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Session Organiser: Dr Charles Riches
Natural Resources Institute,
University of Greenwich, UK

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The importance of legumes for the adoption of effective on-farm *Striga* control strategies in cereal-based systems in the West African savanna

A C Franke, G Tarawali, D Chikoye
International Institute of Tropical Agriculture, Nigeria, C/o Lambourn Ltd, Carolyn House, 26 Dingwall Road, Croydon, CR9 3EE, UK.
E-mail: L.Franke@cgiar.org

J Ellis-Jones, R White
Silsoe Research Institute, Wrest Park, Silsoe, Bedford, MK45 4HS, UK

I Kureh, M A Hussaini
Institute for Agricultural Research, Ahmadu Bello University, PMB 1044, Zaria, Nigeria

ABSTRACT

Farmers participated in testing of integrated *Striga* control (ISC) options in the moist savanna of northern Nigeria, including 154 lead farmers and 763 other adopting farmers who learned from lead farmers. The ISC options involved the use of either *Striga*-tolerant maize for two years or the incorporation of a grain legume into a legume-maize rotation. These rotations were compared with farmers' traditional cereal-based rotations. Data collected on farmers' fields showed that ISC reduced the *Striga* seedbank in a relatively short period of two years, on average by 46%, with crop yields increasing by 90% over farmers' practice. While high yields were also obtained with continuous *Striga*-tolerant maize, this rotation was less effective in reducing *Striga* pressure than rotations including legumes. Despite its tolerance, the maize variety allowed *Striga* plants to reproduce and replenish the seedbank. Lead farmers recognised the importance of legumes for an effective ISC strategy and most other adopting farmers preferred a legume-maize rotation to control *Striga*, using the experience of lead farmers. This farmer-to-farmer extension was found to be an efficient way to spread ISC technologies to a large numbers of farmers.

INTRODUCTION

Striga hermonthica (Del.) Benth. (*Striga*) is a root-parasitic weed that has become a very severe constraint for cereal production in many parts of West Africa, affecting the livelihood of millions of small-scale farmers. *Striga* infestations are often associated with an intensification of land use, reducing the fallow period that used to keep *Striga* at a tolerable level, and with a reduction in soil fertility and degradation of soils, resulting from crop intensification without the adequate nutrient inputs. Various control measures have proven to reduce *Striga* infestations in the field. These include the use of *Striga*-resistant cereal varieties, herbicide seed coating of maize, a judicious use of nutrient inputs, and the incorporation of legumes into cereal-based rotations (Oswald, 2005). The use of legumes has the advantage of contributing to soil fertility, as well as controlling *Striga* by reducing the area under host cereals and by inducing suicidal germination of *Striga* seeds.

It is generally recognised that a single control measure is unlikely to provide satisfactory *Striga* control. The weed's genetic plasticity may allow it to adapt to individual control measures. In addition, the wide diversity of biophysical and socio-economic environments in which farmers work stress the need for a robust ISC strategy that can be adapted to farmers' local conditions. Schulz *et al.* (2003), Kureh *et al.* (2003) and Ellis-Jones *et al.* (2004) have demonstrated the potential agronomic and economic benefits of an ISC package under both on-station and on-farm conditions in northern Nigeria at a small scale. This paper reports on a project that scaled-up ISC technologies to a large number of farmers in the northern Guinea savanna of Nigeria. This allowed the comparison between the performance of an ISC package based on the cultivation of *Striga* tolerant maize with that based on legume-maize rotations, with respect to *Striga* seedbank dynamics, *Striga* plant density, crop yield and the adoption and adaptation of the technologies by farmers.

METHODOLOGY

In villages in Kaduna State in northern Nigeria, where *Striga* had been identified as the main constraint for crop production, 154 lead farmers were selected by community-based organisations and mandated by them to test an ISC package in 2002-2003 (Emechebe *et al.*, 2004). With the support of extension agents, lead farmers were invited to choose between the cultivation of a *Striga*-tolerant maize variety, Across97 TZL Comp.1, for two subsequent years or a two-year legume-maize rotation using improved grain legume varieties in the first year followed by *Striga*-tolerant maize. Soybean-maize strip cropping, involving rows with soybean alternated with rows of *Striga*-tolerant maize in the first year, followed by a sole crop of *Striga*-tolerant maize in the second year, was a further option that was more closely aligned to traditional farming practices. Improved field management aimed at reducing *Striga* pressure, such as rouging of *Striga* plants, the use of clean seed, the spot application of inorganic fertiliser at maize planting positions, and denser planting of crops was also recommended in all ISC rotations. Grain legumes used in the legume-maize rotation were new soybean and groundnut varieties, screened in vitro for their ability to stimulate suicidal germination of *Striga* seeds. ISC rotations were compared with farmers' traditional cereal-based systems at an adjacent plot: the farmers' practice (FP). Here farmers were free to decide on field management and the use of varieties. The *Striga* seedbank was assessed at the beginning and the end of the two-year rotations in both ISC and FP plots, using the potassium carbonate separation method (Berner *et al.*, 1997). Crop yields were measured in both years, while the number of *Striga* plants attached to maize was assessed in 2003 only, when all rotations contained maize. As the different ISC rotations were unequally represented within the area and the data were unbalanced, REML techniques were used to statistically analyse the data. In 2002, when different crops were grown, all yields were converted to maize equivalents using the average crop price in 2001-2003 to facilitate the statistical analyses. Maize equivalent yields predicted by the statistical model were then converted back to crop yields. In tables, *n* refers to the number of observations on which the mean is based, *s.e.* represents the standard error of the mean, and *s.e.d.* is the standard error of the difference between means.

From 2003 onwards, other farmers (secondary farmers) in the community were encouraged to initiate their own ISC trials through farmer-to-farmer extension initiated by lead farmers. In 2003, 763 secondary farmers were identified practicing ISC using the experience, knowledge and improved seed from lead farmers. The adoption and adaptation of ISC technologies among lead farmers and other farmers was monitored through a survey among 147 farmers and detailed case-study assessments of 40 farmers.

RESULTS AND DISCUSSION

At the start of the rotation in 2002, the mean *Striga* soil seed density was similar in FP and ISC plots (Table 1). Over the 2-year rotation, seed densities in the FP increased by 46%. The cultivation of local, *Striga*-susceptible cereals in the FP thus greatly enhanced the *Striga* soil seedbank. In ISC treatments, the mean *Striga* soil seed density reduced by 46% over the 2 years. The initial *Striga* seed densities in 2002, as well as the relative reduction over the experiment, varied considerably among ISC treatments. Where groundnut (Gn) or soybean (Sb) was grown in the first year, initial *Striga* seed densities were more than double that of ISC with continuous *Striga*-tolerant maize (SM-SM) or strip cropping (Sb/SM-SM). Groundnut-maize and soybean-maize rotations showed the greatest reduction over the 2-year period, 46% and 50% respectively. Continuous *Striga*-tolerant maize and strip cropping with soybean achieved lower reductions, 29% and 31% respectively, but from a lower base. The rapid seed decline in rotations with legumes could be the result of suicidal germination of *Striga* seed induced by legumes or a rapid natural decay of *Striga* seed in absence of a host.

Table 1: Predicted *Striga* soil seed density at the beginning and the end of the rotation in soil layer 0-15 cm for the FP and ISC treatments combined and the individual ISC treatments (May 2002 and May 2004, respectively) ($\cdot 10^3$ *Striga* seeds m^{-2}).

Rotation (2002-2003)	*n*	2002		2004		%
		Seeds	*s.e.*	Seeds	*s.e.*	increase
LC-LM (FP)	75	9.86	2.04	14.38	3.02	46%
All crops-SM (ISC)	75	9.55	3.02	5.15	1.05	-46%
SM-SM (ISC)	15	4.79	1.15	3.39	0.69	-29%
Sb-SM (ISC)	39	12.05	2.91	6.01	1.39	-50%
Gn-SM (ISC)	13	10.16	2.85	5.50	1.29	-46%
Sb/SM-SM (ISC)	8	5.25	1.69	3.62	0.91	-31%

LC = Local Cereal, LM = Local Maize, SM = *Striga*-tolerant Maize, Sb = Soybean, Gn = Groundnuts, FP = Farmer Practice, ISC = Integrated *Striga* control

In 2003 when all treatments contained maize, the mean *Striga* plant density in the FP was 132% and 85% higher at 12 weeks after planting (WAP) and at maize harvest, respectively, than the associated mean of the ISC rotations (Table 2). Especially at harvest, rotations with continuous *Striga*-tolerant maize or with soybean-maize strip cropping were less effective in reducing the *Striga* plant population than legume-maize rotations. This is in line with the results of the *Striga* seedbank analyses (Table 1). Interestingly, the lower *Striga* plant densities in legume-maize rotations (Table 2) could not be attributed to lower *Striga* soil seed densities in these rotations (Table 1). Other factors, such as changes in soil physico-chemical characteristics or soil micro-biotic populations as a result of legume cultivations, may have been involved in regulating the *Striga* plant density as well. The high density of *Striga* plants in continuous maize rotations at harvest explains the relatively poor reduction in *Striga* seedbank in these rotations (Table 1), as the plant density is likely to have a large impact on the rate of seed production and the dynamics of the *Striga* seedbank.

Table 2: *Striga* plant density in maize at 12 weeks after planting (WAP) and at harvest in 2003 for the FP and ISC treatments combined and the individual ISC treatments ($\cdot 10^3$ plants /ha).

Rotation (2002-2003)	*n*	12 WAP	*s.e.*	Harvest	*s.e.*
LC-LM (FP)	66	12.3	1.7	18.9	2.3
All crops-SM (ISC)	66	5.3	0.9	10.2	1.4
SM-SM (ISC)	26	5.8	1.4	15.0	2.7
Sb-SM (ISC)	23	5.3	1.8	5.9	1.5
Gn-SM (ISC)	6	3.2	1.6	5.8	2.7
Sb/SM-SM (ISC)	11	5.6	3.5	10.3	3.2

LC = Local Cereal, LM = Local Maize, SM = *Striga*-tolerant Maize, Sb = Soybean, Gn = Groundnuts, FP = Farmer Practice, ISC = Integrated *Striga* control

In 2002, the grain yield of groundnut and soybean in ISC plots varied between 1.0 and 1.5 t/ha, while that of *Striga*-tolerant maize averaged 2.9 t/ha (Table 3). The highest yield in maize equivalents in 2002 was associated with the groundnut crop (3.17 t/ha), which could be attributed to a favourable groundnut grain price relative to that of the other crops. Grain yield from local cereals grown in the FP was well below that of the *Striga*-tolerant maize variety in ISC rotations in both 2002 and 2003. On average across treatments, production in ISC significantly increased over the FP by 77% in 2002 and by 99% in 2003. Maize grain yield in the various ISC treatments in 2003, when all ISC rotations contained *Striga*-tolerant maize, were not significantly different. No beneficial effect on maize yield of the inclusion of legumes above continuous *Striga*-tolerant maize was thus observed in ISC rotations. Also the observed variations in *Striga* plant density at harvest among ISC treatments in 2003 (Table 2) were not reflected by differences in maize yields.

Table 3: Predicted legume and cereal grain yields and maize grain equivalents of the yields in 2002 and 2003 for the FP and ISC treatments combined and the individual ISC treatments (t/ha).

Rotation (2002-2003)	2002			2003	
	n	Maize equivalents[1]	Crop yields[2]	*n*	Maize Yields
LC-LM (FP)	116	1.24	1.24	121	1.68
All crops-SM (ISC)	116	2.20	-	121	3.35
% increase over FP		*77%*			*99%*
s.e.d.		0.125	-		0.139
SM-SM (ISC)	33	2.91	2.91	37	3.44
Sb-SM (ISC)	52	1.66	1.36	55	3.39
Gn-SM (ISC)	16	3.17	1.29	13	3.43
Sb/SM-SM (ISC)	15	2.11	0.87 Sb / 1.06 SM	16	2.71
s.e.d. (ISC)		0.476	-		0.459

LC = Local Cereal, LM = Local Maize, SM = *Striga*-tolerant Maize, Sb = Soybean, Gn = Groundnuts, FP = Farmer Practice, ISC = Integrated *Striga* control

[1] Crop yields converted to maize equivalents using 3-year mean crop prices.
[2] Yields of individual crops converted from maize equivalents using 3-year mean crop prices.

In conclusion, the results of the trials indicated that all ISC options reduced the *Striga* seedbank and, to a certain extent, *Striga* plant density at harvest. In addition, higher crop productivity was achieved in ISC rotations than the FP. While high maize yields were also obtained in the ISC treatment with continuous *Striga*-tolerant maize, this option was less effective in reducing the seedbank than ISC rotations containing legumes in the first year. Despite its *Striga*-tolerance and high yielding characteristics, the maize variety allowed numerous *Striga* plants to emerge, reproduce and replenish the seedbank. The ISC legume-maize rotations, on the other hand, were effective in reducing the *Striga* seedbank in a relatively short period of two years. Therefore, ideally legumes should be an integral part of a longer-term ISC strategy in cereal-based systems of the Guinea savanna.

Further adoption

In 2003, extension agents identified 763 secondary farmers, who had tested at least one component of ISC during the year. Interestingly, these secondary farmers cultivated more soybean and less *Striga*-tolerant maize than lead farmers in the first year of the rotation. This is likely to be related to lead farmers' observation that continuous *Striga*-tolerant maize is less effective for *Striga* control than a legume-maize rotation. This may also reflect the generally growing importance of soybean for domestic consumption and sale in northern Nigeria. Furthermore, the relatively high price of inorganic fertilisers in 2003 probably contributed to the large number of secondary farmers opting for soybean, requiring less fertiliser than maize. This suggests that high fertiliser prices stimulate farmers to cultivate legumes, thereby creating opportunities to promote ISC strategies based on legume-cereal rotations.

The survey and the case studies confirmed that most secondary farmers had received support from lead farmers, increasing their knowledge on *Striga* biology and control, as well as practical training on lead farmers' ISC plots. Although seed was seen as the most important means of spreading ISC between farmers, lead farmers also provided advice on planting, fertilisation and evaluation of the results. Consequently, many secondary farmers also adopted new management practices associated with ISC, such as denser planting of crops and the application of fertilisers in holes. However, many complained of the additional labour required and said they were unlikely to plant large areas in this way. It was therefore common for plant populations and crop spacing to remain similar to traditional methods to diminish the labour input for planting and weeding. Besides changes in crop management, many farmers had modified the recommended ISC by adopting some form of strip cropping, mixed cropping (maize and legumes) or relay cropping with cowpeas. Intercropping or strip cropping legumes and cereals builds on the conventional FP, being a risk management strategy that maximises the likelihood of one of the crops providing adequate yield when the other fails.

Detailed discussions with 40 individual lead and secondary farmers indicated that the mean number of individuals per farmer to whom seed was given, exchanged or sold was 10, of whom 7 were in the same village and 3 were outside the village (Table 4). Extrapolation of the contacts indicated by the 40 case-study farmers to the total number of participating farmers suggested that over 8000 new farmers may have benefited from ISC seed during 2004. This represented a ratio of 1 extension agent to 5 lead farmers, 23 other farmers and over 240 other contacts, highlighting the potential of farmer-to-farmer extension to reach large numbers of farmers.

