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Authors: Muniappan, R., Meyerdirk, D. E., Sengebau, F. M., Berringer, D. D., and Reddy, G. V P.

Source: Florida Entomologist, 89(2) : 212-217

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/0015-4040(2006)89[212:CBCOTP]2.0.CO;2

CLASSICAL BIOLOGICAL CONTROL OF THE PAPAYA MEALYBUG, *PARACOCCUS MARGINATUS* (HEMIPTERA: PSEUDOCOCCIDAE) IN THE REPUBLIC OF PALAU

R. MUNIAPPAN[1,5], D. E. MEYERDIRK[2], F. M. SENGEBAU[3], D. D. BERRINGER[4] AND G. V. P. REDDY[1]
[1]Agricultural Experiment Station, College of Natural and Applied Sciences
University of Guam, Mangilao, Guam 96923, USA

[2]USDA-APHIS, Plant Protection and Quarantine, National Biological Control Institute
4700 River Road, Riverdale, MD 20737-1236, USA

[3]Bureau of Agriculture, P.O. Box 460, Koror-96940, Republic of Palau

[4]USDA-APHIS, Plant Protection and Quarantine, P.O. Box 8769 Tamuning, Guam 96911, USA

[5]Corresponding author; e-mail: rmuni@uog9.uog.edu

ABSTRACT

The papaya mealybug (PM), *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae), a pest in Central America and the Caribbean, was noted to have established on Palau in March 2003 and was causing serious damage to papaya, plumeria, hibiscus, and other plants. The parasitoids *Anagyrus loecki* Noyes, *Pseudleptomastix mexicana* Noyes and Schauff, and *Acerophagus papayae* Noyes and Schauff (Hymenoptera: Encyrtidae) totaling 24,586 were imported from Puerto Rico and field released in Palau from August 2003 to June 2004. *Anagyrus loecki* and *A. papayae* appear to be promising biological control agents of PM in Palau. No field recovery of *P. mexicana* was made in spite of several field releases. The reduction of the papaya mealybug population density levels below detectable levels was observed in a six-month period following the introduction of these exotic parasitoids. Following the successful implementation of a classical biological control program, the risk of this mealybug spreading to other islands in the Republic of Palau and to neighboring Micronesian Islands has been considerably reduced.

Key Words: Papaya mealybug, *Paracoccus marginatus*, Hemiptera, Pseudococcidae, *Anagyrus loecki*, *Pseudleptomastix mexicana*, *Acerophagus papayae*, Hymenoptera, Encyrtidae, biological control, Palau

RESUMEN

El estabecimiento en Palau de la cochinilla de papaya (PC), *Paracoccus marginatus* Williams y Granara de Willink (Hemiptera: Pseudococcidae), una plaga del Centroamerica y el Caribe, fue anotada en marzo del 2003. Esta plaga causa daño severo en papaya, hibiscus y otras plantas. Un total de 24,586 de los parasitoides, *Anagyrus loecki* Noyes, *Pseudleptomastix mexicana* Noyes & Schauff, y *Acerophagus papayae* Noyes & Schauff (Hymenoptera: Encyrtidae), fueron importados de Puerto Rico y liberados en Palau de agosto de 2003 hasta junio de 2004. Las especies *Anagyrus loecki* y *A. papayae* parecen ser agentes de control biológico prometadores de PC en Palau. El parasitoide, *P. mexicana* no fue recuperado en el campo a pesar de varias liberaciones de esta especie en el campo. La reducción en el nivel de la densidad de la población de la cochinilla de papaya a un nivel no detectable fue observada por un período de seis meses después de la introducción de estos parasitoides exóticos. La implementación exitosa de este programa de control biológico clásico ha reducida el riesgo que esta cochinilla se disperse a las otras islas en la Republica de Palau y las Islas de Micronesiano cercanas.

