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Review Article

Biological control of agricultural insect pests in Venezuela; advances, achievements, and future perspectives

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Abstract

Biological control has been practised in Venezuela from the beginning of the 20th century, beginning with the classical introductions of *Rodolia cardinalis* for controlling *Icerya purchasi*, *Aphelinus mali* for the woolly apple aphid (*Eriosoma lanigerum*), and *Apanteles thurberiae* for the cotton pest *Sacadodes pyralis*. These classical introductions were similar to those of other countries of Latin America. However, the first practical attempts at controlling the sugarcane borer, *Diatraea* spp., were begun in the 1950s with the introduction of the Amazonian fly, *Lydella* (= *Metagonistylum*) *minense*. Following on from this success, the most important achievements were the introduction of *Prospaltella opulenta* by which the citrus blackfly, *Aleurocanthus woglumi*, was brought under complete control, and the introductions of *Cotesia flavipes* for controlling *Diatraea* spp. and *Telenomus remus* for controlling the armyworm, *Spodoptera frugiperda*. Several laboratories now rear *C. flavipes* and *T. remus* on a large scale in Venezuela. At the same time, the use of *Metarhizium anisopliae* and other related entomopathogens was developed, and these are nowadays produced on a commercial basis and are extensively used in a number of crops.

Introduction

In South America and the Caribbean region, biological control has been used with much success since the beginning of the twentieth century. However, its practical implementation has been slow, with adequate importance only given to this aspect in the last few decades.

Biological control in Venezuela has a similar historical background to that in other Latin American countries, such as in Peru, Argentina and Bolivia. It began in the 1930s and 40s with the introduction of the coccinellid *Rodolia cardinalis* Mulsant [= *Vedalia cardinalis*] to control cottony cushion scale, *Icerya purchasi* Maskell (Hom., Margarodidae), in citrus, and the parasitoids *Aphelinus mali* (Haldeman) (Hym, Aphelinidae) and *Apanteles thurberiae* Muesebeck (Hym., Braconidae) to control woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Hom., Aphididae), and the cotton pest *Sacadodes pyralis* Dyar (Lep., Noctuidae), respectively.

In recent years a number of institutions, private and governmental, have introduced beneficial insects. Nevertheless, there are still only a few crops in Venezuela in which entomophagous insects have been used to control other pest insects. This is due, amongst other reasons, to an absence of technology transfer and to the trend towards using agrochemical products by producers. However, successful experience of biological control in crops such as sugarcane, maize and sorghum raises the expectation that for many other crops biological control could have major importance from both an economical and ecological point of view.

Historical Perspective

Releases and introductions related to the development of biological pest control in Venezuela are summarized in Table 1.

Biological pest control has been very slow to develop, given how long ago it was first suggested as a solution for pest problems in Venezuela, and the length of time since the first introductions were made. In 1884, Adolfo Ernst and other members of the Public Utility Society (Sociedad de Utilidad Pública) proposed the use of the native parasitoid wasp, *Scelio famelicus* Riley (Hym., Scelionidae), for locust control. They indicated that this control method would probably be successful if it was generally and consistently applied (Guagliumi, 1962).

Between 1939 and 1941, Charles Ballou introduced the predatory coccinellid *Rodolia cardinalis* to control *Icerya purchasi* in citrus, and two parasitoid species, *Aphelinus mali* against woolly apple aphid, *Eriosoma lanigerum*, and *Apanteles thurberiae* to control *Sacadodes pyralis* in cotton (Giraldo, 1988).

Table 1. Species of biological control agents introduced or released as biocontrol agents in Venezuela.

