

## THE EFFECTS OF CROPPING SYSTEMS ON CASSAVA WHITEFLIES IN COLOMBIA: IMPLICATIONS FOR CONTROL OF AFRICAN CASSAVA MOSAIC VIRUS DISEASE

C.S. GOLD

Plant Health Management Division  
International Institute of Tropical Agriculture  
P.O. Box 7878, Kampala, Uganda

### ABSTRACT

The cassava whiteflies *Aleurotrachelus socialis* and *Trialeurodes variabilis* are outbreak pests which cause high yield losses in the Departments of Tolima and Cauca, Colombia. Studies were undertaken to examine the effects of intercropping and cassava varietal mixtures on whitefly population dynamics and related crop growth. Cassava intercropped with cowpea supported 46% fewer whiteflies per leaf and 70% fewer per plant than cassava monocultures. Reductions in whitefly numbers occurred 6 weeks after planting and persisted for 28 weeks after the cowpea crop was harvested. The lower herbivore load in the cassava/cowpea system resulted in a 13% yield loss compared with 58% loss in the monoculture, and intercropped cassava out yielded monoculture. Decreases in whiteflies resulting from intercropping cassava with maize were less substantial and led to no reduction in yield loss. Cassava varietal mixtures, consisting of alternate rows of whitefly-susceptible and partially resistant varieties, resulted in reduced *T. variabilis* densities on the susceptible cultivar. Implications of these results for the control of African cassava mosaic virus disease are discussed.

*Key Words:* *Aleurotrachelus socialis*, *Trialeurodes variabilis*, cowpea, maize, intercropping, yield

### RÉSUMÉ

Les aleurodes du manioc *Aleurotrachelus socialis* et *Trialeurodes variabilis* sont des ravageurs qui pullulent et causent d'importantes pertes de récolte dans les départements de Tolima et Cauca en Colombie. Des études ont été entreprises pour examiner les effets de la culture associée et des mélanges de variétés sur la dynamique des populations d'aleurodes et la croissance de la culture. Le manioc associé au niébé présente, par rapport au manioc en monoculture, 46% de mouches blanches en moins par feuille et 70% en moins par plant. La réduction des effectifs d'aleurodes intervient 6 semaines après la plantation et persiste pendant 28 semaines après la récolte du niébé. La plus faible charge en phytophages dans le système manioc/niébé conduit à une perte de 13% en récolte, comparée à 58% en monoculture et le manioc cultivé en association a produit plus qu'en monoculture. La réduction en aleurodes, qui accompagne l'association du manioc au maïs, a été moins substantielle et n'a abouti à aucune diminution des pertes à la récolte. Des mélanges de variétés de manioc, sous la forme d'une alternance entre des rangs de variétés sensibles aux aleurodes et des rangs de variétés partiellement résistantes, ont conduit à une diminution des densités de *T. variabilis* sur les cultivars sensibles. Les implications de ces résultats pour le contrôle de la mosaïque africaine du manioc sont discutées.

*Mot Clés:* *Aleurotrachelus socialis*, *Trialeurodes variabilis*, niébé, culture associée, rendement

## INTRODUCTION

**Cassava whiteflies.** Cassava (*Manihot esculenta* Crantz) originated in the Americas and was introduced to Africa by Portuguese traders in the 16th century. It is now the principal staple for an estimated 750 million people in Latin America and Africa (Cock, 1982). Whiteflies are important production constraints of cassava in both regions, causing yield loss through direct feeding, production of honeydew and associated sooty moulds, and also as virus vectors. The complex of whiteflies and associated virus diseases on cassava in the Neotropics is distinct from that in the Paletropics (Thresh *et al.*, 1994).

In Latin America, yield losses reaching 80% may be attributed to whitefly outbreaks or the viruses they transmit. Whitefly species attacking cassava include *Aleurotrachelus socialis* Bondar, *Trialeurodes variabilis* (Quaintance), *Bemisia tuberculata* Bondar, *Aleurothrixus floccus* (Maskell), *A. aepim* and *Paraleyrodes* sp. These species all have narrow host ranges and are largely restricted to cassava. More recently, *Bemisia tabaci* (Gennadius) (or the recently distinguished *B. argentifolia*) has been reported on cassava in Florida, Puerto Rico and the Dominican Republic. Frogskin 'virus', vectored by *B. tuberculata*, is the most important whitefly-transmitted cassava pathogen in the Americas (A.C. Bellotti, personal communication).

Whitefly problems in the Neotropics are most commonly restricted to "hot spots". In Colombia, for example, populations at outbreak sites may exceed 900 adults per leaf, 1400 eggs per cm<sup>2</sup> and 40,000 eggs per leaf (Gold, 1987). In the Department of Tolima, Colombia, whitefly outbreaks (populations consisting of 80% *A. socialis* and 20% *T. variabilis*) have been chronic for more than 20 years. Insecticide use on commercial crops (cotton, rice, sesame) in the region is heavy (Gold, 1987) and whiteflies may have become secondary pests because of this practice. In contrast, the cause of *T. variabilis* outbreaks which originated in the early 1980s near Nuevo Pescador, Department of Cauca, Colombia, is not clearly understood.

In Africa, *B. tabaci* is the principal whitefly species on cassava, while *B. afer* (Priesner and

Hosny) and spiralling whitefly, *Aleurodicus dispersus* Russell are of minor importance. Unlike the situation in Latin America, these species are polyphagous and attack a wide range of hosts, although distinct host-restricted biotypes of *B. tabaci* occur (Burban *et al.*, 1992; Legg *et al.*, 1994). *Bemisia tabaci* is a vector of African cassava mosaic geminiviruses (ACMV) which are key cassava production constraints in the continent. *Bemisia afer* appears in low numbers, is not known to transmit ACMVs and seems unimportant (J.P. Legg pers. comm.). Spiralling whitefly outbreaks have been observed recently on cassava in West Africa but the importance of this pest and whether it transmits ACMV is not yet clear (Neuenschwander, 1994).

**Cassava cropping systems.** In Latin America, cassava is mainly grown by small farmers with limited capital and the crop tends to be relegated to marginal land because of its long growing season and poor marketability (Sanders and Lynam, 1981; Cock, 1985). In Africa, cassava is often grown by resource-poor farmers, often under conditions of intensified land use (Nweke *et al.*, 1994). In both regions, traditional cassava production usually involves intercropping and cultivar mixtures (Lozano *et al.*, 1980; Nweke *et al.*, 1994)

The agronomy of cassava intercropping has been treated by Weber *et al.* (1979), Leihner (1983), and Mason (1983). Intercropping facilitates more efficient use of resources, greater return on available land, protection against soil erosion and effective weed management (Norman, 1974; Mead and Willey, 1980). Moreover, short duration intercrops provide an early return in cassava-based cropping systems. However, cassava is a poor competitor during early growth. Although farmers are advised to use additive series intercrops, which involve mixtures of crops each grown at the usual monoculture density, it is recommended that intercrop competition be reduced by departing from normal planting arrangements (Leihner, 1983) and through regular weeding (Doll, 1978).

