African Crop Science Journal,Vol. 2. No.4, pp. 407-417, 1994
Printed in Uganda. All rights reserved

ISSN 1021-9730/94 $ 4.00

ORIGIN AND MANAGEMENT OF NEOTROPICAL CASSAVA ARTHROPOD PESTS

A.C. BELLOTTI, A.R. BRAUN, B. ARIAS, J.A. CASTILLO and J.M. GUERRERO.
Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 6713, Cali, Colombia.

ABSTRACT

Cassava, one of the worlds major food crops is grown throughout the tropical regions of the world. Cassava originated in the neotropics; it was introduced into West Africa from Brazil by slave traders in the 1500's, and taken to Asia during the 17th century. Consequently the greatest diversity of cassava pests, as well as their natural enemies is found in the neotropics. Several species depress yield significantly; these include mites (*Mononychellus* spp.), mealybug (*Phenacoccus herreni*), the cassava hornworm (*Erinnyis ello*), the burrowing bug (*Cyrtomenus bergi*), whiteflies (*Aleurotrachelus socialis*, *Aleurothrixus aepim*), thrips (*Frankliniella williamsi*), and lacebugs (*Vatiga manihotae, V. illudeus* and *Amblystria machalana*). Mites, mealybugs, thrips and lacebugs attack cassava primarily during dry periods, causing severe leaf necrosis. The hornworm will feed on cassava leaves throughout the long growing cycle of the crop, although severe attacks usually coincide with the onset of rains. Burrowing bugs feed directly on cassava roots, rendering them unacceptable for the commercial market. In the early 1970's, the cassava green mite, *Mononychellus tanajoa* and the cassava mealybug *P. manihoti* were inadvertently introduced to Africa from the neotropics. These pests have since spread throughout most of the cassava-growing regions of Africa, causing severe crop losses. The unauthorised movement of cassava germplasm, between and within continents, involves a risk of accidentally introducing additional pests. Control strategies are based on host plant resistance, biological control and cultural practices. Adequate levels of resistance have been identified for mites and whiteflies and moderate levels for mealybugs. Burrowing bug damage is less on varieties with high HCN concentration. Many species of natural enemies have been identified for mites, mealybugs and the cassava hornworm. A granulosis virus is effective in the management of hornworm populations. Chemical pesticide application to control cassava pests is discouraged and efforts are being made to develop Integrated Pest Management (IPM) programmes which do not incorporate pesticide use.

Key Words: Cassava, burrowing bug, mealybug, whiteflies,. mites, neotropics, pest management

RÉSUMÉ

Le manioc, une des cultures vivrières majeures sous les tropiques, est attaqué par une large gamme d'arthropodes. Plusieurs espèces rédvisent significativement les récoltes. Dans les régions tropicales du nouveau monde, les ravageurs les plus importants sont les acariens (*Mononychellus* spp.), les cochenilles Pseudococcidae (*Phenacoccus herreni*), le sphinx du manioc (*Erinnyis ello*), les Hémiptères Cydnidae (*Cyrtomenus bergi*), les aleurodes (*Aleurotrachelus socialis, Aleurothrixus aepim*), les thrips (*Frankliniella williamsi*), et les Tingidae (*Vatiga manihotae, V.illudeus* et *Amblystria machalana*. Les acariens, cochenilles, thrips, et les tingides attaquent le manioc au cours des périodes sèches et provoquent de sévères nécroses des feuilles. Le sphinx se nourrit des feuilles de manioc tout au long du cycle de croissance de la plante, bien que les attaques sévères coïncident habituellement avec le début des pluies. Les punaises cydnides s'alimentent directement sur les tubercules du manioc, ce qui rend ces derniers impropres à la

commercialisation. Les stratégies de contrôle se fondent sur la résistance de la plante, la lutte biologique et les pratiques culturales. Au début des années 70, l'acarien vert du manioc *Mononychellus tanajoa* et la cochenille farineuse *P. Manihotis* ont été accidentellement introduits en Afrique à partir de la zone néotropicale. Ces ravageurs ont depuis envahi la plupart des régions africaines productrices de manioc, provoquant de sévères pertes de récolte. L'échange incontrôlé de matériel végétal, entre et à l'intérieur des continents, fait courir le risque de l'introduction accidentelle de nouveaux ravageurs. De bons niveaux de résistance ont été identifiés pour les acariens et les aleurodes, des niveaux modérés pour les cochenilles, et les dégâts causés pas les cydnides sont moindres sur les variétés à forte concentration d'HCN. De nombreuses espèces d'ennemis naturels ont été identifiées pour les acariens, les cochenilles et le sphinx du manioc. Un virus de granulose est efficace pour la régulation des populations du sphinx. L'utilisation de pesticides pour le contrôle des ravageurs du manioc n'est pas encouragée, et des efforts sont faits pour développer des programmes de gestion intégrée (IPM) excluant l'utilisation des pesticides.

***Mots Clés*: Gestion des ravageurs, neotropicaux, manioc, acariens, cochenille farineuse, aleurodes, punaises cydnides**

INTRODUCTION

Cassava (Euphorbiaceae: *Manihot esculenta* Crantz) is a perennial shrub grown throughout tropical and subtropical regions of the Americas. Its roots accumulate starch in the parenchyma, forming swollen storage organs which are harvested after 7 to 24 months. Cassava originated in the Americas but its exact centre of origin is controversial (Renvoize, 1973). The crop was introduced into Africa in the 16th century and subsequently reached Asia. The recent introduction of two arthropod pests, the cassava green mite (*Mononychellus tanajoa* Bondar) and the cassava mealybug (*Phenacoccus manihoti* Mat. Ferr.) from the Americas into Africa has caused considerable crop loss throughout the cassava belt and has been the object of a massive biological control effort (Herren and Neuenschwander, 1991; Neuenschwander, 1994).

