POSTER SESSION 4A

SUSTAINABLE PEST AND DISEASE MANAGEMENT IN TROPICAL AND SUB-TROPICAL CROPS

Session Organiser: Dr R Black
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A sustainable IPM system for oil palm in Papua New Guinea

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ABSTRACT

Oil palm is an important cash crop in Papua New Guinea (PNG), with about 80,000 hectares in cultivation, grown both on large-scale plantations and by smallholders. The principal pests of oil palm in PNG are a group of insect species from the Tettigoniidae family (Orthoptera), known collectively as sexava. Three species of sexava are pests of oil palm in PNG, *Segestes decoratus*, *S. defoliaria* and *S. novaeguineae*. These insects cause damage by feeding on oil palm fronds and defoliation levels can be very severe where high populations occur. Severe defoliation causes reductions in photosynthesis resulting in yield loss from lower fruit production. During the last five years an integrated system has been developed for the management of sexava. The integrated pest management (IPM) system described here has the following components:- (1) a knowledge of the biology and ecology of the pest, (2) economic thresholds, (3) monitoring system for the pest, (4) precise targeting of chemical control agents, (5) biological control and (6) cultural and physical control. The IPM system is sustainable and environmentally acceptable to the industry. Future research involving the development of strepsipteran parasites for biological control is likely to improve this system still further.

INTRODUCTION

Oil palm is an important cash crop in Papua New Guinea (PNG), with export earnings from crude palm oil and palm kernel oil currently exceeding those of cocoa, tea, copra and coconut oil, and rubber combined. PNG now has about 80,000 hectares of oil palm, grown both on large-scale plantations and by smallholders. The principal pests of oil palm in PNG are a group of species from the Tettigoniidae family (Orthoptera), collectively known as sexava. Three species of sexava are potential pests of oil palm in PNG, *Segestes decoratus*, *S. defoliaria* and *S. novaeguineae*. These insects cause damage by feeding on the oil palm fronds; defoliation levels can be very severe where high population densities occur. During the last five years an integrated pest management (IPM) system has been developed for sexava. This IPM system has the following components:- (1) a knowledge of the biology and ecology of the pest, (2) economic thresholds, (3) monitoring system for the pest, (4) precise targeting of chemical control agents, (5) biological control and (6) cultural and physical control. The background to and development of the IPM system is described below with conclusions drawn about its effectiveness and future role in oil palm cultivation.

THE DEVELOPMENT OF AN INTEGRATED PEST MANAGEMENT SYSTEM

Knowledge of the biology and ecology of the pest

Young (1985) described the basic biology and life cycles of the sexava. Adult sexava lay the majority of their eggs in the soil at the base of oil palm trees. Oviposition occurs at night, with up to 40 eggs laid by a single female. The period from egg deposition to hatching varies between 40-100 days. First instar nymphs climb up to the crown of the palm and feed on the fronds. The newly emerged nymphs are dark green. The juvenile stages and the moult to the adult stages are completed in the crown. The number of moults is reported to be six in the male and seven in the female (Young, 1985). Females take approximately 21-26 weeks to reach the adult stage, and males approximately 20-22. Adults are usually green in colour, although brown variants often occur. The adults tend only to leave the crown of the oil palm to oviposit (Young, 1985).

Economic thresholds

Moderate to severe defoliation by leaf-eating insect pests can reduce the subsequent yield of oil palm by as much as 44% (Wahid, 1993). Field observations have shown that sexava populations are poorly regulated in the oil palm agroecosystem of West New Britain. In most instances, therefore, even low-level populations that are causing light defoliation (less than approximately 10% leaf loss) will, within a relatively short time, result in moderate to severe defoliation. The affected oil palms will then take up to 2.5 years to recover with a full canopy of undamaged fronds. During this time yield losses would be at or above the level of 44% reported by Wahid (1993). Estimates of sexava numbers on oil palm presents difficulties due to their nocturnal behaviour and their feeding habits. Smith & van den Bosch (1967) suggested that economic thresholds should be based on actual crop damage rather than pest numbers, in which case defoliation levels rather than pest numbers should be the determining factor. From the above considerations, any signs of defoliation, light or otherwise, caused by sexava feeding is usually evidence of potentially economic pest damage that, if left untreated, will result in severe defoliation. For sexava IPM in PNG light damage is therefore taken as an economic threshold and is used as a decision-making tool upon which to recommend appropriate control operations.

Monitoring system for pest damage

Oil palm is harvested on a 10-15 day cycle, so most plantation fields or blocks are visited 2-3 times a month for harvesting, pruning and general maintenance. It therefore seemed appropriate to set up a system in which the initial pest detection is undertaken by plantation workers and smallholders. Since 1995 a regular programme of training in entomology has been undertaken for plantation workers, smallholders, and extension officers. This has involved both formal and informal training, as well as features on rural radio stations. The result is that most people that are directly associated with oil palm growing are now able to recognize the very early signs of insect damage as a preliminary to a more thorough census. The census stage of the monitoring system is then undertaken by trained entomologists. A census stage has been developed that involves the visual assessment of feeding damage, using binoculars or the naked eye, and then semi-quantitative scoring into three damage categories (light, moderate, or severe). This allows the observer to view the entire oil palm tree, it allows large areas to be surveyed within each oil palm block, and it allows the trained observer to use his/her knowledge of the pest's behaviour to improve the reliability of the assessment.

Precise targeting of chemical control agents

The control of a large and rapidly increasing sexava population is dependent on the use of precisely targeted chemical control agents. This involves the use of trunk-injected monocrotophos (Nuvacron or Azodrin) (Matthews, 1992). This application technique, by confining the insecticide to the palm, has no impact on other non-target organisms, including beneficial insects (and reduces exposure of workers to these toxic insecticides). The control of sexava using trunk injection involves the application of monocrotophos (10ml of 400ml ai/l formulation) into a single 1.5cm diameter hole, 15cm deep and drilled at a 45° angle into the trunk, 1m above the ground. The active ingredient persists for approximately 60 days in the leaf tissue of the palm. A follow up treatment is required after approximately 12 weeks to coincide with the emergence of nymphs from eggs laid by the original pest population. This method of pesticide application is very effective if performed properly. Treatment is however very time consuming, especially when very large areas of plantation are affected by high sexava populations. Treatment of remote areas can be difficult, and control operations are often disrupted during the rainy season.

Biological control

Fungal pathogens

Surveys for fungal pathogens of sexava were undertaken in West New Britain Province. Two separate methods were used for the surveys, (1) surveying for fungal pathogens from individual sexava hosts, and (2) surveying soil samples collected from the oil palm agroecosytem for fungal pathogens. Several thousand sexava were collected and housed in large walk-in insectaries. Cadavers were collected and kept in the necessary conditions to encourage the development of fungi within the host. Surveying work also involved scouting for sexava cadavers in areas of high pest populations. The cadavers were collected and again kept in the necessary conditions required for fungal sporulation. Unfortunately no evidence of the presence of fungal pathogens was found from the sexava cadavers collected during these studies. A soil isolation technique was also used to survey for fungal pathogens and involved the collection of soil samples from the oil palm agroecosystem in West New Britain. Fungal isolates were then obtained from the soil samples by baiting with larvae of *Galleria mellonella* (greater wax moth), which are highly susceptible to pathogens. Samples of spores were taken from any moth larvae exhibiting signs of external sporulation, these were then stored in the culture collection at the CABI Biosciences. Most of the fungal pathogens isolated in this manner were identified as *Metarhizium* sp. The fungi were then stored as spores obtained from culture. Bioassays of a total of 49 fungal isolates extracted from the soil samples in this manner were undertaken in PNG in 1997. In the bioassays a few of the isolates achieved 100% mortality, but no cadavers exhibited signs of external sporulation and so the candidate fungal pathogens could not be re-isolated. With Koch's postulates unfulfilled it has not been feasible to develop fungal pathogens as biological control tools for sexava.

Strepsipteran parasites

In PNG, female *Stichotrema dallatorreanum* parasitize sexava (Young, 1987). High levels of parasitism (30-40%) of the sexava species, *S. novaeguineae* by *St. dallatorreanum* occurs in oil palm growing areas in mainland PNG and chemical control has not been required on plantations in these areas for many years. By contrast, in West New Britain regular intervention has been required to control *S. defoliaria* and *S. decoratus*. *St. dallatorreanum* has not been reported to parasitize these two species of sexava in West New Britain. A quantitative study into the effect of parasitism by *St. dallatorreanum* on the performance of the *S. novaeguineae* host was undertaken by Solulu *et al.* (1998) who reported that the feeding activity by the host was significantly reduced in parasitized females. It was also found that host reproductive variables were profoundly affected by parasitism. For female *St. dallatorreanum* this included impaired ovarian development, reduced egg number and gonadal weight, the last of which was also reduced in males. Solulu *et al.* (1998) concluded that the ability of *St. dallatorreanum* to reduce feeding and reproduction in the host suggests that it may have potential as a biological control agent for use in sexava management. In view of these findings a series of infectivity trials were undertaken in the laboratory to assess whether the parasite would infect the two species of sexava that are pests of oil palm in West New Britain. Nymphs of the two species were exposed to first instar *St. dallatorreanum* in replicated and controlled cage experiments. The infection levels in test insects from the two species ranged from approximately 70-90%, relative to the healthy control insects. Field studies were also undertaken to survey for male *St. dallatorreanum.* However, relatively few males of the parasite were found during the study period and the role of the males in the life history of the parasite remains unclear. Kathirithamby (personnel communication) suggests that the female *St. dallatorreanum* that infect *S. novaeguineae* in the oil palm growing areas of mainland PNG may be parthenogenetic, or may express this mode of reproduction under certain conditions. In accordance with this, Kathirithamby (personnel communication) also suggests that first instar *St. dallatorreanum* may not be sexually dimorphic, and that reproduction occurs by a combination of parthenogensis, polyembryony, and vivaparity.

