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Management of white grubs (Coleoptera: Scarabaeidae) on groundnut in southern India

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Abstract

The chemical control of groundnut white grubs, *Holotrichia serrata* F. and *H. reynaudi* Blanchard (Coleoptera: Scarabaeidae), was studied in south-central India. Microplot trials demonstrated that chlorpyrifos and imidacloprid seed-dressings were effective against *H. serrata* at rates as low as 0.6 and 3.5 g a.i./kg, respectively, while microplot and on-farm trials showed that 1.2 and 3.5 g a.i./kg of chlorpyrifos and imidacloprid, respectively, were required for *H. reynaudi*. Chlorpyrifos residue analyses indicated that at 20 days after sowing (d.a.s.) rates up to 5.0 g a.i./kg produced residues in soil and groundnut seedlings markedly below the relevant MRL, and no detectable residues at harvest under the southern Indian rainy-season environment. A farmer survey found that in Andhra Pradesh (AP), insecticides (chlorpyrifos and phorate) were applied for white grub control in 37.5% of farms sampled, while no insecticides were applied for this purpose in Karnataka and Tamil Nadu. The white grub density on farms in AP where insecticide had been applied averaged 0.07 larvae/m^2, compared to 1.04 larvae/m^2 in the remaining AP farms. In AP, Karnataka and Tamil Nadu, 70, 42 and 39% of currently untreated groundnut fields, respectively, exceed the provisional economic threshold. A survey in the Anantapur district of AP found that farmer's target and achieved rates for seed treatment averaged 0.44 and 0.52 g a.i./kg, both below optimal rates determined in microplot experiments. These data provide the foundation for an effective and sustainable program of management for groundnut white grubs in south-central India by providing key efficacy data and baseline data on farmer insecticide-use patterns.

Keywords: Holotrichia serrata, Holotrichia reynaudi, *peanut, seed treatment, chlorpyrifos, imidacloprid*

1. Introduction

Holotrichia species (Coleoptera: Scarabaeidae) are pests of many crops in India (Yadava and Sharma 1995) and in other parts of Asia (Setokuchi et al. 1983; Cho et al. 1989; Liu et al. 1993). In India, *H. consanguinea* has been especially important as a pest across the light soils of the Gangetic Plains of northern India since the late 1960s (Musthak Ali 2001), causing widespread damage to groundnut, and other crops in the rotational cycle such as pearl millet and sorghum. Other species attacking groundnut in India include the species reported on here, *H. reynaudi*, *H. serrata* (Yadava and Sharma 1995), and *H.* sp. nr *consanguinea* (Anitha et al. in press).

For many years, the chemical control of *H. consanguinea* on groundnut in northern India has relied largely on seed treatments with chlorpyrifos (5 g a.i./kg of seed, as 20 e.c.) (Yadava and Sharma 1995). Other available treatments include in-furrow soil treatments of phorate, chlorpyrifos or quinalphos granules at sowing, and standing-crop side dressings treatments with chlorpyrifos (in irrigation water or broadcast after mixing in sand or soil, followed by irrigation). There are reports of organophosphate insecticides in groundwater (Mohapatra and Agnihotri 1996) in areas of widespread application. These experiences indicate the need for a cautious approach to the widespread recommendation and use of insecticides for white grub management in groundnut.

The main (rainy season) groundnut growing area of southern-central India extends over 400 – 500 km from Mahbubnagar in central Andhra Pradesh (AP), southwards into northern Tamil Nadu (TN), and westwards into eastern Karnataka; much of this area is a groundnut monoculture in the rainy season (July – October). Scarab adults emerge at the commencement of the monsoon rains—which also triggers groundnut planting—with the result that there is a close association between crop and pest phenologies.

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Despite the yield loss associated with white grub feeding activity (mainly *H. reynaudi*), insecticide application was not the norm when this study started in the early to mid 1990s and was largely restricted to the area around Anantapur (Anitha et al. in press). By 1995, farmers in this region had found that they could control *H. reynaudi* with less chlorpyrifos than the 5 g a.i./kg of seed recommended for *H. consanguinea* in northern India. This indicated that these farmers were anxious to reduce pesticide application to the lowest dose possible, and through informal on-farms observations, had achieved some reductions in chlorpyrifos rates.

