Session 8B

Environmental Audits and their Value in Developing Viable Crop Protection Programmes

Chairman	Dr A R HARDY
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Papers	8B-1 to 8B-3

AGRICULTURAL ENVIRONMENTAL AUDITS IN THE UNITED STATES

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ABSTRACT

Efforts to reduce pesticide contamination of ground and surface water in the U.S. have included: assessments of practices and conditions near wells and well construction factors to prevent point sources of contamination; pesticide management plans for individual farms; state pesticide management plans which identify vulnerable areas and place restrictions on the use of specific pesticides; and educational efforts in localized areas such as the drainage basins of drinking water reservoirs. Currently farms with highly erodible land must implement government-approved conservation plans in order to participate in government farm programs. Pesticide and nutrient management plans may be required in the future. Some farmers already employ consultants to voluntarily develop and implement such plans. Several models have been developed to predict pesticide leaching and runoff risk, and to rank relative leaching and runoff risk based on pesticide and soil properties.

INTRODUCTION

Detections of pesticides in wells and surface water in the U.S. have raised public concerns about potential health effects of contaminants, causing pressure for changes in agricultural practices. Mandatory federal health-based drinking water standards are also being adopted for some pesticides under provisions of the Safe Drinking Water Act. Exceedances of these standards have further demonstrated the need for positive agricultural responses.

This paper will summarize some of the current efforts in the U.S. to conduct audits or assessments of the sources of ground and surface water contamination by pesticides and the vulnerability of specific sites, and efforts to develop Best Management Practices (BMPs) which minimize water contamination.

IDENTIFYING SOURCES OF CONTAMINATION

Preventing water contamination by pesticides requires an understanding of how pesticides reach ground and surface water. Recent monitoring studies and basic research have helped to determine the routes and mechanisms of water contamination and to support the development of effective BMPs. Following the detection of certain pesticides in wells across the U.S. in the

1970s, nonpoint sources were often cited as suspected causes of the contamination. While certain persistent and mobile pesticides have sometimes leached from treated fields to reach wells in detectable concentrations, detections of pesticides in wells have often been traced to point sources near wells. Accumulation of high concentrations of pesticide in the soil at commercial and farm mixing and disposal sites has sometimes led to contamination of nearby wells (Fawcett, 1989). Farm wells are often not properly constructed, allowing entrance of surface runoff or very shallow ground water (Fawcett, 1990).

In a survey of all public water supplies in Iowa, 80% of pesticide detections other than atrazine were in wells with a commercial pesticide mixing-loading site within 300 m of the well (Fawcett, 1989). An Illinois Environmental Protection Agency study monitored over 450 public wells for pesticides and found detects in only three (Clarke & Sinnott, 1987). All three wells were located near commercial pesticide mixing-loading sites. A follow-up study monitored 56 wells selected based on their location near pesticide facilities. Forty-three of these wells had pesticide detects (Long, 1987). These studies led the Illinois Environmental Protection Agency to conclude: "There is no indication from the sampling carried out to date that the field application of pesticides is affecting Illinois' community well systems."

Several models, including DRASTIC, have been developed to predict ground water vulnerability based on soil and geologic characteristics. The National Survey of Pesticides in Drinking Water Wells monitored for 126 pesticides and metabolites in 1300 urban and rural wells. Detections occurred in 10% of urban wells and 4% of rural wells (U.S. Environmental Protection Agency, 1990). In Phase II of the same study, attempts were made to correlate detections with factors such as pesticide use and ground water vulnerability as predicted by DRASTIC (U.S. Environmental Protection Agency, 1992). Very few expected correlations were found. DRASTIC scores were not effective in predicting pesticide detects. These results do not necessarily mean that detectable concentrations of certain pesticides do not leach from treated fields, but that what goes on nearer the well and well construction factors often overwhelm any potential ground water contamination from nonpoint sources. Improvements in practices must begin at and near the well to solve well contamination problems. Once these changes are made, it should be possible to document further improvements in well water quality due to changes in pesticide use practices on fields.

Unlike well contamination, contamination of surface water by pesticides appears to be due largely to nonpoint sources. As soil erodes and water runs off treated fields, pesticides can be carried to surface water. Vulnerability can be predicted based on soil properties, topography, hydrology, and pesticide properties. As with ground water, models have been developed to predict pesticide runoff.

ENVIRONMENTAL AUDIT PROGRAMS

As the importance of point sources in causing well contamination has been recognized, educational efforts have been initiated to address this problem. Following the lead of Iowa, most states now require watertight containment systems at commercial pesticide storage and handling sites (Fawcett, 1989). Farmers are encouraged to mix pesticides and rinse sprayers in the field rather than at the farm well as was often done in the past.

The University of Wisconsin has developed the Farmstead Assessment Program to aid farmers in identifying well contamination risks and in developing voluntary action plans to reduce identified high risks (Jones & Jackson, 1990). A series of worksheets directs farmers to assess practices and structures which have well pollution potential, such as well construction conditions, pesticide storage and handling, fertilizer storage and handling, petroleum product storage, livestock waste management, and silage storage. This evaluation allows the ranking of well risks and planning for changes in management. This program is now being used in several states.

Several systems have also been developed to assist in assessing the vulnerability of specific fields to leaching of pesticides. Predicted leaching of pesticides based on physical properties is then combined with site information to aid in the selection of appropriate pesticide treatments.

The Florida Cooperative Extension Service has developed a pesticide selection decision aid which includes parameters of a relative leaching potential index, a relative runoff potential index, the U.S. Environmental Protection Agency lifetime health advisory level (HAL - a voluntary health-based drinking water standard), and aquatic toxicity (Hornsby, 1992). Soils are also rated for leaching risk. Pesticide selection is accomplished by matching pesticide parameters values for the array of pesticides that control the pest of interest to soil ratings at the application site using selection criteria. Linking of an environmental fate model to a geographic information system has been used to create thematic maps of pesticide leaching potentials in terms of probability of exceeding the HAL in ground water.

The U.S. Soil Conservation Service has developed a screening procedure to evaluate relative loss of pesticides from soils and to assist in implementing water quality for conservation planning (Goss, 1992). The procedure was developed by using the GLEAMS model to evaluate pesticide losses. The model input data were a combination of soils and pesticides with a wide range of properties. Algorithms using pesticide properties were developed to rate pesticides into four loss potential classes for leaching and three loss potential classes for runoff. Algorithms using soil properties were developed to rate soils into four loss potential classes for leaching and three loss potential classes for both runoff losses on sediment and runoff losses in the solution phase. The soil and pesticide groupings are combined in a matrix to give an overall loss potential rating. An extensive database of pesticide and soil properties has been compiled (Wauchope et al., 1992). This system is currently being used by the Soil Conservation Service and by several state extension services.

IMPLEMENTATION AND ACCEPTANCE OF AUDITS

Many voluntary, educational efforts to reduce ground and surface water contamination are currently active in the U.S. Farmers recognize that if the public's concerns about water quality are not addressed and levels of contamination reduced, strict regulations may be enacted, and products may be banned. Exceedance of newly adopted drinking water standards may force drinking water utilities to install costly treatment facilities and will spur action to ban products.

Risk of exceeding drinking water standards is far greater for surface water sources than for ground water. When all Iowa public water supplies were monitored for pesticides in 1987, ½% of well systems exceeded a HAL. All of these cases were caused by point sources of contamination. However, 4% of surface water systems exceeded a HAL (Fawcett, 1991). River water can exceed HAL standards for short periods of time following runoff events. However, usually when annual averages are determined (as mandated by the Safe Drinking Water Act), concentrations are below standards. This is not always the case for surface water reservoirs, as growing season runoff is stored in the reservoir, and certain pesticides may be detected throughout the year. For this reason, intensive educational efforts are underway in the drainage basins of some vulnerable reservoirs.

Southern Iowa relies heavily on surface water reservoirs for drinking water supplies. In response to public concerns over herbicide detects, a coalition of industry, public agencies, and environmental organizations was formed to seek voluntary responses on the part of farmers to adopt BMPs. The Southern Iowa Herbicide Education Program has conducted numerous meetings and distributed educational materials, with major involvement of pesticide dealers. Farmers sign pledge cards, promising to add a new BMP to their farming operations each year.

West Lake, at Osceola, Iowa, is used as the source of drinking water for about 4,000 people. The 138 ha lake has a drainage basin of 2567 ha, most of which is planted to maize and soybeans. In 1991, after frequent runoff events in the early growing season, atrazine and cyanazine exceeded HALs for a period of about one year. Due to these exceedances, an intensive voluntary effort was begun in the watershed to change agricultural practices to reduce herbicide runoff. As sedimentation of the reservoir was a major concern, priority was also placed on reducing erosion. Cost-sharing funds were made available to encourage installation of terraces and grassed waterways, and to practice contouring and non-tillage. Private crop consultants were also provided to evaluate fields, determine pest populations, and recommend appropriate pesticide treatments, resulting in some changes in pesticide use patterns.

From 1991 to 1992, atrazine use declined by 56%, and cyanazine use declined by 11%. Concentrations of both atrazine and cyanazine in the reservoir declined by over 90% from 1991 to 1992, and remained low and below drinking water standards through May, 1993. While changes in weather may account for some of this decline, it is likely that adoption of BMPs in the drainage basin is responsible for much of the improvement in water quality. Many of the soil conservation BMPs adopted have been shown to also reduce pesticide runoff. A summary of published data from pesticide runoff studies under natural rainfall conditions showed that, on average, non-tillage reduced pesticide runoff by 70%, compared to the mouldboard plough (Fawcett et al., In Press). Grassed waterways and filter strips have reduced pesticide runoff by 50 to 90% (Fawcett et al., 1992).

REGULATORY ACTIONS

Several regulatory actions have also been undertaken which entail assessments of vulnerability of sites for leaching or runoff. The U.S. Environmental Protection Agency has adopted a strategy of requiring states to implement pesticide-specific management plans in order to maintain registration of products considered to threaten ground or surface water. Atrazine management plans have been implemented in Iowa, Wisconsin, Minnesota, and Kansas. In Iowa, areas more vulnerable to ground water contamination due to karst geology or presence of agricultural drainage wells were mapped, and rates restricted in such areas. In Wisconsin, atrazine rates have been restricted, and use has been banned in some areas based on well water monitoring data. Restrictions on atrazine in Kansas are due to detections in surface water reservoirs in one region of the state where rates have now been reduced and the use of BMPs introduced.

Label changes have also taken place at the federal level. The atrazine label now requires untreated buffer areas where surface runoff enters streams, lakes, or reservoirs, and around wells and sinkholes. Higher rates are allowed where surface crop residue coverage of 30% or more is present to reduce runoff. The new wheat herbicide, triasulfuron, has been introduced using state-specific management plans which map areas with potentially vulnerable ground water.

Currently, farmers who farm highly erodible land must have a government-approved conservation plan in effect in order to receive any government farm program benefits. These Soil Conservation Service-produced plans mandate various soil conservation measures for each field affected, and are designed to reduce soil erosion to sustainable levels. Using the previously discussed matrix system, the Soil Conservation Service is now also developing pesticide management plans for individual farms. Compliance with these plans is required to qualify for certain cost-sharing programs, but is not necessary for most farm program benefits. It is possible that, in the future, compliance with pesticide and nutrient management plans could be required for participation in all farm programs, as soil conservation compliance is now required. This possibility has been discussed in conjunction with approaching reauthorization of the Clean Water Act.

SUMMARY

The detection of pesticides, especially certain herbicides, in ground and surface water in the U.S. has led to voluntary and regulatory efforts to assess site vulnerability and change management practices or products used to protect water quality. As many cases of well contamination have resulted from point sources and substandard well construction, audits must begin at the well. Once point sources of contamination such as pesticide storage, mixing, and disposal sites are corrected and well construction improved, further improvements in well water quality are possible through changes in pesticide use practices on fields. Contamination of surface water is largely a nonpoint-source problem. BMPs are available to reduce pesticide runoff. Several decision aids are now available to help farmers assess the leaching or runoff risks of sites and to select pesticides with the least water contamination risk.