The papaya mealybug (PM), *Paracoccus marginatus* Williams and Granara de Willink (Hemiptera: Pseudococcidae) is native to Mexico and/or Central America (Miller et al. 1999). It was first described in 1992 (Williams & Granara de Willink 1992) and re-described by Miller & Miller (2002). In April 2003, G.W. Watson, Natural History Museum, London, England (Currently, California Department of Food and Agriculture, Sacramento) confirmed the identity of PM following a March 2003 report of heavy infestations of mealybugs on papaya *Carica papaya* L. (Caricaceae) on the island of Koror and in the southern state of Airai on the island of Babeldaob of the Republic of Palau (Anonymous 2003). Papaya mealybug has a wide host range of over 60 species of plants (Mey-

erdirk & Kauffman 2001). Its distribution and damage symptoms have been reviewed by Meyerdirk et al. (2004). The establishment of PM in Guam in 2002 and Palau in 2003 was flagged as a serious concern for the neighboring islands in the Pacific (Meyerdirk et al. 2004). This concern has been justified by its recent establishment on Maui in the Hawaiian Islands (Heu & Fukada 2004).

Since the establishment of PM in Palau, home gardeners have been washing mealybugs from papaya trees with water using hoses and farmers have been using insecticides to control PM without much success. In response to the pressure from PM some homeowners have elected to cut their papaya trees and some commercial growers have abandoned papaya cultivation.

Successful classical biological control programs on hemipterans in recent years include cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) in Africa (Neuenschwander 2001), mango mealybug, *Rastrococcus invadens* (Williams) (Hemiptera: Pseudococcidae) in West Africa (Bokonon-Ganta & Neuenschwander 1995; Pitan et al. 2000), red coconut scale, *Furcaspis oceanica* Lindinger (Hemiptera: Diaspididae) in Saipan and Guam (Muniappan et al. 2003), pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) in the Caribbean (Kairo et al. 2000), and most recently *P. marginatus* in Guam (Meyerdirk et al. 2004).

In an attempt to develop a classical biological control program for the papaya mealybug, the parasitoids *Anagyrus loecki* Noyes, *Acerophagus papayae* Noyes and Schauff, and *Pseudleptomastix mexicana* Noyes and Schauff (Hymenoptera: Encyrtidae) were collected originally in Mexico. They were later cultured and mass produced in a cooperative effort with the Puerto Rico Department of Agriculture at San Juan, Puerto Rico and USDA, Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ). These parasitoids have been shipped to the Dominican Republic, Florida, and Guam (Meyerdirk et al. 2004).

This paper documents the introduction and establishment of the parasitoids and suppression of PM in the Republic of Palau.

Materials and Methods

Plumeria (*Plumeria* spp.) (Apocynaceae) was selected as the study plant to monitor population densities of PM and the newly released exotic parasitoids as described in Meyerdirk et al. (2004). Even though papaya is one of the main hosts of PM, it was not chosen for sampling because the plants are fragile and heavy infestation of PM kills the plants in a short period. On the other hand, plumeria trees are hardy and are distributed throughout Palau. Samples taken on plumeria included four mature leaves removed from two terminal shoots per quadrant selected at random, totaling 16 leaves per tree for mealybug density counts. The length and width of each leaf were measured. Only the lower surface of the leaves was examined under a dissecting microscope because 99% of all developmental stages of PM are located on the lower surface of the leaves. Mechanical counters were used to tally the total number of mealybugs per stage of development. Stages counted included egg masses as single individual units with eggs alone, egg masses with eggs and crawlers, second and third instars of males and females, adult male and female mealybugs, and mummies with and without exit holes. Second and third instars and adult male and female stages were totaled per leaf. All 16 leaves were used to average the number of stages per leaf per study site. One tree represented one study site. A total of nine study sites, each with one plumeria tree, served as the source of counts for this study.

Additional plumeria leaves were collected from each study site showing signs of PM infestation in order to isolate a total of 100 individual mealybugs. Late second and third instars and adult females were individually collected for percent parasitization records. These counts were conducted on a monthly schedule with mealybugs removed from the leaf samples and individually encapsulated in clear gelatin capsules (size 0). These capsules were labeled and placed in Ziploc plastic bags for 30 days in the laboratory in an air conditioned room (25°C). After the 30-day period, each capsule was examined to determine if the mealybug was parasitized. Emerged parasitoids were counted and identified to species. The parasitoids *A. loecki*, *A. papayae*, and *P. mexicana* were shipped from Puerto Rico to Palau from August 5, 2003, to June 25, 2004, with an interruption from October 2, 2003, to May 6, 2004, because of low parasitoid culture production.