The work reported here is part of an integrated approach to managing the southern Indian peanut white grub problem, within a project funded by the Australian Centre for International Agricultural Research. Firstly, Anitha et al. (in press) report on the distribution and abundance of the most important *Holotrichia* species that attack groundnut crops in the southern Indian states of Andhra Pradesh, Karnataka and Tamil Nadu, namely *H. reynaudi* and *H. serrata*. Rogers et al. (in press) quantify the yield losses on groundnut per white grub for *H. serrata*. The present paper reports on the minimum insecticide seed-dressing rates necessary to control these species (derived by microplot and on-farm trials), a chlorpyrifos residue experiment, and baseline data on white grub populations and chemical use patterns on-farm in south-central India.

2. Materials and methods

2.1. Microplot trials

Rain-fed microplot trials were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Asia Centre, Patancheru, Andhra Pradesh in 1995–1996 and 1998–2000 to determine minimal effective rates of chlorpyrifos and imidacloprid. Microplots were constructed of paving stones set vertically in the soil to form rectangular bays 0.5 m deep and 1.0×0.9 m. These were filled with a sandy local alfisol to promote drainage. Groundnut (ICGS 44) plants were established and thinned to achieve a population of density of 30 plants/microplot. Trials were planted at the commencement of the monsoon (typically June–July) each year. During the growth of the crop, normal agronomic practices were applied. The treatments used in each year are given in Tables II–V. The trials were laid out as randomised complete block designs with at least four replications per harvest date.

For the seed treatments of chlorpyrifos 20 e.c. (all trials), and the imidacloprid 200SL formulations (1998–2000), the required quantity of the insecticide was added to the seed in a rotating drum seed-treater. The seeds were gently mixed in the drum for a few minutes to ensure they were fully coated, care being taken not to damage the testa. Seeds treated with insecticide were sown 1–2 h after treatment to reduce the risk of losing seed viability, a problem that can be associated with this procedure when using chlorpyrifos (Mathur and Bhatnagar 2001). The imidacloprid 70 WS formulation (1995, 1996, 1999) was coated onto the seed by first wetting the seeds with minimal water and then adding the required quantity of the insecticide to the seed.

Grubs of *H. serrata* and *H. reynaudi* were reared from adults that were collected in the field at ICRISAT Asia Centre (*H. serrata*) or at Anantapur (*H. reynaudi*). Larvae were reared in a bed of sand/organic matter mixture in an outdoor screen house, with pearl millet seedlings grown as food for the developing larvae. When the grubs reached second instar, they were collected from the rearing area, weighed and then added to the microplots (20 larvae/plot in 1995, 10 larvae/plot thereafter) (Table I). Larval mortality was assessed 15 days after release by removing the content of each microplot and searching the soil for larvae ('destructive sampling'). In some trials, a separate set of groundnut plots was allowed to grow to maturity to assess yield parameters. Plant mortality, larval mortality and larval weight gain were recorded. In Trial 4, the number of flowers/m^2 also was recorded at the 15 days-after-release assessment. At crop maturity, final plant mortality, weight of plant haulms, pod weight and seed weights were also recorded. Data were analysed by analysis of variance, using Fisher's protected LSD test (Steel and Torrie 1980) for mean separations of pre-planned comparisons to elucidate the efficacy of each chemical and the lowest efficacious dose where

Table I. Details of white-grub species, grub size at experiment commencement, imidacloprid formulations, and grub release and mortality assessment dates for microplot experiments (1995–2000).

Trial	Year	Species	Initial weight (mg)	Imidacloprid formulation	Grub release date (d.a.s.)	Assessment date (d.a.s.)
1	1995	*H. serrata*	200	70 WS	20	35
2	1996	*H. serrata*	300–400	70 WS	20	30
3	1998	*H. serrata*	700–900	200 SL	15	30
4	1999	*H. reynaudi*	300–400	70 WS & 200 SL	15	30
5	2000	*H. serrata*	700	200 SL	15	30
6	2000	*H. reynaudi*	600–700	200 SL	15	30

a range of doses were tested. Some data sets required transformation prior to analysis.