Regulatory changes have also been made. Some pesticide labels have been revised to require specific water protection BMPs. Pesticide-specific state management plans identify vulnerable areas and either require use of BMPs or prohibit use of the pesticide, government-approved conservation plans are already required in order for farmers to receive farm program benefits. Pesticide and nutrient management plans may be required in the future.

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A SELF ASSESSMENT APPROACH TO ENVIRONMENTAL AUDITS AND THEIR USE AS A MANAGEMENT TOOL

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ABSTRACT

Environmental concern lies at the forefront of the western world's agenda. Now that we have the luxury of quantity and quality in the supermarkets, the general public demand full knowledge of how the food they eat is produced and quite rightly so. There are many environmental issues to be addressed on a farm scale, however, their measurement is complex due to the effects of both on-farm impact and of the surrounding areas and off-farm impact.

Environmental audits have a relatively new role to play as an integral part of an organisations management policy. It was in encouraging 'good farm practices' under Integrated Crop Management (ICM) principles that LEAF (Linking Environment And Farming) set out Guidelines for LEAF farms and the LEAF audit.

The audit is for use as a management tool and addresses two areas. It is a statement of current farm practices to record and evaluate the criteria on which decisions about the farm's systems and policies are based and secondly it operates as an assurance for the customer that there is a total commitment towards responsible farming practices.

INTRODUCTION

Concern for the environment has been with us for many generations. One of the first environmental acts was in 1388, the Act for Punishing Nuisances which Cause Corruption of the Air near Cities and Great Towns. The wording of the Act, though couched in the convoluted statutory phraseology of the period, makes its purpose clear: '...... all they which have cast and laid such annoyances, dung, garbage, entrails, and other ordure in ditches, rivers, waters and other places aforesaid, shall cause them utterly to be removed, avoided and carried away betwixt this and the feast of Saint Michael next ensuing after the end of this present Parliament, every one upon pain to lose and to forfeit to our Lord the King twenty pounds.'

The Environmental Protection Act (1990) addresses similar areas, basically the polluter pays. As an agricultural industry we have been faced with a lot of criticism for environmental degradation and there is much data to confirm these effects.

Figures from the RSPB show how the grey partridge has suffered a startling decline as intensive cereal cropping and pesticide use has reduced its food supply. The barn owl has declined by half since the 1930's because prey rich grasslands have been converted to arable (RSPB, 1992). The World Wide Fund for Nature calls for a reduction in pesticide use of 50% over 5 years (WWF, 1992). We cannot hide from the problems that have been a direct result of intensive practices, but likewise we must also clarify and enhance what is currently being done, and what has been carried out for many years, by farmers interested in making a positive contribution to the environment.

The Government's white paper This Common Inheritance (HMSO, 1992) makes it clear that environmental protection involves contributions from everyone and the use of audits and monitoring is a proactive way to take account of what is being done and how to act upon the results to improve practices.

The Oxford Dictionary definition of an audit is 'an official systematic examination of accounts'. This has been expanded from the financial world to embrace environmental science.

An Environmental Audit or assessment is the systematic examination of how any business operation affects the environment. It includes all emissions to air, land and water, legal constraints, the effect on neighbouring community, landscape and ecology and considers products as well as processes.

The International Chamber of Commerce sets out a good, all embracing definition, which has been fairly widely accepted amongst auditors and industry (Croners, 1993). It defines environmental audits as a management tool comprising a systematic, documented, periodic and objective evaluation of how well environmental organisations, management and equipment are performing with the aim of helping to safeguard the environment by:

i) facilitating management control of environment practices;

ii) assessing compliance with company policies, which would include meeting regulatory requirements.

With the onset of British Standard BS5750, larger industry was able to adopt the Total Quality Management approach, though few farmers could afford the expense which promised little financial gain. Now with the onset of the BSI Environmental Management Systems Standard BS7750 there is seen to be more scope. This standard seeks to direct organisations in continually improving their environmental performance (BSI, 1992). It is to be fully operational by the end of the year, and it will be interesting to see if industry will take it up or follow the standards independently. It contains a specification for an environmental management system for ensuring and demonstrating compliance with stated environmental policies and objectives. It also provides guidance on the specification and its implementation within the overall management system of an organisation.

The EC Eco-management and audit scheme regulation, the European standard was adopted in June 1993 as a voluntary regulation (DOE, DTI, 1993). This is a particularly encouraging development as it is a community wide initiative and sets out a common standard throughout Europe. The Scheme aims to encourage companies to undertake positive environmental management, including regular audits, and to report to the public on their environmental performance. BS7750 is not designed as a substitute for the EC System but is intended to complement the Scheme.

We must bear in mind that it is our interpretation of these standards that will have most relevance and use. There is a danger of more legislation being imposed on farmers with respect to use of chemicals and there is pressure on the industry as a whole to minimise off-farm input use (for example pesticides, fertilisers and energy). Setting targets can be misleading and a reductionist approach may not always be appropriate, for example, setting percentage reduction targets depends on the initial level being used. Additionally, it is always easier to assess the environmental impact within an enclosed environment, but this is not the case on the farm. It was with these points in mind that the LEAF audit was developed.

The LEAF audit is a systems approach and covers the whole farm practice. This includes landscape features, wildlife and habitats, management of the soil, crop protection, conservation of energy and organisation and planning. It is a farmer self-assessment, carried out on an annual basis to respond to changes and aim towards continual overall improvement on the farm, both in terms of the environment and the farm's economic viability.

In order to monitor the audit scheme and ensure uniformity of standards, it is envisaged that LEAF will carry out an external audit on a random basis. This audit will be described in more detail later in the paper.

WHO IS DOING WHAT?

In 1991/92 The Body Shop International plc set out its Environmental statement (The Body Shop, 1992) which was its first comprehensive report of the companies environmental performance. The Body Shop is renowned for its environmental concern both at a local level and also globally. The Statement is a list of their recent environmental achievements, and sets out the policies on which their future procedures, targets and challenges will be based, with the ultimate aim to constantly improve performance (The Body Shop, 1993). Their priorities are waste management, energy efficiency and purchasing and packaging. It is a statement not only to take stock of current practice but also to point out short comings. They identify specific targets that are achievable and illustrate commitment to sustainability, to their customers, staff and shareholders. They also collect data on a monthly basis in order to monitor the information regularly.

Many of the County Councils have also adopted the audit approach. Lancashire County Council sets out environmental concerns as one of its top priorities and the audit marks a major step forward in the drive to clean up its local environment (Lancashire County Council, 1993).

An estimated 60% of UK industrial companies now claim to have an environmental management policy, which may or may not incorporate the carrying out of audits (Ambit 1992).

Ask yourself how many of the organisations you know have an environmental statement or policy. On a random telephone call around a number of organisations, it was interesting to hear what is being done. It is evident that the whole idea of an environmental policy is relatively new, it is only since 1990 that many organisations have taken up the environment as a real issue, it is the manufacturing industries that are obviously, most concerned.

Many of the petroleum and chemical companies have well established environmental policies, but for those introducing the concept into their policy the following is being adopted. Firstly, an environmental statement is drawn up and published as a public document, this is then circulated around the company for regional offices to act upon, in some cases targets are set, but in the immediate term,the aim is to encourage continuous improvement and increase awareness and knowledge of what can be done. It is a good stepping stone. In all areas we have a lot to do to make progress and although many of the organisations I contacted did have an environmental statement, seldom was the companies' commitment communicated beyond the head office. I must also add that with some organisations I was treated with the greatest of suspicion!

WHY CARRY OUT AN ENVIRONMENTAL AUDIT?

BSI and Eco-audit were developed in response to increasing concerns about environmental protection and environmental performance. So what has prompted many other organisations to carry out their own environmental policy? The reasons are economics, ethics and genuine environmental concern, public pressure, and for a marketing edge. It may be worth mentioning that economics are the prime motivating factor for the majority of organisations that I contacted. Improving performance through an audit has a number of knock on benefits. It can keep the company ahead of relevant legislation and ensure that it does not face prosecution. It can also uncover areas where costs can be reduced (Ambit 1992).

The LEAF Demonstration Farms have set out their farm policy as a written statement, some LEAF farmers are questioning the environmental efficacy of the people that they trade with. This supports the principle that if they are farming well they should ensure that quality is maintained up and down the line and therefore should expect to receive the same standard from those they deal with.

In the past, agricultural auditing has been confined to taking stock of specific populations, both of plant life and also wildlife.

Much of this work has been very definitive. Indeed, the ongoing work that the Game Conservancy Trust has carried out on one of the LEAF demonstration farms in West Sussex has shown the system where leys are established by the undersowing of a spring cereal, which still continues at Applesham, seems to have helped prevent any decline in the grey partridge (Potts G. R., 1986). Dr Potts attributes this to the encouragement of insects such as sawflies which are preferred food of the partridge chicks.

This work is extremely valuable but the financial cost to farmers to carry out such ongoing work for themselves can be prohibitively high. Furthermore, from the research data we can receive from such information we often have a clear indication as to what is good practice on a particular site and what practices should be best avoided. Pesticide applications for pests, diseases and weeds should not be taken in isolation from rotations, crop nutrition, cultivations and soil management. A whole farm approach is essential.

WHAT CAN A FARMER GET OUT OF AN ENVIRONMENTAL AUDIT?

Currently there are no promises for environmental payments. Government support is just in the form of direct payments for specific management practices, for example, the management of nitrogen sensitive areas (NSA), environmentally sensitive areas (ESA) and non-rotational set aside. Much of these give little scope for direct support to farmers who do not farm in these areas and perhaps have been carrying out sympathetic practices over a number of years. There is already some discussion between farmers and their direct customers about sound production methods and environmental standards, but what is evident is that in the long run, farmers will be expected to carry out or fund the work themselves. A further possibility, is, that if certain baseline standards are not met, the farmer may have difficulty in selling produce at full price. The customer is increasingly demanding more proof of concern and action towards positive environmental care (NFU, 1991) (Millar, F.A., Tranter, R.B., 1988).

THE LEAF APPROACH

In the LEAF guidelines we set out our statement as the following: 'LEAF is committed to the concept of a viable agriculture which is environmentally and socially acceptable and ensures the continuity of supply of wholesome, affordable food while conserving and enhancing the fabric and wildlife of the British countryside for future generations (LEAF, 1992).'

The LEAF audit assesses the management approach to farming and questions how operations are carried out. Designed not to be prescriptive, it addresses the whole farm and all practices that could have an effect on performance. One area it emphasises is that financial viability is of utmost importance. LEAF acknowledges that in order to carry out any environmental improvements a firm financial base is essential. The audit points out that there are substantial benefits to be had from the establishment of field margins, good maintenance of hedgerow and woodlands etc, but there is also much that can be done in the field. This is based on the fundamentals of good soil management.

Following from this the LEAF audit sets out 7 principal areas.

These are:
- landscape features;
- wildlife and habitats;
- management of the soil;
- crop protection;
- conservation of energy;
- pollution control;
- organisation and planning.

Of these the first two - Landscape Features and Wildlife/Habitats - are presented in the form of a farm map, which will need to be prepared separately eg. by FWAG or ADAS, incorporating a short and long term conservation work programme.

The other five sections are covered in the form of self-assessment sheets. It is not designed to be used to decide whether a practice is 'good' or 'bad'. Instead it provides an assessment of current farming position from year to year. It highlights areas where there is a balance in priorities and, in contrast, areas which need attention.

Like farming itself, this audit is a long term project, and the forms, carefully kept (and used) over a period of years, will provide a practical record of progress.

The aim of the audit is to:

1. Set out the environmental plan and statement;
2. Set out the whole farm management policy;
3. Follow the LEAF environmental audit;
4. Identify areas that need to be actioned on.

