FLOODING EXPERIMENTS FOR CONTROL OF WIRE-WORMS ATTACKING VEGETABLE CROPS IN THE EVERGLADES[1]

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ABSTRACT

Either continuous or alternate flooding appears effective for control of *Melanotus communis* and *Conoderus* sp(p). The minimal effective continuous flooding period in these tests was 6 weeks. Since a 4-2-4 weekly alternation of flooding to drying repeatedly showed perfect control and since 2-2-2 alternations produced 71 to 87% mortality, it appears that a 3-2-3 alternation should normally be effective. Ecological factors resulting from flooding evidently are important and should be studied further. Birds attracted to impoundments are particularly beneficial.

During recent seasons a number of Everglades vegetable growers have expressed dissatisfaction with certain currently registered insecticides because of failure to control wireworms. Inspection revealed that the corn wireworm[2], *Melanotus communis* (Gyllenhal), was commonly involved in these failures although the populations often included the southern potato wireworm, *Conderus falli* Lane. It is not implied that wireworm "resistance" to these chemicals was involved in these alleged failures since extraneous factors could usually be implicated. Concurrently with these chemical failures, an increasing volume of questions was received relative to the merits of flooding, time required for wireworm control by flooding, and comparative effectiveness of alternate versus continuous flooding.

HISTORICAL BACKGROUND

A normally abundant water resource, usually available facilities, and water control knowhow have created an ideal situation in the Everglades for water utilization in the control of certain diseases, nematodes, possibly certain weeds, and most subterranean insects. Flooding organic soils for control of soil-borne pests is compatible with sound soil conservation practices since these soils oxidize continuously (due in part to action of aerobic bacteria) except when under water. Evans and Allison (1942) and Clayton (1943) discussed effects of excessive drainage on peat soils. Moore et al. (1949) recommended flooding for control of Sclerotinose disease, *Sclerotinia sclerotiorum* (Lib.) De By. Thames and Stoner (1953) found that flooding of growing low land rice effectively controlled root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood, on

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[2]Not an approved common name by the Committee on Common Names of Insects of the Entomological Society of America although this name is in frequent use in the literature.

a subsequent vegetable crop. Fishler and Winchester (1964) found that flooding intermittently (2 weeks flooded, 2 weeks dried, and 2 weeks re-flooded) controlled nematodes as effectively as 9 months of continuous flooding. Winchester (1964) discussed flooding among other cultural practices for control of nematodes in kenaf. Genung (1957) reported on the heavy and rapid mortality of cutworms *Feltia subterranea* (Fabricus) and *Agrotis ipsilon* (Rottemburg) observed under natural flooding, and more recently (1964) verified these observations in laboratory tests. Orsenigo (1967) found in weed control experiments that flooding might have merit for control of goosegrass. A search of the literature revealed that very little experimental data existed on wireworm control by flooding[3]. Thomas (1930) concluded that flooding for wireworms would be impracticable and ineffective. Everglades growers have practiced flooding for various purposes for a number of years but results were often contradictory insofar as wireworms are concerned. A need for some experimental information on the various aspects of flooding for wireworm control was evident and preliminary investigations in the laboratory and field were initiated. Atmospheric Temperatures during field investigations are given in Table 1.

TABLE 1. TEMPERATURES DURING FIELD FLOODING OPERATIONS FOR PERIOD COVERING OBSERVATIONS DURING 1966, 1967, AND 1969.*

Month	Year	Max.	Min.	Mean max.	Mean min.	Mean
July	1966	93.0	70.0	89.8	73.0	81.4
July	1967	94.0	68.0	90.9	70.7	80.8
July	1969	95.0	70.0	91.0	72.6	81.8
August	1966	94.0	68.0	90.8	71.4	81.1
August	1967	93.0	67.0	90.5	69.7	80.1
August	1969	94.0	65.0	89.7	70.6	80.1
September	1966	94.0	68.0	89.7	71.2	80.4
September	1967	92.0	65.0	89.3	69.5	79.4
September	1969	93.0	68.0	88.1	70.9	79.5

*Data are from official weather station records maintained at the Everglades Experiment Station.

EXPERIMENT 1

The purpose of this experiment was to determine the effect of different time increments of continuous flooding on corn wireworm mortality.