The survey for population density estimation of PM before the release of the parasitoids was carried out on August 5, 2003. Release of *A. loecki*, *A. papayae*, and *P. mexicana* was carried out from August 6, 2003, to June, 2004. In total, 24,586 parasitoids were released at 13 sites over a 10 month period (Table 1).

Cryptolaemus montrouzieri Mulsant (Coleoptera: Coccinellidae), a pre-existing mealybug predator established in 1939 in Palau (Esaki 1940), was sampled during papaya mealybug density counts by using a beat sheet (53 × 53 cm). A total of four strokes with a beating stick (60 cm long) against plumeria terminals were used to knock off *C. montrouzieri* adults and larvae, which were then counted in each quadrant of each plumeria tree at random. Notes were taken on other predators observed at each study site.

Data collected on the number of egg masses, 2nd and 3rd instars, and adult males and females per whole plumeria leaf sample were converted to total number of mealybugs per 100 sq cm of leaf.

TABLE 1. PAPAYA MEALYBUG PARASITOIDS RELEASED AT DIFFERENT LOCATIONS IN PALAU DURING 2003-2004.

Release sites	Parasitoids[1]	Dates of release							
		08/06/03	08/26/03	09/23/03	10/02/03	05/06/04	05/11/04	05/21/04	06/25/04
PITI Compound, Malakal	AP	200	—	200	100	—	20	—	350
	AL	—	200	—	—	—	15	—	125
	PM	—	—	200	—	—	—	—	185
Old Sea Plane Port, Meyuns	AP	200	—	200	100	—	—	—	320
	AL	—	—	200	—	—	17	—	130
	PM	—	200	—	100	—	180	—	145
Palau High School, Medalaii	AP	200	—	200	—	—	—	250	550
	AL	200	—	200	—	—	—	100	120
	PM	200	—	200	—	—	—	130	150
Catholic Church, Ngerbeched	AP	200	200	200	—	—	—	450	—
	AL	200	—	200	—	—	—	135	—
	PM	200	—	200	—	—	—	150	—
Asahi Baseball Field, Ngerbeched	AP	200	—	200	100	—	370	—	580
	AL	—	—	—	—	—	87	—	150
	PM	—	200	—	100	—	—	—	165
Palau Community College, Medalaii	AP	200	—	200	—	—	50	325	—
	AL	—	—	—	—	—	10	150	—
	PM	—	200	—	—	—	—	175	—
Behind Palasia Hotel, Dngeronger	AP	200	—	200	—	—	—	125	—
	AL	—	—	—	—	—	—	150	—
	PM	—	200	—	—	—	—	175	—
City Cab, Iyebukel	AP	400	—	200	—	—	—	125	—
	AL	—	—	—	—	—	—	150	—
	PM	—	200	—	—	—	—	100	—
Airai View Hotel, Airai	AP	200	200	200	—	—	115	150	—
	AL	200	—	200	—	—	92	175	—
	PM	200	—	200	—	—	—	130	—
Chengina Masang, Malakal	AP	—	—	200	—	—	—	950	1565
	AL	—	—	—	—	—	—	825	340
	PM	—	—	—	—	—	—	850	515
Gov. Laura Ierago residence, Meyuns	AP	—	—	200	—	—	—	—	—
	AL	—	—	—	—	—	—	—	—
	PM	—	—	—	—	—	—	—	—
Pasqual Tiakl, Ngerbeched	AP	—	—	200	—	—	—	—	—
	AL	—	—	—	—	—	—	—	—
	PM	—	—	—	—	—	—	—	—
Klou Klubev. Peleliu	AP	—	—	—	—	2000	—	—	—
	AL	—	—	—	—	220	—	—	—
	PM	—	—	—	—	1400	—	—	—
Total	—	3200	1600	4000	500	3620	956	5320	5390

[1]AL: *Anagyrus loecki*; AP: *Acerophagus papayae*; PM: *Pseudleptomastix mexicana*.