An external audit will be carried out on a random basis every 3-5 years or more regularly if required.

The audit is a series of questions that are designed to make the farmer think of his/her current approach to farming and to identify areas that could be a concern in the future or that have previously not been addressed on the farm. The objective is to carry out the audit on an annual basis so as to establish trends and help in the delegation of priorities.

Examples of such questions that relate specifically to weed control are as follows:

Do you use cultivations as a method of weed control?

Do you ensure that all cultivations are appropriately selected and matched to the most suitable tractor/vehicle for the job?

When making decisions to spray which of the following are considered ? (tick all relevant boxes)

in timing of applications consideration of:

[ ] maximum effect on weed, pest or disease
[ ] least damage to wildlife
[ ] regular crop walking
[ ] use of diagnostic kits
[ ] use of computer predictions
[ ] use of an adviser &/or research station
[ ] avoidance of prophylactic/insurance treatments
[ ] use of meteorological information
[ ] regular record keeping (PPMA, UKASTA passport, COSHH)
[ ] threshold levels

In the selection of pesticides which of the following do you always consider? (tick all relevant boxes)

[ ] performance of the pesticide
[ ] mode of action of the pesticide
[ ] cost of application
[ ] potential environmental impact

Do you regularly check and maintain equipment?

Do you hold staff meetings to discuss the farm policy and long term aims?

Is training carried out to achieve environmental awareness amongst of staff?

Do you ask your suppliers about their management and environmental policies?

Targets and action date are then set out. The information will be kept on a data base so as to carry out an information analysis. Like the Body Shop audit it addresses the current commitment, the future commitment and the targets.

RESULTS OF THE LEAF AUDIT

The audit was piloted on 200 farms through out the UK. This included a range of farm size, type and enterprises. The response rate was 49%, very high for such a lengthy questionnaire and we are very grateful for the farmers who took part. The following table sets out the responses to the audit.

TABLE 1. Summary results from the farmer opinions on the LEAF audit

1. Approximately how long did the audit take to complete?
29% 1 hr; 23% 1.5 hrs; 34% 2 hrs; 5% 3 hrs; 9% other.

2. Did you find the audit useful as a management tool?
20% very useful; 27% useful; 37% quite useful; 16% not useful.

3. Did you feel the audit assessed your current farm practices and systems?
30% yes, a lot; 39% yes, average; 30% a little; 1% not at all.

4. Did the audit help you in determining priorities?
9% yes, a lot; 44% yes, average; 33% a little; 14% not at all.

5. Did the audit help you focus on the long term objectives of the farm?
11% yes, a lot; 39% yes, average; 39% a little; 11% not at all.

6. Did the audit help highlight potential problem areas on the farm?
19% yes, a lot; 39% yes, average; 31% a little; 11% not at all.

7. Would you carry out such an audit on an annual basis?
61% yes; 39% no.

8. Do you feel that an external periodic audit would be of use to you?
10% very useful; 37% useful; 28% quite useful; 25% not useful.

9. How often do you feel this external audit should be carried out?
13% not applicable; 25% once every 2 yrs; 54% once every 3 yrs; 8% other.

The audit also highlighted several areas for action. This included quite a strong emphasis on machinery maintenance, with particular emphasis on the need for improved calibration of sprayers and fertilisers. Emergency procedures was another area identified for action as was the requirement for monitoring fuel use. There were slight adjustments to be made to the audit but on the whole we were very encouraged by the response.

OVERALL UPTAKE OF THE AUDIT

LEAF intends to encourage as many farmers as possible to adopt the audit. The audit will direct a fully integrated approach to farming, demonstrating and reassuring the consumer of the farmers' environmental commitment, as well as increasing the effectiveness of farming systems, and thus contributing to the overall professionalism of the farming industry, bringing it into line with the environmental standards required of other industries.

CONCLUSION

The secret of success is to integrate environmental factors into the responsibilities of all company personnel (Croner, 1993). Most effective is the continuous observation and action on the findings of an audit as part of the normal working day. With small scale and low cost changes far more good can be achieved than the once and for all comprehensive audit which stretches the resource limit and may create far more problems than it solves.

The LEAF audit is unique. It offers an easy assessment, which is inexpensive to implement compared to the costs involved in employing an external consultancy business and it addresses the main areas where environmental impact can take place on the whole farm.

All farming is interfering with nature, however, this is not to say that this interference is detrimental to the environment. In any case the impact of these farm practices, which may be detrimental, needs to be minimised and there is much that can be done with respect to attention to detail. Commercial and financial viability are vital for the long term survival of the farm business and also to enhance the environmental and wildlife habitats on and around the farm. It is important that there is a full management and team commitment towards environmental improvements and the LEAF audit provides the management tool through which such progression can be directed.

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ENVIRONMENTAL AUDITING IN AGRICULTURE: POTENTIAL AND PRACTICALITY

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ABSTRACT

Environmental auditing has recently come to prominence in non-agricultural industry, largely due to the draft directive on eco-audits produced by the EC. Although many of these ideas would seem transferable to the agricultural situation, there are two major problems in applying the concept to agriculture. Firstly, difficulties arise in auditing field-based operations where outputs are difficult to quantify and there is an absence of criteria by which to judge their acceptability. Secondly, it remains unclear whether auditing should be seen as a voluntary or regulatory scheme, and in either case how incentives should be structured. Despite these difficulties, environmental auditing would seem to be an excellent concept around which to structure future environmental initiatives in the agricultural sector. This scenario is explored, and a hypothetical framework for agri-environmental policy is presented in which environmental auditing plays a pivotal role.

INTRODUCTION

Developed in the USA in the 1970s, environmental audits are currently coming to prominence in Europe as an idea for reducing the environmental impacts associated with traditional industries (Clement 1991; Richards 1991, Gray 1993). Unfortunately discussion of this concept has been confused by misunderstanding of the exact meaning of the term. Increasingly, however, convergence is being reached on the following definition proposed by the ICC (1989) which suggest environmental audits are:

> "A management tool comprising the systematic, documented, periodic and objective evaluation of how well environmental organisation, management, and equipment are performing with the aim of helping to safeguard the environment by 1) facilitating management control of environmental practices; and 2) assessing compliance with company policies, which would include meeting regulatory requirements".

Thus an environmental audit is a means to analyse the current state of a system. It provides details of the situation at the time of analysis, and is not an end in itself. Indeed audits only become useful when the audit results are used to help meet management goals. As such the audit must be seen as only one element of a more dynamic management system, the essence of which is very simple; assess, review, change and monitor.

When applied in traditional industries the dynamic elements of the process are often enhanced by the existence of a long-term corporate environmental policy. Thus, the results from an environmental audit are compared with the declared objectives of the environmental policy and specific actions may be implemented in order to rectify any short-comings. There may be significant public relations (PR) / marketing value in publishing a corporate environmental strategy stating how the organisation is aiming to improve the performance over time. Thus real incentive exists amongst managers to undertake audit activities. In addition to the PR gains, other direct advantages of utilising audits as part of a corporate environmental strategy include potential cost savings, checking compliance with the law, enablement of insurance and market advantage (Gray 1993). Simultaneous to industrial gains, it is likely that the general public could benefit from a reduction in the environmental impacts of industrial processes. Theoretically, therefore, auditing seems to be good idea which could be applied to many types of industry, and a recent proposal by the EC on eco-auditing outlines a framework for this process.

CURRENT EC PROPOSALS FOR ENVIRONMENTAL AUDITING: THE ECO-AUDIT SCHEME

A draft proposal by the EC (EC 1991) outlined some relevant aims, objectives and methodologies for environmental auditing, and has served as a focus for recent discussion. The draft proposal suggests that such audits (which are defined according to the ICC 1989 definition) would aim at "achieving high levels of environmental protection, normally beyond minimum regulatory requirements applicable" and would be useful for "the evaluation and improvement of environmental performance of industrial activities and the provision of relevant information to the public". Entry into the eco-audit scheme would be voluntary for all industries. However, once registered, companies would be committed to "establish, develop and update as necessary, according to their own needs and choices, an internal environmental protection system, applicable to the activities on the site with a view of achieving a high level of environmental protection".

The draft proposal suggests that audits should be carried out by accredited verifiers, who would follow a standard methodology (Table 1). Central to this methodology is the belief that auditors should concentrate upon understanding management systems, assessing the strengths and weaknesses of management systems, gathering audit evidence, evaluating audit results and reporting audit findings. Companies registered under the eco-audit scheme would be entitled to advertise their participation in the scheme, for example by showing the eco-audit logo on their produce/promotional material etc. Thus some market advantage may accrue to participating companies. However, should the environmental performance of a participating company be judged inadequate by the Competent Authorities, then further use of the logo may be forbidden, and that advantage lost.

There is no mention within this proposal of applying auditing to agriculture. Intuitively, however, it would appear that many of the ideas are directly transferable and, as for industry, may bring benefit to individual farmers and the general public alike. Before this can happen, though, several important issues of both a philosophical and practical nature remain to be resolved. Some of these are discussed briefly below.

PERTINENT ISSUES RELEVANT TO THE APPLICATION OF ENVIRONMENTAL AUDITING TO AGRICULTURE

What is the point of auditing in agriculture?

The reason for conducting an audit of agricultural industry would be; firstly to collect data on the state of the industry and its links with the environment, and secondly as a means of decreasing the adverse environmental impacts of agricultural activities while seeking to enhance the positive aspects of this interaction. In addition, benefits may accrue to individual farmers, such as the cost savings and marketing advantages discussed above, and if auditing were to encompass compliance with existing farm related legislation then there may also be an exchequer saving. To society at large, the greatest benefit would be in terms of environmental protection.

TABLE 1. Issues and requirements for internal environmental protection systems within the framework of Eco-Audit.

Assessment of emissions (including their control, monitoring, and prevention/reduction).
Assessment of other nuisances (noise, odours, landscape).
Energy management, saving, choice.
Raw materials management, savings, choice and transportation, water management and savings.
Waste reduction, recycling and reuse, transportation and elimination.
Selection of production processes.
Prevention and mitigation of accidents.
Staff information, training, participation, on environmental issues.
External information and participation of the public.

At what scale should the audits be conducted?

Audits have been conducted at regional level, and at company level (Gray 1993, Richards 1991). Within agriculture it would seem sensible to conduct them at the level of a single management unit, ie the farm.

Who would conduct the audit?

The eco-audit suggests that a list of verified auditors would conduct audits and would report to a central organisation. If audits were to be run through government then a new, or existing agency(ies) may conduct the audit, e.g. agricultural advisory organisations, Environmental Protection Agency, local councils. Alternatively auditing may arise due to commercial marketing reasons, as has Farm Assured Scottish Livestock (see below and FASL 1992a), in which case the organisation's own auditors may conduct the work.

What would be examined by the audit, and what standards of acceptability would be used?

The basis of any objective evaluation process is a list of parameters which are to be measured. Several organisations have produced evaluation check-lists specifying the parameters to be examined, and a similar process would be required for agriculture. There is no point in collecting data during the audit unless it can be evaluated and acted upon by management. When constructing an evaluatory check-list, therefore, it is not only important to consider which parameters will be measured, but also to state what criteria, or standards of acceptability, would be utilised for assessing the audit results. Within non-agricultural industry these standards are laid down either by law or within the corporate policy.

Establishing appropriate criteria in agriculture will not be easy, as the process is complicated firstly by the absence of corporate policies, secondly by the lack of legislative standards for many areas of concern, and finally by important differences in the nature of the data likely to be collected during the audit. For example, audit parameters will vary in at least three important ways:

a) Source. Some parameters will be directly observable (e.g. presence of a bund around a fuel tank), whereas other will require the farmers to provide data (e.g. fertiliser input).

b) Standards. Some parameters will have existing acceptable standards, probably laid down by law (e.g. safety and anti-pollution measures), whereas other will not (e.g. percentage of land to be planted to deciduous woodland).

c) Form. Some of the parameters may be measured on a categorical scale (ie compliance with law is one of yes/no), whereas other will be measured on a continuous scale (e.g. amount of pesticide applied to a crop).