The parasite is now being introduced into the oil palm growing areas of West New Britain in an attempt to get it established in field populations of *S. defoliaria* and *S. decoratus*. The information so far gained from the sexava IPM project indicates that the successful introduction of the parasite into the oil palm growing areas of West New Britain may have a significant impact on the pest status of the two species of sexava in these areas.

Egg parasitoids

The Oil Palm Research Association has reared the Hymenopteran egg parasitoids *Leefmansia bicolor* and *Doirania leefmansi* in the laboratory for several years. They are reared on sexava eggs and then released into oil palm growing areas where low-level sexava populations are present. Several million of these egg parasitoids are usually released into the field each year. The precise role of the egg parasitoids in regulating sexava populations remains unclear. However, they are a useful biocontrol tool for sexava IPM as they can be used in conjunction with trunk-injected insecticides to manage high-level pest damage, and can also be combined with cultural and physical control methods to provide long-term regulation of low-level populations of sexava.

Cultural and physical control

Sexava adults and nymphs tend to move into the edges of oil palm blocks from their natural hosts; these include wild sago, banana and *Heliconia*. It is therefore essential that these natural host plants are removed from the vicinity of oil palm growing areas. Sexava adults and nymphs are nocturnal in their feeding behaviour and tend to spend the daytime sheltering in the relative shade of the central spear cluster of the oil palm. This preference for shade means that it is important that oil palm is well pruned and kept free of old fronds that tend to hang down from the central cluster. Physical control can involve the hand collecting of sexava adults and nymphs from affected areas.

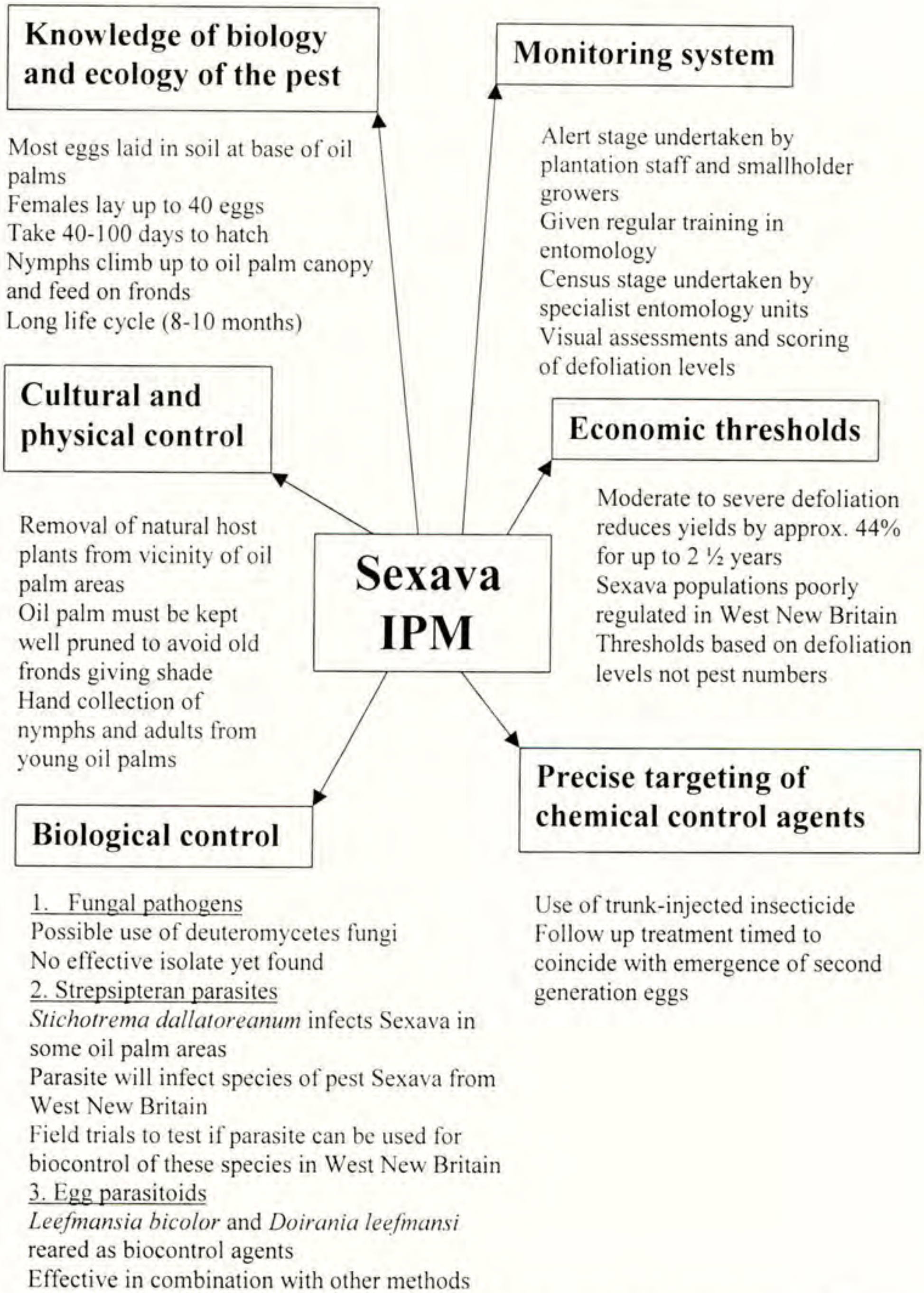

Figure 1. A summary of the IPM system that has been developed for sexava pests of oil palm in Papua New Guinea.

DISCUSSION

A summary of the IPM system that has been developed for sexava is shown in Figure 1. The knowledge of the biology and ecology of the main pest, although far from complete, is enough to enable effective decision making in the other components of the IPM system. The impact of the pest on the yield components of the crop is sufficiently well understood to enable economic thresholds to be determined. The economic thresholds are effective at a field level, and can be used in the area-wide monitoring system for the pest. Pest monitoring is efficient, as evidenced by the regular detection of low level pest damage, and it requires a relatively small input from specialist entomologists. There is no indiscriminate use of insecticides, with the trunk-injection technique providing precise targeting of chemical control agents, thus preventing contamination of the environment and workers, as well as preserving beneficial and non-target organisms.

Future research involving the development of novel agents for biological control is likely to improve this IPM system still further. Successful introduction of the parasitic Strepsipteran, *St. dallatorreanum* into the oil palm growing areas of West New Britain may have a significant impact on the pest status of the two species of sexava in these areas. This is likely to result in further reductions in the use of insecticides, and therefore provide further cost benefits to the oil palm industry in PNG.

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Interactions between the leafminer *Liriomyza trifolii* and the plant pathogen *Alternaria alternata* in the development of leaf necrosis on potato in Oman

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ABSTRACT

Three field experiments were carried out during the 1999/2000 growing season to investigate the relationship between damage caused by *Liriomyza trifolii* and damage caused by *Alternaria alternata* to potato crops in Oman. The first experiment involved screening twelve potato varieties for their susceptibility to attack by the pest and the pathogen. The second experiment involved using an insecticide, partially to control the leafminer population. In both these experiments the results were unambiguous, leafminer damage being highly correlated with damage caused by the pathogen. The third experiment assessed whether temporary exclusion of the leafminer from the crop would be a viable option for control of both pest and pathogen. Again, leafminer damage and pathogen damage were highly correlated. However, pathogenic damage progressed at a much higher rate on the protected crop once the protection was removed. The data collected so far therefore indicate that control of *L. trifolii* will also lead to control of the damage caused by *A. alternata* but the data also suggest some strategies for leafminer control. Experiments that will be undertaken during the 2000/2001 growing season will test these strategies.

INTRODUCTION

Potatoes are a relatively new crop in Oman. Since 1980 the area, yield, and annual total production of potatoes has increased (Figure 1). After tomatoes and onions, potatoes are now the third most important vegetable crop grown in Oman. Expansion of potato production began in the early 1980's following a government-subsidised seed distribution program. Despite the withdrawal of these subsidies in the early 1990's potato production has continued to increase and large commercial farms now produce yields of 35 - 45 t/ha. The future expectation is that potato production will continue to expand in the Sultanate.

At present, the biggest constraints to potato production in Oman comprise a number of pests and diseases. Important pests include the peach potato aphid *Myzus persicae*, the whitefly *Bemisia tabaci*, the jassid *Jacoblasca lybica*, the potato tuber moth *Phthorimea opercullela*, and the leafminer *Liriomyza trifolii*. Important diseases of potato include early blight *Alternaria solanii*, leaf spots caused by *Alternaria alternata* or *Stemphylium solani*, blackleg (*Erwinia carotovora*), and a number of different potato viruses that are vectored primarily by whitefly (Anon, 1991; Moghal, 1993).