Within the neotropics, the introduction in recent decades of previously unreported species to certain areas has led to pest outbreaks and considerable damage to cassava. In the mid-1970s, the mealybug *Phenacoccus herreni* Cox-Williams, was first reported causing considerable damage in northern Brazil (Albuquerque, 1976). Evidence from recent explorations in Venezuela suggests that *P. herreni* may have been introduced into Brazil from northern South America. Its rapid spread, severe damage, and the absence of key natural enemies are indicative of an introduced pest.

Recent studies on the cassava green mite (CGM) (*Mononychellus tanajoa*) demonstrate a higher degree of morphological polymorphism in northern South America than elsewhere in the neotropics where CGM occurs (Guerrero *et al.*, 1994). Several species of neotropical *Mononychellus* are oligophagous and feed primarily on *Manihot*. More species of *Mononychellus* occur on cassava in northern South America than elsewhere. This diversity is associated with greater species richness within the phytoseiid complex which preys upon *Mononychellus* spp. in cassava.

Most authors agree that there are three possible centres of origin of *M. esculenta*: the Brazil/Paraguay region, northern South America, and Mesoamerica (Sauer, 1950; Rogers, 1963; Renvoize, 1973). Sauer (1950) supports northern South America as the area of domestication of cassava, and Renvoize (1973) proposes that 'sweet' manioc was first domesticated in Mesoamerica and 'bitter' manioc in northern South America.

The genetic diversity within certain arthropod herbivores of cassava in northern South America as well as the richness of the associated natural-enemy complexes would support northern South America as the centre of origin of *M. esculenta*. More precise knowledge of the area of origin of cassava and associated arthropods could facilitate development of pest control strategies. Genetic diversity within *M. esculenta* for arthropod pest resistance may be concentrated in this geographic region and there is evidence that key biological control agents of several pest species including *P. herreni* and *M. tanajoa* occur in the region north of the Amazon Basin.

This paper presents information on six important pests of cassava that can cause yield losses in the neotropics: mites, mealybugs, the cassava hornworm, burrowing bugs, whiteflies and lacebugs. Numerous other pests, such as fruit flies, shoot flies, scale insects, gall midges and stemborers can attack the cassava crop, but seldom reduce yields (Bellotti and Schoonhoven, 1978). There is ample resistance to thrips *Frankliniella williamsi* Hood in cassava germplasm (Schoonhoven, 1974) and this pest will not be discussed in this paper.

THE PESTS AND THEIR CONTROL

Cassava Green Mite (CGM). The tetranychid mite, *M. tanajoa*, became internationally infamous after its accidental introduction to Africa in the 1970s. *Mononychellus tanajoa* is native to the neotropics and is specialised to feed on *Manihot* spp. Survey and experimental data suggest that although CGM is present throughout much of the American lowland tropics where cassava is grown, economically significant outbreaks are rare, except in parts of Brazil.

In Colombia, over 50 phytoseiid species have been reported on cassava and 18 species have been collected consistently in field surveys. Ninety two percent of 224 cassava fields surveyed in Colombia were uninfested or had low mite densities ($x < 25$ mites per leaf) (CIAT, 1990). Only 8% of the fields had intermediate densities ($25 < x < 200$ mites per leaf) and none had high ($x > 200$ mites per leaf). In a sample of 325 Brazilian cassava fields, 12% were uninfested and 25% had intermediate or high CGM densities. Only four species of phytoseiids were consistently collected in N.E. Brazil. Data from field experiments demonstrated that fresh and dry root yields in Colombia were reduced by 30% when natural enemies were eliminated (Braun *et al.*, 1989).

Multiple strategies generally offer more stability in pest management at the farm level than single-tactic approaches. Selection of commercially acceptable cassava varieties with resistance to CGM, introduction of phytoseiid species, genetic improvement of phytoseiids to enhance tolerance to low relative humidity, deployment of fungal pathogens cultural practices, natural enemy conservation and augmentation techniques, and habitat manipulation are all potentially useful tactics in the management of CGM in the neotropics, particularly in Brazil where CGM is believed to be an introduced pest.

Cassava Mealybugs. Numerous species of mealybug attack cassava, but, only *Phenacoccus herreni* and *P. manihoti* (Cox and Williams, 1981) are important economically. Both are of neotropical origin but *P. manihoti*, now a major introduced pest of cassava in Africa, is confined to Paraguay, certain areas of Bolivia and the Mato Grosso do Sul area of Brazil. Until recently *P. manihoti* caused heavy yield losses in African cassava. The introduced hymenopteran parasite, *Epidinocarsis lopezi* De Santis, has become established in Africa and has brought the mealybug under control (Hammond *et al.*, 1987; Herren and Neuenschwander, 1991; Neuenschwander, 1994).

Phenacoccus herreni causes damage similar to *P. manihoti* and is reported only from South America. Recent explorations have confirmed its presence in certain areas of Colombia, Venezuela and the Guayanas. *Phenacoccus herreni* is spreading through much of northeast Brazil where it has caused considerable yield reductions in cassava (A.C. Bellotti, pers. obs.). Its feeding causes leaf yellowing, curling, and cabbage-like malformation of the growing points. High densities lead to leaf necrosis, defoliation, stem distortion, and shoot death. Yield reductions in farmer's fields may reach 80%, and studies in experimental plots resulted in 68 to 88% yield reduction, depending on the variety grown (Vargas and Bellotti, 1984).