RESULTS

The sampling sites, numbering one through nine, in Palau are shown in Fig. 1. The locations and number of parasitoids released are given in Table 1. In total, 13, 270 *A. papayae*, 4,441 *A. loecki*, and 6, 875 *P. mexicana* were released. No parasitoids were observed in a pre-release survey conducted on Aug. 5, 2003. Monthly sampling to determine the establishment of the introduced parasitoids and percentage of parasitism is presented in Fig. 2.

Papaya mealybug population densities on plumeria for the nine sampling sites, the reduction in population density of various stages of PM, and parasitoid mummies over a period of one year from the time of release of the parasitoids are shown in Fig. 3. Very few *C. montrouzieri* larvae and adults were encountered in the surveys. It varied from zero to a maximum of nine per survey from nine sites. The increase in leaf length and width of plumeria indicating healthy growth at the sampling sites was the apparent result of the PM pop-

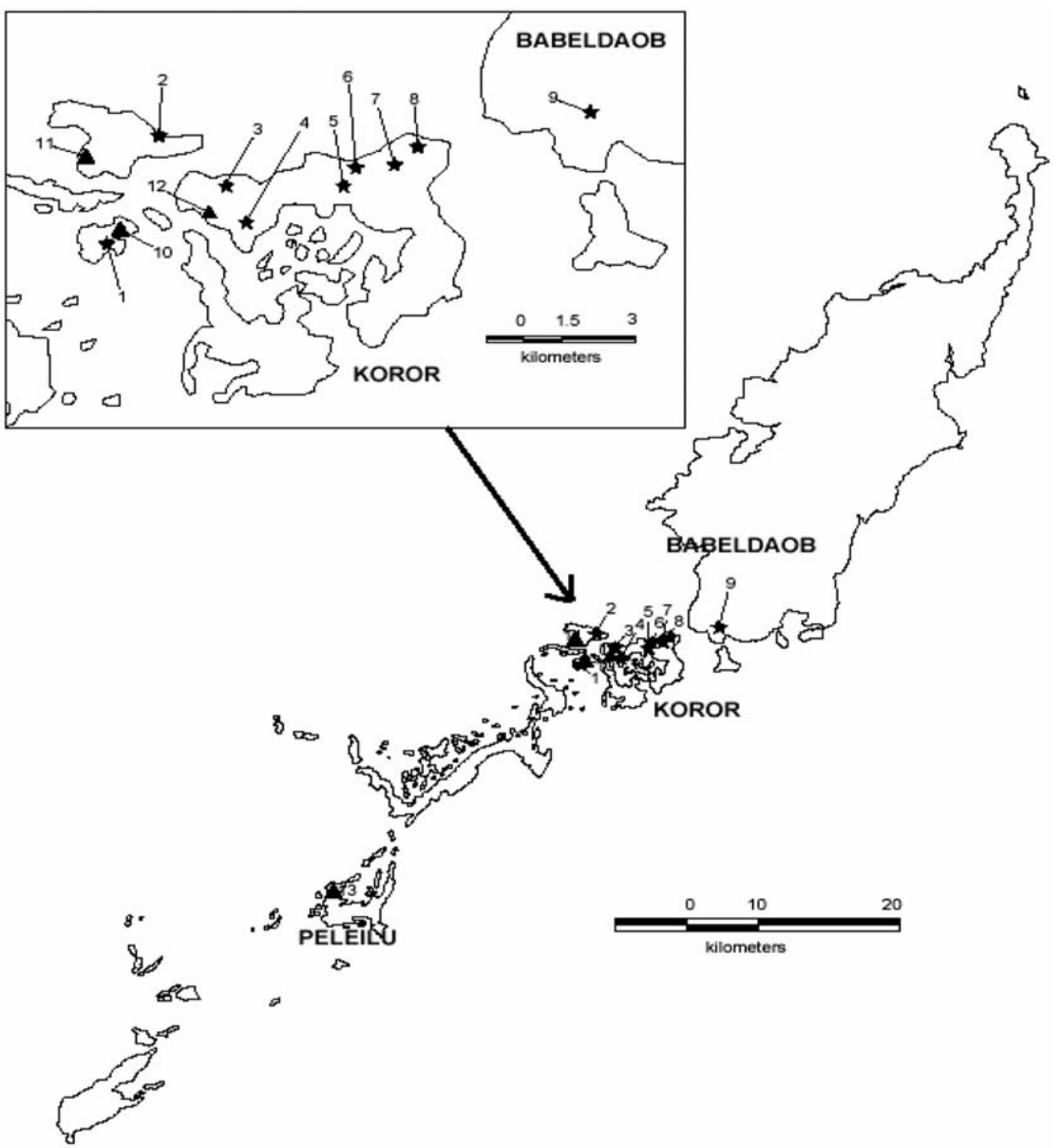

Fig. 1. Parasitoid release and sampling sites in the republic of Palau. ★—Parasitoid release and sampling sites (1 Piti compound; 2 Old sea plane port; 3 Palua high school; 4 Catholic church; 5 Asahi baseball field; 6 Palau community college; 7 Palasia hotel; 8 City cab; 9 Airai View hotel). ▲—Parasitoid release sites only (10 Chengina masang; 11 Governor Laura Ierago's residence; 12 Pasqual Tiaki; 13 Peleliu).

