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CONTROL OF THE VARIEGATED GRASSHOPPER *ZONOCERUS VARIEGATUS* (L.) ON CASSAVA

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ABSTRACT

Zonocerus variegatus is the main grasshopper pest of crops, notably cassava, in the humid lowland forests and savannas of West and Central Africa. In parts of West Africa, hatching is maximal at the start of the dry season (late September - early November), with outbreaks in November - April. From the 1950s, increased agriculture has resulted in forest clearings for cassava, maize and leafy vegetables, which provide ideal habitat for the pest. The aggregated early instars (I-III) prefer herbs off-farm, but later in the dry season (January-March) food-plants are scarce, and the more dispersed instars V, VI and adults move to crops. Although cassava leaves when damaged produce hydrogen cyanide (HCN), feeding in aggregations by the larger instars causes them to wilt and lose HCN quickly. Comparatively high concentrations of glucose in the guts of _Z. variegatus_ feeding on cyanogenic plants suggest that cyanogens are a primary nutrient. The spread of the exotic weed _Chromolaena odorata_ in West Africa coincided with the spread of _Z. variegatus_ perhaps because agricultural clearings are suited to both. For this reason, eradication of the weed will probably not control _Z. variegatus_. Although the grasshopper is attracted to the flowers, aggregation on _C. odorata_ is more likely to be due to oviposition and hatching in its shade, which also occur under other plants. The weed could be useful in distracting _Z. variegatus_ temporarily away from crops and as a spraying target. In 1970, Nigeria declared _Z. variegatus_ a major pest, and subsequently it has become a problem in Côte d'Ivoire, Ghana, Congo, Benin, Uganda, Senegal and Burkina Faso. In national and international campaigns, expensive chemical insecticides (presently the only defence) are applied. Spraying early-instar aggregations roosting on vegetation such as _C. odorata_ in November-December may be practical, provided farmers synchronise operations. However, chemicals are only effective in the short-term, are environmentally damaging, and eliminate the natural enemies of other pests. Spraying chemicals against _Z. variegatus_ kills the parasitoids, _Epidinocarsis lopezi,_ introduced to control the cassava mealybug. The resurgence of the mealybug has probably been a bigger problem than _Z. variegatus_ itself. Alternative methods for use by farmers are therefore necessary. Digging up egg pods for desiccation at the soil surface has given large reductions in populations. Egg pods occur in small areas close to cultivated fields. Farmers can identify these areas because of the large adult aggregations there in March-April. However, egg-pod exposure has so far not been attempted by farmers acting together. Spores of the fungus _Metarhizium flavoviride_ sprayed in kerosene and peanut oil kill 70-95% of field populations. A strain isolated from _Z. variegatus_ caused 90% mortality in 7-9 days in the laboratory. Cheap trap-and-release devices, baited with natural olfactory attractants and containing the spores in powder form, are being developed particularly to reach _Z. variegatus_ in the bush. Grasshoppers leaving the traps died within 10 days, up to 30 m away, and would serve for cross-infection. A single defoliation of cassava (to simulate _Z. variegatus_ feeding damage) does not decrease root yield, but additional ones do. Since many African communities eat the leaves, their loss is also important. An integrated management strategy for _Z. variegatus_, to be made in collaboration with farmers and national programmes, will take into account farmers' attitudes to crop damage, grasshopper trapping and spraying with fungal spores; local agricultural and pest-control

practices; and cost/benefit analyses. Chemicals will not be emphasised but habitat management, based on the grasshopper's feeding and oviposition behaviour, will be.

Key Words: **African agriculture, cassava, chemical control, *Chromolaena odorata*, egg-pod exposure, IPM, *Metarhizium flavoviride*, neem, olfactory traps, socio-economics, *Zonocerus variegatus***