Diversified agroecosystems, including intercrops, often support lower herbivore loads than corresponding monocultures (Altieri and

Letourneau, 1982; Risch *et al.*, 1983). These reductions have been attributed to increased efficacy of natural enemies (Root, 1973; Sheehan, 1986) or differences in "resource concentration" among cropping systems (Tahvanainen and Root, 1972). However, not all crop combinations bring about reduced herbivore loads and, perhaps more importantly, a given herbivore may show variable responses to the same crop combination over space or time (Andow, 1983; Risch *et al.*, 1983). Therefore, it is important to understand the mechanisms by which a cropping system influences an herbivore's population dynamics.

Crop diversification may also be attained through varietal mixtures. Genetic diversity in crops is believed to help maintain herbivores at low levels, although only limited work has been done on this topic (Canteló and Sanford, 1984; Gould, 1986a,b; Altieri and Schmidt, 1987; Power, 1988).

Under the small farm conditions in which cassava is most often grown, pest management options are limited. Manipulation of cropping systems provides an important pest management tool which can be readily adopted by small farmers, many of whom already use mixed cropping systems to intensify production on limited areas of land.

This paper summarises results obtained on the effects of cropping systems on whitefly population dynamics in Colombia. Applications for management of whiteflies and cassava mosaic virus disease in Africa are then discussed.

#### **Intercropping and Cassava Whiteflies: a Case Study.**

To investigate the potential for reducing herbivore load and associated yield loss, cassava intercropping trials were established at a site where chronic outbreaks of cassava whiteflies had occurred for at least 10 years. The objectives of this study were to: (1) determine the abundance patterns of cassava whiteflies in simple and diversified systems; (2) assess possible residual effects of short duration intercrops on cassava whitefly population levels; (3) evaluate whitefly population dynamics in light of the natural enemy and resource concentration hypotheses; (4) ascertain the relative effects of intercrop competition and differential herbivore load on cassava growth and yields.

## **METHODS**

Trials were at the field station of the Instituto Colombiano Agropecuario (ICA), located in Nataima, Department of Tolima, Colombia at 4000 m.a.s.l. The site has two rainy seasons, March - May and September - November, and 1375 mm annual mean precipitation. Average daily temperatures ranged from 26 to 30° C. Nataima is at 4° N latitude and day length varied less than 30 minutes during the year.

A regional (landrace) variety of cassava (MCO 2257) was planted in monoculture and intercropped with cowpea (CE-31) and with maize (ICA Compuesto Tropical). A fourth treatment, 'mixed variety monoculture', consisted of alternate rows of the regional cassava and cassava variety CMC 40. All plots were of 216 m<sup>2</sup> and consisted of ten rows (1.8 m apart) of 20 cassava plants 0.6 m apart. Intercrops were planted between the cassava rows in an additive design. The treatments were replicated 6 times in a randomized complete block design. In order to partition the effects of intercrop competition and differential herbivore load on cassava growth and yields, whiteflies were controlled in two blocks by bi-weekly applications of the insecticide monocrotophos.

Cowpea and maize were harvested 17 weeks after planting (WAP). CMC 40 cassava was harvested 35 WAP and regional cassava at 45 WAP. For analysis, the cassava crop cycle was divided into four periods: establishment (4 - 6 WAP), pre-harvest (8 - 16 WAP), post-harvest (18 - 35 WAP), and mature (39 - 45 WAP), where harvest refers to that of the intercrop.

Bi-weekly egg samples on 25 plants per plot (one leaf per plant) were taken between 4 and 45 WAP. All eggs on half of the central lobe (using alternate sides of the central vein) were counted under a microscope. Leaves number 4 or 5 from the apex were chosen from randomly selected plants. Egg density per half lobe was extrapolated to egg numbers per leaf and per plant (over the two week sampling interval) using data for whitefly egg distribution within leaves and for leaf production per plant (Gold *et al.*, 1990a).

Analyses (by ANOVA) of egg densities were conducted separately for *A. socialis* and *T. variabilis*. To stabilise the variances, the data for *A. socialis* half lobe populations were transformed

to natural logarithms ( $\ln(x+1)$ ) while those for *T. variabilis* were transformed to square roots  $[(x+1/2)^{1/2}]$ . Other data did not require transformation.

The coccinellid predator *Delphastus pusillus* Leconte was monitored bi-weekly by counting larval and adult numbers on 300 leaves (20 plants, 15 leaves per plant) per plot. Potential impact of this coccinellid was determined by assessing consumption rates in petri dishes (Gold *et al.*, 1989a). Parasitism by the platygasterid parasitoid *Amitus aleurodinus* Haldeman and the aphelinid parasitoid *Eretmocerus aleyrodiphaga* (Risbec) was assessed by determining the number of whitefly exit holes, parasite exit holes and dead pupae found on 6-week-old leaves. These data were then used to construct whitefly survivorship rate (partial life tables) for each different cropping regime.

## RESULTS

### Whitefly population trends based on egg counts.

During the 10-month crop cycle (20 observation periods), mean whitefly egg density on regional cassava (all treatments) was 3,600 per leaf for *A. socialis* and 910 for *T. variabilis*. On CMC 40, *A. socialis* and *T. variabilis* averaged 2,365 and 391 eggs per leaf, respectively. Densities were lowest during the establishment phase (0-6 WAP) when all adults were colonisers and plants were small.

*Aleurotrachelus socialis* populations peaked at 10-12 WAP, remained high until 24 WAP and then displayed a second peak at 33 WAP (Fig. 1). *Trialeurodes variabilis* had a single peak at 16-20 WAP and was less abundant than *A. socialis* on all sampling dates. Over the entire trial, *A. socialis* comprised 79% of the whitefly populations, although on individual sampling dates its proportion ranged from 56 to 94%. On CMC 40, *A. socialis* constituted 88% of the total whitefly population.

Cumulative egg populations (from 8 to 35 WAP) per plant on regional cassava averaged 1.07 million *A. socialis* and 0.28 million *T. variabilis*. Egg numbers were peaking at the end of the sample period (35 WAP) suggesting that total load probably exceeded 2 million eggs per plant for the entire crop cycle. Egg numbers per CMC 40 plant (from 8 to 33 WAP) were 1.49 million *A. socialis* and 0.21 million *T. variabilis*. Although egg density per leaf peaked between 12-20 WAP, the increased branching resulted in more terminal leaves and steadily increasing numbers of whiteflies throughout the trial.

**Intercropping and whitefly population dynamics.** Over the entire trial, *A. socialis* egg density per leaf was significantly ( $P < 0.01$ ) lower in cassava/cowpea systems than in other treatments (average 46% lower than in monoculture) (Fig.