ulation suppression as shown in Fig. 4. In March 2004, PM was observed in the southern island Peleliu; however, the parasitoids also had moved with it and kept the population of PM localized and at a very low level. Sampling for parasitoids in the island of Peleliu in June 2004 indicated fortuitous introduction of the parasitoid *A. papayae*. Parasitism ranged from 8 to 49%. Subsequently all three parasitoids were released on this island.

Discussion

The use of exotic natural enemies to suppress pest population has long been an integral part of biological control, which has continually proved very valuable in eliminating pest problems (Van Driesche & Bellows 1996). This tactic has been applied to pests in a wide variety of natural, agricultural, and urban settings (Bellows & Fisher

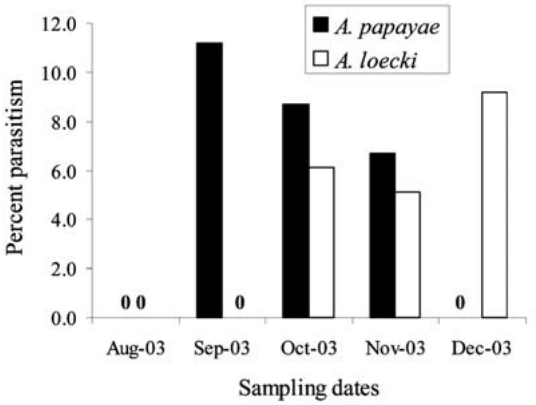

Fig. 2. Percent parasitism on *Paracoccus marginatus* by the parasitoids *Acerophagus papayae* and *Anagyrus loecki*.

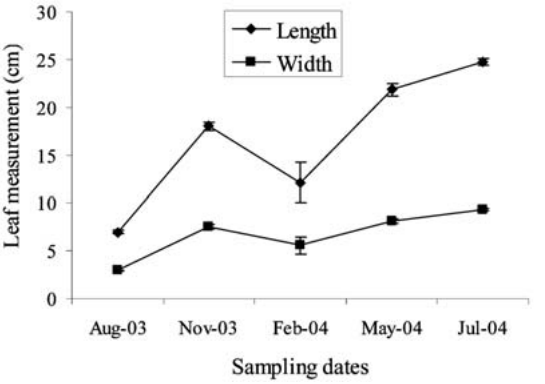

Fig. 4. A measurement (Mean ± SEM) of the *Plumeria* spp. leaves from the time of release of the parasitoids.

1999; Mackauer et al. 1990; Wellings 1998). According to DeBach & Rosen (1991), 164 species of insect pests are being permanently controlled by classical biological control. For example, for 75 species control was "complete", for 74 species "substantial," and for 15 species "partial" control. Meyerdirk et al. (2004) reported successful biological control of PM in Guam, and this study presents yet another successful biological control effort in the western Pacific.

