 3 mm upto egg hatching and the egg site at this time appeared nearly at the centre of the bulb. The place of oviposition showed blackening of the damaged tissues around the laid egg on removing 2 to 3 outer scaly leaves of the bulb. Eggs were stuck in the hole of the bulb tissues and not easily separated from them.

4.1.1.2 Behaviour of the female during oviposition

The holes of oviposition were made by the female by penetrating the rostrum to the depth of 2 mm inside the bulb tissues. The shoots selected by females for oviposition were 2-3 mm in diameter, usually had 4-5 leaves and bulb of which was not below 4

cm deep in soil. More egg laying or infestation was observed in light, semidry and recently ploughed soil. No eggs of the *Cyperus* stem borer, *Bactra* spp. were observed on the plant which already infested by the weevil. The migrated larvae of the moth also avoided the weevil infested plants.

4.1.1.3 Morphological and biometrical characters

The freshly laid eggs of the weevil were transparent and pale cream in colour. Chorion was soft, brittle and irregular shaped. Most of the eggs were oval shaped. Some ones were roundish, curved oval and oblong shaped (Plate 3c). Majority of the eggs possessed an extended narrow portion at one end, where usually the head of the grub was located. Since the chorion of the freshly laid egg was soft, it was rupturing on slightest touch.

At fifth day of incubation, the larval mandibles appeared as two dark blades near the extended portion of the egg. The head became more visible and the mandibles started to move. On tenth day, the larva became totally visible through the chorion and even respiratory system and alimentary canal were visible.

The dimensions of eggs measured with ocular micrometer are shown in Table 1.

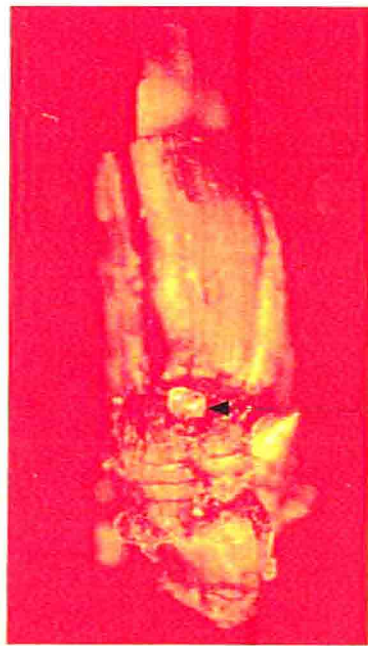
Table 1. Dimensions of 200 eggs of *A. cyperi*

| Length (mm) | | Breadth (mm) | |
|-------------|--------------|--------------|-------------|
| Range | Mean | Range | Mean |
| 1.09 – 1.71 | 1.29 ± 0.076 | 0.78 – 1.08 | 0.90 ± 0.03 |

Plate 3 : Mating and oviposition of *A. cyperi*

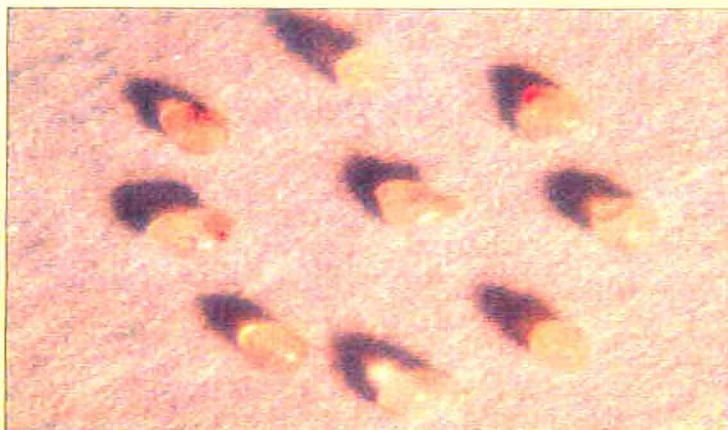


A. Mating



Egg

B. Site of oviposition



The egg size ranged from 1.09 x 0.78 to 1.71 x 1.08 mm with an average of 1.29 ± 0.076 x 0.90 ± 0.03 mm. Habib (1976a) reported that the eggs were pearly white and deposited in the middle region of the bulb.

4.1.1.4 Eclosion

The grub started moving inside the egg before 6 to 8 hours of hatching. It made several rounds inside the egg intermittently; each round required about 10 minutes to complete. The mandibles were always moving and the grub pushed the chorion by its head. Due to repeated action of pushing, the chorion ruptured, usually at the centre of egg and grub came out.

4.1.1.5 Incubation period

The data on incubation period are presented in Table 2.

Table 2. Incubation period of egg of *A. cyperi*

| Period | No. of eggs observed | Incubation period (days) | | Hatching (%) | Average | |
|-----------|----------------------|--------------------------|------------------|--------------|------------|--------|
| | | Range | Mean | | Temp. (°C) | RH (%) |
| Nov. 2001 | 100 | 8-12 | 10.56 ± 0.61 | 94 | 19 | 80 |
| Aug. 2002 | 100 | 7-10 | 8.34 ± 0.49 | 86 | 21 | 80 |

The incubation period ranged from 8 to 12 days with an average of 10.56 ± 0.61 days. The hatching percentage was 94 in November, 2001. The average incubation period in August, 2002 was 8.34 ± 0.49 days with hatching percentage of 86 at ambient temperature. The August, 2002 temperature (21 °C) was seemed to reduce the incubation period and hatching percentage.

The incubation period observed in the present investigations in November, 2001 and August, 2002 was more or less

similar to that (8 to 9 days) reported by Habib (1976a) in Pakistan. However, under the conditions of Hawaii, Poiner (1964) recorded the incubation period of 4-5 days.

4.1.2 Grub

4.1.2.1 Morphological and biometrical characters

There were four instars of the grub.

4.1.2.1.1 First instar

The neonate grub was transparent and pale cream coloured (Plate 4a). The length of the grub ranged from 1.41 to 2.34 mm with an average of 1.96 ± 0.1 mm (Table 3).

Table 3. Body length and width of head capsule of the grub instars

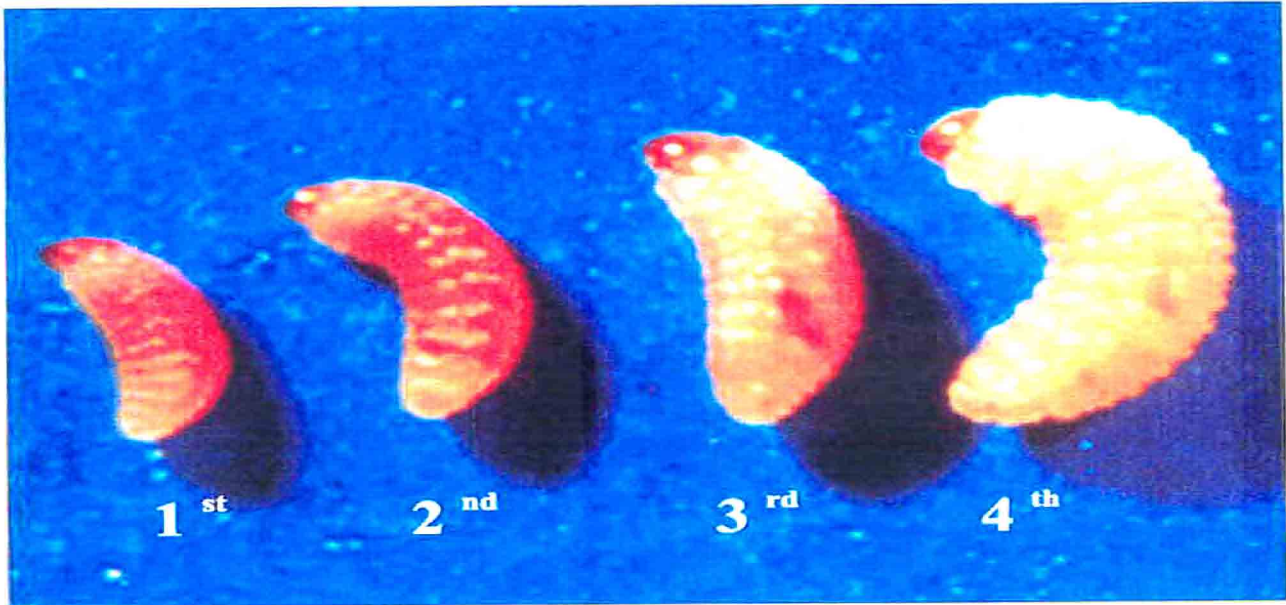
| Grub instars* | Body length (mm) | | Head width (mm) | |
|-------------------|------------------|-----------------|-----------------|-----------------|
| | Range | Mean | Range | Mean |
| I st | 1.41-2.34 | 1.96 ± 0.10 | 0.31-0.55 | 0.43 ± 0.02 |
| II nd | 2.11-3.44 | 2.77 ± 0.15 | 0.36-0.56 | 0.49 ± 0.02 |
| III rd | 2.81-4.27 | 3.58 ± 0.19 | 0.56-0.78 | 0.64 ± 0.03 |
| IV th | 2.97-5.63 | 4.53 ± 0.29 | 0.81-0.98 | 0.89 ± 0.03 |

*Number of observations 100 for each of the instars

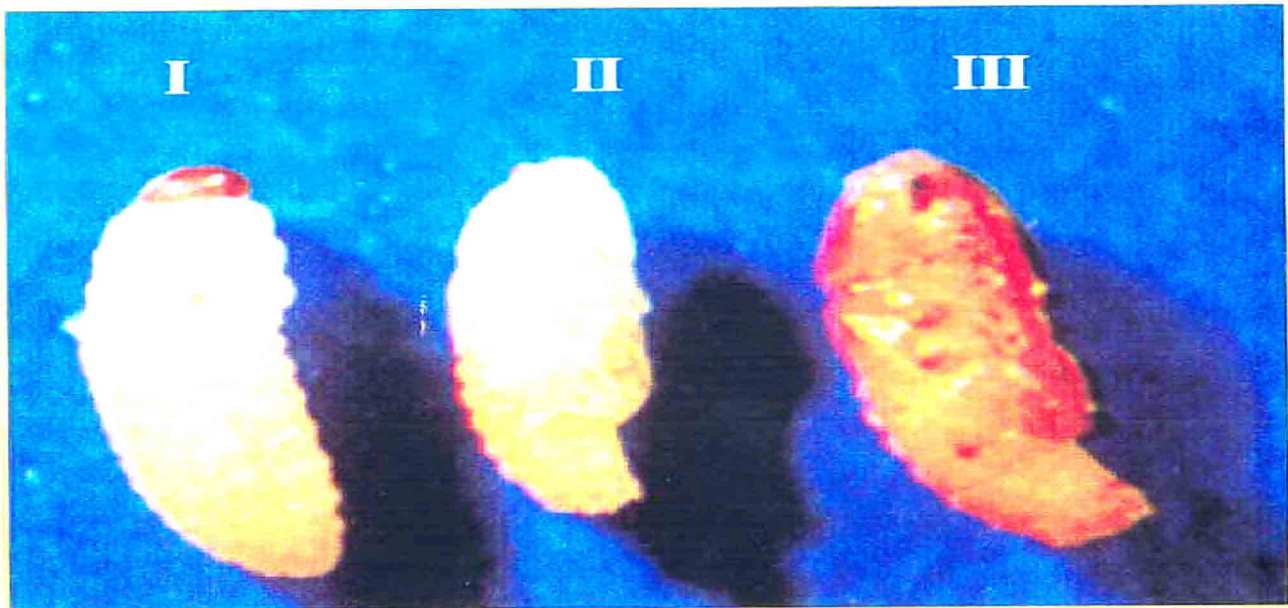
Head : The width of the head capsule ranged from 0.31 to 0.55 mm with an average of 0.43 ± 0.02 mm. The head was pale brown, possessed strong black mandibles having double toothed tips and well developed brown maxillae. Labial palpi were shorter than maxillary palpi. A ring of eight hairs was surrounding the mouth parts.

Thorax : It was transparent. The segments were well developed, distinct and broader on the ventral side. First thoracic segment

Plate 4 : Grubs and pupae of *A.cyperi*



A. Grub instars



B. I. Prepupa , II. Fresh Pupa, III. Matured Pupa

seemed to be slightly covered the base of the head while contraction of the body.

Abdomen : It was also transparent with nine visible segments and a telson. The tracheal system was visible, light brown in colour, running along the body from head to the telson. Tracheal system was peripneustic. A pair of spiracles was present on each segment at lateral side of thorax and abdomen. Total 13 pairs of spiracles were present. Spiracles and lateral trachea connecting main trachea were also visible. Empty and filled digestive system was clearly visible. Colour of the digestive tract changed from reddish to brownish on feeding.

Chaetotaxy : There were 8 pairs of hairs on the head. These were in symmetry on the head region. A pair of hairs was present on each of the sternite of thoracic segments, ventral side of last four abdominal segments and dorsal side of last five abdominal segments. Those hairs were prominent throughout the entire grub development.

4.1.2.1.2 Second instar

The second instar grub was not morphologically much distinct from the first instar (Plate 4a). It was semitransparent. The body length ranged from 2.11 to 3.44 mm with an average of 2.77 ± 0.15 mm. The head capsule was darker than that of first instar and its width ranged from 0.36 to 0.56 mm with an average of 0.49 ± 0.02 mm (Table 3).

4.1.2.1.3 Third instar

It was almost similar to second instar (Plate 4a). The body became more opaque and inner system became invisible. The body length ranged from 2.81 to 4.27 mm with an average of 3.58 ± 0.19 mm. Similarly, head capsule width ranged from 0.56 to 0.78 mm with an average of 0.64 ± 0.02 mm (Table 3).

4.1.2.1.4 Fourth and last instar

The body colour was whitish during initial days. It changed gradually to milky white at the end of the instar. Grub was stout, fleshy and curved (Plate 4a). The body length ranged from 2.97 to 5.63 mm with an average of 4.53 ± 0.29 mm. The width of the head capsule ranged from 0.81 to 0.98 mm with an average of 0.89 ± 0.03 mm (Table 3).

4.1.2.2 Duration

Instarwise duration of the grub is shown in Table 4.

Table 4. Duration of grub stage of *A. cyperi* during October, 2001 to February, 2002.

| Instar | Number observed | Duration (days) | | Temperature ($^{\circ}$ C) | | R.H. % |
|-------------------|--------------------|-----------------|------------------|-----------------------------|------|--------|
| | | Range | Mean | Max. | Min. | |
| I st | 50 | 4-6 | 4.6 ± 0.32 | 29 | 20 | 75 |
| II nd | 50 | 7-14 | 9.16 ± 1.4 | 30 | 18 | 75 |
| III rd | 50 | 8-14 | 10.84 ± 0.89 | 28 | 15 | 75 |
| IV th | 50 | 11-17 | 13.76 ± 0.89 | 28 | 15 | 75 |
| Total | 200 | 30-51 | 38.36 ± 3.14 | 29 | 17 | 75 |

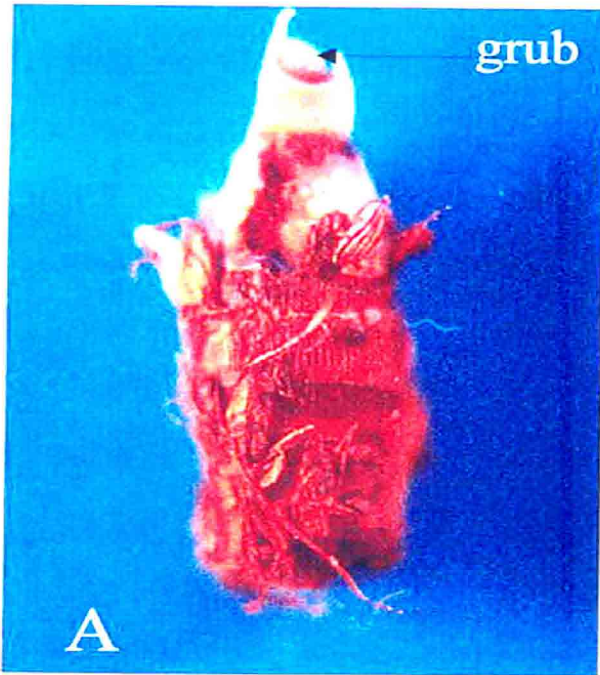
The duration of first, second, third and fourth instar grub of the weevil ranged from 4 to 6, 7 to 14, 8 to 14 and 11 to 17 days with an average of 4.6 ± 0.32 , 9.16 ± 1.4 , 10.84 ± 0.89 and 13.76 ± 0.89 days, respectively, at an average maximum and minimum room temperature of 29 and 17 °C and 75 % R.H. during the period of grub development.

The entire grub development completed within 30 to 51 days with an average of 38.36 ± 3.14 days. Habib (1976a) reported grub duration of 28 to 48 days in December-January in Pakistan at an average of 24 °C. The duration was almost in conformity to that of 30 to 51 days at 23°C.

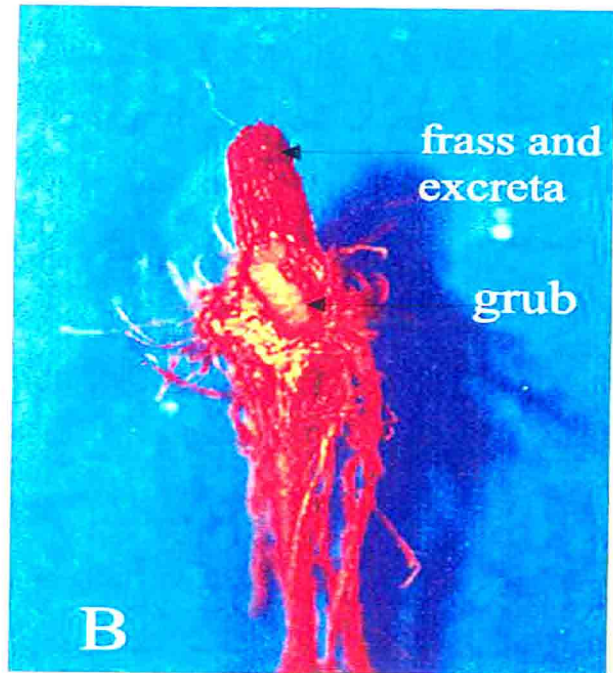
4.1.2.3 Behaviour

After hatching, the neonate grub moved up towards the top of basal bulb. It started feeding immediately and tunnelled its way upwards in sloping manner. First, it fed on the peripheral tissues. Turned in and upward till it reached to the bases of central leaves (Plate 5a). The damage did not affect the growth of the plant shoot. Then, the grub destroyed the bases of 2 to 3 central leaves of the shoot and formed a small roundish pocket at the base of the leaves. The leaves later on turned blackish, drooped and caused dead heart. The grub moulted. The dead heart (Plate 5c) appeared within 6 to 8 days after hatching. The second instar grub fed on the bulb and moved downward by boring the bulb upto one third of its depth. The grub closed the bored portion by pushing its faeces upward. The dead leaves turned pale brown and withered. Third instar grub consumed 2 to 2.5 times more contents of the bulb than second instar. It

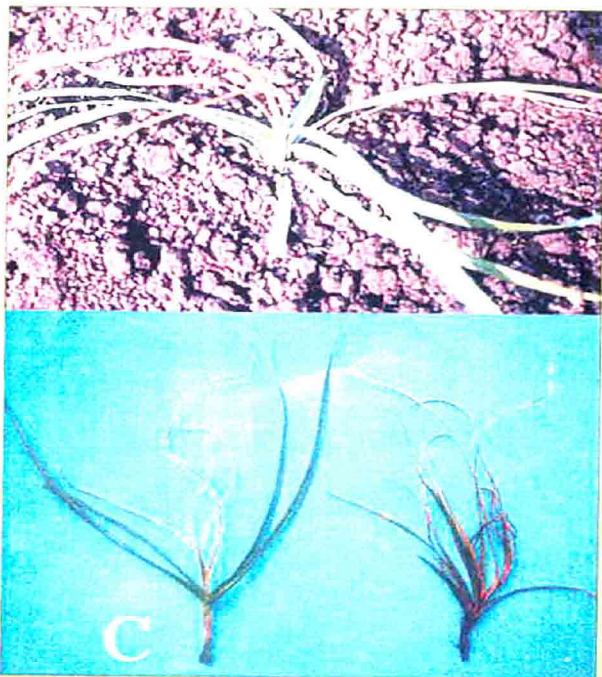
Plate 5 : Damage of *A. cyperi*



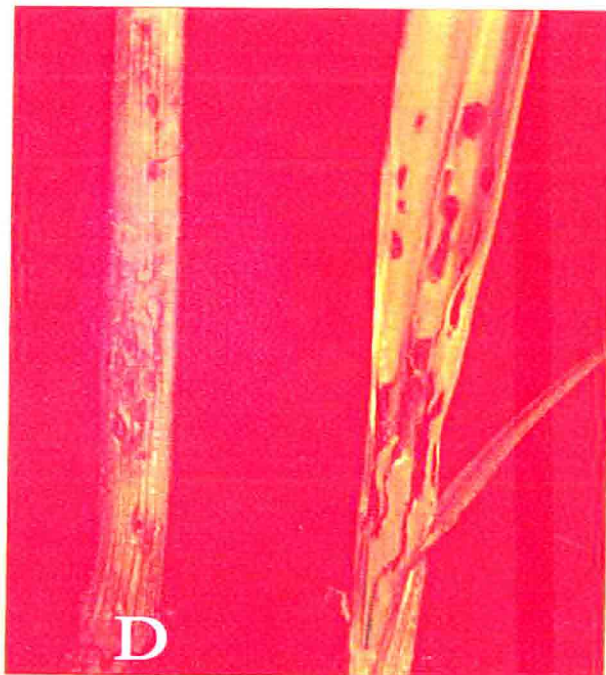
A. First instar grub in tunnel



B. Last instar grub in feeding cavity



C. Dead hearts



D. Damage by weevil

widened and deepened the tunnel in the bulb. At the end of this instar the leaves of the dead heart became brown. The fourth instar grub became voracious feeder keeping its head downward. During this instar the basal bulb of about 6 mm long, 3 mm wide having 0.4 g weight was hollowed out and only outer portion remained intact, although it was hard and not pressed easily and hence it protect the grub from crushing. But at the time of adult emergence, the tissues of the tunnelled bulbs become rotted which facilitate easy emergence of the weevils. At this stage, most of the plant leaves turned brown and withered. At the end of fourth instar, the top of hollowed bulb was closed with faeces of grub forming a hard dome like structure, which was very smooth from the inner side (Plate 5b). The grub reversed its position to keep the head upward, stopped feeding and entered in the resting, prepupal stage.

The grub never left the bulb during its whole life. It was unable to bore itself a newly offered tuber and died within 3 to 4 days. But accepted an artificially bored tuber and continued its life cycle. This observation established that there is no chance of grub migration from infested bulbs to other tubers or plants. The only way of infestation is egg laying in the tuber of *Cyperus* plants. On completion of the grub development, out of the hundred bored bulbs retained for two months only 30 bulbs (30 %) regenerated. While, the healthy one gave rise to 4 to 8 shoots within the two months and produced 2 new tubers in pot culture.

When two eggs were laid in the same bulb, there were two feeding ways to the tip of the bulb, however only one grub

survived ultimately which killed the other. First time such detailed observations on the behaviour of the grub were recorded in the present study.

4.1.2.3.1 Cannibalism

Study to explore possibility of rearing the *A. cyperi* grubs in group established that the phenomenon of cannibalism was observed in all the instars of the grub if more grubs are concealed in a container. When two grubs of same instar or different instars were enclosed together in the same tuber, bigger grub killed the smaller within a day. Nevertheless, the grub killed the prepupal and pupal forms when they were enclosed together. However, adult weevil did not cause harm to any stage. The cannibalism among the grubs was seemed be observed first time and is the bottleneck for mass rearing of the grub even in small group. Although it will not be a problem in nature as the weevil lay the eggs singly almost at all times.

4.1.3 Prepupa

4.1.3.1 Formation

The full grown grub stopped feeding. It turned its body position in reverse way bringing its head from tuber base to tuber top and remained quiescent

4.1.3.2 Morphological and biometrical characters

The early prepupal stage was morphologically almost the same to the fourth instar grub. Later on, the body hardened, became ivory coloured, more strait and quiescent (Plate 4b). Thoracic segments were clearly visible. However, rarely slight movement of the

stage and its mouth parts was noticed. The chaetotaxy on the prepupa was similar to that of grub instars.

4.1.3.3 Duration

The duration of the prepupal stage was 8 to 10 days with an average of 8.88 ± 0.33 days (Table 5). The prepupal stage was found first time in life cycle of the weevil.

Table 5. Duration of prepupal and pupal stages of *A. cyperi* during February-March, 2002

| Stage | Duration (days) | | Temperature (°C) | | R.H. % |
|----------|-----------------|------------------|------------------|------|--------|
| | Range | Mean | Max. | Min. | |
| Prepupal | 8-10 | 8.88 ± 0.33 | 30 | 15 | 70 |
| Pupal | 9-15 | 13.48 ± 0.60 | 30 | 15 | 60 |

4.1.4 Pupa

4.1.4.1 Formation

At the end of prepupal stage, colour of head capsule became pale brown. Abdominal segments became slightly transparent. This was noticed one day before the complete shedding of the exuviae of prepupa. The pupation commenced when the larval skin split at the dorsal side of the head and shed from remaining body by longitudinal contractions and relaxations. Total shedding of prepupal exuviae required four hours.

4.1.4.2 Morphological and biometrical characters

The pupa was exarate type with ovoid shape and ivory in colour (Plate 4b). Body length was 2.34 to 4.92 mm with an average

of 3.33 ± 0.29 mm. Maximum body width, at the third thoracic segment was 1.40 to 2.11 mm with an average of 1.67 ± 0.08 mm. The pupal appendages were adhered to the body. There was a pair of proturbances at dorsal side of the head and another pair was present at abdominal end. Each proturbance possessed a single hair.

Ventral view : Rostrum was extended upto the end of second thoracic segment. It was 0.83 mm long and carrying mouthparts at its tip. A pair of antennae was located on rostrum. The extended scape was inserted at one third portion from its tip and extended upto the compound eyes. Funical segments and club were extended downward. Legs and wings were compact together in a typical fashion of Curculionid species. Abdomen had 6 segments and a telson.

Dorsal view : Head was clearly visible. It was cylindrical shaped and about half size of the prothorax. Apical and anal margins of elytra were extended upto the point between meso and meta sternum. The membranous hind wings were longer than the elytra. Also six abdominal segments were visible and a telson carrying a pair of horny processes.

Chaetotaxy

There was a pair of setae at anterior portion of pupa. Similar pair was also located at the end of the abdomen. The setae on abdomen were shorter than those on head. Two and ten pairs of similar hairs were distributed symmetrically on the dorsal side of head and thorax, respectively. Similarly, two pairs of hairs, each on

lateral side of pygidium and many small hairs on tibia-femur joint were also observed. These hairs disappeared in adult stage.