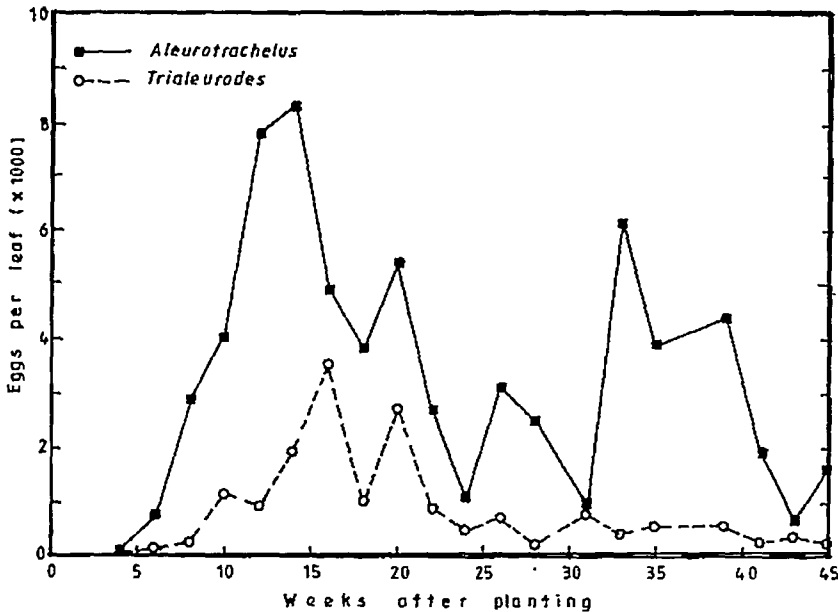


Figure 1. Population fluctuations of *Aleurotrachelus socialis* and *Trialeurodes variabilis* in cassava cropping system trial at ICA-Nataima, Department of Tolima, Colombia, April 1994 to February 1995

2). The influence of the cowpea stand became apparent 6 WAP (most likely reflecting differences in immigration rates) and persisted up to 28 weeks after the intercrop was harvested 45 WAP. Indeed, post-harvest effects were greater than the direct influence of cowpea on whitefly density: egg number was 36% lower than in monoculture

during the intercrop period compared to 59% lower during the 18 weeks following intercrop harvest.

Similarly, cowpea intercrops resulted in significant ( $P < 0.01$ ) reductions of *T. variabilis* relative to other systems (average 48% lower than in monoculture) (Fig. 3). As with *A. socialis*,

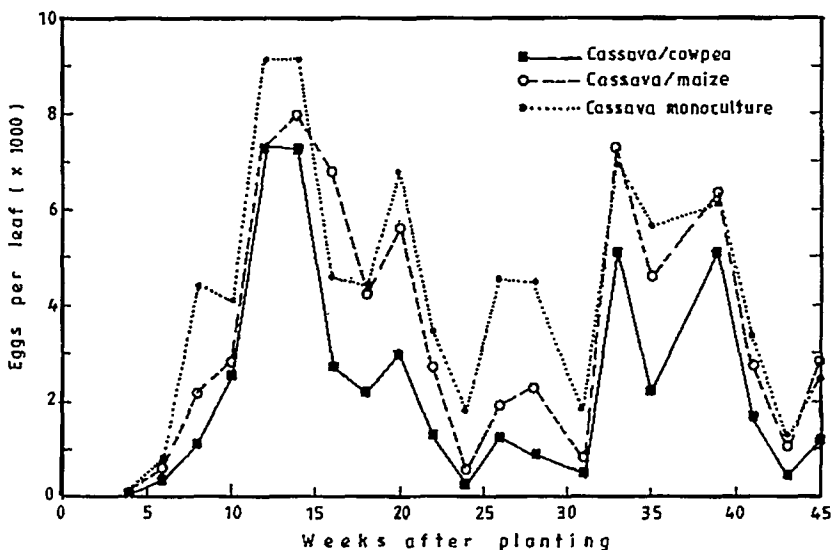


Figure 2. *Aleurotrachelus socialis* eggs per leaf in different cassava cropping systems at ICA-Nataima, Department of Tolima, Colombia, April 1994 to February 1995.

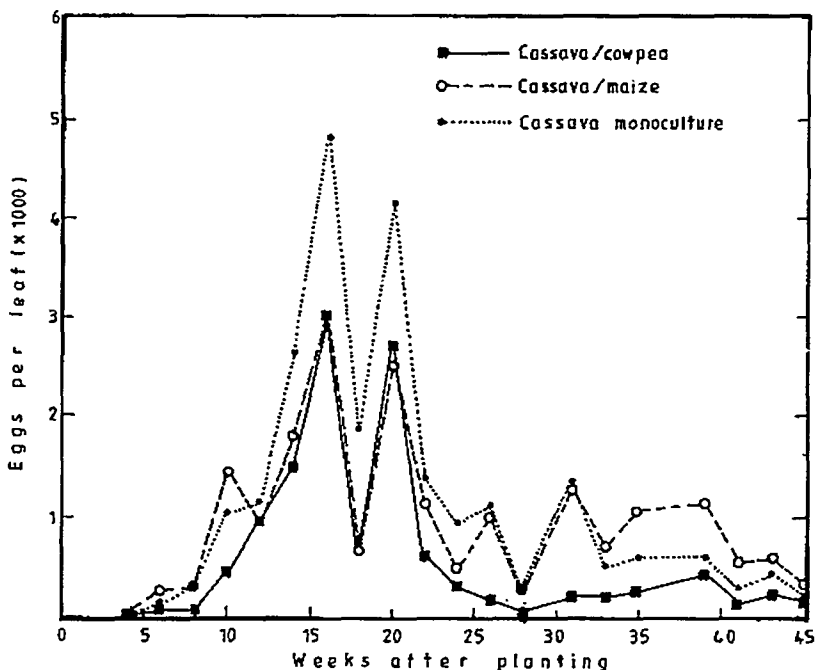


Figure 3. *Trialeurodes variabilis* eggs per leaf in different cassava cropping systems at ICA-Nataima, Department of Tolima, Colombia, April 1994 to February 1995.

lower herbivore load in the cassava/cowpea system persisted throughout the trial with greatest differences after harvesting the intercrop.

The cassava/maize system supported 17% fewer whiteflies per leaf than cassava monoculture, but this difference was not significant. During the final weeks of the trial, greatest whitefly density occurred in the cassava/maize system. This was probably due to differential effects of wind (e.g. dislodging whiteflies) in the different cropping systems. The most exposed (highest) shoot tips were wind damaged and there was a clear negative relationship between whitefly numbers and the height of the terminal above ground shoots (Gold, 1987). The cassava which had been intercropped with maize etiolated and eventually sprawled, thereby encouraging whitefly build-up near ground level.

Overall, *A. socialis* egg numbers per plant were significantly ( $P < 0.01$ ) lower in both intercropped systems (69% in cassava/cowpea and 54% in cassava/maize) than in monoculture (Fig. 4). Greater reductions compared to the monoculture occurred after intercrops were harvested in both the cowpea and maize systems.