[3]A paper by M. Calvino (1922) on flooding for wireworms in Cuba is extant but the writer has not seen the original paper entitled: Nuovo metodo di lotta contro il pasador del tobacco a Cuba. Rev. Agric. Com. il trabajo V.P. lr, Havana Rae. X1, 104. The practice, as described in *Review of Applied Entomology* is a mere saturation and not flooding as practiced in the Everglades and would not be effective against our species.

MATERIALS AND METHODS: The treatments (time increments) included 6 different periods in comparison with an untreated check all of which were replicated 3 times in a randomized complete block design. Glazed, earthenware, 6-inch diam. crocks were partly filled with field collected soil and 10 field collected and apparently healthy, advanced instar larvae of *M. communis* were placed in each. Additional soil was then placed over the wireworms and firmed. Water was then added carefully, to avoid washing out or exposing the larvae. The water level was maintained about 3 inches above the soil in the 18 flooded crocks. The remaining 3 crocks constituted the check and were therefore not flooded. Since preliminary observations indicated that wireworms under flooding became relatively inactive in a short time, no food was supplied those in the treated crocks. Those in the check were supplied Irish potato halves just below soil surface. The flooding increments were: 3 days, 7 days, and weekly periods thereafter up to 35 days. As the time expired for each increment, the water was drained off and the soil carefully examined for live and dead wireworms, including any disintegrating parts, but the check was not examined until the expiration of the experiment. Those that survived were provided with food.

RESULTS: As shown in Table 2 mortality commenced with the 7-day treatment and generally increased thereafter. A delayed mortality (failure to survive 72 hr) after removal of water occurred in the flooded crocks. A

TABLE 2. MORTALITY PERCENTAGES OBTAINED WITH *Melanotus communis* UNDER DIFFERENT PERIODS OF SUSTAINED FLOODING DURING JUNE AND JULY 1966*

Time Increment	Initial Average % Mortality	Delayed Average % Mortality	Total Average % Mortality
3 days	0	0	0
7 days	3.3	10.0	13.3
14 days	3.3	10.0	13.3
21 days	23.3	10.0	33.3
28 days	33.3	43.3	76.6
35 days	63.3	13.3	76.6
Check	10.0	0	10.0

*Mortality in checks due mainly to cannibalism.

light mortality in the checks appeared to be due mainly to cannibalism even though ample food material had been supplied. An average of about 77% mortality was obtained after 35 days of sustained flooding, indicating that a greater time period would be required for control under heavy population conditions.

Experiment 2

This experiment was initiated to compare the recommended practice for nematode control (alternate flooding and drying) with results obtained in the continuous flooding experiment as given above.

Materials and Methods: Two treatments (1) one week flooded, one week dried and one week reflooded and (2) two weeks flooded, two weeks dried, and two weeks reflooded (the standard flooding recommendation for nematodes) were set up in crocks as in Experiment 1, except that 15 wireworms were used per crock. These treatments and an untreated check were replicated 3 times. Food was provided in the checks as mentioned above.

Results: In this experiment the first treatment was entirely inadequate (Table 3). A much better mortality was obtained in the second treatment

TABLE 3. Mortality percentages of *Melanotus communis* under different time periods of alternate flooding and drying during June and July 1966*

Weekly Alternation	Initial Average % Mortality	Delayed Average % Mortality	Time Average % Mortality
1 - 1 - 1	17.8	2.2	20.0
2 - 2 - 2	69.2	2.2	71.4
Check	8.9	0	8.9

*Mortality in checks due mainly to cannibalism.

but under conditions of heavy field infestation would be inadequate for grower needs. It appeared that some mortality in the check was due mainly to the cannibalistic tendency of the larvae.

Experiment 3

This experiment was conducted almost concurrently with Experiment 2 and the purposes were the same; but the present test was in a flooded field instead of the laboratory.

Materials and Methods: 6-inch diam, screen wire, cylindrical cages were partly filled with soil and 10 wireworms added to each. The treatments and replications were the same as in Experiment 2. The cages were submerged in a flooded field until the soil in the cages was even with the soil line in the field. During the second 2-week period because of a temporary subsidence of the water, it was necessary to temporarily place the cages in tubs of water.

Results: Both of the treatments gave better control (70% and 87% respectively) than the laboratory test, but even the results of the 2-week alternation would be barely adequate under very heavy field population conditions. (Table 4).

TABLE 4. PERCENT MORTALITY OF *Melanotus communis* LARVAE OBTAINED IN CAGES IN FLOODED FIELD. JUNE AND JULY 1966.*

Weekly Alternation	Initial Average % Mortality	Delayed Average % Mortality	Total Average % Mortality
1 - 1 - 1	70.0	0	70.0
2 - 2 - 2	80.0	6.7	86.7
Check	13.3	0	13.3

*Mortality in checks due mainly to cannibalism.