Table 4: Observed number of contacts per farmer and estimated total number of farmer-to-farmer contacts exchanging seed and/or knowledge on ISC as a result of the project.

	Observed number of contacts			*Estimated total number of contacts*		
	Lead farmers	Second. farmers	All farmers	Lead farmers	Second. farmers	All farmers
n	14	26	40	154	763	917
Inside village	7.5	6.4	6.9	1155	4883	6038
Outside village	5.8	1.5	3.1	893	1145	2038
Total	13.3	7.9	10.0	2048	6028	8076

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Improving food security through soil fertility management for maize in lowland Tanzania

G Ley, C Massawe, A M Mbwaga, A Moshi, F Mrosso, A Nyaki
Eastern Zone Research (Ilonga and Mlingano Agricultural Research Institutes), Tanzania

J Ellis-Jones, R White
Silsoe Research Institute, Wrest Park, Silsoe, Beds MK45 4RU, UK

J Hella,
Sokoine University of Agriculture, P.O. Box 3007, Morogoro, Tanzania

P Kyakaisho,
District Council, Muheza, Tanzania

C Riches
Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent ME4 4TB, UK

ABSTRACT

Lowland tropical maize (0-1000 masl) comprising 18% of maize production in eastern and southern Africa is often characterised by declining productivity. In the Muheza District of northeast Tanzania, farmers confirmed production of maize, the most important crop, has declined from over four to less than half a tonne per ha within living memory. The main reasons identified by farmers were declining soil fertility, increasing *Striga asiatica* and stem-borer infestation, as well as lack of access to improved seed. In a process involving key stakeholders, farmers selected options for on-farm testing. This included *Striga and* soil fertility management using leguminous green manure cover crops (*Mucuna*, *Canavalia* and sunhemp), as well as resistant maize varieties and stem-borer control. Results indicate that maize yields can be increased by more than 100% when grown after a green manure and that a local maize OPV TMV-1 was favoured by farmers. Training of village extension workers in *Striga* control with green manures using participatory approaches is resulting in widespread farmer testing within the District.

INTRODUCTION

Maize is the predominant staple cereal crop in the Lowland tropical Zone (0-1,000 masl) that includes 18% of the area planted to the crop in eastern and southern Africa (Hassan *et al.* 2002). Most of the Eastern Agricultural Research Zone (EARZ) of Tanzania, which in 1998 had a population of 4.5 million people, is in the lowlands. Farmers here account for 9% of national maize production and 14.5% of the national area planted to the crop. Tanga region accounts for 40% of the maize in EARZ; producing 159 thousand tonnes in 1998/99 (Agricultural Information Services, 2000). Akulumuka *et al.* (2004) reported farmers' main concerns in Muheza district in Tanga to be declining yields linked with falling soil fertility and associated increases in infestation of maize by the parasitic weed *Striga asiatica,* maize stemborers and limited access to improved maize seed. This paper describes the approach used to address maize productivity improvement in Muheza.

METHODS

Community workshops were held in four villages to assess the existing situation, mobilise the community and to agree action plans for resolving key problems (Akulumuka *et al.*, 2004). Subsequently on-farm trials were initiated in two villages during the short *vuli* rains in 2002/3, in two further villages in the long *masika* rains in 2003, with six new villages becoming involved in the *vuli* rains of 2004/5. Typically, the *vuli* season runs from October to January with *masika* rains in April to August Trials assessed rotation of green manure legumes (*Canavalia ensiformis, Mucuna pruriens* or *Crotalaria ochroleuca*) with improved maize cultivars under farmer management. The open pollinated improved maize cultivar TMV1 and the *Striga* tolerant line Syn. 98 were provided for trials. These involved single plots at each site of continuous maize and of a two-season rotation of one of the improved maize cultivars following one of the three green manure species. Maize yields following green manures were assessed at 16 sites in the *masika* season of 2003 and again at 30 sites in *vuli* of 2005. There was widespread maize crop failure in both seasons of 2004. Participatory evaluations in each village were undertaken to 1) Establish advantages and disadvantages of growing a green manure in rotation with maize; 2) Identify farmers' criteria for comparing and ranking the legumes and 3) Develop participatory budgets to compare outputs and inputs for best legume-maize system with continuous maize.

RESULTS

Advantages and disadvantages of growing green manure crops and farmers' rankings

Farmers observed the actual and potential advantages, disadvantages and risks associated with growing green manures (Table 1). In two communities, farmers also evaluated cowpeas

Table 1. Farmer perceptions of advantages and disadvantages of using green manures

	Advantages	Disadvantages
1st season	Soil fertility improvement	A maize crop is lost
Green manure vs maize	Possible livestock feed from green manure crop	Limited knowledge of green manures
	Expected use of green manure as a food crop or seed sales	Other farmers think this is not a useful activity
	Weed suppression	Neighbours do not appreciate the work
	Crop is not eaten by monkeys and therefore guarding is not required	Loss of respect by others for doing something strange
	Reduced soil erosion	Additional labour requirement for establishment of green manure
	Land preparation for maize is easier as soil is softer	
2nd season	Higher yield with better quality grain	More labour required for handling crop
Maize after green manure vs maize after maize	Less weeds, easier weeding	Increased transport and storage problems
	Less *Striga* is observed	Prices of maize may go down and that of other crops may go up
	More produce for sale	Social problems: extra theft, unplanned spending due higher income; more drinking; demands of dependants

(being the most important legume crop grown in association with maize) together with the green manure legume crops. Farmers identified 15 criteria, although this varied depending on the length of time each community had experienced the growing of the legume. The criteria reflected either, i) management, especially labour for establishing and looking after the legume, ii) agronomic considerations which may effect the subsequent maize crop and, iii) potential uses for the legume. Views differed across communities with *Canavalia* and *Crotalaria* being ranked either first or second as green manure crops (Table 2). Cowpea, although not included in the trial, scored highest or second highest in the two communities where it was considered along with green manures, primarily because it had alternative uses. Participatory evaluations undertaken during the 2004-5 *vuli* season indicated that overall *Canavalia* was ranked highest being drought tolerant, *Mucuna* second and *Crotalaria* third. *Crotalaria* suffered from insect pests at many sites. There was considerable variation between villages and within some villages preferences varied, indicating individual and area variations.

Table 2. Ranking of green manures after the 2004-5 *vuli* season.

	Mbambakofi	Mtakuja	Mapatano	Paramba	Total score	Rank
Canavalia	2	1	*1*	3	7	**1st**
Mucuna	*1*	3	3	1	8	**2nd**
Crotalaria	3	2	2	2	9	**3rd**
Cowpea		2/3	2/3	-		

Yield assessments

Yield analysis of on-farm trials is based on a residual maximum likelihood analysis due to the unequal numbers of sites in each village. Results in Table 3 indicate significant effects of previous cropping on maize yield. In 2005, in all villages maize grown after a green manure performed significantly better than maize following maize, but there was no significant difference in response to different legumes. However when the results were combined *Canavalia* significantly outperformed *Crotalaria* ($P<0.001$) which significantly outperformed *Mucuna*. Highest maize followed *Canavalia*, being 50% greater than continuous maize. *Crotalaria* gave a 34% higher yield and *Mucuna* a 17% higher yield. In the *masika* 2003 season maize yields were 21 – 22% higher in rotation with the legumes ($P = 0.002$) but there was no difference in response to the three legumes. There was no significant difference between the mean yields of TMV-1 and Syn 98 WEC (2864 and 2776 kg/ha respectively, S.E.D. 259 with 30 d.f.) or significant interaction between maize variety and yields following the green manure crops. Large variation in *Striga* emergence prevented formal analysis of interactions with variety and green manure. Occurrence is in patches on individual fields and did not occur on all participating farms. Farmers who have planted green manures for 2 or three seasons expressed the opinion that continuous use of these legumes has reduced the incidence of *Striga*. They observed that cultivar Syn 98 is tolerant, performed well on infested fields and was favoured as it is early maturing. Highest yields of biomass in the 2004-5 *vuli* season came from *Canavalia*, followed by *Mucuna* and lastly *Crotalaria*. Trial records from Mlingano Research Institute indicate that the green manures produce about 20% dry matter if harvested at flowering when these species contain approximately 3% nitrogen by dry weight. Using these conversion factors the dry weight and nitrogen yields have been estimated for the trial sites in Muheza. *Canavalia* produced the highest yields and contributed most N. Median yields of *Canavalia* were also close to the mean. Performance of *Crotalaria* was very variable. Gilbert (1998) used a “target biomass concept” to evaluate performance of green manures in

Malawi. This assumes that to achieve an effective response in subsequent maize crops >30 kg/ha fertiliser equivalent needs to added by incorporating a green manure. Based on literature Gilbert assumed green manure to be only 50% as effective as fertiliser N. Therefore 60 kg/ha N will be needed from incorporation of green manure – at 3% N this will be provided by 2000 kg/ha dry biomass. In Muheza this was only achieved on 47% of plots sown to *Crotalaria* compared to 83% and 92% of plots sown to *Mucuna* and *Canavalia* respectively.

Table 3. Mean maize yields following green manure crops (kg/ha)

Maize after	Mbambakofi	Mtakuja	Mapatano	Paramba	Overall	% increase over maize
Vuli 2005	*n=7*	*n=10*	*n=8*	*n=5*	*n=30*	
Canavalia	3396	3933	3972	2317	3386	50%
Crotalaria	3176	3373	3756	1811	3021	34%
Mucuna	2892	3323	4282	2339	2624	17%
Maize	1982	2567	2852	1698	2250	
s.e.d.	*424*	*409*	*354*	*289*	*267*	
P =	*0.004*	*0.042*	*<0.001*	*0.058*	*<0.001*	
Masika 2003	*n=13*	*n=3*			*n=16*	
Canavalia	1466	2733			2048	21%
Crotalaria	1377	3033			2048	21%
Mucuna	0	2800			2076	22%
Maize	1194	2088			1699	
s.e.d.	*149*	*428*			*259*	
P =	*0.292*	*0.14*			0.002	

N = degrees of freedom & farmers

Table 4. Mean green manure fresh weight, dry matter and N yields (kg/ha) (*vuli* season 2005)

Green manure	Fresh weight	Dry matter		N	
		Mean	Median	Mean	Median
Canavalia (n = 21)	19,730	4069	4100	122	123
Crotalaria (n = 23)	13,280	2562	1600	77	48
Mucuna (n = 26)	16,350	3148	2600	94	78
s.e.d.	*2,771*	P = 0.069			

Participatory budgets and economic analysis

End of season evaluation comprising a participatory budget (partial budget analysis) was undertaken with farmers in Mbambakofi and Mtakuja following the 2003 *masika* season after completion of a two season cycle of green manure and maize. Economic analysis has been undertaken for both 2003 and 2005, using information on inputs provided by farmers in 2003. The basis of determining benefits was yield, based on statistical analysis across all villages, where the two-season rotation had been completed (Table 5).

Farmers estimated average yields of 300 kg/ha maize under continuous cropping in *vuli* 2003 when the green manure crops were growing. A small increase (2-4%) in combined output for vuli 2003 and subsequent *masika* season small increase was achieved as a result of growing the green manures. As drought prevented a maize harvest in *masika* 2004 when green manure production was still possible, larger benefits (17-50%) were achieved from maize in the subsequent 2005 *vuli* season. This analysis showed that a yield of 1136 kg/ha maize would have been needed in *masika* 2003 for a maize-maize system to provide greater benefits than *Canavalia*-maize. This however takes no account of any direct benefits from the green manure crop, notably seed.

Table 5. Benefits from green manure based on yield and maize values (kg/ha and US $/ha)

Maize following	2002-3					2004-5				
	Vuli	*Masika*	*Total*	*Increase*	*% increase*	*Masika*	*Vuli*	*Total*	*Increase*	*% increase*
Yields (kg per ha)										
Canavalia	0	2048	2048	49	2%	0	3386	3386	1136	50%
Crotalaria	0	2048	2048	49	2%	0	3021	3021	771	34%
Mucuna	0	2076	2076	77	4%	0	2624	2624	374	17%
Maize	300	1699	1999	0	0%	0	2250	2250	0	0%
Mean (gm)	*0*	*2057*	*2057*	*58*	*3%*	*0*	*3010*	*3010*	*760*	*34%*
Values (US $ per ha)										
Canavalia	0	143	143	3	2%	0	237	237	79	50%
Crotalaria	0	143	143.	3	2%	0	211	211	53	34%
Mucuna	0	145	145	5	4%	0	183	183	26	17%
Maize	21	118	139	0	0%	0	157	157	0	0%
Mean (gm)	*0*	*144*	*144*	*4*	*3%*	*0*	*211*	*211*	*53*	*34%*

Assumptions: Maize is valued at US $0.07 kg^{-1} (Tsh 70 kg^{-1}), US $1=Tsh 1000), gm=green manure

Information provided by farmers during the participatory budgeting (Ellis-Jones *et al.*, 2004) varied. In Mtakuja, farmers indicated that although incorporation of green manure would require additional labour at land preparation, a net saving of labour was experienced (40 days per ha), primarily as a result of decreased weeding both in the green manure and subsequent maize. However at Mbambakofi, farmers indicated that labour requirements had increased by a similar amount for additional land preparation, harvesting, transport, storage and sale of the increased maize. Farmers agreed that there was no increase in seed costs over the two-season rotation as green manure seed costs were similar to those for maize. The net result indicates that the costs do not differ markedly between maize-maize and green manure-maize systems.

DISCUSSION AND CONCLUSIONS

On the basis of this study, it can be concluded that the green manure-maize system can out perform continuous maize. Clearly increased actual and potential benefits make the new technology attractive, in both terms of additional yield and overall productivity. However this needs to be seen against the concerns raised by farmers and the increased risks, if widespread adoption is to occur. It is difficult to reach firm conclusions before more households have had a chance to evaluate a number of cycles of the legume/maize rotation.

Discussion with farmers suggests that green manures are attractive and more likely to be adopted, when:

- Sustained increases in maize yield are achieved and a ready market is available.
- The green manures provide additional benefits over and above improving soil fertility and reducing *Striga* infestation, such as food or fodder for household use or sale.
- Land is not limiting and green manures can be used to improve fallows.

The third criteria would mean that average and well-resourced farmers are the most likely beneficiaries. Green manures are less attractive and less likely to be adopted, when:

- Farmers perceive the risks of using a green manure to be high, due to possible failure of the maize crop due to drought or low market prices.
- Land is limiting. In such cases grain legumes that improve soil fertility and suppress *Striga* may be more appropriate. This could include cowpea, soybean or groundnut crops which induce suicidal germination of *Striga* followed by *Striga* tolerant maize variety (Ellis-Jones *et al.*, 2004; Schulz *et al.*, 2003).