Cassava/cowpea systems also supported significantly ( $P < 0.01$ ) fewer (71%) *T. variabilis* egg populations per plant than the monoculture, with greatest reductions occurring after intercrop

harvest (Fig. 5). There were, on average, 53% fewer *T. variabilis* eggs per plant in cassava/maize systems than in the monoculture, but significant differences occurred only after the maize was harvested.

**Cassava varietal mixtures.** In the cassava varietal mixtures, regional cassava supported more *A. socialis* and *T. variabilis* eggs per leaf but fewer total eggs per plant than CMC 40 (Table 1). This apparent inconsistency was explained by differences in host plant architecture; CMC 40 branched more than regional cassava and produced 2.7 times as many leaves between 6 and 35 WAP (Gold, 1987). As a result, discrimination of whitefly cultivar preference is not immediately clear.

To determine the influence of CMC 40 on whitefly load, egg densities in the mixed variety system were compared to those in the regional variety monoculture. *Aleurotrachelus socialis* density per leaf was similar on regional cassava in mixed and single variety plots (Gold *et al.*, 1989b). However, the regional cassava produced 23% fewer leaves in the varietal mixture (attributable to shading) than in pure stand, and supported 35% fewer *A. socialis* eggs per plant (Fig. 6).

In contrast, *T. variabilis* egg density was 34% lower per leaf and 63% lower per plant in the

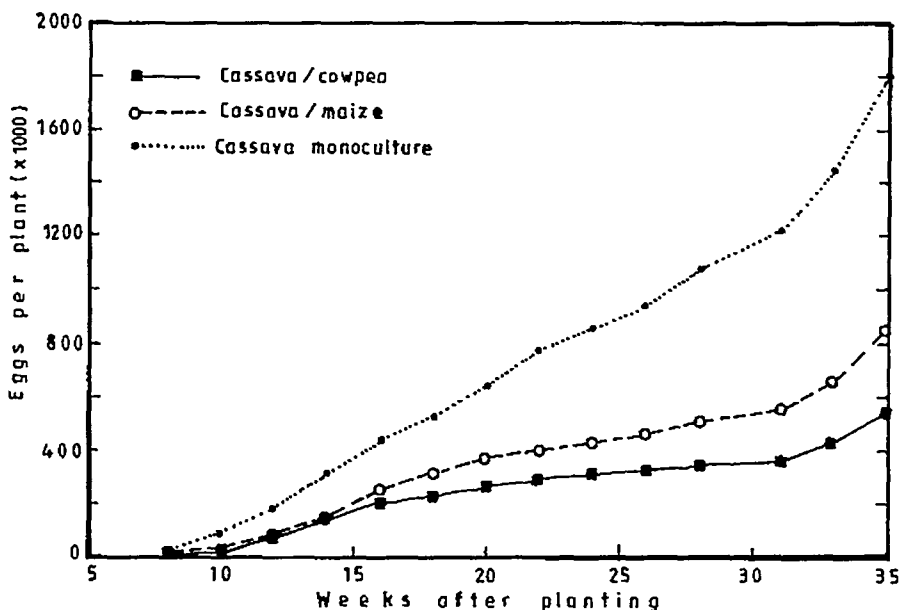


Figure 4. Cumulative *Aleurotrachelus socialis* eggs per plant in different cassava cropping systems at ICA-Nataima, Department of Tolima, Colombia, May 1994 to December 1994.

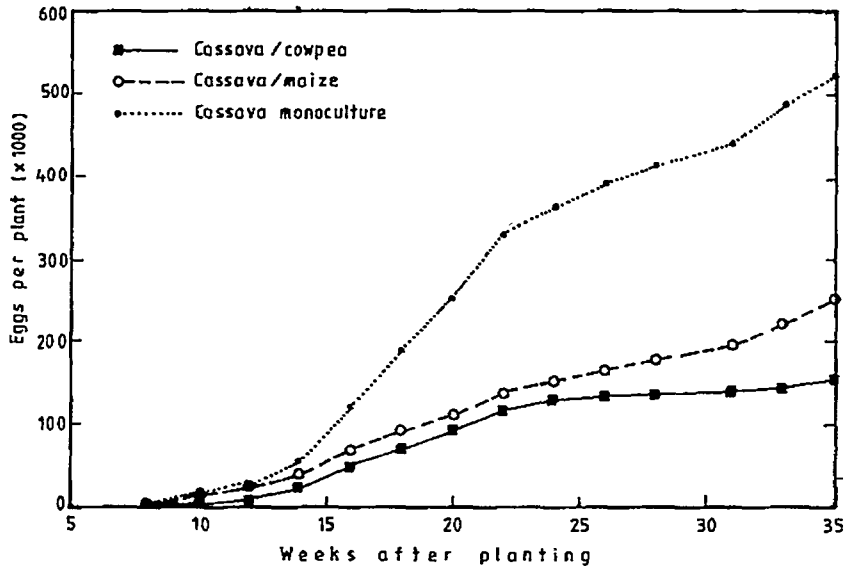


Figure 5. Cumulative *Trialeurodes variabilis* eggs per plant in different cassava cropping systems at ICA-Nataima, Department of Tolima, Colombia, May 1994 to December 1994.

Table 1. Whitefly egg numbers per leaf and per plant (mean for two-week intervals) 8-16, 18-35 and 8-35 weeks after planting in cassava varietal mixtures at ICA-Nataima, Department of Tolima, Colombia

	Per leaf			Per plant (X 1000)		
	8-16	8-35	8-35	8-16	18-35	8-35
<b>a. <i>Aleurotrachelus socialis</i></b>						
Regional	64092 <sup>a</sup>	3527 <sup>a</sup>	4554 <sup>a</sup>	78.3 <sup>b</sup>	83.3 <sup>b</sup>	81.5 <sup>b</sup>
CMC 40	3909 <sup>b</sup>	1918 <sup>b</sup>	2627 <sup>b</sup>	109.2 <sup>a</sup>	23.6 <sup>a</sup>	118.5 <sup>a</sup>
F VALUE <sup>a</sup>	14.77 <sup>**</sup>	14.78 <sup>**</sup>	12.61 <sup>**</sup>	6.96 <sup>**</sup>	10.98 <sup>**</sup>	10.53 <sup>**</sup>
<b>b. <i>Trialeurodes variabilis</i></b>						
Regional	1445 <sup>a</sup>	436 <sup>a</sup>	800 <sup>a</sup>	16.4 <sup>a</sup>	10.1 <sup>b</sup>	12.3 <sup>b</sup>
CMC 40	491 <sup>b</sup>	309 <sup>b</sup>	372 <sup>b</sup>	12.4 <sup>b</sup>	19.3 <sup>a</sup>	16.8 <sup>a</sup>
F VALUE <sup>a</sup>	14.04 <sup>**</sup>	4.24 <sup>**</sup>	32.60 <sup>**</sup>	4.16 <sup>**</sup>	15.70 <sup>**</sup>	13.24 <sup>**</sup>

\*\* p < .01 WAP: Weeks after planting

<sup>a</sup> Leaf populations of *A. socialis* log transformed; *T. socialis* square root transformed

<sup>b</sup> Treatments with same letter are not significantly different by Duncan's New Multiple Range Test.

varietal mixture (Fig. 6). Furthermore, population differences between systems increased as the canopy closed. From 17 to 45 WAP, *T. variabilis* numbers were 66% lower *per leaf* and 76% lower *per plant* in the mixed versus the single variety system.