2.2. Residue trial

Studies on the pesticide residues in soil, seed, seedlings and haulms of groundnut following seed treatment with chlorpyrifos 20 e.c. were carried out in 1995 to evaluate the residue situation under the southern Indian monsoon environment. The treatments were five replicates of chlorpyrifos (20 e.c.) at 1.2, 2.5 and 5.0 g a.i./kg seed, with an untreated control in a randomised block design. The plots were 4×4 m and were sown in an area where contamination from the activities in previous seasons would not interfere with the result. Groundnut (ICGS-44) was treated as in the microplot experiments. Normal agronomic practices were followed during the growth of the crop. Soil and seedling samples for residue analysis were taken 0, 5, 10 and 20 days after sowing. Seed and haulm samples were taken at harvest. Soil samples from all the treatments were drawn from six to eight places in each plot with a soil core. The sample was reduced to 50 g by mixing the cores thoroughly and quartering. The preparation of plant samples for residue analysis is described in detail in Anitha (1997). Residues were quantified with a Fisons 8000 gas chromatograph, with a sensitivity of 0.01 μg/g, following the Indian Standard Method, IS:12365 (1988).

2.3. On-farm trials, 1998 monsoon season

These trials compared the efficacy of imidacloprid and chlorpyrifos as seed dressings for the management of *H. reynaudi* in rain-fed groundnut in on-farm conditions in Anantapur and Chittoor Districts of Andhra Pradesh, India. The trials were carried out in conjunction with local and umbrella non-government organisations (NGOs) (specifically, Agriculture Man Ecology (AME), Bangalore). At Chittoor, these trials were included in the broader AME package of improved production technology for groundnut. This included the application of *Rhizobium,* plus *Trichoderma* (for seedling rot management), mussoriphos (a cheap phosphate source), and farmyard manure (FYM).

In the trials carried out in Chittoor and Anantapur districts, treatments were laid out in approximately 0.1-ha plots in each of five farmer's fields in each village (Table VII). There were 20 farmers in four villages in Anantapur and 10 in two villages at Chittoor. These trials were sown 16–27 July 1998 in Anantapur and 19–22 July 1998 in Chittoor. Project staff either treated the seed (Anantapur) or supervised farmers and NGO staff (Chittoor).

Sampling for grubs occurred between 15 and 30 September in Anantapur District and 14 and 23 September in Chittoor District. Fifteen 30-cm square pits were dug in each plot at random, soil was hand sorted and the number of white grubs recorded. A harvest sample was collected in ten 1-m^2 sub-plots in each treatment. Pod weight and haulm weight were recorded. Data were analysed by analysis of variance, using Fisher's protected LSD test (Steel and Torrie 1980) for mean separations of pre-planned comparisons to elucidate the efficacy of each chemical. Some data sets required transformation prior to analysis.

2.4. Farm survey

During a survey of white grub species distribution and density (Anitha et al. in press), conducted in the main groundnut production regions of southern India during August 1999, farmers were asked if and how they applied insecticides for white grub management. White grub densities in their fields were assessed at the same time. The survey covered the groundnut production region from Mahbubnagar (78°00′E 16°42′N) in the north to Dharmapuri (78°12′E 12°06′N) in the south, an area approximately 500 km north–south and 200 km wide. During the survey, a total of 78 farms in 26 villages in 20 districts were sampled (three individual farmers/village). Of these, 48 were in Andhra Pradesh, 18 in Tamil Nadu and 12 in Karnataka.

2.5. Farmer–treated seed

On 14 July 2000 (during the peak planting season for the 2000 rainy season), samples of farmer-treated seed were collected from eight farms in the Anantapur region, with farmer-supplied information on treatment rate. The amount of chlorpyriphos on the seed was determined by gas chromatography by the Nagarjuna Agricultural Research Development Institute with a Shimadzu 17AAA GC System. These analyses allowed a comparison of the actual rates of application with what farmers believed they were applying.

3. Results

3.1. Microplot trials

3.1.1. H. serrata. Microplot trials conducted between 1995 and 1998 (Table II) indicate that this species can be effectively controlled by chlorpyrifos seed-dressing rates of 1.2 g a.i./kg of seed, i.e. one-quarter that required to control *H. consanguinea* in northern India (Yadava and Sharma 1995). Additionally, the experiments showed that imidacloprid was as effective as chlorpyrifos. The modes of action of these two products are known to be different with imidacloprid having repellant and antifeedant activity against white grubs, in addition to contact and stomach toxicity (McGill et al. 2003). The larval weight change data (Table II) show that larvae in the imidacloprid treatment plots consistently lost weight. Larvae in other plots and in the chlorpyrifos treatments mostly gained weight.