RÉSUMÉ

Zonocerus variegatus **est le principal Acridien ravageur des cultures, surtout du manioc, dans les forêts humides de basse altitude et les savanes de l'Afrique de l'Ouest et de l'Afrique Centrale. Dans certaines régions de l'Afrique de l'Ouest, l'éclosion est maximale au début de la saison sèche (fin septembre-début novembre) et des pullulations se développent en novembre-avril. Depuis les années 50, l'extension de l'agriculture s'est accompagnée d'une déforestation au profit de cultures de manioc, de maïs et de légumes, ce qui a fourni au criquet un habitat idéal. Les jeunes stades agrégatifs (stades I - III) préfèrent les herbes spontanées, mais plus tard, au cours de la saison sèche (janvier-mars) les plantes alimentaires se faisant rares, les stades V et VI, plus dispersés, ainsi que les adultes, se déplacent vers les cultures. Bien que les feuilles de manioc produisent de l'acide cyanhydrique (HCN) quant elles sont endommagées, l'alimentation des stades âgés, agrégés sur les plantes, entraîne le flétrissement des feuilles et la perte rapide de l'HCN. Les fortes concentrations de glucose dans le tube digestif de *Z. variegatus* se nourrissant de plantes cyanogènes suggèrent que les glucosides cyanogènes sont utilisés comme des nutriments primaires. La dispersion de la mauvaise herbe exotique *Chromolaena odorata* en Afrique de l'Ouest a coïncidé avec la présence croissante de *Z. variegatus*, peut-être parce que la déforestation les a tous deux favorisés. En conséquence, l'éradication de la mauvaise herbe ne permettra probablement pas de contrôler *Z. variegatus*. Bien que les criquets soient attirés par les fleurs de *C. odorata*, leur agrégation sur la plante est plus probablement due au fait qu'ils pondent et que les oeufs éclosent à l'ombre du végétal, ce qui peut être le cas pour d'autres plantes. Les zones envahies par la mauvaise herbe peuvent être utiles pour éloigner temporairement *Z. variegatus* des champs cultivés ou pour des applications d'insecticides. En 1970, *Z. variegatus* a été déclaré ravageur principal au Nigeria puis il a posé problème en Côte d'Ivoire, au Ghana, au Congo, au Bénin, en Ouganda, au Sénégal et au Burkina Faso. Au cours de campagnes nationales et internationales de lutte, des insecticides chimiques onéreux (actuellement le seul recours) sont utilisés. Le traitement insecticide des agrégats de jeunes stades perchés sur des plantes, comme *C. odorata* en novembre-décembre, peut être pratiqué à condition que les agriculteurs se groupent pour synchroniser les opérations. Cependant, les insecticides ne sont efficaces que dans le court terme, ils endommagent l'environnement et éliminent les ennemis naturels des autres ravageurs. L'épandage de produits chimiques contre *Z. variegatus* tue le parasitoïde *Epidinocarsis lopezi* introduit en Afrique pour contrôler la cochenille du manioc. La résurgence de la cochenille a probablement été un problème plus important que celui posé par *Z. variegatus* lui-même. Il est donc nécessaire de proposer aux agriculteurs des méthodes alternatives. L'exhumation des oothèques pour les exposer à la dessication à la surface du sol peut réduire considérablement les populations. Les criquets déposent leurs oothèques dans des zones de surface réduite, près des champs cultivés. Les agriculteurs peuvent localiser ces zones car on y trouve de grands rassemblements d'adultes en mars-avril. Cependant, cette technique n'a pas été pratiquée par des agriculteurs travaillant en concertation. L'épandage de spores du champignon *Metarhizium flavoviride*, en suspension dans du kérosène et de l'huile d'arachide, tue 70-95% de la population au champ. Une souche isolée de *Z. variegatus* en a tué 90% en 7-9 jours au laboratoire. Des systèmes bon marché, permettant d'attraper et de relâcher les criquets, appâtés avec des attractifs olfactifs naturels et contenant des spores sous forme de poudre, sont actuellement dévèloppés, tout particulièrement pour atteindre *Z. variegatus* dans la brousse. Les criquets quittent le piège, meurent dans les 10 jours à quelques 30 m de là, et peuvent provoquer des contaminations. Une première défoliation du manioc (pour simuler les dégats de *Z. variegatus*) ne diminue pas la récolte en tubercules, mais des défoliations successives le font. Du fait que de nombreuses communautés africaines consomment les feuilles de manioc, la perte en feuilles est aussi importante. Une stratégie de gestion intégrée dirigée contre *Z. variegatus* impliquant la collaboration entre les agriculteurs et les programmes nationaux, devra prendre en compte le comportement des agriculteurs face aux dégâts du criquet, au piégeage et à la contamination du criquet par des spores du champignon;**

les pratiques locales de l'agriculture et de la lutte contre les ravageurs, et les analyses coût-bénéfice. Plutôt que l'utilisation des pesticides, c'est l'aménagement de l'habitat, fondé sur le comportement alimentaire et le comportement de ponte du criquet, qui sera accentué.

Mots Clés: **Agriculture africaine, *Chromolaena odorata*, exposition des oothèques, lutte chimique, lutte intégrée, manioc, *Metarhizium flavoviride*, neem, pièges olfactifs, socio-économie, *Zonocerus variegatus***

INTRODUCTION

The exclusively African variegated grasshopper species *Zonocerus variegatus* (L.) is the main grasshopper pest of crops in over twenty countries which occupy the extensive forest and savanna areas of West and Central Africa. It feeds on many plant species, including a wide range of plantation and subsistence crops (notably cassava, *Manihot esculenta* Crantz) and horticultural plants. It may also disseminate *Xanthomonas campestris* (Pammel) Dowson, which causes cassava bacterial blight (Daniel *et al.*, 1980). Much of the information on *Zonocerus variegatus* has been reviewed by Toye (1982), Modder (1986), Chapman *et al.* (1986) and Chiffaud and Mestre (1990).

BIONOMICS AND PEST STATUS

Aggregation and parasitism. The early nymphs (instars I to III) feed and roost in cohesive, dense aggregations, but the late nymphs (IV to VI) and the pre-reproductive adults are more dispersed. The reproductive adults re-aggregate at oviposition sites. Aggregation facilitates feeding and growth (Vuillaume, 1955; Bernays *et al.*, 1977; McCaffery *et al.*, 1978), and magnifies both the aposematic colouration of the species and the odour of its repellent fluid, which are warning signals to potential vertebrate predators.

However, aggregation may make populations liable to attack by parasites. *Zonocerus variegatus* is parasitised by the entomopathogenic fungi, *Entomophaga grylli* (Fresenius) Batko (Chapman and Page, 1979; Paraiso *et al.*, 1992), *Metarhizium flavoviride* Gams & Rozsypal (Lomer *et al.*, 1993) and *Beauveria bassiana* (Bals.) Vuill. (Paraiso *et al.*, 1992), and the sarcophagid fly, *Blaesoxipha filipjevi* Rohdendorf (Chapman and Page, 1979; Paraiso *et al.*, 1992). With *Entomophaga grylli*, mortality is high following rain when the grasshoppers are wet (Chapman and Page, 1979). *Entomophaga grylli* kills both nymphs and adults, and *B. filipjevi* kills adults aggregated at oviposition sites by larvipositing in them.

Diapause and hatching. Eggs laid in southern Nigeria at the start of the wet season, in March/April, diapause during May and June (Chapman and Page, 1978; Modder, 1978). They hatch in October, six to seven months later, at the start of the dry season. However, eggs laid later in the wet season apparently do not diapause because they hatch in about four months (Page, 1980). The diapause could be a means of reducing the probability of mortality from fungi that sporulate under humid conditions, by causing the production of fewer nymphal aggregations in the rainy season (Chapman *et al.*, 1986).

Observed decreases of about 40% in the numbers of first-instar nymphs hatching at sites near Ibadan, Nigeria, from one year's dry season (1992/93) to the next (Modder and Tamu, 1994), may be the result of natural enemies. Termites of the species *Macrotermes nigeriensis* Sjöstedt have been observed feeding on egg pods (Tamu, 1990).