These results suggest that *A. socialis* did not discriminate between regional cassava and CMC 40, whereas *T. variabilis* preferred the regional cultivar. Moreover, presence of CMC 40 not only decreased absolute numbers of *T. variabilis* within

varietal mixtures but also reduced egg density on the regional cassava. This effect intensified as the cassava canopy closed, suggesting that CMC 40 acted partly as a repellent.

**Factors influencing whitefly population dynamics.** The persistence of lower *A. socialis* and *T. variabilis* egg densities in cassava/cowpea systems suggests a residual effect of the intercrop on whitefly population dynamics. There are three possible mechanisms: (1) cowpea directly

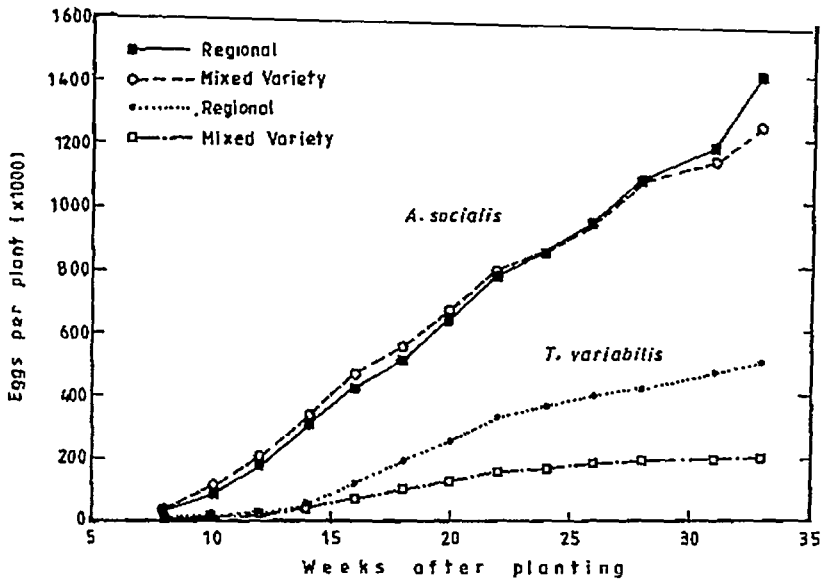


Figure 6. Cumulative *Aleurotrachelus socialis* and *Trialeurodes variabilis* eggs per plant in cassava varietal mixtures (cvs MCOL 2257 and CMC 40) and single variety (MCOL 2257). Plots at ICA-Nataima, Department of Tolima, Colombia, May 1994 to December 1994.

influenced whiteflies, suppressing populations which then lagged behind those in the monoculture for the remainder of the trial; (2) natural enemies built up in the intercropped system and continued to restrict whitefly populations following intercrop harvest; (3) intercropping with cowpea influenced cassava growth and architecture which in turn affected whitefly populations. The effects on host plant growth persisted after the intercrop period.

Intercrops may lower herbivore populations by directly interfering with the colonisation of host-plants, by reducing the tenure time and by increasing emigration rates (Bach, 1980; Risch, 1981). Such effects may, in fact, have occurred in cassava/cowpea systems during the intercrop period. Lower whitefly numbers early in the crop cycle suggest reduced immigration of dispersing whiteflies (e.g. due to physical or semiochemical barriers) or increased emigration rates. In separate trials at Nuevo Pescador, whiteflies landing on non-host plants tended to fly above the canopy where they were swept out of the system by wind currents (Gold, 1987).

If direct effects of the intercrop are critical factors in the reduction of cassava whiteflies, residual effects would be limited and intercrop influence on population levels would gradually disappear over time. In this study, however,

treatment differences were even greater following intercrop harvest than previously. This suggests that direct effects of cowpea on cassava whiteflies played only a minor role in suppressing whitefly numbers.

Lower whitefly populations in intercrops did not result from increased natural enemy control within these systems. *Delphastus pusillus* displayed a functional response and was more abundant in monoculture cassava (Gold *et al.*, 1989a). Concurrently, parasitisation rates of *A. socialis* immatures did not differ between cropping systems. Parasitism of *T. variabilis* was less than 1% in all treatments. Moreover, survivorship indices for *A. socialis* suggested that 8 to 10% of the whiteflies developed successfully from egg to adult with no significant differences between systems (Table 2) (Gold *et al.*, 1991).

Intercropping may affect herbivore density indirectly through changes in host plant quality, including effects on plant size, leaf area and/or leaf nutrient content. For example, differences in host plant size and architecture (e.g. lower leaf production rates and less dense canopies) may, in turn, affect whiteflies by altering microclimates at oviposition sites within cassava shoot terminals.

In this study, whitefly distribution between cropping systems and within plots appeared to be



TABLE 2. Partial life tables for *Aleurotrachelus socialis* in different cropping systems, Department of Tolima, Colombia, May-December 1984

## a. Field-side survivorship

Stage x	Number entering stage lx	Rate of mortality		100 qx	100 rx
		Mortality factor DxF	Number dying dx		
Egg	1000	Hatch failure	10	1.0	1.0
Crawler	990	Disappearance	198	10.0	19.8
Instar 1,2	792	Predation	64	8.1	6.4
		Unknown	335	42.3	33.5
Instar 3,4	393	Predation	46	11.7	4.6
		Unknown	74	18.8	7.4
		Parasitism	87	22.1	8.7
		Pupal failure	101	25.7	10.1
Adult	85	Total mortality			91.5
Eggs per female: 161		Observed sex ratio 1:1		$R_0$ :6.8	

## b. Survivorship by cropping system

Stage	Cropping system					
	Cassava mono		Cassava/cowpea		Cassava/maize	
	lx	dx	lx	dx	lx	dx
Egg						
hatch failure	679	7	344	3	514	5
Crawler	672		341		509	
Disappearance		134		68		102
Instar 1,2	538		273		407	
Predation		48		20		33
Unknown		260		99		172
Instar 3,4	230		154		202	
Predation		35		14		23
Unknown		28		38		37
Parasitism		57		30		46
Pupal failure		62		41		48
Adult	48		31		48	
$R_0$	5.8		7.3		7.5	

related to differences in host plant quality, especially leaf production and canopy cover. The influence of the host plant on whitefly density appears to be mediated through the effects of plant size on adult aggregation patterns. Whitefly adults tended to aggregate in more vigorous plant assemblages (e.g. monocultures) and also on larger plants within plots.