Plant-response data (Table III) from these trials confirmed the efficacy of both products, with reductions in plant mortality and increases in pod yield. Imidacloprid treatment resulted in higher pod yields for equivalent larval mortality (Table II). The pod yield data reflect more the differences in larval weight gain than differences in the mortality data, perhaps reflecting a greater reduction in white grub feeding on the groundnut plants in the imidacloprid plots from its anti-feedant and/or repellent action. An additional reason for the yield increases resulting from the application of imidacloprid may lie in its systemic effect on leaf miners and sucking insects (jassids, aphids and thrips) (Jyothirmai et al. 2002) that inevitably infest rainy season groundnut crops in southern India (Wightman and Ranga Rao 1994).

Table II. Efficacy of chlorpyrifos 20 e.c. and imidacloprid 70 WS seed treatments against larvae of *Holotrichia serrata* on groundnut (1995 – 1998), assessed 35 days after sowing.

Trial and treatment	% Larval mortality	Larval weight gain (mg)
Trial 1 (1995)		
Untreated	27.0 a	393 a
Chlorpyrifos 1.2 g a.i./kg	85.0 c	106 b
Chlorpyrifos 2.5 g a.i./kg	90.0 c	113 b
Imidacloprid 3.5 g a.i./kg	66.0 b	−13 c
Imidacloprid 7 g a.i./kg	85.0 c	−91 d
Trial 2 (1996)		
Untreated	6.0 a	348 a
Chlorpyrifos 1.2 g a.i./kg	72.0 b	−38 b
Imidacloprid 3.5 g a.i./kg	56.0 b	−78 c
Trial 3 (1998)		
Untreated	18.0 a*	726 a
Chlorpyrifos 1.2 g a.i./kg	86.0 b	197 b
Imidacloprid 3.5 g a.i./kg	84.0 b	−297 c

Within each trial and parameter, means followed by the same letter are not significantly different (protected LSD Test, $P < 0.05$). *Arc sin transformation used in this analysis. Equivalent means are presented.

Lower rates of both products were evaluated in the 2000 season (Table IV). Chlorpyrifos at rates down to 0.6 g a.i./kg and imidacloprid at 3.5 g a.i./kg provided equivalent, and high, levels of control. There was no significant diminution in larval mortality from imidacloprid down to 0.25 g a.i./kg, although imidacloprid rates below 1.0 g a.i./kg were inferior to chlorpyrifos at 0.6 and 1.2 g a.i./kg. These data indicate that farmers in *H. serrata* endemic areas can apply chlorpyriphos at 12.5% the rate recommended for *H. consanguinea* and still achieve effective control.

3.1.2. H. reynaudi. The 1999 microplot trial on *H. reynaudi* confirmed growers' observations (unpublished) that this species is susceptible to lower rates of chlorpyriphos than *H. consanguinea* (Table V): 1.2 g ai/kg seed produced 100% mortality in *H. reynaudi*. Imidacloprid at 3.5 g a.i./kg produced equivalent control to chlorpyrifos at 1.2 g a.i./kg, but lower rates were somewhat less efficacious than the 1.2-g chlorpyrifos rate. However, there were no differences in either the larval mortality or weight gain data for the three imidacloprid treatments. This data showed

Table III. Groundnut plant response to control of *Holotrichia serrata* larvae with chlorpyrifos and imidacloprid seed treatments, 110 days after sowing (1996), and 115 days after sowing (1998).

Trial and treatment	% Plant mortality	Pod yield (g/m^2)
Trial 2 (1996)		
Untreated	30.7 a*	62.2 a
Chlorpyrifos 1.2 g a.i./kg	4.0 b	132.2 b
Imidacloprid 3.5 g a.i./kg	2.0 b	212.2 c
Trial 3 (1998)		
Untreated	22.7 a**	100.0 a
Chlorpyrifos 1.2 g a.i./kg	13.3 ab	140.2 ab
Imidacloprid 3.5 g a.i./kg	8.0 b	163.6 b

Within each trial and parameter, means followed by the same letter are not significantly different (protected LSD test, $P < 0.05$). *Square root transformation used in analysis. Equivalent means are presented. **Arc sin transformation used in analysis. Equivalent means are presented.