Although hatching may occur throughout the year, it is maximal at the start of the dry season (late September - early November), presumably because both diapausing and non-diapausing eggs laid in the wet season hatch then. It is this large early dry season population which later in the dry season (January - March) attacks cassava and other crops.

Forest clearings and grasshopper abundance. In the humid lowland forests, *Z. variegatus* is restricted to the sun-lit edges and clearings, and nymphs and adults bask motionless in the sun for long periods. This would dry them and probably would raise body temperatures to levels which inhibit the development of pathogenic fungi. This strategy against *E. grylli* has been reported in another grasshopper, *Camnula pellucida* (Scudder) (Carruthers *et al.*, 1992).

From the 1950s onwards, extensive deforestation and intensified agriculture in West Africa have opened up habitats suitable for *Z. variegatus*, namely forest clearings in which subsistence crops including cassava, maize and leafy vegetables are grown. All these crops are attacked because the agroecosystem is ideal for *Z. variegatus*. Firstly, the plantings provide fresh food late in the dry season. Thus, in southern Nigeria, as the dry season progresses and preferred herbaceous food-plants become scarce, the late instars (V, VI) and adults move from the surrounding vegetation onto cassava in January - March (Bernays *et al.*, 1975; Bernays *et al.*, 1977). Secondly, the fields are surrounded by bush or fallow which, even at the end of the dry season, provides good oviposition sites. Oviposition requires shade and soil soft enough to allow ovipositor insertion (Page and McCaffery, 1979) and moist enough to provide water for certain stages of egg development (Chapman and Page, 1978; Modder, 1978).

Zonocerus variegatus is non-migratory and probably does not move more than 0.5-1 km during its life-history. In the forest clearings, it occurs from year to year at widely different levels of abundance but with characteristic peaks in the dry season. Abundance is determined mainly by rainfall acting through such factors as quality and availability of food-plants, suitability of the soil for oviposition and egg-development, and moist conditions for fungal epizootics. The grasshoppers' relative immobility, and occupation of what are effectively "island" habitats in the forest liable to fluctuating micro-climatic conditions, means that its outbreaks are often localised and difficult to predict.

In south-western Nigeria outbreaks are restricted to November-April (Anon., 1977). They are determined by the size of the population hatching in October - November, and this depends on the number of adults surviving as long as the preceding April, which in turn depends on when the rains start in February - March. Early rain, in February, may facilitate epizootics which reduce the number of reproductive adults. It also brings about faster regeneration of damaged cassava plants and mitigates the effects of *Z. variegatus* attack. However, early rain makes more food-plants available, and Page and Richards (1977) suggest that more eggs would be produced and at a faster rate . A late start of the rains, after late March, would be expected to have the opposite effects.

Feeding on cassava. Numerous grasshopper species are known to feed on cassava in Africa and the Americas, but only in Africa are grasshoppers (namely *Z. variegatus* and its congeneric, *Zonocerus elegans* [Thunberg]) major cassava pests (Bellotti and van Schoonhoven, 1978). Cassava has the potential to produce hydrogen cyanide (HCN) which presumably gives it relative immunity from most insects (Wood, 1966), although other secondary plant chemicals may also be involved. Cassava contains cyanogenic ß-glucosides, linamarin and some lotaustralin. In intact leaves, linamarin is thought to occur within the cells, spatially separated from the corresponding ß-glucosidase enzyme ("linamarase") which is localised in the cell walls (Mkpong *et al.*, 1990). Damage to the leaf, as when it is chewed, would bring substrate and enzyme together causing production and release of HCN in solution or as gas (Bernays *et al.*, 1977). Linamarase activity in the damaged cassava leaf, rather than cyanogen content, appears to be the important factor in deterring feeding by herbivores such as *Z. variegatus*. Leaf consumption by fifth-instar *Z. variegatus* nymphs, in free-choice experiments with six cassava clones, was found to be unrelated to their cyanogenic ß-glucoside content, which ranged from 80 to 167 mg CN per 100 g of fresh leaves (W.W.D. Modder, unpublished).

Although nutritionally adequate for the survival and reproduction of *Z. variegatus* (Kaufmann, 1965; Bernays *et al.*, 1975; McCaffery *et al.*, 1978; Tamu, 1990), cassava is not a preferred food, even of the late instars which feed on it in the field. First- and second-instar nymphs will die rather than eat it (Bernays *et al.*, 1977). However, wilted cassava leaves are readily fed on. It is possible that the size of the latex globules suddenly appearing when normal turgid leaves are bitten, or the HCN produced during mechanical injury of leaf tissue and passing into the leaf fluid and latex, deter feeding by the smaller instars. Feeding in aggregations, at least by instars later than the third, overcomes the deterrence, probably because the leaves wilt and lose HCN quickly once feeding begins. The damage to cassava is, therefore, caused by late-instar nymphs and pre-reproductive and copulatory adults.

Zonocerus variegatus maintained on cassava and on another cyanogenic euphorb, *Cnidoscolus aconitifolius* (Miller) Johnson, were found to have free glucose in the foregut, although those on two non-cyanogenic plants (*Chromolaena odorata* King and Robinson and the euphorb *Acalypha wilkesiana* Müll. Arg.) did not, suggesting that this grasshopper can digest cyanogens to obtain glucose (T.A. Modder and W.W.D. Modder, unpublished). It is possible, therefore, that cyanogenic ß-glucosides are a primary nutrient for *Z. variegatus*. Interestingly, another cassava pest, the mealybug, *Phenacoccus manihoti* Mat.-Ferr., may also benefit from the cyanogens: the nitrogen from cassava cyanide is apparently used in mealybug development (Le Rü and Calatayud, 1994).