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Weed communities of *gogorancah* and *walik jerami* rice in Indonesia and reflections on management

H Pane, E Sutisna Noor,
Indonesian Institute for Rice Research, Sukamandi, Subang 41256, West Java

S Y Jatmiko
Research Station for Agricultural Environment Preservation, Jakenan, Pati 59182, Central Java

D E Johnson
International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines

M Mortimer
School of Biological Sciences, University of Liverpool, Liverpool, L69 7ZB, UK

ABSTRACT

Dry-seeded bunded rice (*gogorancah*) followed by minimum-tillage transplanted rice (*walik jerami*) is an annual rain-fed crop production system that underpins rice production in Indonesia on sloping lands. Adaptive research to investigate points of intervention for improved yields in both crops was conducted by survey to characterise the weed flora and by on-farm experiment comparing nutrient addition and intensive weeding. Rice yields in weed-free researcher-managed trials in both crops varied between 3 and 6 t ha depending on toposequence position, and tended to be greater in *gogorancah*. The highest yields were found in lower toposequence positions with differences of approximately 1 t/ha being recorded across toposequence. Average on-farm yields were significantly lower. The greatest yield improvement resulted from additional fertiliser. Canonical correspondence analysis indicated that the weed flora after farmer weeding was diverse, with weed densities up to 100 plants / m^2 and showed no strong relation to soil fertility.

INTRODUCTION

The Jakenan region in Central Java, Indonesia, with an average of less than 1,500 mm of annual rainfall, allows rainfed lowland rice to be grown on land experiencing non-continuous flooding of variable depth and duration. Dry-seeded, bunded rice (*gogorancah*) is grown from the onset of the wet season (October-November) through to January-February, followed by minimum-tillage transplanted rice (*walik jerami*) through to May-June. A secondary, non-rice crop may be grown on residual moisture for the remainder of the dry season. Rice is grown in bunded fields on a toposequence of sloping lands, with up to a 30-degree slope. Land at the base of the toposequence tends to be flooded more frequently whereas at the top may be drought prone. Moreover considerable small-scale spatial variability occurs in the cropping environment with respect to agro-hydrologic processes (driven by topography, rainfall, and soil texture) and soil fertility. The weed flora in these areas is potentially very diverse since fields may exhibit soils that range from aerobic through saturated to fully flooded for varying parts of the crop cycle. Typically, during the first three to four weeks (depending on rainfall) of *gogorancah*, rice grows as an upland crop in moist soil only to be flooded as rainfall intensity increases, as a result of impounded water. In *walik jerami* rice is transplanted into saturated soil and closely follows *gogorancah* rice harvest and after the rice stubble has been inverted by tillage. Weed flora of *walik jerami* often exhibits species in common with *gogorancah* but typically includes obligate aquatic species. Weed control in *gogorancah* and *walik jerami* rice continues to rely on manual weeding. In *gogorancah*, weeding with a small hoe begins at the three-leaf stage of rice about 2 wk after emergence (WAE) with further weedings at 5–6 WAE and sometimes at 7–8 WAE, 80 labor-days / ha being the estimated effort (Fagi, 1995). In *walik jerami*, the crop is usually hand weeded only twice, 2–4 wk after transplanting (WAT) and at 6–7 WAT, needing 48 labor-days / ha. This paper selectively summarizes studies made from 1998 to 2004 investigating constraints to yields and opportunities for intervention. In the heterogeneous environment of rainfed rice, the appropriate integration of agronomic and water management practices to ensure rapid crop establishment of a competitive crop stand, and fertilizer management and weed control interventions after crop establishment remain important adaptive research issues (Boling *et al.* 2004).

MATERIALS AND METHODS

Field survey

Twenty-five farm sites were chosen in sub-districts within 50 km of the Jakenan experimental station of the Central Research Institute for Food Crops in the districts of Pati and Rembang, Central Java, Indonesia. All showed sloping lands (5–30°). At each farm, three positions (upper, mid, and lower) on the toposequence were identified for census of the weed flora. The range in elevation across the toposequence at all study sites did not exceed 10 m. During February and March 1999 in *walik jerami* crops, the weed flora assessed when rice was at the booting stage, approximately 60–70 d after sowing (DAS). Four 1 m^2 quadrats were placed randomly within the crop at each toposequence position and the density of individual weed species (plants / m^2) enumerated by destructive removal of all plants beyond the small seedling stage. Prior to data collection, farmers were briefly interviewed to confirm that rice weeding had been finished and to ascertain nutrient management practices. At each toposequence location, bulk soil samples were taken by pooling soil samples from each individual quadrat used for weed sampling. Two replicate sets were obtained in a like manner. Soil parameters, including pH, were measured following standard analytical practice: percent total organic carbon in soil was measured spectrophotometrically, % total N by semimicro Kjeldahl, soluble phosphorus and exchangeable K using Bray's method, and cation exchange capacity, CEC, by Schollenberger's semimicro percolation method.

Farm experiment

Farms at four locations in Pati and Rembang district were selected exhibiting a range of four toposequence positions by relative height (high, upper- mid, lower- mid and low). In each, six treatments were imposed on individual plots (5m x 6m) : 1) Farmer practice (FP) of crop management; 2) FP with weeding excluded; 3) FP with intensive regular weeding; 4) FP with no fertiliser application at all; 5) FP with improved fertiliser management (N 120kg /ha, P 22.5 kg /ha, K 90 kg /ha, S 20 kg /ha, applied in three split applications); 6) FP with improved fertiliser management and intensive regular weeding. Yield was measured in a central 2m x 2.5 m plot over four cropping seasons, 2000 *gogorancah*, 2001 *walik jerami*, 2001 *gogorancah*, 2002 *walik jerami*.

RESULTS AND DISCUSSION

Comparison of yields from farmer managed plots (treatment 1) and plots with additional fertiliser and weeding (treatment 6) indicated that significant ($P < 0.05$, analysis of variance) yield gains were obtained from additional resource input (Figure 1). Yields were higher in the *gogorancah* season than in *walik jerami* and yield gains from additions were larger. Table 2 shows gains from individual management components and standard errors of means reflect the intrinsic variability present in farmers' fields. Gains from farmer weeding were larger in the *gogorancah* season than in *walik jerami* and tended to be lower in plots at the base of the toposequence. Intensive weeding did not accrue additional yield ($P > 0.1$). Farmer applied fertiliser regimes resulted in yield responses similar in range to those from weeding and there were no simple relationship to toposequence. On average, additional fertiliser elevated yields more than additional weeding.

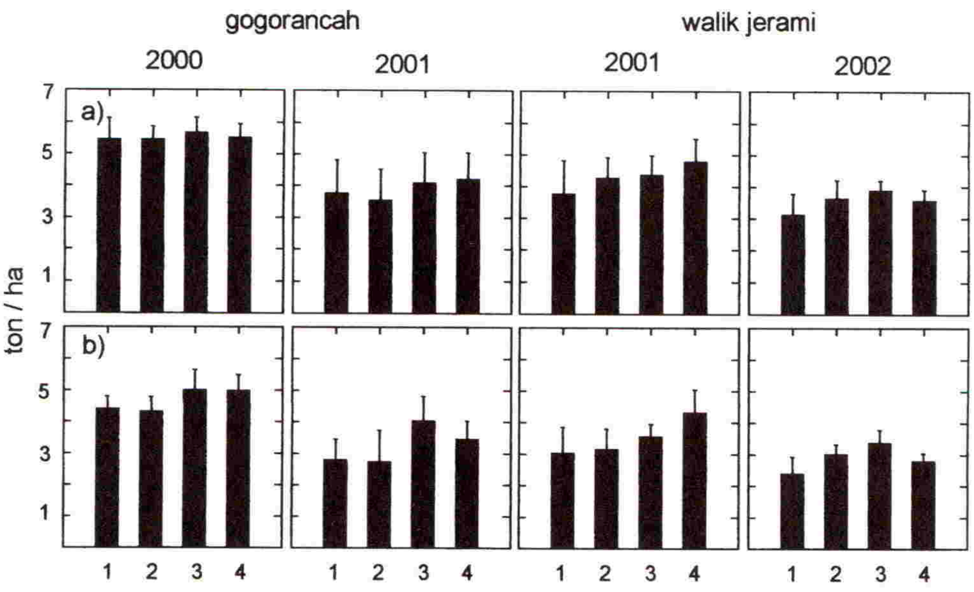

Figure 1. Rice grain yield (mean ± s.e.m, t / ha) in relation to toposequence position and cropping season: a) yield with intensive weeding and fertiliser; b) yield under conventional farmer practices. Toposequence position: 1 = high, 2 = upper mid, 3 = low mid, 4 = low.

Sixty-seven weed species were recorded by survey in 1999, most of which were previously reported by Pane *et al*, (2000) as present in *gogorancah* (Table 2). These species were recorded at the booting stage of rice, after the last manual weeding, and represent late recruits to the weed flora of a maturing rice crop. Weed communities were diverse and in some sites densities greater than 100 / m^2 were recorded. Whilst the mean number of species was similar at each position on the toposequence, densities at low positions were significantly less than at mid and high locations (38, 78 and 91 plants /m^2 respectively). Contrastingly in *gogorancah*, Pane *et al*, (2000) recorded higher densities (> 150 plants /m^2), post weeding. Canonical correspondence analysis (Figure 2, ter Braak, 1985) was used to examine species-soil relationships in *walik* *jerami*, 53.6 percent of the species-environment relationship being explained by the first two axes of the analysis. The first axis was strongly correlated with soil pH (r = –0.54) and the second axis with CEC (r = -0.42). The biplot indicates a higher soil nutritional status in the lower right quadrant but there was no clear delineation of sites with respect to toposequence position. Limited species discrimination was evident (11% of species variation on the first two axes), with axis 2 (ordinate) tending to differentiate upland rice weeds characteristic of aerobic soils (high scores) from those of permanently flooded soils (low scores).

The results suggest that under current farming practices, weed control methods are optimal despite the observation that rice crops retained a substantial weed flora during grain filling. No simple relationship between yield and toposequence position was however revealed by this analysis of grain yield across sites. A further detailed approach taking into account changes within-season hydrological changes will be published later. Alteration to on-farm fertiliser recommendations is however clearly indicated as an intervention in improving yields. The suite of weed species present however, contained common aggressive grass weeds (eg *Ischaemum rugosum*) typically associated with high soil fertility (Figure 2). As such, improved soil fertility will need to be introduced combined with improved weed management methods.

Table 1. Yield gains (kg/ha, means over sites) in relation to treatments. Toposequence position 1 = high, 2 = upper mid, 3 = low mid, 4 = low.

Year and season	Topo-sequence position	Gain by farm weeding	Gain by additional weeding	Gain by farm fertiliser	Gain by additional fertiliser	Gain by additional fertiliser and weeding
2000 *Gogorancah*						
	1	1653	80	778	782	278
	2	1059	-	1345	980	154
	3	1147	188	630	460	192
	4	712	294	1001	112	416
	Overall s.e. 522					
2001 *Gogorancah*						
	1	1368	2	962	540	431
	2	819	220	845	410	413
	3	1529	130	1006	132	-
	4	772	266	779	487	268
	Overall s.e. 354					
2001 *Walik jerami*						
	1	256	-	1227	408	355
	2		291	870	516	611
	3	170	277	1178	342	467
	4	116	157	1212	246	232
	Overall s.e. 537					
2002 *Walik jerami*						
	1	299	80	736	825	-
	2	812	60	1411	418	217
	3	461	332	816	534	-
	4	269	235	277	674	94
	Overall s.e. 305					

Table 2. Weed inventories for *gogorancah* (G) and *walik jerami* (W) cropping seasons. Authorities quoted are largely from Soerjani *et al*, 1987.

Ageratum conyzoides L.	G	W	*Hedyotis corymbosa* (L.) Lam.	G	W
Alternanthera philoxeroides (Mart.) Griseb.	G	W	*Heliotropium indicum* L.	G	W
Alternanthera sessilis (L.) DC.	G	W	*Hydrolea zeylanica* (L.) Vahl		W
Amaranthus sp.	G	W	*Hymenachne acutigluma* (Steud.) Gilliland	G	
Ammania baccifera L.	G		*Ipomoea triloba* L.	G	W
Bacopa rotundifolia (Michx.) Wettst.		W	*Isachne globosa* (Thunb.) O.K.		W
Borreria alata (Aubl.) DC.	G		*Ischaemum rugosum* Salisb.	G	W
Brachiaria mutica (Forsk.) Stapf	G		*Ischaemum timorense* Kunth		W
Ceratopteris thalictroides (L.) Brongn.		W	*Leersia hexandra* Sw.		W
Commelina benghalensis L.	G	W	*Leptochloa chinensis* (L.) Nees	G	W
Cynodon dactylon (L.) Pers.	G	W	*Lindernia crustacea* (L.) F. Muell.	G	
Cyperus compressus L.	G		*Lindernia* spp.	G	W
Cyperus difformis L.	G	W	*Ludwigia adscendens* (L.) Hara	G	W
Cyperus halpan L.	G		*Ludwigia hyssopifolia* (G. Don) Exell	G	W
Cyperus iria L.	G	W	*Ludwigia octovalvis* (Jacq.) Raven	G	W
Cyperus kyllingia Endl.	G		*Marsilea crenata* Presl	G	W
Cyperus rotundus L.	G	W	*Mollugo pentaphylla* L.	G	W
Cyperus tenuispica Steud.	G	W	*Monochoria vaginalis* (Burm.f.) Presl	G	
Dactyloctenium aegyptium (L.) Willd.	G		*Murdannia nudiflora* (L.) Brenan	G	W
Digitaria ciliaris (Retz.) Koel.	G	W	*Panicum maximum* Jacq.	G	
Digitaria longiflora (Retz.) Pers.	G		*Paspalum distichum* L.	G	W
Dopatrium junceum (Roxb.) Buch. Ham. ex Benth.		W	*Phyllanthus debilis* Klein ex Willd.	G	W
Echinochloa colona (L.) Link	G	W	*Phyllanthus urinaria* L.	G	
Echinochloa crus-galli (L.) P. Beauv.	G	W	*Phyllanthus virgatus* Forst. f.		W
Eclipta prostrata (L.) L.	G	W	*Polytrias amaura* (Buese) O.K.	G	
Eleocharis acicularis (L.) R. & S.	G		*Portulaca oleracea* L.	G	W
Eleocharis congesta D. Don		W	*Scirpus juncoides* Roxb.	G	
Eleusine indica (L.) Gaertn.	G		*Scirpus lateriflorus* Gmel.		W
Emilia sonchifolia (L.) DC. ex Wight		W	*Sphaeranthus indicus* L.	G	W
Eragrostis tenella (L.) Beauv. ex R. & S.	G	W	*Sphenoclea zeylanica* Gaertn.	G	W
Eragrostis unioloides (Retz.) Nees ex Steud.		W	*Tridax procumbens* L.	G	
Euphorbia hirta L.	G		*Typhonium trilobatum* (L.) Schott	G	W
Fimbristylis miliacea (L.) Vahl	G	W	*Vernonia cinerea* (L.) Less.	G	
Hedyotis sp.	G				