Date	Scientist responsible	Control agent	Pest	Crop
1884	Adolfo Ernst	*Scelio fermerelis* Riley	*Schistocerca cancellata* Serville as *S. paranensis* (Burmeister)	various
1913	Ernst	*Cocobacillus acridorium*	*S. cancellata* as *S. paranensis*	various
1939-41	Charles H. Balou	*Rodolia cardinalis* Mulsant (as *Vedalia cardinalis*)	Coccidae	citrus
		Aphelinus mali (Haldeman)	Aphididae	fruit crops
		Apanteles thurberiae Muesebeck	*Sacadodes pyralis* Dyar	cotton
1946-53	Harold Box	*Lydella minense* (Townsend) (=*Metagonistylum minense*)	*Diatraea* spp.	sugarcane
		Paratheresia claripalpis Wulp		
1952	Pedro Guagliumi	*Lixophaga diatraea* Townsend	*Diatraea* spp.	sugarcane
1956	F. Kern	*Bacillus thuringiensis*	*Spodoptera frugiperda*	maize & various other crops
1960	W. Szumkowsky	*Hippodamia convergens* Guérin-Méneville	various pests	various crops
1975	Francis Geraud	*Prospaltella opulenta* Silvestri	*Aleurocanthus woglumi* Ashby	citrus
1975-80	ANCA[1]	*Trichogramma* spp.	Lepidoptera	cotton
1979	F. Linares & Francisco Ferrer	*Cotesia flavipes* Cameron	*Diatraea* spp.	sugarcane
1986	D. Hernández & Ferrer	*Telenomus remus* Nixon	*Spodoptera frugiperda*	maize
1987-92	Ferrer	*Spalangia endius* Walker	Muscidae	-
		Muscidifurax raptor Girault & Sanders		
1991-92	Ferrer	*Copidosoma koehleri* Blanchard	*Phthorimaea operculella* (Zeller)	potato, tomato
		baculovirus		
1991-92	Hugo Chávez	*Cotesia plutellae* Kurdyumov	*Plutella xylostella* (L.)	crucifers
1992-99	SERVBIO	*Chrysoperla externa* (Hagen)	various pests	various crops
		baculovirus	*P. operculella*	potato, tomato

[1] Asociación Nacional de Cultivadores de Algodón [National Cotton Growers Association].

[2] Servicio Biológico C.A. [Biological Control Service Company].

Table 2. History of *Telenomus remus* use in Venezuela.

Year	Activity	Maize (ha)	Other crops (ha)	Total *Telenomus* released (1000s)	Effect
1979	introduction				
1980-86	laboratory studies				
1987	1st field trials	10		4	90% parasitism
1988	field trials	10		200	24-100% parasitism
1989	semi-commercial	50		200	90% parasitism
1990	semi-commercial	120		480	50-80% parasitism
1991	commercial	658	1990	19560	50% reduction
1992	commercial	600	1300	15655	ND[1]
1993	commercial	100	833	7470	ND[1]
1994	commercial	1500	1000	19925	50% reduction
1995	commercial	1321	900	17772	50% reduction
1996	commercial	4252	0	25512	50% reduction
1997	commercial	1015	535	9320	50% reduction
1998	commercial	569	0	3414	70% reduction
1999	commercial	1640	200	9838	80% reduction
Totals 1979-99		11845	6758	129350	

[1]No data.

In 1946, the entomologist Harold Box and his collaborators at the Ministry of Agriculture at Maracay (Aragua State) began the introduction and breeding of the Amazonian fly, *Lydella minense* (Townsend) (= *Metagonistylum minense*) (Dipt., Tachinidae) to control sugarcane borers, *Diatraea* spp. The fly was reared in laboratories at the Ministry of Agriculture Experimental Station and the sugarcane factory El Palmar, at Maracay. From this starting point, several sugar mill companies adopted the method of controlling the sugarcane borer, using flies reared under controlled conditions in specially constructed laboratories. Strains of *Paratheresia claripalpis* Wulp (Tachinidae) from Trinidad, Mexico and Peru were introduced in 1950 and 1952 (Box, 1953). The Cuban fly *Lixophaga diatraeae* Townsend (Tachinidae) was also introduced in 1952, by Pedro Guagliumi.

Subsequently, the coccinellid *Hippodamia convergens* Guérin-Méneville was detected by W. Szumkowski, but there is no record of its introduction into Venezuela, and it is thought that it could have migrated from neighbouring countries (Guagliumi, 1962).

