Biological Control and Its Integration in Weed Management Systems for Purple and Yellow Nutsedge (*Cyperus rotundus* and *C. esculentus*)[1]

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INTRODUCTION

Observations of the effects of living organisms on weeds dates from 1795 when an insect, *Dactylopius ceylonicus*, was introduced for drooping pricklypear (*Opuntia vulgaris* Miller) control over a vast area (42, 60, 93, 112). Since that time, biological control of weeds employed mainly the classical strategy of introducing natural enemies from areas of co-evolution. Self-perpetuation and dissemination of these introduced enemies was essential to suppress successfully the weed below economic levels (6, 8). This classical tactic is suited particularly for weeds that are distributed widely in less intensively cropped or noncropped areas (6, 41). Guidelines to introduce foreign organisms for biological control of weeds in the United States have been established (63).

The strategy of augmenting an indigenous natural enemy to kill or to suppress the weed host by applying high inoculum pressure at an appropriate time has been termed bioherbicide tactic (108, 109) or inundative biological control (119). This strategy also is referred to as a biological herbicide, a microbial pesticide, or a mycoherbicide; the latter term refers to fungal pathogens only. It is best suited for weed control in annual crops where rapid control or suppression of the weed is generally desired.

CLASSICAL BIOLOGICAL CONTROL WITH INSECTS

Julien (60) listed the introduction of 225 organisms against 111 weed species, including 178 insects and 6 mites. The catalogue has many examples of successful control and several examples of failure.

A total of 132 insects have been associated with purple (*Cyperus rotundus* L. #[3] CYPRO) and/or yellow nutsedge (*Cyperus esculentus* L. # CYPES) (Table 1). Approximately half of these insects are known to feed on crop plants. Four insects on nutsedges have been studied in detail. Three moths, *Bactra verutana* Zeller in the United States, *B. minima* Meyrick and *B. venosana* Zeller in the Indian subcontinent, and one weevil, *Athesapeuta cyperi* Marshall in southeast Asia (34). All are adequately host-plant specific, but none have proved effective as classical biological control agents. For example, *A. cyperi* was introduced to control purple nutsedge in Barbados in 1973, Cook Islands in 1971 and 1973, and Fiji and Tonga in 1971 but has not been recovered. It did become established in Hawaii following releases in 1925 but had negligible effect on purple nutsedge. *B. minima* was released in the Cook Islands in 1973 and Fiji and Tonga in 1971 but also was not recovered. *B. venosana* was released with similar results in Barbados in 1973 and Cook Islands in 1971. It was established in Fiji from releases in 1936 and 1971 but was subject to high parasitism. Thus, attempts to control purple nutsedge with classical biological control have failed with the four insects tested at several locations.

INUNDATIVE BIOLOGICAL CONTROL WITH INSECTS

In Mississippi, as a result of having a continuous supply of *B. verutana* available (40), the effects of augmentation in a series of greenhouse (37, 38) and field tests under cages (35) were studied. In preliminary tests, the introduction of freshly emerged adult moths into cages did not produce consistent infestations. In the field, the percentages of infestation were proportional to the numbers of adults used, i.e., field cages (2 by 2 by 2 m or 2 by 4 by 2 m) receiving 2, 10, and 60 pairs of adults had 0, 33, and 100% of the purple nut-

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[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Table 1. Insects of *Cyperus rotundus* and/or *Cyperus esculentus*.