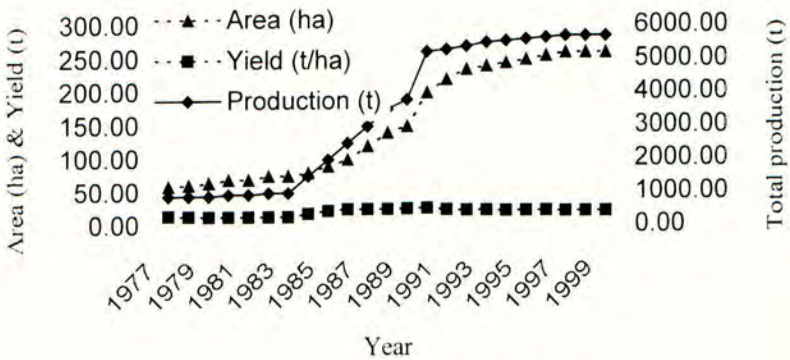

Figure 1. Change in potato production in Oman 1977 - 1999. Data abstracted from FAO statistical database at http://apps.fao.org.

To control these pests and diseases the current recommendations involve the application of an insecticide or a fungicide. Products that are currently recommended for pest control include butocarboxim, ethiofencarb and pirimicarb (systemic carbamates), deltamethrin, alpha-cypermethrin and fenvalerate (contact pyrethroids), phosphamidon (systemic organophosphate) and phenthoate (contact organophosphate). Products that are recommended for pathogen control include cymoxanil, mancozeb, and copper oxychloride (all protectants). The actual product that a grower uses will depend on its price, availability, and the user's knowledge of the chemical. Whichever pesticide is finally selected, it will be mixed with water and sprayed at high volume using hydraulic application equipment. It is not unusual for farmers to combine an insecticide and a fungicide when spraying, and plants are typically sprayed until run-off (Thacker *et al.*, 2000). There are no action thresholds for pest and disease control, and large commercial farms frequently apply pesticides programmatically.

Preliminary research had indicated differential sensitivity of potato to leaf spot damage (Khan *et al.*, 2000). The aim of the research described in this paper was to look at the significance of possible interactions between a common pest and a common leaf spot pathogen *viz. L. trifolii* and *A. alternata*. Both the pest and the pathogen cause leaf necrosis and consistent field observations had indicated that these two organisms may interact and enhance their damaging effects on potato. Our overall aim was to develop an integrated control strategy for these pest organisms.

MATERIALS AND METHODS

Three field experiments were undertaken during the 1999/2000 growing season to investigate the relationship between *L. trifolii* and *A. alternata*, and the development of leaf necrosis. The first experiment involved an assessment of varietal responses to attack by the pest and the pathogen. The second experiment involved using an insecticide partially to control the leafminer population. The third experiment involved using polyester fleece to exclude the leafminer from the potato crop. All field work was undertaken at the university farm.

Experiment 1 - Varietal trials

Twenty four rows of potato were divided into six replicate blocks. Each row was 60 m long and was divided into three 20 m sections. Row spacing was 1 m. Within each block 12 potato varieties were sown, one variety per 20 m section. Varieties were allocated to sections within a block randomly.

Experiment 2 - Leafminer control by insecticide

Sixty potato rows, 60 m long with 1 m spacing, were sown with two varieties. Varieties were alternated between rows. The field was then divided into twelve plots measuring 20 m by 15 m. Each plot was allocated one of the following treatments - no spray, one spray, two sprays. Treatments were allocated randomly. Sprays were applied one and two months after plant emergence. The insecticide lambda-cyhalothrin was applied using a knapsack sprayer fitted with a hollow cone nozzle at a volume application rate of 200 l/ha.

Experiment 3 - Leafminer exclusion using fleece

Twelve potato rows, 60 m long with 1 m spacing, were sown with a single variety. The field was then divided into 4 replicate blocks. Within each block the three rows were randomly allocated one of the following treatment - no cover, cover to 34 days, cover to 41 days. Rows were covered with polyester fleece.

Assessment of *L. trifolii* and *A. alternata* incidence

Assessments of leafminer and pathogen levels were carried out weekly from emergence to crop senescence. The assessment procedure for the leafminer and the pathogen was the same for all three experiments. All sampling was carried out on plants located in the centre of treatment plots. Leafminer incidence was assessed as a percentage of the leaflets mined on a plant. Pathogen incidence was assessed on a score of 0 - 10 where zero was equal to no necrosis and 10 was equal to a totally necrotic leaf. A score of 5 would indicate a plant with approximately 50% necrotic tissue. Presence of the pathogen was confirmed by culturing field-collected samples in the laboratory.

Data Analysis

For all experiments the data were analysed using correlation and regression techniques. Pathogen incidence was plotted against the percentage of leaves that had been attacked by leafminers. For the varietal trial, comparisons were made both within and between varieties. The data presented here however include the total data set for all varieties and all sampling occasions. With the fleece trial the data were plotted as percentage leafminer or necrosis through time. The slope and intercept associated with regression models for these data were then analysed using analysis of variance.

RESULTS

All the data collected in the varietal trial are shown in Figure 2 as leaf spot score against percentage leafminer presence. The data were analysed with a polynomial regression model. The result was a significant fit of the model ($Y = 0.00002X^3 - 0.0026X^2 + 0.1282X + 0.5273$) to the data set ($r^2 = 0.8715$, $P < 0.001$). The model shows that necrosis caused by *A. alternata* was highly dependent on leafminer damage. The pattern of damage across all varieties suggests that there may be two phases of rapid pathogenic damage development. However, this may simply reflect the fact that the data represent interactions between pathogen and pest damage across twelve varieties. More detailed analysis of the data will be reported elsewhere. What is clear however is the strong association between pathogen and leafminer damage.

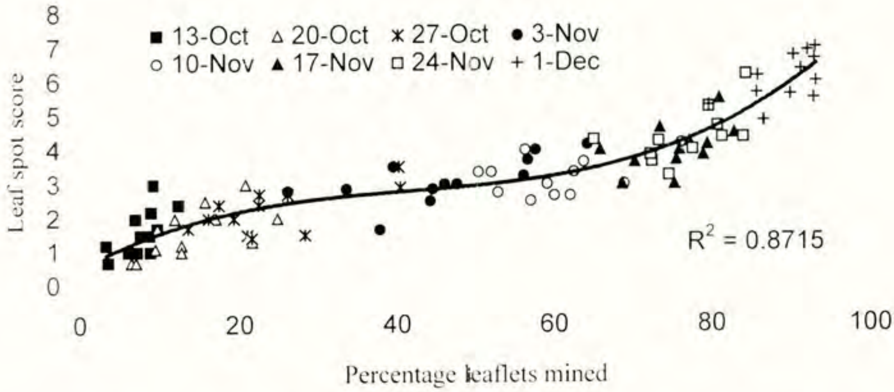

Figure 2. Regression analysis of necrosis (leaf spot score) against percentage leafminer presence. Data are for all varieties and all sampling dates.

Figure 3 shows the results of the experiment 2. Leaf spot scores for all treatments were regressed against leafminer presence. The figure shows a significant relationship between the variables. The figure also shows the progression of necrosis through time for plots that were unsprayed or sprayed once. For plots that were sprayed twice, the leaf spot score (and associated leafminer presence) remained low. This suggests that the insecticide was effective in partially deterring the leafminer from ovipositing in plots that had been sprayed twice.

Figures 4 and 5 show the effects of covering the crop on mine and necrosis development. The figures show that the cover delayed the development of insect and pathogen attack. However, the figures also show that at 70 days after planting there were no differences in either leafminer presence or necrosis between the different treatments. This indicates that although the cover may temporarily protect the crop from attack, that when the cover is removed the insect (and the pathogen) increase their rate of attack on the crop, prior to harvest, *ca.* 80 days after planting.

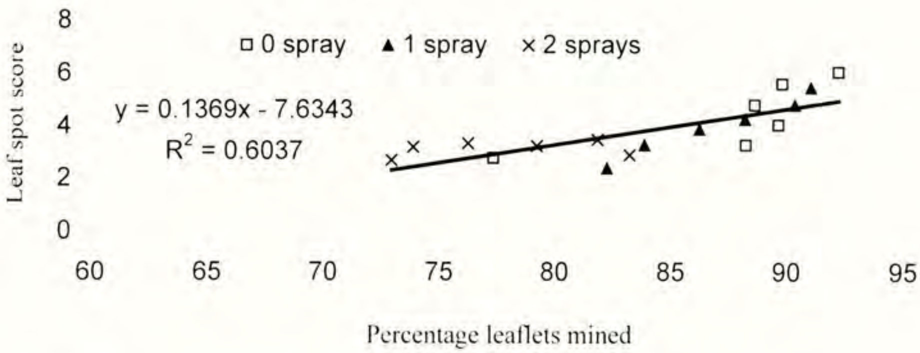

Figure 3. Regression analysis of leaf spot score against percentage leafminer presence. Data are for all treatments. Symbols within a treatment represent sequential sampling occasions.