Association with the weed *Chromolaena odorata*. Nowadays bush and fallow in much of humid West Africa is to a large extent made up of the accidentally introduced weed, *Chromolaena odorata* (Cruttwell McFadyen, 1988). Its spread in southern Nigeria in the 1960s and in Côte d'Ivoire in the 1970s coincided with the increase and spread of *Z. variegatus*, and so the suggestion has been made that it is a factor in inducing outbreaks of the grasshopper (Chapman *et al.*,1986; Popov,1988; Boppré,1991). All instars of *Z. variegatus* are attracted by olfactory stimuli to the inflorescences of *C. odorata* (Modder, 1984), probably because they contain pyrrolizidine alkaloids (Boppré, 1991), but nymphs aggregate densely on the weed early in the dry season, even before flowering has occurred. The reason may be that hatching commonly occurs in the shade of its thickets. The adults do not deliberately seek out these thickets as oviposition shelters; they may oviposit under other plants even when *C. odorata* thickets are available nearby (W.W.D. Modder, unpublished). Nutritionally, *C. odorata* is inadequate for *Z. variegatus* (Bernays *et al.*,1975; McCaffery and Page, 1978; Iheagwam, 1979). However, *Z. variegatus* has a mixed diet (Modder, 1984 ; Marks and Seddon, 1985) and, as one component of this diet, *C. odorata* appears to be useful (Tamu, 1990). The probable reason for the association is that forest clearings happen to be the ideal habitat for both *C. odorata* (Cruttwell McFadyen, 1988) and *Z. variegatus*, and the ubiquitous *C. odorata* thickets are merely convenient for the grasshopper's oviposition and roosting.

IMPACT ON AFRICAN AGRICULTURE

Reports of damage to crops by *Z. variegatus*, in particular to cassava and other staples, have increased in recent years. It is apparent that populations of this grasshopper have increased and become more widespread in the humid zones of Africa, wherever forest land is being cleared for subsistence agriculture, and perhaps also in riverine areas of the Sahel. The attacks on crops such as cassava, maize and vegetables are particularly threatening to the livelihood of the many poor subsistence farmers.

Nigeria. In southern Nigeria, over 50% of the cassava crop is estimated to be lost in years of high *Z. variegatus* abundance (Barker *et al.*, 1977). As early as 1970, the outbreaks of *Z. variegatus* in Nigeria were becoming so large and frequent that the National Agricultural Technical Committee declared it a major pest (Chapman *et al.*, 1986). This led to a joint research programme by the Centre for Overseas Pest Research, London (now part of the Natural Resources Institute) and the University of Ibadan, Nigeria (the COPR/UI project) from 1973 to 1976.

Côte d'Ivoire. From being a minor pest in Côte d'Ivoire, *Z. variegatus* increased dramatically in numbers from 1975 "to cover practically the whole of the forest zone by 1979" (Popov, 1988). In 1980, a FAO Technical Cooperation Programme in the country recommended further coordinated research against *Z. variegatus* (Chapman *et al.*, 1986).

Ghana. In Ghana, *Z. variegatus* has been a pest from the 1980s and is so damaging to crops that it is described as a major constraint to agricultural production (Acting Director, Plant Protection & Regulatory Services Department (PPRSD), *in litt.*). It occurs in every eco-geographical zone (the northern savanna, the forest belt and the coastal savanna) and in every administrative region of the country. It attacks over 100,000 ha of diverse crops annually (PPRSD Ann. Reports).

Congo. *Z. variegatus* is the only grasshopper species to be regarded as an economic pest in Congo. It is described as a permanent menace in the vegetable growing areas, and in the forest zone of Mayombe as the single most important pest of cassava (Bani, 1992). In the early 1980s, as a result of *Z. variegatus* attacks, cassava production was drastically reduced in Mayombe (Bani, 1990). Arising from this, the Congolese Government requested and was given assistance by FAO to control the pest.

Benin. According to Paraiso *et al.* (1992), *Z. variegatus* is the most serious and prevalent grasshopper pest in southern Benin, 150,000 ha being infested annually (Anon., 1986). There was an unprecedented country-wide outbreak of grasshopper species in 1982 and following this, from 1985 onwards, *Z. variegatus* has become an important crop pest in the south (Coffi, 1992).

Uganda. *Z. variegatus* is reported to be a serious pest of cassava in the West Nile Region and in the eastern and northern parts of Uganda (J.A. Ogwang, *in litt.*; Anon., 1994b). It may destroy entire crop stands and such devastation is common, especially in West Nile.

The Sahel. Although *Z. variegatus* does not attack millet, which is the major staple in the Sahel, reports from both Senegal and Burkina Faso repeatedly place *Z. variegatus* in the top four or five pest grasshopper species in those countries, particularly in vegetable crops (C.J. Lomer, Cotonou, 1993, personal communication). These species include *Oedaleus senegalensis* (Krauss), *Kraussaria angulifera* (Krauss), *Hieroglyphus daganensis* Krauss, *Cataloipus cymbiferus* (Krauss) and *Ornithacris turbida* Walker.

CHEMICAL CONTROL AND ITS DANGERS

Frequent crop losses due to *Z. variegatus* are perceived as serious enough by farmers, governments and other authorities to cause them to attempt chemical control, since at present chemicals are the only available defence against grasshoppers. Control efforts against *Z. variegatus*, particularly during sudden, large-scale outbreaks, usually involve *ad hoc* and widespread spraying campaigns with broad-spectrum, organochlorine, or nowadays organophosphate or carbamate insecticides.

Feasibility studies. During the COPR/UI project in Nigeria (1973-1976), the possibility of controlling *Z. variegatus* with chemical insecticide formulations, commercially available in Nigeria at the time, was examined in laboratory assays and field trials (Anon., 1975, 1977).

The organochlorine, benzene hexachloride ("Gammalin 20"), and the organophosphate, fenitrothion ("Agrothion 20"), were found to be the most suitable. They are effective against all the instars and, moreover, were more readily available in Nigeria, were less expensive, and are not as toxic to mammals as other insecticides that are also effective.