Organism	Common name	Species infected	References
Aleurocybotus sp., whitefly		*Cyperus rotundus*	87, 94
A. occiduus sp.n.		*C. rotundus* and *C. esculentus*	86
Althaeus hibisci (Oliver)		*C. esculentus*	16
Amsacta moorei (Btlr.)		*C. rotundus*	115
Anacentrinus blanditus (Casey)		*C. rotundus*	34
Anthomyza sp.		*C. esculentus*	16
Antonina australis (Green) [syn. of *Kuwanina hilli*, (Laing)]		*C. rotundus*	18
Apis indica		*C. rotundus*	78
Athesapeuta cyperi (Mshl.)		*C. rotundus* and *C. esculentus*	9, 62, 86, 90
Bactra bactrana (Kennel)		*C. rotundus*	34
B. furfurana (Haworth)		*C. rotundus* and *C. esculentus*	4
B. lanceolana (Hubner)		*C. rotundus* and *C. esculentus*	4
B. minima minima (Meyrick)		*C. rotundus*	25, 27, 62, 96, 97
B. phaeopis (Meyr.)		*C. rotundus* and *C. esculentus*	118
B. truculenta [syn. of *venosana* (Meyr.)]		*C. rotundus* and *C. esculentus*	86
B. venosana (Zeller)		*C. rotundus*	27, 62, 71, 72, 96
B. verutana (Zeller)		*C. rotundus* and *C. esculentus*	16, 34, 38, 39, 87
Bagrada cruciferarum		*C. rotundus*	116
Barinus squamolineatus (Casey)		*C. esculentus*	87
B. curticollis (Casey)		*C. esculentus*	87
Barilepis grisea (Leconte)		*C. esculentus*	87
Calendra sp.		*C. esculentus*	16
Calligypona striatella (Fall.)		*C. rotundus*	47
Carolinaia cyperi (Ainslie) aphid		*C. esculentus*	87, 103
Chaetocnema denticulata (Ill.)		*C. esculentus*	16
Chaeocnema pulicaria (Melsheimer)		*C. rotundus*	16, 34
Chaetopsis fulvifrons (Macquart)		*C. esculentus*	16
Chiloides copidotis (Meyrick)		*C. rotundus*	34
Chlorops sp.		*C. esculentus*	16
Chorizococcus rostellum (Hoke) mealybug		*C. rotundus* and *C. esculentus*	34, 87
Cisseps fulvicollis (Hubner)		*C. rotundus*	34
Corimelaena pulicaria (German)		*C. esculentus*	16
Culex pipiens quinque sp. *fasciatus*		*C. rotundus*	79
Cydia perfricta (Meyr.)		*C. rotundus*	120
Delphacodes puella (Van Duzee)		*C. rotundus*	34
Delphacodes basivitta (Van Duzee)		*C. esculentus*	16
Deltocephalus sonorus (Ball)		*C. rotundus*	34
Diabrotica undecempunctata howardi (Barber)		*C. esculentus*	16
Dorcadothrips coespitis (Priesner.)		*C. rotundus*	87
Draculacephala portola (Ball)		*C. rotundus*	34
Elachiptera nigriceps (Loew.)		*C. esculentus*	16
Elasmopalpus lignosellus (Zeller)		*C. rotundus*	34
Elliponeura debilis (Loew.)		*C. esculentus*	16
Euscyrtus concinnus		*C. rotundus*	15
Evylaeus sp.		*C. rotundus*	78
Exitianus exitiosus (Uhler)		*C. rotundus*	34
Ferrisia virgata (Cockrell)		*C. rotundus*	99
Frankliniella fusca (Hinds)		*C. rotundus*	34
Gastrimargus transversus (Thnb.)		*C. rotundus*	70
Glyphipterix impigritella (Clemens)		*C. rotundus* and *C. esculentus*	34
Glyphipteryx prob. *impigritella*		*C. esculentus*	16
Graminella nigrifrons (Forbes)		*C. rotundus*	16, 34, 85
Halticus bracteatus (Say)		*C. esculentus*	16
Halictus lucidipennis		*C. rotundus*	78
Haplaxius crudus (Van D.)		*C. esculentus*	111
Heliothis virescens Tobacco budworm		*C. rotundus*	43
Laodelphax striatella (Fallen)		*C. rotundus*	48
Lasiglossum albescens		*C. rotundus*	78
Laspeyresia perfricta (Meyrick)		*C. rotundus*	110
Lerema accius (Smith)		*C. rotundus*	34
Liburniella ornata (Stal)		*C. esculentus*	16
Lissorhoptrus brevirostris (Suffr.)		*C. esculentus*	73
Locusta migratoria capito (Sauss.)		*C. esculentus*	65
Macrosiphum avenae		*C. esculentus*	92
Macrosteles fascifrons (Stal)		*C. rotundus*	34
Marasmia trapezalis (Gn.)		*C. rotundus*	12

(continued)

Table 1. (continued) Insects of *Cyperus rotundus* and/or *Cyperus esculentus*.