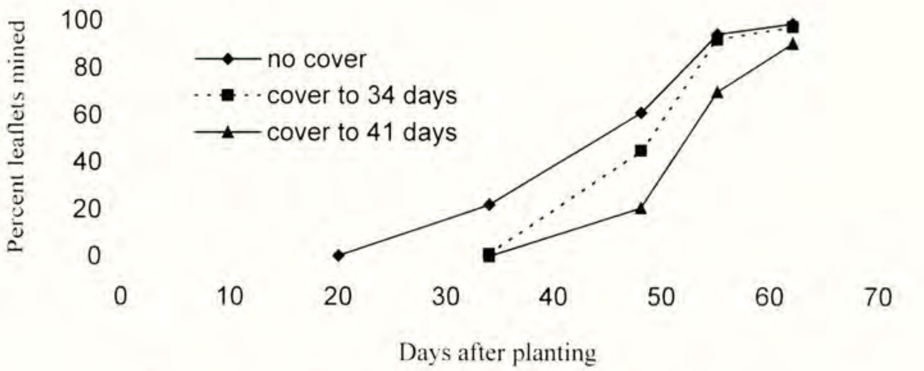

Figure 4. The effects of crop cover on leafminer presence.

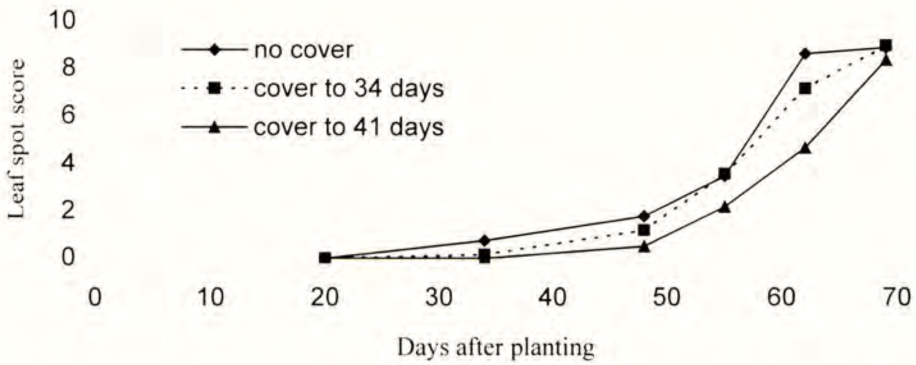

Figure 5. The effects of crop cover on leaf spot development.

DISCUSSION

The data presented in this paper indicate a clear association between damage to potato crops in Oman caused by *L. trifolii* and damage caused by *A. alternata*. Although newly recognised in Oman, it is well known that weak pathogens, like *A. alternata*, use damage caused by leafminers as foci for attack on crop plants. What is novel with our data, however, is the comparison of different methods for leafminer control. It is clear that simply covering the crop is not an appropriate tactic. The data indicate that a newly uncovered crop is rapidly attacked by the insect, and then by the pathogen. Attack by the pathogen is therefore not random, but is mediated by the insect. The insecticide tested in the research appeared partially to control the leafminer and therefore the necrosis caused by the pathogen. Further research on chemical control is required to evaluate optimal timing for applications. Data are also required on the most effective chemicals for use in an integrated pest and disease control program. What is clear however is that control of the miner can lead to control of the pathogen. Data on varietal differences in susceptibility to the leafminer are not presented here because of space constraints. These data will be presented elsewhere. In summary, the data in this paper indicate that leaf necrosis on potato in Oman is caused by the combined attack of an insect and a pathogen. The data show that controlling the insect will lead to control of the pathogen. Further experiments in the 2000/2001 growing season will assess the best methods for protecting potatoes from harmful organisms in the Sultanate.

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Impact of healthy planting material and improved management practices on plantain production in Ghana

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ABSTRACT

Plantain (*Musa* spp., AAB group) is an important staple crop in Ghana. In recent years, declining yields and reduced plantation life have been attributed to a pest and disease complex including nematodes, banana weevil and black sigatoka. An on-farm trial was undertaken (1997-1999) to determine the effect of planting material treatment (hot water, 53-55°C, 20 min) and improved management practices (optimum plant spacing and regular weeding) on plantain pests and diseases, and production. Hot water-treated suckers and nursery-derived suckers were tested in comparison with untreated planting material under traditional and improved management practices at six farms in each of three plantain-growing regions. Planting material treatments significantly reduced the density of the most damaging nematode species, *Pratylenchus coffeae*, in plantain roots and the percentage of dead roots at flowering. Percentage bunch loss (due to toppling, stem breakage, failure to flower or premature death) was significantly reduced by planting material treatments and improved management. Yields were approximately trebled due to the use of treated suckers and regular weeding in comparison with untreated material under traditional management.

INTRODUCTION

Plantain is a primary staple food in Ghana, providing a source of food and cash income for resource-poor farmers throughout the year. In recent years, there has been a substantial decline and reduction in plantation life (<3 years) within the country. Severe plant toppling in the first season and rapidly diminishing yields in ratoon cycles mean that plantain is commonly treated as an annual rather than a perennial crop. This situation necessitates frequent land clearing which is costly to the farmer and the environment. The decline in plantain production is attributed to high levels of nematodes, banana weevils and foliar disease (black sigatoka) together with poor soil fertility (resulting from shortened fallows) and the high cost of crop management (Karikari, 1970; Schill *et al.*, 2000). Plantain

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damage due to nematodes and weevils is frequently compounded by the use of infested planting material since farmers are usually unaware that suckers are the main source of inoculum for these pests. Lack of healthy planting material represents a major constraint to plantain farmers in Ghana (Schill *et al.*, 1997). Suckers are costly, they are often infested with nematodes and weevils, and may not be available when the farmer is ready to plant.

Techniques for the production and rapid multiplication of healthy plantain planting material have been developed. Suckers free of nematodes and weevils can be produced either by paring with a cutlass (removal of roots, outer corm layers and necrotic tissue) or more effectively, by paring followed by hot water treatment (Colbran, 1967). In addition, healthy suckers can be multiplied using a simple split-corm technique (Adelaja, 1995) followed by germination in sawdust and transfer to nursery beds. The resulting suckers can either be used by the farmer or sold as planting materials. Although disinfestation of planting material can help to alleviate pest problems, the crop may still not reach its yield potential if farm management (particularly weeding) is inadequate (Schill *et al.*, 1996a) or when soil fertility is poor. Farmer-participatory trials were established in 1995 and 1997 in three plantain production regions of Ghana to study the effects of healthy planting material and improved management practices on pest and disease dynamics, and plantain production. This paper reports key results from the 1997 trial.

METHODS AND MATERIALS

Experimental design

The experiment was conducted at one village in each of three regions of Ghana known for high levels of plantain production: Pramkese in Eastern Region (0 45'W 6 05'N), Nyinahin in Ashanti Region (2 05'W, 6 35'N) and Gyedu in Brong Ahafo Region (2 20'W, 7 05'N). In each village, six treatments were replicated at six farms with 100 plantain plants per plot. Each farm was divided into six plots of 0.1 ha and the treatments were assigned at random to the plots. The treatments evaluated were:

1. Untreated plantain planting material and farmer's management (U-FM)
2. Untreated plantain planting material and alternative management (U-AM)
3. Nursery-derived plantain planting material and farmer's management (N-FM)
4. Nursery-derived plantain planting material and alternative management (N-AM)
5. Hot water-treated plantain planting material and farmer's management (H-FM)
6. Hot water-treated plantain planting material and alternative management (H-AM)

At each site, fields that had been fallowed for 3-10 years were used. The fields were cleared and burned in April/May 1997. The experiment was planted from late May to early June, 1997, and maintained until June 1999. Plantain planting materials were of the widely preferred local cultivar, Apantu-pa (false-horn). For treatments U-FM and U-AM, plantain suckers were uprooted from old farms and planted with no further treatment. For H-FM and H-AM, suckers uprooted from old farms were pared by removing roots and outer corm layers to a depth of 0.3 cm and hot water-treated (55°C, 20 min) to eliminate nematodes and banana weevils (Colbran, 1967). For N-FM and N-AM, suckers uprooted from old farms were pared, hot water-treated, split into several setts and pre-sprouted in sawdust beds before transfer to a field nursery for 3-5 months (Danso *et al.*, 1999).

Farmer's traditional management practices involved planting at a spacing of approximately 2 m x 2 m (not necessarily in rows), irregular spacing of intercrops (maize and cocoyam), and weeding when labour was available and could be afforded. For alternative management practices, plantain and intercrops were planted in rows (plantain, 3 m x 3 m; maize, 0.75 m x 0.75 m, two seeds per hole; cocoyam, 1.5 m x 1.5 m). The plots were weeded once per month during the first six months after planting and thereafter every six to eight weeks, depending on the fallow period and rainfall in the area.

Data collection

For each treatment, twenty five plants were selected at random for root health assessments at flowering, using the methods of Speijer & de Waele (1997). Nematodes were extracted, identified and counted from functional roots using a modified Baermann's technique (Hooper, 1990). Percentage sucker emergence was recorded, followed by plant height at flowering and the number of suckers produced at harvest. Bunch weight was determined at harvest and the number of bunches lost due to toppling, stem breakage, plant death or failure to flower, was also recorded.