EXPERIMENT 4

This was an evaluation of (1) field flooding in comparison with 2 other conditions; (2) unflooded but treated with parathion the previous winter and (3) unflooded and with no recent history of insecticide treatment.

METHODS: About 1½ acres in preparation as a celery seed bed at the Everglades Experiment Station was flooded for 4 weeks, dried out for 2 weeks, and reflooded for 4 additional weeks. The second area was an adjacent comparable sized block that had been in sweet corn earlier in the spring and had been treated with parathion 5 lb/acre the previous winter. The unflooded check, a more distant comparable area, was selected because it had been continuously free from soil insecticidal treatment during recent years. Two-hundred evenly spaced soil cores 3 inches in diam and 6 inches deep were taken on all 3 areas after termination of flooding and examined by finely pulverizing and sifting the soil for wireworms.

RESULTS: As shown in Table 5, the flooded area samples were completely free of wireworms. The adjacent area treated the previous winter had

TABLE 5. RESULTS OF FIELD FLOODING FOR WIREWORM CONTROL IN COMPARISON WITH TWO OTHER CONDITIONS, DURING JUNE, JULY TO MID-SEPTEMBER 1966.

Treatment	Number Soil Samples	Number *M. Communis*	Number *Conoderus spp.*	Total Wire-worms	% Samples Positive
Flooded*	200	0	0	0	0
Insecticide**	200	10	0	10	5.0
Unflooded†	200	6	7	13	6.5

*4 - 2 - 4 weekly alternation
**Treated with parathion about 4 months previously
†No recent insecticidal history

more *M. communis* than the check but no *Conoderus* spp. A moderately high infestation occurred in the check area. If projected on a per acre basis the wireworm population in the check would undoubtedly be of economic proportions.

EXPERIMENT 5

This was almost identical with Experiment 4 except that the insecticidally treated area was replaced by a partially but insufficiently fallowed area.

RESULTS: No wireworms were found in the flooded area. The insufficiently fallowed area was moderately infested and the check quite heavily infested with wireworms. (Table 6).

TABLE 6. RESULTS OF FIELD FLOODING FOR WIREWORM CONTROL IN COMPARISON WITH TWO OTHER CONDITIONS DURING JULY, AUGUST TO MID-SEPTEMBER 1967.

Treatment	Number Soil Samples	Number *M. Communis*	Number *Conoderus spp.*	Total Wire-worms	% Samples Positive
Flooded*	200	0	0	0	0
Fallowed**	200	6	2	8	4.0
Unflooded	200	14	4	18	9.0

*4 - 2 - 4 weekly alternation.
**Fallow not perfectly maintained.

EXPERIMENT 6

In a test conducted in 1969, 2 additional conditions were compared with a 4-2-4 alternation with post flooding fallow well maintained. These were a 4-2-4 alternation where the post flooding fallow was rather inadequately maintained, and a continuously flooded treatment with inundation maintained without any lapse for 6 weeks. Because of factors beyond the writer's control it was possible to examine only 100 samples per treatment instead of the desired 200 samples.

RESULTS: Despite the reduced sample size a greater total number of wireworms as well as numbers of individual species were recorded in the check than in the previous field tests. A single wireworm and several corn rootworms indicate that some reinfestation is liable to occur in flooded fields unless the post flooding fallow is carefully maintained. The treatments and a full breakdown of data are shown in Table 7.

TABLE 7. COMPARISON OF EFFECTS OF ALTERNATE FLOODING AS RELATED TO GOOD AND MEDIOCRE POST FLOODING FALLOW AND IN COMPARISON WITH CONTINUOUS FLOODING.

Treatment	No. Samples	No. *M. communis*	No. *Conoderus sp.*	No. miscel.	Total Wire-worms	% Samples positive
Flooding* + good post flood fallow	100	0	0	0	0	0
Flooding** — good post flood fallow	100	1	0	0	1	1
Flooding† continuous	100	0	0	0	0	0
Check, no treatment	100	30	14	4	48	42

*4 - 2 - 4 alternation.
**4 - 2 - 4 alternation. In addition to wireworm 3 corn rootworms, probably *Diabrotica balteata* Le Conte, were taken under this treatment.
†Flooded for 6 weeks.