4.1.4.3 Duration

The duration of pupal stage ranged from 9 to 15 days with an average of 13.48 ± 0.60 days at ambient temperature with 60 per cent relative humidity (Table 5). The duration of pupal stage observed in present study is more or less in agreement with that of 10 to 11 days reported by Poiner (1964) in Hawaii and 12 to 16 days by Habib (1976a) in Pakistan.

4.1.4.4 Formation of Imago

At fourth day of pupation, the antennal club became loose and the striae of the elytra became visible. Abdomen started intermittent movement. On the fifth day, brown compound eyes became black (Plate 4b). Mandibles and maxillae were brownish. Rostrum, antennae and wings were free and ivory coloured. On seventh day, rostrum became brown, but its tip had pale brown colour. Legs were brown, antennal club was black and its segments were pale brown. Apical area of the hind wings turned blackish and the compound eyes became fully developed and black. On eleventh day, abdomen turned brown and its posterior end was ivory coloured. At this stage, the insect could move. Finally the body became totally shiny black and rigid.

4.1.4.5 Eclosion

After transformation of the pupa into imago in the *Cyperus* bulb, the weevil bored an exit hole in the dome shaped faecal material at top of the bulb. The adult emerged from this hole was

smearred with dust. Within few minutes the adult started movement to search food and the dust on the body dislodged.

4.1.5 Duration of life cycle from egg to adult emergence

The total duration of life cycle is presented in Table 6 and depicted in Fig. 1a.

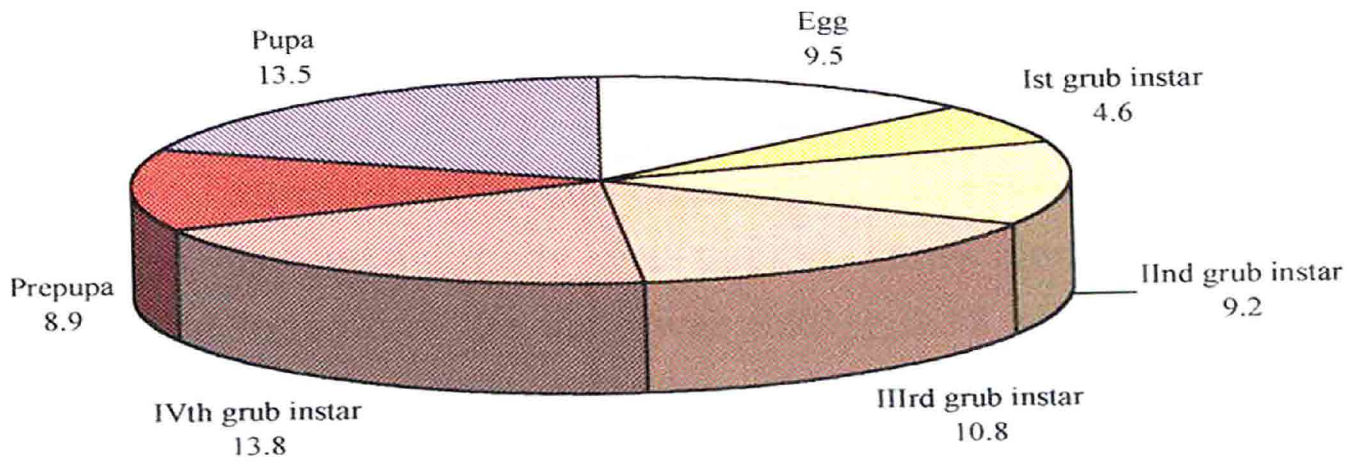
Table 6. Duration of life cycle of *A. cyperi* from egg to adult emergence

| Sr. No. | <i>A. cyperi</i> stage | Duration (days) | | Temp. (°C) | | RH (%) |
|---------|------------------------|-----------------|--------------|------------|------|--------|
| | | Range | Mean | Max. | Min. | |
| 1. | Egg | 8-12 | 10.56 ± 0.61 | 29 | 18 | 80 |
| 2. | Grub | 30-51 | 38.36 ± 3.14 | 29 | 17 | 75 |
| 3. | Prepupa | 8-10 | 8.88 ± 0.33 | 30 | 15 | 70 |
| 4. | Pupa | 9-15 | 13.48 ± 0.60 | 30 | 15 | 60 |
| | Total | 55-88 | 71.28 ± 4.68 | 29.4 | 16.3 | 71.3 |

The data presented in Table 6 revealed that duration of *A. cyperi* egg, grub, prepupal and pupal stages ranged from 8 to 12, 30 to 51, 8 to 10 and 9 to 15 days with an average of 10.56 ± 0.61, 38.36 ± 3.14, 8.88 ± 0.33 and 13.48 ± 0.60 days, respectively. The maximum and minimum temperatures and R.H. during the period varied from 29 to 30°C, 15 to 18°C and 60 to 80 per cent, respectively.

The total duration of life cycle of the weevil ranged from 55 to 88 days with an average of 71.28 ± 4.68 days when the average maximum and minimum temperatures and R.H. were 29.4 °C, 16.3 °C and 71.3 %, respectively. Habib (1976a), reported a total

a. Egg to adult emergence



b. Preoviposition to death of weevil

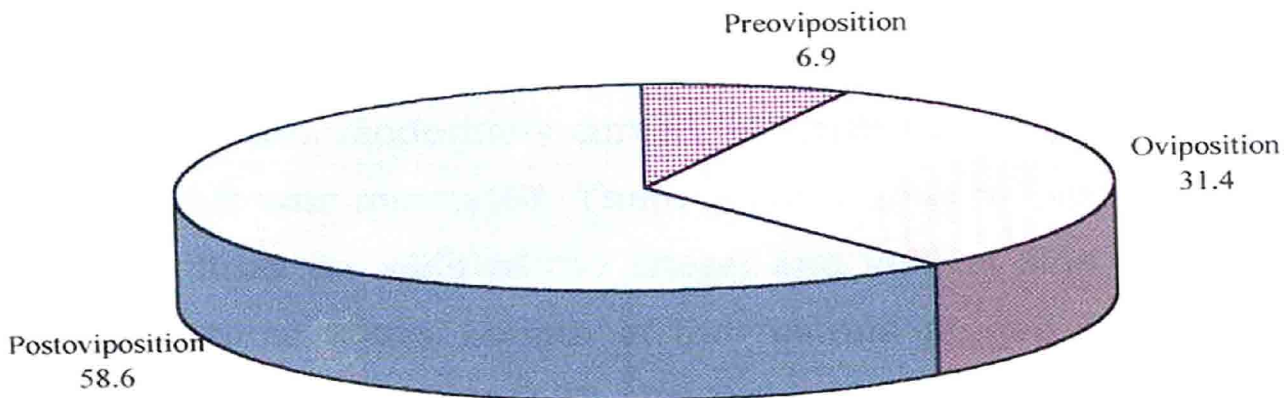


Fig. 1. Duration (days) of various stages in life cycle of *Cyperus* bulb borer, *A. cyperi*

duration of 40 to 64 days in Pakistan, which was lesser than that was (55 to 88 days) observed in the present study due to climatic variations.

4.1.6 Adult

4.1.6.1 Morphological and biometrical characters

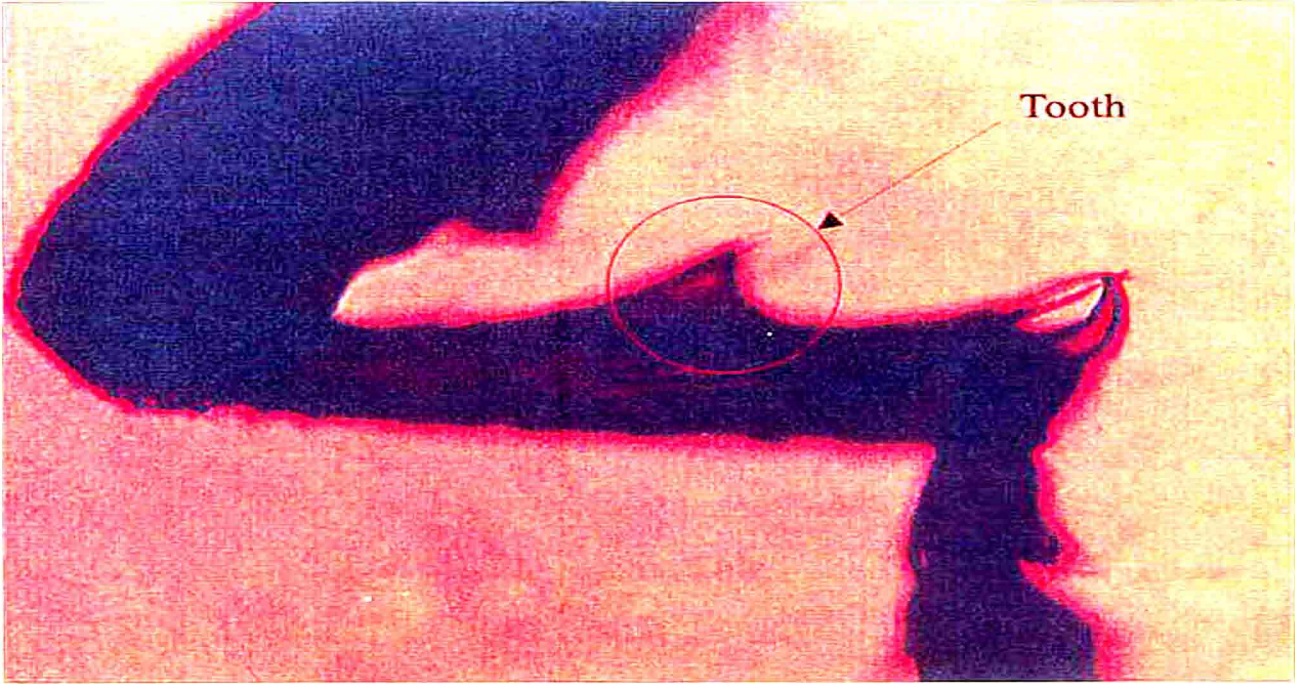
The weevil body was slender, shiny black. The average length and breadth of the male was $3.22 \pm 0.12 \times 1.17 \pm 0.05$ mm against the figures of $3.17 \pm 0.12 \times 1.23 \pm 0.05$ mm, for the female. The antennae, tibiae and the lateral and apical margins of the elytra were red brown (Plate 3a).

Head : The head was black, bare, globular and set well into the prothoracic cavity. It was 0.7 mm in diameter and punctated. Compound eyes were oval, convex, 0.39 x 0.1 mm in dimension and located at the lateral side of the base of rostrum.

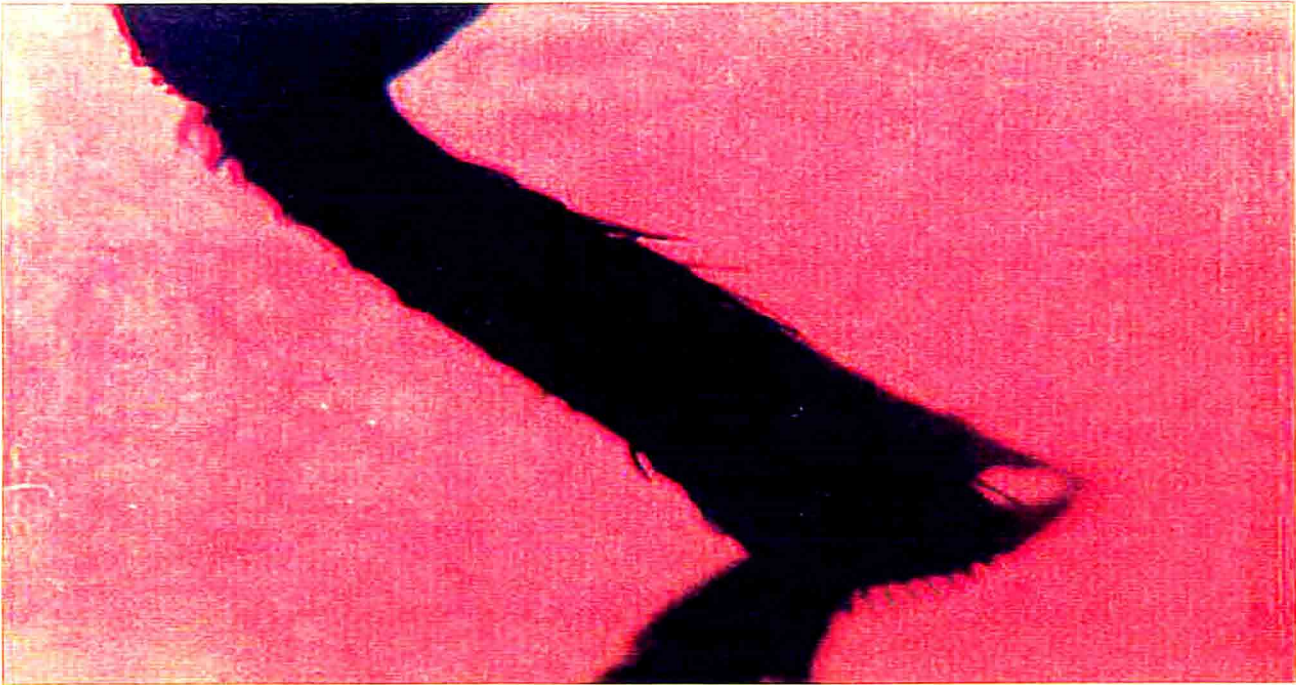
Rostrum : It was half the length of the body or equal to that of head and pronotum, moderately curved, blackish except at apex which was reddish. It was punctated. There were 4 lines of punctures on upper side, 3 lines on each of the lateral and ventral side. The punctures were without setae. Length of the rostrum ranged from 0.65 to 1.6 mm with an average of 0.83 mm and width was 0.1 to 0.26 mm with an average of 0.4 mm. The scrobe was elongated and 0.15 mm in length.

Mouth parts : These were typical chewing type. Mandibles were rigid, short, black and doubled toothed. Palpi of the maxillae were very short, rigid and brown in colour.

Plate 6 : Front tibiae of *A. cyperi* weevil



A. Presence of the tooth in ♂



B. Absence of the tooth in ♀

Antennae : These were geniculate type, inserted at apical third of the rostrum. Scape was longer than funicular segments. Average length of the scape, funicular and club was 0.6, 0.5 and 0.26 mm, respectively. The tip of the scape was enlarged. The first funicular segment was longer (0.2 mm) than other 6 segments (0.05 mm). The 4 coalesced club segments in male were oval and covered with dense short hairs.

Thorax : The consolidation of the thoracic sclerites and absence of the sharp carina separating the dorsal from the lateral surfaces was also observed in the weevil like other Curculionids. It was trapezoid shaped and punctated totally and each puncture bore striated whitish seta. However, there was a smooth stripe on the middle of the pronotum.

Elytra : These were strongly sclerotized, oblong, ovate and little broader than the prothorax, separately rounded at the apex with bulge at their base. Each elytron bore 9 prominent longitudinal punctated lines or striae. At apex, except two lines along middle, the lines were fused to form 'U' shape and giving appearance of small 'Us' in big 'Us'. The setae distribution pattern on the elytra was almost similar in the same gender. The setae distributed mainly at the centre of the elytra between all striae and in between strium 3 and 4 at base of elytron in both sexes. However, in male, there were about 10 setae on the bulged anterior and lateral corner of elytron. Elytral length ranged from 1.6 to 2.5 mm with an average of 2.2 mm while the width ranged from 0.6 to 1.4 mm with an average of 0.9 mm. Costal margin of the elytra possessed a row of hairs upto its middle, while anal margin had a membranous reddish cuticle. Elytra was little

shorter than the abdomen and the pygidium was punctated and 0.1 mm long.

Hind wings : The venation of the hind wing was very simple. Costal and subcostal veins were unbranched. At the end of second branch of the radius there was a spine like structure. Median was branched at the middle. A distal half portion of the hind wings bore small grayish hairs which imparted grayish colour to that area of the wing. Apical margin was hairy. The hind wing measured 3.22 mm in length and 0.72 mm in width.

Abdomen :

Female : Six punctated tergites were clearly visible. The lateral end portion of the last one seemed to be extended backward on both sides covering lateral sides of abdominal end. There were 5 punctated and 1 smooth sternites. The last one was smooth and bore a curve slit, the genital opening. The extended last tergite ended at the side of the opening. The abdominal end was curved.

Male : The number of tergites were similar in both sexes. However, males bore only 5 sternites. Last one was very broad, slightly curved and blunt. Protractile genitalia were located at the end of abdomen, which was visible from ventral side only. It appears as a circular disc surrounded by hairs. The distinctive features of male and female are presented in Table 7.

Legs : Legs were black, fully punctated and covered with elongated whitish setae. Fore femora were longer than middle and hind ones. Tibiae were shorter than femora. The front tibiae of the male were with a stout sharp tooth on the inner edge at about the middle (Plate

6a), when it was absent in the female tibiae (Plate 6b). The tarsi were apparently two segmented, the pretarsi were bilobed and holding a claw between them. The claw end was bispined. Marshall (1928) reported the presence of the tooth on the fore tibiae of the male as it was also noted above.

Table 7. Distinctive features of male and female

| Sr. No. | Particulars | Male | Female |
|---------|-------------------------------------|------------------|-----------------------------|
| 1. | Tooth on the front tibiae | Present | Absent |
| 2. | Hairs on distal end of elytral base | Present (10) | Absent |
| 3. | Number of sternites | 5 | 6 |
| 4. | Genital opening | | |
| | a. Location | At posterior end | On 6 th sternite |
| | b. Shape | Protractile | Curved slit |
| 5. | Hairs on antennal club | Dense | Sparse |

4.1.6.2 Sex ratio and mating behaviour

Sex ratio : Out of 300 weevils examined, 159 were males and 141 were females. Thus, the male to female ratio was 1.13 : 1 indicating more number of males than females in the weevil population.

Mating : The mating took place within 2 to 15 days with an average of 3.5 days after eclosion of pupa. The first mating lasted for 30 to 150 minutes with an average of 70 minutes, while subsequent matings lasted for 30 to 60 minutes with an average of 33 minutes. Multiple mating during the active period of adult span appeared to be the normal behaviour of the weevil. During copulation male mounted

on the dorsum of the female catching her at lateral constriction at pro-mesothorax joint using the stout teeth on fore tibiae (Plate 3a). Mating took place between 10 pm to 7 am and the couple move around.

4.1.6.3 Oviposition and fecundity

The data presented in Table 8 and depiction in Fig. 1 b showed that the duration of preoviposition, oviposition and postoviposition ranged from 3 to 18, 22 to 55 and 40 to 137 days with an average of 6.94 ± 0.87 , 31.36 ± 2.24 and 58.58 ± 6.72 days, respectively. The preoviposition period of 11 days reported by Habib (1976a) under the conditions of Pakistan was somewhat more than that was observed in the present investigation. However, Poiner (1964) reported prolong preoviposition period of two months or longer in South America.

Table 8. Preoviposition, oviposition, postoviposition periods and fecundity of *A. cyperi* in September to December, 2001

| Particulars | | Number observed | Range | Mean |
|------------------|--------|-----------------|--------|------------------|
| Preoviposition | (Days) | 50 | 3-18 | 6.94 ± 0.87 |
| Oviposition | (Days) | 50 | 22-55 | 31.36 ± 2.24 |
| Postoviposition | (Days) | 50 | 40-137 | 58.58 ± 6.72 |
| Fecundity/day | (Eggs) | 50 | 0-2 | 1.02 ± 0.15 |
| Fecundity/female | (Eggs) | 50 | 35-46 | 42.1 ± 0.62 |

Almost all the females oviposited 0 to 2 eggs with an average of 1.02 ± 0.15 eggs/day. The fecundity ranged between 35 and 46 eggs with an average of 42.1 ± 0.62 eggs during the

oviposition span of 31.36 ± 2.24 days. The range of fecundity observed here was more than that of 27 to 29 eggs reported by Habib (1976a) wherein only few females oviposited. The female was observed to prefer *Cyperus* plants grown in soil with 2 to 3 mm stem girth and 4 to 5 fully opened leaves for the oviposition during the present study.

4.1.6.4 Behaviour

The female weevils are soil dwelling, dark loving and inhabiting in cracks, under stones or plant debris. So, when they were exposed to sunlight they hide in the plant leaves and soil cracks. Females fly seldom due to disturbance by strong light and not by any other types of manual disturbance. Males are good flyers. Adults preferred to feed on newly sprouted shoots by inserting their rostrum deep in whorled leaves and subterranean portion of the *Cyperus* stem. The damaged leaves showed series of punctures on opening (Plate 5c). Females made one and at the most two holes at the proximal portion of the bulb by its rostrum and laid single egg in each hole. The weevil did not prefer *Cyperus* stem borer, *B. venosana* infested plants and vice-versa. Adults feign death only on first disturbance.

Female showed polyandrous habit and mate frequently with different males. Adult did not swim, but remained floating above the water surface upto 5 days. This phenomenon may help the adult to survive during flood condition or irrigation.

In pot culture, during watering, some adults observed to cling to nearest plants. Ploughed fields showed more infestation than

roadsides and unploughed fields as ploughing facilitated the movement of the females. Succulent *Cyperus* plants showed more infestation of the bioagent. There were three generations, the first generation appeared to be in March, the second was in July and the last one was in November. The generation was considered when more than 80 per cent of the infested shoots were having pupae.

However, the second generation appeared in November, was the generation of the peak activity of the bioagent the year as evidenced from the high infestation. Habib (1976a) observed weevil diapause during winter in Pakistan, which was not observed in the present study and the infestation was noticed round the year. Number of intermingled generations was determined during the present study.

4.1.6.5 Longevity

The data on influence of water and food on the survival of the adult weevils are presented in Table 9.

Table 9. Longevity of *A. cyperi* adults at ambient temperature during June to December, 2001

| Subsistence | Longevity (days) | | | | R.H. (%) |
|------------------|------------------|--------------|------------|---------------|----------|
| | 50 males | | 50 Females | | |
| | Range | Mean | Range | Mean | |
| No food no water | 2-15 | 5.38 ± 1.11 | 8-18 | 11.68 ± 0.79 | 80 |
| Water only | 2-16 | 6.54 ± 1.01 | 10-18 | 12.52 ± 0.54 | > 80 |
| Food only | 30-43 | 36.54 ± 1.33 | 65-210 | 106.74 ± 9.23 | 80 |
| Food and water | 31-48 | 40.26 ± 1.66 | 69-220 | 109.4 ± 12.36 | > 80 |

Under the conditions of providing (i) no food and no water (ii) only water (iii) only food and (iv) both food and water, the male

weevils survived for 2 to 15, 2 to 16, 30 to 43 and 31 to 48 days with an average of 5.38 ± 1.11 , 6.54 ± 1.01 , 36.54 ± 1.33 and 40.26 ± 1.66 days, when the average longevity of the female weevils was 11.68 ± 0.79 , 12.52 ± 0.54 , 106.74 ± 9.23 and 109.4 ± 12.36 days, respectively. Thus, females lived longer than the males and food was main constituent for lengthening the survival of the weevil bioagent. Habib (1976a) without specifying study conditions reported the survival of most of the adult upto two months and few for one year.

4.1.7 Duration of life cycle

The average duration of life cycle including survival period of male and female weevil from the egg to adult death was 76.7 and 83.1 without food against 107.8 and 178 days by providing sprouted *Cyperus* tubers as food, respectively.

4.2 Host specificity test for *A. cyperi*

The results of the reaction of the weevils and grubs to feeding on the exposed plant genotypes are indicated in Table 10.

Weevils : The weevil, *A. cyperi* neither fed nor attracted to any of the test crops, Graminaceous weeds, *Typha latifolia* or *Scirpus martinus*. They were deterred from the nonpreferred plants and gathered at the top of the container. They fed on *C. iria*, *C. difformis* and *C. alternifolius* in the absence and on *C. esculentus* in the presence of the main host, *C. rotundus*. Although, the adult feeding caused negligible damage to the *Cyperus* spp. which did not affect the plant growth.