Early instars in the large aggregations occurring in November and December are the easiest targets. They are conveniently sprayed when they are most visible and roosting on vegetation surrounding farmers' fields in the early morning and late evening. Spraying at this time avoids direct contamination of crops and wastage of insecticide since only discrete aggregations are treated. Low concentrations of the insecticides (minimum: 0.5% w/v of active ingredient in aqueous solution, at 2-7 l ha^{-1}) delivered by a hand-held sprayer were found to be satisfactory.

Control of the early instars over large areas may be practicable and economical, if all the farmers in a locality cooperate at the appropriate time of year to locate nymphal aggregations and synchronise spraying operations.

Spraying later than December, when the late nymphal instars and adults are already on cassava, is not economical, safe or effective. More insecticide (about 200 l ha^{-1}) delivered by heavy knapsack sprayers would then be needed, and the greater dispersion of the late instars means that comparatively large areas of farm land would need to be sprayed. A single application may give protection for only a few days and frequent, perhaps even weekly, spraying may become necessary if there is continual re-invasion of treated fields from outside the sprayed area by the more mobile late instars.

Scale and monetary costs. Precise and reliable information on the amounts of insecticides involved, and the monetary costs of chemical campaigns mounted by individual countries in trying to control *Z. variegatus* and other grasshoppers is not readily available. This is because, during grasshopper outbreaks, chemicals are often diverted from other uses and taken from stockpiles meant for general pest control. However, it is known that in 1986-87 donors gave a total of US$ 62 million for general grasshopper control in the Sahel using chemical insecticides (Brader, 1988), and that 4.6 million ha were blanket sprayed with fenitrothion (Anon., 1990). Chemical pesticides are costly in foreign exchange and increase a developing country's dependence on imports.

In Ghana, the only control against *Z. variegatus* has been the widespread use of chemical pesticides (Acting Director, PPRSD, *in litt.*), over 6,000 ha being treated annually (PPRSD Annual Reports).

In Congo, chemical control operations against *Z. variegatus* are carried out, with uncertain results, by private and public enterprises in costly short-term projects (G. Bani, *in litt.*).

In Uganda, plant protection officers routinely use contact chemical insecticides against *Z. variegatus* (J.A. Ogwang, *in litt.*).

Disadvantages and dangers. The use of chemical insecticides is psychologically satisfying to those involved because results are immediately visible. It is not, however, financially or ecologically sustainable and not, in the mid- and long-term, effective. Neuenschwander (1993) points out that chemicals are not a satisfactory option on small-holder farms against well-established pests because of relative inefficiency, likely side-effects and the difficulty in proper timing of applications, and because the chemicals and spraying equipment are too expensive for the small holder to use on a low-value crop like cassava. In Ghana, for example, peasant farmers can only afford to treat limited portions of their farms during *Z. variegatus* outbreaks (Acting Director, PPRSD, *in litt.*). Surrounding fallow lands harbouring the grasshoppers are left untreated, and serve as foci of re-infestation.

Chemical insecticides cannot, therefore, give significant overall control. They merely cause or increase environmental pollution and degradation, and constitute immediate or long-term health hazards. They are a danger to human communities, domestic animals, wildlife and plants, and they chronically disrupt food-chains. They eliminate natural enemies which might otherwise keep pest populations within manageable limits. (One example of this, concerning the cassava mealybug pest, is given later in this paper.) Eliminating such natural control agents results in increased dependence on chemicals to control pests, which conceivably might not have been numerous enough to be pests if chemicals had not been used in the first place. The dangers of chemical insecticide use have been stressed by van den Bosch (1978).

There is public resistance to the use of chemical pesticides, although it is not always given prominence. For instance, according to plant protection services in Benin and Mali, poisoning by pesticides is a recurring problem, and farmers have expressed concern at the toxicity of currently-used insecticides and their effects on fish and wildlife (C.J. Lomer, Cotonou, 1993, personal communication). Attention is not always given to the safe and appropriate use and storage of chemical pesticides in developing countries.

In summary, chemical insecticide use is not sustainable or ultimately effective. It threatens health and the environment, saps national economies, and interferes with rational pest control procedures.

Despite the disadvantages, synthetic chemical insecticides are being used and will continue to be used in crisis situations where rapid control of outbreaks is essential. It is therefore imperative to develop alternative, environmentally compatible, inexpensive methods of non-chemical control which could be used directly by peasant farmers, or better in the framework of integrated pest management.

CONTROL BY EGG-POD EXPOSURE

The only firm recommendation for *Z. variegatus* control in the final report of the COPR/UI project (Anon., 1977) was the exhumation of egg pods and their desiccation at the soil surface (Page, 1978). As with all grasshoppers, water at certain crucial periods is essential for the development of *Z. variegatus* eggs (Chapman and Page, 1978; Modder, 1978), and egg-pod exposure is therefore a simple way of stopping development.

Identification of oviposition sites. Although *Z. variegatus* adults begin to copulate while dispersed, for example in cassava fields, they finally aggregate at sites suitable for oviposition, in bush (usually *C. odorata* thickets), in the shade of trees or shrubs which may have ground cover such as fallen leaves, or under heaps of stalks or withered vegetation resulting from harvesting or weeding. Oviposition sites are usually less than 30 m from farmers' fields (Page and McCaffery, 1979; Tamu, 1990), and pairs *in copula* and single individuals (predominantly males) aggregate there, in large numbers in the case of dry-season populations. Recognition of oviposition sites by farmers in March-April is therefore not difficult, since they are in the fields at this time, at the start of the rains, preparing for a new growing season.