The citrus blackfly, *Aleurocanthus woglumi* Ashby (Hom., Aleyrodidae) had spread to all parts of the country since 1965, causing serious damage to citrus. In 1972, the entomologist Jose M. Osorio Rojas of the West–Central University (Universidad Centro Occidental 'Lisandro Alvarado', UCLA) at Barquisimeto (Lara State) reported on the main natural enemies of this pest in Venezuela for the first time (Osorio *et al*., 1972).

In 1975, to combat *A. woglumi*, experts from the Farmers' Foundation (Fundación para el Agricultor, FUSAGRI), the Venezuelan Central University (Universidad Central de Venezuela, UCV), the National Agricultural Investigation Fund (Fondo Nacional de Investigaciones Agropecuarias, FONAIAP) and the National Agricultural Research Centre (Centro Nacional de Investigaciones Agropecuarias, CENIAP) introduced the parasitoid *Prospaltella opulenta* Silvestri (Hym., Aphelinidae) from Mexico. This is one of the few examples of almost complete biological control achieved by the introduction of a parasitoid (Geraud *et al.*, 1977; Noticias Agricolas, 1978). Further studies on the impact of *P. opulenta* (Chávez, 1980) showed that in the Central-Western Region of Venezuela, complete biological control of *A. woglumi* was observed 18 months after the releases were made.

In 1975 the Asian braconid, *Cotesia flavipes* Cameron, was introduced from Colombia for biological control of *Diatraea* spp., but attempts to use it were aborted following unsuccessful initial results. In 1981, *C. flavipes* breeding was begun again with material from Trinidad. Several thousand *C. flavipes* were produced and released in a number of regions from 1981 to 1982 by the Biological Control Service Company (Servicio Biológico C. A., SERVBIO) located in Barquisimeto, Venezuela (Ferrer, 1984), but without any positive effects being recorded. Then in 1985, abundant parasitism was detected for the first time in Ureña (Táchira State) and Cariaco (Monagas State) (Linares & Ferrer, 1990; Linares & Yepéz, 1992). More parasitoids were bred and redistributed using specimens captured at these locations. The programme soon began to achieve good results after these releases were made. Nowadays, *C. flavipes* provides substantial control of *Diatraea* spp. in several areas of the country (Ferrer & Guédez, 1990; Linares & Ferrer, 1990).

In 1979, *T. remus* was introduced by Francisco Ferrer from Trinidad for controlling the corn armyworm, *Spodoptera frugiperda* J. E. Smith (Lep., Noctuidae) (Yaseen *et al*., 1981; Morales *et al*., 2000). Parasitoid mass breeding and release began in several regions of the country. Positive results were obtained in Yaritagua, Yaracuy State (Hernández *et al*., 1989). Later *T. remus* was used extensively in a number of areas, and in some of these an immediate response was recorded. For example, in Túren (Portuguesa State), a very humid area, parasitism reached 90%. In other warmer and drier localities results were less striking. Overall, as discussed further below, the parasitoid has reduced the cost of using pesticides in integrated insect pest management (Ferrer, 1992).

In 1992, 80 million *T. remus* were produced in an attempt to protect some 6000-7000 ha of maize, but 80% of the material could not be distributed owing to lack of coordination between laboratories, producers and agricultural companies. Since then, however, *T. remus* has been used on a continuous basis in several areas of the country with good results (Table 2), especially in Las Velas, Yaracuy State, where the use of pesticides has been reduced by nearly 80%.

Current Status of Biological Insect Pest Control

Various state and private institutions are currently working in biological control in Venezuela (Table 3), although the main state institutions have so far done little in the field of technology transfer. The Entomology Department at UCLA has worked on the biology and reproduction of *Cotesia plutellae* Kurdyumov, and is conducting field tests to assess its ability to control *Plutella xylostella* (L.) (Lep., Plutellidae) (Chávez *et al.*, 1992). This department is also studying the reproduction of *Copidosoma koehleri* Blanchard (Hym., Encyrtidae), a biological control agent of potato moth, *Phthorimaea opercullela* (Zeller) (Lep., Gelechiidae). FONAIAP is involved in research on and production of *Trichogramma* spp., while UCV has a laboratory that produces predatory mites.