Statistical analyses

Prior to analysis, count data were log(x+1) transformed and percentage data were subjected to arcsin transformation. Treatment effects were tested using analysis of variance based on mixed model procedures (SAS, 1997). Orthogonal contrasts were used to test significant differences for nematode densities, root damage, plant growth and yield for 1) farmers' management versus alternative management, 2) untreated planting material versus hot water-treated and nursery-derived planting materials, and 3) hot water-treated planting material versus nursery-derived planting materials. Site differences were generally not significant and therefore means for the three sites are presented.

RESULTS AND DISCUSSION

Table 1 shows root densities of *Pratylenchus coffeae*, the most widespread and damaging nematode species on plantain in Ghana (Schill *et al.*, 1996b; Brentu *et al.*, 1999). Plants from untreated suckers had significantly higher densities of *P. coffeae* at flowering compared with plants from treated suckers. Correspondingly, there was an effect of planting material treatment on root health, with plants from untreated suckers having a significantly higher percentage of dead roots at flowering compared with plants from hot water-treated or nursery-derived plants. There was no effect of crop management on nematode densities or root health at flowering.

Percentage sucker emergence was not affected by planting material treatment but farmer management gave significantly lower levels of emergence than alternative management practices, probably due to less frequent weeding in the first few months after planting.

Although there was no effect of hot water treatment on plant emergence in this trial, previous research has shown that there can be a deleterious treatment effect if suckers weighing <0.8 kg are hot water-treated (Brentu, 2000). At flowering, plants derived from treated materials were taller than those from untreated suckers but there was no effect of crop management on plant growth. The number of suckers at harvest was affected both by planting material treatment and crop management, with the highest number of suckers recorded for nursery-derived plants under alternative management. Participating farmers noted this as an advantage of planting material treatment, since suckers derived from healthy plants can be detached and multiplied for use as planting material (Green & Afreh-Nuamah, 1999).

Table 1. Effect of planting material treatments and crop management on nematode densities, root damage, plant growth and yield of plantain, at three villages in Ghana (1997-1999)

Treatment	% sucker emergence	*P.coffeae* density at flowering /100 g roots	Dead roots at flowering (%)	Plant height at flowering (cm)	Sucker number at harvest	Bunch weight (kg)	% bunches lost	Production t/ha
FM UT	83	7,292	27.1	288	8.0	6.3	77.5	2.3
FM H	84	1,503	4.5	300	5.5	8.0	56.3	5.8
FM N	83	2,482	4.4	314	6.1	8.3	64.2	5.0
AM UT	87	8,518	22.8	284	7.7	7.1	63.2	4.4
AM H	86	898	4.9	301	6.7	8.0	43.2	7.6
AM N	92	2,017	4.1	302	6.9	8.7	47.5	7.7
Treatment effect	*	***	***	***	***	***	***	***
Contrasts:								
FMvs AM	**	Ns	Ns	Ns	***	Ns	***	**
UTvs H&N	Ns	***	***	***	***	***	***	***
H vs N	Ns	Ns	Ns	Ns	**	Ns	Ns	Ns

*, **, ***: F-tests significant at $P<0.05$, 0.01 and 0.001 respectively
Ns: No significant differences $P<0.05$

FM UT Farmers' management, untreated planting material
FM H Farmers' management, hot water-treated planting material
FM N Farmers' management, nursery-derived planting material
AM UT Alternative management, untreated planting material
AM H Alternative management, hot water-treated planting material
AM N Alternative management, nursery-derived planting material

At harvest, the heaviest bunches were obtained from plants derived from treated materials. There was no effect due to management practices. The poor fruit filling and reduced bunch size typical of plants from untreated suckers was indicative of severe root damage and reduced ability to absorb moisture and nutrients (Stover & Simmonds, 1987). Production for the plant crop was relatively low for all treatments (<8 t/ha) and this was attributed to the time of flowering coinciding with a prolonged drought, such that bunch filling was impaired. Nevertheless, production was significantly affected by both planting material treatment and management practices, with yields more than trebled due to the use of treated suckers and regular weeding, in comparison with untreated materials under traditional management. These results are in agreement with results from on-station trials in Ghana, in which yields from hot-water treated suckers were compared with yields from nematode-infested suckers (Brentu, 2000; Brentu *et al.*, 1999). It was encouraging to note that nursery-derived suckers performed as well as hot water-treated materials, such that the use of plantain nurseries as a source of clean suckers for planting new farms can be promoted.

The disparity in yield between the plants from treated and untreated suckers was due largely to the high percentage of bunches (>63 %) lost prior to maturity of the plant crop due to toppling, stem breakage, failure to flower or premature death. These symptoms are consistent with the presence of severe root damage due to *P. coffeae* (Gowen & Quénehervé, 1990; Brentu *et al.*, 1999). Mats from which plants have toppled have a greatly reduced chance of producing a mature bunch in the next cycle. Therefore an even higher loss can be expected for subsequent crop cycles (Speijer *et al.*, 1999). Percentage bunch loss was significantly reduced by both planting material treatment and alternative management strategies.

In addition to improved yields, it was observed from the trial planted in 1995 that planting material treatment and regular weeding substantially lengthened plantation longevity (Green & Afreh-Nuamah, 1999). Farmers' plots with untreated materials were largely abandoned after the first season due to the high incidence of plant toppling. In contrast, hot water-treated materials that were well-managed, continued to yield for at least 3 years.

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Pesticide residues in irrigated cereal ecosystems

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ABSTRACT

It is likely that pesticide use (especially herbicide use) in rice paddies in South East Asia will increase. Due to the particular vulnerability of rice paddies to pesticide contamination, it is important to take measures to minimise the impact of pesticide use. A decision support system named 'PRICE' has been developed to help evaluate the environmental costs and benefits of use of a range of pesticides. The system is based around a database of pesticide properties which is linked to a scenario-based model assessment of economic and environmental considerations.

INTRODUCTION

Asian rice production continues to be under stress due to the reduction in the world-wide price of rice, increasing populations and the changing labour structure of the region. The changing labour structure is due to the slow, yet marked, migration of labour from rural communities to the industrialising urban areas, which causes increased labour costs for farming. Because of the importance of rice production in the economy (see Table 1), Asian rice production must continue to become more efficient both in terms of labour and other costs. Efficiency can be enhanced by reducing crop losses and by adopting more efficient cultural practices.

Table 1. Proportion of the global rice herbicide market in 1993.

	%	Amount (US$)
India	2	23 million
Bangladesh	0.4	5 million

(After IRRI, 1995).

Cultural practices

In Bangladesh, labour costs are as much as 44% of the variable costs of production (IRRI, 1995). Direct seeding is increasingly replacing transplanting as the dominant cropping system due to the economic advantages that it offers. The use of direct seeding reduces labour costs by eliminating the need for labour to maintain nurseries and for transplanting. Direct seeding is a viable system in high-productivity irrigated systems if cost-effective herbicides are used to control weeds (Naylor, 1996).

Reducing crop losses

Reduction of crop losses due to insect pests, weeds and diseases is likely to involve an increase in the amount of pesticide used. Chemical control of pests has proved expensive in the past, but is now becoming more economic because of the increase in labour costs for hand weeding, and because older chemicals are becoming cheaper and more widely available. In Asian rice production, insecticides and fungicides have been used for many years, their use is not likely to increase greatly, but the use of herbicides is likely to increase in the near future.

'Weeds are the most severe and widespread biological constraint to rice production' (Moody, 1991). Weeds constrain rice production through reduced grain yields, and through harbouring pathogens and pests as alternative hosts to the rice crop. World-wide, it is estimated that 10% of rice yield loss is due to weeds after weed control has taken place (Ampong-Nyarko & De Datta, 1994). There is considerable variation in this figure among rice producing countries, particularly in tropical areas such as Asia, where the majority of control is by cultural or manual methods. Improvement in weed control practices by farmers is essential in increasing future yields.

Herbicide use reduces costs in both direct seeded and transplanted rice by reducing the cost of labour for hand weeding. Research has shown a benefit to cost ratio of 16:1 (up to 25:1 with complete control) for use of herbicides compared to 3.3:1 for hand weeding (Naylor, 1996). There is a dramatic difference in labour requirements between direct seeded rice with herbicide use (1.8 person days / ha), and transplanted with hand weeding (25 person days / ha) (IRRI, 1995).

Managing pesticide risks

The major concern is how best to govern, regulate and minimise the risk of herbicide use as this use becomes more widespread. In order to do this, it is necessary to understand the effects of use on the population of the area, the effects of use on the environment, and the economic implications of usage or non-usage of herbicides.

Increased use of pesticides implies increased risk to human and environmental health in the short term and the possibility of the build up of residues in the rice paddy ecosystem. The use of decision support tools from the outset of the use of chemicals to predict fate, as well as provide information on the chemicals, would help to minimise environmental impact in a fragile environment such as the land/water interface-based system (rice paddy). PRICE (Pesticide Residues in Irrigated Cereal Ecosystems) has been developed as a decision support tool to help evaluate the costs and benefits of pesticide use. PRICE was developed with the use of herbicides in mind, but it can also be expanded to include insecticides and fungicides if proved successful in helping to control rice herbicide residue impacts.