Clearly the easiest parameters to audit are those which are easily observable, are measured on a categorical scale and have an accepted standard associated with them, for example, those for which a law or regulation exists, e.g. structure of silage and slurry pits. This type of parameter would present no difficulties to the auditor. Unfortunately though, many important aspects of agricultural/environment interactions do not fall into this category. Consider for example, the application of nitrates and pesticides which may be measured on a continuous scale, are not directly observable and do not have widely accepted standards of acceptability. Incorporating these parameters within an audit would be difficult, because although in general, a farm using minimum pesticides and nitrate is probably less environmentally damaging than a heavy user, in certain situations even when similar chemicals are applied to similar crops, variations in environmental damage may occur due to timing of application, soil types, proximity to watercourses and application technique.

One approach for auditing this type of process would be to quantify the outputs from the agricultural system to the environment, for example, measure pesticide residues in the soil, in various water sources or in harvested produce. This approach has the advantages of being quantifiable, and comparable to agreed standards. However, the complexities of accurate sampling combined with the cost of analysis would seem to preclude this approach at present.

The nature of a third type of parameter is exemplified by considering farmers' commitment to habitat creation/protection, e.g. existence of conservation headlands, hedgerows, ponds and woodlands. Although it is not difficult to record the presence of habitats, it is difficult to evaluate the data as there are no standards which specify what percentage of a farm "should" be given over to these initiatives.

These latter two examples represent major difficulties in applying auditing to agriculture, and would need to be overcome if the principle were ever to be put into practice. At present, if, as suggested, measuring outputs is too expensive and/or statistically invalid, then it seems that one way forward would be to compare current practices with agreed best practice, or best practicable environmental option (BPEO) (RCEP 1988).

Table 2. An outline procedure for adoption of the Best Practicable Environmental Option. (adapted from RCEP 1988).

Steps in the BPEO procedure

1: Define the objective State objectives of the proposal in terms which do not prejudice the means by which the objectives are to be achieved.

2: Generate options Identify the full range of options early so that a "best" option is not missed.

3: Evaluate the options Expose the advantages and disadvantages for the environment of each option. Use quantitative methods were appropriate, although qualitative evaluation may also be needed.

4: Summarise and present the evaluation Present results in a form which can highlight the advantages and disadvantages of each option. Values placed on different aspects in the evaluation stage must be recorded, the scale for which must be explained.

5: Select the preferred option There may be more than one BPEO. Final decisions may be dependant on the individual, and will reflect the weighting given to the environmental impacts.

6: Review the preferred option Scrutinise the preferred design and operational procedure to ensure that no pollution risks or hazards have been overlooked. This should be done by independent experts.

7: Implement and monitor Monitor achieved performance against the desired targets, especially those for environmental quality. This provides a check on the design assumptions, and provides feedback for future developments and designs.

According to Elkington (1990) BPEO "establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole at acceptable cost in the long term as well as in the short term". The pragmatic nature of this concept is reinforced by the definition of practicable as "reasonably practicable, having regard amongst other things to local conditions and circumstances, to the financial implications and to the current state of technical knowledge" (RCEP 1988).

Adoption of this concept in agriculture would require a recognised body to agree on the BPEO for all agricultural situations. This would be complicated by the necessity to introduce flexibility into the BPEOs in order to reflect regional variation in agricultural and environmental systems. However, this process could benefit from adopting a methodology similar to that currently utilised for identifying BPEO in non-agricultural industries (Table 2).

There is no doubt that given the variation in agricultural systems and situations, development of BPEOs for agricultural practice would be an enormous task, but not necessarily impossible. In fact there are only a limited number of processes in most agricultural systems, the variation between them arising from variation in the local environment, weather, timing of operations and economics. Adoption of Systems methodologies, and simple tools such as input-process-output models would aid the analysis (Edwards-Jones, Gotts & McGregor 1992), and in many cases existing Codes of Good Practice (e.g. SOAFD 1992) could be adapted.

Upon adoption of the BPEO concept, the performance of the individual farm for any given activity could be compared with this standard and deficiencies identified. Such an approach would be suitable, not only for determining appropriate levels of inputs, but also for evaluating the conservation initiatives undertaken by farmers, e.g. conservation headlands, where again a "best practicable environmental option" could be determined.

Pest management ("pest" being the generic term for damaging species of arthropod, weed and disease) would be one of the areas presenting most difficulty to the formulaters of BPEO. If even minimum profit levels are to be achieved then in practice some pesticides will probably have to be applied to the land, so the aim of the BPEO would be to encourage application of the minimum required. Although the inherent variation in the pest management decision would undoubtedly lead to difficulties in definition, it should be remembered that, in many pest situations, standard recommendations are possible, and that expert (or knowledge-based systems) have the ability to provide expert level recommendations across a variety of situations (Edwards-Jones 1992). One of the major problems with seeking a BPEO for pest management would arise as substitutions and additions were made to the of array of available pesticides, as this would require the BPEO to be constantly re-evaluated. A second challenge to the process in crop production, and in other field-based operations, is that the accuracy of the audit would be totally dependent on the farmer providing exact information on the stage of the crop and the pest prior to application, as well as details of the timing and amount of pesticide applied. Indeed the possibility that farmers may provide inaccurate information about the management of, and inputs to, an enterprise is a serious hurdle to the success of auditing in agriculture.

WHAT INCENTIVES WOULD BE SUITABLE FOR ENCOURAGING UPTAKE OF ENVIRONMENTAL AUDITING?

In addition to the amount of work required to establish a practical BPEO scheme, the development of appropriate incentives for encouraging the uptake of auditing amongst farmers would also be necessary. A wide array of instruments exists for encouraging the uptake of environmental initiatives by farmers (Coleman, Crabtree, Froud & O'Carroll 1992). Given the requirement for an instrument which can be linked with regular environmental audits, and provide incentive to continuously improve environmental standards, two particular instruments warrant further discussion.

Price premium

The EC proposal on eco-audits suggests that participants in the scheme may advertise their membership by use of a logo, and presumably gain some market advantage from so doing. Such a mechanism where the consumer pays a premium on produce from sources which use socially desirable production methods has a precedent within the agricultural sector in the form of Farm Assured Scotch Livestock (FASL). This is a company limited by guarantee who's main objective is "to accelerate the ability of the Scottish beef and lamb industry to meet consumer requirements in the 1990s". FASL currently has over 1000 members (FASL 1992b) and is concerned with maintaining standards of animal production (feed and housing), animal welfare (veterinary care, transport) and the overall level of stockmanship (FASL 1992a). Annual inspections are performed to check compliance with the scheme's rules and eligible members receive a price premium on their produce. The scheme hopes to expand to include cereals, potatoes, soft fruit, farmed trout and venison and, as such, move towards a Farm Assured Scheme which would cover all farm produce.

Although the success of this initiative suggests that both farmers and consumers may be amenable to a more expansive scheme, aimed at environmental protection, it is not certain whether the price premium mechanism, as used by FASL and suggested for eco-audit, is the correct instrument for encouraging environmental protection. It is important that environmental protection does not become a luxury good, only purchased when personal prosperity is high. Should this occur then in times of recession consumers may choose not to pay the "environment premium", thus encouraging environmental degradation. It is also important to the success of such a scheme that the public have sufficient understanding to enable purchasing decisions based upon their personal environmental values. Consumer research into the public understanding of the term "organic", as used to describe organic agriculture revealed that "very few, if any respondents seemed to understand the full implications of organic farming" (McGregor & Blackholly 1991). This suggests that any scheme charging a price premium must aim to be as simple as possible, although in the longer term education may increase the level of consumer understanding.

Finally, it is difficult to reconcile any scheme where the consumer pays a premium for goods produced by socially desirable production methods with the central tenet of EC policy, that the polluter pays. Within any voluntary price-premium scheme there is the potential for companies to continue polluting activities and sell their goods cheaper than their competitors who adopt pollution free production processes. So unless the "pays" within "polluter pays" is interpreted as "foregoes a potential market advantage" then encouraging environmental protection through price premiums does not lie within stated EC policy.

Cross-compliance

The basis of this approach is that direct payments are made to farmers which can be manipulated according to environmental performance, and, to date, two types of policy utilising this principle have been implemented. In the first, the so-called "red-ticket approach", participation in certain government programmes is contingent upon farmers' attainment of specific environmental standards, while in the second, "the green-ticket approach", access to the benefits of farm support increases as farmers raise environmental standards and output of public goods (Coleman *et al* 1992). Use of cross compliance in the USA has revealed it to have the twin advantages of reducing government spending on environmental protection by internalising the costs of damage, and possessing the ability to be targeted at environmentally sensitive areas / practices. If cross-compliance were to be used as a means to encourage the uptake of environmental auditing, then the size of the direct payment could be linked to the performance revealed by the audit.

Problems with instruments

One problem with both of these schemes is that of aggregation. Should the farm be audited as a whole, or on an enterprise basis? In the former, if a mixed farm was seen to be operating within the agreed environmental standards for cereal production, but not for beef, then it would seem unfair to penalise the arable part of the farm, but on the other hand disaggregation becomes complex and costly to administer.

The eco-logo approach may be better suited to the disaggregated situation than would cross-compliance. If, however, the farm were being audited as a whole then it may be possible to construct an index which would express the overall performance of the farm against the accepted standards. Such an 'Environmental index' has been produced by Rhone-Poulenc since 1987, and this now plays an important part in corporate environmental management (Gray 1993). In this situation an incentive scheme based around the principles of 'green-ticket' cross compliance could link direct payments to this index.

The choice of instrument is also influenced by the statutory nature of auditing: voluntary or regulated. For voluntary, market led audit schemes, the eco-logo approach would seem to have many advantages, although it may not be that profitable for farmers. Conversely, if auditing were to be made compulsory then some form of cross compliance could be adopted.

A HYPOTHETICAL FRAMEWORK FOR AGRI-ENVIRONMENTAL POLICY AND MANAGEMENT: THE POTENTIAL ROLE OF ENVIRONMENTAL AUDITING

The concept implicit in environmental auditing, namely measure, review, and change seems a good one, and when coupled with the prospect of financial reward for implementing change according to societal preferences the idea assumes great potential. Given this potential it is possible to construct a hypothetical framework for agri-environmental policy in which environmental auditing would play a pivotal role.

For example, consider a situation were BPEOs, sensitive to environmental and social constraints, would be agreed for all agricultural practices. On-farm audits would occur annually or biannually, and would provide an overview of current performance, which would then be compared with the BPEO for that farm system in that locality. The scope of the audits could include ensuring compliance with current legislation, and other broader management aspects (the inclusion of legislative checks within the system would supersede other on-farm checks and legislative organisations). The advances in computer technology are such that it would be feasible for the auditor to enter relevant details into a lap-top computer on the farm, and immediately present the results to the farmer. Thus the major outputs of the audit would be an overall assessment of current performance, expressed for individual processes and as an aggregate index, and a list of recommendations suggesting how that individual farmer could strive to improve his environmental performance. Continued encouragement for increased commitment to meet the BPEOs would arise from linkages between audit results and direct payments to farmers.

This methodology would not guarantee a perfect environment, as not even strict enforcement of good management practise could ensure that freak weather conditions would not cause overflow of slurry stores, or remove human error from dealings with farm machinery, but it does have several advantages. First, it brings the disparate elements of health and safety, pollution control, nature conservation and good management within one banner, so recognising the interconnectedness of both the farm system and the environment. Second, the farmer would be free to manage his land as he wished, and would make his own trade-offs between improved performance and financial support. Third, it would provide a method of collecting and collating data on agricultural activities. Assuming that BPEOs could be defined, and a suitable system for relating rewards to performance constructed the major disadvantages of this system are that it is undoubtedly time consuming, as all farms will need to be visited at least annually, and that it depends largely upon the honesty of the farmer.