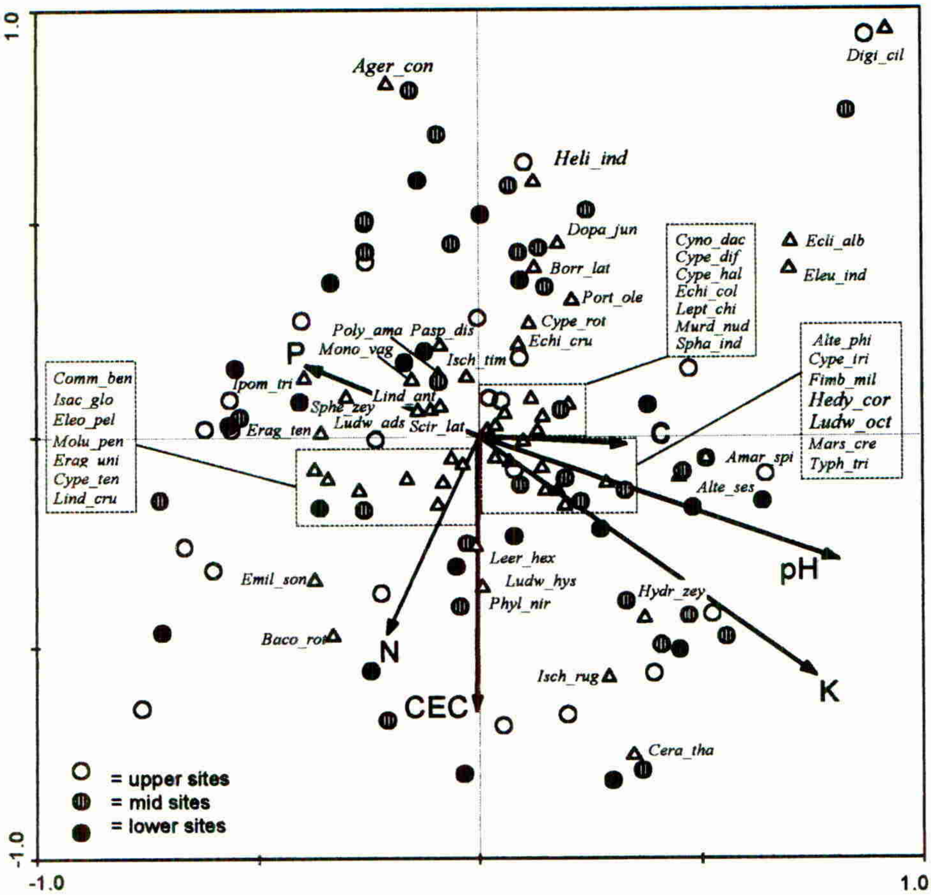

Figure 2. Biplot analysis of species abundance and soil nutritional status from canonical correspondence analysis. Species names are truncated (see Table 2).

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Increasing productivity of rainfed rice-based systems in NW Bangladesh: establishment, nutrient and weed management

M Mazid, M A Jabber, B Karmakar
Bangladesh Rice Research Institute, Joydepur, Gazipur, 1701, Bangladesh

M Mortimer
School of Biological Sciences, University of Liverpool, Liverpool L69 7ZB, UK

L Wade
School of Plant Biology, University of Western Australia, Crawley WA 6009, Australia

C R Riches, A W Orr
Natural Resources Institute, University of Greenwich, Chatham, Kent ME4 4TB, UK

ABSTRACT

Results from four cycles of a rice-chickpea rotation demonstrated that rice productivity can be increased and the rice harvested earlier in the drought-prone Barind Tract of Bangladesh by switching from transplanting (TPR) to direct–seeding (DSR). Dual objectives of the switch to direct seeding are to avoid terminal drought in rice and lengthen the window when soil moisture remains adequate for post-rice crop establishment. Direct-seeded rice yields were equivalent to or increased compared to transplanting. Yields were elevated by application of nitrogen fertiliser and weeds were adequately controlled by pre-emergence application of oxadiazon. The abundance of some species, notably *Cynodon dactylon*, *Echinochloa crus-galli* and *Fimbrystilis miliacea* increased under DSR. Occasional rotation of DSR with TRP may prevent these weeds becoming long-term problems.

INTRODUCTION

Delayed transplanting due to low rainfall early in the monsoon and, drought spells during grain filling are common rice production constraints in the Barind Tract of NW Bangladesh, which covers about 0.16 million ha of which nearly 0.1 million is rainfed (Saleh *et al.*, 2000). To improve the productivity of the area, where 80% of the land lies fallow in the post-rice season, research has focused on introducing direct-seeded rice (DSR) to replace transplanting (TPR) while promoting intensification through increased production of drought-tolerant crops, including chickpea grown on residual moisture after rice harvest. The widely grown rice cultivar Swarna, matures after 140 to 145 days and when transplanted may not be harvested until early to mid-November. In many years soil is drying rapidly at this time, reducing the likelihood of successfully establishing a chickpea crop. Direct seeding, can be completed after land preparation following 150 mm cumulative rainfall, compared to 600 mm needed for transplanting. DSR crops can therefore be planted earlier to mature 1-2 weeks before TPR reducing the risk of terminal drought, while allowing more reliable chickpea establishment (Saleh and Bhuiyan, 1995; Saleh *et al.*, 2000). Labour shortages prevent timely first weeding of TPR for many households in the Barind; with current practices 34% of farmers lose over 0.5 t/ha of the attainable yield due to weed competition (Mazid *et al.*, 2001). Weeds constrain adoption of DSR as the advantage of weed suppression through puddling and transplanting into standing water is lost. However, weed problems in DSR may be overcome by applying a pre-emergence herbicide (Mazid *et al.*, 2001; 2003). Other practices that can contribute to increased output in the rice-chickpea system in the Barind are the use of nitrogen fertilisers and planting early maturing cultivars to advance the rice harvest (Mazid *et al.* 1998; Mazid *et al.*, 2003). This paper discusses the effects of crop establishment, nutrient and weed management practices on crop performance in four cycles of a rice-chickpea rotation in a trial implemented with the aim of developing a reliable and productive rain-fed cropping system for promotion to Barind farmers.

METHODS

Cultivar BRRI dhan 39 (BR39) (maturity 120–125 days) was compared with Swarna (maturity 145–150 days) when direct-seeded or transplanted on farmland at Rajabari, Rajshahi District from 2001 to 2004. The experiment was conducted with a split-split plot design with 3 main plots as crop establishment and associated weed management, 4 subplots as nutrient management, and 2 sub-subplots as cultivars. Establishment treatments were (1) *transplanted rice (TPR)*—soil puddled prior to transplanting and plots hand-weeded twice at 30 and 45 days after transplanting (DAT); (2) *direct-seeded rice (DSR)*—soil ploughed prior to dry seeding (2001 and 2004) or ploughed and puddled before sowing pre-germinated seed (2002 and 2003) in rows by hand, with hand weeding at 21, 33, and 45 days after sowing (DAS); (3) *direct-seeded rice with chemical weed control (DSRH)*—as with DSR but with oxadiazon (375 g a.i./ha) applied 2–4 days after seeding, with one hand weeding at 33 DAS. Nutrient regimes (kg/ha) were (1) single superphosphate, 40 P + 40 K; (2) compound 60 N + 40 P + 40 K; (3) farmyard manure (FYM) + inorganic fertilizer totalling 60 N + 50 P + 50 K; and (4) diammonium phosphate (DAP) (18% N) + controlled-release urea (CR-N 45% N) totalling 43 N + 40 P + 40 K. Rice was harvested in a 5 m^2 area. Density of individual weed species was recorded in two unweeded quadrats per plot at 28 DAS/DAT. Chickpea (cv. Barisola 2) was broadcast sown following ox-ploughing after harvest of DSR into moist soil and covered by cross ploughing.

RESULTS

Yield responses

Rainfall in May and early June was sufficient in 2001 and 2004 for sowing dry-seeded rice into moist soil during June (Table 1). In 2002 and 2003, an abrupt onset of the monsoon resulted in flooded fields so pre-germinated seed was sown on saturated soil in DSR plots after water levels fell. Drought during July and August 2003 delayed transplanting until late September, 92 days after DSR. Yields of DSR and DSRH exceeded TPR (Figure 1) in both cultivars except for 2002 (cv. BR39) and 2001 (cv. Swarna) when cropping system did not significantly influence yield. Over four years mean yields were highest from direct seeded rice ($P<0.001$), TPR producing 1.81 ton/ha compared to 2.63 for DSR and 2.94 ton/ha for DSRH (S.E.D. 0.13). The higher yields under direct seeding were accompanied by earlier maturity and harvesting dates (3 – 10d) especially with BR39. On average the longer duration cultivar Swarna outperformed BR39 ($P<0.001$).

Table 1. Planting dates, direct seeding method and monthly rainfall 2001- 2004.

	2001	2002	2003	2004
DSR Plant date	26/6 dry seed	3/7 wet seed	20/6 wet seed	14/6 dry seed
TPR Plant date	27/7	2/8	27/9	16/7
Rainfall (mm)				
May	235	95	73	100
June	367	312	248	454
July	268	228	97	176
August	182	341	111	177
September	176	252	130	145
October	198	95	163	185

As expected, fertiliser source significantly ($P < 0.001$) influenced tiller density, panicle density and final grain yield. Highest grain yields resulted from use of NPK or diamonium phosphate + controlled release N in DSR (Table 2a). Over the four seasons grain yields were however variable (Table 2b) especially in TPR, lowest yield variability being seen in long duration Swarna with controlled-release fertiliser. BR39 on average exhibited a greater number of unproductive (non-panicle bearing) tillers than Swarna (25% and 21% respectively) and more were present under TPR than DSR (28% and 18% respectively). Unproductive tiller densities were not significantly effected by fertiliser source ($P = 0.127$) and were determined by seasonal responses of cultivars to methods of establishment and management ($P < 0.001$). Rice yields following pre-emergence application of herbicide with a follow-up hand weeding (DSRH) were similar to those achieved by hand weeding alone (DSR).

Table 2. a) Mean effect of fertiliser on rice yield (t/ha), over cultivar, in relation to establishment method and weed control – 2002 to 2004. b) Cultivar variability (coefficient of variation) in yield in relation to fertiliser and method of establishment.

a) Grain yield

Establishment Method	Fertiliser 1. (PK)	2. NPK	3. NPK +FYM	4 DAP + CR-N
TPR	1.560	1.909	1.821	1.948
DSR	1.916	3.076	2.455	3.087
DSRH	2.349	3.290	2.805	3.316
Standard error of difference of mean	0.1615			

b) Variability (Coefficient of variation)

Establishment method	Cultivar				
TPR	BR39	51.6	44.7	51.1	48.1
	Swarna	54.0	55.8	51.4	56.2
DSR+DSRH	BR39	40.6	25.5	31.8	32.8
	Swarna	30.2	20.6	19.3	15.2

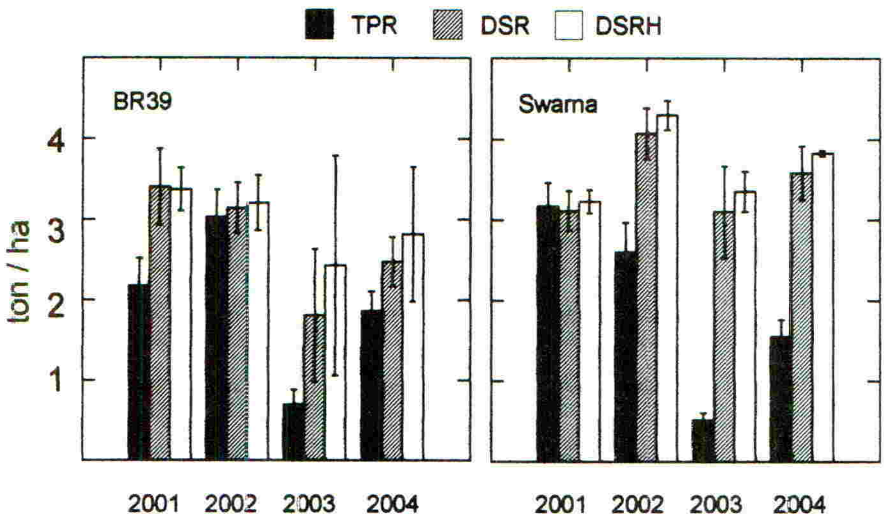

Figure 1. Effect of crop establishment and weed control method on grain yields (t/ha) over time of two rice cultivars. Yields are for DAP+K+CR-N nutrient treatment.

Yields of chickpea grown after DSR declined from 2001 (Table 3). Cultivar Barisola 2 was uses throughout but proved susceptible to soil borne *Fusarium* wilt disease. Over the period of the trial, yields were higher (P = 0.030) for crops planted after the earlier maturing rice cultivar BR 39 compared to those planted following Swarna. In associated on-farm trials in 2003 the *Fusarium* tolerant cv. Barisola 5 was sown after TPR. Rice harvest and subsequent chickpea sowing dates and chickpea stands were significantly effected by previous rice cultivar (P<0.0001). Rice harvest and subsequent chickpea sowing dates and chickpea stands were significantly effected by previous rice cultivar (P<0.0001). On average earlier maturing rice cv. BR 32 was harvested 7.4 days before Swarna and chickpea after BR 32 was sown a mean of 6 days earlier. Earlier planting after BR 32 resulted in a better stand, but chickpea yield (878 kg/ha ± 28) was not significantly higher than that after Swarna (821 kg/ha ± 26). Rain in November 2003 provided ideal seedbed moisture for chickpea establishment.

Table 3. Effect of rice cultivar on grain yield (t/ha ± S.E.) of chickpea sown after harvest of direct-seeded rice.

	Previous rice variety	
Season	BR39	Swarna
2001-2	1.01 ± 0.06	0.91 ± 0.05
2002-3	0.76 ± 0.05	0.49 ± 0.04
2003-4	0.38 ± 0.04	0.16 ± 0.02
2004 -5	0.31 ± 0.06	0.35 ± 0.06

Weed responses

Differential responses to crop establishment were observed for some important weed species (Figure 2). Densities of the perennial and annual grasses, *Cynodon dactylon* and *Echinochloa crus-galli*, and the annual sedge *Fimbrystilis miliacea* all increased under DSR while the broadleaf *Ludwigia octovalvis* and the sedge *Cyperus difformis* increased in TPR. Density of

Monochoria vaginalis declined in both cases. Larger changes appear to be associated with the standing water found early in the crop cycle with TPR.

