JEPPSON, L. R., H. H. KEIFER, AND E. W. BAKER. 1975. Mites injurious to economic plants. Univ. of California Press. Berkeley. 614 p., 74 pls.

KRANTZ, G. W. 1978. A manual of acarology, 2nd edition. OSU Bookstores, Corvallis, Oregon.

MANDON, D. C. M. 1963. Seven new species of false spider mites (Tenuipalpidae: Acarina). Acarologia 5(2): 213-224.

MCGREGOR, E. A. 1949. Nearctic mites of the family Pseudoleptidae. Mem. South. Calif. Acad. Sci. 3(2): 1-45.

MEYER, M. K. P. S. 1979. The Tenuipalpidae (Acari) of Africa with keys to the world fauna. S. African Dept. Agr. Tech. Serv. Entomol. Mem. Rpt. 50: 1-135.

OCHOA, R. 1985. Reconocimiento preliminar de los acaros fitoparasitos del genero *Brevipalpus* en Costa Rica. Ing. Agr. Thesis, Universidad de Costa Rica, Facult. de Agronomia 124p.

OCHOA, R. 1988. Diagnostico y reconocimiento de los acaros de importancia agricola. Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE), Proyecto MIP, p. 1-30 (unpublished).

OCHOA, R., AND L. A. SALAS. 1989. The genus *Brevipalpus* in Costa Rica. Int. J. Acarol. 15 (1): 21-30.

PRITCHARD, A. E., AND E. W. BAKER. 1952. The false spider mites of California (Acarina: Phytoptipalpidae). Univ. California Pub. Entomol. 9(1): 1-94.

PRITCHARD, A. E., AND E. W. BAKER. 1958. The false spider mites (Acarina: Tenuipalpidae). Univ. California Pub. Entomol. 14 (3): 175-274.

SAYED, M. T. 1938. Sur un novelle sous-famille et deux nouveaux genres de Tetranyques. Bull Mus. Hist. Nat. Paris (ser. 2) 10: 601-610.

UMAÑA, G., R. OCHOA, E. VARGAS, AND L. A. SALAS. 1990. Potencial de control biologico de acaros en Costa Rica por medio del hongo Hirsutella sp.. Bolletin informativo (Centro Agronomico Tropical de Investigacion y Enseñanza), No. 15, p. 5-6.

EFFECT OF TEMPERATURE IN FLOODING TO CONTROL THE WIREWORM *MELANOTUS COMMUNIS* (COLEOPTERA: ELATERIDAE)

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ABSTRACT

Larvae of *Melanotus communis* (Gyllenhal) collected from sugarcane fields in southern Florida were held in soil flooded with water for 1, 2, 3, 4, 5 or 6 weeks at 18, 21, 24 or 27°C. At each temperature, regression analyses indicated that the percentage of wireworms killed increased linearly as flood duration was increased. Increasing the temperature maintained during a flood significantly increased the percentage of wireworms that died. Multiple regression analysis indicated that Y = -94.4 + 7.1X_1 + 4.3X_2, where Y was the expected percent mortality, X_1 was flood duration in weeks, and X_2 was temperature in degrees Celsius (R^2 = .76). The equation may be used to estimate how long a flood should be continued at a given temperature to obtain a desired level of wireworm control under field conditions.

RESUMEN

Se colectaron larvas de *Melanotus communis* (Gyllenhal) en campos de cana de azucar en el sur de Florida y se mantuvieron en suelo inundado con agua por espacio de 1, 2, 3, 4, 5 o 6 semanas a temperaturas de 18, 21, 24, or o 27 oC. Los analisis de regresion indicaron que para cada temperatura, el percentaje de mortalidad de los gusanos alambre incrementaba linearmente a medida que el periodo de inundacion aumentaba. El incremento de temperatura durante una inundacion, aumento el porcentaje de mortalidad de los gusanos alambre. Los analisis de regresiones multiples indicaron que Y = -94.4 + 7.1X1 + 4.3X2, donde Y es el porcentaje de mortalidad esperada, X1 es la duracion de la inundacion en semanas, y X2 fue la temperatura en grados Celsius (R2 = .76). La ecuacion puede ser usada para estimar por cuanto tiempo debe continuarse una inundacion a una temperatura dada con el fin de obtener un nivel deseado de control de los gusanos alambre bajo condiciones de campo.