Organism	Common name	Species infected	References
Matsumuratettix hiroglyphicus (Mats.)	leafhopper	*C. rotundus*	26
Megelethes sp.		*C. esculentus*	16
Megaloceroea recticornis (Geoffroy)		*C. esculentus*	16
Megapis dorsatta		*C. rotundus*	78
Melipona laeviceps		*C. rotundus*	78
Micrapis florea		*C. rotundus*	78
Mumetopia occipitalis (Mel.)		*C. esculentus*	16
Nannobactra blepharopsis (Meyrick)		*C. rotundus*	34
N. cultellana (Zeller)		*C. esculentus*	34
N. minima minima (Meyrick) (Syn. of *B. minima*)		*C. rotundus*	34
N. oceani (Diakonoff)		*C. rotundus*	34
Nephotettix nigropictus (Stal.)		*C. rotundus*	30
N. virescens		*C. rotundus*	88
Nomia andrenina		*C. rotundus*	78
N. westwoodii		*C. rotundus*	78
Nymphula depunctalis (Guenee)	rice case-worm	*C. rotundus*	84, 117
Orthoperus sp.		*C. esculentus*	16
Oryctes rhinoceros (L.)		*C. rotundus*	32
Oscinella sp.		*C. esculentus*	16
Oxya velox (F.)		*C. rotundus*	13
Pachynematus corniger (Norton)		*C. esculentus*	16
Paraphlepsius abruptus (DeLong)		*C. rotundus*	34
Peregrinus maidis (Ashmead)	corn planthopper	*C. rotundus*	77
Phalacris politus (Melsh.)		*C. esculentus*	16
Phenacoccus solani (Ferris)	mealybug	*C. rotundus*	87
Pleurophorus sp.		*C. esculentus*	16
Pseudaletia unipuncta (Haworth)		*C. rotundus*	34
Rhizoecus cacticans (Hambleton)	mealybug	*C. rotundus*	87
Rhopalosiphum maidis (Fitch)		*C. esculentus*	16
R. padi		*C. esculentus*	92
R. rufiabdominalis (Sasaki)		*C. rotundus* and *C. esculentus*	16, 34
Sanctanus sanctus (Say)		*C. esculentus*	16
Sanctanus fasciatus	leafhopper	*C. rotundus*	28
Schizaphis cyperi (van der Gott)	aphid	*C. esculentus*	3
Schizaphis siniscirpi		*C. rotundus*	125
Schizaphis rotundiventris (Sign.)		*C. esculentus*	49
Sitobion hillerislambersi (Sp.n.)		*C. esculentus*	50
Sibariops confusa (Boheman)		*C. esculentus*	16, 87
Spathosternum prasiniferum (Walker)		*C. rotundus*	56
Spissistilus festinus (Say)	threecornered alfalfa hopper	*C. esculentus*	76
S. frugiperda (J. E. Smith)	fall army worm	*C. esculentus* and *C. rotundus*	34, 80, 81
Sphenophorus callosus (Oliver)	southern corn billbug	*C. esculentus*	34, 87, 122, 123
S. cariosus (Oliver)		*C. rotundus* and *C. esculentus*	34, 87
S. destructor (Chittenden)		*C. esculentus*	87
S. parvulus (Gyllenhal)		*C. esculentus*	87
S. phoeniciensis (Chittenden)	billbug	*C. rotundus*	87
S. scoparius (Horn)		*C. rotundus*	34, 87
S. venatus sp. (Chittenden)		*C. rotundus*	34, 87
S. zeae (Walsh)		*C. esculentus*	87
Spodoptera exempta (Wlk.)		*C. rotundus*	19
S. ornithogalli		*C. rotundus*	34
Stenocranus rufilinearis (Guenee)		*C. rotundus*	31
Stenomicra angustata (Coq.)		*C. esculentus*	16
Stenoscinis atriceps (Loew)		*C. esculentus*	16
Stilbus apicalis (Melsh.)		*C. esculentus*	16
S. pallidus (Casey)		*C. esculentus*	16
Syrphus sp.		*C. rotundus*	78
Taphrocerus schaefferi (Nicolay & Weiss)	leaf miner	*C. esculentus*	16, 105, 106
Telephanus velox (Hald.)		*C. esculentus*	16
Tetranychus yusti		*C. esculentus*	92
Thaumatomyia glabra (Meigen)		*C. esculentus*	16
Thysanoptera	thrips	*C. esculentus*	16, 87
Toramus sp.		*C. esculentus*	16
Trigonorhinus sticticus (Boh.)		*C. esculentus*	16
Truxalis grandis grandis (Klug)	acridid grasshopper	*C. rotundus*	2
Truxalis sp.		*C. rotundus*	1

sedge infested, respectively. In the greenhouse, two pairs of adults introduced into small cages in two series of tests produced infestations in 60 and 66% of the cages. The erratic results probably reflect a lack of food and moisture that killed or weakened the females during their 2-day preoviposition period (40).