In Tolima, whitefly density per leaf was highest in monocultures, even though adult and immature numbers were diluted over a greater number of leaves. In contrast, cassava intercropped with cowpea was smaller, less branched and leaf production was less than for cassava in other treatments (Gold *et al.*, 1989c). Cropping system effects on host plant growth and vigour appeared

TABLE 3. Summary of Kendall Tau correlations of adult populations of *Trialeurodes variabilis* with cassava plant size at Pescador, Department of Cauca, Colombia, March to August 1985

Tau	Plot	Block
≥ .50	38%	41%
.40-.49	29%	37%
.30-.39	16%	15%
.20-.29	11%	7%
< .20	6%	0

early in the trial, persisted after intercrop harvest and, therefore, might explain the residual effect of intercrops on whitefly numbers.

Moreover, three plots (mixed variety treatment in block 1, cassava/cowpea in block 2, and cassava/maize in block 3) suffered drainage problems after storms and subsequent plant growth and leaf production were retarded. These plots contained many stunted plants and supported lower egg numbers of *A. socialis* (27% per leaf, 41% per plant) and *T. variabilis* (38% per leaf, 52% per plant) than the same treatments in other blocks (Gold *et al.*, 1990a).

Adult whiteflies also tended to accumulate on larger plants within plots. For example, *T. variabilis* adult numbers per shoot were consistently and positively correlated with plant size in a separate trial at Nuevo Pescador (Table 3).

*Aleurotrachelus socialis* and *T. variabilis* displayed strong dispersal capabilities. Cassava planted in land recently cleared of coffee and surrounded by woodland (Melgar, Department of Tolima) was infested at 5 WAP by *A. socialis*, even though the nearest cassava field was 8 km away. In Tolima, blocks being protected by insecticide were consistently re-invaded by adult whiteflies necessitating fortnightly application of chemical. Moreover, isolated potted plants placed 100 meters from cassava fields were often infested by both species within three days. These results suggest extensive movement of adult whiteflies within and between cassava plantings.

Whiteflies are weak flyers and have limited flight capability; although they must fly to remain air-borne, dispersal between fields may

be predominantly through passive movement in wind currents (Price, 1976; Taylor, 1984). Vigorous cassava plants with greater leaf area, as in monocultures, were probably more efficient at "filtering" out air-borne whiteflies which would then congregate on leaf terminals at higher populations than on less vigorous plants.

Moreover, wind speeds decrease within crops creating sheltered patches to leeward of individual plants (Pedgley, 1982) and the lowest wind velocities are likely in plots containing large plants, as in monocultures. Whiteflies, presumably, would have more control over their movement in the calmer air of cassava monocultures. Moreover, such reductions in air movement might allow a greater number of landings of dispersing whiteflies (Pedgley, 1982) and also reduce the rate of dislodgement of adults from terminal leaves.

Although cropping systems may affect cassava leaf biochemistry (including secondary plant substances, amino acid profiles, metabolites, and minerals), it appears that physical factors related to host plant size and dispersal of whiteflies may be more critical in determining population levels. Cassava tends to adjust its growth rate to nutrient availability, so maintaining a stable leaf nutrient content (Cock, 1983). Therefore, competition for resources in intercropped systems would be likely to affect cassava size but not nutrient profiles (Cock, pers. comm., Howeler, pers. comm.). In both the Tolima and Cauca trials, leaf NPK contents were similar in different treatments (Gold, 1987, 1990b).

**Intercrop competition, whiteflies and cassava production.** Cassava in insecticide-protected plots grew taller and had significantly greater branching and leaf production per terminal than cassava in non-protected plots. Differences in height and leaf production per terminal were first seen at 14 WAP, coincident with peak whitefly populations per leaf (Gold, 1987). Greater branching in protected plots was first evident at 31 WAP.

Whitefly attack reduced the duration of individual leaves from an overall average of 12.9 weeks in protected plots to 8.7 weeks in non-protected plots; reductions averaged 16% in cassava/cowpea systems, 42% in cassava/maize and 31% in cassava monoculture. Greatest reductions in leaf duration occurred during peak periods of infestation (Gold *et al.*, 1989b).

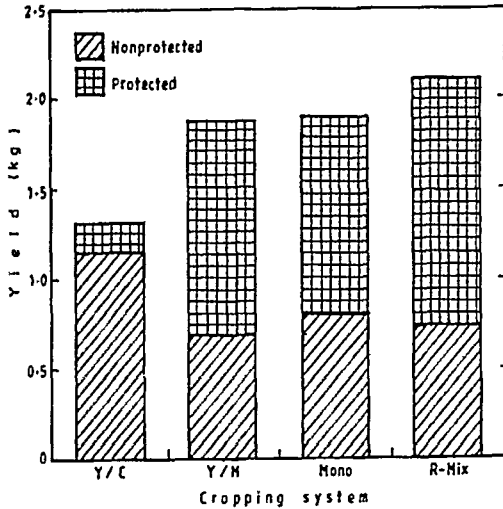


Figure 7. Cassava yields (marketable root weights) and yield losses due to whiteflies in different cropping systems at ICA-Nataima, Department of Tolima, Colombia, Feb. 1995. Y/C: cassava/cowpea intercrop; Y/M: cassava/maize intercrop; Mono: cassava monoculture; R-Mix: regional cassava (MCOI 2257) in mixture with cassava variety CMC 40.

In protected plots, cassava intercropped with cowpea produced fewer tuberous roots and had lower yields than in other systems (Fig. 7). Yields of regional cassava intercropped with maize, in monoculture and in varietal mixtures were similar. However, there were only two replicates, and treatment differences were not significant.

Cassava intercropped with cowpea supported lower infestation of whitefly and suffered less yield reduction than other cassava systems (Fig. 7). For example, yield loss in cassava/cowpea intercrops was 13% compared to 58% in monoculture. Moreover, commercial (marketable) root number was reduced by only 3% in cassava/cowpea intercrops compared to 43% in monoculture (Fig. 8). Finally, reduction in root size was 9% in cassava/cowpea intercrops against 28% in monoculture (Fig. 9). Yield losses were similar in cassava/maize, cassava monoculture, and mixed cultivar plots. Consequently, cassava intercropped with cowpea out-yielded other cassava systems when unprotected. Yield differences between treatments primarily reflected

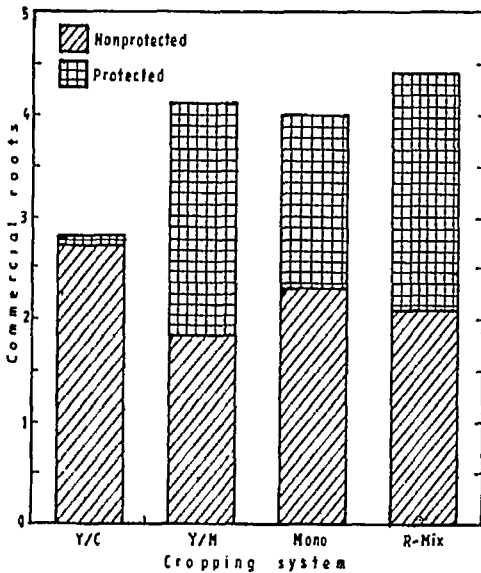


Figure 8. Cassava yields (marketable root number) and yield losses due to whiteflies in different cropping systems at ICA-Nataima, Department of Tolima, Colombia, Feb. 1995. Y/C: cassava/cowpea intercrop; Y/M: cassava/maize intercrop; Mono: cassava monoculture; R-Mix: regional cassava (MCOI 2257) in mixture with cassava variety CMC 40.