The wireworm *Melanotus communis* (Gyllenhal) is an important pest of several crops in Florida including sugarcane (Gifford 1964, Hall 1988), potatoes (Wolfenbarger 1965, Baranowski & Waddill 1975), celery and peppers (Wilson 1940). Pre-plant diskings help reduce population levels of *M. communis* by physically injuring wireworms and by bringing wireworms to the soil surface which subjects them to desiccation (Genung 1970) and predation by birds. *Melanotus communis* is sometimes controlled by a parasitoid, *Pristocera armifera* (Say) (Hymenoptera: Bethylidae) (Hall 1982). However, disking in combination with natural control factors in southern Florida is often insufficient for preventing economic damage by *M. communis*. Chemical insecticides generally offer good protection against the wireworm and have been a reliable management tactic. Flooding fields with water has been recognized as another control strategy for wireworms as well as for some other insect pests, weeds, and plant parasitic nematodes (Snyder 1987). Depending on such factors as water availability, legal regulations and ecological considerations, flooding can be and is sometimes used as a pest management strategy in southern Florida.

Reports from researchers in Florida have indicated that flooding for wireworm control is a slow process (Genung 1970) enhanced to some extent by warm temperatures (Ingram et al. 1938). However, Ingram et al. (1938) concluded that flooding during warm weather for up to 30 days was of little use against *M. communis* wireworms. Flooding for as long as 2 weeks during April, August or September was of little value against wireworms (Ingram et al. 1951). Wilson (1940) reported that flooding during July and August proved to be ineffective against *M. communis* wireworms. In contrast to investigations that indicated flooding gave poor wireworm control, Genung (1970) reported that a continuous 35-day flood provided 76.6% control of *M. communis* wireworms; the temperature of flooded soil in this test was not noted. In a later report, Genung (1976) pointed out that the duration of a flood was a key factor in the success of flooding for wireworm control but did not address the role of temperature.

Research on flooding in other areas of the United States with other wireworm species has shown that, as a group, wireworm species can be difficult to kill by drowning

(Cameron 1913, Hyslop 1915, Thomas 1930). Lane & Jones (1936) pointed out that early research on wireworm control by flooding did not consider temperature; laboratory and field experiments by these researchers indicated temperature was an important factor governing the speed of death of *Limonius* spp. during a flood. Campbell & Stone (1938) found that flooding to control *Limonius californicus* (Mann.) was ineffective unless the soil temperature was above 21.1°C, even when flooding was conducted for as long as 15 to 18 days.

Presented here are the results of a laboratory assessment of flooding to control *M. communis* wireworms using different flood durations at different temperatures.

Materials and Methods

Melanotus communis larvae were held in containers of soil flooded for 1, 2, 3, 4, 5 or 6 weeks at 18, 21, 24 or 27°C. This temperature range was studied because 18 and 27°C have been reported as minimum and maximum seasonal temperatures of flood waters within the Everglades Agricultural Area of southern Florida (Cherry 1984). The wireworms were field-collected from sugarcane fields during December and subjected to the flooding treatments during January and February. After collection, wireworms were maintained in large pans containing soil and wheat seeds or carrots in the laboratory until enough had been collected to start the flooding tests. Wireworm mortality data from floods at 18 and 27°C were collected in 1991, data from floods at 21 and 24°C were collected in 1992.