ADOPTION OF ENVIRONMENTAL AUDITING IN AGRICULTURE - THE REALITY?

The ideas presented above are little more than an outline of the role environmental auditing could theoretically have in the future. These are clearly a long way from the current situation, and the difficulties involved in establishing BPEO for agricultural practices may be too great for this, or a similar, framework ever to become practicable.

If auditing is to be adopted on farms in the near future, then it seems most likely that this will be as part of marketing initiative, which, for example, may aim to emphasise the quality aspect of the food and its production system (cf. FASL). In this situation it is unlikely that environmental auditing will have a wide-scale impact on environmental quality, as it is probable that the audit administrators would tackle the easy-to-measure parameters of farm systems, before those of most immediate environmental importance. But perhaps even such a limited beginning would bring some benefits over the current situation, and may pave the way for more expansive schemes in the future.

CONCLUSIONS

Within traditional industry, environmental audits have the potential to play an important part in preventing environmental degradation. Although the underlying theory seems to render this concept transferable to the agricultural situation, in reality there are several major hurdles to its adoption. These difficulties arise mainly due to an absence of standards for use in the review phase of the audit, a problem particularly apparent when considering field based operations. Although the development of BPEO could circumvent these problems, it seems unlikely that these ideas will be adopted in the near future. The reality of the situation is that auditing will probably only be adopted on a piecemeal basis, probably as part of a marketing initiative, and that only simple parameters will be included within the audit. This is unfortunate as the simple ideas behind the environmental audit would seem to offer much of merit.

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Session 8C

Weed Control in Tropical and Sub-tropical Crops

Session Organiser	Dr C R RICHES
Posters	8C-1 to 8C-10

WEEDS IN BHUTAN

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ABSTRACT

Weed problems in Bhutan were surveyed over a period of six man-months and the results and output from these surveys are reported. Weeds were recorded, collected and photographed, a weed herbarium established and a database developed. A temporary weed identification manual was made up, based on photocopies of dried specimens. Finally a colour-illustrated weed identification manual was prepared, covering 187 species. Weed problems are not generally severe, but are diverse and the flora includes some unusual species. Weed control in Bhutan is still mainly achieved by traditional manual and cultural methods but granular butachlor is being successfully used in transplanted rice.

INTRODUCTION

The Kingdom of Bhutan is a country of 46,500 km^2 with diverse ecologies ranging from wet tropical forest, little above sea level, to the alpine conditions of the high Himalaya Mountains ranging up to 7500 m altitude. Rainfall varies correspondingly from 5000 mm to 500 mm. Much of the terrain is either too steep or too cold for cultivation but some 100,000 ha are cultivated, including 26,000 ha of rice, much of this on narrow terraces cut into the sides of the valleys. Other major subsistence crops are maize (41,000 ha), wheat and barley (9,000 ha) and buckwheat (7,000 ha) while potatoes (2,500 ha), citrus (9,000 ha) and apple (1,000 ha) are important cash crops relatively recently developed for their export potential. Farm size is mostly between 1 and 2 hectares. Substantial quantities of food need to be imported including rice, wheat and sugar, and the country is seeking to increase its agricultural production in a range of ways. An Agricultural Research programme has been developed over the past 10 years with assistance from a number of national and multinational institutions, including the European Community (E.C.). Most relevant to this paper has been an E.C. Plant Protection Project. The first phase of this project, from 1984 to 1988, was concerned almost exclusively with insects and diseases. After a lapse of 2 years, a second phase, from 1990 to 1992, included provision for a basic survey of weeds and weed problems which forms the subject of this paper.

SURVEY METHODS AND OUTPUT

From a base in the capital, Thimphu, at about 2400 m, a series of field visits were made during the months of March, July and August 1991 and May, June and July, 1992. Most of the major agricultural areas of the middle and higher altitudes (1200-2500 m) were visited at least once, but access to the lower altitude areas, below 1200 m, was restricted for security reasons and these areas were not well covered. Surveys were mainly restricted to cultivated fields, but some attention was also paid to parasitic weeds of forestry, and wild plants with potential for poisoning cattle. On each trip a series of representative fields were visited and all but the rarest weeds were recorded for entry into a data base (see below). Herbarium specimens were collected as necessary for identification, and to establish a reference weed herbarium, and photographs were taken for purposes of establishing a reference collection and for preparation of an identification manual.

Database

The database, using DBase III Plus, had 12 fields, for genus, species, family, reference herbarium number, village, block, district, agro-ecological zone, date, altitude, intensity and crop. The agro-ecological zones of Bhutan are five: wet sub-tropical (mainly below 600 m altitude), humid sub-tropical (mainly 600-1200 m), dry sub-tropical (1200-1800 m), warm temperate (1800-2400 m) and temperate (above 2400 m). Intensity was recorded on a subjective 1-4 scale: 1 - rare, 2 - occasional, 3 - common and 4 - abundant to dominant and/or especially serious in the view of the local farmers or agricultural staff. In any one village, a single list of weeds was prepared for the major crop, based on one or more fields visited. Occurrence in other crops was also noted but not usually recorded separately, unless the species were notably different. If a range of crops were infested by a similar range of weeds, they were recorded as occurring in 'miscellaneous crops'. A total of about 1500 records were accumulated from which it is possible to extract lists of those occurring at different intensities, in different crops, localities or agro-ecological zones.

Herbarium specimens

About 300 specimens were collected. Samples of most of these were incorporated into a collection for the National Plant Protection Centre (NPPC) at Simtokha, while duplicates were also donated to the Bhutan National Herbarium at Forestry Research Institute, Taba. Many were also donated to the Royal Botanic Garden, Edinburgh in return for invaluable assistance with identification. Further samples have been lodged with the tropical weed herbarium at Long Ashton Research Station, Bristol.

Photography

Colour transparencies of most species were taken, and a reference collection of several hundred slides established at the NPPC. Nearly 300 of these were used in the preparation of a colour-illustrated manual.

Photocopy manual

During the second visit, in 1991, 'A first Manual of Bhutan Weeds' was prepared as an interim aid to weed identification. This was based on photocopies made directly from dried, pressed herbarium specimens, before mounting. They were trimmed to occupy about 75% of an A4 sheet, leaving space at the top for names and family, and at the bottom for notes on identification, distribution and control. Two hundred and eight species were illustrated in this way and some 20 photocopied sets were bound for distribution to the main research and extension bodies in Bhutan. This technique is not known to have been used before, but is recommended as a relatively simple and inexpensive means of producing a limited number of identification manuals. Although many details of the flower are lost and no colour is recorded (without the vastly greater expense of colour-photocopying), leaf shapes, the branching structure of the plant and the pattern of inflorescence, especially in grasses and sedges, is well reproduced, perhaps more usefully than in a photograph. The venation and texture of leaves is also well preserved, given correct exposure.

Colour manual

At the end of the second visit, it was agreed that a colour manual should be produced. Further slides were obtained during the third visit and a manual was completed a few weeks later with the excellent technical assistance of Sayce Publishing, Exeter (Parker, 1992). This includes nearly 300 plates, illustrating some 187 species, many at seedling as well as mature stages. Preliminary chapters cover the importance and biology of weeds, general methods of weed control and notes on identification and collection.

RESULTS

The main weeds

A total of 85 species were recorded as common or abundant at one or more sites. Many of these are cosmopolitan species, as will be apparent below. Others are more regional, known mainly from neighbouring countries including India and Nepal. A few appear to be almost unique to Bhutan.

Notes on some individual species

Potamogeton distinctus
This perennial aquatic plant is the most difficult weed of rice in several of the major rice growing areas above 1200 m. It does not occur at lower altitudes and is apparently adapted to relatively temperate conditions. It is thought to be native, but it also occurs as a weed in Japan and Korea, where its biology has been well studied. It develops a rhizome system between 10 and 20 cm depth in the soil, making its removal in established rice virtually impossible. The rhizome tips become dormant in September after which most of the rhizome system decays, but the tips persist as turions over the winter and regrow very rapidly after flooding is applied for the following crop. Not only is it the quickest weed to establish after rice planting, but it is also resistant to butachlor, the one herbicide being widely used in Bhutan.

Persicaria runcinata (= *Polygonum runcinatum*)
This is a perennial weed, known also from neighbouring parts of India, occurring mainly at higher altitudes, above 1000 m. It spreads by shallow stolons, which form tubers at the nodes, making it difficult to remove and allowing rapid establishment in following crops. It is one of the most intractable weeds of many dryland crops, requiring repeated hand-pulling and heaping or removal from the field to prevent re-establishment.

Persicaria nepalensis (= *Polygonum nepalense*)
This species has the same local names as *P. runcinata* and in spite of distinct differences in leaf shape and life form, the two are very much confused. It is annual and does not offer the same special difficulties as *P. runcinata*. It is also used by farmers as a fodder for cattle and pigs, but it is often the most dominant species in annual or perennial crops, causing serious competition and/or increasing the costs of weeding.

Rumex nepalensis
This is an erect deep-rooted perennial but also establishes quickly from seed. It is difficult to hand-pull or to destroy with normal hand or

animal-drawn implements and its broad leaves provide serious competition for light. It occurs in most dryland crops, also in orchards and grazing land and is often pointed out by farmers as their most troublesome weed.

Fagopyrum dibotrys

This is a perennial of higher altitudes, above 1200 m, related to buckwheat, and not known to occur as a significant weed outside Bhutan. It has a strong, extensive rhizome system down to at least 20 cm depth and shoots which can reach 2 m high. It is troublesome in many dryland crops, especially in eastern Bhutan.

Arisaema flavum

This perennial *Arisaema* (family Araceae) appears to be the commonest member of the genus as a weed in Bhutan and is not known elsewhere as a weed. It grows from a deep potato-like corm and produces large leaves up to 1 m high. This is a localised problem, above 1500 m, but is regarded as the most difficult weed of potato in several districts, requiring repeated hand-pulling as it regrows from the corm, which is too deep for easy removal. Parts of the plant are poisonous.

Commelina maculata

This is a perennial of high altitudes, above 1800 m, not known as a weed elsewhere. Identification proved quite difficult as it rarely, if ever, flowers in Bhutan. Most farmers claimed they had never seen flowers. It grows from a long tuberous root and is regarded as one of the major problem weeds of potato in eastern districts of Bhutan.

Pennisetum flaccidum

This is a robust perennial grass of high altitudes, over 2000 m, growing up to 2 m high, with an extensive rhizome system down to at least 20 cm depth. This is a major problem in potato and cereals in central districts and in apples in western Bhutan.

Digitaria ciliaris

This is the commonest annual grass and perhaps the commonest of all annual weeds in Bhutan, at least at altitudes over 1000 m, often totally dominant in annual and perennial dryland crops. Closely related species may replace it in some localities, e.g. *D. timorensis* at low altitudes.

Galinsoga parviflora

This introduced weed is probably the commonest annual broad-leaved weed of altitudes above 1000 m.

Weeds and weed control methods in the main crops

Rice

The major weeds in rice at altitudes above 1000 m are quite few in number, with *Potamogeton distinctus* the outstanding problem in the districts where it occurs, plus *Schoenoplectus juncoides* (= *Scirpus juncoides*), *Monochoria vaginalis* next in importance, followed by the widespread *Echinochloa crus-galli* (and *E. glabrescens*) and *Cyperus difformis*. Locally abundant species include *Acmella uliginosa*, *Bidens tripartita*, *Dopatrium junceum*, *Fimbristylis littoralis*, *Persicaria tenella* and *Rotala densiflora*. Other species are likely to be more important at lower altitudes, but were not adequately surveyed. Methods of weed control in Bhutan are still very largely traditional. In rice, which is transplanted into generally well-prepared land, the first weeding 2-3 weeks after transplanting involves destruction of young weeds by fingers and feet. This is commonly followed a few weeks later by hand-pulling. Rotary weeders are used to some extent in valley bottoms where the individual terraces are sufficiently wide. Total labour used may be 50 or more man-days per ha. Following successful trials in the mid 1980s, granular butachlor has become a popular herbicide for rice growers in several districts, in spite of no subsidy. It is applied by hand at 1-1.25 kg a.i./ha and has provided consistent control of most of the common rice weeds, with the notable exception of *P. distinctus* which has probably tended to increase with herbicide use. Otherwise, its use has been largely trouble-free, surprising in view of the limited literacy of the farmers and lack of extension support. New herbicides have been evaluated by the Bhutan-IRRI (International Rice Research Institute) Rice Farming Systems Project and two, pyrazolate ('Sanbird') and pyrazosulfuron-ethyl (NC 311) show promise for control of *P. distichum*. Unfortunately these are expensive, and improved control of this weed may depend on cultural methods.