SOME ECOLOGICAL ASPECTS OF WIREWORM CONTROL BY FLOODING

Observations in both the field and laboratory show that 40% or more of wireworms under flooding or simulated flooding, may eventually make their way to the soil surface. In the field this percentage would be more vulnerable to attack by various aquatic organisms. Soon after flooding many semi-aquatic and wading birds move into the flooded areas. It is believed that the surfacing soil organisms including wireworms are a major attractions to birds in these impoundments. Under natural flooding in pastures, earth worms, white grubs, cutworms, and wireworms were observed at the surface where many birds were gathering. Brids observed at wireworm flooding sites included: mottled duck, *Anas fulvigula fulvigula* Ridgeway; king rail, *Rallus elegans elegans* Audubon; killdeer, *Charadrius vociferus vociferus* Linnaeus; snipe, *Capella gallinage delicata* (Ord); blacknecked stilt, *Himantopus mexicanus* (Muller); gulls *Larus* sp(p).; American egret, *Casmerodius albus egretta* (Gmelin); little blue heron, Florida *caerula caerula* (L.); white ibis, *Eudocimus albus* (L.); glossy ibis, *Plegadis falcinellus falcinellus* (L.); limpkin, *Aramus guarouna pictes* (myer); and Weston's boat tailed grackle, *Cassidix mexicanus westoni* Sprunt.[4]

In Laboratory experiments many of the wireworms under simulated

[4]Source for scientific names of birds: *Florida Bird Life*, Alexander Sprunt, Jr. 1954. Coward-McCann, Inc., New York, Nat. Audubon Soc. and Fla. Game and Fresh Water Fish Commission, Cooperating.

flooding were observed to have, after 2 to 3 weeks, a filamentous type of algal growth attached to the integument so firmly that the growth could not be removed without injury to the insect. Although pathogenicity of the organism was not established, it seems noteworthy that none of the affected larvae survived over 72 hrs when removed from the crocks.

Many predatory aquatic insects, reptiles, and amphibians find a suitable habitat in flooded fields but our knowledge of their possible effects on wireworms is at present too limited for comment.

Discussion

Flooding for wireworm control is a slow process. The time requirement may be one reason some growers feel wireworms cannot be drowned in practicable percentages. This method appears highly effective if continued for a long enough time and is in complete harmony with good organic soils conservation practices. In addition, flooding can be practiced when crop acreages are at a minimum, during the summer months. Besides drowning the current population, flooding prevents further oviposition during the period of inundation.

Reportedly wireworms soon reappear on land that has been flooded thus indicating a belief that previously flooded land holds affinity for the adult ovipositing elaterids. More probably, such lands are not maintained in a proper state of clean fallow prior to planting and resulting weed growth therefore encourages oviposition. It is important that the land be as well prepared for flooding as for planting and that the entire field is completely inundated. Field observations indicate that improperly prepared land results in poorer control by flooding than where reasonable care is taken. Wireworms have a better chance of survival where there are many unrotted stalks and other coarse organic debris. Unlevel land with many spots of protruding ground also contributes to poorer control.

It is evident that flooding for wireworm control produces an ecological situation in which benefits are derived from various biological agents among the most important of which are birds. It is also evident that our knowledge of what all these factors are and how they operate is very incomplete.

Flooding is not an unmixed blessing. That populations of carabid larvae and other predators in and on the soil were reduced was indicated by the sampling of flooded and unflooded areas. A determination of the full ecological effects of flooding on these lands would be a worthwhile study.

Conclusions

Alternate flooding and drying on a 4-2-4 weekly basis indicated excellent control of wireworms on organic soils. Since 5 weeks of continuous simulated flooding in the laboratory gave only about 77% control it was desirable to test 6 weeks of continuous flooding of carefully prepared land. This was done in the field in 1969 and excellent control was obtained. However, additional tests of this increment should be made. While a 2-2-2 weekly alternate flooding to drying gave only fair control it can be projected from the data that a 3-2-3 alternation would probably be quite satisfactory. Since only *M. communis* was used in the laboratory tests and since that species and *Conoderus* sp. generally predominated in the field the results obtained are only considered applicable to those species.

Since field observations indicate that dehydration is more quickly lethal to wireworms than flooding, it is suggested that during dry seasons fields could, where feasible, be disked frequently to good advantage prior to flooding.

More field tests on the effectiveness of flooding should be conducted. These should also include careful observations on the ecological aspects both from the positive and negative sides.

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