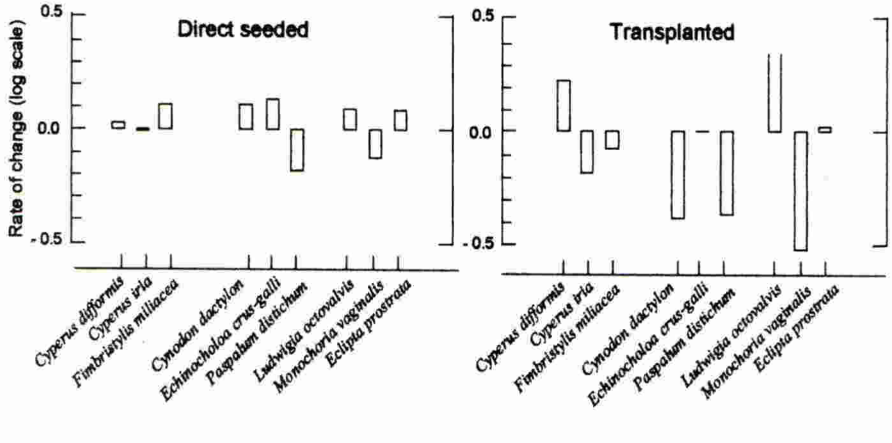

Figure 2. Trajectories (logarithm mean rate of change in density (plants m^{-2})) of selected individual weed species in response to crop establishment method. Census point 28 DAS/DAT in 2002 and 2004.

DISCUSSION AND CONCLUSIONS

The single rice crop, land pressure and a high proportion of share-cropping and other tenancy arrangements in the Barind, place a premium on optimising rice yield for household food security (Mazid *et al.*, 2001; 2003). Our results show that yields are maintained or increased compared to TPR when the crop is either dry- or wet-seeded. DSR is a robust option producing stable yields over seasons with quite different rainfall patterns. Nitrogen fertiliser use reliably enhanced yield of direct-seeded crops, controlled-release forms being of greater value in the highly variable soil types of the Barind. DSR was a particular advantage in 2003 when drought delayed transplanting to late September and in 2004 when 327mm rainfall fell in 24 h 14 days after sowing aiding weed suppression, and 185 mm in the first two weeks of October provided ideal conditions for grain filling. As rainfall is unpredictable early in the monsoon farmers need the flexibility to sow either dry or pre-germinated seed. In the trial seed was sown manually into rows marked by a hoe. Farmers in Rajshahi District implemented field-scale DSR by broadcasting. In 2004 this produced 5.34 t/ha $\pm$ 0.20 Swarna compared to 5.20 t/ha $\pm$ 0.30 from TPR at the same sites. However, heavy rain after sowing destroyed a number of broadcast crops. Dry DSR was also successful when sowing into rows opened by a locally fabricated furrow opener (*lithao*). Yields of Swarna established by *lithao*, with weed control by pre-emergence herbicide and hand weeding averaged 6.09 t/ha $\pm$ 0.24 compared to 5.71 t/ha $\pm$ 0.14 for TPR. Farmers found direct seeding by lithao to be a practical, labour and cost saving planting method. The estimated cost of a lithao is US$ 4.50 and farmers suggested that 5 to 7 families could share this tool. A recently introduced hand-pulled drum seeder allows pre-germinated seed to be sown on wet soil. On-farm yields in 2004 from this option averaged 5.61 t/ha $\pm$ 0.37. Further work is needed to determine the economic viability of drum seeding. Our data demonstrate the responsiveness of major weeds to rice establishment method. While herbicides reduce labour costs for weed control in DSR (Mazid *et al.* 2001) hand weeding is also needed to prevent survival of herbicide tolerant species including perennial grasses (e.g. *C. dactylon*) and a later flush of free-seeding annuals (e.g. *E. crus-galli and F. miliacea*). Alternating TPR with DSR every few years may be necessary to prevent an increase in the abundance of such species.

Direct seeding advanced rice harvest by 7 to 10 days. Earlier harvest reduce the problem of terminal drought in rice when rains end abruptly in October and will ensure post-rice crops are sown while seedbeds are moist. Farmers with the least land under cultivation (0.6 ha for the lowest quartile of households) on average plant 43% to post-rice crops, often on least favourable land where moisture is limiting (Mazid *et al.*, 2003). Our trials suggest that this group can maximise rice yield and achieve timely planting of a high value chickpea crop by direct seeding rice. On larger farms (> 2.5 ha for upper quartile) a lower proportion of land is planted after rice, using more favourable soils. Adoption of DSR by this group could increase in the area planted to chickpea. On level, well drained fields, direct seeding and herbicide use have potential to maintain or increase rice yield, overcome labour constraints and increase post-rice crop planting to enhance the productivity of Barind agriculture.

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System-level effects in weed management in rice-wheat cropping in India

G Singh, Y Singh, V P Singh
G.B. Pant University of Agriculture and Technology, Pantnagar, Uttaranchal, India

D E Johnson
International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines

M Mortimer,
School of Biological Sciences, University of Liverpool, Liverpool, L69 7ZB, UK

ABSTRACT

Rice-wheat is the principal cropping system of the Indo-Gangetic Plains and its sustainability is vital to the livelihoods of the farmers of the region and national food security. Changing rice establishment from transplanting to direct seeding offers labour and water savings and zero-tillage in wheat may improve productivity. Studies over four cropping cycles confirmed that with intensive weed control, yields under wet seeding of rice were superior to transplanted rice, dry direct seeded and zero-tilled rice. Conventional and zero-tillage in wheat gave similar yields. The inclusion of appropriate early post emergence chemical weed control followed by manual weeding for rice improved yields over conventional hand weeding. Underlying the pattern of selective recruitment of weeds by method of rice establishment were the impacts of wheat tillage method. Densities of *Echinochloa colona* in rice were reduced with zero-tilled wheat whereas abundance of *Caesulia axillaris* increased. Over four cropping cycles of direct seeding there were noticeable increases in *Ischaemum rugosum, Leptochloa chinensis and Fimbristylis miliacea* in wet seeded rice, while *Cyperus rotundus* became incorporated into the weed flora of dry direct seeded rice with highest abundance in plots zero-tilled for wheat.

INTRODUCTION

Rice and wheat are the staple food crops of India, contributing nearly 80% of the total food-grain production, and the rice-wheat rotation is the principal cropping pattern of the Indo-Gangetic Plains, where the system occupies some 13.5 million ha. Rice is traditionally transplanted at the end of the dry season (May/June) and, wheat is sown (November/December) after rice harvest. Demand for food grains in India is expected to grow and the requirement for 2025 is estimated to need a 40% production increase compared with 2003-04. There has, however, been stagnation in rice productivity in recent years, a declining rice yield trend has been observed (Padre & Ladha 2004), and labour and water shortage for agriculture in areas with high production potential have been recently reported. Direct seeding of rice has already replaced transplanting in many parts of Southeast Asia. Pandey & Velasco (2002) argued that low wage rates and adequate water supply favor transplanting but direct seeding is likely to increase in circumstances of labor scarcity and increasing wage rates. Singh *et al.* (2001a) and Singh *et al.* (2003) reported upon the potential for direct seeding of rice as a replacement for transplanting and described early findings of a long term system trial designed to examine the impact of changes in rice and wheat crop establishment methods on crop yield and on the weed flora in rice. Responses in rice weed community structure to the introduction of sugar cane into the rice-wheat rotation have been recorded (Singh *et al.*, 2001b) and reduced tillage agriculture is well known to have an impact on weed community composition (Derksen *et al.*, 1993). This paper assesses changes to the weed flora in rice in relation to differing direct seeding methods, coupled with changes in wheat establishment in the rice-wheat system.

MATERIALS AND METHODS

A long term replicated field experiment was established in 2000 at the field station of G.B. Pant University of Agriculture and Technology, Uttaranchal. Full experimental details are given in Singh *et al.* (2003) and in summary, five rice establishment methods were examined in factorial combination with two wheat establishment methods (Table 1) with three weeding levels.

Table 1. Experimental details. DAS, days after seeding; DAT days after transplanting.

	Establishment method	Land preparation and sowing	Herbicide used in intensive weeding
Rice			
	TP conventionally transplanted	Ploughed, puddled and levelled; hand transplanted 21-day-old plants 20 cm × 20-cm spacing.	Butachlor 1.5 kg a.i. / ha, 2 DAT.
	WS wet (pre-germinated) seeded	Ploughed, puddled and levelled; drum-seeded, 35 kg / ha, 20 cm row spacing.	Anilophos 0.4 kg a.i. / ha, 5 DAS.
	DS dry drill seeded	Ploughed, harrowed; drill seeded, 50 kg / ha, 20 cm row spacing.	Pendimethalin 1.0 kg a.i. / ha, 1 DAS.
	DSf dry drill seeded with stale seed bed treatment	As DS, with a flush irrigation and subsequent 7d glyphosate application prior to seeding; 50 kg / ha, 20 cm row spacing.	Pendimethalin 1.0 kg a.i. / ha, 1 DAS.
	ZR dry drill seeded with zero tillage	Flush irrigation and subsequent 7d glyphosate application prior to drilling; 50 kg / ha, 20 cm row spacing.	Pendimethalin 1.0 kg a.i. / ha, 1 DAS.
Wheat			
	CW conventional tillage	Ploughed, harrowed; drill seeded, 100 kg / ha, 20-cm row spacing.	Isoproturon kg a.i./ ha 35 DAS, follow-up handweeding as required.
	ZW zero tillage	Drill seeded into rice stubbles after paraquat, 0.5 kg a.i. /ha; 100 kg / ha, 20-cm row spacing.	Isoproturon kg a.i./ ha 35 DAS, follow-up handweeding as required.

Rice for transplanting was sown in a nursery at the same time as plots were direct seeded, and transplanted 28 days later. Rice plots were either intensively weeded (herbicide followed by manual weeding), manually weeded at 28 d (and 56 d if required) after crop establishment, or unweeded. All plots in the wheat phase were intensively weeded (post-emergence herbicide and hand weeding) In each rice plot, weed abundance (weed density and biomass, fresh and dry weight, by species) was measured in two 0.25m x 1m quadrats covering 5 crop rows at 28 d, 56 d after crop establishment, and prior to manual weeding, and at harvest. A water depth of 100 mm was maintained for one month after transplanting, thereafter soil being saturated unless flooding occurred through rainfall. In wet seeded plots, soil was kept saturated by water management for 21 DAS to ensure rice establishment. Dry seeding was into aerobic soil. Supplemental irrigation was given as required. Rice and wheat yields were taken from 5 m^2. Data were analysed by residual maximum likelihood repeated measures analysis of variance.

RESULTS AND DISCUSSION

Yields

Highest grain yields of rice were achieved in all seasons 2001 to 2004 (Figure 1 a) from wet seeded rice (mean 7.1 t/ha), lowest yields in weed free plots being obtained on average from zero-tillage (mean 5.69 t/ha) whilst transplanted rice gave 6.54 t/ha. The yield response however varied in relation to establishment method and weed control over seasons ($P < 0.001$). The yield loss resulting from the absence of early post emergence herbicide and reliance on manual weeding alone (Figure 1 b) was noticeably higher in 2001 than in other years, a year in which rainfall in the first 28 days following drill seeded crop establishment was at least 100 mm higher than in the comparative period in subsequent years. Characteristically, in the absence of weeding, yield losses due to weed competition from weeds were least under transplanting (Figure 1 c) and varied under direct seeding from 3.5 t/ha to greater than 6 t/ha.

Averaged over the four years, wheat yields were not significantly influenced by either rice or wheat establishment method (mean yield 3.9 t/ha). Tripathi *et al* (1999) also recorded comparable yields of wheat from zero- and conventional tillage irrespective of different rice seeding/transplanting methods.

Weed responses

Fourteen principal species were recorded over the four cropping seasons: *Caesulia axillaris, Commelina diffusa, Cynotis* spp, *Cyperus difformis, Cyperus iria, Cyperus rotundus, Echinochloa colona, Echinochloa crus-galli, Eragrostis japonica, Fimbristylis miliacea, Ischaemum rugosum, Leptochloa chinensis* and *Paspalum distichum.* Weed community changes in response to crop establishment method of rice are common (Mortimer & Hill, 1999) and at the start of the trial in 2000 in unweeded plots *Echinochloa colona, Caesulia axillaris,* and *Fimbristylis miliacea* were the most abundant weeds in both the transplanted and dry-seeded rice plots (Singh *et al,* 2001a). Differentiation in the flora according to rice establishment method was noticeable (Figure 2) by 2003 with *Ischaemum rugosum* being dominant in wet seeded plots, *E. colona* dominating in dry seeded plots and *Cyperus iria* and *E. colona* being most abundant under transplanting ($P < 0.001$, multivariate analysis not shown). Four years after the initiation of the trial, *Leptochloa chinensis* and *Cyperus rotundus,* were present in all direct seeded plots. Table 2 summarises the responses of selected species to rice and wheat establishment as indicated by density 28 d after crop establishment in 2004

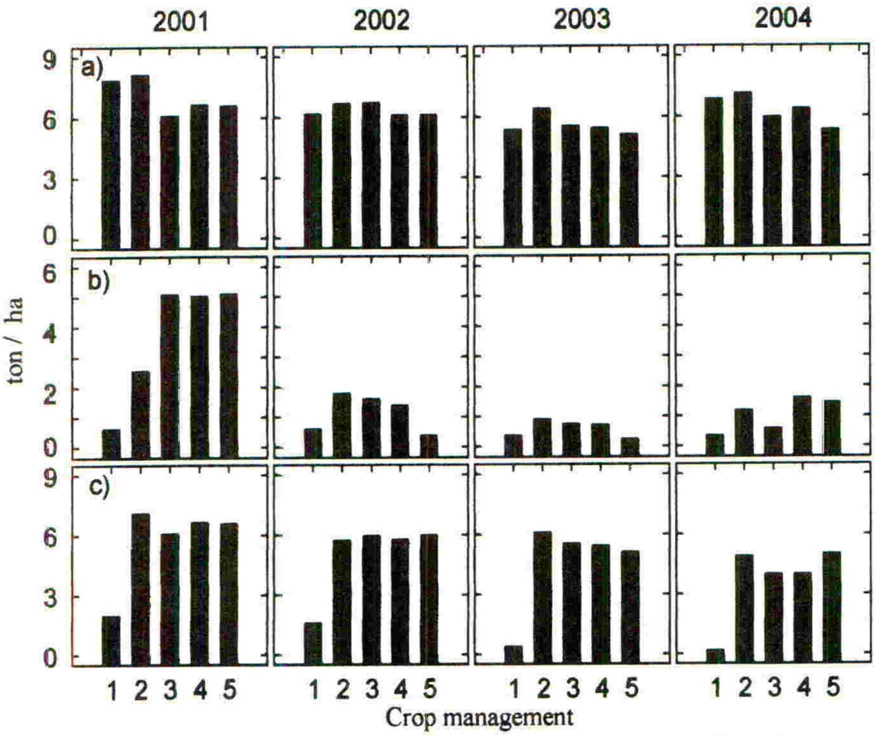

Figure 1. Rice yield (t/ha) under different methods of establishment and weed management a) grain yield under under weed free conditions S.E.D = 0.35 ton / ha ; b) yield gap with manual weeding; c) yield gap with no weeding. 1 = TP, 2 = WS, 3 = DS, 4 = DSf, 5 = ZR.

in unweeded rice plots. Densities of *Echinochloa crus-galli*, *Cyperus difformis* and *Eragrostis japonica* were not influenced by establishment methods in either crops over the previous 4 years. Conversely population densities of *Echinochloa colona* and *Caesulia axillaris* in rice were dependent on land preparation for wheat. In conventionally tilled wheat plots, mean *E. colona* densities were three fold greater than in zero-tilled wheat plots, a two fold difference being measured for *C. axillaris*, the higher abundance occurring under zero tillage. Rice establishment methods selectively influenced recruitment and in particular, direct seeding with a prior stale seed bed (DSf) reduced densities of *C. axillaris*, *L. chinensis* and *Cyperus iria*. The abundance of *Cyperus rotundus* was promoted under DSf rice and elevated by zero tillage of wheat. The selective effects of land preparation and of crop establishment on recruitment of rice weeds and by implication soil seed banks are well known (Mortimer & Hill, 1999) and these results highlight the responsiveness of major rice weeds. As a single observation in time, they suggest that underlying weed succession may result from to cultural practices. Further analysis (not shown) of population dynamics support the hypothesis of succession for *Caesulia axillaris* and *E. colona* since monotonic increases in density were seen over years at comparable census points, despite seasonal climatic variation. Similar increases occurred for *Cyperus rotundus*, although spatial heterogeneity over plots precluded statistical significance. Whilst substantially reducing weed biomass, hand weeding alone did not alter the dominant weed species in residual biomass (comparison of curves, Figure 2) in most instances. Mechanistic processes underlying the dynamics of germination, seed longevity and dormancy for many of these species remain poorly understood.