Exhumation of egg pods. Oviposition sites are relatively small, discrete areas closely packed with egg pods. Few sites are more than 20 m^2 in surface area (Page, 1978). Thirty-four sites studied near cassava farms in Ayepe, south-western Nigeria were between 0.3 and 15.2 m^2, and most of them contained similar numbers of egg pods (of the order of 200), irrespective of surface area (Tamu, 1990). Exhumation of a large proportion of the egg pods laid in or near farmers' fields is therefore not impossible.

Once oviposition sites have been identified and tagged in March-April, egg-pod exhumation is best done from late July to September when exposed eggs would lose most of their water (Modder, 1979). Exhumation only involves using simple implements such as hoes and trowels, because the egg pods are usually deposited less than 10 cm below the soil surface.

Community action. Control by egg-pod exposure has been tried in the field with good success. Page (1978) obtained reductions in population of 83% and 91%, Tamu (1990) nearly 100%, and Modder and Tamu (1994) about 90%. In a farming community, location and excavation of all or most of the oviposition sites present would be best achieved by joint action (farmers' cooperatives or village brigades). Attention to only some of the oviposition sites by a few farmers acting individually would be ineffective, since their fields could be re-invaded from untreated sites. The goal is reduction of the pest populations below an economic damage threshold, and this level may be maintained for several years following an extensive exhumation effort (Anon., 1977).

Adoption by farmers. Egg-pod exposure to control *Z. variegatus* was first suggested many years ago (Mallamaire, 1934; Vilardebo, 1948, 1954). Despite strong recommendations, for example at a COPR/UI project workshop for Nigerian agriculturists and extension workers in December 1976, and in the project's final report (Anon., 1977), it has apparently not been tried to any extent in farmers' fields. Rosenfield *et al.* (1983), who described the method as technically sound, pointed out that there were not enough extension workers to explain it, and suggested that its very simplicity makes farmers doubtful that it will significantly reduce populations. Farmers were therefore unwilling to spend time identifying sites and exhuming pods.

Criticisms have been made regarding the impracticality of locating and excavating oviposition sites in thick bush and difficult terrain. On the contrary, sites are not difficult to locate because most of them are just 10-20 m from cassava farms (Tamu, 1990) and carry large adult aggregations, or to excavate successfully because of the dense clustering of egg pods over a few square metres in shallow soil. Indeed, a few Nigerian subsistence farmers have been using the method on their own initiative (Barker *et al.*, 1977). Some of them in Kabba, Kwara State have been digging up oviposition sites but with limited success because their efforts were on an individual rather than community basis (Page and Richards, 1977).

BIOLOGICAL CONTROL

Natural reductions in populations of *Z. variegatus* occur as a result of infection by *Entomophaga grylli* and attack by *Blaesoxipha filipjevi* (Chapman and Page, 1979; Paraiso *et al.*, 1992). Isolates of the fungus *M. flavoviride* have been evaluated for use in biological control programmes against this grasshopper with encouraging results (Lomer *et al.*, 1993).

Laboratory and field evaluations. One strain of *M. flavoviride* isolated from *Z. variegatus* itself in Ouémé Province, southern Benin in 1991 is the most virulent of all *M. flavoviride* and *B. bassiana* strains tested against this grasshopper in the laboratory; the lethal time for 50% mortality (LT_{50}) is 5-7 days at a dose of 10^5 conidia per insect (Lomer *et al.*, 1993). The conidia are grown, under sterile conditions, relatively cheaply in plastic tubs with rice as substrate, and formulated in kerosene and peanut oil. The formulation was applied to natural populations of *Z. variegatus* in small plots (*c.* 0.25 ha) of mixed vegetation, at a concentration of 2×10^{12} conidia ha^{-1} using ultra-low volume (ULV) sprayers. A high proportion (70 - 95%) of the nymphs and adults collected up to 7 days after spraying succumbed to the fungus. Trials were repeated in larger (1 ha) plots containing cassava and other vegetation (O.-K. Douro-Kpindou *et al.*, in preparation). Populations of sixth-instar nymphs and pre-reproductive adults were reduced by about 90%, 10-15 days after spraying. However, because death takes longer than with chemical insecticides, reproductively mature adults sprayed while in cassava fields were still able to leave for oviposition sites in thickets inaccessible to spraying.

The oil-based *M. flavoviride* formulation is probably the most appropriate mycoinsecticide for control of desert locusts and Sahelian grasshoppers, and although it has given good results it is not necessarily the best formulation for a humid zone grasshopper like *Z. variegatus*. The production of water-soluble conidia by certain strains of *M. flavoviride* growing in liquid media (Jenkins and Prior, 1993) opens the possibility of spore production using a single-stage fermentation process, based on an industrial fermenter, which would be much cheaper than oil-based production. The hydrophilic conidia in water-based (WULV) sprays could be used against *Z. variegatus* with simple hydraulic knapsack sprayers. Technology also exists for producing dry spores and for formulating them for application as dusts or powders, for example in attractant traps.

Odour traps. As well as direct mycoinsecticide application, by ULV and WULV spraying, to *Z. variegatus* when they are in farmers' fields and other accessible locations, simple trap-and-release devices baited with natural olfactory attractants (such as *C. odorata* allomones and the grasshopper's own pheromones) could be used to spread the fungal spores among aggregations at oviposition sites or in thick bush. The deployment and timing of the traps will be based on our recent knowledge of *Z. variegatus* ecology and attractancy behaviour.

Bait traps are now being developed to increase the efficacy of *M. flavoviride* applications and reach the grasshoppers while they are ovipositing or in thick vegetation. In preliminary trials, *Chromolaena odorata* extracts were used to attract the grasshoppers into traps dispensing conidia formulated as dry powder. The traps are designed to put trapped and infected grasshoppers back into the general population to serve as foci of infection. Released *Z. variegatus* died within 10 days and dispersed up to 30 m from the traps (Adu-Mensah, J. in preparation).

The introduction of the trapping technology to resource-poor cassava farmers might prove more appropriate than the relatively expensive ULV spraying. The low-cost odour-based traps for dispensing the fungus will hopefully be sustainable by local farming communities, without continuing scientific or financial contributions from external agencies.