Table 10. Host specificity test for oviposition and feeding of *A. cyperi* in absence and presence of *C. rotundus*

| Sr. No. | Test species | | Oviposition test | | Feeding response | | |
|--------------|-----------------------|-------------------------------|------------------|-----|------------------|-----|-----------------|
| | Common name | Botanical nomenclature | A* | P* | Weevils | | Grubs |
| | | | | | A | P | |
| Weeds | | | | | | | |
| 1. | Rice flat sedge | <i>Cyperus iria</i> | -ve | -ve | +ve | -ve | < 10 days |
| 2. | Small flower Umbrella | <i>C. difformis</i> | -ve | -ve | +ve | -ve | < 10 days |
| 3. | Yellow nutsedge | <i>C. esculentus</i> | +ve | +ve | +ve | +ve | Fully developed |
| 4. | Umbrella grass | <i>C. alternifolius</i> | -ve | -ve | +ve | -ve | -ve |
| 5. | Bulrush | <i>Scirpus martinus</i> | -ve | -ve | -ve | -ve | -ve |
| 6. | Fimbristylis | <i>Fimbristylis feruginea</i> | -ve | -ve | -ve | -ve | < 10 days |
| 7. | Field brome | <i>Bromus sterilis</i> | -ve | -ve | -ve | -ve | -ve |
| 8. | Bermuda grass | <i>Cynodon dactylon</i> | -ve | -ve | -ve | -ve | -ve |
| 9. | Crabgrass | <i>Digitaria sanguinalis</i> | -ve | -ve | -ve | -ve | -ve |
| 10. | Jungle rice | <i>Echinocoloa colona</i> | -ve | -ve | -ve | -ve | -ve |
| 11. | Goose grass | <i>Elusine indica</i> | -ve | -ve | -ve | -ve | -ve |
| 12. | Cattail | <i>Typha latifolia</i> | -ve | -ve | -ve | -ve | -ve |
| Crops | | | | | | | |
| 13. | Amaranthus | <i>Amaranthus tricolor</i> | -ve | -ve | -ve | -ve | -ve |
| 14. | Niger | <i>Guizotia abyssinica</i> | -ve | -ve | -ve | -ve | -ve |
| 15. | Sunflower | <i>Helianthus annus</i> | -ve | -ve | -ve | -ve | -ve |
| 16. | Sweet potato | <i>Ipomoea batatas</i> | -ve | -ve | -ve | -ve | -ve |
| 17. | Bottle gourd | <i>Lagenaria siceraria</i> | -ve | -ve | -ve | -ve | -ve |
| 18. | Bitter gourd | <i>Momordica charantia</i> | -ve | -ve | -ve | -ve | -ve |
| 19. | Cucumber | <i>Cucumis sativus</i> | -ve | -ve | -ve | -ve | -ve |
| 20. | Ridge gourd | <i>Luffa acutangula</i> | -ve | -ve | -ve | -ve | -ve |
| 21. | Rice | <i>Oryza sativa</i> | -ve | -ve | -ve | -ve | -ve |
| 22. | Sorghum | <i>Sorghum bicolor</i> | -ve | -ve | -ve | -ve | -ve |
| 23. | Barley | <i>Hordeum vulgare</i> | -ve | -ve | -ve | -ve | -ve |
| 24. | Maize | <i>Zea mays</i> | -ve | -ve | -ve | -ve | -ve |

Table 10 contd.....

| Sr. No. | Test species | | Oviposition test | | Feeding response | | |
|---------|--------------|--------------------------------|------------------|-----|------------------|-----|-------|
| | Common name | Botanical nomenclature | A* | P* | Weevils | | Grubs |
| | | | | | A | P | |
| 25. | Pearl millet | <i>Pennisetum typhoides</i> | -ve | -ve | -ve | -ve | -ve |
| 26. | Wheat | <i>Triticum aestivum</i> | -ve | -ve | -ve | -ve | -ve |
| 27. | Cowpea | <i>Vigna sinensis</i> | -ve | -ve | -ve | -ve | -ve |
| 28. | Gram | <i>Cicer arietinum</i> | -ve | -ve | -ve | -ve | -ve |
| 29. | Groundnut | <i>Arachis hypogaea</i> | -ve | -ve | -ve | -ve | -ve |
| 30. | Pigeonpea | <i>Cajanus cajan</i> | -ve | -ve | -ve | -ve | -ve |
| 31. | Soybean | <i>Glycine max</i> | -ve | -ve | -ve | -ve | -ve |
| 32. | Onion | <i>Allium cepa</i> | -ve | -ve | -ve | -ve | -ve |
| 33. | Cotton | <i>Gossypium arboreum</i> | -ve | -ve | -ve | -ve | -ve |
| 34. | Okra | <i>Abelmoschus esculentus</i> | -ve | -ve | -ve | -ve | -ve |
| 35. | Chilli | <i>Capsicum annum</i> | -ve | -ve | -ve | -ve | -ve |
| 36. | Potato | <i>Solanum tuberosum</i> | -ve | -ve | -ve | -ve | -ve |
| 37. | Tomato | <i>Lycopersicon esculentum</i> | -ve | -ve | -ve | -ve | -ve |

*A : In the absence of *C. rotundus*, P : In the presence of *C. rotundus*

Grubs : The results of grub feeding test on suspected crops were also negative. The grubs inserted inside the tissues of the stem bases of *C. iria*, *C. difformis* and *Fimbristylis ferruginea* survived for 10 days and died before completing development, but the grubs completed their development in the tubers of *C. esculentus* in the laboratory experiment. However, under field conditions, *C. esculentus* did not show infestation of the bioagent in present studies. Instead of inserting inside the stem, the grubs released on all the test plants were died without feeding.

The released mated female weevils oviposited only on *C. rotundus* and *C. esculentus*. Habib (1976a) observed that the grub fed

on *F. ferruginea* and completed their development on *C. esculentus* and *C. eleusinoides*. The only other host of the weevil in nature was *C. bulbosus*. The grubs feeding on former species also observed in present study. Rama Krishna Ayyar (1922) stated that the weevil was not a pest of rice which was conformed in the present study. There is no published literature on the feeding test on remaining plant genotypes included in the study.

4.3 Seasonal incidence of *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae* at M.P.K.V., Rahuri Farm

Two years data on seasonal incidence of both the bioagents and the grub parasitoid with number of *Cyperus* plants presented in Table 11 to 13 revealed that the trend of purple nutsedge stand, infestation of the bioagents and parasitoid during both years was more or less similar. Hence, only pooled results are described below and depicted in Fig. 2.

4.3.1 Abundance of *C. rotundus*

On the basis of pooled number of *Cyperus* plants/m², the period from 1st April (12th MW) to 15th July (27th MW) was unfavourable for *C. rotundus* as evidenced from survival of 37.5 to 66.5 plants/m² against 69.7 to 128.7 plants/m² during rest of the months of the years (Table 13). The average air and soil temperature and R.H. during the unfavourable period was 27°C, 36°C and 55.1 per cent, respectively, against the corresponding figures of 22.9°C, 28.6°C and 63.9 per cent during rest of the months of the years.

Table 11. Seasonal incidence of *Cyperus* plants, *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae* at M.P.K.V., Rahuri Farm (First year, 2000-01)

| Meteo. Week | Date | No. of plants/m ² | <i>A. cyperi</i> | <i>B. venosana</i> | <i>A. calandrae</i> | Air temperature [°C] | | | Soil temperature [°C] | | | Relative humidity [%] | | | Rain fall (mm) |
|-------------|------------------------|------------------------------|------------------|--------------------|---------------------|----------------------|------|------|-----------------------|------|------|-----------------------|------|------|----------------|
| | | | Max. | Min. | Mean | Max. | Min. | Mean | Max. | Min. | Mean | Mor. | Eve. | Mean | |
| 35 | 1 st Sept | 97.0 | 7.5 | 13.2 | 2.0 | 28.7 | 21.8 | 10.9 | 29.6 | 24.5 | 27.1 | 91.8 | 75.2 | 83.5 | 17.4 |
| 37 | 16 th Sept. | 91.7 | 8.9 | 13.5 | 2.1 | 30.2 | 19.3 | 24.8 | 34.3 | 23.0 | 28.7 | 85.0 | 53.8 | 69.4 | 0.1 |
| 39 | 1 st Oct. | 105.3 | 8.5 | 11.9 | 2.3 | 32.4 | 20.0 | 26.2 | 39.7 | 24.9 | 32.3 | 87.5 | 49.7 | 68.6 | 3.2 |
| 41 | 16 th Oct. | 108.0 | 11.1 | 11.1 | 2.0 | 31.6 | 18.7 | 25.2 | 37.3 | 22.9 | 30.1 | 88.9 | 47.0 | 68.0 | 2.6 |
| 43 | 1 st Nov. | 125.0 | 10.8 | 6.1 | 1.8 | 33.0 | 14.8 | 23.9 | 39.7 | 19.8 | 29.8 | 85.7 | 28.9 | 57.3 | 0.0 |
| 45 | 16 th Nov | 130.7 | 11.2 | 5.6 | 1.6 | 32.2 | 13.5 | 22.9 | 38.1 | 18.6 | 28.4 | 80.8 | 30.2 | 55.5 | 0.0 |
| 47 | 1 st Dec. | 109.7 | 10.3 | 3.7 | 1.0 | 31.1 | 10.9 | 21.0 | 36.9 | 18.5 | 27.7 | 79.2 | 35.5 | 57.4 | 0.0 |
| 49 | 16 th Dec. | 116.0 | 9.2 | 0.7 | 1.5 | 29.4 | 6.7 | 18.1 | 34.9 | 13.9 | 24.4 | 83.8 | 28.7 | 56.3 | 0.0 |
| 51 | 1 st Jan. | 98.3 | 6.1 | 0.0 | 1.6 | 27.9 | 7.5 | 17.7 | 35.1 | 13.8 | 24.5 | 84.2 | 35.2 | 59.7 | 0.5 |
| 1 | 16 th Jan. | 81.0 | 5.8 | 0.0 | 1.1 | 30.1 | 10.1 | 20.1 | 36.4 | 16.6 | 26.5 | 82.7 | 38.5 | 60.6 | 0.0 |
| 3 | 1 st Feb. | 75.0 | 5.4 | 0.0 | 0.9 | 29.9 | 9.7 | 19.8 | 37.5 | 15.8 | 26.7 | 82.4 | 31.2 | 56.8 | 0.0 |
| 5 | 16 th Feb. | 85.3 | 4.8 | 0.0 | 0.8 | 33.6 | 8.3 | 21.0 | 37.1 | 15.7 | 26.4 | 76.6 | 22.7 | 49.7 | 0.0 |
| 7 | 1 st Mar. | 91.3 | 5.1 | 1.6 | 0.0 | 33.7 | 11.5 | 22.6 | 42.3 | 20.1 | 31.2 | 77.8 | 23.4 | 50.6 | 0.0 |
| 10 | 16 th Mar. | 98.3 | 4.1 | 4.1 | 0.0 | 34.0 | 13.0 | 23.5 | 43.5 | 21.5 | 32.5 | 79.8 | 23.4 | 51.6 | 0.0 |
| 12 | 1 st Apr. | 33.0 | 3.0 | 7.1 | 0.0 | 35.5 | 14.2 | 24.9 | 45.3 | 23.9 | 34.6 | 69.3 | 21.6 | 45.5 | 0.0 |
| 14 | 16 th Apr. | 32.0 | 3.1 | 7.5 | 0.0 | 36.5 | 18.5 | 27.5 | 43.6 | 27.4 | 35.5 | 62.9 | 32.8 | 47.9 | 0.0 |
| 17 | 1 st May | 41.7 | 3.2 | 9.2 | 0.0 | 37.7 | 13.4 | 25.6 | 48.2 | 28.5 | 38.4 | 64.4 | 27.1 | 45.8 | 0.0 |
| 19 | 16 th May | 39.0 | 4.3 | 10.3 | 0.0 | 39.9 | 20.1 | 30.0 | 46.0 | 29.8 | 37.9 | 68.2 | 27.9 | 48.1 | 0.0 |
| 22 | 1 st June | 31.3 | 5.4 | 12.8 | 1.1 | 37.2 | 26.6 | 31.9 | 47.0 | 31.3 | 39.2 | 72.5 | 34.4 | 53.5 | 0.0 |
| 24 | 16 th June | 38.7 | 5.0 | 9.8 | 1.3 | 34.9 | 22.3 | 28.6 | 42.3 | 29.3 | 35.8 | 83.8 | 50.7 | 67.3 | 14.0 |
| 26 | 1 st July | 44.3 | 8.8 | 8.5 | 2.1 | 30.2 | 22.2 | 26.2 | 33.4 | 25.7 | 29.6 | 82.0 | 64.9 | 73.5 | 28.0 |
| 28 | 16 th July | 63.0 | 11.3 | 16.5 | 2.3 | 31.2 | 22.0 | 26.6 | 36.0 | 27.0 | 31.5 | 82.2 | 63.4 | 72.8 | 1.1 |
| 30 | 1 st Aug. | 69.0 | 14.7 | 17.9 | 2.8 | 30.4 | 21.2 | 25.8 | 34.5 | 26.5 | 30.5 | 82.7 | 59.9 | 71.3 | 2.8 |
| 33 | 16 th Aug. | 74.7 | 12.7 | 21.4 | 2.3 | 29.6 | 21.4 | 25.5 | 33.7 | 24.7 | 29.2 | 87.8 | 69.8 | 78.8 | 43.3 |

Table 12. Seasonal incidence of *Cyperus* plants, *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae* at M.P.K.V., Rahuri Farm (Second year, 2001-02)

| Meteo. Week | Date | No. of plants/m ² | Infestation (%) | | | Air temperature (°C) | | | Soil temperature (°C) | | | Relative humidity (%) | | | Rain fall (mm) |
|-------------|------------------------|------------------------------|------------------|--------------------|---------------------|----------------------|------|------|-----------------------|------|------|-----------------------|------|------|----------------|
| | | | <i>A. cyperi</i> | <i>B. venosana</i> | <i>A. calandrae</i> | Max. | Min. | Mean | Max. | Min. | Mean | Mor. | Eve. | Mean | |
| 35 | 1 st Sept | 84.3 | 7.4 | 12.2 | 3.9 | 29.5 | 20.6 | 25.1 | 33.4 | 24.5 | 29.0 | 89.0 | 62.8 | 75.9 | 4.7 |
| 37 | 16 th Sept. | 91.0 | 9.8 | 13.4 | 3.8 | 31.3 | 20.4 | 25.9 | 38.1 | 25.5 | 31.8 | 85.3 | 54.6 | 70.0 | 9.5 |
| 39 | 1 st Oct. | 96.3 | 11.7 | 10.7 | 2.1 | 31.5 | 20.3 | 25.9 | 37.3 | 24.7 | 31.0 | 91.7 | 58.1 | 74.9 | 49.2 |
| 41 | 16 th Oct. | 114.7 | 11.3 | 14.6 | 1.9 | 30.4 | 20.8 | 25.6 | 36.1 | 24.5 | 30.3 | 95.8 | 66.1 | 81.0 | 60.9 |
| 43 | 1 st Nov. | 119.0 | 12.1 | 8.6 | 2.9 | 31.2 | 15.3 | 23.3 | 38.4 | 22.5 | 30.5 | 89.7 | 32.0 | 60.9 | 0.0 |
| 45 | 16 th Nov | 126.7 | 19.9 | 5.0 | 3.0 | 31.5 | 12.0 | 21.8 | 38.9 | 19.9 | 29.4 | 84.3 | 33.2 | 58.8 | 0.0 |
| 47 | 1 st Dec. | 100.7 | 13.9 | 2.9 | 2.1 | 30.8 | 14.2 | 22.5 | 37.1 | 19.8 | 28.5 | 85.5 | 35.6 | 60.6 | 0.0 |
| 49 | 16 th Dec. | 105.3 | 9.9 | 1.5 | 1.8 | 29.7 | 9.2 | 19.5 | 37.0 | 18.7 | 27.9 | 88.4 | 33.0 | 60.7 | 0.0 |
| 51 | 1 st Jan. | 69.0 | 5.7 | 1.4 | 1.0 | 29.6 | 9.5 | 19.6 | 35.7 | 17.6 | 26.7 | 89.1 | 33.5 | 61.3 | 0.0 |
| 1 | 16 th Jan. | 58.3 | 5.6 | 0.0 | 0.9 | 27.2 | 8.6 | 17.9 | 34.1 | 16.1 | 25.1 | 87.7 | 36.2 | 62.0 | 0.0 |
| 3 | 1 st Feb. | 72.3 | 6.9 | 0.0 | 1.0 | 28.9 | 6.6 | 17.8 | 36.1 | 15.4 | 25.8 | 86.4 | 34.2 | 60.3 | 0.0 |
| 5 | 16 th Feb. | 81.0 | 6.2 | 0.0 | 1.0 | 28.4 | 9.9 | 19.2 | 32.5 | 17.0 | 24.8 | 85.9 | 35.0 | 60.5 | 4.8 |
| 7 | 1 st Mar. | 88.0 | 5.7 | 1.1 | 0.0 | 32.9 | 12.8 | 22.9 | 39.0 | 18.5 | 28.8 | 89.8 | 22.2 | 56.0 | 0.0 |
| 10 | 16 th Mar. | 78.7 | 3.8 | 3.9 | 0.0 | 34.5 | 12.1 | 23.3 | 43.8 | 21.3 | 32.6 | 59.0 | 24.6 | 41.8 | 0.0 |
| 12 | 1 st Apr. | 42.0 | 2.1 | 7.3 | 0.0 | 34.5 | 18.1 | 26.3 | 44.7 | 23.2 | 34.0 | 55.0 | 20.7 | 37.9 | 0.0 |
| 14 | 16 th Apr. | 39.7 | 2.8 | 6.6 | 0.0 | 36.8 | 18.3 | 27.6 | 46.9 | 24.8 | 35.9 | 56.8 | 19.6 | 38.2 | 0.5 |
| 17 | 1 st May | 35.7 | 2.8 | 10.1 | 0.0 | 39.8 | 20.2 | 30.0 | 49.3 | 28.5 | 38.9 | 52.1 | 24.3 | 38.2 | 0.0 |
| 19 | 16 th May | 42.3 | 2.4 | 11.6 | 1.2 | 38.1 | 16.2 | 27.2 | 48.5 | 30.8 | 39.7 | 78.9 | 46.2 | 62.6 | 0.0 |
| 22 | 1 st June | 27.3 | 4.9 | 12.2 | 2.1 | 36.7 | 16.5 | 26.6 | 49.4 | 30.2 | 39.8 | 87.0 | 52.1 | 69.6 | 0.0 |
| 24 | 16 th June | 31.7 | 3.2 | 10.5 | 1.7 | 35.0 | 13.7 | 24.4 | 44.5 | 29.0 | 36.8 | 86.9 | 53.8 | 70.4 | 25.9 |
| 26 | 1 st July | 40.7 | 11.1 | 10.2 | 1.9 | 30.2 | 12.0 | 21.1 | 32.9 | 25.8 | 29.4 | 82.4 | 64.4 | 73.4 | 32.8 |
| 28 | 16 th July | 70.0 | 12.2 | 13.0 | 2.5 | 32.0 | 19.3 | 25.7 | 37.5 | 27.0 | 32.3 | 80.3 | 51.6 | 66.0 | 0.0 |
| 30 | 1 st Aug. | 79.7 | 13.0 | 22.6 | 4.0 | 30.8 | 23.3 | 27.1 | 33.6 | 25.6 | 29.6 | 86.4 | 61.9 | 74.2 | 4.6 |
| 33 | 16 th Aug. | 88.0 | 12.0 | 18.0 | 4.0 | 27.9 | 21.6 | 24.8 | 32.7 | 24.6 | 28.7 | 89.1 | 62.5 | 75.8 | 2.8 |

Table 13. Pooled data on seasonal incidence of *Cyperus* plants, *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromatus calandrarum* at M.P.K.V., Rahuri Farm (2000-02)

| Meteo. Week | Date | No. of plants/m ² | Infestation (%) | | Air temperature [°C] | | | Soil temperature [°C] | | | Relative humidity [%] | | | Rain fall (mm) | |
|-------------|------------------------|------------------------------|------------------|--------------------|----------------------|------|------|-----------------------|------|------|-----------------------|------|------|----------------|-------|
| | | | <i>A. cyperi</i> | <i>B. venosana</i> | Max. | Min. | Mean | Max. | Min. | Mean | Max. | Min. | Mean | | Even. |
| 35 | 1 st Sept | 90.7 | 7.5 | 12.7 | 3.0 | 29.1 | 21.2 | 25.2 | 31.5 | 24.5 | 28.0 | 90.4 | 69.0 | 79.7 | 11.1 |
| 37 | 16 th Sept. | 91.3 | 9.4 | 13.5 | 3.0 | 30.8 | 19.9 | 25.3 | 36.2 | 24.3 | 30.2 | 85.2 | 54.2 | 69.7 | 4.8 |
| 39 | 1 st Oct. | 100.8 | 10.1 | 11.3 | 2.2 | 32.0 | 20.2 | 26.1 | 38.5 | 24.8 | 31.7 | 89.6 | 53.9 | 71.8 | 26.2 |
| 41 | 16 th Oct. | 111.3 | 11.2 | 12.9 | 2.0 | 31.0 | 19.8 | 25.4 | 36.7 | 23.7 | 30.2 | 92.4 | 56.6 | 74.5 | 31.7 |
| 43 | 1 st Nov. | 122.0 | 11.5 | 7.3 | 2.4 | 32.1 | 15.1 | 23.6 | 39.1 | 21.2 | 30.1 | 87.7 | 30.5 | 59.1 | 0.0 |
| 45 | 16 th Nov | 128.7 | 15.6 | 5.3 | 2.3 | 31.9 | 12.8 | 22.3 | 38.5 | 19.3 | 28.9 | 82.6 | 31.7 | 57.1 | 0.0 |
| 47 | 1 st Dec. | 105.2 | 12.1 | 3.3 | 1.6 | 31.0 | 12.6 | 21.8 | 37.0 | 19.2 | 28.1 | 82.4 | 35.6 | 59.0 | 0.0 |
| 49 | 16 th Dec. | 110.7 | 9.6 | 1.1 | 1.7 | 29.6 | 8.0 | 18.8 | 36.0 | 16.3 | 26.1 | 86.1 | 30.9 | 58.5 | 0.0 |
| 51 | 1 st Jan. | 83.7 | 5.9 | 0.7 | 1.3 | 28.8 | 8.5 | 18.6 | 35.4 | 15.7 | 25.6 | 86.7 | 34.4 | 60.5 | 0.3 |
| 1 | 16 th Jan. | 69.7 | 5.7 | 0.0 | 1.0 | 28.7 | 9.4 | 19.0 | 35.3 | 16.4 | 25.8 | 85.2 | 37.4 | 61.3 | 0.0 |
| 3 | 1 st Feb. | 73.7 | 6.2 | 0.0 | 1.0 | 29.4 | 8.2 | 18.8 | 36.8 | 15.6 | 26.2 | 84.4 | 32.7 | 58.6 | 0.0 |
| 5 | 16 th Feb. | 83.2 | 5.5 | 0.0 | 0.9 | 31.0 | 9.1 | 20.1 | 34.8 | 16.4 | 25.6 | 81.3 | 28.9 | 55.1 | 2.4 |
| 7 | 1 st Mar. | 89.7 | 5.4 | 1.4 | 0.0 | 33.3 | 12.2 | 22.7 | 40.7 | 19.3 | 30.0 | 83.8 | 22.8 | 53.3 | 0.0 |
| 10 | 16 th Mar. | 88.5 | 4.0 | 4.0 | 0.0 | 34.3 | 12.6 | 23.4 | 43.7 | 21.4 | 32.5 | 69.4 | 24.0 | 46.7 | 0.0 |
| 12 | 1 st Apr. | 37.5 | 2.6 | 7.2 | 0.0 | 35.0 | 16.2 | 25.6 | 45.0 | 23.6 | 34.3 | 62.2 | 21.2 | 41.7 | 0.0 |
| 14 | 16 th Apr. | 35.8 | 3.0 | 7.1 | 0.0 | 36.7 | 18.4 | 27.5 | 45.3 | 26.1 | 35.7 | 59.9 | 26.2 | 43.0 | 0.2 |
| 17 | 1 st May | 38.7 | 3.0 | 9.7 | 0.0 | 38.8 | 16.8 | 27.8 | 48.8 | 28.5 | 38.6 | 58.3 | 25.7 | 42.0 | 0.0 |
| 19 | 16 th May | 40.7 | 3.4 | 11.0 | 0.6 | 39.0 | 18.2 | 28.6 | 47.3 | 30.3 | 38.8 | 73.6 | 37.1 | 55.3 | 0.0 |
| 22 | 1 st June | 29.3 | 5.2 | 12.5 | 1.6 | 37.0 | 21.6 | 29.3 | 48.2 | 30.8 | 39.5 | 79.8 | 43.3 | 61.5 | 0.0 |
| 24 | 16 th June | 35.2 | 4.1 | 10.2 | 1.5 | 35.0 | 18.0 | 26.5 | 43.4 | 29.2 | 36.3 | 85.4 | 52.3 | 68.8 | 20.0 |
| 26 | 1 st July | 42.5 | 10.0 | 9.4 | 2.0 | 30.2 | 17.1 | 23.7 | 33.2 | 25.8 | 29.5 | 82.2 | 64.7 | 73.4 | 30.4 |
| 28 | 16 th July | 66.5 | 11.8 | 14.8 | 2.4 | 31.6 | 20.7 | 26.1 | 36.8 | 27.0 | 31.9 | 81.3 | 57.5 | 69.4 | 0.6 |
| 30 | 1 st Aug. | 74.3 | 13.9 | 20.3 | 3.4 | 30.6 | 22.2 | 26.4 | 34.1 | 26.1 | 30.1 | 84.6 | 60.9 | 72.7 | 3.7 |
| 33 | 16 th Aug. | 81.3 | 12.4 | 19.7 | 3.2 | 28.8 | 21.5 | 25.1 | 33.2 | 24.7 | 28.9 | 88.5 | 66.2 | 77.3 | 23.1 |

There was negative correlation between maximum air temperature ($r = -0.59$), maximum ($r = -0.55$) and minimum ($r = -0.60$) soil temperatures and *Cyperus* plants survival (Table 16). However, there was positive correlation with morning R.H. ($r = 0.59$). The multiple regression between number of *Cyperus* plants and main weather parameters indicated that these factors affecting the survival of *Cyperus* plants by 74 per cent (Table 17) and only minimum air temperature and morning R.H. were significantly affected the plant number. This might be due to frequent irrigations given to the field.

4.3.2 Incidence of *A. cyperi*

The 2 years pooled data on average infestation of *A. cyperi* presented in Table 13 established that the weevil incidence ranged from 2.6 to 15.6 per cent with an average of 7.9 per cent. The infestation was low (2.6 to 6.2 %) from January to June (1st to 25th MW). There were two peaks of the weevil infestation in 45th MW (middle November) (15.6 %) and 30th MW (1st August) (13.9 %). The infestation was negatively correlated with maximum air ($r = -0.57$) and soil ($r = -0.63$) temperature. However, it was positively correlated with morning and evening relative humidity where 'r' values were 0.61 and 0.5, respectively (Table 16). The results of multiple regression analysis (Table 17) showed that meteorological factors affected 59 per cent of the weevil infestation. However, all the non significant regression coefficients indicated that other abiotic and biotic factors affecting the weevil population. Those factors are (i) Traditional cultural practices (ii) Host preference and selection of suitable stage of *Cyperus* by *A. cyperi* for oviposition (iii) Use of

chemical pesticides on main crop (iv) Parasitism (0 – 3.4 %) and (v) Competition with *Bactra* spp.

Sankaran and Srinath (1966) reported that the weevil was more active during September (16.5 %) when as per the findings of the present investigation, the highest peak activities were recorded in August (13.9 %) and November (15.6 %) which might be attributed to climatic variation of Central India. Habib (1976a) recorded no infestation of the weevil during February and March at Karachi, Pakistan. The lowering of the activity (4 to 6.2 %) of weevil during the period is in agreement to the findings of the present investigation. Although the activities further reduced (2.6 to 5.2) also during April to June.

4.3.3 Incidence of *B. venosana*

The infestation of the *Cyperus* stem borer, *B. venosana* ranged from 0 to 20.3 per cent (Table 13). There was no infestation from 16th January to February end (1st to 6th MW) and it was low (1.1 to 3.3 %) in December (47th to 50th MW) and (1.4 to 4 %) in March (7th to 11th MW). The highest peak (20.3 %) of the infestation was recorded on 1st August (30th MW).