The use of first-instar larvae generally gave consistent results. In the greenhouse, an infestation of shoots with a single application of 2 or 5 larvae per shoot (37) or with 3 larvae per shoot (38) caused significant damage to purple nutsedge. Weekly introductions were more damaging than a single one: single introductions averaged 55% reduction in shoot dry weight; 2, 3, or 4 introductions resulted in average reduction of 77%; and eight introductions reduced top growth 98% (38). The number and weight of tubers were reduced 86 and 88%, respectively, in the greenhouse (37) but were only 26 and 38%, respectively, in the field. Early release of larvae increased damage in the field but not as much as in the greenhouse.

According to Frick (34), 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 inundation so the larvae can attack the plants early in the growth cycle before the crop is established. The crop provides partial shading to suppress subsequent growth of the weed and concurrently reduces efficacy. Using this approach, Frick and Chandler (36) reduced aboveground growth of purple nutsedge by 30 to 60% within 4 to 7 weeks after last release, depending on the number of larvae per release and the number of releases. Yield of seed cotton (*Gossypium hirsutum* L.) following purple nutsedge control with 3 to 5 releases of *B. verutana* was equivalent to yield from crops not infested with the weed. However, a cost effective procedure has not been developed for field scale use.

BIOLOGICAL CONTROL WITH PLANT PATHOGENS

The idea of controlling weeds with plant pathogens dates from 1893 and 1894 in New Jersey when experiment station bulletins reported a list of fungi injurious to weed seedlings (44, 45). At the same time, a grower wrote in a letter to the New Jersey Experiment Station, "Two years ago about an acre of a farm was over run by Canada thistle [*Cirsium arvense* (L.) Scop. # CIRAR], but by the time they were in full bloom a rust struck and hardly any of them matured. We plowed the land in the fall and last year scarcely a thistle appeared. If this rust could be disseminated through the country, the Canada thistle would receive a substantial check" (121). In his review on using plant pathogens in weed control, Wilson (121) said, "To write a conclusion for this subject in its present state of growth seems premature. So let us consider where we might go from here."

Books edited by Charudattan and Walker (23) and Kurstak (64) access the substantial progress made since the initial reports. Templeton (107) reported 42 active projects, while Scheepens and van Zon (100) listed 43 projects using plant pathogens to control weeds. One project not cited involves use of the fungus, *Puccinia canaliculata* (Schw.) Lagerh., for yellow nutsedge control. By altering epidemiology of rust fungus, Phatak et al. (83) demonstrated that release of the rust early in the spring reduced yellow nutsedge stand by 46%, tuber formation by 66%, and completely inhibited flowering. Another strain of *P. canaliculata* pathogenic to a nutsedge biotype from the eastern shore of Maryland reduced nutsedge stand by 9% and tuber formation by 33% (W. Bruckart[4]). A detailed study by Callaway et al. (20) using microplots indicated that rust significantly reduced living leaf area, number of living plants, tuber number, and tuber weight. Castellani (22) described two diseases of *Cyperus rotundus* a rust caused by *P. canaliculata* and a smut identified as *Citractia peribebuyensis*. He reported both diseases offered some possibility of biological control. However, the two rust strains being evaluated do not infect purple nutsedge (Phatak, unpublished, and W. Bruckart[4]). Numerous other fungal diseases are associated with purple and yellow nutsedges (Table 2). Nematodes, bacteria, viruses, animals, and birds are known to attack or to eat nutsedges (Table 3).

[4]W. R. Bruckart. 1985. Personal communications. USDA-ARS, Foreign Disease-Weed Science Res. Unit, Frederick, MD.

INTEGRATION OF BIOLOGICAL CONTROL IN INTEGRATED WEED MANAGEMENT SYSTEMS

Little effort has been directed toward integrating biological control with more conventional weed control practices (7). Integration of insects (7) and plant pathogens (91) have been discussed.

Quimby and Frick (90) used a novel approach to extend the effectiveness of *B. verutana* by first coating larvae with glyphosate [*N*-(phosphonomethyl)glycine], and releasing them to attack and to carry the glyphosate into *Cyperus*. Untreated larvae caused some reduction in plant dry weight. However, this approach may not be practical because of the ineffectiveness of the insect larvae.