Mealybugs extract calcium from cassava leaves during feeding. When cassava leaves were analysed for Ca, P and K, non-infested leaves were found to contain 32% more Ca than infested leaves, whereas no significant changes in N, P or K were detected (Vargas *et al.*, 1989). Reduction in Ca may result in weakened, less rigid cell walls and may lead to the curling that is characteristic of mealybug feeding damage. Reductions in photosynthetic rate, transpiration, and mesophyll efficiency, and moderate increases in water pressure deficit, internal $C0_2$, and leaf temperature were found in infested plants (CIAT, 1988). There was a positive correlation between low photosynthetic rate and lower leaf calcium content, suggesting that Ca-rich clones may be more tolerant of *P. herreni* attack than Ca-poor clones.

Phenacoccus herreni populations peak during the dry season (Van Driesche *et al.*, 1990). Rains reduce pest populations and permit crop recovery. The optimal temperature range for female development is 25°-30°C (Herrera *et al.*, 1989).

Mealybug control. A combination of host plant resistance and biological control should result in adequate control of the cassava mealybug. Although only low to moderate levels of resistance to *P. herreni* have been identified (Porter, 1988), host plant resistance can reduce populations to levels which make biological control more effective. Many species of mealybug natural enemies are generally present in cassava fields and, therefore, high levels of host plant resistance may not be required in order to maintain mealybug populations below economic injury levels. The curling of cassava leaves associated with mealybug feeding may protect mealybugs from insecticides and natural enemies (IITA, 1985). Selection of cassava varieties which curl less in response to mealybug feeding could result in the increased exposure of mealybugs to attack by natural enemies.

Biological control. Many successes in biological control of mealybugs in perennial systems have been reported and cassava is considered a functional perennial in the tropics. The successful introduction of *E. lopezi* to control *P. manihoti* in Africa is a recent example of effective classical biological control of a mealybug in a quasi-perennial system (Neuenschwander, 1994). The recent identification of several key natural enemies of *P. herreni*, may result in introductions to areas where natural enemies are lacking or ineffective and thus improve control of this species in certain areas of the neotropics.

Approximately 70 species of parasites and predators of cassava mealybugs have been identified in the neotropics. Parasites of *P. herreni* identified from Colombia, include *Acerophagus coccois* Smith. *E. diversicornis* Howard, *Anagyrus putonophilus* Compere, *A. insolitus* Howard and *Apoanagyrus elgeri* Kerrich. Recent explorations in Venezuela have identified *Aenasius vexans* Kerrich as an important parasite of *P. herreni* (Bellotti *et al.*, 1983a).

Epidinocarsis diversicornis prefers third instar nymphs, whereas *A. coccois* parasitizes male cocoons, adult females and 2nd instar nymphs with equal frequency. Ovipositor penetration by *E. diversicornis* caused 13% mortality of first nymphal instars (Van Driesche *et al.*, 1990.). *Aenasius vexans* prefers second and third instar nymphs and adult females with equal frequency (CIAT, 1990). In caged greenhouse studies on parasite species competition, *E. diversicornis* was displaced by *A. vexans* and *A. coccois* after several generations. *Aenasius vexans* and *A. coccois* were able to co-exist (CIAT, 1993).

Field studies were conducted to determine percent parasitism using trap plants infested with mealybug hosts set out in cassava fields (Van Driesche *et al.*, 1988). By using the method of Bellows *et al.* (1991), 55% mortality was estimated for the combined action of two parasitoid species present (van Driesche *et al.*, 1990). *Acerophagus coccois* was the principal species recovered from mummified mealybugs.

Survey data from South America indicate that the mealybug parasitoid and predator complex is larger in Colombia and Venezuela than in northeast Brazil, where *P. herreni* populations cause severe crop damage. We suggest that *P. herreni* is of Venezuelan origin and was disseminated along the eastern coast of South America to northeast Brazil where it appears to be an introduced pest. The first reports of severe damage from *P. herreni* in north Brazil were in the early 1970's (Albuquerque, 1976). Classical biological control could stabilise *P. herreni* below economic levels in the northeast Brazil.

The Cassava Hornworm. The cassava hornworm, *Erinnyis ello* (L.) (Lepidoptera: Sphingidae) is a serious pest in nearly all cassava growing regions of the neotropics (Bellotti and Schoonhoven, 1978). *Erinnyis ello* has a broad geographical range and is polyphagous with at least 35 food plants recorded, including 21 species of Euphorbiaceae (Winder, 1976). The genus *Erinnyis* consists of several species, although *E. ello* is the most commonly reported species attacking cassava. The sub-species *E. ello ello* is reported from the Neotropics and the Nearctic, and *E. ello encantado* is reported from the Galapagos Islands (Carvalho, 1980).

Severe hornworm attacks can cause complete plant defoliation, resulting in bulk root loss and poor root quality. Losses in root production are influenced by plant age, soil fertility, environmental factors (especially rainfall) and frequency of attack. Yield losses in fertile soils ranged from 0 to 25% after one attack, and up to 47% after two consecutive attacks. On infertile soil, losses varied between 15 and 45% after one attack and up to 64% after two attacks (Arias and Bellotti, 1984). During its five instar larval cycle, each hornworm consumes *c.* 1100 cm^2 of foliage; *c.* 75% of this being ingested during the fifth instar.

Hornworm adults are nocturnal grey moths that oviposit small, round, light green to yellow eggs individually on the upper surface of cassava leaves. Eggs hatch in 3 to 5 days. Larval duration at 15°, 20°, 25°, and 30°C averages 105, 52, 29 and 23 days, respectively. This suggests that peak hornworm activity should occur in lowland to middle altitudes (800 to 1200 m) in the tropics and during the summer in the subtropics (Bellotti and Arias, 1988). Few hornworm attacks have been reported from high altitude areas (1500-2200 m) where cassava is cultivated.