Private enterprise has taken a lead in facilitating the implementation of biological control. For example, the most important advances in biological control of sugarcane pests have been made by private companies. The PROBIOAGRO Company (Productos Biológicos para el Agro, C. A.) annually treats several thousand hectares of sugarcane with *Metarhizium anisopliae* (Metsch) Sorok. to control *Aeneolamia varia* (F.) (Hom., Cercopidae) (Sosa & Zambrano, 1987; Zambrano *et al*., 1987, 1993). This is complementary to the long-standing use of entomophages against sugarcane borers. In the 1960s and 70s the Institute for the Promotion of Agricultural Productivity (Instituto para el Fomento de la Productividad Agropecuaria, IFPA) had seven laboratories producing sugarcane borer parasitoids. Since 1977, biological control agent production has been a function of SERVBIO, which currently serves several sugar mill factories, and has undertaken the work of the IFPA laboratories (Ferrer, 1984). SERVBIO together with a new Foundation for the Development of Sugarcane (FUNDACAÑA) have the production capacity to treat approximately 40,000 ha of sugarcane per year by releasing the larval parasitoids *C. flavipes* and *L. minense*.

Major Uses of Biological Control

Sugarcane

The area of production of sugarcane in Venezuela is approximately 120,000 ha, and some 20 factories are involved in the industry, which produces about 60% of the national needs. Two main pests are important in the sugar industry in Venezuela: the sugarcane borer *Diatraea* spp., which comprises five important species (*D. saccharalis* (F.), *D. rosa* Heinrich, *D. centrella* Moscher, *D. impersonatella* (Walker), and *D. busckella* Dyar & Heinrich), and the sugarcane froghopper, *Aeneolamia varia*. These pests cause serious losses because they blight the leaves of the sugarcane leading to serious impairment of photosynthesis.

Table 3. Main centres working in biological pest control in Venezuela.

Centre		Acronym	Expertise[1]
Consejo Nacional de Investigaciones Científicas y Tecnológicas	National Board of Scientific and Technological Research	CONICIT	E, I, P
Instituto Venezolano de Investigaciones Científicas	Venezuelan Institute for Scientific Research	IVIC	E, I, P
Fondo Nacional de Investigaciones Agropecuarias	National Agricultural Investigation Fund	FONAIAP	E, I
Centro de Investigaciones del Estado para la Producción Experimental Agroindustrial	State Research Centre for Experimental Agro-industrial Production	CIEPE	E, P
Servicio Biológico C.A.	Biological Control Service Company	SERVBIO	CB, E, P
Productos Biológicos para le Agro C.A, Acarigua, Portuguesa State	Biological Products for Agriculture Company	PROBIOAGRO	CB, P
Centro de Producción Biológica, C.A., Guaríco State	Centre of Biological Production Company	CEPROBIOLCA	E
AGROBICA C.A., Valencia, Carabobo State	Agrobiologicals Company	AGROBICA	P
Laboratory de Ingenios Azucareros, FUNDACAÑA Central Matilde (Yaritagua) Central La Pastora (El Palmar)	Sugar refineries' engineering laboratories		E
Asociación Nacional de Cultivadores de Algodón	National Cotton Growers Association	ANCA	E, P
Algonodera Mata, Anzoátegui State	Mata Cotton Station	ALMACA	E
Universidad Centro Occidental 'Lisandro Alvarado', Departamento de Entomología, Barquisimeto, Lara State	Central–West University, Entomology Department	UCLA	E, I
Instituto de Zoología, Universidad Central de Venezuela, Fac. Agronomía, Maracay, Aragua State	Zoology Institute, Central University of Venezuela, Agronomy Faculty	UCV	E, I, P

[1] CB = general biological control; E = entomophages; I = research; P = entomopathogens.

Table 4. Distribution of IPM costs in commercial maize fields in Portuguesa, Lara, Yaracuy and Barinas States, Venezuela during the rainy season, 1994.

State	Area (ha)	*Telenomus* releases (1000s)	Monitoring visits	Estimated cost without IPM (US$)	Total cost with IPM (US$)	Estimated saving with IPM (US$)[1]
Portuguesa	501	3350	133	30925	19961	10964
Lara	100	926	31	6173	1969	4204
Yaracuy	759	3365	ND[2]	46881	20121	26760
Barinas	200	1600	ND[2]	8320	5190	3130
Totals	1560	9241	164	92299	47241	45058

[1] The overall benefit-cost of IPM was 48.82%.