EXISTING SOURCES OF INFORMATION

Pesticide properties

There are a number of databases available that contain information on the environmental effects of pesticides. Several can be found on the Internet, including the *ARS Pesticide Properties Database* (Herner, 1999) and the *Extension Toxicology Network* (EXTOXNET) (Johnson, 1987). The ARS database presents physico-chemical information about the pesticides, including results of laboratory analyses of the fate of pesticides in soils, and aqueous solutions. The EXTOXNET database concentrates on information about the toxicology and ecotoxicological effects of the pesticides. *The Pesticide Manual* (Tomlin,

1997) is now also available as a CD-ROM based database. This gives the same information as that available in the hardcopy version. These databases are all useful, containing information on a large number of pesticides. However, because these sources are intended to be general information sources, the information may not be relevant to the particular conditions of rice culture.

Decision support tools

There are various decision tools available for pesticide use in various crops, but in each case the tools tend to focus on one specific crop or one specific crop production area. Furthermore, there is little information on the consequences of pesticide use.

Lateblight (Fry *et al.*, 1990) predicts the likely amount of crop damage in a potato crop from infection by the late blight fungus, *Phytophthora infestans*, under various environmental conditions such as length of season, emergence date and weather. The level of resistance of potato varieties and distance from possible disease sources is also taken into consideration.

SIRIUS (Semenov, 1998) is a wheat crop model used to determine the effects of pesticide use on crop output determined by applied chemical dosage and time of application. This model has been used in conjunction with a stochastic weather generator program in order to determine the effects of climate change on wheat production in Europe. In time it may be feasible to convert such a model for use in paddy rice production in the tropics.

The TropRice decision support tool of the International Rice Research Institute (Bell, 1999) is an excellent rice production management database, which contains information on various aspects of the management and production of tropical rice. Among the data within the programme is information on application of pesticides, and their target organisms.

DEVELOPMENT OF PRICE

PRICE was developed to give access to information about the range of herbicides available, so that the potential effects can be understood before application takes place. It is also intended to act as a first-tier risk assessment tool, to summarise the areas where environmental problems are most likely to occur, under a given scenario and choice of chemical. It can also be used to estimate the potential cost-benefit of using any weed control strategy.

The PRICE database

The PRICE database contains information on all the herbicides that are used in rice production. The chemicals are split into two groups: those registered for use in the Indo-Gangetic floodplain, and those that are not. Only limited information is given for the first group, such as manufacturer, product names and use. The second group has a much wider amount of information, such as mammalian toxicology, ecotoxicology, environmental fate, metabolic pathways and species controlled. In this way, decision makers can have all the necessary information available to them in an easily accessible manner. The information within the database was compiled from a number of sources such as:

- *The Pesticide Manual* (Tomlin, 1997),
- *Metabolic Pathways of Agrochemicals* (Roberts, 1998),
- *Metabolic Maps of Pesticides* (Aizawa, 1982),
- EXTOXNET toxicology database (Johnson, 1987) and,
- The *ARS Pesticide Properties Database* (Herner, 1999).

In addition to the pesticide information, there is information on important soil, cultural and climatological parameters that affect the predictions of pesticide fate in the environment in the PRICE simulation system.

The PRICE simulation system

The purpose of this part of the system is to allow a rapid screening of weed control measures for potential environmental problems and economic feasibility. It is not intended to be an exhaustive prediction of the environmental effects of a weed control measure, nor is it intended to be an absolute predictor of the farmer's income at the end of the season.

The environmental processes considered include degradation in the soil, in the water and on the plant; sorption of the pesticide onto the soil and suspended sediment; volatilisation from the water to the atmosphere; pesticide leaching through the soil; and pesticide runoff from the paddy. Most of the equations used to calculate the herbicide fate in the environment are taken from the user manual for the model RICEWQ, version 1.6.1 (Williams *et al.*, 1999). Predictions are made of herbicide amounts in the environmental compartments of soil, paddy water, run-off water and leachate water. A mass balance is drawn up at the end of the simulation, to show the likely fate of the pesticide. The predicted peak and average concentrations in the soil and water are used to perform a risk assessment of the chemicals, based on available toxicological data.

The parameters needed to drive the simulation fall into the categories of pesticide properties (sorption coefficient, Henry's law constant, degradation rates etc.), soil properties (hydraulic conductivity, bulk density, suspended sediment concentration etc.) and environmental properties (water inflow, daily rainfall, daily evaporation). These parameters can be edited directly in the database itself.

The model includes the simplification that the soil is assumed permanently saturated. A fixed time-step (1 day) explicit numerical scheme is used for the calculations. This scheme is easy to understand, but in some cases may allow numerical errors to occur. The errors generally do not significantly affect the outcomes of the calculations.

The economic calculations are relevant whatever control method is used. They are based on a simple model of the economic costs and benefits of weed control strategies. Yield loss due to weeds is computed according to a relative damage coefficient of the weed (perniciousness), the leaf area index of the weed compared to the crop and the maximum yield loss if left uncontrolled (Kropff & Lotz, 1993). The economic effect of the weeds and weed control measure is considered using the value of the increased yield if the control measure is adopted (Auld *et al.*, 1987). The model will predict the net benefit of using the weed control measure, and calculates the threshold level of weed infestation at which the weed control measure should be adopted.

This section is parameterised in terms of the potential yield, the perniciousness of the weed species, the severity of infestation and the effectiveness of the control measures. The costs and benefits relate to the current growing season only. Consideration of weed resistance to herbicides, enhanced degradation, reduction of the weed seed bank for future growing seasons or herbicide phytotoxicity to the rice plant must be considered using appropriate parameterisation. The parameters can be edited and adjusted using the same interface as for the database.

THE FUTURE OF PRICE

With PRICE, a system has been developed to allow decision-makers in the Indo-Gangetic plain to access a wide range of relevant pesticide information. This information is important during a time when pesticide usage looks set likely to increase.

It is most likely to be used by the policy makers and extension workers to help inform the advice they give to farmers (rather than by the farmers themselves). It may also be used by registration authorities to help quickly identify problem compounds. The question remains as to whether such a system would be used. Factors to be addressed include the 'look and feel' of the software, and the reliability of the predictions.

Future research is certainly required on the fate of rice herbicides in paddy soils in order to validate the data and model predictions of PRICE. This would require extensive experimentation on both fate and toxicology under the conditions of the Indo-Gangetic region. PRICE may help research groups to define research priorities.

Whilst the project is based on the Indo-Gangetic Plain, there is no reason why the model could not be used in other paddy rice growing areas if the appropriate parameters on the soil, pesticide and climate were obtained. It could be extended to other classes of compounds (insecticides or fungicides) if appropriate pesticide and crop yield data could be obtained. Eventually, it could be incorporated into more general model systems, such as IRRI's TropRice, in order to enhance their applicability.

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An integrated approach for managing hot pepper pests in the Caribbean

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ABSTRACT

Towards developing a sustainable pest management strategy for hot pepper, (*Capsicum chinense*), four surveys were conducted in Jamaica to determine pest and disease incidence, pest management methods employed by farmers and the relationship of these practices to pest incidence. A total of 106 farms across various agro-ecological zones were surveyed. Viruses (tobacco etch and potato Y), aphids (*Myzus persicae, Aphis gossypii)*, the broad mite (*Polyphagotarsonemus latus)* and gall midges (*Contarinia lycopersci* and *Prodiplosis longifila)* were the major pests recorded. Viruses occurred on 97% of farms and the other three pests on more than 30% of farms. Seventy-eight percent of the farmers used pesticides and a total of 21 different types were recorded (14 insecticides and 7 fungicides). A clear direct relationship was observed between pesticide use and broad mite incidence; farmers using pesticides had three times more broad mites as compared to those who used no pesticides or very little. The implications of these results on the development of a biologically-based management strategy for hot peppers are discussed.

INTRODUCTION

As Caribbean countries identify alternatives to take the place of the dwindling banana market, hot pepper (*Capsicum chinense)* an has become a lucrative option not only because of the increasing worldwide demand and expanded markets, but its suitability to the tropical climes of the Caribbean and the economic returns that can be obtained from even small acreages (McDonald 1998). Countries within the region have therefore sought to expand hot pepper production and today the crop injects over US$30 million into economies and provides close to fifteen thousand persons with jobs in fresh pepper production and processing industries (McDonald 1998).

A major impediment to hot pepper production and marketing in the region are pests, including leaf spot (*Cercospora* spp); fruit rots (*Alternaria* spp); viruses (tobacco etch and potato Y); aphids (*Myzus persicae, Aphis gossypii)*; whiteflies, broad mites (*Polyphagotarsonemus latus)*, mealybugs (*Psuedococcus* spp); thrips, fall army worms, (*Spodoptera* spp.) and, most recently in Jamaica, the gall midges (*Contarinia lycopersci* and *Prodiplosis longifila)* (USAID – IPM CRSP, 1996*)*. Collectively, these pests reduce hot pepper production significantly, in particular in Jamaica where yields and exports have been reduced by up to 30% in the past year. Given the limitations these pests exert on production, and the need to develop a strategy to improve the quality and quantity of hot pepper being produced, a series of baseline surveys were developed to determine the current status of the hot pepper pest complex and the practices being utilised by farmers to reduce yield losses. Jamaica, as the center of IPM for the Caribbean Agricultural Research and Development Institute (CARDI), and a major hot pepper exporter in the Caribbean region, was the first country in which such baseline information was collected. The results of these surveys provide a basis for the development of an IPM strategy for Jamaican and other Caribbean farmers

METHODOLOGY

General pest survey (1997-1998)

Eight agroeological zones were identified based on rainfall, elevation, and temperature. Two to five farms were selected in each zone. On each farm, 20 plants were selected systematically and assessed for the presence of viral symptoms and arthropod pests. Viral symptoms were scored from 0-4; 0 being no symptoms and 4 being severe leaf reduction and deformation. The incidence of arthropod pests was based on their presence and absence on the top, middle and bottom sections of the plant. A questionnaire to determine current agronomic practices and farmer perception of pests and pest management practices was also developed. Analysis of Variance (ANOVA) was used to assess differences in virus severity and arthropod incidence among seasons and among districts.