Table 2. The influence of rice and wheat crop establishment methods on abundance (mean plant density, m^{-2}) 28 DAS / DAT of selected weed species in unweeded plots of rice in 2004. The lowest and highest abundance is indicated by method of establishment for each crop.

Species	Response to crop establishment method									
	Rice					Wheat				
	Abundance					Abundance				
	Low		High		S.E.D	Low		High		S.E.D
Caesulia axillaris	DSf	16.0	ZR	21.5	5.5	CW	9.3	ZW	19.4	2.26
Commelina diffusa	WS	1.8	ZR	84.2	12.8					
Echinochloa colona	WS	5.2	ZR	22.0	8.7	ZW	5.9	CW	20.0	5.86
Ischaemum rugosum	ZR	0.0	WS	7.8	2.7					
Leptochloa chinensis	DSf	0.2	WS	8.8	2.0					
Fimbrystilis miliacea	DS	4.2	WS	37.2	12.6					
Cyperus iria	DSf	8.8	ZR	68.5	27.4					
Cyperus rotundus	WS	4.0	DSf	175.0	37.0	CW	42.0	ZW	106.0	36.20

All comparisons significant ($P<0.05$) except CW versus ZW in *Cyperus rotundus* ($P=0.17$)
Mean density (m^{-2}) of species not responsive to establishment method:
Cyperus difformis = 17.9, *Echinochloa crus-galli* = 10.2, *Eragrostis japonica* = 1.1

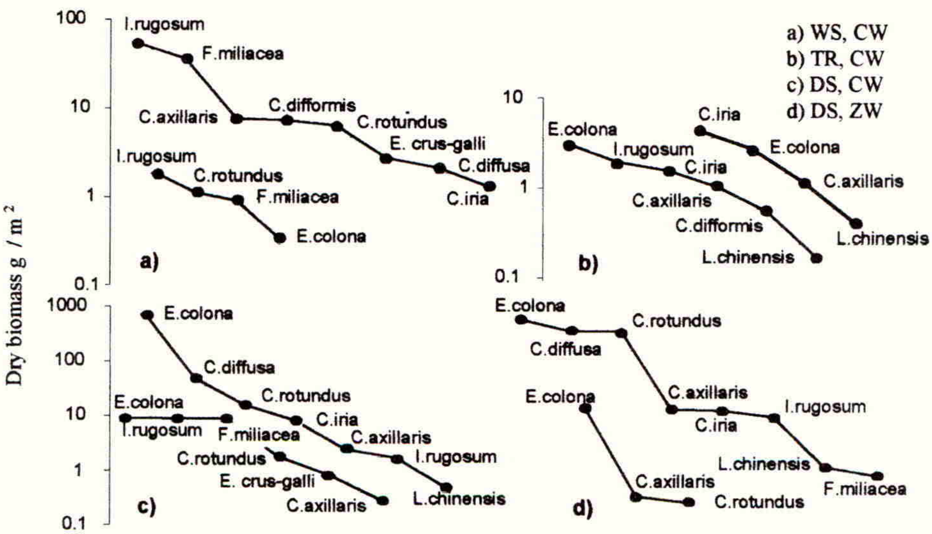

Figure 2. Log rank curves of weed dry weight, 56d after establishment for selected treatments. The upper curve of each pair is from unweeded plots, the lower from manually weeded plots.

Successful yield protection from weed competition in direct seeded rice relies on effective early chemical control followed by manual weeding, the latter to remove aggressive late emerging species not adequately suppressed by the developing rice canopy. Understanding the underlying dynamics of weed communities underpins decision support systems that identify important target weeds and potential shifts in populations, and determines appropriate control measures. In rice-wheat a change to zero-tillage for improved wheat productivity (Hobbs *et al*, 2002) has the potential to reduce time and costs spent hand weeding for *E. colona* in rice especially if coupled with wet seeding but may increase the risk of ingress of *C. rotundus*.

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Evaluation of azadirachtin A formulations for the control of dubas bug on date palm in Oman

I H S Al-Mahmooli, M L Deadman, A K Al-Wahaibi
Department of Crop Sciences, College of Agriculture, Sultan Qaboos University, PO Box 34, Al-Khod 123, Sultanate of Oman
Email: issah@squ.edu.om

J R M Thacker
Pesticides Research Group, Biological Sciences, University of Paisley, Paisley PA1 2BE, UK
Email: Richard.thacker@paisley.ac.uk

ABSTRACT

The dubas bug *Ommatissus lybicus* attacks date palm twice a year in the Sultanate of Oman and it is considered the most important pest of this tree. Currently, the government subsidises the control of this pest by paying for applications of synthetic insecticides in plantations that experience pest outbreaks. The aim of the research that is described in this paper was to evaluate whether environmentally benign neem formulations might make a contribution to the management of the dubas bug, perhaps as alternatives to the organosphosphate insecticides in use at present. The dubas bug population was monitored in a plantation on the Batinah coast over a 6 month period from January – June 2005. Direct measurements of pest numbers were made by counting nymphs on leaflets on suckers at the base of trees that are located at a height of about 1 metre. Indirect measurements of pest numbers were made by recording honeydew droplets on water sensitive papers. The data collected indicated a high degree of correlation between direct and indirect counts however, the pest population did not approach a level that would have required chemical intervention. Laboratory studies with field collected dubas bug nymphs were undertaken in which three different neem formulations were evaluated in relation to their topical toxicity to the pest. The highest mortality recorded from the topical toxicity bioassays was approximately 30%. This was with a formulation that comprised 17% of the active ingredient Azadirachtin A. The data collected are therefore preliminary. It is hoped that field trials will be undertaken later on this year.

INTRODUCTION

The sap-sucking homopterous pest, the dubas bug *Ommatissus lybicus*, feeds on date palm throughout the Middle East and North Africa (Hussain, 1963; Klein & Venezian, 1985; Abd-Allah et al., 1998; Asche & Wilson, 1989). In Oman, on the Arabian peninsula, there are approximately 10 million trees that are at risk of damage from this pest (Thacker *et al.*, 2003). The dubas bug is not a disease vector (Howard, 2001), rather it causes direct damage to trees as a result of sap-sucking. In addition however, this feeding activity leads to copious honeydew production, which can then act as a trophic resource for sooty moulds (Klein & Venezian, 1985; Elwan & Al-Tamiemi, 1999). These moulds block photosynthetic activity and they can also cause partial suffocation of the date palm (Gassouma, 2004). Partial or even complete crop failure has been recorded in date palms with severe infestations that have been left untreated.

In the Sultanate of Oman, the Ministry of Agriculture spends in the region of RO 150,000 – 200,000 (US$ 390,00 – 520,000) annually to support an aerial chemical spraying programme to control this pest in date palm plantations in which outbreaks have been detected by extension workers (Thacker *et al.*, 2003; Government of Oman, 2000). Synthetic chemical insecticides that are currently recommended by the FAO for the specific control of this pest include the organophosphate insecticides chlorpyrifos, fenitrothion, and phenthoate, as well as the non-ester pyrthroid insecticide etofenoprox. In Oman, the insecticide that has been used most extensively in recent years is fenitrothion. All of the recommended products are contact insecticides with no systemic activity, despite the fact that the pest itself feeds from the vascular system of the plant.

As a result of the many general concerns that are associated with the use of synthetic chemical insecticides there is a desire at present to find alternative products that may be more environmentally friendly. In the case of the dubas bug there are references in the Iranian, Iraqi and Saudi Arabian literature to an egg parasitoid and to some coccinellid predators of the dubas bug but no further research on these relationships has as yet been undertaken (Gassouma, 2004). That said, it would obviously be prudent to use products that exacted the minimum disruption to any endemic biological control of this pest within the date palm ecosystem.

The aim of the research that is described in this paper was to evaluate the potential of an environmentally friendly botanical insecticide for dubas bug management. The formulations tested comprised NeemAzal-T/S, a neem seed extract containing 1% azadirachtin A, NeemAzal-T (5% azadirachtin), and NeemAzal-U (17% azadirachtin). Research carried out elsewhere has described the potential of neem extracts for the management of sap-sucking pests (Schmutterer, 1990; Basedow *et al.*, 2002; Daly *et al.*, 2003; Thoeming *et al.*, 2003). Our aim was evaluate such potential against the dubas bug.

MATERIALS AND METHODS

Population dynamics of *Ommatissus lybicus*

All fieldwork was conducted at the village of Hubra, in the Batinah area of the Sultanate of Oman. Dubas bug numbers were sampled fortnightly for six months from January to June 2005. The environmental conditions within the data palm plantation comprised temperatures ranging between 28-35^{o}C and a relative humidity of 70-80%. Visual assessments of the numbers of dubas bugs present were made by counting on the upper and lower side of four leaflets on the sucker plants that are located at a height of about one metre at the base of trees. This is the standard method by which extension workers assess the magnitude of the dubas bug pest populations (Mokhtar & Al-Mjeini, 1999). Indirect measurements of the size of the pest population were made by using water sensitive papers (WSPs) to record honeydew production (Thacker *et al.*, 2003). The WSPs were placed on the ground at each compass point at a distance of 1.5 m from the date palm trunk. The area of each WSPs was 7cm * 5cm. The WSPs were left in the plantation for a two hour period prior to collection. Thereafter, the WSPs were collected and the number of droplets present was counted and recorded. Six replicate trees were used for the experiment. The data were analysed by correlating the visual dubas bug count with the honeydew droplet density recorded on the WSPs.

Laboratory Topical Toxicity Experiments

The topical toxicity of a range of neem formulations was assessed in the laboratory at Sultan Qaboos University, Oman. The formulations assayed comprised 1% azadirachtin A, 5% azadirachtin A, and 17% azadirachtin A. These formulations were supplied by Trifolio GmbH (Germany). A range of field collected instars were used in the topical toxicity experiment. In each bioassay 5 – 15 nymnphs were used. The field-collected nymphs were first placed in a 9 cm diameter petri dish that contained a 6 cm fresh green frond. The nymphs were then sprayed once using a hand-held Delta sprayer (Mythos, Italy). The concentrations of the formulations sprayed comprised 3 ml of each formulation mixed in 100 ml water with two drops of Tween 20. Each bioassay was replicated six times. The control spray comprised water plus Tween 20. The mortality of nymphs was assessed after 24 hrs. The data generated were analysed using analysis of variance (ANOVA) followed by a Tukey mean's separation test.

RESULTS

Population dynamics of *Ommatissus lybicus*

The mean number of honeydew droplets recorded on water sensitive papers throughout the sampling period is shown in Figure 1. It is clear from the data collected that the pest population was very small. In other studies far higher droplet densities have been recorded (Mokhtar & Al-Mjeini, 1999; Thacker *et al.*, 2003). There was no pest outbreak at this location during the first half of 2005. As a result no pesticide applications were made within the date palm plantation that was being monitored. The mean number of dubas bugs per count is also shown in Figure 1. The number recorded were substantially below that at which pest control would have been carried out (Mokhtar & Al-Mjeini, 1999).

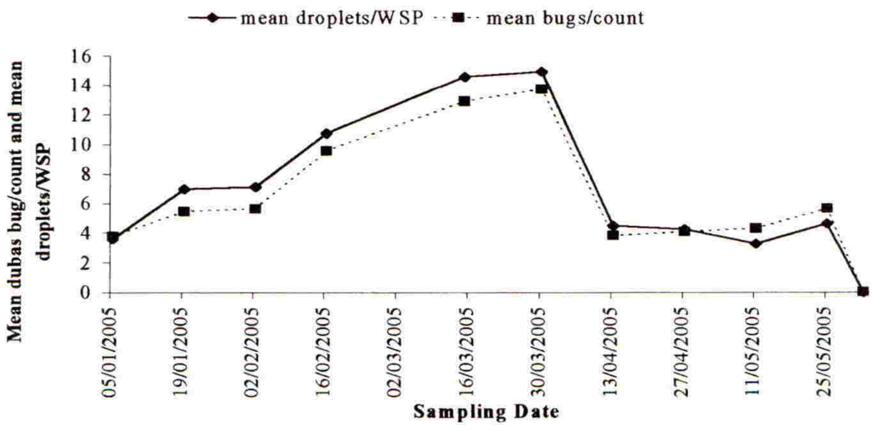

Figure 1. Mean number of dubas bug and honeydew droplets recorded on water sensitive papers at trial site from January – June 2005.

Figure 1 shows that the, albeit small, pest population begins to increase from January onwards and that it peaks towards the end of March. By the end of May no more bugs were detected within the plantation. This is consistent with what has been reported elsewhere (Thacker *et al.*, 2003). Figure one shows that there was a clear correlation between pest counts and between the number of droplets that were recorded on the water sensitive papers. Analysis of the strength of this correlation using the summed data is shown in Figure 2.

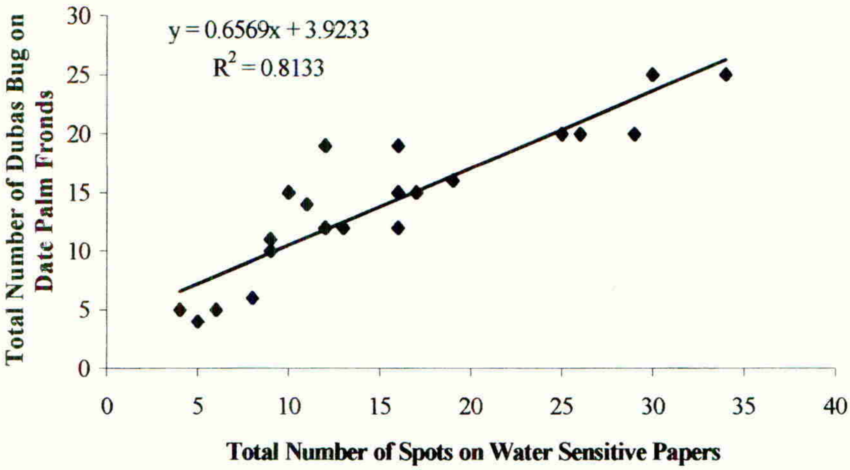

Figure 2. Relationship between pest numbers and droplet counts at the trial site.