The migratory flight capacity of *E. ello* is well documented (Winder and Abreu, 1976; Janzen, 1986, 1987) and is probably responsible for its wide distribution throughout the neotropics. Adults migrate *en masse*, and will oviposit many eggs in cassava fields (Bellotti and Arias, 1988). These invasions have been detected in light trap surveys in Colombia, Brazil and Mexico, and result in explosions of hornworms which, if not detected and controlled, result in severe crop defoliation and yield reduction.

Hornworm control. Several pesticides give adequate control if hornworm populations are detected and treated during the first three instars. Larval populations in the 4th and 5th instar are difficult to control with pesticides and applications against late instars are generally uneconomic because considerable defoliation has already occurred. In addition, pesticide use disrupts natural enemy populations and can lead to more frequent attacks (Urias *et al.*, 1987).

A large complex of natural enemies is associated with *E. ello* in the Americas (Winder, 1976; Bellotti and Schoonhoven, 1978; Bellotti and Arias, 1988; Bellotti *et al.*, 1990a). Approximately 40 species of parasites, predators and pathogens of the egg, larvae and pupa stages have been identified. Eight microhymenopteran species of the families Trichogrammatidae, Scelionidae, and Encyrtidae are egg parasites. Of these, *Trichogramma* and *Telenomus* are the most important (Bellotti *et al.*, 1983b). Numerous dipteran and hymenopteran parasites attack hornworm larvae. Tachinid flies are the most important group among the dipteran and the Braconidae, particularly *Apanteles* spp., are the most important hymenopteran (Winder, 1976).

A large group of predators attack hornworm eggs, larvae and pupae. The most common egg predators are *Chrysopa* spp. The most important larval predators are *Polistes* spp. (Hymenoptera: Vespidae), *Podisus* spp. (Hemiptera: Pentatomidae) and a number of spider species. The mycelium of *Cordiceps* sp. (Aconycetes: Clavicipitaceae), a soil-borne fungus, invades hornworm pupa causing mortality.

A granulosis virus of the family Baculoviruiidae infects hornworn larvae and is useful in the management of hornworm populations (Bellotti *et al.*, 1990). Infested larvae collected from the field are macerated in a blender, filtered through cheesecloth, mixed with water and applied to hornworm-infested cassava fields. In a field trial in El Patía, Colombia, a virus concentration of 0.35g per litre of water was applied to hornworm-infested fields and resulted in 99.8% mortality 48 hours after application (Bellotti *et al.*, 1990, 1992).

Migration is a possible defence against the complex of natural enemies associated with *E. ello*. Natural enemy populations cannot increase rapidly enough to control *E. ello* eruptions. Since *E. ello* outbreaks are cyclic and erratic, it is difficult to synchronise the release of predators and parasites with them. The hornworm virus provides a management option that can be manipulated and maintained at relatively low cost. Preparations of the virus can be refrigerated and stored until required. The *E. ello* virus combined with timely detection of hornworm outbreaks offers an effective and economical control method.

Cassava Burrowing Bug. The burrowing bug, *Cyrtomenus bergi* Froeschner, was first recorded as a pest in Caicedonia, Valle, Colombia (García and Bellotti, 1980). Nymphs and adults of this subterranean sucking insect feed on cassava roots by means of a thin, strong stylet. As it feeds, the bug inoculates the roots with soil-borne pathogens such as *Aspergillus, Diplodia, Fusarium, Genicularia, Phytophthora* and *Pythium* spp. (Bellotti *et al.*, 1988). Brown or black lesions develop on the white fleshy roots, rendering them commercially unacceptable.

Surveys in Colombia and Panama have revealed that onion, peanut, maize, sorghum, sugar-cane, coffee, coriander, pasture grasses, potato and numerous weed species are also hosts of *C. bergi.* Yield losses in peanut and onion are considerable and require repeated pesticide applications for effective control, since other control measures are currently not available.

Cyrtomenus bergi populations are present in the soil throughout the cassava crop cycle, and root damage increases with plant age (Arias and Bellotti, 1985). Root damage can reach 70 to 80% of total roots with more than a 50% reduction in starch content. *Cyrtomenus bergi* has five nymphal instars. The life cycle lasts more than one year, and cassava roots may be the only food source exploited (García and Bellotti, 1980). Recent studies indicate that *C. bergi* develops faster on maize than on cassava and prefers maize to cassava in free-choice feeding tests (78 vs. 22%) (CIAT, 1990; Riis, 1990). Oviposition was seven times greater on maize than on cassava.

Field trials suggest that resistance to *C. bergi* may be related to the HCN content of the roots. In laboratory tests, adults and nymphs fed on a high HCN clone had longer nymphal development (140 vs. 70 days), reduced adult longevity (41 vs. 106 days), reduced egg production (24 vs. 234 eggs) and increased mortality (80 vs. 20%) (CIAT, 1986).

Crop Management. Intercropping of *Crotalaria* sp. (sunne hemp) with cassava is a potential means of controlling *C. bergi*. Trials in farmers' fields showed that intercropping with *Crotalaria* reduced damaged roots to 4% compared to 61% in cassava monoculture (Castaño *et al.*, 1985). Cassava yield is reduced by 22% when it is intercropped with *Crotalaria.* Although alternative spacing patterns increased cassava yields, adequate control of *C. bergi* is obtained only when *Crotalaria* is planted between every cassava row.