Future needs. Large-scale on-farm trials of *M. flavoviride* formulations with national programmes and as farmer participatory activities are needed. While serving to refine existing technology, they would provide training in the field use of mycoinsecticides, and would perhaps serve to convince scientists, farmers and government of their efficacy.

Mass production, perhaps as rural or commercial activities, using rice or possibly a cheaper substrate, will supply the spore formulations for field applications. An important consideration will be cost-effectiveness and the use, as far as possible, of inexpensive material available or produced locally.

CONTROL BY BOTANICAL PESTICIDES

Extracts of the neem tree *Azadirachta indica* A. Juss (main active ingredient: azadirachtin), sprayed onto foliage, have phagorepellent or antifeedant effects against acridoids including *Z. variegatus* (Olaifa and Adenuga, 1988; Schmutterer *et al.*, 1993). Popov (1988) particularly recommended their application to "valuable" crops, as protection against grasshopper and locust attack.

When contacted or ingested by acridoids, the extracts cause malformations of antennae, legs and wings, reduction in vigour, and death (Schmutterer *et al.*, 1993). Mortality, however, takes much longer than with synthetic contact insecticides. In field trials in Benin, the seed kernel oil and water extracts gave good results against *Z. variegatus*, and the oil used as a barrier spray prevented movement of nymphs into a teak plantation (Schmutterer *et al.*, 1993).

However, the seed oil and water extracts, sprayed onto cassava, became inactive within 11-14 days in the dry season in south-west Nigeria (Olaifa and Adenuga, 1988). Water extracts would also be washed off by rain or irrigation water more readily than the oil. Re-applications are therefore necessary: oil every 8-10 days and water extracts every 6-12 days.

The possible advantage of neem extracts is that they can be made and applied by farmers relatively cheaply and easily (Olaifa and Adenuga, 1988), particularly where the trees occur locally. However, their non-durability under field conditions at their present stage of development makes their use in *Z. variegatus* management problematical.

THE IMPORTANCE OF INTEGRATION IN CONTROL

Preoccupation with control of a single pest species by means of any one technology is not always good for an agroecosystem. A pest has to be regarded holistically, in the context of the total agroecosystem including its host plants, other pests and potential pests. An integrated, multi-disciplinary approach is needed in studying, for example, the impact of *Z. variegatus* on cassava. Thus, regrowth of cassava after pest (or drought) stress involves depletion of root and stem reserves (Schulthess *et al.*, 1991) and this may increase susceptibility to root rot (Schulthess and Saka, 1992). Consideration has to be given, therefore, to the vigour of the plants which depends on age, soil fertility and season with respect to rainfall.

The dangers inherent in piecemeal measures may be illustrated by two examples involving *Z. variegatus* and the cassava mealybug *Phenacoccus manihoti* Mat-Ferr.) and *Z. variegatus* and *Chromolaena odorata.*

Resurgence of the cassava mealybug. The use of chemical insecticides can lead to secondary outbreaks of non-target pests by indiscriminately killing natural biological agents (parasitoids, predators or pathogens) which may have been released earlier, with much effort and expense, to keep these pests in check. Chemicals interfere with biological control programmes that are otherwise sustainable. Chemicals sprayed in cassava fields in attempts to control *Z. variegatus* have been known to kill the exotic parasitoids, *Epidinocarsis lopezi* (De Santis), introduced in the highly successful Africa-wide programme to keep attacks of the cassava mealybug within economic limits (Herren and Neuenschwander, 1991).

The experience in the Tororo and Nebbi districts of Uganda, where chemicals are used to control *Z. variegatus* and other pests, is that the chemicals cause resurgence of cassava mealybug where it had before been controlled by introduced *E. lopezi* (J.A. Ogwang, *in litt.*). Thus, in April 1994, farmers sprayed chemicals to contain *Z. variegatus* outbreaks in West Nile, Tororo and western Uganda, and this is reported by the National Biological Control Programme of Uganda as jeopardising their efforts against the mealybug (Anon., 1994b). It was observed in Ghana, Benin and Nigeria that the resurgence of the mealybug following chemical spraying against *Z. variegatus* created a more or equally serious problem than the initial grasshopper attack (Neuenschwander, 1994 and personal communication).

***Chromolaena odorata:* weed or resource?** While its benefits have been recognised, *C. odorata* is considered a noxious weed for various reasons, including that of harbouring *Z. variegatus,* and many countries have initiated programmes for its control (Anon., 1994a). However, the association between it and *Z. variegatus* could be merely the result of a coincidental meeting in the forest clearings of West Africa and, although the suggestion has been made, it is not proven that the weed is responsible for *Z. variegatus* outbreaks .

In my view, containment and eradication of the weed, whatever other benefits they may give, are unlikely to influence *Z. variegatus* numbers. Even without *C. odorata, Z. variegatus* would probably be a pest given the present intensity of agriculture and deforestation in West Africa. On the other hand, *C. odorata* could be positively useful in the integrated management of *Z. variegatus* and may be regarded as a resource, at least from that point of view. Although it is not a trap plant for the grasshoppers, *C. odorata* when in flower could be useful in temporarily distracting them away from crops and as a holding site where *Z. variegatus,* which frequently roost on it at night, might be conveniently sprayed with chemical insecticides if such a measure is necessary (Modder, 1986), or with the recently developed mycoinsecticides (Lomer *et al.*, 1993). The weed might also serve as an inexpensive, indigenous source of the volatiles which have been shown to attract *Z. variegatus,* for example to mycoinsecticide-dispensing traps.

THE SOCIO-ECONOMICS OF CONTROL

Integrated management of an agroecosystem is the weighing and harmonisation of all feasible methods, firstly, to obtain stable and sustainable crop yields (crop management and use of pest-resistant cultivars) and, secondly, to restrict the damage caused by crop pests to a point where it is not economically significant (pest management). Usually decisions have to be based on a cost:benefit analysis: is it cheaper to apply a pest control technology or to lose some of the crop? Preserving ecological balance and reducing risks to health and the environment (so-called "green" issues) are also important considerations in integrated management.