[2] No data.

Table 5. Summary of real costs of IPM rural programme in Yaracuy State, Venezuela in 1997.

		Costs of IPM (US$/ha)						
Organization/ community	Area (ha)	*Telenomus*	Monitoring	Insecticide	IPM total	Real expenditure with IPM (US$)[1]	Budgeted cost without IPM (US$)[2]	Estimated saving with IPM (US$)[3]
Valle Blanco	128	11.49	0.44	10.09	22.02	2819	7466	4647
El Palmar	206	16.11	7.22	9.12	32.43	6681	12016	5335
Las Cañadas	127	10.32	5.24	10.54	26.10	3315	7408	4093
Las Velas	319	8.50	8.45	22.09	39.04	12454	18607	6153
El Rodeo	112	17.55	10.08	6.25	33.88	3795	6533	2738
Agua Viva	52	7.55	10.49	17.70	35.74	1858	3033	1175
Average		11.92	6.98	12.63	31.53			
Total	944					30922	55063	24141

[1] Cost per ha with IPM averaged US$32.76 (Bolivares 16,380); US$1 = Bolivares 500.

[2] Budgeted cost per ha US$58.33 (Bolivares 29,165).

[3] The benefit-cost of using IPM was 43.84%.

As described above, the Amazonian fly, *L. minense*, has been released against *Diatraea* sugarcane borers continuously since 1951, and its effectiveness is demonstrated by an average parasitism rate of 17.34% over 36 years (Linares & Ferrer, 1990). This parasitoid showed a preference for *D. saccharalis*, which was the dominant species in the 1950s. In 1959, Box reported stem-borer populations comprising 81% *D. saccharalis*, 11% *D. busckella* and 7% *D. centrella*, and he found parasitism rates in *D. saccharalis* of 45-74% (Box, 1959). In 1976, the entomologist Jhonny Saldivia stated that the species proportions had changed to 90% *D. busckella*, 7% *D. saccharalis* and 3% *D. centrella*, indicating a significant decrease in the proportion of *D. saccharalis* (Ferrer, 1984). In a more recent study, however, Linares (1987) reported that *D. busckella* was non-existent in the Turbio River sugar refinery area (Lara State), but that *D. rosa* was present. Although he confirmed that there has been a shift in *Diatraea* species composition and relative abundance since biological control was first implemented, his work suggests there have been some mistakes made in species identifications during this period.

Since the first releases, the braconid *Cotesia flavipes* has also contributed significantly to reducing crop losses from sugarcane borers. Parasitism rates of 90% have been recorded. In the Turbio River area, the stem-borer infestation rate (assessed by percentage perforated internodes) was reduced from 20% (in the 1950s) to 9% in 1981 following continuous release of *L. minense*. An average infestation rate of 6-7% was maintained until 1988, but this was reduced further, to less than 2.5%, between 1990 and 1992 following mass *C. flavipes* releases (Ferrer, 1995). Similar results have been reported by many other sugar refineries (Salazar, 1993). The add-on effect of *C. flavipes* can be attributed to its ability to parasitize all the predominant species: *D. centrella*, *D. rosa* and *D. saccharalis.*

SERVBIO released 7,051,619 *L. minense* in the period 1981-92, and 265,337,000 *C. flavipes* in 1988-99.

Control of the cercopid *A. varia* by *Metarhizium anisopliae* was first attempted in 1986. The first positive results were obtained in small plots of less than 20 ha (Sosa & Zambrano, 1987; Zambrano *et. al*., 1987). Nowadays, most sugarcane growers use microbial biological control for this pest, but to varying extents.

In 1986-90, CORBICAN-1 mycoinsecticide (containing *M. anisopliae* as the active ingredient) was applied to an accumulated area of 87,000 ha, throughout the country (Molina *et al.*, 1992). In Venezuela, as in Brazil, environmental conditions allow epizootics to be produced in *A. varia*. The entomopathogen is becoming increasingly accepted by sugarcane growers with each successive year (Zambrano *et al*., 1993). For example, El Palmar and Tacarigua sugar refineries applied the fungus via aerial and terrestrial spraying on 89.87% of their combined sugarcane growing area of 15,000 ha in 1990 (N. Molina, pers. comm.).