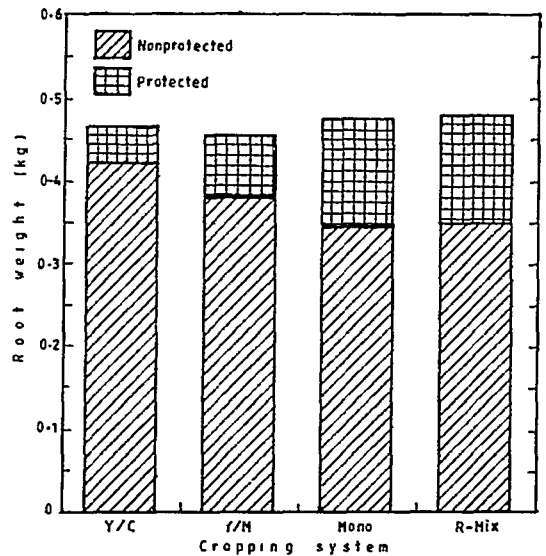


Figure 9. Cassava yields (mean marketable root weight) and yield losses due to whiteflies in different cropping systems at ICA-Nataima, Department of Tolima, Colombia, Feb. 1995. Y/C: cassava/cowpea intercrop; Y/M: cassava/maize intercrop; Mono: cassava monoculture; R-Mix: regional cassava (MCOI 2257) in mixture with cassava variety CMC 40.

differences in root size. Moreover, land equivalent ratios (LER), comparing productivity of intercrops and monoculture (a ratio of 1 shows equal productivity), exceeded 1.5 for both intercropped systems in protected and non-protected systems. Greatest yield advantages were provided by non-protected cassava/cowpea intercrops (LER 2.15) and by protected cassava/maize systems (LER 1.72).

## DISCUSSION

In Colombia, *A. socialis* and *T. variabilis* are direct pests of cassava, causing yield losses of up to 80% in outbreak areas. Research trials in the Department of Tolima demonstrated the potential for intercropping to reduce whitefly loads such that intercropped cassava outyielded monoculture. Host plant size and architecture appear to play an important role in whitefly population dynamics.

Interactions between component crops make intercropping systems inherently complex (Parkhurst and Francis 1986). Farming systems are defined by site-specific factors (e.g. climate, soils, ecology), farm history (previous crops, soil management), crop parameters (crop combinations, cultivar selected, quality of planting material, relative planting dates, crop density, spacing and planting arrangement, pests and diseases), farmer inputs (soil amendments, weed control) and the competitive balance between crops during a given crop cycle. In turn, cropping system texture and host plant quality are likely to influence herbivore colonization, tenure time, survivorship and reproduction.

Intercrop conditions favouring or discouraging insect increase may not be intrinsic to a crop combination and may vary between crop cycles. The competitive balance between cropping system components may be altered by relative planting dates, densities and arrangements, selection of cultivars, quality of planting material and site-specific conditions. For example, application of phosphorous to cassava/cowpea systems favoured cowpea, altering the competitive balance between the two crops and reducing cassava yields at sites where phosphorous increased yields in cassava monocultures (Leihner, 1983).

Therefore, extrapolation of results from farming system trials must always be done with caution.

Such extrapolation is even more tenuous in applying the research results from Colombia reported here to other species of whiteflies in African cassava farming systems.

**Implications for cassava mosaic virus disease control in Africa.** In contrast to the situation in Latin America, the status of *B. tabaci* as a pest of cassava in Africa is because it transmits the geminiviruses that cause African cassava mosaic disease (ACMD). Pest thresholds are not well known but preliminary information on vector potential suggests that low densities of whiteflies can be quite efficient at spreading ACMV (Dubern, 1994).

Therefore, the relevance to Africa of a South American study on intercropping and outbreak levels of whiteflies is not clear. Emerging questions relate to finding the response of whiteflies to different crop combinations, if any reductions in herbivore numbers that occur have meaningful impact on ACMD incidence and if such systems might be adopted by farmers.

Nevertheless, the use of multiple cropping systems as a means of reducing whitefly load and transmission of ACMV in Africa warrants study. Of special interest would be the presence of other biotypes of *B. tabaci* (c.f. Legg *et al.*, 1994) on associated intercrops (e.g. cotton, sweet potato) which could influence natural enemy populations and control of cassava whiteflies. Studies on cassava intercropping systems might also include research into whitefly/host plant relationships (nutritional quality of the host plant) and the influence of cropping systems on whitefly colonisation and subsequent movement patterns within crops.

Ideally, studies on intercropping and cassava whiteflies should provide insights into pest population dynamics and lead to the recommendation of cropping systems which are likely to be adopted by farmers. Purely academic studies may be useful to gain an understanding of the underlying mechanisms affecting pest abundance patterns which can then guide further research. Results from such studies can identify the types of systems which might be advantageous. These must then be put into the context of which system might be adopted and what type of adjustments farmers might be willing to make.

## ACKNOWLEDGEMENTS

I thank Miguel Altieri and Tony Bellotti for their thoughtful suggestions at all stages of this research. The tireless assistance of Gustavo Trujillo, Luis Carlos de la Pava and Artemio Ortiz in data collection is gratefully acknowledged. Miguel Altieri, Tony Bellotti, Roy van Driesche, John Wightman, James Legg, William Otim-Nape and Michael Thresh provided critical reviews of earlier versions of this paper.