There was significant and positive correlation between the moth infestation and minimum air ($r = 0.94$), soil ($r = 0.77$) temperatures, evening R.H. ($r = 0.74$) and rainfall ($r = 0.45$) (Table 16). The multiple regression analysis showed that 92 per cent of the moth infestation was correlated to the meteorological parameters and only minimum air temperature was significant (Table 17). The other factors affecting the *Bactra* population might be egg parasitization by

Table 14. Correlation coefficient for correlation between number of *Cyperus* plants, infestation of *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae* with meteorological parameters at M.P.K.V., Rahuri Farm (First year, 2000-01)

| Meteorological Parameters | | No. of <i>Cyperus</i> plants/m ² | Infestation (%) | | |
|---------------------------|------|---|-------------------|--------------------|---------------------|
| | | | <i>A. cyperi</i> | <i>B. venosana</i> | <i>A. calandrae</i> |
| Air temperature (°C) | Max. | -0.57** | -0.58** | 0.04 | -0.69** |
| | Min. | -0.46* | 0.24 | 0.85** | 0.38 |
| | Mean | -0.62** | -0.06 | 0.71** | 0.00 |
| Soil temperature (°C) | Max. | -0.50** | -0.64** | -0.11 | -0.75** |
| | Min. | -0.69** | -0.07 | 0.74** | -0.01 |
| | Mean | -0.70** | -0.42* | 0.38 | -0.44* |
| Relative humidity (%) | Mor. | 0.64** | 0.64** | 0.15 | 0.78** |
| | Eve. | -0.04 | 0.57** | 0.72** | 0.78** |
| | Mean | 0.18 | 0.66** | 0.60** | 0.86** |
| Rain fall (mm) | | -0.19 | 0.31 | 0.50** | 0.41* |

* Significant at 5 %

** Significant at 1 %

Table 15. Correlation coefficient for correlation between number of *Cyperus* plants, infestation of *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae* with meteorological parameters at M.P.K.V., Rahuri Farm (Second year, 2001-02)

| Meteorological Parameters | | No. of <i>Cyperus</i> plants/m ² | Infestation (%) | | |
|---------------------------|------|---|-------------------|--------------------|---------------------|
| | | | <i>A. cyperi</i> | <i>B. venosana</i> | <i>A. calandrae</i> |
| Air temperature (°C) | Max. | -0.57** | -0.52** | 0.17 | -0.43 |
| | Min. | -0.01 | 0.12 | 0.87** | 0.44* |
| | Mean | -0.29 | -0.17 | 0.72** | 0.10 |
| Soil temperature (°C) | Max. | -0.56** | -0.57** | 0.02 | -0.50** |
| | Min. | -0.46* | -0.15 | 0.77** | 0.23 |
| | Mean | -0.67** | -0.61** | 0.40* | -0.24 |
| Relative humidity (%) | Mor. | 0.50** | 0.51** | 0.07 | 0.58** |
| | Eve. | 0.07 | 0.38 | 0.72** | 0.73** |
| | Mean | 0.29 | 0.50** | 0.46* | 0.74** |
| Rain fall (mm) | | 0.14 | 0.20 | 0.32 | 0.12 |

* Significant at 5 %

** Significant at 1 %

Table 16. Correlation coefficient for correlation between number of *Cyperus* plants, infestation of *A. cyperi*, *B. venosana* and the grub parasitoid, *Anisopteromalus calandrae* with meteorological parameters at M.P.K.V., Rahuri Farm (Pooled, 2000-02)

| Meteorological Parameters | | No. of <i>Cyperus</i> plants/m ² | Infestation (%) | | |
|---------------------------|------|---|-------------------|--------------------|---------------------|
| | | | <i>A. cyperi</i> | <i>B. venosana</i> | <i>A. calandrae</i> |
| Air temperature (°C) | Max. | -0.59** | -0.57** | 0.11 | -0.57** |
| | Min. | -0.29 | 0.19 | 0.94** | 0.47* |
| | Mean | -0.50** | -0.13 | 0.76** | 0.07 |
| Soil temperature (°C) | Max. | -0.55** | -0.63** | -0.03 | -0.66** |
| | Min. | -0.60** | -0.13 | 0.77** | 0.12 |
| | Mean | -0.71** | -0.53** | 0.40* | -0.35 |
| Relative humidity (%) | Mor. | 0.59** | 0.61** | 0.10 | 0.71** |
| | Eve. | 0.01 | 0.50** | 0.74** | 0.81** |
| | Mean | 0.25 | 0.60** | 0.54** | 0.86** |
| Rain fall (mm) | | 0.03 | 0.28 | 0.45* | 0.40* |

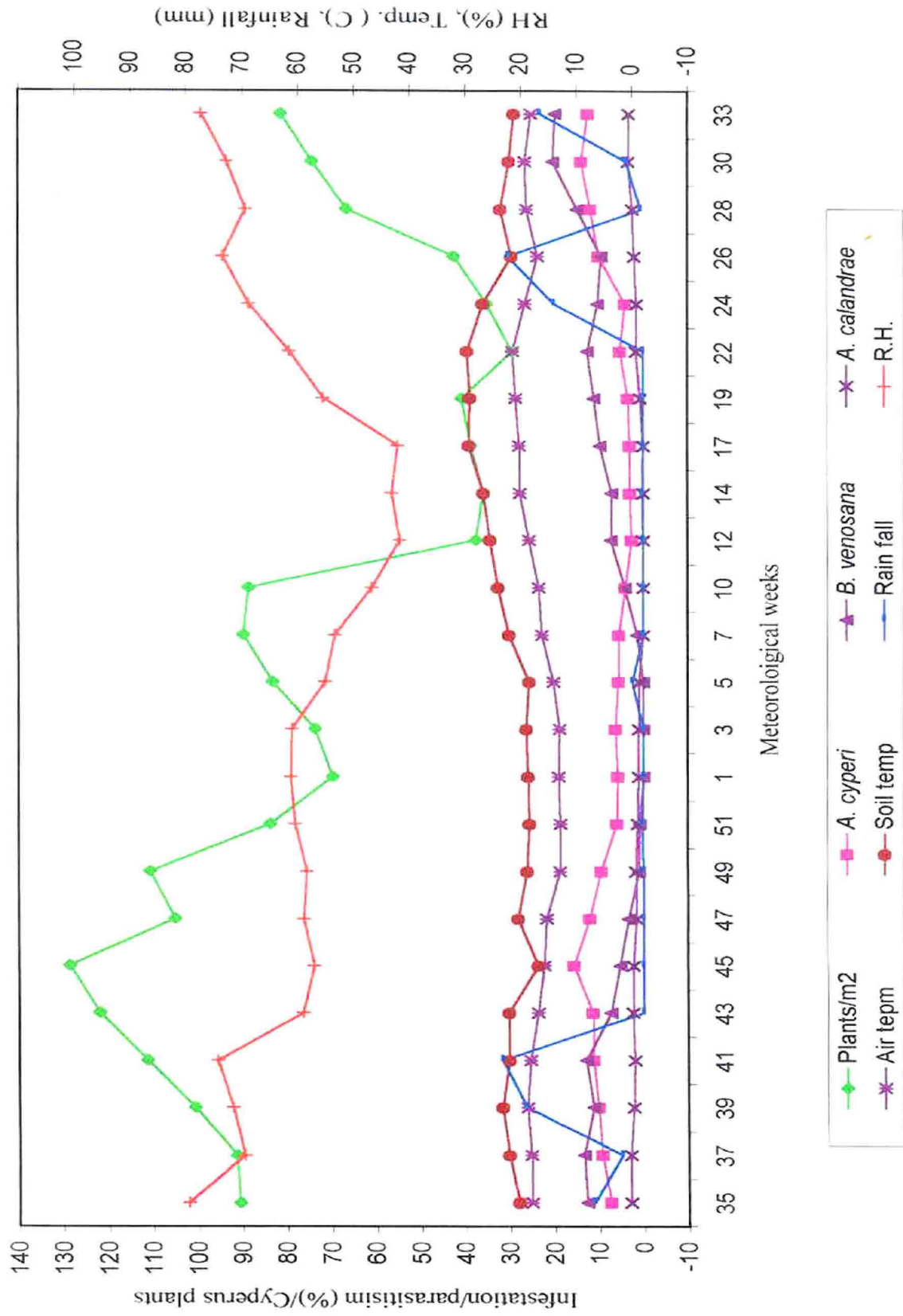


Fig. 2. Seasonal incidence of *Cyperus* bulb borer (*A. cyperi*), stem borer (*B. venosana*) and grub parasitoid (*Anisopteromalus calandrae*) at M.P.K.V., Rahuri Farm (Pooled, 2000-02)

Trichogrammatoidea bactrae, predation by Coccinellids and Chrysopids and traditional cultural activities.

Habib (1976b) reported 8 per cent of *B. venosana* infestation during December in Karachi and it was below 5 per cent during the rest of the year. However, the infestation was zero from February to April as it noticed from 15 January to 15 February.

4.3.4 Incidence of the grub parasitoid, *Anisopteromalus calandrae*

The data in Table 13 revealed that the parasitoid infestation ranged from 0 to 3.4 per cent (av. 1.53). It was zero from 1st March to 15th May (7th to 18th MW). It was below 3 per cent from October to July (39th to 29th MW). There was significant and negative correlation between maximum air ($r = -0.57$) and soil ($r = -0.66$) temperature (Table 16). On the basis of the multiple regression analysis there was significant and positive correlation of the grub parasitoid with morning R.H. and rainfall (Table 17). However, weather parameters affected the parasitoid population by 73 per cent.

Table 17. Regression coefficients of number of *Cyperus* plants, bulb borer, stem borer and the grub parasitoid with meteorological parameters at M.P.K.V., Rahuri Farm (Pooled, 2000-02)

| Year | Characters | Regression coefficients | | | | | | R ² | Intercept | |
|-------------------------|----------------|-------------------------|------|------------|------|---------|-------|----------------|-----------|----------|
| | | Air Temp. | | Soil Temp. | | RH. (%) | | | | Rainfall |
| | | Max. | Min. | Max. | Min. | Morn. | Even. | | | |
| I st | Plant number | 1.5 | -1.7 | -5.1 | 3.3 | 4* | -1.9 | -0.4 | 0.77 | -65.6 |
| | Weevil (%) | -1 | 0.01 | -1 | 1.2 | 0.2 | -0.4 | 0.02 | 0.6 | 46.8 |
| | Moth (%) | -0.7 | 0.01 | -0.5 | 1.5 | 0.1 | -0.1 | 0.04 | 0.8 | 9.3 |
| | Parasitoid (%) | -0.13 | 0.08 | -0.06 | 0.03 | 0.04 | -0.01 | -0.01 | 0.83 | 3.2 |
| II nd | Plant number | -1 | 3.8* | -1.1 | -1.9 | 1.5* | -1.3 | 0.3 | 0.62 | -62.2 |
| | Weevil (%) | -0.1 | 0.2 | -0.6 | 0.4 | 0.2 | -0.1 | 0.01 | 0.44 | 1.3 |
| | Moth (%) | -0.1 | 0.7* | -0.1 | 0.5 | 0.02 | 0.2 | -0.05 | 0.92 | -10.5 |
| | Parasitoid (%) | -0.27 | 0.1* | 0.01 | 0.14 | 0.04* | 0.02 | -0.03 | 0.83 | 1.47 |
| Pooled of 2 years | Plant number | 7.5 | 6.7* | -3.8 | -7.9 | 2.2* | -1.3 | 0.2 | 0.74 | -67.0 |
| | Weevil (%) | -0.9 | 0.4 | -0.8 | 1 | 0.2 | -0.4 | 0.01 | 0.59 | 35.7 |
| | Moth (%) | -0.9 | 1* | -0.1 | 0.7 | 0.01 | -0.1 | -0.03 | 0.92 | 13.1 |
| | Parasitoid (%) | -0.28 | 0.08 | -0.1 | 0.23 | 0.06* | -0.04 | -0.02* | 0.88 | 4.7 |

4.4 Biosuppression of *C. rotundus*

4.4.1 Damage potential of an individual weevil

Each gravid female caused 13 to 25 dead hearts with an average of 20.8 ± 0.43 damage against about double the fecundity of 42.1 ± 0.62 eggs. This difference between fecundity and number of dead hearts might be due to (i) Less (90 %) hatchability, (ii) Couple of eggs laid/plant (iii) Preference of the female to oviposit on about 15 to 20 days old plants with 4 to 5 leaves. The 70 per cent damaged bulbs failed to regenerate. Besides the grubs, the weevils were also found to feed on stem tissue and whorled leaves (Plate 5d). The female cut one

or two holes on basal bulbs for oviposition. The feeding and oviposition injuries may act as entry site for pathogens. Release of 2 mated females of *Cyperus* bulb borer/100 *Cyperus* plants caused 40 per cent dead hearts against only 23 per cent damage potential by 10 larvae of *B. venosana* and stopped regrowth of 30 per cent of damaged plants. However, combination of the bioagents resulted in 62 per cent damage to the weed. Khan (1971) observed that a grub completely destroyed one potted plant and no regeneration occurred.

4.4.2 Pot culture experiments

4.4.2.1 Influence of integrated measures on suppression of *C. rotundus* in pot culture

The results of the trial on influence of integration of mix cropping in sorghum with the *Cyperus* bulb borer (*A. cyperi*), stem borer (*B. venosana*), rust fungus (*Puccinia romagnoliana* Maire and Sacc.), a herbicide (atrazine) and hand weeding on suppression of *C. rotundus* (Plate 7a) are presented in Table 18 to 20.

A. Above ground portion

i. Impact on *Cyperus* plant stand

The 15 *Cyperus* tubers sown in (T_{21}) *Cyperus* alone, raised to significantly maximum (50) plants against only 13.7 plants in (T_{20}) C + S + hw. Later was at par with the treatments (T_{19}) C + S + bb + sb + atz + rf, (T_{18}) C + S + bb + sb + atz, (T_{12}) C + S + A + bb + rf, (T_{10}) C + S + bb + rf, (T_{11}) C + S + G + bb + rf and (T_8) C + S + G + bb giving rise to 14, 17.3, 18, 18, 19 and 19.3 plants, respectively (Plate 8).

Plate 7 : Experimental snaps



A. Pot culture



B. Sorghum plot



C. Harvested Okra

Table 18. Influence of interactions among components of treatments on growth of above ground portion of *C. rotundus*/pot

| Sr. No. | Treatments | Plant No. | Length of leaves (cm) | Infested plants (%) | Dry weight (g) |
|---------|----------------------------|-----------|-----------------------|---------------------|----------------|
| 1. | C + G | 22.3 | 14.3 | 4.0 (9.2)* | 2.7 |
| 2. | C + A | 24.7 | 14.0 | 6.1 (11.7) | 2.1 |
| 3. | C + W | 23.7 | 12.2 | 9.8 (18.2) | 2.3 |
| 4. | C + S | 22.0 | 12.0 | 7.4 (15.8) | 1.8 |
| 5. | C + S + G | 20.0 | 10.5 | 11.6 (19.9) | 1.6 |
| 6. | C + S + A | 20.0 | 10.5 | 5.1 (13.0) | 1.6 |
| 7. | C + S + bb | 20.7 | 10.5 | 39.4 (38.8) | 1.2 |
| 8. | C + S + G + bb | 19.3 | 13.2 | 52.1 (46.2) | 1.1 |
| 9. | C + S + A + bb | 22.0 | 10.8 | 39.6 (39.0) | 1.0 |
| 10. | C + S + bb + rf | 18.0 | 10.2 | 43.1 (41.0) | 1.0 |
| 11. | C + S + G + bb + rf | 19.0 | 10.8 | 37.5 (37.7) | 0.9 |
| 12. | C + S + A + bb + rf | 18.0 | 10.0 | 39.2 (38.0) | 0.8 |
| 13. | C + S + sb | 21.0 | 14.0 | 19.6 (26.0) | 1.3 |
| 14. | C + S + atz | 22.3 | 14.0 | 2.8 (7.9) | 1.6 |
| 15. | C + S + bb + sb | 20.0 | 10.2 | 44.9 (42.1) | 1.2 |
| 16. | C + S + bb + atz | 22.0 | 10.8 | 30.0 (33.0) | 1.2 |
| 17. | C + S + sb + rf | 21.0 | 13.2 | 17.8 (24.8) | 1.2 |
| 18. | C + S + bb + sb + atz | 17.3 | 11.3 | 50.2 (45.1) | 0.8 |
| 19. | C + S + bb + sb + atz + rf | 14 | 8.8 | 54.8 (47.8) | 0.6 |
| 20. | C + S + hw | 13.7 | 9.7 | 11.4 (19.7) | 0.3 |
| 21. | C only | 50.0 | 19.0 | 1.3 (5.3) | 11.5 |
| 22. | S only | - | - | - | - |
| | S.E. \pm | 2.0 | 0.7 | 2.7 | 0.1 |
| | CD at 5 % | 5.8 | 2.0 | 7.7 | 0.4 |
| | CV % | 9.9 | 6.0 | 10.2 | 7.8 |

Where,

| | | | |
|-----|----------------------|----|-----------------------|
| C | : <i>C. rotundus</i> | G. | : Gram |
| A | : Amaranthus | W | : Wheat |
| S | : Sorghum | bb | : Bulb borer (weevil) |
| rf | : Rust fungus | sb | : Stem borer (moth) |
| atz | : Atrazine | hw | : Hand weeding |

* Figures in parentheses indicate arcsin value

ii. Length of leaves

The shortest leaf (8.8 cm) was recorded in (T₁₉) C + S + bb + sb + atz + rf, which was at par with (T₂₀) C + S + hw, (T₁₂) C + S + A + bb + rf, (T₁₀) C + S + bb + rf, (T₁₅) C + S + bb + sb, (T₇) C + S + bb, (T₆) C + S + A, (T₅) C + S + G, (T₉) C + S + A + bb, (T₁₁) C + S + G + bb + rf and (T₁₆) C + S + bb + atz, with leaf length of 9.7 to 10.8 cm.

iii. Bioagent infested *Cyperus* plants (%)

The treatment (T₁₉) C + S + bb + sb + atz + rf showed maximum (54.8 %) infestation of bioagents on *Cyperus* plants and it was at par to that in (T₈) C + S + G + bb (52.1 %), (T₁₈) C + S + bb + sb + rf (50.2 %), (T₁₅) C + S + bb + sb (44.9 %), (T₁₀) C + S + bb + rf (41 %). Although no bioagents were released on (T₂₁) *Cyperus*, the infestation was 1.3 per cent, probably due to migration of the bioagents from other treatments.

iv. Dry weight of green portion

The *Cyperus* dry weight was lowest (0.3 g) in (T₂₀) C + S + hw, which was at par with (T₁₉) C + S + bb + sb + atz + rf (0.6 g). However, the (T₁₉) was at par with (T₁₈) C + S + bb + sb + rf (0.8 g), (T₁₂) C + S + A + bb + rf (0.8 g), (T₁₁) C + S + G + bb + rf (0.9 g), (T₁₀) C + S + bb + rf (1 g) and (T₉) C + S + A + bb (1 g). Among crops, the *Cyperus* plants in sorghum crop (T₄) had least (1.8 g) dry weight followed by (T₂) amaranthus (2.1 g), (T₃) wheat (2.3 g) and (T₁) gram (2.7 g). The shade effect of sorghum in reducing the dry weight was significantly superior to that of wheat and gram.

b. Under ground part

i. Number of tubers multiplied from 15 sown tubers/pot

The number of *Cyperus* tubers multiplied was highest (99.7) in (T₂₁) *Cyperus* alone, when the number in rest of treatments was 11 to 60.3 (Plate 10). As compared to the multiplication in (T₂₁) *Cyperus* alone, the number reduced by 2.5, 2.3, 2 and 1.7 times by shade effect of crop and growth competition in (T₄) sorghum, (T₃) wheat, (T₂) amaranthus and (T₁) gram, respectively. The maximum (9.1 times) reduction was found in (T₁₉) C + S + bb + sb + atz + rf, recording only 11 tubers/pot. Two hand weedings in (T₂₀) of *Cyperus* in sorghum reduced the tuber number by 1.97 times as compared to (T₄) C + S. In comparison to (T₄), the share of weevil in reduction of the number of tubers was 1.5 times in (T₇) C + S + bb, against that of 1.01 times by *Cyperus* stem borer in (T₁₃) C + S + sb.

ii. Weight of tubers

Lowest weight (4.8 g) of tubers was recorded in (T₁₉) C + S + bb + sb + atz + rf and it was at par to the treatments (T₁₀) C + S + bb + rf, (T₉) C + S + A + bb, (T₇) C + S + bb, (T₂₀) C + S + hw, (T₁₈) C + S + bb + sb + atz, (T₁₂) C + S + A + bb + rf and (T₁₁) C + S + G + bb + rf recording the weight of tubers from 5.2 to 9.5 g. The weight of tubers under different cropping system as compared to (T₂₁) *Cyperus* alone, reduced by 3.4, 3.1, 3 and 2.9 times under sorghum, amaranthus, wheat and gram, respectively. The impact of the weevil alone in reducing tuber weight under sorghum crop was 2.4 times.

Table 19. Impact of the interactions among components of treatments on multiplication of *Cyperus* tubers

| Sr. No. | Treatments | Multiplied <i>C. rotundus</i> tubers | | | | |
|---------|----------------------------|--------------------------------------|------------|----------------------------|---------------|---------------------------|
| | | No./15 sown tubers | Weight (g) | Sprouted number at 20 days | Sprouting (%) | Multiplicability ratio 1: |
| 1. | C + G | 60.3 | 21.4 | 38.3 | 63.5 | 2.5 |
| 2. | C + A | 50.3 | 19.5 | 38.3 | (61.0)* | 2.5 |
| 3. | C + W | 43.7 | 20.4 | 25.3 | 76.2 | 1.7 |
| 4. | C + S | 40.0 | 18.1 | 22.0 | (53.5) | 1.47 |
| 5. | C + S + G | 32.7 | 14.4 | 24.3 | 57.9 | 1.6 |
| 6. | C + S + A | 30.7 | 13.8 | 20.0 | (49.7) | 1.33 |
| 7. | C + S + bb | 27.0 | 7.6 | 13.7 | 55.7 | 0.9 |
| 8. | C + S + G + bb | 26.7 | 11.2 | 13.3 | (48.4) | 0.9 |
| 9. | C + S + A + bb | 25.3 | 7.6 | 12.0 | 75.8 | 0.8 |
| 10. | C + S + bb + rf | 14.0 | 5.2 | 6.3 | (60.7) | 0.43 |
| 11. | C + S + G + bb + rf | 14.7 | 9.5 | 7.3 | 67.6 | 0.47 |
| 12. | C + S + A + bb + rf | 13.3 | 9.4 | 5.3 | (58.4) | 0.33 |
| 13. | C + S + sb | 39.7 | 17.2 | 21.0 | 50.5 | 1.4 |
| 14. | C + S + atz | 39.7 | 17.8 | 21.3 | (45.3) | 1.42 |
| 15. | C + S + bb + sb | 24.0 | 12.2 | 12.7 | 51.6 | 0.87 |
| 16. | C + S + bb + atz | 24.7 | 10.8 | 10.3 | (45.9) | 0.63 |
| 17. | C + S + sb + rf | 35.7 | 15.3 | 15.0 | 47.5 | 0.97 |
| 18. | C + S + bb + sb + atz | 18.7 | 9.2 | 8.0 | (43.5) | 0.53 |
| 19. | C + S + bb + sb + atz + rf | 11.0 | 4.8 | 4.3 | 52.9 | 0.3 |
| 20. | C + S + hw | 20.3 | 9.0 | 6.0 | (46.3) | 0.43 |
| 21. | C only | 99.7 | 61.0 | 84.3 | 53.6 | 5.63 |
| 22. | S only | - | - | - | (47.1) | - |
| | S.E. \pm | 2.9 | 1.9 | 1.4 | 52.9 | 1.6 |
| | CD at 5 % | 8.3 | 5.3 | 4.0 | (46.6) | 0.2 |
| | CV % | 9.3 | 12.9 | 7.5 | 41.9 | 7.6 |

Plate 8. : Pot culture experiment



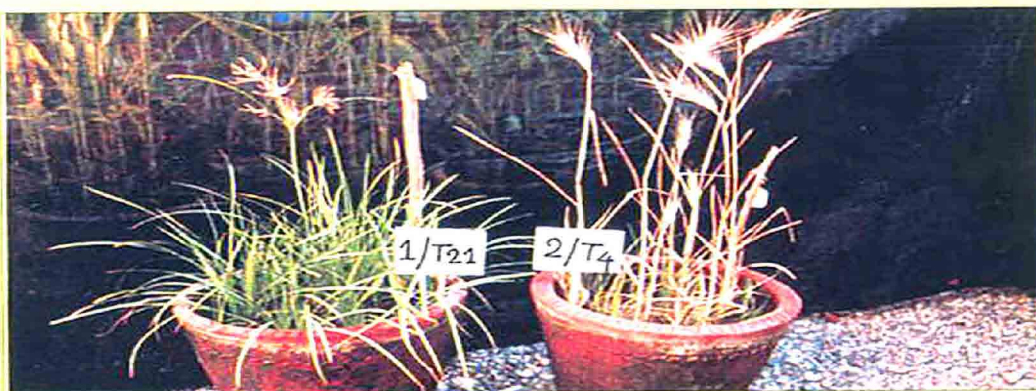
A. 1. C 2. C + S 3. C + S + bb + rf



B. 1. C 2. C + S + G + bb + rf



C. 1. C 2. C + S + A + bb + rf



D. 1. C 2. C + W

iii. Effect of interactions on sprouting of multiplied tubers

The data on sprouted tubers and per cent sprouting recorded at 20 days of incubation are presented in Table 19.

No. of sprouted tuber : The treatment (T₁₉) C + S + bb + sb + atz + rf, adversely affected the sprouting of the multiplied tubers allowing only 4.3 tubers to sprout out of 11 tubers. The next promising and at par treatments to (T₁₉) were (T₁₂) C + S + A + bb + rf, (T₂₀) C + S + hw, (T₁₀) C + S + bb + rf, (T₁₁) C + S + G + bb + rf and (T₁₈) C + S + bb + sb + atz, wherein number of sprouted tubers was 5.3 to 8 only.

Tuber sprouting (%) : The per cent sprouting was lowest (35.8 %) in (T₂₀) C + S + hw. However, it was on par to (T₁₉) C + S + bb + sb + atz + rf, (T₁₂) C + S + A + bb + rf, (T₁₆) C + S + bb + atz, (T₁₈) C + S + bb + sb + atz, (T₁₇) C + S + sb + rf, (T₁₀) C + S + bb + rf, (T₉) C + S + A + bb and (T₁₁) C + S + G + bb + rf, which allowed to sprout 38.4 to 44.8 per cent tubers. Although some dormant tubers may sprout after 20 days but these will not affect the growth of the plants significantly. Because first 4 to 6 weeks are crucial for the competition of the crop with the weed.

iv. Multiplicability ratio : It is the ratio of sown tubers to sprouted tubers out of multiplied tubers counted at the harvest of crops. The impact of crop pattern, bioagents and other weed control measures implemented in this trial was vividly and ultimately reflected in the multiplicability ratio of the tubers. The lowest ratio (1 : 0.3) was observed in (T₁₉) C + S + bb + sb + atz + rf, which was at par with (T₁₂) C + S + A + bb + rf (1 : 0.33), (T₁₀) C + S + bb + rf (1 : 0.43), (T₂₀) C + S + hw (1 : 0.43) and (T₁₁) C + S + G + bb + rf (1 : 0.47).