Maize

A wide range of annual and perennial weeds occur in maize (and other summer-grown crops), among which the commonest annuals include *Ageratum conyzoides*, *Amaranthus hybridus*, *Bidens pilosa*, *Chenopodium album*, *C. ficifolium*, *Commelina benghalensis*, *C. diffusa*, *C. haskarlii*, *Cynoglossum furcatum*, *Digitaria ciliaris*, *D. timorensis*, *Galinsoga parviflora*, *Persicaria nepalensis*, *Setaria pumila*, *Siegesbeckia orientalis* and *Xanthium indicum*. Important perennials include *Commelina maculata*, *Cynodon dactylon*, *Cyperus rotundus*, *Fagopyrum dibotrys*, *Pennisetum clandestinum* and *Persicaria runcinata*. Weed control is all by traditional methods, hoeing and hand-pulling, which in a season with dry intervals is largely adequate. In a more continuously wet season, considerable difficulties and losses are expected, but the presence of so many perennial weed species will make it difficult to find adequately selective herbicides.

Potatoes

This crop has largely the same weeds as maize, with some additional perennial species, including *Arisaema flavum*, *Equisetum* spp., *Pteridium aquilinum* and *Rumex nepalensis* recorded locally. Weed control is currently by traditional methods, but there is a demand from the farmers for development of herbicides. Metribuzin has been used successfully in experiments, but will not be made freely available until it is shown to be sufficiently effective on the main perennial weeds, and is safe enough in the hands of the farmer.

Temperate cereals, buckwheat and mustard

These crops are grown mainly in the winter season and are affected by a weed flora remarkably familiar to a European, including *Spergula arvensis*, *Stellaria media*, *Chenopodium* spp., *Thlaspi arvense*, *Capsella bursa-pastoris*, *Alopecurus aequalis*, *Avena fatua*, *Poa annua*, *Phalaris minor*, *Lamium amplexicaule*, *Vicia hirsuta*, *V. sativa*, *Oxalis corniculata*, *Polygonum aviculare*, *A. plebeium*, *Anagallis arvensis*, *Galium aparine*, *Veronica persica* and *Solanum nigrum*. Less familiar species include *Plantago erosa*, the local *Soliva anthelmifolia* and the introduced *Polypogon fugax*. Weeding in these crops is usually limited to the roguing of problem species such as *A. fatua* and is often non-existent. Significant yield loss must sometimes occur and be tolerated as preferable to the effort of weeding, but weeds are often very sparse, perhaps due to judicious timing of tillage following irrigation.

Perennial crops

Predominant weeds in orchards include most of those recorded for maize, potato and winter cereals, plus many others, especially in citrus and other tropical fruit at lower altitudes. Additional species in both tropical and temperate orchards include annuals such as *Amaranthus spinosus*, *Drymaria cordata*, *Crassocephalum crepidoides*, *Tagetes minuta*, *Eleusine indica*, and perennials such as *Imperata cylindrica*, while at low altitudes, a further range of species includes *Mikania micrantha*, *Brachiaria ramosa*, *Paspalum conjugatum*, *Cassia tora*, *Sida acuta* and *Spermacoce latifolia*. No herbicides are used yet but glyphosate should be made available in due course. Tree crops are locally affected by a range of semi-parasitic mistletoes, including *Scurrula elata* in apple, *Macrosolen psilanthus* and *Helixanthera parasitica* in citrus and *Scurrula parasitica* in both. In forestry, conifers are affected by *S. parasitica* and *Taxillus kaempferi* and the very damaging dwarf mistletoes, *Arceuthobium minutissimum* and *A. pini*.

Grassland and non-crop land

Weeds occurring in grazing land include a number that can cause severe toxicity to livestock. *Ligularia amplexicaule* and *L. mortonii* are normally avoided by stock but in districts subject to drought and over-grazing, have resulted in death of yaks. Others causing occasional poisoning include *Rhododendron barbatum*, *Pieris formosa*, *Aconitum* spp. and *Coriaria napalensis*. Introduced species encroaching on natural vegetation to an undesirable degree include *Eupatorium adenophorum* and the allergenic *Parthenium hysterophorus*.

CONCLUSION

The weed problems of Bhutan are not exceptionally severe, but they are diverse and the flora includes some unusual species, a number of which are perennials for which there is little information on biology or control. Bhutanese manpower resources for agricultural research are extremely limited and there will not for some time be any indigenous weed science specialist. In the meantime, staff of the National Plant Protection Centre and crop agronomists in the research service have been advised to survey the farmers' current problems and practices and to study the biology of the most important weed species. Solutions to many of the problems may depend on cultural approaches for some time to come but limited herbicide evaluation is proposed. Use of directed herbicide, especially glyphosate, in orchards should be feasible with a minimum of further work. The use by farmers of selective herbicides in annual crops such as maize and potato will depend on more prolonged research and the development of adequate extension support. The apparently trouble-free use of butachlor in rice is an interesting endorsement of the advantage of granular herbicide for resource-poor farmers.

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FARMERS' PERCEPTIONS OF RICE WEEDS AND CONTROL METHODS IN COTE D'IVOIRE, WEST AFRICA

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ABSTRACT

An inter-disciplinary survey of farmers' perceptions of rice pests and control methods was undertaken in three agro-ecological zones of Côte d'Ivoire. Weeds were the pest problem most widely reported by farmers. Farmers identified a range of weed species which were particularly problematic, those which were becoming increasingly serious, and some weed species which had useful properties. Traditional weed control methods were used by the majority of farmers, and only a small number of farmers relied exclusively on herbicides. The results are discussed in relation to the findings of other researchers, and how these results may assist research aimed at improved weed control methods.

INTRODUCTION

The range of weed species infesting rice in Côte d'Ivoire and elsewhere in West Africa has been described by a number of authors, including Merlier (1974), Akobundu & Fagade (1978), Marnotte (1984), and Rouw (1991). The extensive lists have distinguished species occurring in differing ecological zones. Such information is an essential pre-cursor to the development of effective weed control measures. To complement this knowledge, an understanding of farmers' perceptions of weeds, and existing control measures is clearly important if integrated pest management (IPM) strategies, well adapted to farmers' reality, are to be developed. Tait (1987) suggested that IPM strategies should be based on a clear understanding of farmers' beliefs of pests, control measures used and their efficacy. Further, Warren (1989) argued that technologies are more likely to be appropriate if based on existing, indigenous knowledge of farmers. This paper describes the results of an inter-disciplinary survey, undertaken in 1992, of smallholder rice farmers in Côte d'Ivoire. The survey sought to determine farmers' perceptions of rice pests and control measures, in order to guide research efforts. Aspects of the survey relating to weed problems are emphasised in this paper.

RICE PRODUCTION AND AREAS OF SURVEY

The main rice production systems of Côte d'Ivoire have been described in detail by Becker & Diallo (1992). Rice, which is found in most agro-ecological zones of the country, is grown mainly by smallholder farmers within diverse production systems. Approximately two thirds of the total rice area (329,000 ha in 1990) is within the humid forest zone, with the remainder being grown in the savanna zone. Upland systems predominate, with rice often being intercropped with maize, or relay cropped with cassava in the humid forest zone, while in the savanna, rice is grown in rotation with maize, yams or cotton, or intercropped with sorghum or maize. Generally, natural fallows of varying duration follow periods of cultivation.

The inter-disciplinary survey was undertaken among 178 farmers, selected at random within three study zones (Table 1). A formal survey using a questionnaire was undertaken by field staff indigenous to the survey area, using the local language. This was complemented by field observations and discussions with farmers.

TABLE 1. Survey areas of Côte d'Ivoire, 1992.

Site	Ecological Zone	Latitude	Annual[1] Rainfall (mm)	Rainfall Distribution
Gagnoa	Humid Forest	6°10′ N	1489	Bi-modal
Touba	Forest-Savanna	8°20′ N	1406	Mono-modal
Boundiali	Savanna	9°30′ N	1433	Mono-modal

[1] Girard et al., (1971)

RESULTS

Among the farmers selected, 46% grew upland rice, 29% grew lowland rice, and 25% grew rice in uplands and lowlands. Weeds were cited by all farmers as a pest seriously limiting rice production, followed by birds (84% of farmers), rodents (60%), insects (40%) and diseases (9%). Fifty three weed species were cited as being common weeds of rice fields. The most widely reported species are shown in Table 2, as well as those which farmers cited as becoming increasingly serious in recent years. *Solanum nigrum*, *Chromolaena odorata* and *Hibiscus* sp. were cited as having some beneficial uses, mainly nutritional or medicinal, though seven farmers thought *C. odorata* was useful in suppressing other weed species. Weed competition was reported to be most serious approximately thirty to sixty days after sowing, suggesting that land preparation only provides effective control during the early stages of crop growth.

TABLE 2. Principal weed species of rice fields, as cited by farmers. Percentage of farmers in each ecological zone, Côte d'Ivoire, 1992.

		Humid Forest	Forest-Savanna	Savanna
Panicum laxum	*	100	-	-
Chromolaena odorata	*	68	-	-
Centrosema sp.		42	-	-
Scleria sp.		32	-	-
Fimbristylis spp.	*	20	2	2
Ageratum conyzoides	*	2	62	26
Imperata cylindrica	*	-	72	14
Paspalum scrobiculatum		-	37	10
Digitaria horizontalis	*	-	33	2
Rottboellia cochinchinensis	*	7	30	45
Commelina spp.		3	22	3
Euphorbia heterophylla	*	2	3	22
Oryza spp. (O.barthii/O.longistaminata)		-	-	21
Pennisetum subangustum	*	-	20	3

* Weed species farmers regard as becoming increasingly serious.

Fifty three percent of farmers reported that their rice fields were not always weeded. A reason given for this by almost two thirds of these, was that weed infestation in the crop may be so severe that weeding was not always worthwhile, therefore, the field would be effectively abandoned, at least in part. Other reasons given for not weeding included low levels of weed infestation (31%), lack of cash to hire labour (27%), sickness (24%), and lack of labour (15%).

Almost 80% of farmers said that if weeds were less of a problem they would increase the area of land under cultivation. Further, more than 90% of farmers reported that weeds influenced the choice of land under cultivation, in that fields which were likely to become badly infested with weeds were avoided. A large proportion of these farmers thought that weeds were linked to poor soil. Widely reported weed management strategies were the use of long fallow periods, pre-planting soil tillage, and early sowing of the rice (Table 3). In the humid forest zone, tillage is primarily used in the lowland areas, while in the forest-savanna and savanna zones it is used for both upland and lowland. In the lowlands, the most widely used method of soil tillage is with hand hoe, while in the uplands of the forest-savanna and savanna, hand hoe, animal traction, or mechanisation may be used. Hand pulling of weeds and the use of hoes were the most commonly cited methods of weeding, while 24% used both these methods in combination with herbicides; only 2% of farmers relied exclusively on herbicides. Farmers reported certain advantages that accrue to herbicide use, including, efficient weed control, allowing larger areas to be cultivated, avoiding long and tedious labour, and enabling the rice crop to develop well. Reasons given for not using herbicides were: a shortage of funds (53%), the high cost of herbicides (21%), preference for traditional methods (16%), lack of knowledge about herbicides (11%), and herbicides not being available at the correct time (9%). Of those farmers that did use herbicides, 30% said that they would discontinue their use if the price of herbicides increased. In the humid forest and forest-savanna zones, herbicides were used largely by those farmers growing lowland rice, while in the savanna, more than half the farmers using herbicides grew upland rice.