Flooding was accomplished in polypropylene plastic beakers (9.5 cm high, 8.5 cm diameter) containing 300 ml muck soil (>45% organic matter). Prior to adding the soil, 35 to 40 small holes were made in the container bottoms. These holes were small enough to prevent wireworms from escaping but allowed water to enter. Pieces of carrot as a food source for wireworms were buried in the soil. Twenty-five wireworms were placed onto the soil in each container and allowed 3 h to dig into the soil. The containers were then flooded with water by placing them into large pans (30 X 23 cm, 10 cm high) containing water. Water seeped upward into each wireworm container until the final water level was about 1.5 cm above the soil surface. This water level was maintained throughout each flooding duration by adding water as required. The containers in the pans were held in the dark inside environmental chambers at constant temperatures (±1°C). Four containers were subjected to each flood duration at each temperature. In addition to flooded containers, 4 containers not flooded, each containing soil, carrots and 25 wireworms, were maintained at each temperature as controls. Carrots and water were added as needed at weekly intervals to maintain wireworms in the control containers. The wireworms used in the study appeared to be mostly late-instar larvae. Prior to flooding, 20 wireworms per temperature treatment were each weighed to provide an indicator of the body size of the wireworms studied; the average weight of the wireworms was 0.065 g ($s = 0.0334$). After each flooding period, the containers were drained and placed back into their respective temperature chambers. One week later, the wireworms were removed from the containers and mortality was determined. A one-week recovery period was used because wireworms usually are comatose after a flood but sometimes recover. Wireworms which displayed any movement after the recovery period were considered to be alive.

Percent mortality of *M. communis* after each flood was calculated. Mortality of wireworms in control containers was assessed after each of the 6 flood durations at each temperature; the percent mortality of wireworms in flooded containers was adjusted for mortality in control containers using Abbott's formula (Abbott 1925). Linear regression analyses were conducted using PROC GLM (SAS Institute 1985) on the percent mortality data across the flood durations studied at each temperature. Statistical confi-