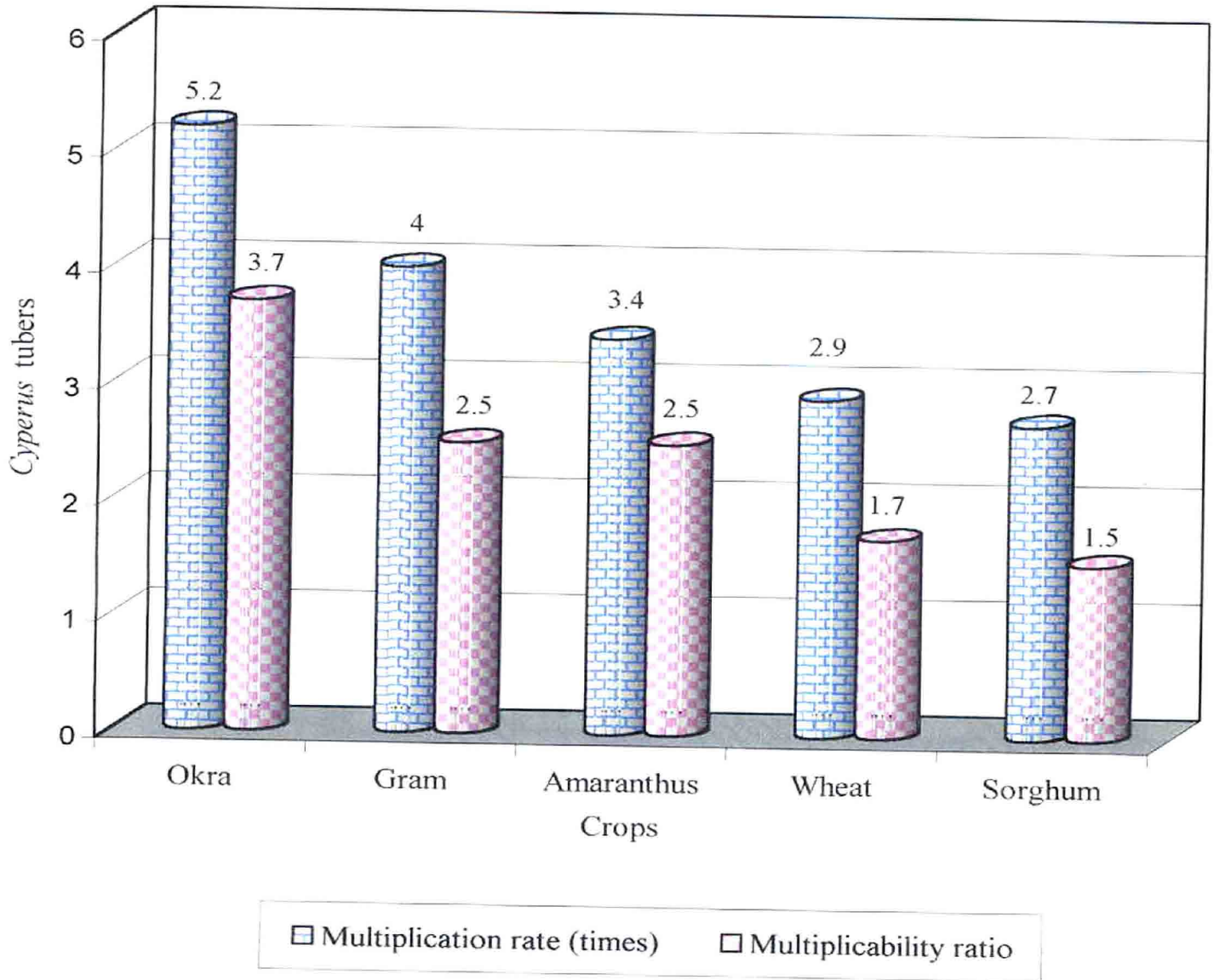


Fig. 3. Influence of crops on multiplication of *C. rotundus* in pot culture experiment

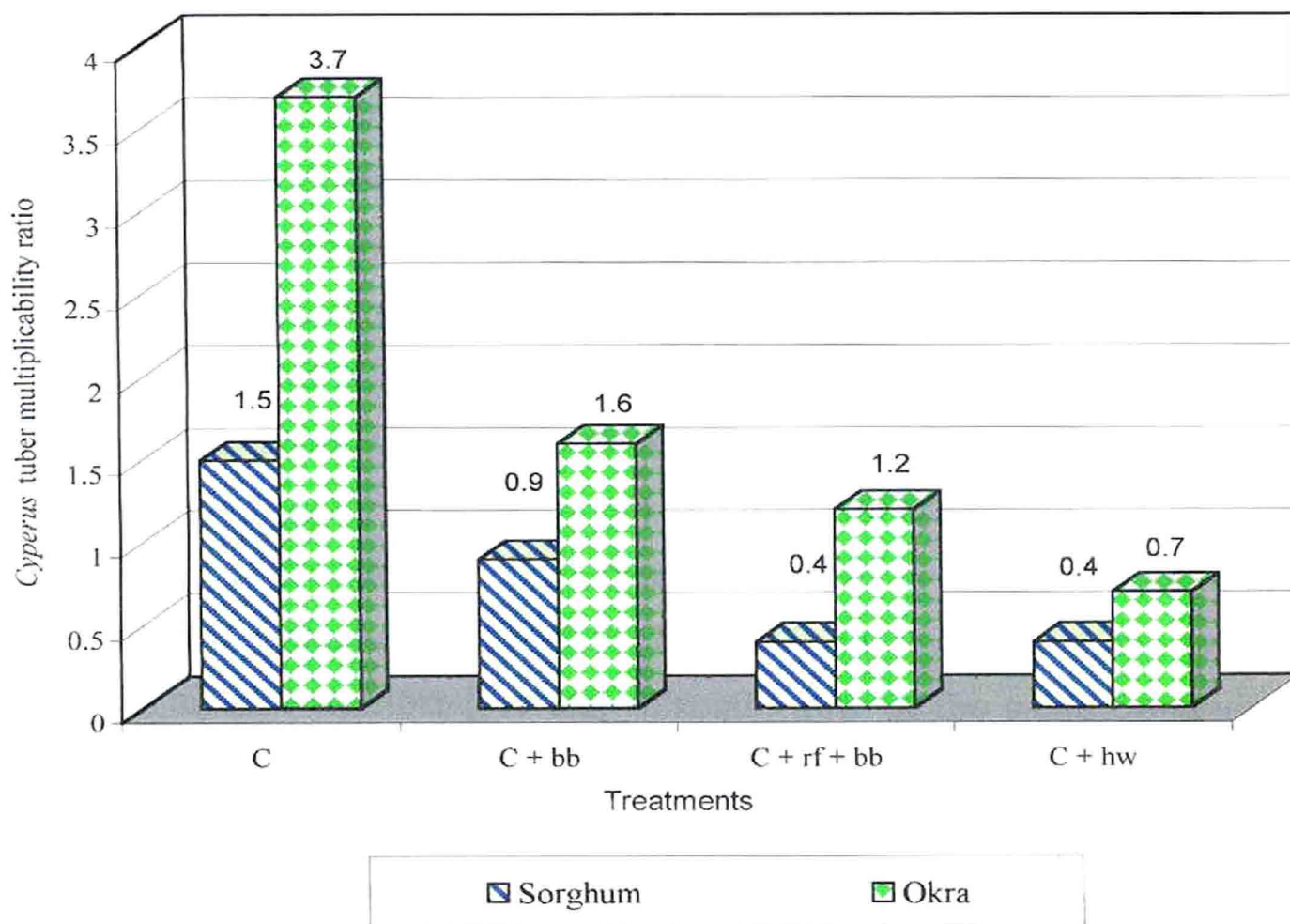


Fig. 4. Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in sorghum and okra in pot culture

Considering tuber multiplicability as most precise parameter, the combination of bulb borer and rust fungus emerged as the best treatments for biosuppression among all other treatments. However, the (T₇) C + S + bb was better than (T₁₃) C + S + sb and (T₁₇) C + S + sb + rf.

Among crops (T₄) sorghum yielded the best result in lowering multiplicability ratio (1 : 1.47) followed by (T₃) wheat (1 : 1.7), (T₂) amaranthus (1 : 2.5) and (T₁) gram (1 : 2.5).

v. Other characters

Number of tubers in series were significantly highest (7.7) in T₂₁ *Cyperus* alone against lowest (1) in (T₂₀) C + S + hw and (T₁₉) C + S + bb + sb + atz + rf and it was 1.3 to 5 in rest of the treatments. Under sorghum crop tubers in series were significantly lesser (2.3) than wheat (3.7), amaranthus (4) and gram (4) (Table 20).

Longest (3 cm) tuber was found in (T₂₁) *Cyperus* alone, against the smallest (0.4 cm) in (T₂₀) C + S + hw. Similarly, the longest (54 cm) and shortest (9.7 cm) rhizome grew in the same treatments, respectively.

vi. Yield value Rs./ha

The yield data of single crop or mixed crops as per treatments are presented in Table 20. For precise economic evaluation of the treatments, the value of the return has been calculated. T₁₉, C + S + bb + sb + atz + rf gave maximum return of Rs. 12985 among all the crop + *Cyperus* comprising treatments (T₁ to T₂₀). Other promising and at par treatments to (T₁₉) in their descending order of economical superiority were (T₁₀) C + S + bb + rf (Rs. 12600),

Table 20. Influence of the interactions among components of treatments on underground portion of *C. rotundus* and crop yields and value

| Sr. No. | Treatments | <i>C. rotundus</i> | | | Yield (q/ha) | | | | Income (Rs/ha)* |
|---------|----------------------------|-------------------------|--------------------|----------------------|--------------|------|------------|-------|-----------------|
| | | Under ground portion | | | Sorghum | Gram | Amaranthus | Wheat | |
| | | No. of tubers in series | Biggest tuber (cm) | Longest rhizome (cm) | | | | | |
| 1. | C + G | 4 | 2 | 23.3 | - | 4.4 | - | - | 6600 |
| 2. | C + A | 4 | 1.8 | 25.0 | - | - | 4.2 | - | 6300 |
| 3. | C + W | 3.7 | 1.5 | 23.3 | - | - | - | 3.1 | 2300 |
| 4. | C + S | 2.3 | 1.5 | 16.7 | 9.1 | - | - | - | 6335 |
| 5. | C + S + G | 3.7 | 1.7 | 15.0 | 8.1 | 1.3 | - | - | 7557 |
| 6. | C + S + A | 3.0 | 1.3 | 18.3 | 7.6 | - | 1.9 | - | 8174 |
| 7. | C + S + bb | 2.0 | 1.2 | 16.7 | 14.0 | - | - | - | 9800 |
| 8. | C + S + G + bb | 3.3 | 1.3 | 16.7 | 9.9 | 1.4 | - | - | 9009 |
| 9. | C + S + A + bb | 3.7 | 1.3 | 16.7 | 8.5 | - | 2.2 | - | 9239 |
| 10. | C + S + bb + rf | 2.3 | 1.2 | 16.7 | 18.0 | - | - | - | 12600 |
| 11. | C + S + G + bb + rf | 2.0 | 0.9 | 20.0 | 11.2 | 2.3 | - | - | 11330 |
| 12. | C + S + A + bb + rf | 2.3 | 0.8 | 19.3 | 8.9 | - | 2.4 | - | 9769 |
| 13. | C + S + sb | 5.0 | 1.5 | 20.0 | 9.2 | - | - | - | 6405 |
| 14. | C + S + atz | 2.7 | 2.0 | 18.3 | 9.1 | - | - | - | 6359 |
| 15. | C + S + bb + sb | 2.0 | 1.2 | 15.0 | 14.5 | - | - | - | 10150 |
| 16. | C + S + bb + atz | 2.3 | 1.5 | 15.0 | 14.4 | - | - | - | 10069 |
| 17. | C + S + sb + rf | 3.0 | 1.8 | 15 | 11.0 | - | - | - | 7663 |
| 18. | C + S + bb + sb + atz | 1.3 | 0.9 | 11.7 | 15.0 | - | - | - | 10430 |
| 19. | C + S + bb + sb + atz + rf | 1.0 | 0.6 | 10.0 | 18.6 | - | - | - | 12985 |
| 20. | C + S + hw | 1.0 | 0.4 | 5.0 | 17.8 | - | - | - | 12449 |
| 21. | C only | 7.7 | 3.0 | 54.0 | - | - | - | - | - |
| 22. | S only | - | - | - | 25.8 | - | - | - | 18060 |
| | S.E. ± | 0.5 | 0.2 | 2.2 | - | - | - | - | 748 |
| | CD at 5 % | 1.3 | 0.6 | 6.3 | - | - | - | - | 2125 |
| | CV % | 17.2 | 16.0 | 12.5 | - | - | - | - | 8.5 |

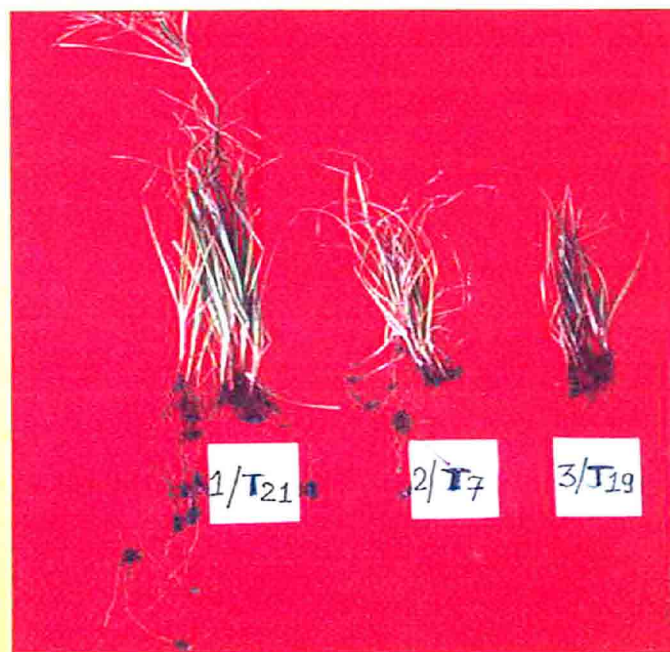
* At prevailing prices (Rs/q)

S : Sorghum, Rs. 700, G : Gram, Rs. 1500, A : Amaranthus, Rs. 1500
W : Wheat, Rs. 750

Plate 9 : Effect of *C. rotundus* on sorghum growth



Plate 10 : Effect of suppression measures on *C. rotundus*



1. Control, 2. C + S +bb, 3. C + S +bb +sb +atz +rf

(T₂₀) C + S + hw (Rs. 12449), and (T₁₁) C + S + G + bb + rf (Rs. 11330). However, the later (T₁₁) was on par to (T₁₈) C + S + bb + sb + atz (Rs. 10430), (T₁₅) C + S + bb + sb (Rs. 10150), (T₁₆) C + S + bb + atz (Rs. 10069), (T₇) C + S + bb (Rs. 9800), (T₁₂) C + S + A + bb + rf (9769) and (T₉) C + S + A + bb (Rs. 9239). Although *Cyperus* free sorghum resulted in highest return of Rs. 18060 in the pot culture experiment against the returns of Rs. 6335 in (T₄) C + S which indicated that *Cyperus* caused the (2.9 times) loss of Rs. 11725 (About 65 % over potential of the crop). Growth of sorghum plants was stunted due to *Cyperus* growth (Plate 9). Gupta (1977) reported that *A. cyperi*, *B. minima* and *B. venosana* appeared to keep *Cyperus* under biotic pressure. Smith and Fick (1937) found that a single tuber in green house produced 149 tubers in 3-5 months. The detailed observations on the aspect in present study strongly corroborate the reported observations.

4.4.2.2 Influence of hand weeding and bioagents on suppression of *C. rotundus* in pot cultured okra

The results of suppression of *C. rotundus* by the weevil and rust fungus in okra variety Arka Anamika are presented in Table 21.

i. Above ground portion

Number of *Cyperus* plants : The highest (50) number of *Cyperus* plants were observed in (T₆) *Cyperus* alone, and it was at par with (T₁) O + C, indicating that okra plant alone cannot suppress the growth of *Cyperus*. The lowest (24.7) number of *Cyperus* plants were recorded

in (T₅) O + C + rf + bb. However, later was at par with (T₂) O + C + hw (27) and (T₄) O + C + bb (29.3).

Bulb borer infestation : The infestation of *Cyperus* bulb borer was highest (42 %) in (T₄) O + C + bb and was on par to that (40.4 %) in (T₅) O + C + rf + bb, when the natural infestation in rest of the treatments was 5.3 to 12.8 per cent.

ii. Under ground portion (tubers)

Number of tubers/pot : At harvest, the highest (98.3) number of tubers were recovered in (T₆) *Cyperus* alone, followed by (T₁) O + C (77.3). The number reduced by 2.65 and 2.6 times in (T₅) O + C + rf + bb and (T₂) O + C + hw, respectively, in comparison to (T₆) *Cyperus* alone. The release of either bulb borer or rust fungus alone reduced the number of tubers by 2.1 and 1.4 times, respectively.

Weight of tubers : The tuber weight was lowest (15 g) in (T₅) O + C + rf + bb and it was at par with that in (T₄) O + C + bb (15.7 g) and (T₂) O + C + hw (20.4 g).

Number and per cent sprouted tubers : Significantly highest (84) number of sprouted tubers were observed in (T₆) *Cyperus* alone, among all the treatments. The least (10) number of sprouted tubers were found in (T₂) O + C + hw, which was at par with (T₅) O + C + rf + bb (17.3). The percentage of sprouted tubers in (T₂) O + C + hw was significantly lowest. (T₅) O + C + rf + bb was at par with (T₄) O + C + bb and (T₃) O + C + rf.

Tuber multiplicability ratio : It was lowest (1 : 0.7) in (T₂) O + C + hw and was at par with that in (T₅) O + C + rf + bb (1 : 1.2). In pot cultured okra crop (T₁) reduced the multiplicability ratio (1 : 1.37) of

Cyperus tubers as compared to (T₆) *Cyperus* alone (1 : 5.6). The results of both the pot culture experiments revealed that *Cyperus* multiplication rate in sorghum, wheat, amaranthus, gram and okra was 2.7, 2.9, 3.4, 4 and 5.2 times against the multiplicability ratio of 1.5, 1.7, 2.5, 2.5 and 3.7, respectively (Fig. 3). As such sorghum emerged as the most suitable test crop for suppression of the *C. rotundus* by shade and crop competition effect.

iii. Okra yield (q/ha)

The highest (63.3 q) yield was obtained from (T₇) *Cyperus* free okra. As compared to (T₇) the yield reduced by 4.9 times in (T₁) O + C (13.0 q), indicating heavy losses in okra yield due to *Cyperus* competition. In case of (T₂) O + C + hw, the yield was 43.5 q and it was at par with (T₅) O + C + rf + bb (43.3 q). The treatments with release of either *Cyperus* bulb borer or spray of rust fungus alone yielded 33.6 and 26.5 q, respectively.

Considering the performance of common treatments evaluated for *Cyperus* suppression in sorghum (4.4.2.1) and okra (4.4.2.2) pot culture and reflected in *Cyperus* multiplicability ratio (Fig. 4), the treatment with C + hw, C + rf + bb and C + bb emerged as most promising management tactics for the weed. However, the suppression effect was more pronounced in that in sorghum than okra.

Table 21. Influence of hand weeding and bioagents on multiplicability of *C. rotundus* in okra (Arka Anamika) in pot culture

| Sr. Treatment | <i>C. rotundus</i> | | | | | | | Okra yield g/pot (q/ha) |
|--------------------|------------------------|---------------------|--------|------------|-----------------|-------------------------------|------------------------|-------------------------|
| | Above ground part /pot | | | Tubers/pot | | | | |
| No. | No. of plants | Infested plants (%) | Number | Weight (g) | Sprouted number | Per cent sprouting at 20 days | Multiplicability ratio | |
| 1. O + C | 42.3 | 4 (11.2)* | 77.3 | 38.9 | 55.3 | 71.6 (58.1)* | 1 : 3.7 | 12.9 (13.0) |
| 2. O + C + hw | 27.0 | 5.1 (12.8) | 37.7 | 20.4 | 10 | 26.6 (30.9) | 1 : 0.7 | 43.5 (43.5) |
| 3. O + C + rf | 39 | 3.3 (10.5) | 69.7 | 29.9 | 39 | 55.8 (48.3) | 1 : 2.6 | 26.5 (26.5) |
| 4. O + C + bb | 29.3 | 4.2 (40.4) | 48.0 | 15.7 | 24 | 50.6 (45.4) | 1 : 1.6 | 33.6 (33.6) |
| 5. O + C + rf + bb | 24.7 | 40.4 (39.4) | 37.0 | 15.0 | 17.3 | 46.4 (42.9) | 1 : 1.2 | 43.3 (43.3) |
| 6. C only | 50.0 | 1.3 (5.3) | 98.3 | 61 | 84.0 | 85.7 (67.8) | 1 : 5.6 | - |
| 7. O only | - | - | - | - | - | - | - | 63.3 (63.3) |
| S.E. ± | 3.3 | 1.6 | 2.8 | 2.8 | 2.4 | 2.2 | 0.2 | 2.0 |
| CD at 5% | 10.2 | 4.9 | 8.5 | 8.4 | 7.4 | 6.9 | 0.5 | 6.2 |
| C.V. % | 11.0 | 9.3 | 5.3 | 10.7 | 7.4 | 5.4 | 7.5 | 6.4 |

*Figures in parentheses indicate arcsin values.

4.4.3 Field experiments

4.4.3.1 Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in Sorghum CSH-9 in field

The results of the experiment on impact of *Cyperus* bulb borer and rust fungus on the growth of *Cyperus* in sorghum CSH-9 are presented in Table 22 and depicted in Fig. 5.

i. *Cyperus* dead hearts

The highest percentage (22.2) of dead hearts occurred in (T₃) S + C + bb + chw, which was at par with (T₅) S + C + bb (18.2) and (T₆) S + C + rf + bb (16.3). However, in other treatments where the bulb borer was not released the infestation ranged from 7.8 to 9.5 per cent due to wild population of the *Cyperus* bulb borer and stem borer and probable migration of the weevils in these treatments from other treatments.

ii. Multiplication rate of the tubers

The highest (8.5 times) multiplication rate of the tubers occurred in (T₇) *Cyperus* alone. Shade effect of sorghum crop (T₁) S + C reduced the multiplication rate by 18.8 per cent as compared to (T₇) *Cyperus* alone. The most promising treatment for lowering the multiplication rate was (T₃) S + C + bb + chw (3.7 times) followed by the at par treatments (T₂) S + C + hw (3.8 times), (T₆) S + C + rf + bb (4.2 times) and (T₅) S + C + bb (5 times). The rust fungus (T₄) S + C + rf, reduced multiplication rate by 13 per cent as compared to (T₁) S + C.

Table 22. Influence of hand weeding and bioagents on multiplicability of *C. rotundus* in sorghum (CSH-9) in field

| Sr. Treatments | <i>C. rotundus</i> / 1.5 m ² | | | | | | | Sorghum g/plot (q/ha) | |
|---------------------|---|---------------------|------------|--------------|---------------------|-------------------------------|------------------------------|-----------------------|---------------|
| | Above ground part | | | Tubers/ | | | | | |
| No. | No. of plants | Infested plants (%) | Pre sowing | Post harvest | Multiplication rate | Per cent sprouting at 20 days | Multiplication ability ratio | Yield | Biomass |
| 1. S + C | 149.7 | 9.5 (17.9)* | 7 | 49 | 6.9 | 65.5 (54.1)* | 1 : 4.5 | 374 (13.9) | 3780 (140) |
| 2. S + C + hw | 98.7 | 7.8 (16.2) | 8.7 | 32.3 | 3.8 | 51.3 (45.7) | 1 : 2.0 | 576 (21.3) | 6030 (223) |
| 3. S + C + bb + chw | 70.0 | 22.2 (28.0) | 6.7 | 24.0 | 3.7 | 35.6 (36.5) | 1 : 1.3 | 603 (22.3) | 6300 (233) |
| 4. S + C + rf | 125.7 | 9 (17.4) | 7.0 | 42.3 | 6.0 | 61.9 (51.9) | 1 : 3.7 | 495 (18.3) | 3966 (147) |
| 5. S + C + bb | 104.0 | 18.2 (25.2) | 6.3 | 33.0 | 5.0 | 55.3 (48.1) | 1 : 2.8 | 531 (19.7) | 4500 (167) |
| 6. S + C + rf + bb | 93.7 | 16.3 (23.7) | 7 | 29.3 | 4.2 | 52.7 (46.5) | 1 : 2.2 | 558 (20.7) | 5999 (222) |
| 7. C only | 181.3 | 9.4 (17.8) | 7 | 60.3 | 8.5 | 72.8 (58.8) | 1 : 6.2 | - | - |
| S.E. ± | 18.0 | 1.5 | 0.9 | 6.7 | 0.5 | 1.9 | 0.4 | 32.4 (12.0) | 709 (26) |
| CD at 5 % | 55.5 | 4.6 | N.S. | 20.7 | 1.7 | 6.0 | 1.4 | 100.0 (3.7) | 2189 (81) |
| C.V. % | 16.5 | 12.3 | 18.6 | 18.1 | 17.2 | 6.9 | 16.6 | 12.5 | 18.2 |

*Figures in parentheses indicate arcsin values.