Recent studies indicate that entomopathogenic nematodes may have potential for controlling *C. bergi.* The species *Steinernema carpocapsae* Weiser successfully parasitised *C. bergi* in the laboratory, and a native species *Heterorhabditis bacteriophora* Poinar was found parasitising *C. bergi* in the field (CIAT, 1993).

Whiteflies. Numerous species of whiteflies are reported on cassava. The predominant species in the neotropics are *Aleurotrachelus socialis* Bondar, *Trialeurodes variabilis* (Quaintance), *Bemisia tuberculata* Bondar *Aleurothrixus aepim* (Goeldi) and *Bemisia tabaci* (Gennadius) (Bellotti *et al.*, 1978). Whiteflies damage cassava by feeding on the phloem of the leaves, resulting in considerable reduction in root yield if prolonged feeding occurs (Gold, 1994). There is a correlation between duration of whitefly attack and yield loss; an 11-months attack resulted in a 79% yield loss (Vargas and Bellotti, 1981). The predominant species in Colombia is *A. socialis* and in northeast Brazil it is *A. aepim.*

Whitefly control. Natural enemies of cassava whiteflies include the predator, *Delphastus pusillus* (Le Conte), and the parasites *Amitus aleurodinus* (Haldeman) and *Eretmocerus aleurodiphagus* (Risbec). Predators seem to play a minor role in whitefly population dynamics (Gold *et al.*, 1989a). However, parasitism of *A. socialis* by *A. aleurodinus* and *E. aleurodiphagus* ranged from 49% to 54% in experimental plots, indicating that parasites may be an important mortality factor (CIAT, 1989).

Cassava as traditionally grown crop is often intercropped with other species (Gold, 1994). Intercropping cassava with cowpea reduced egg populations of two whitefly species (*A. socialis* and *T. variabilis*) relative to those in monoculture. These effects were residual, persisting up to six months after harvesting of the intercrops (Gold *et al.*, 1990). Intercropping with maize did not reduce egg populations. Yield losses in cassava/maize, cassava monoculture, and mixed cassava variety systems were about 60%, whereas in cassava/cowpea intercrops yield losses were 12% and yields were superior to those in other systems (Gold *et al.*, 1989b). Intercropping may offer the small-scale farmer a valuable means of reducing pest populations.

Host plant resistance (HPR) offers a low cost and sustainable solution to cassava losses from whitefly damage. HPR studies at CIAT with *A. socialis, T. variabilis* and *B. tuberculata* were initiated more than 10 years ago, and more than 2000 clones have now been evaluated. Several sources of resistance have been identified and the clone MEcu 72 has consistently expressed the highest level of resistance. This and other selected clones were used in a crossing programme to provide whitefly-resistant, high-yielding cassava clones. Using estimates of yield depression and plant damage ratings to compare resistance levels, three progeny, CG 489-34, CG 489-23, CG 489-31, showed no significant difference in yield between insecticide-treated and non-treated plots.

The parents MEcu 72, MBra 12 and their aforementioned progeny were evaluated to determine resistance mechanisms in the field and greenhouse. The hybrids CG 489-31 and CG 489-34 and the female parent MEcu 72 were least preferred for oviposition with 19.0, 20.5 and 40.4 eggs per leaf, respectively; CMC-40 and MBra 12 were highest with 75.2 and 82.1, respectively. Whitefly mortality studies indicate an antibiosis mechanism for the hybrids CG 489-23 and CG 489-31 and MEcu 72. The developmental periods were longest on MEcu 72, CG 489-34 and CG 489-31. These studies indicate that resistance to whiteflies is available in cassava germplasm.

Cassava Lacebugs. Several species of lacebugs (Hemiptera: Tingidae) are reported feeding on cassava; *Vatiga manihotae* (Drake) and *Amblysteia machalana* (Drake) are the predominant species in Colombia, Venezuela and Ecuador, while *V. illudens* (Drake) predominates in Brazil. Prolonged dry periods are favourable for increased lacebug populations. Adults and nymphs feed on the undersurfaces of the lower plant leaves. Feeding damage of *A. machalana* is manifested by considerable speckling which under severe infestations can whiten leaves and cause considerable defoliation.

The relationship between damage, population density and duration is unknown. However, in a field trial at CIAT, with the variety MCol 22 under natural infestation by *A. machalana* resulted in 39% yield reduction compared to pesticide-treated plots (CIAT, 1990).

Preliminary screening of cassava germplasm indicates that HPR may be available, but considerable research is still required. Few natural enemies of lacebugs have been observed.

PESTICIDE USE IN CASSAVA

Throughout the neotropics, cassava receives minimal pesticide applications. Brazil produces *c.* 75% of the cassava in Latin America and although it is a major user of pesticides on other crops, only minimal amounts of pesticides are used on cassava (Bellotti *et al.*, 1990b). It is estimated that pesticide use will more than double in Latin America during the next decade. Brazil is expected to increase its share of the pesticide market significantly, although other control strategies have potential for impact throughout the country (Bellotti *et al.*, 1990b). Since few insecticides are currently used for arthropod control on cassava, every effort should be made to develop IPM programmes for cassava which do not involve pesticides.

DISCUSSION

Cassava production is expanding in the neotropics and in certain regions, where economic incentives are high, cultivation is intensifying with a potential for increased use of agrochemicals. Historically, in many crops, such production intensification has been accompanied by increased insecticide use, followed by a crisis due to failure of chemical control (Metcalf and Luckman, 1982). In some cases, production has become so uneconomic that the crop is abandoned. The implementation of IPM has revived the cultivation of some crops after such a crisis. Integration of appropriate agronomic practices with biological control and HPR can result in ecologically sustainable and economically viable cassava cultivation (Bellotti *et al.*, 1990a). The role of pesticides in cassava cultivation is currently limited because it is rarely justifiable economically in the context of a low value, small farmer crop with an annual or biennial cycle. The reduction of natural enemies from insecticide misuse has been documented for hornworm (Urias *et al.*, 1987). The elimination of mite predators with pesticides resulted in increased mite populations and lower yields than in unsprayed plots (Braun *et al.*, 1989).