Broad mite survey (1999)

Six farms, on which routine pesticide applications were being made and another six farms on which no pesticides were used on the hot pepper crop, were surveyed for broad mite and associated natural enemy populations. On each farm, a total of 6 leaves were taken from each of the top, middle and bottom sections of ten plants. Leaves were taken to the laboratory for extraction of mites. This entailed first putting the leaves into hot water, washing them into a nested sieve (106μm aperture) to remove large arthropods, and pouring the suspension through two nested sieves of 106μm and 53μm apertures. Mites and other arthropod pests collected on the two sieves were then washed into vials with 70% alcohol. Broad and predatory mite and spider populations were identified.

Gall midge survey (1998)

Thirty farms in the major hot pepper growing zone of Jamaica were visited and the distribution and incidence of the gall midge complex determined. On each farm 20 plants were selected systematically and on one branch from each plant the total number of fruits were recorded. The fruits were separated into three size categories (button, immature green and mature) and the proportions infested with gall midge larvae recorded. On farms where the pest was not detected, after the assessment of the 20 plants, additional plants examined until the pest was found or all plants examined. Farmers were interviewed to determine the production and marketing systems of each farm. ANOVA was used to compare the incidence of gall midges among fruit size categories.

RESULTS

General pest survey

A total of 64 farms were visited over four planting seasons (123 visits). The farms surveyed ranged from 0.04 ha (200 plants) to 4 ha (10,800 plants) of mainly Scotch Bonnet and West Indian Red Hot Pepper varieties. The most abundant pest affecting hot pepper fruits were the viruses tobacco etch and/or potato Y which were detected on 97% of farms (Figure 1), the average virus severity index being 2.41. Aphid species, which are known vectors of these viruses, were the most abundant arthropod pests observed, detected on 74% of farms ($P<0.001$). The second most frequently observed arthropod was the broad mite, and was observed on 37% of farms. Whiteflies, thrips and stinkbugs were present on 34%, 27% and 26% of farms respectively. Pest incidence did not differ significantly over the samplings.

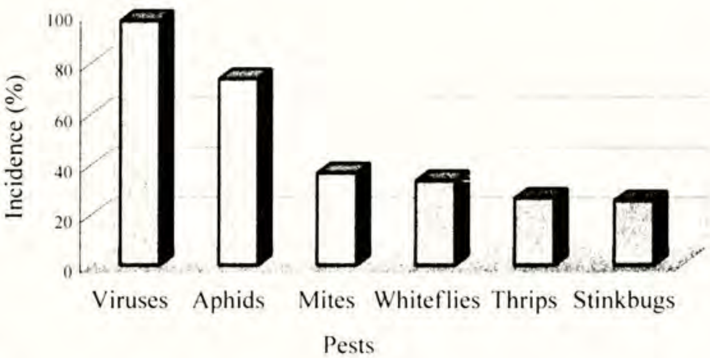

Figure 1. Hot pepper pest complex

In relation to farmer perceptions of pest severity, 30% thought that viruses were the major pests, but very few were aware that the aphids transmit viruses and considered then as harmless pests requiring no control. Twenty percent viewed mites as the major pest due to the relatively fast and noticeable defoliation of the growing parts and hardening of the fruits. Twenty-three percent of farmers believed that they had no major pest problems.

Frequent use of pesticides was the predominant method used by farmers to reduce pest damage. Seventy-eight percent of the farmers used pesticides, overall 21 different pesticides were used; 14 insecticides and 7 fungicides (Figure 2). The insecticides used most commonly were diafenthurion and profenofos against the broad mite.

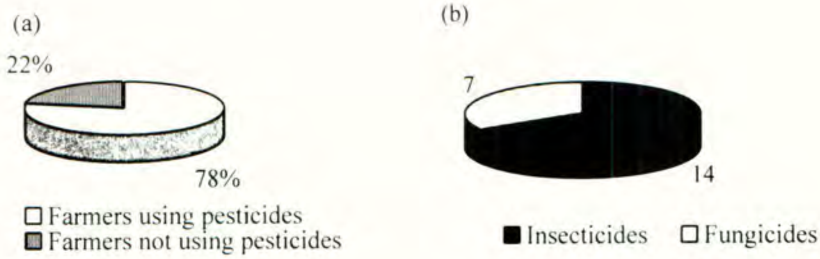

Figure 2. (a) Pesticide use patterns of hot pepper farmers. (b) Types and numbers of pesticides used by farmers.

Analyses of mite incidence and pesticide use demonstrated that the hot pepper crops of farmers who used pesticides had significantly higher populations of mites than those of farmers who did not use many pesticides ($F=4.76$, $df=102$, $P>0.03$); the incidence was 42.68% and 13.64% respectively (Figure 3).

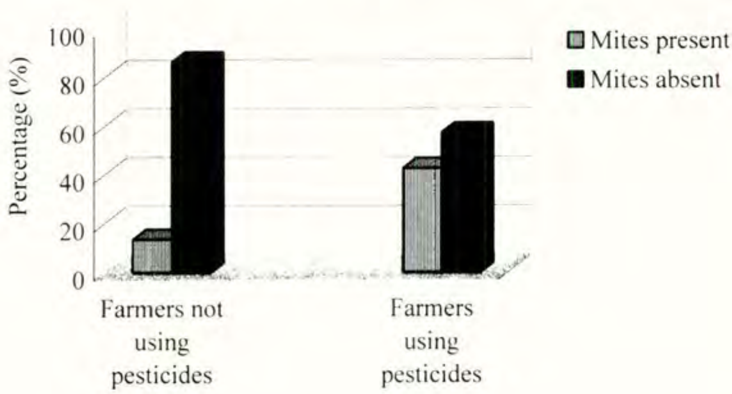

Figure 3. Broad mite incidence with respect to pesticide use

Broad mite survey

Populations of broad mites, predatory mites and spiders were detected on all the farms surveyed. Higher numbers of broad mites were found on farms, which routinely used pesticides (75.67, SE± 9.82) than those farms on which pesticides were not used at all or infrequently (7.23, SE± 19.98). There were no differences in the numbers of natural enemies (predatory mites and spiders) associated with pesticide treated and untreated hot pepper plants.

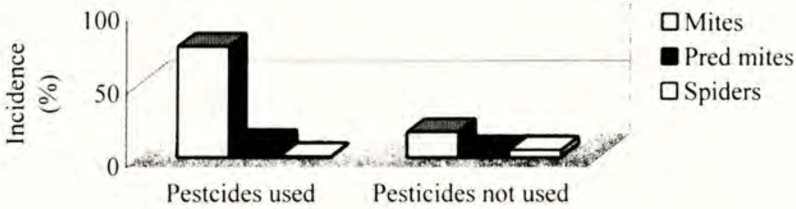

Figure 4. Mite incidence with respect to pesticide use

Gall midge survey

Gall midges were present on all farms in the parishes surveyed; however numbers varied. All farms in Hanover and St James had midges, 86% in Westmoreland and 27% in St Elizabeth had midges. The mean incidence of the midge across all farms was 2.8% (SE± 0.89, range 0 – 18%). Thirty percent of farms had infestation levels of 0-5%, whereas 7% had between 5% -10% and 13% had > 10%. Significant differences were observed among fruit sizes, green mature fruits having had the highest infestation at 16.5%. Many farmers used pesticides but they were not directed to control the midge. Cultural pest control practices were conducted poorly on the majority of farms visited.

Table 1: Gall midge infestation across major hot pepper growing parishes

Parish	No. of farms	Infestation levels (%)	
		Mean (SE)	Range
St Elizabeth	11	0.2 (0.2)	0 - 1.5
Westmoreland	7	2.2 (1.4)	0 – 10.0
Hanover	7	4.6 (2.1)	0 – 16.0
St James	5	6.4 (3.5)	0 – 18.0
Overall	30	2.8 (0.9)	0 - 18.0

DISCUSSION

The surveys demonstrate that viruses, aphids, broad mites and gall midges are the major economic pests affecting hot pepper production and marketing in Jamaica. The high positive correlation between mite incidence and pesticide use, reports by farmers of the use of pesticide cocktails because some pesticides were not effective, and the recent emergence of the gall midge complex as major pests, raises serious concerns of the effects of the current heavy pesticide use on the stability and sustainability of hot pepper cropping systems. The development of an IPM strategy is urgently needed to increase the Caribbean's current market share in the international arena.