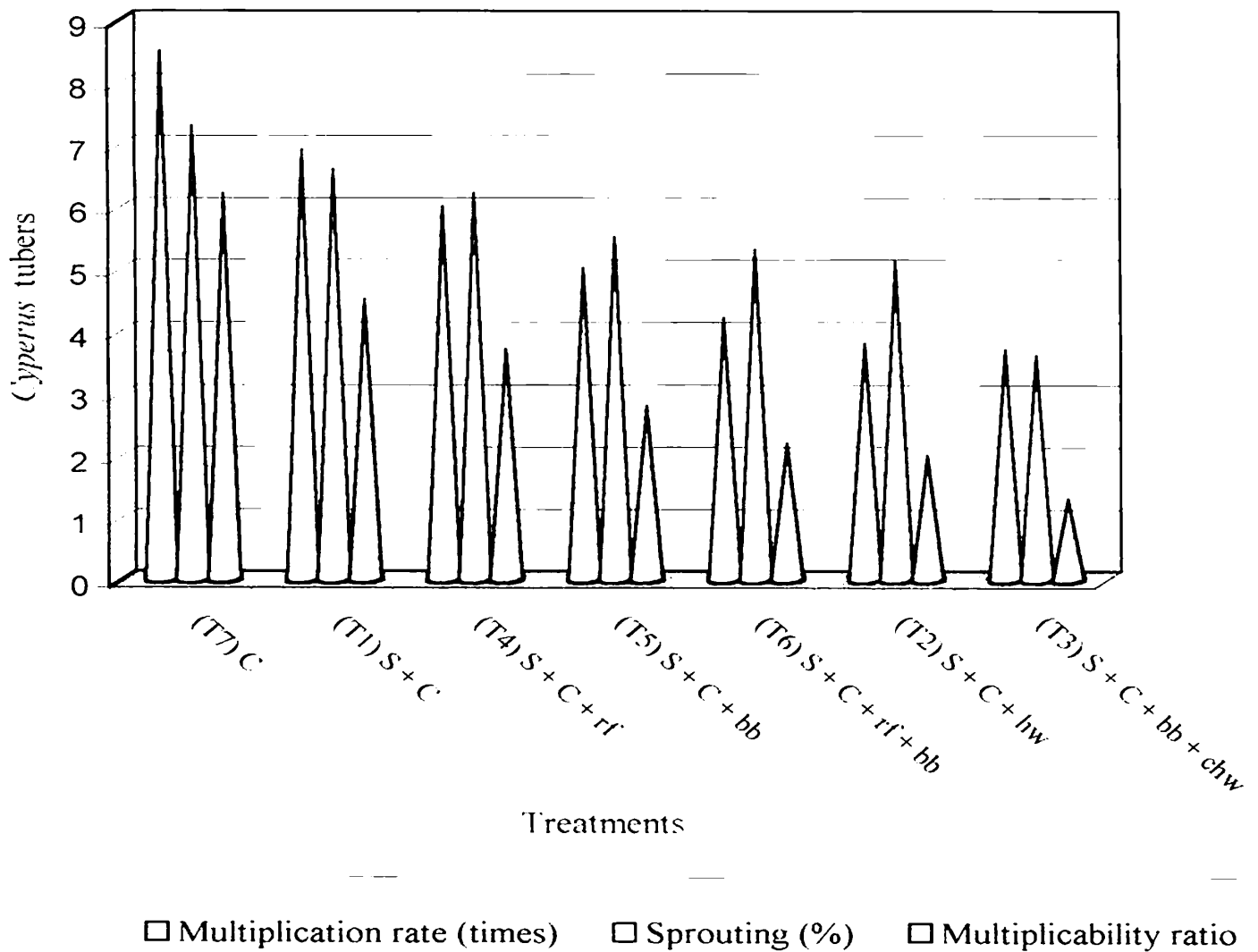


Fig. 5. Impact of the treatments on growth of *Cyperus* in sorghum CSH-9 in field

iii. Sprouting of tubers (%)

The lowest (35.6 %) percentage of sprouting was recorded in (T₃) S + C + bb + chw. The next promising (51.3 %) treatment for reducing the sprouting was (T₂) S + C + hw, which was at par with (T₆) S + C + rf + bb (52.7 %) and (T₅) S + C + bb (55.3 %).

iv. Tuber multiplicability ratio

The lowest (1 : 1.3) ratio was obtained in (T₃) S + C + bb + chw, which was at par with (T₂) S + C + hw (1 : 2) and (T₆) S + C + rf + bb (1 : 2.2). The multiplicability ratio of the weed in (T₁) S + C, was significantly lesser (1 : 4.5) than that in (T₇) *Cyperus* alone (1 : 6.2). It indicated that sorghum is a competitive crop. So, it could be included in crop rotation in *Cyperus* problem area.

v. Sorghum yield (q/ha)

The (T₃) S + C + bb + chw, gave the highest yield (22.3 q) and it was on par with (T₂) S + C + hw (21.3 q), (T₆) S + C + rf + bb (20.7 q) and (T₅) S + C + bb (19.7 q). The trend of fodder biomass produced was similar to that of grain yield. The trend of results obtained for T₆ and T₅ in pot culture experiment (2.2.4.1) were confirmed in the field trial.

4.4.3.2 Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in okra in field

The data on influence of okra crop and *Cyperus* bioagents on the suppression of *C. rotundus* are presented in Table 23 and depicted in Fig. 6.

Table 23. Influence of hand weeding and bioagents on multiplicability of *C. rotundus* in okra (Arka Anamica) in field

| Sr. Treatment | <i>C. rotundus</i> /1.5 m ² | | | | | | | Okra g/plot (q/ha) | |
|---------------------|--|---------------------|------------|--------------|---------------------|-------------------|------------------------------|--------------------|-------------|
| | Above ground part | | | Tubers | | | | | |
| No. | No. of plants | Infested plants (%) | Pre sowing | Post harvest | Multiplication rate | Percent sprouting | Multiplication ability ratio | Dry fruits | Biomass |
| 1. O + C | 160.7 | 8.3 (16.0)* | 7.3 | 61 | 8.2 | 69.8 (56.8)* | 1 : 5.7 | 409 (14.2) | 877 (30.5) |
| 2. O + C + hw | 94 | 8.2 (16.7) | 5.0 | 29.7 | 6.1 | 52.9 (46.7) | 1 : 3.2 | 647 (22.5) | 1165 (40.5) |
| 3. O + C + bb + chw | 98 | 18.6 (25.6) | 6.3 | 32.0 | 5.0 | 47.8 (43.7) | 1 : 2.4 | 720 (25.0) | 1492 (51.8) |
| 4. O + C + rf | 138 | 7.0 (15.3) | 6.3 | 46.7 | 7.1 | 69.4 (56.6) | 1 : 4.9 | 432 (20.0) | 927 (32.2) |
| 5. O + C + bb | 108 | 17.6 (24.7) | 5.7 | 36.3 | 6.5 | 62.0 (51.9) | 1 : 4.0 | 461 (16.0) | 947 (32.9) |
| 6. O + C + rf + bb | 99.7 | 17.1 (24.5) | 5.3 | 33.7 | 6.3 | 57.5 (49.5) | 1 : 3.6 | 540 (18.7) | 1018 (26.0) |
| 7. C only | 188.7 | 10.2 (18.6) | 6.0 | 52.3 | 8.8 | 76.9 (61.4) | 1 : 6.7 | - | - |
| S.E. ± | 26.2 | 1.0 | 1.0 | 9.2 | 0.6 | 2.7 | 0.4 | 36.5 (1.3) | 119 (4.1) |
| CD at 5 % | N.S. | 3.1 | N.S. | N.S. | 2.0 | 8.5 | 1.3 | 114.0 (3.9) | 365 (12.7) |
| C.V. % | 17.8 | 8.7 | 19.3 | 18.2 | 16.0 | 9.1 | 17.1 | 13.8 | 12.3 |

*Figures in parentheses indicate arcsin values.

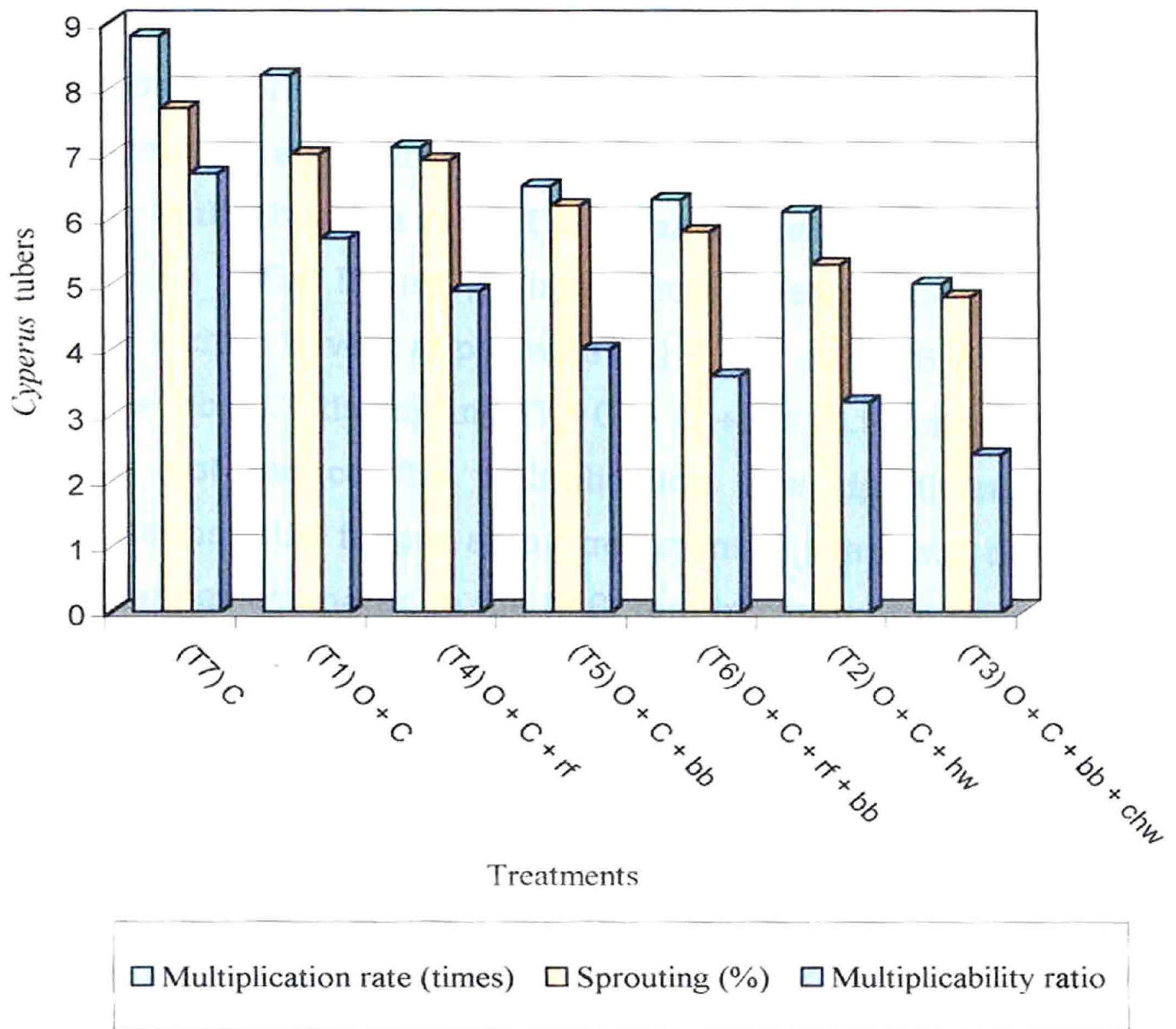


Fig. 6. Influence of the treatments on multiplication of *Cyperus* in okra (Arka Anamica) in field

i. Bioagents infestation in *C. rotundus*

T₃, O + C + bb + chw, showed highest (18.6 %) dead hearts caused by the bioagents and it was at par with (T₅) O + C + bb (17.6 %) and (T₆) O + C + rf + bb (17.1 %). In rest of the treatments the bulb borer was not released, however the natural dead hearts percentage ranged from 7 to 10.2 per cent.

ii. Multiplication rate of *C. rotundus* tubers

The lowest (5 times) multiplication rate was in (T₃) O + C + bb + chw. T₃ was at par with (T₂) O + C + hw (6.1 times), (T₆) O + C + rf + bb (6.3 times) and (T₅) O + C + bb (6.5 times). The okra crop could not reduce the multiplication rate significantly under field conditions. Rust fungus spray treatment (T₄) reduced the rate by 19.3 per cent as compared to the (8.8) rate in control treatment (T₇).

iii. Sprouting of the tubers

The highest (76.9 %) sprouting resulted in (T₇) *Cyperus* alone. However, it reduced upto 47.8 per cent in (T₃) O + C + bb + chw. The later was at par with (T₂) O + C + hw (52.9 %), (T₆) O + C + rf + bb (57.5 %) and (T₅) O + C + bb (62 %). The sprouting (69.4 to 76.9 %) was at par in (T₁) O + C, (T₄) O + C + rf and (T₇) C, which indicated that okra crop alone or spray of *Cyperus* rust fungus in okra crop did not affect the tuber sprouting significantly.

iv. Tuber multiplicability ratio

The lowest (2.4) ratio was obtained from (T₃) O + C + bb + chw. It was at par with (T₂) O + C + hw (3.2) and (T₆) O + C + rf + bb (3.6). However, okra crop alone (T₁) O + C, could not reduce the ratio significantly, indicating that okra is not a competitive plant for

affecting subsequent *Cyperus* generations. These results confirmed the trend of results found in pot culture experiment 4.4.2.2.

Okra fruit yield

The highest (25 q) dry fruit yield was recorded in (T₃) O + C + bb + chw and it was on par with (T₂) O + C + hw (22.5 q). The (T₆) O + C + rf + bb gave significantly more (18.7 q) yield than (T₁) O + C (14.2 q). The trend of biomass produced was similar to that of fruit yield. The treatment of care hand weeding was more laborious than hand weeding treatment, but the advantage of this method is that it conserves the *Cyperus* bulb borer population which is suppressed by normal cultural practices. William and Warren (1975) reported 62 per cent losses in yield of okra due to competition of 400-1000 *Cyperus* plants/m², more or less confirmed 79.6 per cent reduction in yield in the present investigation at weed density of 470 plants/m² in pot culture. The result on non competence of okra to suppress the weed is in agreement with William (1976) who opined that long duration of weed control is necessary for maximum yield of non competitive crops like garlic or okra.

The comparison of *Cyperus* multiplicability ratio influenced by various treatments as depicted in Fig. 7 confirmed the results of pot culture experiments on sorghum and okra in field also in respect of the treatments with C + hw, C + rf + bb and C + bb. Besides that C + bb + chw emerged as most promising treatment for suppression of the weed in both the crops. Although, the suppression effect was predominant in sorghum as compared to okra crop.

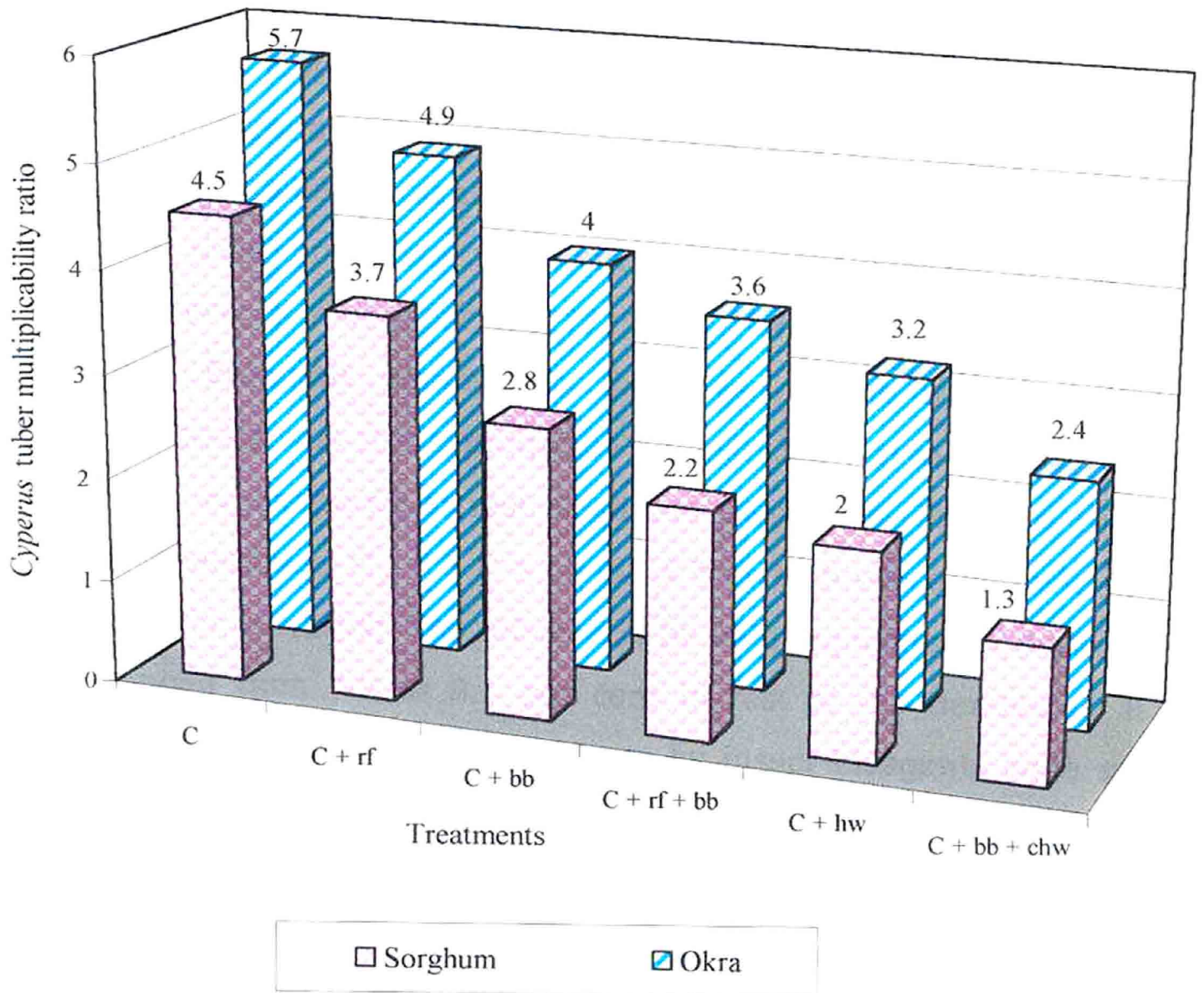


Fig. 7. Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in sorghum (CSH-9) and okra (Arka Anamika) in field

4.4.3.3 Influence of *Cyperus* bulb borer and rust fungus on multiplicability of newly sown *Cyperus* tubers in sorghum M35-1 in field

The data on effect of *A. cyperi* and *P. romagnoliana* on the growth and multiplicability of newly sown *Cyperus* tubers in sorghum crop are presented in Table 24 and depicted in Fig. 8.

i. ***Cyperus* plants/plot** : Significantly and substantially lowest (24.7) number of plants were found in (T₂) S + C + bb + chw. It was the most promising treatment for the suppression of the weed. However, it was at par with (T₅) S + C + rf + bb (32.3).

ii. **Bioagent damage to the weed** : The infestation by the bioagents was also significantly highest (34.6 %) in (T₂) S + C + bb + chw as compared to rest of all the treatments. The next promising treatment was (T₄) S + C + bb (23.4 %) which was at par with (T₅) S + C + rf + bb (20.4). The infestation by wild population of the bioagents ranged from 7.8 to 9.1 per cent in rest of the treatments. It was observed that the infested plants by insect bioagents were severely infected by the rust fungus. It indicated that bioagents intensified the disease development.

iii. **Fungus damage score** : *Cyperus* fungus treated plots of (T₃) S + C + rf and (T₅) S + C + rf + bb showed heavy infection and damage score (4.3 to 4.7) against significantly less : (0.7 to 1.3) damage score in rest of the treatments.

iv. **Dry biomass produced** : The maximum (75.0 %) reduction in the dry weight of *Cyperus* plants was registered in (T₂) S + C + bb + chw, followed by and at par (T₅) S + C + rf + bb (60.5 %) and (T₃) S +



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Table 24. Influence of *Cyperus* bulb borer and rust fungus on multiplicability of newly sown 25 *Cyperus* tubers/plot in sorghum (M35-1)

| Sl. No. | Treatment | <i>C. rotundus</i> | | | | | | | | | | Sorghum | |
|---------|------------------|---------------------------|--------------|-----------------|--|------------|---------------------------------------|----------------------|------------------------|----------------|-----------------------------|---------|---------|
| | | Plants/1.5 m ² | | | | | Tubers | | | | | g/plot | (q/ha) |
| | | No. damage (%) | Fungus score | Dry biomass (g) | Weight Reducti on over (T ₂) (%) | No. / plot | Reducti on over (T ₂) (%) | Multipli cation rate | Weight /100 tubers (g) | Sprouti ng (%) | Multipli cability ratio 1 : | Grain | Fodder |
| 1. | S + C | 36.7 | 9.1 | 6.9 | 41.4 | 81.0 | 6.2 | 3.24 | 53 | 56.6 | 1.81 | 324 | 1728 |
| | | (17.6)* | | | | | | | | (48.8)* | | (12) | (64.0) |
| 2. | S + C + bb + chw | 24.7 | 34.6 | 3.1 | 75.0 | 25.3 | 19.3 | 1.01 | 31 | 36.9 | 0.37 | 468 | 2444 |
| | | (36.0) | | | | | | | | (37.4) | | (17.3) | (90.47) |
| 3. | S + C + rf | 34.0 | 7.8 | 5.6 | 54.8 | 66.3 | 51.0 | 2.65 | 51 | 53.7 | 1.41 | 360 | 1764 |
| | | (16.2) | | | | | | | | (47.1) | | (13.3) | (65.3) |
| 4. | S + C + bb | 35.7 | 23.4 | 6.3 | 49.2 | 56.0 | 43.1 | 2.24 | 41 | 52.5 | 1.17 | 386 | 1926 |
| | | (29.0) | | | | | | | | (46.4) | | (14.3) | (71.33) |
| 5. | S + C + rf + bb | 32.3 | 20.4 | 4.9 | 60.5 | 46.7 | 35.9 | 1.87 | 37 | 44.4 | 0.83 | 423 | 2160 |
| | | (26.6) | | | | | | | | (41.8) | | (15.7) | (80.00) |
| 6. | C alone | 41.3 | 8.3 | 12.4 | - | 130.0 | 0.0 | 5.2 | 68 | 68.8 | 3.59 | - | - |
| | | (16.7) | | | | | | | | (56.1) | | 506 | 2490 |
| 7. | S alone | - | - | - | - | - | - | - | - | - | - | (18.7) | (92.2) |
| | S.E. ± | 2.8 | 1.0 | 0.3 | 0.9 | 4.6 | 3.5 | 0.2 | 3.0 | 1.2 | 0.13 | 15.3 | 84.6 |
| | CD at 5 % | 8.7 | 3.2 | 0.9 | 2.9 | 14.2 | 10.9 | 0.56 | 9.0 | 3.8 | 0.39 | 46.8 | 261 |
| | C.V. % | 16.8 | 8.8 | 17.0 | 18.6 | 13.8 | 17.2 | 13.8 | 12.7 | 5.4 | 16.7 | 7.5 | 8.2 |

*Figures in parentheses indicate arcsin values.

C + rf (54.8 %) in which the dry weight was 3.1 to 5.6 g against the significantly highest (12.4 g) biomass produced in (T₆) *Cyperus* alone. The shade effect of sorghum plants (T₁) reduced the dry weight of *Cyperus* plants by 44.4 per cent.

v. Increase in the tubers : The multiplication rate in (T₂) S + C + bb + chw was least and remained almost same (1.01 times) as compared to 5.2 folds increased in (T₆) C alone. While, the sorghum crop (T₁) allowed 3.24 folds tuber multiplication. (T₅) S + C + rf + bb (1.87) and (T₄) S + C + bb (2.24) were the next promising and at par treatments to adversely affect the tuber multiplication.

vi. Weight of 100 tubers : The lowest (31 g) weight of the tubers in (T₂) S + C + bb + chw was at par with (T₅) S + C + rf + bb (37 g). Shade effect of sorghum (T₁) on *Cyperus* reduced the tuber weight (53 g) by 22 per cent over weight of 68 g in the control (T₆) C alone.

vii. Impact on the tuber sprouting : The lowest (36.9 %) tuber sprouting was found in (T₂) S + C + bb + chw. The next promising treatment was (T₅) S + C + bb + rf (44.4). The sprouting was at par in (T₄) S + C + bb (52.5 %) and (T₃) S + C + rf (53.7). It was reduced by 18 per cent in (T₁) S + C due to shade and growth competition effect of sorghum as compared to the control (T₆) C alone.

viii. Tuber multiplicability ratio : The ratio was lowest (1 : 0.37) in (T₂) S + C + bb + chw and hence it emerged as the best integrated measure treatment to suppress the weed in short and long term. The next promising biointensive treatment for the weed suppression was (T₅) S + C + rf + bb (1 : 0.83). However, it was on par to (T₄) S + C + bb (1 : 1.17). The ratio was at par in (T₄) S + C + bb (1.17) and (T₃) S

+ C + rf (1.41) against significantly highest multiplicability ratio of 1 : 3.59 in control (T_6) C alone. The bulb borer alone (T_4) and rust fungus alone (T_3) in sorghum reduced the ratio by 67.4 and 60.2 per cent, respectively over the control (T_6). The trend of multiplicability observed in the experiment is the reconfirmation of the results of earlier pot culture (4.4.2.1) and field trial (4.4.3.1).

ix. Sorghum grain yield : The treatment (T_7) sorghum without *Cyperus* gave the highest (18.7 q/ha) yield, but it was on par to (17.3 q/ha) the grain yield in (T_2) S + C + bb + chw. The yield (14.3 q/ha) in *Cyperus* bulb borer (T_4) S + C + bb and (13.3 q/ha) in the rust fungus (T_3) S + C + rf treatments did not differ significantly. The *Cyperus* in sorghum (T_1) reduced 36 per cent grain yield over that of the *Cyperus* free sorghum (T_7). The bulb borer alone (T_4) and rust fungus alone (T_3) saved the yield by 15.9 and 10 per cent from the weed, respectively as compared to (T_1) S + C. However, in combination, both the bioagents saved 23.4 per cent yield.

x. Sorghum fodder yield (q/ha) : The fodder yield varied from 64 q in (T_1) *Cyperus* infested sorghum to 92.2 q in (T_7) *Cyperus* free sorghum. Although the trend of the fodder yield was more or less similar to that of the grain yield.