Table IV. Efficacy of chlorpyrifos and imidacloprid seed treatments against larvae of *Holotrichia serrata* and *H. reynaudi* on groundnut, and plant response (Trials 5 and 6, 2000).

	H. serrata		*H. reynaudi*
Treatment	Larval mortality, 30 DAS (%)	Plant mortality, at harvest (%)	Larval mortality, 30 DAS (%)
Untreated (with larvae)	20.0 a	29.3 a	60 a
Chlorpyrifos 0.15 g a.i./kg	67.5 bc	5.3 b	97.5 b
Chlorpyrifos 0.3 g a.i./kg	72.5 bc	0 b	95.0 b
Chlorpyrifos 0.6 g a.i./kg	85.0 cd	0 b	97.5 b
Chlorpyrifos 1.2 g a.i./kg	95.0 d	0 b	97.5 b
Imidacloprid 0.25 g a.i/kg	60.0 b	1.8 b	92.5 b
Imidacloprid 0.5 g a.i/kg	57.5 b	0 b	97.5 b
Imidacloprid 1.0 g a.i/kg	62.5 b	0 b	95.0 b
Imidacloprid 3.5 g a.i/kg	75.0 bcd	0 b	95.0 b

For each parameter, means followed by the same letter are not significantly different (protected LSD test, $P < 0.05$).

equivalent levels of control from the two imidacloprid formulations compared. The implication is that farmers need not look beyond the cheapest product, provided it came from a reliable source. Additionally, there was no diminution in control from the 200 SL formulation at 1.0 g, compared to 3.5 g. Chlorpyrifos and imidacloprid produced significant, and equivalent plant responses – lower plant mortality and increased numbers of flowers at 30 d.a.s.

The experiment in 2000 with *H. reynaudi* compared lower rates of both chemicals (Table V). However, the trial was adversely affected by flooding during assessment and many surviving larvae appear to have drowned. This is the reason for the high control mortality. The single control plot assessed prior to the rain had 30% mortality, compared to 60–80% in plots assessed after the flooding. This limited the experiment's ability to discriminate between chemical dose rates, and all rates of both chemicals had equivalent mortality.

3.2. Residue trial

When the seed was treated with chlorpyrifos at 5 g a.i./kg seed (the rate recommended for *H. consanguinea* control in northern India), the residue in the seed peaked at 0.17 ppm (SE = 0.012) at 5 d.a.s., and by 20 d.a.s. had decreased to 0.03 ppm (SE = 0.005) (Table VI). Lower doses had proportionally lower residues and all soil residues were well below the maximum residue limit (MRL) of 2 ppm. In seedlings, the residues in the 5 g/kg rate were 1.3705 ppm by 20 d.a.s. Again, seedling residues at all rates and times after treatment were less than the MRL for chlorpyrifos in vegetables (2 ppm). No detectable chlorpyrifos residues were recorded in either kernels or haulms at harvest (110 DAS) from all dose rates.

3.3. On-farm trials, 1998 monsoon season

The on-farm trials at Anantapur and Chittoor (Table VII) confirmed the results of the microplot trials against *H. reynaudi* (Table V). At Anantapur, the two chemical treatments were equally effective with an 89% reduction in population density. At Chittoor, high levels of control were achieved, with *H. reynaudi* larval populations being significantly lower for imidacloprid than chlorpyrifos. At the Chittoor site, the use of the AME management package of biological additives, phosphorus fertiliser and organic matter also produced a 60% reduction in *H. reynaudi* populations. The reasons for this are unknown, but at least a partial explanation may lie in the likely impact of FYM on *H. reynaudi* development. Pot trials with *H. serrata* have demonstrated that the addition of FYM alters the patterns of larval growth and plant mortality in a similar soil (V. Anitha unpublished data).

3.4. Farm survey

The survey showed that average white grub densities in the absence of insecticide were higher in Andhra Pradesh (1.04 larvae/m^2) than in either Karnataka (0.55 larvae/m^2) or Tamil Nadu (0.53 larvae/m^2). Areas in Andhra Pradesh – such as around Anantapur – have experienced white grub problems in groundnut crops for a number of years (Anitha 1992).

Table V. Efficacy of chlorpyrifos 20 e.c. and imidacloprid 70 WS and 200 SL seed treatments against larvae of *Holotrichia reynaudi* on groundnut, and plant response, assessed 30 days after sowing (Trial 4, 1999).