Sugarcane is an example of well-organized IPM. The inter-institutional IPM programme for control of *Aeneolamia* and sugarcane borers (Programa Inter-Institucional de Combate de la Candelilla y el Taladrador, PICANTA), formed in 1984, established a workplan that included monitoring, parasitoid releases and entomopathogenic applications for each sugar refinery area. Control achievements with sugarcane borers are illustrated by an economic analysis, which shows that for each bolivar invested in biological control, a minimum of 22 bolivares has been saved (Ferrer, 1995).

However, more threats are emerging. A new pest, the sugarcane delphacid, *Perkinsiella saccharicida* Kirkaldy, has been detected in Lara and Yaracuy States. This is the main pest of sugarcane in Fiji, and is thus potentially very serious. In addition, Salazar *et al.* (1991) report that *Fulmekiola serrata* (Kobus) (Thysanopt., Thripidae) is now causing pest problems in sugarcane in Venezuela.

Maize and sorghum

Maize and sorghum crops are of special importance for a large part of the Venezuelan rural population; for instance in the year 1988 the combined area of the crops reached 800,000 ha. The main pests in these crops are the armyworm, *Spodoptera frugiperda* and, to a lesser extent, *Mocis latipes* Guenée (Noctuidae), and *Helicoverpa zea* Boddie (Noctuidae). Several pesticides are used for controlling these pests, but as maize price and production (about 3000 kg/ha) are both low, it is not possible to use excessive control measures. For this reason, biological control is an alternative that should be taken in account.

The first field trials with *Telenomus remus* were conducted near Yaritagua (Yaracuy State) in 1987 (see Table 2). Six weeks after the first releases, 90% parasitism of pest *Spodoptera* spp. eggs was recorded within a 100-m radius of the release sites (Hernández *et al.*, 1989). In 1988, another field trial was conducted in order to continue the study of *T. remus* dispersion. A total of 165,000 individuals was released over a 0.8-ha plot. Results indicated 14% parasitism one week after first releases, and 100% eight weeks later (Meléndez, 1988).

In 1989, semi-commercial releases of *T. remus* were made around Turén (Portuguesa State) (Ferrer & Meléndez, 1990). Parallel with the releases, and as set out in the agreement between the University of Los Llanos (Barinas, Portuguesa State) and the National Association of Cotton Growers (Asociación Nacional de Cultivadores de Algodón, ANCA), a trial was set up in commercially planted maize to study (a) levels of *Telenomus* parasitism in *Spodoptera* eggs, and (b) the effective range of the parasitoid. Parasitism levels of 55.7-71.4% were recorded, and *Telenomus* was found to be active for a distance 60 m from the point of release, within 24 h.

In 1990, *T. remus* was released in an area spread over several states, a total of 120 ha. In 1991, the release programme covered 658 ha of winter maize in areas of four states: Lara, Yaracuy, Portuguesa and Guárico. A total of five million wasps was released and positive control results were obtained in all except warm dry areas such as, for example, at El Sombrero in Guárico State (Ferrer, 1992).

At the end of 1991, an IPM programme was begun in sorghum in El Tigre (Anzoátegui State). The programme was implemented over an area of 1990 ha by individual producers and was financed by a company that produces sorghum seeds, Agropecuaria Los Riecitos. A total of 18,820,000 *T. remus* was released along with 89.375 square inches of *Trichogramma* sp. wasps (one square inch is equivalent to 2500 to 3000 trichogramma wasps). Together the releases led to farmers reducing their pest control costs by an average of US$23/ha (at that time US$1 = Bolivares 171) over the budgeted cost for non-IPM management of close to US$72/ha (12,300 bolivares). Some farmers saved US$ 50/ha (Ferrer, 1992; Ferrer, 1996). In 1992, SERVBIO planned the management of 5000 ha of maize using biological inputs in the winter season. However, only 600 ha in Portuguesa, Lara and Yaracuy States were included. Producers were discouraged by low maize prices, and by the fact that loan and input supplies were made available out of time.