Kondap *et al.* (1982) estimated the losses of 12 per cent in sorghum yield due to *Cyperus* competition, while in the present study the losses were 36 per cent. The variation in the losses might be attributed to variation in sorghum cultivar, growth, environment and density of the weed. Patterson (1982) observed that shading the

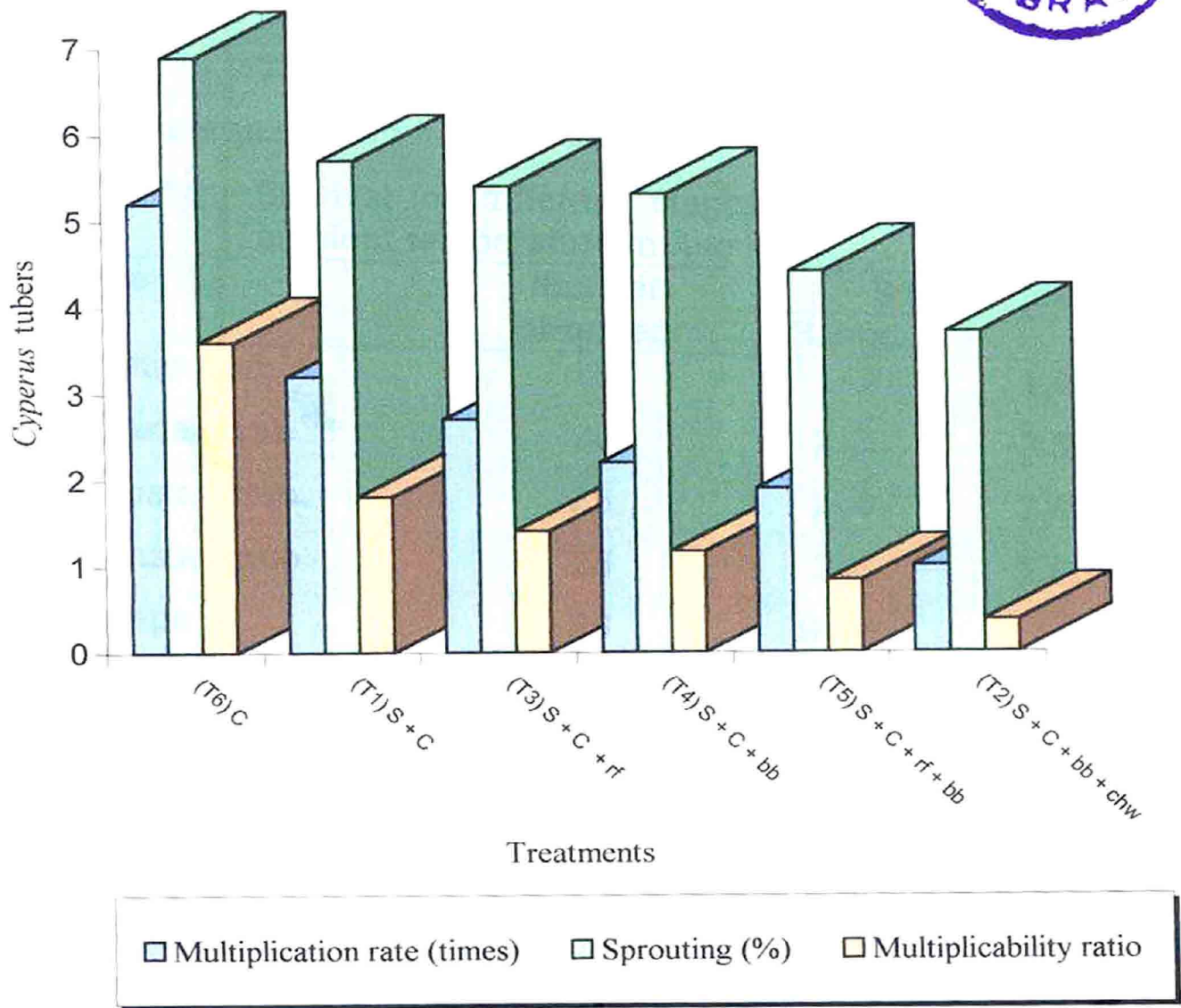


Fig. 8. Effect of the treatments on multiplication of 25 *Cyperus* tubers sown/plot with sorghum (M 35-1)

Cyperus plants created shortage of food for storage into tubers and rhizomes. It may affect the tuber viability.

4.5 Ancillary observations

4.5.1 Survival of different stages of *A. cyperi* in water

The data on survival of different stages of *A. cyperi* in water are presented in Table 25.

Table 25. Survival of different stages of *A. cyperi* in water at ambient temperature in August

| Stage | Number observed | Survival (days) | |
|-------------------------------|-----------------|-----------------|--------------|
| | | Range | Mean |
| I st instar grub | 25 | 1-3 | 1.47 ± 0.33 |
| II nd instar grub | 25 | 2-3 | 2.33 ± 0.25 |
| III rd instar grub | 25 | 2-4 | 2.53 ± 0.33 |
| IV th instar grub | 25 | 2-4 | 2.60 ± 0.42 |
| Prepupa | 25 | 9-16 | 11.73 ± 1.32 |
| Pupa | 25 | 8-12 | 9.6 ± 0.82 |
| Weevil | 25 | 4-9 | 5 ± 0.78 |

The data in Table 25 revealed that grub instars survived under water for 1 to 4 days with an average of 1.47 ± 0.33 to 2.6 ± 0.42 days against the average longevity of 4.6 ± 0.22 to 13.76 ± 0.89 days (as per 4.1.2.2) for Ist to IVth instar. Although IInd to IVth instar grubs feeding in bulb may resist few more days to water flooding in field but it may cause heavy decline in the population of neonate grub. The prepupal and pupal stages were quite resistant to the flooding and survived for 11.73 ± 1.32 and 9.6 ± 0.82 days,

respectively. Adults could survive for 5 ± 0.78 days in the flood conditions.

4.5.2 Parasitism on *A. cyperi*

In the present investigation, only a parasitoid species was found to attack the bulb borer grubs. The ectoparasitoid, *Anisopteromalus calandrae* Howard (Hymenoptera : Pteromalidae) (Plate 11a) parasitized the grubs, usually in the second and third instars. Finally, the grub shrunken (Plate 11b) and the parasitoid larva pupated. Last larval instar of the parasitoid was ivory in colour, spindle shaped, 2 to 2.5 mm in length and the head was inserted in the host body. Pupa was of exarate type 2-3 mm length and having red eyes. Adult was black wasp and 2-3 mm in length. Larval and pupal periods were 12 to 15 and 6 to 7 days, respectively. The wasp was not active from March to May and during the rest of the year the infestation ranged from 0.6 to 3.4 % (Table 13).

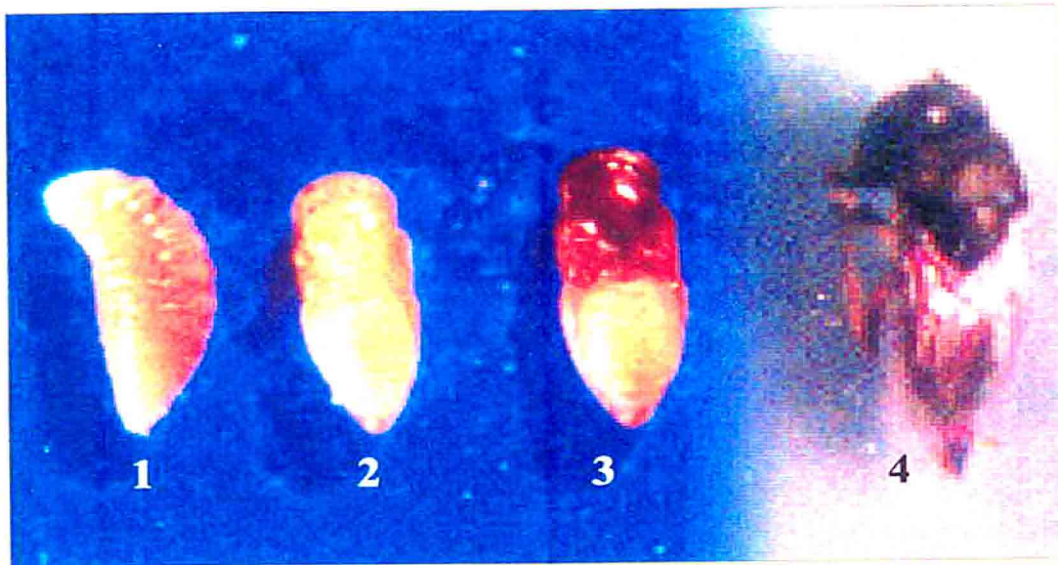
Habib (1976a) reported a parasitism of 1 to 22 per cent by an unidentified Braconid during May-August and 1 to 4.5 per cent of *A. calandrae* during April-August at Mirpur Khan in Pakistan in 1970. The observation of negligible parasitism by *A. calandrae* is in agreement with Habib (1976a). Poinar (1964) mentioned that no any parasitoid of *A. cyperi* was recorded in Hawaii.

4.5.3 *Cyperus* stem borer, *Bactra venosana*

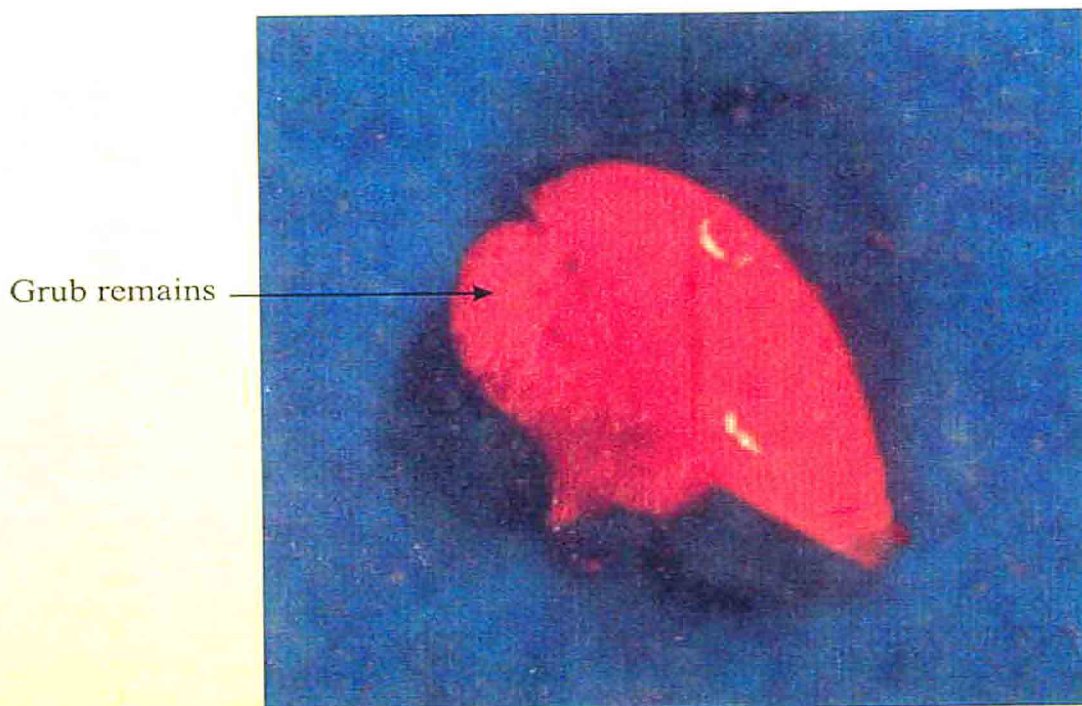
4.5.3.1 Biology

The moth male and female mated immediately after emergence. Preoviposition period was two days. Creamish white eggs were deposited in 2 to 3 rows (50 eggs/row) along midrib on upper

Plate 11: Pteromalid parasitoid, *Anisopteromalus calandrae*
on *A.cyperi*



A. 1.Larva, 2.Fresh Pupa, 3.Matured pupa , 4. Adult



B. Fully grown parasitoid larva on the grub remains

Plate12: *Cyperus* stem borer, *Bactra venosana*



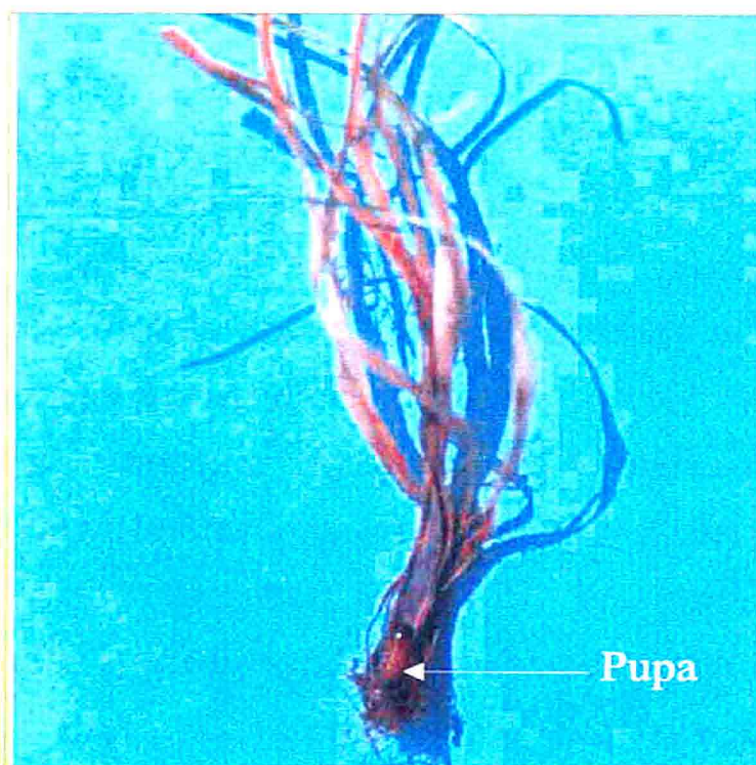
Larva



Pupa



Adult



Damaged plant with pupa

surface of *Cyperus* leaves. Fecundity was 20 to 170 eggs with an average of 74.7 eggs. Egg hatched within 2 to 3 days. Only one neonate caterpillar moved down and entered between leaf sheath and stem of *Cyperus* plant and started feeding in the whorled leaves. Other caterpillars searched separate plants. The larval migration from one plant to another for feeding was most common. Larval period was 14 to 19 days with an average of 16 days in March. The caterpillars damaged the tip of the basal bulb where they pupated (Plate 12). The pupal stage lasted for 8 days. Total life cycle from egg to moth emergence was completed in 22 to 27 days with an average of 24.3 days. Adult lived for 6 to 8 days. Sankaran and Rao (1972) reported the egg laying along the midrib of *C. rotundus*. Frick and Garcia (1975) stated that the life cycle of *B. verutana* was about 30 days. Habib (1976b) reported the total life cycle of 27 to 29 days (Av. 28 days) and fecundity of 17 to 241 eggs (Av. 80 eggs) under the condition of Pakistan. Vesalakshy Ganga (2002) reported the fecundity of 222 eggs and larval developmental period of 22.8 days in India, under Laboratory conditions. The results of present investigation vary slightly due to variation in study environment.

4.5.3.2 Damage potential

Each caterpillar injured 2 to 4 plants (Av. 2.5) before pupation. The dead hearts appeared within 6-8 days. However, upto 30 per cent of the damaged plants by the stem borer failed to regenerate. Habib (1976b) reported that a larva injured 2 to 3 plants. Hundred larvae might kill 147 plants and 65 per cent of the infested plants failed to regenerate which was higher than that (30 %)

observed in the present investigation. Frick and Garcia (1975) suggested the need for 6 generations to achieve high degree of infestation and concluded that application of 2 to 5 larvae/shoot caused significant damage to purple nutsedge. While Frick and Quimby (1977) suggested the release of 3 larvae/shoot to achieve good control. Frick and Chandler (1978) reduced above ground growth of *Cyperus* by 30 to 60 per cent within 4 to 7 weeks after last release. They observed that 3 to 5 releases of *B. verutana* in cotton field resulted in equivalent yield to that of *Cyperus* free cotton field.

4.5.4 Differences between the infestation of *A. cyperi* and *B. venosana* on *C. rotundus*

The main differences between the infestation and damage to the *Cyperus* plants are given in Table 26.

Table 26. Main differences between infestation of *A. cyperi* and *B. venosana*

| Sr. No. | Particulars | <i>A. cyperi</i> | <i>B. venosana</i> |
|---------|--|---|---|
| 1. | Adult feeding | Show series of holes on leaves | Nil |
| 2. | Damaging stage and plant part attacked | Grub - bulb Adult - leaves | Larva - stem |
| 3. | Oviposition site Egg | In bulbs (Singly) Irregular shaped and pale cream | On leaves in rows Roundish, creamy yellowish |
| 4. | Preferred plants | Of moderate age | Of any age |
| 5. | Frass and excreta | Dry and used for dome shaped plugging on the hollowed bulbs | Wet and spread along feeding way |
| 6. | Site of exit hole | On top of the bulb | On stem at collar portion |

4.5.5 Effect of *Cyperus* rust fungus, *P. romagnoliana* on *C. rotundus*

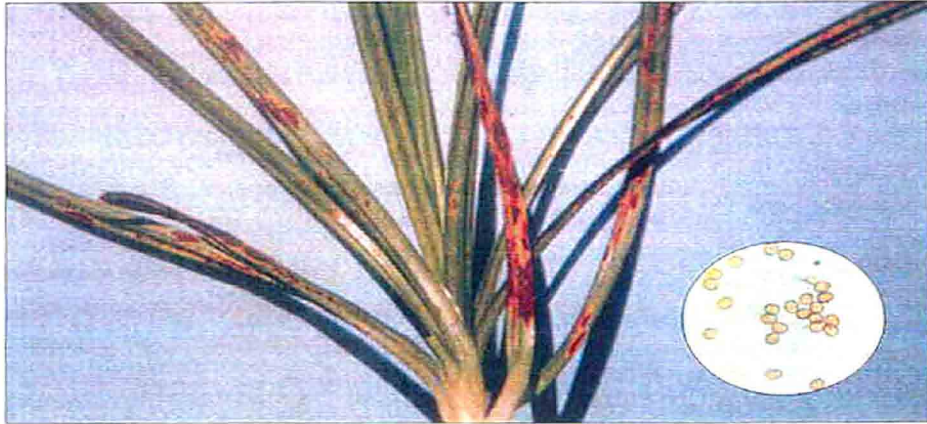
All the leaves in the treated plots after one month from the third and last spray were infected severely and dried due to the rust fungus infection (Plate 13). The data on the effect of the fungus on the tuber are presented in Table 27.

Table 27. Influence of *Cyperus* rust fungus, *P. romagnoliana* on multiplicability of *Cyperus* tubers

| Treatment | No. of plants/sq ft. | Tubers/Cu ft | | | | | | | |
|---------------------|----------------------|--------------|------------|---------------------|------------|--------------|---------------|-------------|------------------------|
| | | Pre count | Post count | Multiplication rate | Weight (g) | Sprouted No. | Sprouting (%) | Tuber/plant | Multiplicability ratio |
| Rust fungus treated | 72 | 15 | 105 | 7 | 85 | 80 | 76.2 | 1.46 | 5.33 |
| Untreated control | 65 | 14 | 118 | 8.43 | 107 | 105 | 89.0 | 1.82 | 7.5 |

The number of tubers increased by 7 times in the rust fungus treated plot against 8.43 times in untreated plots. The tuber/plant in former reduced by 0.36 (19.8 %). The number of sprouted tubers were 80 (76.2 %) and 105 (89.0 %) in the treated and untreated plots, respectively. However, the multiplicability ratio of the *Cyperus* plant reduced by 2.17 (28.9 %) due to the fungal infection. In the present investigation the reduction in number of tuber/plant was 0.36 in one year old plants and it was lower (19.8 %) than that 1.37 (47.1 %) observed by Bedi and Sokhi (1994) in 3 weeks old plants. The fungus, *Trichothecium roseum* (Pers.) Linkex. Gray was found associated with *P. romagnoliana*.

Plate 13 *Cyperus* rust fungus, *Puccinia romagnoliana*



A. Damaged plant and the fungus spores



B. *Cyperus* plot before the fungal infection



C. *Cyperus* plot after infection

4.5.6 Smothering effect of natural vegetation on *C. rotundus*

The weed, *Hierarcium vagum* grew upto height of 1.2 m in *Cyperus* plots and has a fast growing habit and medium canopy. It was observed to suppress the growth of *Cyperus*. So, additional observations were recorded and the data are presented in Table 28.

Table 28. Smothering effect of *H. vagum* on *C. rotundus* from August 2002 to January, 2003

| Sr. No. | Treatment | Number of plants/m ² | | <i>Cyperus</i> tubers/Cu ft. | | | |
|---------|----------------------------------|---------------------------------|-----------------|------------------------------|------------|-----------------|---------------|
| | | <i>Cyperus</i> | <i>H. vagum</i> | Number | Weight (g) | Sprouted number | Sprouting (%) |
| 1. | <i>Cyperus</i> + <i>H. vagum</i> | 105 | 65 | 185 | 160 | 108 | 58.4 |
| 2. | <i>Cyperus</i> alone | 140 | - | 220 | 205 | 173 | 78.6 |
| | Reduction (%) | 25 | - | 15.9 | 22 | 37.6 | 25.7 |

The data in Table 28 clearly showed that the weed, *H. vagum* grown for 6 months had potential of competitive displacement since it reduced number of *Cyperus* plants and number, weight, sprouted number and per cent sprouting of tubers by 25, 15.9, 22, 37.6 and 25.7 per cent, respectively in comparison to control plot of *Cyperus* alone. There is no published literature on the aspect of suppressing *Cyperus* by *H. vagum*.

However, Pollock (1925) attempted to eradicate purple nutsedge by means of smother crop and suggested that *Pennisetum clandestinum* Hochst must be cut and mulch the ground for 3 years before control is effective.

4.5.7 Incidence of *A. cyperi* and *B. venosana* on *Cyperus* in cucumber in polyhouse (June to December, 2001)

The data recorded on infestation of the bioagents attacking *C. rotundus* in poly house are presented in Table 29.

Table 29. Incidence of *A. cyperi* and *B. venosana* on *Cyperus* in polyhouse grown cucumber (June-December, 2001)

| Month 2001 | Number of plants/m ² | | <i>Cyperus</i> dead hearts (%) | | | | | |
|---------------|------------------------------------|-------|--------------------------------|-------|--------------------|-------|---------------|-------|
| | Poly house | Field | <i>A. cyperi</i> | | <i>B. venosana</i> | | Total | |
| | | | Poly house | Field | Poly house | Field | Poly house | Field |
| July* | 42 | 53.7 | -* | 10.1 | - | 12.5 | - | 22.6 |
| August | 67 | 71.9 | 19.4 | 13.7 | 14.4 | 19.7 | 33.8 | 33.4 |
| September | 60 | 87.7 | - | 8.6 | - | 12.8 | - | 21.4 |
| October | 45.3 | 105.5 | 30.1 | 11.5 | 13.9 | 12.7 | 44.0 | 24.2 |
| November | 66 | 122.9 | 24.7 | 6.8 | 7.1 | 1.5 | 31.8 | 8.3 |
| December | 50 | 103 | - | 11.9 | - | 2.2 | - | 14.1 |

* Due to hand weeding the plant growth was slight and inadequate for infestation

Due to frequent cultural practices in the polyhouse observation on the infestation dynamics in June and December could not be taken. However, there was higher (33.8 to 44.0 %) infestation of the bioagents in the polyhouse than that observed in the field for the respective months. The infestation of bioagents was 33.8, 44.0 and 31.8 per cent in August, October and November, 2001, respectively.

It was also noticed that the infestation of *Cyperus* by *A. cyperi* was higher than that of *B. venosana*. These observations indicated that the bioagents could cause more damage to *Cyperus*

plants in polyhouse conditions and could be implemented to control the weed successfully.

4.6 Formulation of strategy for purple nutsedge (*C. rotundus*) management

The *Cyperus* management strategy has been proposed to suppress the weed on the basis of the research findings of the present investigations supplementing information under review chapter.

Cyperus tubers are the potential dispersal unit and the bulbs are vital part for normal functioning of the plant. The tuber sprouting or initiation of tuber development are most vital stages to attack the weed for the potential suppression. Targeting destruction of the basal bulbs eventually adversely affects the multiplication of tubers. The *Cyperus* dead hearts caused by *A. cyperi* and *B. venosana* and leaf damage are the important tools of biosuppression of the weed. However, viable strategy to reduce number of tubers can be achieved by integrated use of bioagents and cultural practices to prevent the establishment of basal bulbs.

Considering available tactics of the weed management following strategy is suggested to suppress the weed.

Before planting of crop

- i. Uproot the bioagent infested plants before ploughing and keep them in moist soil near water source or in plastic tubs for their conservation, especially in March, July and November. The *Cyperus* bulb borer appeared mostly in pupal stage during these periods in present study.

- ii. Undertake deep preparatory tillage to bring most of the tubers near and on soil surface, collect and destroy them by sun drying for a week or by crushing. Because, the tubers are the main source of dispersal and multiplication. In dry soils (< 16 % moisture) the tuber dry and die within 5 weeks (Andrews, 1940). The tubers on the soil surface dry in 4 days (Smith and Fick, 1937).
- iii. Facilitate draining of rain water to ensure continuous activity of the bulb borer (*A. cyperi*) as the weevil can survive under water for about 5 days but cannot oviposit and the 1st instar grub cannot be saved under water for more than 35 hours as it was observed in the biology of the weevil.
- iv. Adopt recommended packages of practices for healthy and rapid growth of the crops. It will help to suppress the weed activity by shade effect and crop growth competition as per the present studies on biosuppression.
- v. Allow to grow few patches of *Cyperus* plants along border of the field in endemic areas to conserve the wild population of *A. cyperi* and *B. venosana*. Since the seasonal incidence studies showed on an average 7.9 and 8.1 per cent infestation of the bulb borer and stem borer on the weed, respectively.

At planting of crop

Select wide canopy crops and keep minimum recommended plant spacing for effective suppression of *Cyperus* growth by shade effect. In present studies sorghum and okra caused

27 and 15 per cent reduction in tuber multiplicability due to shade effect and growth competition.

At seedling and mid growth stage

- i. Undertake two care hand weedings at 3 and 6 weeks of germination of crop by avoiding *Cyperus* dead hearts and newly sprouted plants to augment the wild population of the *Cyperus* bulb borer and stem borer. Also avoid the rust fungus infected *Cyperus* plants for enhancing the infection in subsequent weed growth. Thakur (1955) found that the starch storage level in *Cyperus* tubers at 18 days of sprouting was lowest and suggested to utilize the period for controlling the weed.
- ii. Try to avoid drift of chemical insecticides on soil or the weed while spraying on the crop to conserve the bioagents.
- iii. On the basis of the seasonal incidence experiment considering 8 lakhs *Cyperus* plants/ha in a crop, release the *Cyperus* bulb borer, *A. cyperi* @ 1000 weevils/ha in groups of 10 weevils/100 sq.m for inoculative release and 5000 weevils/ha in groups of 50 weevils/100 sq.m. for inundative release. The fecundity of *A. cyperi* was 42 eggs and a female could cause 20.8 dead hearts. Release *Cyperus* stem borer (*B. venosana*) @ 1000 pupae/ha for inoculative and 5000 pupae/ha for inundative release in similar groups mentioned above for the *Cyperus* bulb borer.
- iv. Spray the muslin cloth filtered *Cyperus* rust fungus (*P. romagnoliana*) infected leaf powder in rainy season to intensify rust fungus damage to *Cyperus* as observed in the

biosuppression studies. Normally, for one hectare soak one kg powder of rust fungus infected leaves of *Cyperus* in 10 litres of water for 10 minutes, homogenize using hand blender and filter through muslin cloth. Mix 15 to 20 ml spore suspension in 10 litres of water. The inoculum load required in the spray suspension should be 2×10^5 spores/ml or more (Bedi and Sokhi, 1994).