Stable HPR offers a practical long term solution for maintaining reduced pest populations. In some cases, as with thrips in cassava (Schoonhoven, 1974), resistance suffices to maintain pest populations below economic injury levels. Sources of resistance have been identified for mites, lacebugs, whiteflies, thrips, burrowing bugs, and other arthropod pests of cassava (Bellotti and Kawano, 1980; Byrne, 1984; Bellotti *et al.*, 1985).

Immunity has not been identified for any pest, but available levels of resistance, combined with other pest management tactics, can be used to reduce pest populations.

Host plant resistance is usually compatible with other cassava pest management tactics. HPR and biological control are complementary, especially in areas where pests and natural enemies have coevolved on land races which have been under a long process of selection by farmer-breeders.

Recent data from extensive surveys of cassava growing areas in the neotropics corroborates archaeological data which suggest that cassava may have been domesticated in the area north of the Amazon Basin. Mites of the genus *Mononychellus*, and mealybugs, and their natural enemy complexes exhibit greater species richness in northern South America than elsewhere in the neotropics. CGM populations reach their highest level of polymorphism in this area. Population densities of CGM are generally higher and damage is more severe in northeast Brazil than elsewhere in the neotropics (CIAT, 1990). Classical biological control holds considerable potential for areas where natural enemy complexes are presently inadequate, particularly if used in combination with augmentation and conservation of natural enemies, and if the available genetic diversity can be exploited to establish strains which are tolerant of adverse ecological conditions, such as low relative humidity.

Classical introductions of natural enemies of cassava pests within the neotropics, would include the deployment of pathogens. The cassava hornworm virus, which is used successfully for hornworm control in southern Brazil (Schmidt, 1988) has been recorded from a number of areas (eg. Cuba, Mexico) where *E. ello* is a reported pest.

There are several cultural practices that can reduce pest populations (Lozano and Bellotti, 1980; Bellotti *et al.*, 1987). These include the use of insect-free cuttings as planting material, the destruction of plant parts containing stemborers, scale insects and mealybugs, intercropping, and the planting of several varieties in a single plantation. Since many cassava pests are not widely distributed, especially from one continent to another, it is important that an efficient quarantine programme be developed and enforced within and between continents (Frison and Feliu, 1991).

CONCLUSION

The challenge to crop protectionists in the future is to contribute to sustainable production systems, especially for small-scale farmers. IPM minimizes chemical pesticide use and contributes to ecological stability in agricultural systems.

Cassava grown in seasonally dry semi-arid lowland areas of the tropics is vulnerable to arthropod pest and disease attack. Dry season pests generally cause the greatest yield losses in cassava (Bellotti *et al.*, 1987). A holistic approach is needed to allow IPM to contribute to sustainable cassava production in lowland environments, where there exists a complex of pests. Technology components should be developed, tested and modified with active farmer participation to ensure their relevance to farmer needs (Braun *et al.*, 1993). The integrated management of a complex of cassava pests, with active farmer participation is presently being implemented in northeastern Brazil, in a UNDP-sponsored project involving EMBRAPA/CNPMF (Empresa Brasileira de Pesquisa Agropecuária/Centro Nacional de Pesquisa de Mandioca e Fruticultura Tropical) and CIAT.

REFERENCES

Albuquerque, M. De. 1976. Cochonilha em mandioca na Amazonia. Empresa Brasileira de Pesquisa Agropecuaria. Belem, Brasil. 10pp.

Arias, B. and Bellotti, A.C. 1984. Pérdidas en rendimiento (dao simulado) causadas por *Erinnyis ello* (L) y niveles críticos de poblaciones en diferentes etapas de desarrollo en tres clones de yuca. *Revista Colombiana de Entomologia* 10 (3-4):28-35.

Arias, B. and Bellotti, A.C. 1985. Aspectos ecológicos y de manejo de *Cyrtomenus bergi*, Froeschner, chinche de la viruela en el cultivo de la yuca (*Manihot esculenta* Crantz). *Revista Colombiana de Entomologia* 11(2):42-46.

Bellotti, A.C. and Van Schoonhoven, A. 1978. Mite and insect pests of cassava. *Annual Review of Entomology* 23:39-67.

Bellotti, A.C. and Kawano, K. 1980. Breeding approaches in cassava, In: *Breeding plants resistant to insects*. Maxwell, F. G. and Jennings, P.R. (Eds.), pp. 314-335. Wiley, New York.

Bellotti, A.C., Reyes, J.A. and Varela, A.M. 1983a. Observaciones de los piojos harinosos de la yuca en las Américas; su biología, ecología y enemigos naturales. In: *Yuca: Control Integrado de Plagas*. J.A. Reyes (Ed.), pp. 313-339. CIAT, Cali, Colombia.

Bellotti, A.C., Reyes, J.A., Arias, B., Segura, P., Urias, M.A. and Schimidt, A.T. 1983b. Manejo de una explosión del gusano cachón *Erinnyis ello* (L). In: *Yuca: Control Integrado de Plagas*. Reyes, J.A. (Ed.), pp. 305-312. CIAT. Cali, Colombia.

Bellotti, A.C., Hershey, C. and Vargas, O. 1985. Recent advances in resistance to insect and mite pests of cassava (*Manihot esculenta* Crantz). In: *Cassava: Research Production and Utilization*. Cock, J. H. and Reyes, J. A. (Eds.), pp. 441-471. Cali, Colombia. CIAT.