Based the current practices recorded, it is imperative that IPM research for hot peppers, addresses immediately the development of appropriate tools (sampling plans for scouting, early warning devices and action thresholds) to reduce the current excessive pesticide use. In addition, more selective pesticides e.g. insect growth regulators and microbial insecticides need to be evaluated and introduced to replace some of the more persistent toxic organophosphate and carbamates being used currently by farmers. The second phase of the development strategy should focus largely on evaluation and incorporation of biologically based tactics/techniques including conservation and augmentation of endemic/imported natural enemies, trap/barrier crops, mulches, and cultural practices. The integration of these tactics to produce effective IPM strategies will be challenging given the wide variation in production methods, soils, climate, pest complexes and socio-economic factors. However, this process can be advanced rapidly if a participatory approach, which involves farmer involvement from the onset of the research, is used. Training of farmers in pest management will be key to the successful adoption of IPM strategies developed. The use of a principle-based approach to transfer technologies is crucial to enable farmers to make pest management decisions for their own unique situation. Given the poor knowledge level of farmers in pest diagnosis, training must address pest identification, biology and behavior. The selection of appropriate tactics and rationale for recommendations will also be vital to the optimal use of technologies.

The suggested IPM system has to be developed in the context of an integrated commodity research approach in which there is an interface and interactions among the components of soil and water management, plant genetic resources, post harvest technology development, research coordination and linkages, development of information materials and agribusiness services (Edwards *et al.*, 1993; CARDI, 1999). Considering these factors in the development of IPM will greatly assist in ensuring a sustainable and profitable hot pepper industry for Jamaica and the Caribbean.

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Natural biological control by spiders in rice

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ABSTRACT

In unsprayed irrigated rice there are few pest problems. *Atypena formosana* (Araneae: Linyphiidae) and *Pardosa pseudoannulata* (Araneae: Lycosidae) are early colonisers of newly established rice, and play an important role in insect pest control. Studies of functional and numerical responses of both spiders have demonstrated their potential to control populations of brown planthopper (BPH), *Nilaparvata lugens* (Hemiptera; Delphacidae) and green leafhopper (GLH), *Nephotettix virescens* (Hemiptera: Cicadellidae). Biological control of BPH and GLH may depend on a high density of predators in the field early in the cropping season. To support a high density of spiders in the field, a community of alternative prey would be advantageous, provided a suitable prey diet was available. During fallow and early crop establishment alternative prey such as Collembola and small Dipterans are numerous in the rice field and its surroundings.

INTRODUCTION

Unsprayed irrigated rice has few insect pest problems because natural enemies are able to keep the insect pests including plant- and leafhoppers in check. In this study we concentrate on two hoppers. The green leafhopper (GLH) *Nephotettix virescens* (Distant) (Hemiptera: Cicadellidae) is a vector of rice tungro – which can be a serious loss factor in rice. Heavy attack by the brown planthopper (BPH), *Nilaparvata lugens* Stål (Hemiptera; Delphacidae) causes hopperburn. With the green revolution BPH became perhaps the most serious pest in rice (Matteson, 1999). Earlier it had been a minor pest. Research by among others IRRI scientists showed that insecticides not only killed the pest but also its predators. Since predators took longer to recover after an insecticide treatment hoppers were able to escape natural control.

In terms of absolute numbers true bugs (Hemiptera) are the most important predators in rice (Heong *et al.*, 1991). However, spiders are the early colonisers of rice, and play a central role in the early biological control of insect pests in rice. The dominant spiders early in the cropping season are the wolf spider (*Pardosa pseudoannulata*) and the space-web builder (*Atypena formosana*). Both spiders occur throughout the year, and both are mostly found near the base of the rice. In the Philippines, *P. pseudoannulata* is the most prevalent spider throughout the season in the Philippines (Heong *et al.*, 1991). Across the remaining South and Southeast Asian countries *Pardosa* sp. and *Atypena* sp. are second and third in prevalence respectively with the orb-weaver *Tetragnatha* sp. being the most prevalent (Barrion & Litsinger, 1995). Though orb-weavers are the most prevalent, they increase in numbers at a time where insect damage has already occurred.

P. pseudoannulata is a significant biological control agent of insect pests in irrigated rice, and perhaps the single most important predator of BPH (see for example Kiritani *et al.*, 1972; Kenmore *et al.*, 1984; Ooi and Shepard 1994). Field studies shows that populations of both *P. pseudoannulata* and *A. formosana* fluctuate with the densities of dipterans, and all hoppers (Reddy & Heong, 1991). Evidence for the potential of *A. formosana* as biological control agent exists from field studies and visual observations (Barrion, 1999). Studies of functional and numerical responses of *A. formosana* and *P. pseudoannulata* have further demonstrated their potential to control populations of BPH and GLH (Heong & Rubia, 1989; Sigsgaard & Villareal, 1999).

Biological control of BPH and GLH may depend on a high density of predators in the field early in the cropping season. A community of alternative prey would help to support a high density of spiders in the field (Guo *et al.*, 1995; Settle *et al.*, 1996), provided prey of adequate dietary quality was present.

MATERIALS AND METHODS

Densities of arthropods were studied at IRRI in the Philippines from June to December 1998 thus including the wet season and the following fallow. Sampling was done with blower-vac in the rice field, the bund, and the immediate field surroundings. The total number of samples was 108 of which 88 were from within the field. Each sample was taken from an area of 0.06 m^2. Data presented here focus on the principal two spiders, the hoppers and the alternative prey.

In laboratory experiments we subsequently designed an experiment to assess the dietary quality of the most common prey in irrigated rice, represented by BPH for planthoppers, GLH for leafhoppers, *D. melanogaster* (Diptera: Drosophilidae) for flies, and Collembola (Entomobryidae). Drosophila has been used in many studies of spiders, and can thus serve also as a reference prey. Quality was assessed as survival and development time of *A. formosana* on diets of BPH, GLH, Collembola, a mixed diet, and the fecundities of both spiders on these diets and a diet of *D. melanogaster*, and two other prey mixtures.

RESULTS

During fallow we found densities of Collembola of $65/m^2$ within the field. One week after transplanting of rice the number of Collembola within the field fell to almost zero, and then they rose to an average of $40/m^2$ by the end of the cropping season. After crop establishment at a time when the number of Collembola was low, Dipterans increased in the field from an average of $5/m^2$ one week after transplanting to almost $690/m^2$ the following week (mostly Chironomid larvae), then dropped to $160/m^2$ three weeks after transplanting. At this time, hoppers had increased to over $100/m^2$, of which 80% were GLH, and 6% BPH.

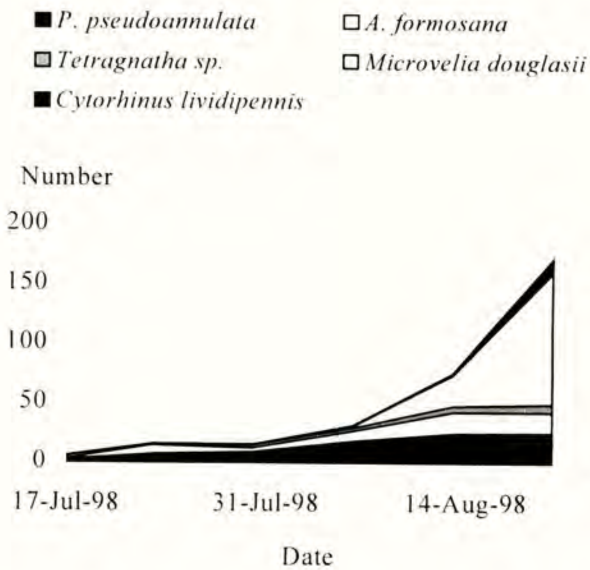

Figure 1. The most common predators in rice the first weeks after crop establishment, at IRRI, wet season 1998.

Apart from predatory bugs, the most numerous arthropods caught in the field were spiders. Early in the season spiders dominated (Figure 1).

Survival of *A. formosana* spiderlings to adult was poor on pure diets of GLH and BPH, where less than 10% survived, and best on Collembola and the mixed diet (of BPH, GLH, Collembola and *D. melanogaster*), where 70% and 100% respectively survived (n = 20). Fecundity of adult *A. formosana* was lowest on pure diets of BPH, GLH, and a mixed diet of BPH and GLH, with average egg production of less than 30 eggs per female (n = 15) while diets of alternative prey (Collembola, Drosophila) and other prey mixtures resulted in significantly higher egg production of more than 80 eggs per female (t-test $p < 0.05$). The lowest egg production in *P. pseudoannulata* was found in the GLH and the mixed BPH-GLH diet with less than 100 eggs per female. The remaining diets, including the BPH diet, had significantly higher egg production of more than 120 eggs per female (t-test, $p < 0.05$).

DISCUSSION

Early in the cropping season and during fallow, alternative prey for spiders including Collembola and Dipterans are found in the irrigated rice field. Spiders are the early predators in rice. Later predatory bugs become more numerous. Data show that they are in the field already by crop establishment. Laboratory data show that alternative prey may provide a good quality diet for the spiders. For both spiders GLH is a low quality prey. For *A.*

formosana this is also the case with the other hopper studied, BPH. Still, earlier studies of functional and numerical response have shown that these two spiders are able to respond efficiently to high densities of hoppers. Data suggest that alternative prey is both an important resource for maintaining spiders in the field, nutritionally necessary for the spider population, and thus a prerequisite for obtaining good biological control from the spider population.

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