Phatak (82) demonstrated that rust-paraquat [1,1′-dimethyl-4,4′-bipyridinium ion] combinations provided 99% control of yellow nutsedge compared with 60% control with rust and 10% with paraquat alone. Callaway et al. (20) reported significant interactions when sequential applications of rust followed by imazaquin [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid], bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide], and metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one]. Most rust-herbicide combinations reduced number of live plants, total tuber weight, and tuber number. Bruckert[4] also observed enhanced control from combining the Maryland rust strain with bentazon.

PROSPECTS FOR THE FUTURE

According to Frick (34), purple nutsedge control with a native species of *Bactra* spp. has been achieved in research plots. However, the procedure, even if successful on a field scale, will be feasible only if it is cost effective.

Research on *P. canaliculata* to control yellow

Table 2. Fungal pathogens on *Cyperus esculentus* and/or *C. rotundus*.

Organism / Common name	Species infected	References
Alternaria tenuissima	C. rotundus	17
Ascochyta sp.	*C. esculentus*	120
Cintractia limitata (Clint.)	*C. esculentus* and *C. rotundus*	66
C. minor (Clint.) Jacks.	*C. rotundus*	95, 120
C. peribebuyensis	*C. rotundus*	22
Claviceps cyperi	*C. esculentus* and *C. rotundus*	67
Curvularia tuberculata (Jain.)	*C. rotundus*	74, 75
Drechslera maydis	*C. rotundus*	5
Fusarium oxysporum	*C. esculentus*	D. K. Bell[a]
F. lateritium	*C. esculentus*	D. K. Bell[a]
Phyllachora cyperi Rehm Etarspot	*C. esculentus* and *C. rotundus*	120
Puccinia canaliculata (Schw.) Lagerh.	*C. esculentus* and *C. rotundus*	11, 21, 22, 58, 61, 104, 120
P. cyperi (Arth.)	*C. rotundus*	120
P. philippinensis	*C. rotundus*	124
Puccinia romagnoliana (Mair. and Sacc.)	*C. rotundus*	89
Phytophthora cyperi-rotundati (Sawada)	*C. rotundus*	98, 101
Phyllosticta zingiberi	*C. rotundus*	69
Piricularia higginsii sp. nov.	*C. rotundus*	68
Puccinia conclusa	*C. rotundus*	102
Rhizoctonia solani (Kuhn) root and culm rot	*C. rotundus*	120
R. bataticola (new: *Macrophonia phaseoli*)	*C. rotundus*	29
Sclerotinia homoeocarpa	*C. rotundus*	14
Ustilago scitaminea	*C. esculentus*	10
Verticillium dahliae	*C. esculentus*	59
Balansia cyperi	*C. rotundus*	126
Cercospora sp.	*C. esculentus*	127

[a]D. K. Bell. 1985. Personal communications. Assoc. Prof., Dep. Plant Path., Coastal Plain Exp. Stn., Univ. Georgia, Tifton.

Table 3. Various other organisms on *C. rotundus* and *C. esculentus*.

Organism / Common name	Species infected	References
Nematodes:		
Criconemoides onoensis ring nematode	*Cyperus esculentus* *C. rotundus*	52, 53, 54
Heterodera marioni (Cornu) Goodey	*C. esculentus* and *C. rotundus*	53, 120
Heterodera cyperi	*C. esculentus*	92
H. mothi cyst nematode	*C. rotundus*	55
Hoplolaimus columbus	*C. esculentus* and *C. rotundus*	51, 52
Meloidogyne graminicola	*C. rotundus*	114
M. incognita	*C. esculentus* and *C. rotundus*	51, 52
Pratylenchus brachyurus	*C. esculentus* and *C. rotundus*	51, 52
Rotylenchus similis (Cobb) Filip.	*C. rotundus*	53, 120
Trichodorus spp. rhizosphere soil only	*C. esculentus* and *C. rotundus*	51, 52
Bacteria:		
Azotobacter	*C. rotundus*	57
Xanthomonas oryzae	*Cyperus rotundus*	24
Virus:		
V. lucerne dwarf (Freitag) virus	*C. esculentus*	33, 113
Animals:		
Pigs	*C. rotundus*	46
Birds:		
Ducks	*C. esculentus*	a
Geese	*C. esculentus*	a

[a]These birds were commonly allowed to feed in nutsedge-infested areas to reduce nutsedge populations.

nutsedge has been successful. Availability of rust for on-farm grower use depends on the ability to mass produce spores, to formulate the spores, and to store the formulated spores under growers' conditions. Nutsedge biotype and rust strain interactions along with the interactions with herbicides need intensive research. Also, the search for other organisms attacking nutsedges should continue.

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