- v. Use recommended herbicides in case of severe infestation. Although none of the chemical gave very effective control and there are always chances of phytotoxicity to the main crops. The following herbicides can be used.

| Sr. No. | Herbicide | Time of application | Dose a.i. kg/ha | Reference |
|---------|---------------------|---------------------|-----------------|---------------------------------------|
| 1. | Atrazine 50 WP | Post emergence | 2-2.5 | Power et al. (2000) |
| 2. | Glyphosate 41 % SL | Post emergence | 0.8-4.5 | Nadanassababady and Kandaswamy (2000) |
| 3. | Metolachlor EC 720 | Pre sowing | 2 | Wilcut et al. (1994) |
| 4. | Dichlobenil WP 45 % | Pre sowing | 6 | Willam et al. (2000) |
| 5. | EPTC 720 EC | Pre sowing | 9 | Warren and Coble (1999) |

After harvest of crop

- i. Collect and conserve bioagent infested *Cyperus* plants as stated above.
- ii. Collect rust fungus infected leaves, dry them in shade, grind and store in paper bags in cool and dry place. The storability is 2 to 3 months, so use before the period.

The strategy shall be more effective in polyhouses than the fields.



**SUMMARY
AND
CONCLUSIONS**

5. SUMMARY AND CONCLUSIONS

Cyperus bulb borer, *Athesapeuta cyperi* Marshall (Coleoptera : Curculionidae) attacks the world's worst weed, purple nutsedge, *Cyperus rotundus* Linnaeus. The weed found in 52 crops in more than 90 countries. It is known as 'Lavhala' in Marathi and *Alsaad* in Arabic. It is an extremely difficult weed to control, as it bears polychained subterranean tuber – rhizome system. The tubers are the potential source of dispersal and high multiplicability. It can cause 12 to 89 per cent losses in crop yields and has allelopathic effects on the crop health. The weed possesses highly efficient C₄ dicarboxylic acid photosynthetic pathway, harbours some pests and more or less resistant to almost all conventional measures of control.

Biological control of weed is an optimistic approach for suppression of the weed. *Cyperus* stem borers, *Bactra minima* Meyrick and *B. venosana* Zeller (Lepidoptera : Tortricidae), bulb borer, *A. cyperi* and rust fungus, *Puccinia romagnoliana* Maire and Sacc are of the concern of biological control of the *Cyperus*. *Bactra* spp. activities are limited by the egg parasitoid, *Trichogrammatoidea bactrae* and the rust fungus, *P. romagnoliana* flourish only in humid climate. Similarly, regeneration of the affected *Cyperus* plants by these bioagents dilutes their importance as potential bioagents. So, the less studied bulb borer becomes a pivotal bioagent of the weed suppression as it damages the vital part, the bulb of the weed. Therefore, studies on biology of *A. cyperi* and biosuppression of *C.*

rotundus were carried out during 2000-2003 at the Biocontrol Research Laboratory and farm of Department of Entomology, M.P.K.V., Rahuri, Maharashtra state, India. The summary and conclusions of the results are presented in this chapter.

5.1 Summary

5.1.1 Biology of *A. cyperi*

5.1.1.1 Egg

Female oviposited exclusively in the basal bulbs of 2 weeks old *C. rotundus* plants having girth of 2-3 mm and 4-5 leaves. The eggs laid in holes made by the female with rostrum at the proximal area of the bulbs. Eggs were delicate, irregular shaped, pale cream, transparent and 1.29 x 0.9 mm in dimensions. The incubation period was 8 to 12 (av. 10.56) days in November, 2001 and 7 to 10 (av. 8.34) days in August, 2002 with hatching percentage of 86 to 94.

5.1.1.2 Grub

The grubs were reared by developing (i) tuber slit method to study grub instars and (ii) tuber top beheaded method to study total duration of the grub. The neonate grub was transparent, pale cream coloured, 1.41 to 2.34 (av. 1.96) mm in length. The head capsule was 0.31 to 0.55 (av. 0.43) mm. Three thoracic, nine abdominal segments with a telson were visible. Eight pairs of hairs in symmetry were distributed on the head region. A pair of hairs was present on each of the sternites of the thoracic segments, ventral side of last four abdominal segments and dorsal side of last five abdominal segments. These hairs were prominent throughout the grub stage. The average body length and width of head capsule of 2nd, 3rd and 4th

instar grubs were 2.77 and 0.36, 3.58 and 0.56 and 4.53 and 0.81 mm, respectively. The duration of the 1st, 2nd, 3rd and 4th instar grubs was 4 to 6 (av. 4.6), 7 to 14 (av. 9.16), 8 to 14 (av. 10.84) and 11 to 17 (av. 13.76) days, respectively. The pale cream colour of 1st instar grub became milky white in the last instar. The entire grub development required 30 to 51 (av. 38.36) days. Complete development of the grub appeared in the bulb. Dead hearts appeared within 6 to 8 days after hatching. Only 30 per cent of the damaged bulbs, by the grub, regenerated.

5.1.1.3 Prepupa

The full grown grub ceased feeding, become ivory coloured, turned its position in reverse way and remained quiescent. This stage lasted for 8 to 10 (av. 8.88) days.

5.1.1.4 Pupa

The pupation commenced when the larval skin split at the dorsal side of the head and shed from remaining body. The pupa was exarate, ovoid shaped and ivory coloured. Body length was 2.34 to 4.92 (av. 3.33) mm. Duration of the pupal stage was 9 to 15 (av. 13.48) days. Pupation occurred in the hollowed bulb.

5.1.1.5 Duration of life cycle from egg to adult emergence

This period was 55 to 88 (av. 71.28) days.

5.1.1.6 Adult

The weevil body was slender and shiny black. The average length and breadth of the males and females were 3.22 x 1.17 and 3.17 x 1.23 mm, respectively. Male to female sex ratio was 1.13 : 1. The most distinguished feature between the sexes was, the

presence of a sharp tooth on the fore tibiae of the male. Males were observed to fly normally but females flew seldom. Premating period was 2 to 15 (av. 3.5) days and copulation lasted for 30 to 150 (av. 70) minutes. Females showed polyandrous habit. Preoviposition, oviposition and postoviposition periods were 3 to 18 (av. 6.94), 22 to 55 (av. 31.36) and 44 to 137 (av. 58.58) days, respectively. Fecundity was 35 to 46 (av. 42.1) eggs. There were 3 generations in which over 80 per cent population was appeared in pupal stage in March, July and November. Males survived for 2 to 15 (av. 5.38), 2 to 16 (av. 6.54), 30 to 43 (av. 36.54) and 31 to 48 (av. 40.26) days by providing (i) no food and no water (ii) only water (iii) only food and (iv) both food and water, against the corresponding figures of 8 to 18 (av. 11.68), 10 to 18 (av. 12.52), 65 to 210 (av. 106.74) and 69 to 220 (109.4) days for the females. The weevils could be mass multiplied on potted *Cyperus* plants. The average duration of life cycle including survival period of male and female weevils from the egg to adult death was 76.7 and 83.1 without food against 107.8 and 178 days by providing sprouted *Cyperus* tubers as food, respectively.

5.1.2 Host specificity test

The weevil was not attracted to any of the 25 test crops, *Typha latifolia*, *Scirpus martinus* and 5 Graminaceous weeds. The oviposition was observed only on *C. esculentus*. The adults were observed to feed on *C. iria*, *C. difformis*, *C. esculentus* and *C. alternifolius*. Grubs completed its development in the tubers of *C. esculentus* and survived for less than 10 days in stem of *C. irid*, *C. difformis* and *Fimbristylis feruginea*. The results of feeding test

showed that the weevil had a high degree of behavioural adaptation to *C. rotundus* and the oviposition and feeding was restricted to the genus *Cyperus*.

5.1.3 Seasonal incidence of *A. cyperi*, *B. venosana* and grub parasitoid, *A. calandrae* at M.P.K.V., Rahuri farm

5.1.3.1 Abundance of *C. rotundus*

Number of *Cyperus* plants was low from April to middle of May (12th to 27th MW) as evidenced from survival of 37.5 to 66.5 plants/m² against 69.7 to 128.7 plants/m² during the rest of the year. It was negatively correlated with maximum air, maximum and minimum soil temperature and positively correlated with morning relative humidity. The meteorological parameters affected the plant stand by 74 per cent.

5.1.3.2 Incidence of *A. cyperi*

The weevil incidence ranged from 2.6 to 15.6 per cent (av. 7.9). The infestation was low (2.6 to 6.2 %) from January to June (1st to 25th MW). The peak (15.6 %) activity of the bioagent appeared in middle of November (45th MW) when average air and soil temperature and relative humidity was 22.3°C, 28.9°C and 57.1 per cent, respectively. The infestation was negatively correlated with maximum air and soil temperature and positively correlated with morning and evening relative humidity. The weather factors affected the weevil population by 59 per cent. The other factors affecting on the weevil population are (i) Traditional cultural practices (ii) Host preference and selection of 4 to 5 leaf stage *Cyperus* plants by the weevil for oviposition (iii) Use of chemical pesticides on main crop (iv)

Parasitism (0 – 3.4 %) and (v) Competition with *Cyperus* stem borer, *Bactra* spp.

5.1.3.3 Incidence of *B. venosana*

The infestation of *B. venosana* was 0 to 20.3 (av. 8.1) per cent. However, there was no infestation from 1st to 6th MW and it was low (1.1 to 3.3 %) from 47th to 50th MW. The highest (20.3 %) peak was recorded in 1st week of August (30th MW). Significant and positive correlation between the climatic factors (minimum air and soil temperature, evening relative humidity and rainfall) and the moth infestation was recorded. However, the weather parameters as a whole substantially affected the moth infestation by 92 per cent.

5.1.3.4 Incidence of grub parasitoid *A. calandrae*

The parasitism of the grub was negligible, 0 to 3.4 (av. 1.53) per cent. It was negatively correlated with maximum air and soil temperature and the weather factors affected its survival by 73 per cent.

5.1.4 Biosuppression of *C. rotundus*

5.1.4.1 Damage potential of individual weevil

Each female caused 13 to 25 (av. 20.9) dead hearts. The release of 2 mated females of *A. cyperi*, caused 40 per cent dead hearts against 23 per cent dead hearts caused by 10 larvae of *B. venosana* in *Cyperus* plants concealed with muslin cloth. However, the combination of the two bioagents resulted in 62 per cent damage to the weed.

5.1.4.2 Pot culture experiments

5.1.4.2.1 Influence of integrated measures on suppression of *C. rotundus* in pot culture

Number of *Cyperus* plants developed/15 tubers : The (T₂₁) *Cyperus* alone, raised to maximum 50 plants against significantly lowest 13.7 plants in (T₂₀) C + S + hw. Later was at par to (T₁₀) C + S + bb + rf and (T₁₉) C + S + bb + sb + atz + rf. The 22.0, 22.3, 23.7 and 24.7 plants grown in sorghum (T₄), gram (T₁), wheat (T₃) and amaranthus (T₄) crops, respectively were at par.

Bioagent infested *Cyperus* plants : Bioagent comprising treatments resulted in 30 to 54.8 per cent infestation in T₇ to T₁₃ and T₁₅ to T₁₉. However, due to migration of the weevils to other pots, the infestation was 1.3 to 11.6 per cent in the treatments where the bioagents were not released. *Bactra* larvae alone caused 19.6 per cent infestation in (T₁₃) C + S + sb.

Dry weight of biomass : The lowest (0.3 g) dry weight was found in (T₂₀) C + S + hw followed by the at par (T₁₉) C + S + bb + sb + atz + rf (0.6 g). Among the crops, the dry weight of biomass was 1.8, 2.1, 2.3 and 2.7 g in sorghum, amaranthus, wheat and gram, respectively.

Number of tubers/pot : The tubers in (T₂₁) *Cyperus* only, were highest (99.7). The highly promising treatment to reduce the tuber number was (T₁₉) C + S + bb + sb + atz + rf, which allowed 11 tubers to grow only. It was on par to (T₁₀) C + S + bb + rf. The sorghum crop was the best for reducing the number of tubers among other test crops.

Multiplicability ratio : Significantly, the lowest (1 : 0.3) ratio was observed in (T₁₉) C + S + bb + sb + atz + rf, over other treatments except (T₁₂) C + S + A + bb + rf (1 : 0.33), (T₁₀) C + S + bb + rf (1 : 0.43), (T₂₀) C + S + hw (1 : 0.43) and (T₁₁) C + S + G + bb + rf (1 : 0.47). Among crops, the ratio was significantly lowest (1 : 1.47) in sorghum, followed by the ratios of 1 : 1.7, 1 : 2.5 and 1 : 2.5 in wheat, amaranthus and gram, respectively. So, sorghum was the most effective suppressant to the weed by shade and competitive growth effect.

Yield value Rs./ha : The significantly highest income (Rs. 12985) was obtained in (T₁₉) C + S + bb + sb + atz + rf. The next promising and at par economical treatments to (T₁₉) were (T₁₀) C + S + bb + rf (Rs. 12600), (T₂₀) C + S + hw (Rs. 12449) and (T₁₁) C + S + G + bb + rf (Rs. 11330) facing the multiple interactions among crops, *Cyperus* weed and bioagents. *Cyperus* caused 65% loss in yield value.

5.1.4.2.2 Influence of hand weeding and bioagents on suppression of *Cyperus* in pot cultured okra

Number of *Cyperus* plants/pot : Number of *Cyperus* plants (50) in (T₆) *Cyperus* alone and (T₁) O + C (42.3) were at par indicating that okra crop cannot suppress the *Cyperus* growth effectively. However, the lowest (24.7) number of plants were observed in (T₅) O + C + rf + bb and it was on par with (T₂) O + C + hw (27) and (T₄) O + C + bb (29.3).

Bulb borer infestation : The highest (42 %) infestation occurred in (T₄) O + C + bb and it was at par with (T₅) O + C + rf + bb (40.4 %).

Number and weight of tubers/pot : The number of tubers reduced by 2.65 and 2.6 times in (T₅) O + C + rf + bb and (T₂) O + C + hw, respectively over that of the control (T₈) *Cyperus* alone (98.3 tubers). The weight was lowest (15 g) in (T₅) O + C + rf + bb and it was at par with (T₃) O + C + bb (15.7 g) and (T₂) O + C + hw (20.4 g) against highest wt.(61 g) in (T₈) C only.

Multiplicability ratio of tubers : It was least in (T₂) O + C + hw (1 : 0.7) but on par with (T₅) O + C + rf + bb (1 : 1.2). Okra crop reduced the ratio by 33.9 per cent over the control (T₈) *Cyperus* alone.

Yield of okra (green fruits)/ha : *Cyperus* competition reduced the yield of okra by 79.6 per cent (4.9 times), indicating heavy losses in the yield. Highest yield was obtained in (T₇) okra alone (63.3 q). Hand weeding treatment yielded 43.5 q and it was at par with (T₅) O + C + rf + bb (43.3 q).

5.1.4.4.3 Field experiments

5.1.4.4.3.1 Impact of hand weeding and bioagents on multiplicability of *C. rotundus* in sorghum CSH-9 in field

***Cyperus* dead hearts** : The highest (22.2) percentage of infestation occurred in (T₃) S + C + bb + chw and it was at par with (T₅) S + C + bb (18.2 %) and (T₆) S + C + rf + bb (16.3 %).

Multiplication rate of tubers : Shade and growth competition effect of sorghum crop reduced the multiplication rate by 21.2 per cent as compared to (T₇) *Cyperus* alone. The lowest (3.7 times) multiplication rate was observed in (T₃) S + C + bb + chw followed by at par treatments (T₂) S + C + hw (3.8 times), (T₆) S + C + rf + bb (4.2 times)

and (T₅) S + C + bb (5 times). The rust fungus spray on *Cyperus* reduced the rate by 10.4 per cent as compared to the unsprayed *Cyperus* control treatment.

Multiplicability ratio : It was lowest (1 : 1.3) in (T₃) S + C + bb + chw but at par with (T₂) S + C + hw (1 : 2.2). The ratio in sorghum crop + *Cyperus* (T₁) was low (1 : 4.5) as compared to highest ratio of 1 : 6.2 in (T₇) *Cyperus* alone. It reflected the ability of sorghum to suppress the weed by shade and competition effect.

Sorghum yield/ha : Highest (22.3 q) yield was registered in (T₃) S + C + bb + chw which was at par with (T₂) S + C + hw (21.3 q), (T₆) S + C + rf + bb (20.7 g) and (T₅) S + C + bb (19.7 q) and these were considered as promising treatments for management of the weed.

5.1.4.3.2 Impact of hand weeding and bioagents on suppression of *Cyperus* in okra in field

Infestation of bioagents : (T₃) O + C + bb + chw showed the highest (18.6 %) dead hearts and it was on par with (T₅) O + C + bb (17.6 %) and (T₆) O + C + rf + bb (17.1 %).

Multiplication rate of tubers : The lowest multiplication was found in (T₃) O + C + bb + chw (5 times) and it was at par with (T₂) O + C + hw (6.1 times), (T₆) O + C + rf + bb (6.3 times) and (T₅) O + C + bb (6.5 times).

Tuber multiplicability ratio : Smallest ratio was recorded in (T₃) O + C + bb + chw (1 : 2.4) and it was at par with (T₂) O + C + hw (1 : 3.2) and (T₆) O + C + rf + bb (1 : 3.6). Okra crop in (T₁) O + C could not reduce the ratio (1 : 5.7) significantly as compared to that (1 : 6.7) in (T₇) *Cyperus* alone.

Okra dry fruit yield/ha : The highest yield (25 q) of dry fruits was obtained in (T₃) O + C + bb + chw and it was at par with (T₂) O + C + hw (22.5 q). The rust fungus treatment (T₄) O + C + rf yielded 18.7 q

5.1.4.4.3.3 Influence of *Cyperus* bulb borer and rust fungus on multiplicability of newly sown tubers in sorghum M 35-1 in field

Cyperus plants/plot : Significantly and substantially lowest (24.7) number of plants were found in (T₂) S + C + bb + chw. However, it was at par with (T₅) S + C + rf + bb (32.3 plants) when (T₆) *Cyperus* alone, recorded 41.3 plants.

Cyperus dead hearts (%) : Highest (34.6 %) dead hearts were observed in (T₂) S + C + bb + chw. The next promising treatment for suppressing the weed was (T₄) S + C + bb (23.4 %). The natural infestation in treatments T₁, T₃ and T₆ without bioagent release was 7.8 to 9.1 per cent.

Fungus damage score : The rust fungus infection score, recorded in the rust treated plots was 4.3 and 4.7 in (T₃) S + C + rf and (T₅) S + C + rf + bb.

Dry weight of biomass : The maximum (75.0 %) reduction in the dry weight of *Cyperus* was registered in (T₂) S + C + bb + chw, followed by at par reduction (60.5 %) in (T₅) S + C + rf + bb and (T₃) S + C + rf (54.8 %). The shade and competition effect of sorghum reduced the biomass by 41.4 per cent over that of the control of *Cyperus* alone treatment.

Multiplication rate of tubers : The multiplication of newly sown tubers/plot was lowest (1.01 times) in (T₂) S + C + bb + chw. It

indicated that T_2 was the most successful treatment for preventing the multiplication of the tubers. The sorghum crop allowed 3.24 folds increase against 5.2 folds multiplication in (T_6) *Cyperus* alone treatment.

Tuber multiplicability ratio : (T_2) registered the lowest (1 : 0.37) ratio. The next promising treatments for suppressing the multiplicability of the tubers were (T_5) S + C + rf + bb (1 : 0.83) and (T_4) S + C + bb (1 : 1.7). The multiplicability ratio was at par in *Cyperus* bulb borer (T_4) and rust fungus (T_3) treatments.

Sorghum yield/ha : The highest (18.7 q) yield was obtained from (T_7) sorghum alone. However, it was at par with (T_2) S + C + bb + chw (17.3 q). *Cyperus* plants reduced the yield of sorghum (T_1) by 36 per cent over the highest (18.7 q) yield in *Cyperus* free sorghum. As such the weed caused 36 per cent loss in the yield.

5.1.6 Ancillary observations

5.1.6.1 Survival of different stages of *A. cyperi* in water

The grub survived for 1 to 4 days (av. 2.23) in water. However, flooding more than 35 hours could adversely affect the survival of 1st instar grub, since, other instars feed inside the bulb. But the prepupal and pupal stages were quite resistant to the flooding and survived for 11.73 and 9.6 days, respectively. The weevils survived for 5 days.

5.1.6.2 Parasitism on *A. cyperi*

The ectoparasitoid, *Anisopteromalus calandrae* parasitized the grub, *A. cyperi* during 2nd and 3rd instars. However,

extent of parasitism was negligible (0 to 3.4 %). The larval and pupal periods of the parasitoid were 12 to 15 and 6 to 7 days, respectively.

5.1.6.3 Biology and damage potential of *B. venosana*

The moth, *B. venosana* laid 20 to 170 eggs (av. 74.7) on *Cyperus* leaves. Eggs hatched within 2 to 3 days and neonate larvae penetrated the stem and fed on whorled leaves. Each larva damaged 2 to 4 *Cyperus* stems and completed its development in 14 to 19 (av. 16) days. Pupal stage was 8 days. Life cycle from egg to adult emergence was completed in 22 to 27 (av. 24.3) days. The larvae bored the stem and caused dead heart, but fed slightly on the *Cyperus* bulbs. So, 70 per cent of the damaged bulbs were regenerated.

5.1.6.4 Difference between *A. cyperi* and *B. venosana* infestation

Adult of *A. cyperi* fed on the *Cyperus* stem tissues and caused series of holes on leaves. The grub damaged by hollowing the bulb and stopped regeneration of about 70 per cent of the bulbs. The eggs were laid singly in the bulbs. The grub closed top of the feeding tunnel with the dry excreta mixed with the frass in dome form and pupated inside the bulbs. The weevil made emergence hole at the top of bulb.

While, the Adult, *B. venosana* laid eggs in rows on the leaves, larvae entered the stem and fed on whorled leaves. It tunnel the stem caused dead heart and spread the excreta along the feeding way. It made emergence hole for the adult at collar portion and pupated at the base of the stem.

5.1.6.5 **Effect of *Cyperus* rust fungus, *P. romagnoliana***

The three rust fungus sprays at 15 days interval starting from 20 days aged *Cyperus* plants caused drying of all leaves, within 3 months. However, the tubers in the treated plots reduced by 0.36 (19.8 %) and the multiplicability ratio reduced by 2.17 (28.9 %) over the untreated plot.

5.1.6.6 **Smothering effect of natural vegetation on *C. rotundus***

Hierarcium vagum Jacq., the fast growing, 1.2 m heighted weed reduced the *Cyperus* plants and number, weight, sprouted number and per cent sprouting of tubers by 25, 15.9, 22, 32.6 and 25.7 per cent, respectively, in comparison to the *Cyperus* plot without the competitive weed. *H. vagum* is easily destroyable weed, so it is an source for competitive displacement to *C. rotundus* especially in uncultivated lands.

5.1.6.7 **Incidence of *A. cyperi* and *B. venosana* on *Cyperus* in cucumber in polyhouse (June to December, 2001)**

The infestation of the bioagents in polyhouse was higher than that observed in the field for the respective months. The infestation was 33.8, 44 and 31.8 per cent in August, October and November, 2001 in polyhouse, against 33.4, 24.2 and 8.3 per cent in field, respectively.

5.2 **Conclusions**

1. **Losses by the purple nutsedge, *Cyperus rotundus*** : It caused 65 (2.9 times) and 79.6 (4.9 times) per cent losses in yield of sorghum and okra in pot culture experiment, respectively. The loss was 36 per cent in sorghum in field.

2. **Biology of *Cyperus* bulb borer, *A. cyperi*** : The average pre-mating, pre-oviposition, oviposition and post-oviposition periods were 3.5, 6.94, 31.36 and 58.58 days, respectively. There were 4 instars of the grub. The 1st to 4th instar lasted for 4 to 6, 7 to 14, 8 to 14 and 11 to 17 days, respectively. Longevity of the male and female weevils was 36.54 and 106.74 days with food, when it was 5.38 and 11.68 days without food, respectively. Male to female sex ratio was 1.13 : 1 and the fecundity was 42.1. The female showed polyandrous habit. Tuber slit and tuber top beheaded methods were developed for rearing of the internal borer.
3. **The bulb borer host specificity test** : The test proved to be negative for the 25 suspected test crops and nevertheless for *Typha latifolia*, *Scirpus martinus* and 5 Graminaceous weeds also. The bioagent activities confined to genus *Cyperus* only.
4. **Seasonal incidence** : *A. cyperi* was active throughout the year and showed two peaks of infestation in July (13.9 %) and middle of November (15.6 %) against a peak (20.3 %) for *B. venosana* in July end. The Pteromalid parasitoid of *A. cyperi* showed negligible (0 to 3.4 %) parasitism on grubs.
5. **Damage potential of the bioagents** : A pair of *Cyperus* bulb borer weevils, *A. cyperi* caused 20.8 per cent dead hearts. Over 70 per cent damaged plants failed to regenerate. The weevil reduced the multiplicability of *Cyperus* plants by 37.7 per cent in sorghum and 29.8 per cent in okra crop. Ten neonate caterpillars of the stem borer (*B. venosana*) caused 23 *Cyperus*

dead hearts and the bioagent reduced the multiplicability of tubers by 4.8 per cent in sorghum crop against the 17.8 per cent reduction by *Cyperus* rust fungus *P. romagnoliana* in sorghum and 14 per cent in okra.

6. **Most promising bioagent** : The *Cyperus* bulb borer, *A. cyperi* was observed to be the key bioagent for suppression of the *Cyperus*.
7. **Biosuppression of *C. rotundus***

Competitive crop : Sorghum was the most promising test crop for suppression of the weed by shade and competitive effects.

Promising treatments : Considering the tuber multiplication as the most precise parameter for judging the suppression effects, the treatment with bulb borer + rust fungus, and tuber borer + care hand weeding, avoiding bioagent damaged *Cyperus* plants in sorghum or okra emerged as highly promising treatments for management of the weed.
8. **Smothering effect of natural vegetation** : *Hierarcium vagum*, a weed was found to be a source of competitive displacement for *Cyperus* in uncultivated land.
9. **Management strategy** : The proposed *Cyperus* management strategy, comprised of soil tillage, protecting *Cyperus* dead hearts for conserving bioagents, soil drainage, incorporating wide canopy crops in rotation, avoiding drift of chemical insecticides on weed, inoculative and inundative releases of *A. cyperi* and *B. venosana*, spray of rust fungus, *P. romagnoliana* on the weed and need based use of recommended herbicides.

**LITERATURE
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6. LITERATURE CITED

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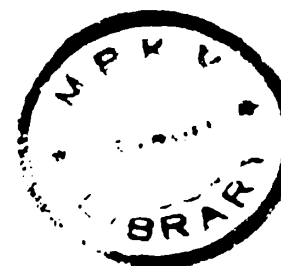
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VITA

7. VITA

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