Survey of PM on Palau before the release of the parasitoids proved that there were no local parasitoids that shifted to this mealybug. A few adults and larvae of *C. montrouzieri* were collected in the beat-net samples. Parasitoids of PM imported from Puerto Rico were released within four months of confirmation of the establishment of PM on Palau. Even though the establishment of the parasitoids was confirmed within a month of their release at the sampling sites, releases were continued until June 2004 in an effort to suppress the PM population and to prevent further spread to different parts of Palau. Four months after introduction of the parasitoids there was a reduction in PM population density below a detectable level in the surveys. In February 2004, one out of nine sites had 106 egg masses, 212 second and third instars and adults, and 12 mummies per 100 sq. cm. Other sites had none, possibly due to local extinction of the parasitoids in those areas. In May 2004, a few PM were observed in two out of nine sites; however, in these sites 17 and 2047 mummies also were recorded. In July 2004, no detectable incidence of PM or the mummies was observed.

Among the three parasitoids released, only *A. papayae* and *A. loecki* were recovered from the field; *P. mexicana* was not found. Recovery of the parasitoids from the field indicated that *A. papayae* was the first to become established. *A. loecki* was also established, but was recovered a month later. When the releases of parasitoids were discontinued in early October, *A. papayae* was recovered from the field in November 2003, but not in December. On the other hand *A. loecki* was recovered until December 2003. Of the three parasitoids released in Koror and Airai, *A. papayae* was the only parasitoid that established fortuitously in Peleliu.

A low incidence of the hyperparasitoids, *Eunotus* sp. (Hymenoptera: Pteromalidae) 0.4% and *Procheiloneurus dactylopii* (Hymenoptera: Encyrtidae) 0.8%, also was observed. The introduction of the parasitoids and the suppression of the PM have resulted in steady increase in width and length of the plumeria leaves. Almost all papaya, plumeria, and hibiscus plants recovered and no symptoms of damage were noted a year after introduction of the parasitoids. Suppression of PM in Guam (Meyerdirk et al. 2004) and in Palau has considerably reduced the possibility of this mealybug spreading to other Micronesian islands.

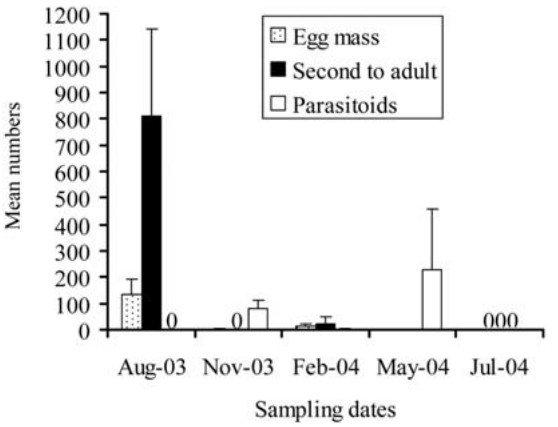

Fig. 3. Population (Mean ± SEM) fluctuations of papaya mealybug and its parasitoids in Palau

Similar results have been noted in the Dominican Republic, Puerto Rico, and Guam with about 97% reduction in PM populations a year after the introduction of the parasitoids (Kauffman et al. 2001; Meyerdirk & Kauffman 2001; Meyerdirk et al. 2004). The programs in Guam and Palau are classic examples of technology transfer of a classical biological control program from the Caribbean to the Pacific.

ACKNOWLEDGMENTS

We acknowledge Dr. Amy Roda, USDA, APHIS for arranging the shipment of the parasitoids, Ms. Lourdes Saez, Puerto Rico Department of Agriculture for shipping the parasitoids, Ms. Carol Russell, USDA, APHIS, PPQ, Hawaii for taking care of administrative transactions and Mr. Jesse Bamba, Mr. Richard Warkentin, Mr. Konrad Englberger, and Dr. Nelson Esguerra for assistance in the field. We thank the editor and two anonymous referees for input to an earlier version of this paper. This publication was made possible, in part, by a Cooperative Agreement from the United States Department of Agriculture's Animal and Plant Health Inspection Service (APHIS). This article was co-authored by two U.S. Federal employees; however, it does not necessarily reflect U.S. Department of Agriculture policy.

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