In 1994, IPM programmes implemented in Lara, Yaracuy, Portuguesa and Guárico States made cost savings of 49%, compared to the budgeted cost of non-IPM management. The figures for these states are summarised in Table 4.

Since 1991, *Telenomus remus* has been released in Las Velas valley, Yaracuy State and outstanding results have been obtained over an area of 944 ha (Table 5). The monitoring activity for this programme was managed by an NGO, the Inter-Institutional Cooperative Movement of Las Velas and El Palmar (Movimiento Ecológico Cooperativo de Investigacion Las Velas–El Palmar, MECOIVEPAL), in collaboration with SERVBIO, who provided laboratory services and supplied *T. remus* to the programme. In 1997 the average number of *Telenomus* released was 3848 wasps/ha, together with a small number of *Trichogramma pretiosum* Riley (Hym., Trichogrammatidae). It was evident that substantial savings were made when insecticide costs were considered. In total, 34.2% and 21.8% of the amounts of powder and liquid insecticides, respectively, budgeted for use in non-IPM areas were used in the IPM programme, and the total cost of *Spodoptera* control in the IPM area was reduced by nearly 50% (Ferrer, 1995). In 1999, this success was repeated when growers from Las Velas applied almost no insecticides in nearly 1600 ha of IPM maize (F. Ferrer, unpublished data).

On this basis, if the maize crop of the whole country, averaging some 300,000 ha, were managed under IPM, the saving would be nearly 3,556,193,200 bolivares, or some US$7 million. This, however, is likely to be an underestimate of the actual saving, because the budgeted cost of pest control in Las Velas rural sector (29,166 bolivares/ha, or near US$58.33) is low compared to figures for the country as a whole.

Spodoptera nuclear polyhedrosis virus (NPV) is produced by SERVBIO as one of its research projects in biological control, which aims to provide an alternative for *Spodoptera* control in maize. In 1992, laboratory and field bioassays were conducted to determine the infective capacity of Spodopterin, a commercial *Spodopera* NPV product produced by Calliope, France (Romero, 1997). At the laboratory level, studies were conducted on inoculation dose, effect of larval size, and the time scale of virus action. Field applications were tested on established maize crops. Although more research is still needed, expertise in laboratory production of NPVs has been developed, and it is intended to adapt the production system for native NPV isolates.

There is potential for integrating NPV use with a wide range of biological inputs to improve control in the maize system, for example *Nomurea rileyi* (Farlow) Samson and *Bacillus thuringiensis* as well as *Telenomus remus* and *Trichogramma* spp.

Cotton

Biological control in cotton through *Trichogramma* spp. releases has been facilitated by the activities of several laboratories (one of which is the National Association of Cotton Growers, ANCA) since the middle of the 1970s. The use of parasitoids has reduced insecticide applications by a significant amount.

The basic studies for mass rearing *Trichogramma* spp. began in 1973 under an agreement between the Cotton Development Fund (FDA), ANCA, and the Experimental Station at Araure – FONAIAP (Portuguesa State). Between 1973 and 1976 releases of this parasitoid to control *Heliothis* spp. and *Alabama argillacea* Hübner (Noctuidae) were initiated in cotton fields of Portuguesa and Anzoátegui States in the east of the country. The goal of this project was to establish, together with other cultural practices, the training of technical personnel. The application of pesticides was reduced from 14.8 to 6 applications (Salas, 1993). The establishment of a *Trichogramma* laboratory was achieved in Anzoátegui in 1987, and recently (1997) SERVBIO has installed a laboratory in the locality of Sanare (Lara State) with the aim of controlling several lepidopteran pests on vegetables and other crops (Giraldo, 1988).

Trichogramma is a parasitic wasp in common use by the national producer groups, but this service has been diminished in the last four years because of a reduction in the areas of cotton in the country. This reduction was due to the high costs of national cotton production compared to imported cotton prices. At present (2001) the government is providing financial help for the cotton growers and it seems likely that this will lead to a revival of this crop, with good prospects for biological control.