## REFERENCES

- Altieri, M.A. and Letourneau, D.K. 1982. Vegetation management and biological control in agroecosystems. *Crop Protection* 1:405-430.
- Altieri, M.A. and Schmidt, L. 1987. Mixing broccoli cultivars reduces cabbage aphid numbers. *California Agriculture* 41:24-26.
- Andow, D. 1983. *Plant Diversity and Insect Populations: Interactions Among Beans, Weeds, and Insects*. Ph.D. Dissertation. Cornell University. 201 pp.
- Bach, C.E. 1980. Effects of plant density and diversity on the population dynamics of a specialist herbivore, the cucumber beetle, *Acalymma vittata* (Fab.). *Ecology* 61:1515-1530.
- Burban, C., Fishpool, L.D.C., Fauquet, C., Fargette, D. and Thouvenel, J.-C. 1992. Host-associated biotypes within West African populations of the whitefly *Bemisia tabaci* (Genn.) (Hom., Aleyrodidae). *Journal of Applied Entomology* 113:416-423.
- Cantelo, W.W. and Sanford, L.L. 1984. Insect population response to mixed and uniform plantings of resistant and susceptible plant material. *Environmental Entomology* 13:1443-1445.
- Cock, J.H. 1982. Cassava: A basic energy source in the tropics. *Science* 218:755-762.
- Cock, J.H. 1983. Cassava. In *Potential Productivity in Field Crops Under Different Environmental Conditions*. Yoshida, S. (Ed.), pp. 341-349. IRRI, Los Banos, Philippines.
- Cock, J.H. 1985. *Cassava: New Potential for a Neglected Crop*. Westview Press. 191 pp.
- Doll, J. 1978. Weeds: an economic problem in cassava. In: *Proceedings Cassava Protection Workshop*. Brekelbaum, T., Bellotti, A.C. and Lozano, J.C. (Eds.), pp. 65-69. CIAT, Cali, Colombia.
- Dubern, J. 1994. Transmission of Africa cassava mosaic geminivirus by the whitefly (*Bemisia tabaci*). *Tropical Science* 34:82-91.
- Gold, C.S. 1987. *Crop Diversification and Tropical Herbivores: Effects of Intercropping and Mixed Varieties on the Cassava Whiteflies, Aleurotrachelus socialis Bondar and Trialeurodes variabilis (Quaintance), in Colombia*. Unpubl. Ph.D. Dissertation. Univ. of California, Berkeley. 362 pp.
- 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 in Colombia: An examination of the "natural enemies hypothesis". *Bulletin of Entomological Research* 79:115-121.
- Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1989b. Effects of varietal mixtures on the cassava whiteflies, *Aleurotrachelus socialis* Bondar and *Trialeurodes variabilis* (Quaintance) in Colombia. *Entomologia Experimentalis et Applicata* 53:195-202.
- Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1989c. 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., 1990a. Direct and residual effects of short duration intercrops on the cassava whiteflies *Aleurotrachelus socialis* and *Trialeurodes variabilis* in Colombia. *Agriculture, Ecosystems and Environment* 32:57-67.
- Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1990b. Response of the cassava whitefly, *Trialeurodes variabilis* (Quaintance) (Homoptera: Aleyrodidae) to host plant size: implications for cropping system management. *Acta Oecologica* 11:35-41.
- Gold, C.S., Altieri, M.A. and Bellotti, A.C. 1991. Survivorship of the cassava whiteflies, *Aleurotrachelus socialis* and *Trialeurodes variabilis* (Homoptera: Aleyrodidae) under

- different cropping systems in Colombia. *Crop Protection* 10:305-309.
- Gould, F. 1986a. Simulation models for predicting durability of insect-resistant germplasm: A deterministic diploid, two-locus model. *Environmental Entomology* 15:1-10.
- Gould, F. 1986b. Simulation models for predicting durability of insect-resistant germplasm: Hessian fly (Diptera:Cecidomyiidae)-resistant winter wheat. *Environmental Entomology* 15:11-23.
- Legg, J.P., Gibson, R.W. and Otim-Nape, G.W. 1994. Genetic polymorphism amongst Ugandan populations of *Bemisia tabaci* (Gennadius) (Homoptera:Aleyrodidae), vector of African cassava mosaic geminivirus. *Tropical Science* 34:73-81.
- Leihner, D.E. 1983. *Management and Evaluation of Intercropping Systems with Cassava*. CIAT. Cali, Colombia. 70pp.
- Lozano, J.D., Byrne, D. and Bellotti, A. 1980. Cassava/ecosystem relationships and their influence on breeding strategy. *Tropical Pest Management* 26:180-187.
- Mason, S.C. 1983. *Land Use Efficiency, Canopy Development, Dry Matter Production, and Plant Nutrition of Cassava-Grain Intercropping*. Ph.D. Dissertation. Purdue University.
- Mead, R. and Willey, R.W. 1980. The concept of "land equivalent ratio" and advantages in yields from intercropping. *Experimental Agriculture* 16:217-228.
- Neuenschwander, P. 1994. The spiralling whitefly, *Aleurodicus dispersus*, a recent invader and new cassava pest. *African Crop Science Journal* 2:419-421.
- Norman, D.W. 1974. Rationalizing mixed cropping under indigenous conditions: the example of northern Nigeria. *Journal of Development Studies* 1:3-31.
- Nweke, F., Dixon, A.G.O., Asiedu, R. and Folayan, S.A. 1994. *Cassava Varietal Needs of Farmers and Potential for Production Growth in Africa*. COSCA Working Paper No. 10. IITA, Ibadan. 239 pp.
- Parkhurst, A.M. and Francis, C.A. 1986. Research methods for multiple cropping systems. In: *Multiple Cropping Systems*. Francis, C.A. (Ed.), pp. 285-316. MacMillan. London.
- Pedgley, D. 1982. *Windborne Pests and Diseases: Meteorology of Airborne Organisms*. Ellis Horwood Ltd. Chichester. 250 pp.
- Power, A.G. 1988. Leafhopper response to genetically diverse maize stands. *Entomologica Experimentalis et Applicata* 49:213-219.
- Price, P.W. 1976. Colonization of crops by arthropods: non-equilibrium communities in soybean fields. *Environmental Entomology* 5:605-611.
- Risch, S.J. 1981. Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. *Ecology* 62:1325-1340.
- Risch, S.J., Andow, D. and Altieri, M.A. 1983. Agroecosystem diversity and pest control: Data, tentative conclusions and new research directions. *Environmental Entomology* 12:625-629.
- Root, R.B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). *Ecological Monographs* 43:95-124.
- Sanders, J.H. and Lynam, J.K. 1981. New agricultural technology and small farmers in Latin America. *Food Policy* 6:11-18.
- Sheehan, W. 1986. Response by specialist and generalist natural enemies to agroecosystem diversification: a selective review. *Environmental Entomology* 15:456-461.
- Tahvanainen, J.O. and Root, R.B. 1972. The influence of vegetational diversity on the populational ecology of a specialized herbivore, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). *Oecologia* 10:321-346.
- Taylor, L.R. 1984. Assessing and interpreting spatial distributions of insect populations. *Annual Review of Entomology* 29:321-357.
- Thresh, J. M., Fargette, D. and Otim-Nape, G.W. 1994. The viruses and virus diseases of cassava in Africa. *African Crop Science Journal* 2:459-478.
- Weber, E., Nestel, B. and Campbell, M. 1979. *Intercropping With Cassava*. IDRC, Ottawa, 142 pp.