Treatments	Larval mortality (%)	Larval weight gain (mg)	Plant mortality (%)	Flowers/m^2
Untreated	20 a	422 a	14.1 a	112 a
Chlorpyrifos (1.2 g a.i./kg)	100 c	–	0 b	228 b
Imidacloprid 70 WS (1.0 g a.i./kg)	70 b	72 b	0 b	293 b
Imidacloprid 200 SL (1.0 g a.i./kg)	70 b	68 b	0 b	290 b
Imidacloprid 200 SL (3.5 g a.i./kg)	80 bc	57 b	0 b	324 b

For each parameter, means followed by the same letter are not significantly different (protected LSD test, $P < 0.05$).

Table VI. Chlorpyrifos residues (ppm) (mean ± SE) in soil and groundnut seedlings 20 DAS, and groundnut kernels and haulms at harvest following seed treatment.

	Seed treatment rate (g a.i./kg seed)		
Material analysed	1.25	2.5	5.0
Soil 20 d.a.s.	0.0170 ± 0.00248	0.0176 ± 0.00176	0.0291 ± 0.00456
Seedlings 20 d.a.s.	0.3389 ± 0.00839	0.7649 ± 0.02287	1.3705 ± 0.14134
Kernels 110 d.a.s.	BDL*	BDL	BDL
Haulms 110 d.a.s.	BDL	BDL	BDL

*BDL, Below detectable levels.

The survey found that only farmers in Andhra Pradesh applied insecticides for whitegrub management (18 farms in five districts from the 48 farms in 14 districts sampled in the State), and was concentrated in the area between the Krishna River and Anantapur. Farmers in the southerly sections of the south-central Indian groundnut production region did not use insecticides to manage white grubs. Of the chemicals used, chlorpyrifos was the choice of all adopters. Two-thirds had also tried phorate.

The white grub densities on farms where seed had, or had not, been treated with insecticide (Figure 1) provides evidence that these treatments reduced white grub populations under groundnut (maximum likelihood $\chi^2 = 20.56$, $P < 0.001$, df = 4). In areas that did not use insecticide, 48% of farms had populations greater than 0.3 larvae/m^2, while no farms that applied insecticide exceeded this level (Figure 1). In terms of average larval densities, areas that used insecticide averaged 0.07 larvae/m^2, compared to 1.04 larvae/m^2 from areas of Andhra Pradesh where insecticide was not applied.

Table VII. Efficacy of chlorpyrifos 20 e.c. and imidacloprid 70 WS seed treatments against larvae of *Holotrichia reynaudi* on groundnut in on-farm trials at Anantapur (four villages, five farms/village) and Chittor (two villages, five farms/village), 1998.

Location and treatment	Larvae/m^2**
Anantapur	
Untreated	4.25 a
Chlorpyrifos 1.2 g a.i./kg	0.67 b
Imidacloprid 3.5 g a.i./kg	0.30 b
Chittor	
Untreated	2.38 a
Untreated (+ NGO nutrient package*)	0.96 b
Chlorpyrifos 1.2 g a.i./kg (+ NGO nutrient package*)	0.53 c
Imidacloprid 3.5 g a.i./kg (+ NGO nutrient package*)	0.08 d

*NGO nutrient package consisted of *Rhizobium*, *Trichoderma*, mussoriphos rock phosphate, and farm yard manure and was part of the Agriculture Man Ecology participatory technological development program. **At each site, means followed by the same letter are not significantly different ($P < 0.05$, Protected LSD test).

3.5. Farmer-treated seed

Discussions with farmers about their seed treatment process showed that the target rates of were either 2 or 2.5 mL/kg (i.e. 0.4 or 0.5 g a.i./kg of seed) (Table VIII). This is well below most of the rates evaluated in the microplot trials, and an order of magnitude lower than the rate recommended for *H. consanguinea* in northern India. Achieved treatment rates varied widely, from almost an order of magnitude below target to more than four times over target (Table VIII). Six of the eight achieved rates below 0.6 g a.i./kg, which was the lowest effective dose in the microplot trials (Tables II, IV and V) against *H. serrata*. Seven of the eight were below the 1.2 g that was highly effective against *H. reynaudi* (Table V). These farmers were from a *H. reynaudi* endemic area.