Other crops

Since 1998, an IPM package (which includes the use of chrysopids and *Trichogramma*, sticky traps and weekly monitoring) has been in use in vegetable crops, and has been particularly successfully applied in sweet pepper, cucumber, tomato, potato and melon. In 1998 in Humocaro (Lara State), for example, where sweet pepper is an important crop, producers made savings of 80% in pest control costs by adopting the IPM practices rather than applying pesticides in the conventional programmed manner. In 1999, excellent results were achieved using chrysopids in melon in Isle of Margarita (Nueva Esparta State), where there was almost no necessity for pesticide applications because of successful control of the whitefly (*Bemisia tabaci* (Gennadius); Hom., Aleyrodidae) by these predators.

Future Prospects

Recently, PROBIOAGRO has begun to produce the entomopathogenic fungus *Verticillium lecanii* (Zimmerman) Viegas for controlling *B. tabaci*, *Nomurea rileyi* for controlling *Spodoptera frugiperda*, and *Beauveria bassiana* (Balsamo) Vuillemin for controlling a number of different pests. From 1987 to 1992, SERVBIO introduced *Spalangia endius* Walker (Hym., Pteromalidae), *Muscidifurax raptor* Girault & Sanders (Pteromalidae) and *Copidosoma koehleri* from the Centre for Introduction and Breeding of Useful Insects (Centro de Introducción y Cría de Insecto Utiles, CICIU), Peru; *Spalangia cameroni* Perkins from Colombia, and *Baculovirus phthorimaea* from the International Potato Centre (CIP), Peru. All of these are currently under investigation and/or in use. More recently, from 1996 to 1999, SERVBIO has established a laboratory to produce *Trichogramma* and *Chrysoperla*.

Demand for biological control in IPM in Venezuela is growing, owing to recent pest outbreaks that have affected extensive agriculture. Although physical, budgetary and human resources are limited, some incentives have appeared to encourage adoption and implementation of biological control. Many farmers with extensive areas planted to sorghum and maize are supervised by the Integral Technical Assistance (Asistencia Técnica Integral, ATI) programme of PALMAVEN (a subsidiary of the company Petróleos de Venezuela). This organization has an agreement to promote IPM. Field days have been held to show the effectiveness of IPM, and interest in it is growing. Some 3500 ha of cereal crops were expected to be under IPM in 2001. An annual increase in the area under IPM of 5% is anticipated, as experience has already shown that 50% savings in the pest control budget can be made (Ferrer *et al.*, 1992). The IPM package includes: a monitoring system for pests (with the recommendation that chemicals products be used only when the economic threshold is exceeded), the use of *N. rileyi*, *Telenomus remus* and *Trichogramma* spp., and various other biologically-based techniques.

Conclusions

Even though Venezuelan national organizations are in a critical economic situation, research must still be conducted that is directed towards immediate transfer of IPM technology, to generate income, which will then help to develop projects. It is essential to establish better communication inside Venezuela so those projects can be executed. Nowadays, very few researchers really understand that the economic situation means that the Government is not a realistic source of funding. Instead, a way of tapping other sources from national and international institutions has to be found so that basic and applied research can continue. Researchers need to become more aware of grant-awarding bodies such as the National Board of Scientific and Technological Research (Consejo Nacional de Investigaciones Científicas y Tecnológicas, CONICIT) and a number of international organizations. In this context, the formation of an NGO might be a useful step.

A growing demand for IPM services in a number of crops has arisen because of a realization of the problems created by misuse of agrochemicals. Agricultural products free from pollutants are also demanded in the majority of industrialized countries, so IPM services are becoming essential. However, the reality shows that little preparation has been made to cope with this change in strategy. In view of the scattered resources in Latin America to tackle the problem, technology exchange and improved communications are vital. In this way, achievements in one country would be able to spread more quickly to others, and the challenge can be confronted regionally.

Many factors affecting the success of biological control need to be taken into account when working directly with producers. Hence, it is necessary to deal separately with each social and economic group. The key approach to technology transfer activities should be through demonstrations of economic cost-benefit, and the beneficial effects of biological control on the environment and human health.

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