Laboratory Topical Toxicity Experiments

Figure 3 shows the percentage mortality of the dubas bugs exposed to the three neem formulations 24 hours after treatment. The figure shows that the mortality recorded ranged from 17 and 31 percent. There was a clear trend for an increase in mortality that was associated with an increasing concentration of azadirachtin A. None of the control dubas bugs died.

The greatest mortality realised was with the 17% azadirachtin. The level of mortality was statistically different from both the control and from the mortality recorded with the formulation with the lowest concentration of azadirachtin. The bioassay indicates all of the neem formulations assayed resulted in a level of mortality that was statistically different from the control. The associated error terms indicate that there was no significant difference in the level of mortality recorded between 1% and 5% azadirachtin.

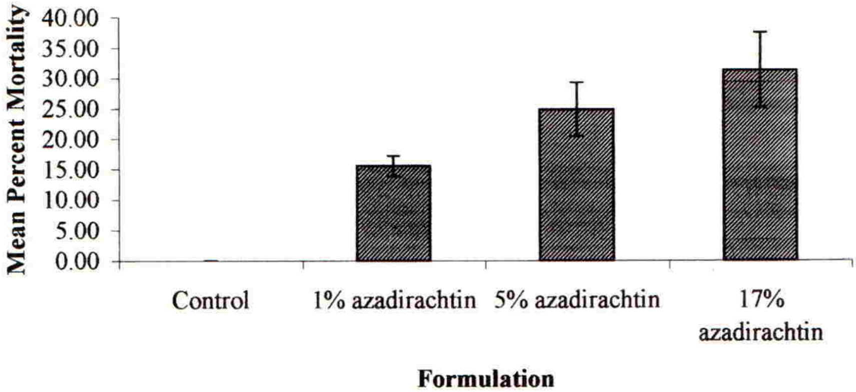

Figure 3. Effects of the different neem formulations on the mortality of dubas bug in laboratory experiments. Columns with different letters are significantly different at the 5% level.

DISCUSSION

The data collected show that the dubas bug population in this area was at its lowest recorded level for the last 10 years. Normally, there would be two peaks of dubas bug activity annually, during September-October and during March-April (Mohktar & Al-Mjeini, 1999; Thacker *et al.*, 2003). The exact reason for this substantial decline is unknown but because it is the spring population that lays the eggs from which the second peak population develops (Abd-Allah *et al.*, 1998) it may be expected that the Autumn pest population, at this location, will also be small.

The results provide further evidence regarding the reliability of using water sensitive papers to monitor the actual number of dubas bug that are present within date palm plantations and so support previous work in this area (Mohktar & Al-Mjeini, 1999; Thacker *et al.*, 2003). Using water sensitive papers to record feeding activity is simple, cheap and less labour intensive than visual inspection methods.

The results with the neem formulations show that these are able to reduce the number of live dubas bugs in a laboratory bioassay. Moreover, the magnitude of this effect appears to be related to the concentration of azadirachtin within a formulation. However, because only a single concentration was used in this bioassay, more research is needed in this area. Overall, the data demonstrate that azadirachtin is toxic to the dubas bug.

Much more work on dose optimisation and concentration is required, as are studies on actual field toxicity. In the present study the small size of the pest population did not make field trials feasible. It is hoped that such trials will be possible within the near future.

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Farmer perceptions and pesticide use practices in vegetable production in Ghana

W J Ntow
CSIR Water Research Institute, PO Box AH 38, Achimota, Ghana
Email: ntow@excite.com

H J Gijzen, P Kelderman
UNESCO-IHE Institute for Water Education, PO Box 3015, 2601 DA Delft, The Netherlands

P Drechsel
International Water Management Institute (IWMI), PMB CT 112, Accra, Ghana

ABSTRACT

Survey results of 137 Ghanaian farmers who applied pesticides in vegetable production indicated much overuse, misuse and abuse of the chemicals. The practices of use of the chemicals defied some of the basic principles of insecticide management, and presented great potential for exposure of the farmers to the chemicals from both skin contact and inhalation. Various poisoning symptoms were reported among the farmers. Young farmers (less than 45 years of age) were the most vulnerable group. Even though the farmers could differentiate pesticides in terms of their effectiveness against pests and hazard to human health, their perception was not too different from that of Experts using WHO ranking. Farmers' perception of pesticide hazard did not relate to its perceived effectiveness against pests ($p < 0.05$).

INTRODUCTION

Urban food needs in cities and towns in Ghana are growing, and increasingly vegetables are grown in urban and peri-urban areas to meet the demand. However, traditional vegetable farming systems (that is, without any chemical inputs) are incapable to meet this challenging demand. For instance, pests and diseases, which are real bottlenecks to vegetable production, require intensive pest management to control them. Chemical pesticide use is a common practice to control pests and diseases in vegetable cultivation in Ghana (Dinham 2003). But, besides the beneficial effects, pesticides are accepted to have potential environmental and public health impacts as well. If improperly used, pesticides can cause direct human poisoning, accumulate as residues in food and the environment or lead to the development of resistant strains of pests. These problems can arise from misuse of the pesticides or over-reliance on them, particularly if the users are not conscious of these potential problems. In Ghana, there are already some levels of contamination of pesticides in water, sediment, crops and human blood and breast milk in areas of highly intensive vegetable production (Ntow, 2001). There exist species of aphids which have developed resistance to some insecticides, and there are probably other pests resistant to other pesticides, which are yet undetected (Biney 2001).

While pesticides are in general considered a panacea for farmers' pest concerns, the farmers' perceptions and use of the chemicals have not received much attention in research. However, the perceptions of farmers regarding, particularly, pesticide risks to human health are important for several reasons. The current study aimed at obtaining information on the type, scope and extent of use of pesticides, farmers' knowledge of the pesticides, and their perceptions about the chemicals' effectiveness and potential for harm.

MATERIALS AND METHODS

Diagnostic surveys, formal and informal interviews, field observations, and ranking games were used to gather information about farmers' pesticide use, perceptions on health effects, and pest management practices. Formal interviews dealt with the general vegetable farming system and farmers' pest control practices while the other methods assessed farmer pesticide use and perception of pesticide hazards. In the formal interviews, structured questionnaires were used to collect information from farmers. In addition to the interviews, field observation surveys and spraying practices of respondent farmers were discreetly conducted. The farmers were not informed beforehand in order to avoid modifications in pesticide handling behaviour. The questionnaire data were analysed by the statistical software SPSS (release 11.0; SPSS Inc. Chicago, Illinois, USA). Group meetings were also held to gather information simultaneously from a large number of farmers. Pesticide perceptions and health risks were assessed through a ranking game described in Warburton *et al.* (1995).

RESULTS AND DISCUSSION

All the respondents in the present survey sprayed their crops with pesticides to control pests and diseases. The proportions of various classes of pesticides used by vegetable farmers in our survey were herbicides (44%), fungicides (23%) and insecticides (33%).

Vegetable farmers sprayed the same very wide range of pesticides on all their crops. For instance, farmers in our survey reported spraying insecticides like lambda cyhalothrin (Karate 2.5 EC/ULV), cypermethrin (Cyperdin, Cymbush), dimethoate (Perferkthion 400 EC), and endosulfan (Thionex 35 EC/ULV, Thiodan 50 EC) on tomato, pepper, okra, egg plant (garden eggs), cabbage, and lettuce. This information has an implication for public health. For instance, endosulfan has been registered in Ghana for use on cotton (Table 1). Yet it is used on vegetables. Although there are no obvious indications of a public health problem as a result of the misuse of endosulfan, the risk is clearly there.

Herbicide and fungicide use are mostly under World Health Organization (WHO) Hazard Category III, with a few under category II. All the insecticides used are under Hazard Category II, which WHO classifies as moderately hazardous (Table 1). This category includes organochlorines (OCs), organophosphates (OPs), and pyrethroids. Endosulfan was the only OC mentioned in use in the survey. The usage of endosulfan in Ghana on vegetables is worrying given its toxicity and persistence in the environment. Our study results are corroborated by Ntow (2001) who has demonstrated the presence of organochlorine pesticides and their active metabolites in milk and food crops in Ghana. This is mainly because organochlorines, relative to other classes of pesticides, are resistant to environmental degradation, which allows them to accumulate in plant and animal tissue and to get concentrated in the upper part of the food pyramid (Mbakaya *et al.*, 1994).

Table 1. Pesticides applied in vegetable production in Ghana

Pesticide (% of total number in use)	Active ingredient (a.i.)	Registered for use on	Chemical a.i. Hazard Category (WHO)
Herbicide (44%)	Pendimethalin	Tomatoes, onions	III
	2,4-D	Rice, sugarcane	II
	propanil	Rice	III
	MCPA-thioethyl	Not registered	III
	Oxadiazon	Not registered	III
	Oxyfluorfen	Not registered	III
	Bensulfuron-methyl	Rice	III
	Glyphosate	Various crops	III
	Paraquat dichloride	Various crops	II
	Acifluorfen	Not registered	III
	Metolachlor	Not registered	III
	Phenmedipham	Not registered	III
Fungicide (23%)	Mancozeb	Mangoes, vegetables	III
	Metalaxyl-M	Not registered	II
	Thiophanate-methyl	Various crops	III
	Carbendazim	Not registered	III
	Benomyl	Not registered	III
Insecticide (33%)	Lambda-cyhalothrin	Vegetables	II
	Chlorpyrifos	Citrus, Public Health	II
	Endosulan	Cotton	II
	Dimethoate	Not registered	II
	Cypermethrin	Not registered	II
	Deltamethrin	Various crops	II

Pesticides are readily available in agricultural retail stores, and those responsible for the retailing (pesticide dealers) have adopted the extensive practise of measuring out quantities of the pesticides from a larger container. Most of the farmers come from the poorer sections of the community and as pesticides are expensive for them, they can purchase relatively small quantities. Farmers also purchase the less expensive products, even if they are less suited to the pest requiring control. Information on pesticide application rates mainly come from Agricultural Extension Officers and/or pesticide labels. To a more limited extent, information also comes from other farmers, pesticide dealers or advertisements (Radio, TV, Newspaper). To measure pesticides, farmers used spoons, measuring cylinders, cans, and bottles. Others used 'the dose' (i.e. the amount contained in a packet, can or bottle for a given volume of water or for a given acreage). A wide range of dose-rates (both reduced and excessive) was applied on some crops. For instance, in applications on tomato and pepper, dose of lambda cyhalothrin (Karate 2.5 CE) was 4.13 g a.i. ha^{-1} while for chlorpyrifos (Dursban 4E) it varied from 20 to 40 g a.i. ha^{-1}. The recommended dose for lambda cyhalothrin (in Karate 2.5 CE) is 12.5 g a.i. ha^{-1}. For chlorpyrifos (in Dursban 4E), the recommended dose is 24 g a.i. ha^{-1}. Although it is undeniable that vegetable crops need large quantities of pesticides for control of their pests and diseases, it remains doubtful whether all the sprays are really necessary. A high level of pesticide use is unnecessary as well as harmful. Integrated Pest Management and organic agricultural strategies produce comparable yields, but adoption of these approaches remains so far low for a variety of reasons (Danso *et al*., 2002).

Chemical pesticides were usually sprayed in combination and the efficacy of one may mask the inefficacy of others in the mixture. This practice of the use of indiscriminate combinations of pesticides, particularly of insecticides, may have contributed to the increase in the incidences of insect pest infestation of tomato in Ghana (Biney 2001). Metcalf (1980) in his recommendation of strategies for pesticide management states that the use of mixtures of insecticides must be avoided since mixtures of insecticides, generally, results in the simultaneous development of resistance.

The number of spray applications per crop season, however, varied widely for crops, location, and among the farmers interviewed in the survey. For instance, in a tomato growing season of about 90 days at Akumadan in the Ashanti Region, farmers sprayed an average of six to twelve times with three to six kinds of pesticides on a calendar basis. The usual spraying interval was seven days. The spraying regime of the farmers also varied between the climatic seasons; farmers utilise more sprays during the wet season. During the wet season, pests and diseases proliferate. Besides, increased wash-off with rainfall call for more applications of pesticides.

The investigations showed that farmers' opinion on the direction of spraying varied. While some farmers considered the wind direction during spraying and, therefore, sprayed with the wind direction, others did not. The latter category of farmers sprayed along rows, back and forth, even against the wind or perpendicular to wind direction. Where this occurs, the wind may blow the chemicals into the body, including face, of the farmer. This faulty spraying practice presents great potential for exposure of the farmers to the chemicals from both skin contact and inhalation.

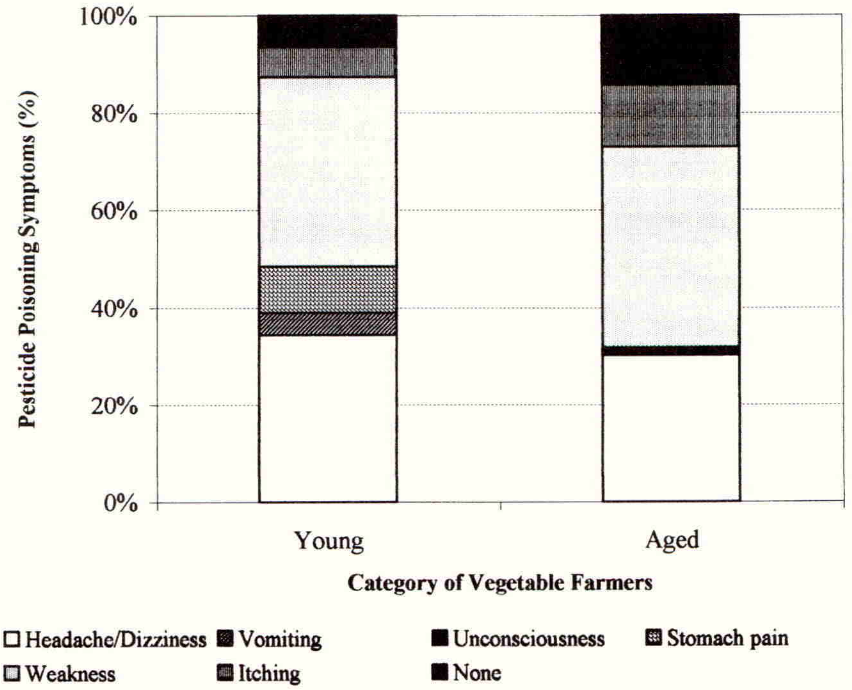
Farmers used very little personal protection during spraying. Some farmers (25.9%), especially those within cooperatives did use some protective clothing. This included rubber boots, coveralls with long sleeves, gloves, and a piece of cloth to cover the mouth. The majority wore trousers and a long-sleeved shirt. However, some wore short-sleeved shirts and short pants, and no gloves, and barefooted farmers (they wore slippers which exposed a greater part of their feet) even used their bare hands to mix pesticides in a container. As a consequence, their legs and feet, hands come into contact with pesticides. About 80% of the farmers have been made ill from pesticide exposure. The frequent symptoms are reported as weakness, headache and/or dizziness.