TABLE 3. Weed management strategies and control measures used by farmers in Côte d'Ivoire by ecological zone, percentage of farmers in each zone who used a particular method.

	Humid Forest	Forest-Savanna	Savanna
Hand pulling of weeds in the rice	98	62	95
Hand hoeing of weeds in the rice	68	92	90
Long fallow period	78	97	31
Soil tillage before sowing/planting	42	50	52
Use herbicides	30	30	55
Early sowing of rice	30	2	10

DISCUSSION

Of the principal weeds cited by farmers (Table 2), all were included in the list of Marnotte (1984), and a number were noted by Merlier (1974) as being weed species which were either invasive, or difficult to control. However, other species were not listed by Merlier, including: *C. odorata*, *Euphorbia heterophylla*, *Imperata cylindrica*, *Oryza* spp., *Panicum laxum*, and *Scleria* sp.. This may be due to the fact that Merlier's list was based on data from experimental areas, where the composition of the weed flora was influenced by the history of the site, or the experimental treatments. In addition, *E. heterophylla* and *C. odorata* are species which have become problems in Côte d'Ivoire in recent years. The former had become a serious weed by the end of the seventies (Diallo, 1981), with it's spread having been hastened by the distribution of contaminated rice seed (Becker & Diallo, 1992). *C. odorata* invaded the humid-forest zone in the early to mid-seventies, following the direction of the prevailing winds and secondary sources of infestation such as equipment for road construction (Delabarre, 1977); both species are now widely established. *P. laxum* and *C. odorata* were found to be important weeds in the humid forest zone by Rouw (1991), who showed that if upland rice was grown for three consecutive years after clearing forest, the crop was overwhelmed by weed growth, including these species. Rouw also reported that *C. odorata* eventually grew to a height of 1.5 m and suppressed all other species; a characteristic noted by some farmers in the 1992 survey.

Infestations of the parasitic weeds *Striga asiatica*, *S. aspera*, and *S. hermonthica* in rice have been reported in Côte d'Ivoire (Marnotte, 1984; Riches, 1992). However, farmers did not cite these species as being significant in our survey, but this could be due to the localised occurrence of these weeds in the savanna zone, in areas not covered by the survey.

The list of principal weeds cited by farmers was somewhat shorter than many of the lists developed by scientists. This is likely to reflect the particular importance farmers place on a limited number of species, rather than the wider range of weeds which are of scientific interest. In conjunction with complementary field studies, farmers' lists, based largely on economic importance, may be a valuable guide for research to focus on a limited range of species. With this objective, subsequent studies may be aimed at farmers in circumstances of increased land pressure, a situation which will be more widely faced by farmers in future. These studies would enable any changes in weed species or infestation due to increased cropping intensity to be monitored. Future research may also seek to determine if farmers rely on certain weeds as indicators of soil fertility or stages of the fallow cycle.

In many areas of Côte d'Ivoire, there is still sufficient land available for several years of fallow between crops, however, the demand for land is increasing and inevitably fallow periods are being reduced. The survey shows that farmers rely on traditional methods to control weed infestations. Where these fail and serious weed growth results, entire fields or portions of fields are often abandoned. Further, due to the limited use of herbicides and the constraints of family labour, weeding is often delayed or inadequately done, and as a consequence yields are reduced. Until recently, herbicides have been available to lowland rice farmers at subsidised rates, but with economic reforms this is no longer the case. As a result, herbicide use is likely to decrease. The same may be true among those farmers using herbicides in rice in the savanna zone, where rice is often grown in rotation with cotton. In these farming systems, the recent decline in the profitability of cotton may result in decreased use of inputs. We conclude that cultural practices and hand weeding are likely to remain the most important methods of weed control in the near future.

Improved, appropriate weed control measures are required if rice production is to intensify on a sustainable basis. The majority of farmers are resource poor with limited scope for investment. Therefore considerable attention is required to determine the factors that guide farmers' decision making. Such information might include: levels of weed infestation which lead farmers to abandon their fields; the cost at which herbicides become widely acceptable to farmers; and the scope for improved weeding during the early stages of the rice crop.

CONCLUSION

The survey has shown that farmers regard weeds as the major pest of rice, and that traditional weed control methods continue to dominate. It is hoped that by gaining more information on farmers' perceptions and practices, research can be guided towards the development of more appropriate weed control technologies that build on farmers' cultural practices and are compatible with their resources. This preliminary survey has been a step in that direction.

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INCORPORATING FARMER KNOWLEDGE IN THE DESIGN OF WEED CONTROL STRATEGIES FOR SMALLHOLDERS

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ABSTRACT

Weed control is the most labour-demanding pre-harvest activity in crop production. Recommendations have tended to be purely technical with little reference to farmers' resource levels and their understanding of the dynamics of the system. Smallholder farmers often have few resources to commit to crop production and protection. It is vital that the design of weed control measures is based on a clear understanding of farmer constraints and on their knowledge of weed biology and ecology.

INTRODUCTION

Weed control, using either manual labour or draught inputs, is the most labour-demanding phase of pre-harvest crop protection, often needing between 45% and 60% of total pre-harvest labour inputs (Akobundu, 1987). Parker and Fryer (1975) estimated that late weeding as a result of labour shortages often causes up to 25% yield loss. However, purely recommending timely weeding is not the whole solution. Vernon and Parker (1983) estimated that only 5% of the farmers they studied in Zambia could increase weeding frequency in order to reduce maize yield loss, but for the majority this option was beyond available resources. In Zimbabwe, Shumba *et al.* (1992), showed that reducing draught inputs using tine cultivation could lead to timely planting, but most farmers had insufficient labour to cope with the resulting increased weed pressure early in the season. Those who could afford herbicides could adopt the system, but "cash-poor farmers might find the tine cultivation unattractive because of the cost of atrazine or the increased labour requirements for hand weeding if herbicide is not used".

Weed control recommendations have changed little with changing agricultural systems. Recommendations still tend to be based on technical considerations such as the critical period of competition, with little reference to how farmers' resource levels and their understanding of the dynamics of the production system as a whole affect their view of the technologies and subsequent adoption. For most annual crops, recommendations emphasise at least two timely weedings during the first 6 to 8 weeks following planting.

Baker (1987) found that recommendations for early and multiple weeding in Botswana are unlikely to be adopted, particularly in drought years; farmers are unwilling to invest limited labour resources to weeding until they are certain the rains will be sufficient to produce a yield: "Multiple weeding is done only as a response to special circumstances.... Farmers try to avoid (it) by not weeding too early, but sometimes make mistakes".

FARMERS' DECISION-MAKING STRATEGIES

Risk

There is a tendency to think that the risk farmers face is simply that of crop loss. However, farmers also risk undertaking an uneconomic activity if the investment is not reflected in increased output. In assessing the costs and benefits of a single activity, it is implicitly assumed that the activity is somehow divorced from the rest of the farm system and that labour cannot be usefully employed elsewhere. It is often assumed that family labour is free but Baker (1987) observes that in Botswana there is a shortage of male labour for weeding "due to competing labour activities such as wage employment, livestock tending and fencing".

Labour in all activities has an 'opportunity cost', a value in alternative uses, and farmers weigh up the risks of making an uneconomic decision when they choose which activity they will devote their time to. When asked why they do not weed more than once, farmers in Botswana noted that the end of the first weeding coincides with the start of birdscaring and that priority has to be given to the latter. Even if weeding is done by women or children, its opportunity cost needs to be calculated when making recommendations on its timing and labour requirement. Women may be able to earn more by small-scale trading, gathering fuel or other off-farm activities.

Interactions between weeding and the rest of the farming system

Farmers may well know more about the dynamics of the farming system than they have been given credit for. They are aware that weeds compete with their crops causing a degree of loss and know that timely weeding is important. In Zimbabwe, Ellis Jones *et al.* (1993) found a widespread appreciation of the importance of early weeding, not only for weed suppression but also to improve rainfall infiltration. In the same system, farmers recognised that multiple mouldboard ploughing during the dry season is necessary to suppress *Cynodon dactylon* in the subsequent crop. In Botswana, for the same species, it was observed that some farmers were able to suppress *C. dactylon* by ploughing twice prior to planting and an extension recommendation was generated following research into this practice (Phillips, 1993).

Richards (1985) notes that whereas formal weed research in West Africa concentrates on weeds which grow along with the rice, no investigations have been done on weed growth between clearing and planting; the farmers' priority. Weeding post-clearing is especially important because it determines how difficult it will be to hoe the land after the rice seed has been broadcast.

Farmers in Thuchila in southern Malawi, where termite pressure is particularly heavy, say that disturbing the soil on the tops of the ridges attracts termites which cause the maize plants to lodge. During their second weeding, at approximately 6 weeks following planting, they therefore only remove weeds in the furrows and at the sides of the ridges, perceiving potential losses to termites as higher than the loss from weed competition.

The uses of "weeds"

The definition of a "weed" depends on who is providing it. Scientists tend to concentrate on removing any plant not "recognised" as a crop but many plants traditionally thought of as "weeds" are eaten, fed to animals or used for medicine. *Galinsoga parviflora, Bidens pilosa, Gynandropsis gynandra* and *Ceratotheca sesamoides* are commonly eaten by farmers in southern Malawi; *Commelina* sp., *Euphorbia* sp., *G. parviflora, B. pilosa* and *Eleusine indica* are used as animal feed and *Trichodesma zeylanicum, Ocimum canum, Euphorbia* sp. and *Tridax procumbens* are used as medicine. Farmers may selectively remove "weeds" without alternative uses and leave the useful species. One author has seen a field of maize where all weeds except *B. pilosa* had been removed.

USING FARMER KNOWLEDGE CRITICALLY

There has been little critical evaluation of what farmers know and how this compares with scientists' knowledge. Examples have been given above of aspects of weed control that tend not to be taken into account when determining recommendations based on critical periods of competition. However, documentation of farmer knowledge (generally by social scientists) has tended to be uncritical and focused on aspects of the farming system about which farmers appear to know more than scientists. Less work has been done on what farmers do not know about particular problems and on how this affects their ability to adopt recommended technologies. In Kenya, Bonitatibus (1991) was impressed by the richness of local people's knowledge but remarked that "there was another area of indigenous knowledge which appeared built on wrong assumptions, reinforced by misleading and partial observations". Bentley (1989) points out that "what farmers don't know can't help them": the knowledge gaps of both farmers and scientists need to be addressed in the development of sustainable agricultural technologies.

FARMER KNOWLEDGE OF *STRIGA*

The parasitic witchweeds, *Striga* species, are considered to be a major constraint to increased cereal production in sub-Saharan Africa (Mboob, 1989; Sauerborn, 1991). Control recommendations have emphasised hand removal of emerged parasite stems, application of fertiliser and rotation (Parker, 1991). Despite the extension of these approaches, with legal sanction against defaulters in some parts of East Africa in the past, the severity and extent of infestation has continued to increase. We discussed the problem of *S. asiatica* infestation of maize with farmers in Malawi and have compared their knowledge with that of farmers in western Kenya whose fields are infested by *S. hermonthica* (Connelly, 1988; Bonitatibus, 1991). There is a clear pattern to their knowledge which has important implications for the design of future research and extension programmes.