Bellotti, A.C., Braun, A.R., Yaninek, J.S., Herren, H.R. and Neuenschwander, P. 1987. Cassava agroecosystems and the evolutions of pest complexes. *Proceedings 11th International Congress of Plant Protection*. Oc. 5-9, 1987. Belen, E.H. and Villanueva, M. (Eds.), pp. 81-89. Manila Philippines.

Bellotti, A.C. and Arias, B. 1988. Manejo integrado de *Erinnyis ello* (L). Serie: 04SC-04.01. CIAT, Cali, Colombia.

Bellotti, A.C., Vargas, O., Arias, B., Castaño, O. and García, C. 1988. *Cyrtomenus bergi* Froeschner, a new pest of cassava: biology, ecology, and control. *7th Symposium of the International Society of Tropical Root Crops*, Gosier (Guadeloupe), 1-6 July 1985. Degras, L. (Ed.). INRA, Paris.

Bellotti, A.C., Arias, B. and Reyes, J.A. 1990a. Biological control of the cassava hornworm, *Erinnyis ello* (Lepidoptera: Sphingidae) with emphasis on the hornworm virus. *Proceedings 8th Symposium International Society of Tropical Root and Tuber Crops*. Howeler, R.H. (Ed.), pp. 354-62. Bangkok, Thailand, 1988.

Bellotti, A.C., Cardona, C. and Lapointe, S.L. 1990b. Trends in pesticide use in Colombia and Brazil. *Journal of Agricultural Entomology* 7:191-201.

Bellotti, A.C., Arias, B. and Guzmán, O.L. 1992. Biological control of the cassava hornworm *Erinnyis ello* (Lepidoptera: Sphingidae) *Florida Entomologist* 75:506-515.

Bellows, T.S., Jr., Van Driesche, R.G. and Elkinton, J.S. 1989. Extensions to Southwood and Jepson's geographical method of estimating numbers entering a stage for calculating losses to parasitism. *Research in Population Ecology* 31:169-184.

Braun, A.R., Bellotti, A.C., Guerrero, J.M. and Wilson, L.T. 1989. Effect of predator exclusion on cassava infested with tetranychid mites (Acari: Tetranychidae). *Environmental Entomology* 18:711-714.

Braun, A.R., Bellotti, A.C. and Lozano, J.C. 1993. Implementation of IPM for small-scale cassava farmers. In: *Crop Protection Strategies for Subsistence Farmers*. Altieri, M.A. (Ed.), pp. 103-115. Westview Press Inc.

Byrne, D. 1984. Breeding Cassava. *Plant Breeding Reviews* 2:73-134.

Carvalho, D.F. 1980. Aspectos biologicos, tecnicos para obtencao de ovos em condicoes de laboratorio e evaliacao da danos de *Erinnyis ello* (Linnaeus, 1978) (Lepidoptera Sphingidae) em mandioca em condicoes de campo. Tese Maq. Sc. Piracicaba, SP. Luis de Queiroz. 87 p. Port.

Castaño, O., Bellotti, A.C. and Vargas, O. 1985. Efecto del HCN y de cultivos intercalados sobre daño causado por la "Chinche de la Viruela" *Cyrtomenus bergi* Froeschner, al cultivo de la yuca. *Revista Colombiana de Entomologia* 11(2):24-26.

CIAT. 1986. *Annual Report, Cassava Program.* Centro Internacional de Agricultura Tropical. Cali, Colombia.

CIAT. 1988. *Annual Report, Cassava Program.* Centro Internacional de Agricultura Tropical. Cali, Colombia.

CIAT. 1989. *Annual Report, Cassava Program.* Centro Internacional de Agricultura Tropical. Cali, Colombia.

CIAT. 1990. *Annual Report, Cassava Program.* Centro Internacional de Agricultura Tropical. Cali, Colombia.

CIAT. 1993. *Annual Report, Cassava Program.* Centro Internacional de Agricultura Tropical. Cali, Colombia.

Cox, J.M. and Williams, D.J. 1981. An account of cassava mealybug (Hemiptera: Pseudococcidae) with a description of a new species. *Bulletin of Entomological Research* 71:247-258.

Frison, E.A. and Feliu, E. (Eds.). 1991. FAO/IBPGR. *Technical Guidelines for the Safe Movement of Cassava Germplasm.* Food and Agriculture Organization of the United Nations, Rome/International Board for Plant Genetic Resources, Rome.

García, C.A., and Bellotti, A.C. 1980. Estudio preliminar de la biología y morfología de *Cyrtomenus bergi* Froeschner, nueva plaga de la yuca. *Review of Colombian Entomology* 6 (324):55-61.

Gold, C.S. 1994. The effect of cropping systems on cassava whiteflies in Colombia: implications for control of African cassava mosaic virus dieases. *African Crop Science Journal* 2:423-436.

Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1989a. The effects of intercropping and mixed varieties on predators and parasitoids of cassava whiteflies (Hemiptera: Aleurodidae) in Colombia. *Bulletin of Entomological Research* 79:115-121.

Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1989b. Effects of intercrop competition and differential herbivore numbers on cassava growth and yields. *Agriculture, Ecosystems and Environment* 26:131-146.

Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1990. Direct and residual effects of short duration intercrops on the cassava whiteflies *Aleurotrachellus socialis* and *Trialeurodes variabilis* (Homoptera: Aleyrodidae) in Colombia. *Agriculture, Ecosystems and Environment* 32:57-67.