With regard to pesticide application procedures, the knapsack was the most popular spraying equipment used on the farms. A few farmers used motorised sprayers. Lack of capital is the main reason why farmers endeavoured to use the knapsack sprayer. In some cases (3.6%) farmers used a brush, broom or leaves tied together to splash pesticides from a bucket. This could not be surprising since over 50% of the respondents in the survey did not own a sprayer. Where this practice occurs, users are clearly exposed to the pesticide, especially as very few can afford or have available protective clothing. During spraying also, farmers do not distinguish between target and non-target crops. Non-target susceptible crops are therefore exposed to the pesticide.

The commonest way of disposing of sprayer wash water (88.3% of farmers) and empty pesticide containers (80.2%) among the interviewed farmers was by throwing on the field in the farm. As one walks at the edges of the farms, one can easily see pesticide containers lying about (over 60% of farms). Where the farms are close to water ways (which is the case in many farming communities), the disposal of the unwanted pesticide solutions and empty containers presents a potential pollution problem for aquatic systems which are sources of livelihood for human communities, and support varied animal and plant life.

Possible poisoning symptoms were reported more among the young (24-43 years) than the aged (45-80 years) farmers. For instance, while about 6% of the young farmers said they have not had any symptoms of pesticide poisoning, about 14% of the aged group said they have not (Figure 1). The apparent association between age and possible poisoning cases is not reasonably attributable to chance ($\chi^2 = 13.5$; N = 127; d.f. = 6; $p < 0.05$).

Figure 1. Comparison of distribution of possible pesticide poisoning symptoms for the Young and the Aged



Results of the ranking game (Tables 2 & 3) show that farmers can differentiate pesticides in terms of effectiveness and hazard to human health.

Table 2. Farmers perceptions of efficacy levels of three common insecticides in Ghana

Chemical Name	*Efficacy Level*[a]					*Total Responses*	*Average Level*
	1	*2*	*3*	*4*	*5*		
Endosulfan	18	13	7	2	9	49	2.4
Lambda-cyhalothrin	35	11	3	1	2	52	1.5
Cypermethrin	42	5	0	1	6	54	1.6

a. Level 1 = 75-100 percent insect control; Level 2 = 50-75 percent insect control; Level 3 = below 50 percent insect control; Level 4 = not effective; Level 5 = causes more pest problems

Both scientists and farmers believe – when explicitly asked - that pesticides are hazardous. However, farmers' perception of relative hazard was not too different from that of the experts using WHO ranking, given that both use different (short-term/long-term) criteria. For instance, while farmers classify endosulfan, lambda cyhalothrin and cypermethrin as extremely hazardous (Table 3), WHO classifies all of them as moderately hazardous. Inhalation and irritation were perceived as the main indicators of a pesticide's hazard level. Farmers would therefore be expected to be more concerned with avoiding pesticide inhalation or skin exposure. Unfortunately, less than 30% of the respondents wore full protective covering, which shows the difference between passive and active (decision-making) knowledge.

Table 3. Farmers perceptions of hazard levels of three common insecticides in Ghana

Chemical Name	*Hazard Level[b]*					*Total*	*Average*
	1	*2*	*3*	*4*	*5*	*Responses*	*Level*
Endosulfan	63	7	1	1	3	75	1.3
Lambda-cyhalothrin	45	4	1	0	0	50	1.1
Cypermethrin	27	1	0	1	2	31	1.4

b. Level 1 = extremely hazardous; Level 2 = moderately hazardous; Level 3 = slightly hazardous; Level 4 = least hazardous; Level 5 = no effects

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Development of a tomato variety Rajitha having bacterial wilt resistance, high yield potential and good fruit quality characters

R Peiris, T K Wickremesinghe
Horticultural Crop Research and Development Institute, Sri Lanka
Email: rrpeiris@sltnet.lk

ABSTRACT

Bacterial wilt caused by *Ralstonia solanacearum* is one of the major production constraints for successful and extensive cultivation of tomato in the tropics. The objective of this study was to develop a genotype with bacterial wilt resistance, high yield potential and good fruit quality attributes. Several crosses were performed using desirable donors and promising progenies were selected from the cross between T-245 and Caribe. A bulk method of selection was adopted. In the F_6 generation a line 1-16-38 was identified and tested for its yielding ability in preliminary yield trials during the dry and wet seasons. During both seasons line 1-16-38 gave significantly higher yields (>25 t/ha) than the standard check variety T-245. Bacterial wilt screening in the field and laboratory demonstrated that 1-16-38 was moderately resistant. The National Coordinated Varietial Trials conformed that it was a promising line under different agro-ecological zones in both dry and wet seasons. 0n-farm trials indicated the farmer acceptability was higher for this line than the check variety. Fruit quality characters such as a fruit size of 82g/fruit, thick pericarp and good keeping quality satisfied the farmers and acceptance was very high. Line 1-16-38 was officially released as variety Rajitha by the Department of Agriculture in 2001.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most popular vegetables widely cultivated in Sri Lanka. Bacterial Wilt (*Ralstonia solanacearum*) is the most devastating soil borne disease, causing yield losses to the extent of 100 % in major tomato growing regions of the country (Peiris, 2000). The effective method to manage this disease is the adoption of bacterial wilt resistant varieties/hybrids. Therefore, a breeding programme was aimed to identify genotypes having high yield potential, bacterial wilt resistance and acceptable fruit quality characters.

MATERIALS AND METHODS

The study was carried out from 1992-2000 at Horticultural Crop Research and Development Institute (HORDI), Gannoruwa, Peradeniya, Sri Lanka. Several crosses were performed using desirable donor parents. A modified bulk method was used in the selection process (Allarld, 1960 ; Sharma, 1994). Seven promising lines were identified in the F_6 generation, based on plant type, yield, reaction to bacterial wilt disease and fruit quality characters. During Maha (wet season) and Yala (dry season) the promising lines were field tested at Gannoruwa. The experiment was a randomized complete block design (RCBD) with three replications. The plot size was 2.4m x 3.5m and the spacing was 80cm between rows and 50cm between plants. The 14-day-old seedlings were transplanted in the field at one seedling per hill. The recommended fertilizer levels of 90 kg N/ha, 150 kg P_2O_3/ha and 80 kg K_2O/ha were applied at the appropriate time. Staking was done at 21days after transplanting. Weeding and irrigation were done as and when necessary Bacterial wilt (BW) screening was conducted in the field and laboratory. From previous studies ST_6 isolate of *Ralstonia solanacearum* was selected as the most virulent one and it was used in this study. The cultures were prepared in Sucrose Peptone Agar (SPA) slant media and transferred to sterilized cool distilled water under aseptic condition. Distilled water with the pathogen acts as an inoculum. Ten ml of inoculum were injected to 10 holes on the stem starting from 1cm above the soil. Plants were inoculated at the five-leaf stage and again one to two weeks later. One day before inoculation date watering was stopped to induce moisture stress in the test plants. After inoculation soil moisture and temperature were maintained at a high level, conducive pathogen development. Appearance of wilt symptoms and death of inoculated plants were observed daily. Disease was recorded at three days intervals, from day after inoculation, based on the following scale;

0	-	No symptom
1	-	One leaf wilt
2	-	Two or three leaves wilted
3	-	All leaves wilted except top two or three
4	-	All leaves wilted
5	-	Plant death

The % diseased plants were then calculated.

Type of plant reaction was based on disease percentage, as follows:

Highly resistance (0)	-	0%
Resistance (1)	-	1%-25%
Moderately resistance (2)	-	26%-50%
Moderately susceptible (3)	-	51%-75%
Susceptible (4)	-	76%-99%
Highly susceptible (5)	-	100%

A fruit quality analysis was also carried out based on the reaction to BW, yield, and fruit quality characters. The line 1-16-38 was included in National Co-ordinated Varietial Trials (NCVT) and these trials were carried out in different agro-ecological zones. The standard evaluation procedure was carried in NCVT. Finally line 1- 16 -38 was tested in farmer fields during wet season of 1999/2000 (5 sites) and 2000/01 (6 sites) and, in the dry season of 2000 (8 sites). Trials were located in a range of climatic zones representative of tomato production in the country. The Seed Division of the Department of Agriculture collected data on distinctness, uniformity and stability (DUS) of line 1 – 16 – 38.

RESULT AND DISCUSSION

Hybridization and selection

Several crosses were performed and modified bulk method was applied to select the best lines in the F_6 generation. In the F_6 generation best lines were selected on the basis of fruit quality, reaction to BW disease and yield (Table 1).

Table 1. Selected promising lines in F_6 generation

Variety/line	Pedigree
5 –14 –60	Punjab Chhuhara/ KWR // T 245
1 – 16 – 38	T 245/ Caribe
23 – 11 – 6	C – 32 – 01 – 2 – 0/ CLN 915 – 93 - 1 – 04 // T 244 / Bianz
44 – 4 – 2	T 244 / Bianz // C – 32 – 01 – 2 – 0/ CLN 915 – 93 - 1 – 04
66 – 2 – 1	T 244 / Roma
1 – 16 – 34	BL 355 / Suprema
HT – 01	Solarset / KWR

Fruit quality characters

Fruit quality characters of the most promising line 1-16-38 as compared with the check variety
T 245 which is widely grown as a commercial variety are presented in Table 2

Table 2. Fruit quality characters of 1-16-38 and T 245

Character	Variety	
	1-16-38	T 245
Average fruit weight (g)	82.4	71.8
Fruit colour	orange	orange
Fruit circumference (cm)	18.5	14.3
Fruit height (cm)	8.9	8.2
Thickness (cm)	0.4	0.4
Fruit shape	slightly flattened	slightly flattened
Firmness	medium	medium
No. of locules	4	3 - 6
pH	3.7	3.8
Acidity % as citric acid	0.94	0.80
Brix	3.9	5.0
Cracking	very mild	mild
Keeping quality	very good	good

Line 1-16-38 had medium size fruits, good keeping quality and less damage in long distance transportation. Therefore consumers prefer to purchase fruits of 1-16-38 than the check variety T 245. The farmers are paid a higher price for 1-16-38 than the check variety T 245.

Marketable fruit yield

During dry and wet seasons the line 1-16-38 gave higher yields than the check variety (P=0.05). However, during the wet season no significant difference was observed (Table 3). This is due to low disease pressure in the tested location.

Table 3. Yield performance of 1-16-38 as compared with the check variety, T 245 in an on-station trial at Gannoruwa

Line/variety	Marketable fruit yield t/ha	
	Dry season	Wet season
1-16-38	23.5	39.8
T 245 (check)	20.7	37.8
SED (18 d.f.)	1.04	1.23

In NCVT trials conducted more than one season in different agro-ecological zones clearly revealed that 1-16-38 is having high yield potential than the check variety T 245 (Table 4). DUS test indicated that 1-16-38 can be distinguished from T 245 and is sufficiently uniform and stable in morphological characteristics.

Table 4. Yield t/ha of tomato lines 1-16-38 and T 245 in National Co-ordinated Variety Trials

Variety/line	Agro-ecological zone			
	Wet zone	Intermediate zone		Dry zone
	Mid-country (a)	Low country (b)	Up country (c)	Low-country (d)*
16-1-38	26.4	22.9	21.5	4.6
T245 (check)	21.4	18.1	20.2	3.6

a – Gannoruwa — Average of 06 seasons
b – Makandura — Average of 04 seasons
c - Bandarawela — Average of 04 seasons
d – Mahailluppalama, Giradurukotte — Average of 03 seasons
* low yields reported due to high temperature

Reaction to BW disease

The reaction to BW disease in the laboratory and field screening studies demonstrated that line 1-16-38 is resistant to bacterial wilt disease (Table 5).

Table 5. Susceptibility of selected tomato lines to bacterial wilt in laboratory (reaction 1) and field (reaction 2) in Sri Lanka.

Variety/line	Reaction 1	Reaction 2
1-16-38	Moderate resistance (score 2)	Resistant (15%)
T 245	Moderate Susceptibility (score 3)	Susceptible (77%)
Marglobe[1]	Susceptible (score 4)	Susceptible (98%)
KWR[2]	High resistance (score 0)	High resistance (0%)

[1] susceptible check [2] Resistant check

The variation in yield data in different agro-ecological zones is due to the disease pressure in the tested locations. However, the mean yield except during the wet season of 1999/2000, in all the other seasons the line 1-16-38 gave higher yield than T 245.

Table 6. Yield performance of 1-16-38 in variety adaptability trials t/a.

Season	Location		Agro-ecological zone	T 245	1-16-38
Maha 1999/2000	**Kandy**	Godamune	Mid country wet 3	9.3	8.0
(Wet season)		Kundasale	Mid country intermediate 3	15.9	13.2
		Imbuldeniya	Mid country wet 2	12.8	18.0
	Kegalle	Beminiwatte	Mid country wet 3	12.1	11.3
		Rambukkana	Mid country wet 3	8.0	3.5
Variety Mean				11.6	10.8
Variety Deviation Mean				4.3	5.1
Variety Deviation Variance				42.0	13.3
Yala 2000	**Kandy**	Wewela	Mid country wet	27.5	37.8
(Dry season)		Marassana	Mid country intermediate	23.3	22.1
	Matale	Walawela	Mid country intermediate	9.4	8.4
		Weeragama	Mid country intermediate	8.4	6.3
	Kegalle	Beminiwatte	Mid country wet	12.3	14.5
		Rambukkana	Mid country wet	12.5	9.8
	Nuwera Eliya	Mungwatte	Upcountry intermediate	7.3	6.8
		Karalliyadda	Mid country intermediate	9.5	7.3
Variety Mean				13.8	14.1
Variety Deviation Mean				2.1	2.6
Variety Deviation Variance				5.9	2.6
Maha 2000/01	**Kandy**	Godamune	Mid country wet 3	12.8	12.5
(Wet season)		Kundasale	Mid country intermediate 3	8.3	7.4
		Imbuldeniya	Mid country wet 2	22.9	26.1
	Kegalle	Pinnawela	Mid country wet 3	11.0	13.1
		Beminiwatte	Mid country wet 3	6.4	6.9
		Rambukkana	Mid country wet 3	13.2	13.7
Variety mean				12.4	13.3
Variety Deviation mean				1.4	0.5
Variety Deviation Variance				1.2	0.4

Marketable fruit yield from on-farm trials revealed that the line 1-16-38 had low deviation variance values than the check variety T 245 indicating its superior adaptability and stability (Table 6).

The results of this long-term study clearly indicated that 1-16-38 is a promising elite line having moderate resistance to BW, high yield potential (>25t/ha) and acceptable fruit quality characters such as medium fruit size (82g), firm long shelf life and thick pericarp. Subsequently the line was officially released as variety Rajitha by the Department of Agriculture.

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