Yield-loss assessments. The first step in initiating a management programme for a pest should be to establish its pest status. Pest status may be obvious as with the cassava mealybug when it invaded Africa in the early 1970s, but assessments of yield loss may be necessary in many cases. The mere presence of a potential pest is not *ipso facto* a pest problem since plants have mechanisms to tolerate, and even compensate for, pest damage. The cassava canopy, for example, is especially tolerant to arthropod attack, and the plant can sustain a single complete defoliation without root yield loss (Cock, 1978).

Since cassava is one of the more important crops attacked by *Z. variegatus,* yield loss assessments have been made on it (e.g. Page *et al.*, 1982; F. Schulthess, unpublished). As *Z. variegatus* is a mobile, highly aggregated insect, assessments are most conveniently done using simulations of feeding damage, such as artificial defoliations and detoppings. Generally, a single complete defoliation of well-established cassava during the dry season has little or no effect on cassava root yields (Page *et al.*, 1982; Porto and Hamers, 1987; F. Schulthess, unpublished). Detopping might even be beneficial depending on cassava variety, time of detopping and time of harvest. However, each additional, even partial, defoliation (to simulate *Z. variegatus* invading a field in successive waves) does decrease root yield linearly (F. Schulthess, unpublished).

In communities where cassava leaves are eaten, leaf loss or spoilage from *Z. variegatus* attack is perhaps as important as root yield loss. Apart from the tuberous roots, the leaves are a significant part of the diet in many parts of Africa, for example in Zaire, Congo and Sierra Leone, and defoliation by the grasshoppers is an immediately felt hardship.

The major shortcomings of the cassava yield-loss assessments involving simulated *Z. variegatus* attack are that (a) they concentrated on the roots and neglected the leaves, (b) they did not assess changes in the quality of cassava-root starch, and (c) they did not consider damage to the stems which are used as planting material. There are now plans to study the effect of *Z. variegatus* itself on cassava leaf and root yield, and root and stem quality.

Farmer perceptions and cost-benefits. The social, economic and biological parameters determining acceptance of a new control technology require careful study. Control programmes for agricultural pests have to take into account the concerns and perceptions of farming communities and the general public, which differ in different regions. Thus, the acceptable threshold of crop damage by grasshoppers, even what constitutes damage, might not be uniform within a country or between countries. Grasshopper IPM with new methods, such as mycoinsecticides and naturally-occurring attractants, would be more effective and sustainable in the long term if established by means of research projects having the participation of farmers, who are to be the immediate and direct beneficiaries. Such a locally-established IPM scheme would place the responsibility for, and the benefits of, grasshopper control in the hands of the farmers.

The pressure on national and local governments and other bodies to control pests may be driven by social or psychological, as well as economic, factors. Apart from justified concern arising from actual or potential crop damage, panic reactions develop in farming communities and in agricultural extension services during *Z. variegatus* outbreaks, because these grasshoppers are perceived as serious pests needing control, whatever yield-loss assessments may or may not show. Perceptions are as important as reality. Governments and their agencies are therefore impelled to muster scarce resources for the purchase and dissemination of chemical insecticides.

Since there is a growing general awareness of the dangers of chemical use, integrated management which relies on demonstrably safe, biological methods is likely to be welcomed. However, aspects of such practices as trapping and fungal-spore dispersion for controlling grasshoppers might cause concern, perhaps for reasons not immediately evident. Although an ULV formulation of *M. flavoviride* conidia has given control of *Z. variegatus* in field experiments, the relevance and acceptability of this technology in different farming systems remain to be determined.

Considerations of cost are obviously important in the acceptability of a control technology. The high cost of application of ULV formulations may prove a deterrent. For this reason, different application systems, including traps, baits, dry-spore powders and water-based ULV would ideally be field-tested in collaboration with farmers, with costs and benefits being balanced all the time. Apart from application costs, the costs of spore production, transport and storage would be considered in relation to benefits. Since chemical pesticides cause environmental damage, there would be an evaluation of the reduction in this damage were chemical insecticides to be replaced with mycoinsecticides. The analysis would therefore take into account the reduced environmental damage ensuing from a reduction in the use of chemical pesticides.

CONCLUSION: THE OUTLOOK FOR INTEGRATED CONTROL

There is a clear need for some of the promising technologies against *Z. variegatus*, now available or being developed, to be incorporated in an integrated pest management (IPM) strategy. Control measures for other acridoids such as locusts may also be considered for use against this species. If IPM can be established, the prognosis for preventing *Z. variegatus* damage on cassava is good.

An earlier IPM protocol for *Z. variegatus* (Modder, 1986) could be improved by inserting an ecological element, namely habitat management, based on growing knowledge of the grasshopper's feeding and oviposition behaviour, and by de-emphasis of the chemical element. The latter is necessary particularly because of the resurgence of the cassava mealybug following chemical insecticide use, but more generally because an IPM in cassava which relies largely on biological control, that is a 'biological' IPM, is more sustainable and less hazardous than a 'chemical' one. The promising *M. flavoviride* formulations (mycoinsecticides) would therefore replace synthetic chemical insecticides, except where use of the chemicals is unavoidable, for example during large and damaging outbreaks requiring quick control.

A more realistic picture is also necessary of the importance of *Z. variegatus*, before and after the application of intervention technologies, based on its impact on cassava root and leaf yield and total biomass, and on root and stem quality.

The IPM will make use of socio-economic data on cost: benefit ratios (including environmental costs). It will be aware of farmer and public perceptions of the grasshopper's impact and of the control methods. Finally, it will incorporate as far as possible traditional local knowledge of grasshopper incidence, behaviour and management.

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