4. Discussion

Seed-dressing treatments for *H. consanguinea* are well established in northern India (Yadava and Sharma 1995), e.g., chlorpyrifos at 5.0 g a.i./kg seed.

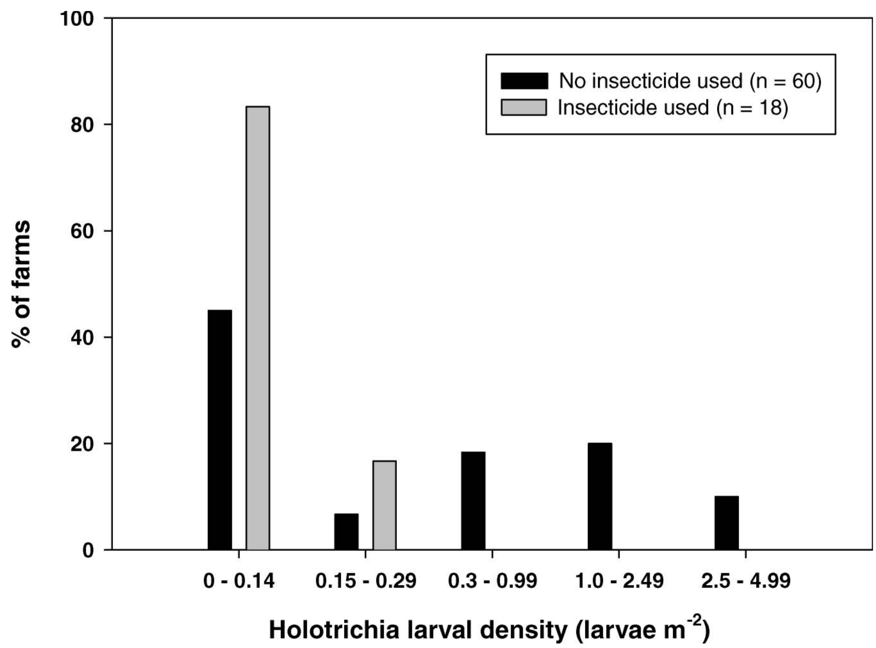

Figure 1. White grub density on groundnut in Andhra Pradesh, Karnataka and Tamil Nadu on farms that used and did not use insecticide for white grub control.

Table VIII. Farmer-reported and analysed seed-dressing chlorpyrifos rate for control of *H. reynaudi* in groundnut at Anantapur, Andhra Pradesh, 2000 monsoon season.

Farmer	Farmer reported rate of chlorpyrifos 20 e.c. (mL/kg)	Applied rate from residue analysis (mL of 20 e.c./kg)
1	2	0.23
2	2	2.61
3	2	2.86
4	2	3.68
5	2	8.37
6	2.5	0.23
7	2.5	1.22
8	2.5	1.72

However in south-central India, with its harsh and highly variable climate, growers have indicated that the insecticide treatments at rates used in northern India are beyond their economic means, given the low average yields (Ali 2003) and high risk of crop failure. In southern areas, with severe white grub problems, growers experimented with lower rates of seed treatment, finding that control of southern species (*H. reynaudi* and *H. serrata*) was possible with reduced rates. The series of experiments reported here confirm the growers' observations that the two main southern species can be controlled with a fraction of the rate recommend for *H. consanguinea*, namely one-eighth and one-quarter of the *H. consanguinea* doses for *H. serrata* and *H. reynaudi*, respectively. Because of problems with adverse weather conditions in a key *H. reynaudi* trial, it is possible that the minimum effective rate for *H. reynaudi* is lower than the one-quarter *H. consanguinea* rate reported here.

The choice between chlorpyrifos and imidacloprid is likely to be made by the farmer on the basis of cost. The greater cost of the latter product indicates that chlorpyrifos is most likely to receive widespread use. Imidacloprid would, however, provide control of thrips, leafhoppers and other sucking insects. Thus in situations where these pest groups are important during the first 6 weeks of crop growth, imidacloprid may provide substantial practical advantage over chlorpyrifos. This points to the importance of assessing technological improvements, such as insecticides for white grubs, within the context of the farming system as a whole. In the present case, the relative impacts of various possible changes to farmer inputs needs to be considered in the context of the economic costs and benefits of the extra inputs. Low-cost changes with large impacts (e.g., chlorpyrifos at 1.2 g a.i./kg of seed) may find easy acceptance, while more difficult-to-implement, or higher-cost, changes may be more problematic, even though they may provide a broader range of benefits.