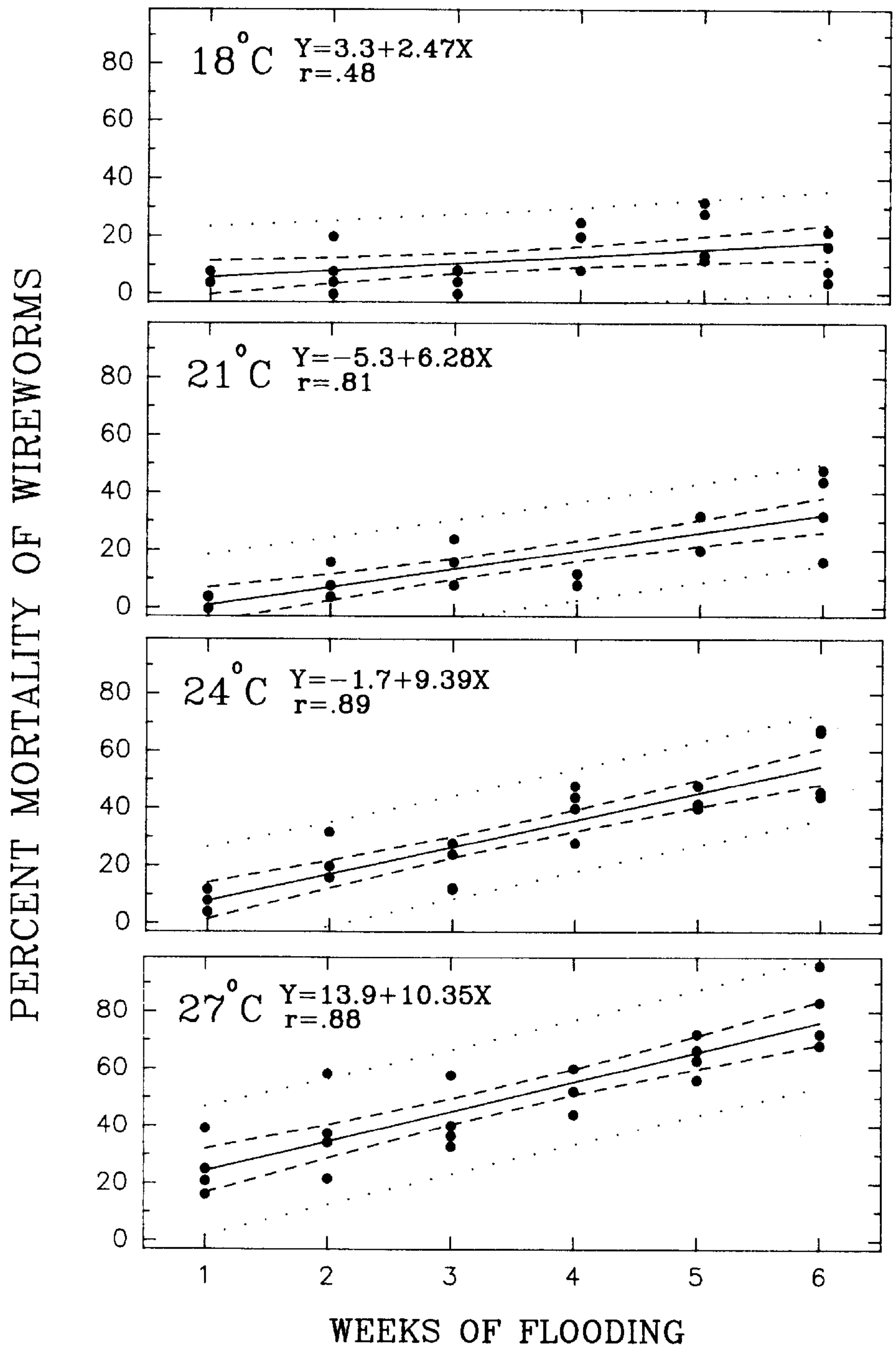

Fig. 1. Percent mortality of *Melanotus communis* larvae during different flood durations at 18, 21, 24 and 27°C. For each temperature, the solid line is the prediction line from a regression analysis, dashed lines represent 95% confidence limits for mean estimates, and dotted lines represent 95% confidence limits for an individual estimate. Additional statistics from the regressions: at 18°C: $F = 6.6$, $Pr > F = 0.0175$, d.f. $= 23$, $r = .48$; at 21°C: $F = 42.9$, $Pr > F = 0.0001$, d.f. $= 23$, $r = .81$; at 24°C: $F = 86.6$, $Pr > F = 0.0001$, d.f. $= 23$, $r = .89$; at 27C: $F = 72.2$, $Pr > F = 0.0001$, d.f. $= 23$, $r = .88$.

dence limits (95%) for the regressions were determined using the SAS GLM options CLM and CLI (SAS Institute 1985).

RESULTS AND DISCUSSION

Mortality data indicated that *M. communis* wireworms were slow to die during a flood. This finding agreed with reports by Genung (1970) and Ingram et al. (1938, 1951). The rate of wireworm mortality during a flood was less than has been reported for other pests in southern Florida including two species of sugarcane grubs (Cherry 1984) and some cutworm species (Genung 1964). Increasing the temperature at which flooding was conducted increased the rate at which wireworms died. The data indicated that substantial percentages (e.g., 40% or more) of wireworms could be killed by flooding but, in general, the flood duration had to be at least 4 to 5 weeks at water temperatures above around 24°C. More than 6 weeks of continuous flooding would have been needed to achieve 100% wireworm control, even at 27°C.

Regression analyses indicated that mortality of *M. communis* wireworms was influenced by both flood duration and temperature (Fig. 1). At each of the four temperatures, increasing the flood duration significantly increased the percentage of wireworms killed (Fig. 1). From the basis of the standard errors associated with the regression slopes, increasing the temperature from 18 to 21 to 24°C significantly increased the percentage mortality of wireworms during a flood while increasing the temperature from 24 to 27°C did not. The 95% mean prediction intervals depicted in Fig. 1 indicated that, on the average, the expected error margin of each prediction line was ±5% or less. As indicated by the 95% individual prediction estimates in Fig. 1, the widest expected error margin for a single prediction was usually less than ±10%.

A multiple regression equation indicated

$$Y = -94.4 + 7.12\,X_1 + 4.31\,X_2$$

where Y = expected percent mortality of wireworms, X_1 = number of weeks of continuous flooding, and X_2 = flooding temperature in degrees Celsius ($R^2 = .76$, $F = 150.3$, $Pr > F = .0001$, d.f. = 95). Because flood duration and temperature are integrated into this equation, it can be used to estimate how long a flood should be continued at a given water temperature to obtain a desired level of wireworm control.