Guerrero, J.M., Fletchmann, C.H.W., Duque, M.C., Gaigl, A., Bellotti, A.C., Moraes, G.J. and Braun, A.R. 1996. Biogeography and taxonomy of *Mononychellus* species associated with *Manihot esculenta* Crantz in the Americas. In Press.

Hammond, W.N.O., Neuenschwander, P. and Herren, H.R. 1987. Impact of the exotic parasitoid *Epidinocarsis lopezi* on cassava mealybug (*Phenacoccus manihoti*) populations. *Insect Science and its Application.* 8:887-891.

Herren, H.R. and Neuenschwander, P. 1991. Biological control of cassava pests in Africa. *Annual Review of Entomology* 36:257-284.

Herrera, J.C., Van Driesche, R.G. and Bellotti, A.C. 1989. Temperature-dependent growth rates for the cassava mealybug, *Phenacoccus herreni,* and two of its encyrtid parasitoids, *Epidinocarsis diversicornis* and *Acerophagus coccois* in Colombia. *Entomologia Experimentalis et Applicata* 50:21-27.

IITA. 1985. Biological control of cassava mealybug and green spider mites. IITA Africa-wide Biological Control Project Information series. No.16, IITA, Ibadan, Nigeria, 25pp.

Janzen, D.H. 1986. Biogeography of an unexceptional place: What determines the saturnial and sphyngidal moth fauna of Santa Rosa National Park, Costa Rica, and what does it mean to conservation biology. *Benesia* 25/26:51-87.

Janzen, D.H. 1987. When and when not to leave. *Oikos* 49:241-243.

Lozano, J.C. and Bellotti, A.C. 1980. Control integrado de enfermedades y pestes de la yuca

(*Manihot esculenta* Crantz). *Fitopatología Colombiana* 2:97-104.

Lozano, J.C. and Bellotti, A.C. 1980. Control integrado de enfermedades y pestes de lay yuca (*Manihot esculenta* Crantz). *Fitopatologia Colombiana* 2: 97-104.

Metcalf, R.L. and Luckmann, (Eds.). 1982. *Introduction to Insect Pest Management*. 2nd. ed. Wiley, New York. 577 pp.

Neuenschwander, P. 1994. Control of cassava mealybug in Africa: lessons from a biological control project. *African Crop Science Journal* 2:369-383.

Porter, R.I. 1988. Evaluation of Germplasm of Cassava (*Manihot esculenta* Crantz) for Resistance to the Mealybug (*Phenacoccus herreni* Cox & Williams).Thesis Dissertation, Cornell University, Ithaca, N.Y.

Renvoize, B.S. 1973. The area of origin of *Manihot esculenta*, as a crop plant - a review of the evidence. *Economic Botany* 26:352-360.

Riis, L. 1990. The subterranean burrowing bug *Cyrtomenus bergi* Froeschner, an increasing pest in tropical Latin America: behavioral studies, population fluctuations, botanical control, with special reference to cassava. Thesis, M.SC. Institute of Ecological and Molecular Biology, Section of Zoology, The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Rogers, D.J. 1963. Studies of *Manihot esculenta* Crantz and related species. *Bulletin of the Torrey Botanical Club* 90:43-54.

Sauer, C.O. 1950. Cultivated plants of South and Central America. Handbook of South American Indians. *Bureau of American Ethnological Bulletin* 1436: 487-543.

Schoonhoven, A. Van. 1974. Resistance to thrips damage in cassava. *Journal of Economic Entomology* 67:728-730.

Schmidt, A.T. 1988. Uso de *Baculovirus erinnyis* para el control biológico del gusano cachón de la yuca. *Yuca Boletín Informativo* 12:1-4.

Urias, López, M.A., Bellotti, A.C., Bravo Mojica, H. and Carrillo Sánchez, J.L. 1987. Impacto de insecticidas sobre tres parasitoides de *Erinnyis ello* (L) gusano de cuerno de la yuca. *Agrociencia* 67:137-146.

Van Driesche, R.G., Castillo, J.A. and Bellotti, A.C. 1988. Field placement of mealybug-infested potted cassava plants for the study of parasitism of *Phenacoccus herreni*. *Entomologia Experimentalis et Applicata* 46:117-123.

Van Driesche, R.G., Bellotti, A.C., Castillo, J.A. and Herrera, C.J. 1990. Estimating total losses from parasitoids for a field population of a continuously breeding insect, cassava mealybug, *Phenacoccus herreni*, (Homoptera: Pseudococcidae) in Colombia, S.A. *Florida Entomologist* 73:133-143.

Vargas, O. and Bellotti, A.C. 1981. Pérdidas en rendimiento causadas por moscas blancas en el cultivo de la yuca. *Revista Colombiana de Entomologia* 7 (1 & 2):13-20.

Vargas, H.O. and Bellotti, A.C. 1984. Pérdidas en rendimiento causadas por *Phenacoccus herreni* Cox and Williams en dos clones de yuca. *Revista Colombiana de Entomologia* 10:41-46.

Vargas, H.O., Bellotti, A.C., El-Sharkawy, M. and Hernández, M. del P. 1989. Extracción del calcio por *Phenacoccus herreni*, síntomas y efectos en la fotosíntesis de la yuca. *Yuca, Boletín Informativo* 13:8-10.

Winder, J.A. 1976. Ecology and control of *Erinnyis ello* and *E. alope*, important insect pests in the New World. *PANS* 22:449-466.

Winder, J.A. and De Abreu, J.M. 1976. Preliminary observations on the flight behavior of the Sphingid moths *Erinnyis ello* L. and *E. alope* Drury (Lepidoptera), based on light trapping. *Ciencia e Cultura* 28:444-448.