The residue trial indicates that for the main product, chlorpyrifos, there are unlikely to be residue issues in soil, plant material or harvested product within the southern India environment. Thus, these data point to the minimum effective chlorpyrifos rates reported here being environmentally sustainable, as well as being highly efficacious. However, the analyses of farmer-treated seed indicates that farmers who currently use chlorpyrifos are applying it at sub-optimal rates. While these sub-optimal rates will provide moderate levels of control (Table IV), they also may increase the risk of insecticide resistance emerging in the southern species. This risk from the use of sub-optimal rates appears greater than that associated with optimal rates. Presuming the white grub population in groundnut is only a fraction of the population on a farm basis, any selection for resistance by the fully effective rates is likely to be swamped by unselected individuals from adjacent untreated crops and non-cropped areas. Sub-optimal doses, however, would permit the preferential survival of partially resistant individuals within groundnut fields, potentially leading to the emergence of chemical-breaking resistance. In this situation, on-going monitoring of susceptibility status of both southern species appears desirable.

The analyses of the farmer-treated seed indicated that the farmers were not good at calculating and applying the chemicals at pre-determined rates. This result points to the need for intensive farmer education in areas where insecticide seed-dressings are employed.

The farm survey indicates that average levels of white grub infestation are higher in Andhra Pradesh than the two neighbouring states. However, significant infestations occur in all three. Based on the provisional economic threshold of 0.14 larvae/m^2 for *H. serrata* (Rogers et al. in press), 70, 42 and 39% of currently untreated groundnut fields in Andhra Pradesh, Karnataka and Tamil Nadu exceed the threshold for treatment with insecticide. Additionally, at the limit of detection of a larval population using the recommended sampling regime (i.e. one larva in fifteen 30 × 30-cm samples), the estimated losses from *H. serrata* are worth approximately Rs 600, compared to seed treatment costs of Rs 100 – 120/ha. Thus for a larval population at the limit of detection, the benefit: cost (B/C) ratio from treatment would be between 5 and 6. B/C ratios would be proportionately higher for the population densities observed across south-central India. On this basis of these two scenarios, there are grounds to argue for the widespread adoption of white-grub management on groundnut in southern India.

In the immediate future, management options could include the insecticide seed-dressings discussed here, as well as community action to collect adults from feeding trees (as used in northern India against *H. consanguinea* (Yadava and Sharma 1995)). These adult control options are feasible in southern India, now that the adult-feeding trees have been identified for *H. reynaudi* and *H. serrata* in the groundnut production regions (Anitha et al. in press). However, the aggregation-pheromone mediated trap-and-kill method being developed against *H. consanguinea* (Leal et al. 1996) is not relevant for *H. reynaudi* because anisole is only a male attractant in *H. reynaudi*, rather than also being an aggregation trigger for both sexes (as for *H. consanguinea* (Ward et al. 2002)). In the longer term, *Metarhizium anisopliae* (Gupta 2001) may provide additional options in southern India, but this requires much more work. *M. anisopliae* strains highly pathogenic to southern species are required, as the best strain for *H. consanguinea* is much less effective against *H. serrata* (R.B.L. Gupta personal communication). Additionally, the optimum placement of *M. anisopliae* spores for inoculum survival and infection of larvae (20 cm depth) (R.B.L. Gupta, personal communication) is not compatible with southern Indian tillage practices.

In this region, seed is applied at 100 – 120 kg/ha. At a 1.2 g a.i./kg rate, this points to the application of 120 – 150 g/ha of chlorpyrifos over, perhaps, some hundreds of thousands of hectares of southern India. The residue analyses and efficacy trials reported here indicate no adverse environmental or health issues would be expected from the area-wide application of this technology. However, on-going monitoring of chlorpyrifos residues in soil and the environment would be prudent if large-scale use occurred. There is considerable scope for broad-scale economic benefits from the introduction of refined white grub management processes in the south-central Indian groundnut production region. These economic benefits would bring with them broad-scale social and community benefits for a large number of people who currently are at the margins of an increasingly prosperous society.

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