Total control (i.e., 100% mortality) of *M. communis* wireworms may not always be needed in sugarcane (Hall 1990). If the wireworm density in a field is estimated prior to a flood, then the minimum flood duration needed to reduce wireworm levels to below those that cause economic losses can be estimated. Most oviposition by *M. communis* occurs during May-July in southern Florida (Cherry & Hall 1986), and adult females avoid ovipositing in water (Wilson 1946). Flooding as a once-a-year management strategy against wireworms would therefore be practical as long as the flood is timed toward the end of or after the ovipositional period each year before soil temperatures drop to below about 24°C.

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REFERENCES CITED

ABBOTT, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

BARANOWSKI, R. M., AND V. H. WADDILL. 1975. Soil applications of insecticides for control of potato infesting wireworms. Proc. Florida State Hort. Soc. 88: 173-175.

CAMERON, A. E. 1913. General survey of the insect fauna of soil within a limited area near Manchester. J. Econ. Biol. 8: 159-204.

CAMPBELL, R. E., AND M. W. STONE. 1938. Flooding for the control of wireworms in California. J. Econ. Entomol. 31: 286-291.

CHERRY, R. H. 1984. Flooding to control the grub *Ligyrus subtropicus* (Coleoptera: Scarabaeidae) in Florida sugarcane. J. Econ. Entomol. 77: 254-257.

CHERRY, R. H., AND D. G. HALL. 1986. Flight activity of *Melanotus communis* (Coleoptera:Elateridae) in Florida sugarcane fields. J. Econ. Entomol. 79: 626-628.

GENUNG, W. G. 1964. Cutworm control studies. Florida Agr. Exp. Station Annu. Rep., p. 279.

———. 1970. Flooding experiments for control of wireworms attacking vegetables crops in the Everglades. Florida Entomol. 53: 55-63.

———. 1976. Flooding in Everglades soil pest management. Proc. Tall Timbers Conf. on Ecological Animal Control by Habitat Management. 6: 165-172.

GIFFORD, J. R. 1964. A brief review of sugarcane insect research in Florida, 1960-1964. Proc. Soil and Crop Sci. Soc. Florida. 24: 449-453.

HALL, D. G. 1982. A parasite, *Pristocera armifera* (Say), of the wireworm *Melanotus communis* (Gyll.) in south Florida. Florida Entomol. 65: 574.

———. 1988. Insects and mites associated with sugarcane in Florida. Florida Entomol. 71: 138-150.

———. 1990. Stand and yield losses in sugarcane caused by the wireworm *Melanotus communis* (Coleoptera: Elateridae) infesting the plant cane in Florida. Florida Entomol. 73: 298-302.

HYSLOP, J. A. 1915. Wireworms attacking cereal and forage crops. U.S.D.A. Bul. 156, 34 pp.

INGRAM, J. W., H. A. JAYNES, AND R. N. LOBDELL. 1938. Sugarcane pests in Florida. Proc. Internat'l Soc. Sugar Cane Technol. 6: 89-98.

INGRAM, J. W., E. K. BYNUM, R. MATHES, W. E. HALEY, AND L. J. CHARPENTIER. 1951. Pests of sugarcane and their control. U.S.D.A. Cir. 878, 38 pp.

LAND, M. C., AND E. W. JONES. 1936. Flooding as a means of reducing wireworm infestation. J. Econ. Entomol. 29: 842-850.

SAS INSTITUTE. 1985. SAS user's guide:statistics, version 5 ed. SAS Institute, Cary, N.C.

SNYDER, G. H. 1987. Agricultural Flooding of Organic Soils. Agr. Exp. Station, Institut. Food & Agr. Sciences, Univ. Florida, Techn. Bul. 870, 63pp.

THOMAS, C. A. 1930. A review of research on the control of wireworms. Pennsylvania State Coll. School Ag. Exp. Sta. Bul. 259, 52 pp.

WILSON, J. W. 1940. Preliminary report on wireworm investigations in the Everglades. Florida Entomol. 23: 1-6.

———. 1946. Present status of the wireworm problem in south Florida. Proc. Florida State Hort. Soc. 59: 103-106.

WOLFENBARGER, D. O. 1965. Wireworm control experiments on potatoes and corn in south Florida. Florida. Entomol. 48: 85-88.