Striga and soil fertility

Farmers in Malawi and Kenya are aware of the symptoms of *Striga* attack: some can differentiate between maize plants attacked by pre-emergence *Striga* and those suffering whitegrub damage. They recognise that water and nutrient stressed maize is found in areas where the parasite is also seen. This tends to be attributed to direct competition for water and nutrients, although one Malawian suggested that *Striga* released poisonous substances into the soil which affected maize growth (c.f. toxins). They also noted that increased infestations were associated with declining soil fertility. Bonitatibus (1991) spoke to Kenyan farmers who were aware that *Striga* attached itself to the roots of host plants, but no Malawian farmer interviewed by the authors knew this.

Connelly (1988) found that "some farmers intentionally select areas of their fields with low fertility and high *Striga* infestation as the place to tether their animals during the dry season". This was based on the belief that manure increased the soil's nutrient content and reduced infestation. However, they generally have only a small amount of manure available and this has alternative value as fuel and building material. The value of increasing soil fertility at infested sites has been demonstrated by trials in Malawi (Kabambe, 1991). Malawian farmers indicated that fertiliser application does not have a strong effect on the amount of *Striga* seen in their fields, though maize yields are better at infested sites when fertiliser is applied. Fertiliser application in the seedbed does reduce parasite germination and attachment (Cechin and Press, 1993) but recommendations in Malawi are for application when the crop is 15-20 cm high, probably too late to have an effect on the *Striga*.

Striga reproduction

Neither Connelly (1988), Bonitatibus (1991) nor the authors have met any farmers who appreciate the enormous quantity of seed produced by each *Striga* plant and the ease with which it is dispersed. No farmer the authors spoke to could identify where the seeds were located on the plant. Connelly and the authors have noted that farmers become dispirited with constant hand weeding. In Malawi, little systematic attempt is made to remove *Striga* from the field after weeding. Farmers leave the stems in the inter-rows or bury them when making mid-season ridges, by which stage a proportion of *Striga* will have set seed.

Crop rotation and the potential for trap cropping

Connelly (1988) reported that in cases of severe infestation, farmers rotated their grains with crops that are not susceptible, though this becomes increasingly difficult as population pressure reduces the land available for growing grain. Some crops, including cowpea and sunflower, produce

Striga asiatica germination stimulant but are not parasitised (Parker, 1991). However, this does not appear to be known by the farming community. No strong view emerged from the authors' questions to Malawian farmers as to whether *Striga* was more common in sole or intercropped maize (surprising given the prevalence of maize/cowpea and maize/groundnut intercrops). One farmer in Malawi had heard that intercropping with velvet bean (*Mucuna pruriens*) should reduce the parasite population by producing a toxin to *Striga* from its roots. He had not seen any effect, probably because the velvet bean population was too sparse to produce a noticeable response.

PLANNING A PROGRAMME FOR WEED CONTROL

It is not enough simply to document instances in which farmers appear to know more than scientists and those in which the reverse is true. The differences between farmer and scientist knowledge of the problem is the key to designing weed control measures and policies that are understood by the farmers and that are appropriate. While farmers constantly experiment, they often do so with imperfect information and become disillusioned and frustrated when the methods they have developed in accordance with their understanding of the system do not work.

Table 1 summarises some of the scientific knowledge about *Striga* and compares it with the details farmers in southern Malawi have given the authors about the parasite. This form of presentation makes for easy comparison between farmer and scientist understanding of a problem and gives insights into why farmers have or have not adopted different control measures.

TABLE 1. Comparison between farmers' and scientists' knowledge of the biology and ecology of *Striga* spp. in southern Malawi (number of asterisks represents frequency of occurrence).

Farmers are aware that *Striga*....	Farmers are less aware or unaware of....	Scientists may not have taken into account....	Farmers' attempted control measures
Is an important pest.****	Parasitism of cereals.****	Farmers can distinguish between effects of pre-emergence *Striga* and white-grub on maize.	Handpulling.****
Causes crop failure in many cereals.****	Parasitic mechanism.****	Weed emerges after first weeding operation.	'Kaselera' cultivation (building ridges mid and late season) to kill *Striga* and reduce seed reserve.****
Is most serious in less fertile fields.****	Seed size.***	Farmers' links between scientific and magico-religious principles (some believe it to be one of the prophesied plagues).	Shifting cultivation.***
Effects plants before its emergence.****	Period of seed dormancy and its varying maturation.****		Discontinuing maize cultivation.**
Effects on hosts increase with moisture stress.***	Method of seed dispersal.****		Improving soil fertility by:
Is difficult to control.**	Trap cropping and effects of rotation.***		• applying animal manure.**
Releases 'toxins' which are taken up by plants.*	Methods of reducing seed reservoir in soil.***		• applying maize bran.*
Spatial and temporal occurrence depends on the season.*			• intercropping with velvet bean.*

Extension messages need to explain far more about why and how a control measure has been developed. We need to be realistic about the use of farmer knowledge or Indigenous Technical Knowledge (ITK) in general in agricultural research. Social scientists have tended to emphasise what farmers know without critically examining how this relates to scientific knowledge and how the gaps in farmer comprehension hinder their ability to experiment and to understand the rationale behind control measures. Natural scientists have tended to emphasise what farmers do not know and have been sceptical about social scientists who document farmer knowledge without making recommendations about how to use it. Bonitatibus (1991) points out that "...ITK is neither *just* 'old wives tales', nor *just* all 'essential information.... farmers... have a deep understanding of their environment and are able to take sound decisions according to their specific needs and to their situation. But a lot of contradictions, of wrong assumptions, of misleading beliefs coexist with these insights. ITK appears to be a peculiar mixture of both. It would be therefore unfair either to exalt the whole of it or to denigrate it".

Specific recommendations for weed control

Recommendations in 1936 for *Striga* control in Kenya (Connelly 1988) include hand weeding and burning before the parasite sets seed, the use of early maturing varieties, rotation of non-susceptible crops and the use of farm manure. Connelly (1988) observed that although "...farmers are apt to claim that they are 'helpless' in the face of heavy *Striga* infestation... several of these recommendations are part of the indigenous weed management system and, as far as can be determined, predate the intervention of colonial agricultural research".

In spite of this, farmers have little understanding of the rationale behind some of the recommendations (Table 1). To minimise parasite infestations they will need to be taught about seed production, longevity and dispersal as a prelude to stressing why it is important to remove *Striga* stems from the field, rather than leaving them to dry out on the surface of the soil.

Intercropping maize and a legume is a common practice in *Striga* infested regions of Africa. Preliminary results from trials in Mali (Webb, 1993) indicate that *S. hermonthica* can be suppressed by a cowpea cover crop. More work needs to be done on intercropping to see if there is a noticeable effect on the subsequent maize crop when an adequate population of groundnuts or cowpea is planted. Indeterminate cowpeas produce ground cover quickly and may more effectively suppress *Striga* infestations. Farmers are well aware of the association between *Striga* infestation and low soil fertility. Researchers need to build on this knowledge by developing recommendations which will assist farmers to use the limited quantities of fertiliser which they can afford most efficiently.

By giving farmers information rather than prescriptions, we allow them to work out for themselves what they can and cannot afford to do. We give them a better idea of the true risks involved and leave it up to them to make the decisions. There has been much talk about "empowering" farmers to help them take control of their own lives. Finding out and providing them with the information they need is a vital part of this process.

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A SURVEY OF WEED PROBLEMS IN A REGION OF MALI

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ABSTRACT

The weed flora and management regimes of 140 fields in North West Mali were surveyed during 1990. Sixty five species were identified, with a mean of 13 species per field. The results of correspondence analysis and TWINSPAN showed that zone, manuring level and fallowing regime were most important in influencing weed community composition. The weed flora of fields in Nara, the most northerly and driest of the zones surveyed, was distinct from that of the other zones.

INTRODUCTION

Much research on weeds concentrates on methods for the control of single weed species, but a crop in any one field is competing with an assemblage of species, and more than one of these is usually capable of becoming dominant depending on the conditions. An environmental gradient does not just affect individual species but will affect the composition of the weed community. Multivariate techniques have been used extensively in the analysis of natural vegetation but relatively rarely for weed communities. They are potentially important in the analysis of weed survey data because they allow hypotheses to be made about the nature of weed communities, and the effects of the environment and management practices on these communities. Such knowledge can assist in the development of practices which take into account the whole weed community rather than concentrating on single species. Multivariate methods are also valuable in the analysis of data sets consisting of many variables, since a single analysis can pinpoint the important relationships between these variables. These relationships may then be tested for statistical significance using methods such as the $\chi 2$ test. On the other hand the techniques may be mathematically complicated, the results are not clear cut, and they may be difficult to interpret or even spurious. This paper concentrates on the application of two techniques, correspondence analysis and TWINSPAN, to weed survey data from a region of Mali.

METHOD

The survey was conducted in September and October 1990. This timing minimized the effects of within survey variation since there is little weeding or new germination of weeds at this time. Fourteen villages were selected in the zones of Nara, Mourdiah, Dilli and Fallou in N.W. Mali. Selections covered a range of environmental conditions, particularly rainfall which ranged from 298mm in the north (Nara) to 486mm in the south (Mourdiah) over the 1990 cropping season. Within each village 10 to 15 fields were surveyed along a transect from the centre of the village outwards to represent a range of field types. In every field a species list was made and cover was recorded for each species as a proportion of the total on a modified Braun Blanquet scale: (1) Isolated; (2) Scattered, cover small; (3) Scattered, cover 2-3%; (4) Abundant, cover about 5%; (5) Abundant cover, 7-15%; (6) Cover 20%; (7) Cover 25-50%; (8) Cover 50-75%; (9) Cover >75%. Details of the crop and intercrop, and sowing, manuring and fallowing practices were taken in each field.

Correspondence analysis was conducted on 130 fields. Ten fields of Berzag, in Nara, with a highly distinctive weed flora were excluded from the ordinations and classification.

The analysis was confined to 26 species variables to simplify interpretation. Species included were those observed in at least 25 fields. The geographical and cultural variables were incorporated as supplementary variables. Possible associations were tested for significance by $\chi 2$ or 't' tests. The TWINSPAN analysis (Two Way Indicator Species Analysis; Hill, Bunce and Shaw, 1975) was carried out using the VESPAN II Computer Package (Malloch, 1988). It is a divisive, polythetic method of cluster analysis based on the ordination method of reciprocal averaging which is very similar to correspondence analysis. For each division the indicator species are those at the opposite ends of the reciprocal averaging axis which may represent an environmental gradient. Preferential species are those which are more frequent in one group than the other. The analysis was carried out on 130 sites and all observed species were included. For each subgroup the weed diversity, i.e. the mean number of weed species per field, was estimated.

RESULTS

A wide range of main crops was found in the 140 fields surveyed, long cycle (souna) and short cycle (sanio) millet, long cycle (kenigue) and short cycle (gadiaba) sorghum, groundnuts, okra, and bambara nut. These, and roselle and cowpea were also found as intercrops. The commonest crop, souna millet, observed in 87 fields, is normally intercropped with kenigue or gadiaba sorghum or cowpea. The fields surveyed were recognised as being of two types, village fields and bush fields. The former were under continuous cultivation, they were close to the village and therefore well manured by the local cattle. Generally the level of manuring decreased with distance from the village. Bush fields were furthest from the village, they were in a bush fallow rotation of variable length and did not usually receive any manure. Sixty five weed species were identified in the survey. From 4 to 24 species, mean 13 species, were identified per field. The most frequently observed weeds are listed in Table 1. Annual *Digitaria* spp., *Cyperus rotundus*, and *Striga hermonthica* were particularly frequent at high abundance. The proportion of fields in which a species was observed at high abundance was variable, see Table 1. The weed flora in 10 of 13 fields in the village of Berzag in Nara was highly distinctive. Nine out of 10 of these fields were under continuous cultivation with high manure inputs, the other was in bush fallow rotation. Weed diversity in these 10 fields was very low, 4-7 species per field. Two of the species observed here, *Trianthema portulacrastrum* and *Gynandropsis gynandra* were not observed elsewhere, and two others, *Brachiaria ramosa* and *Amaranthus* sp. were observed elsewhere only occasionally.

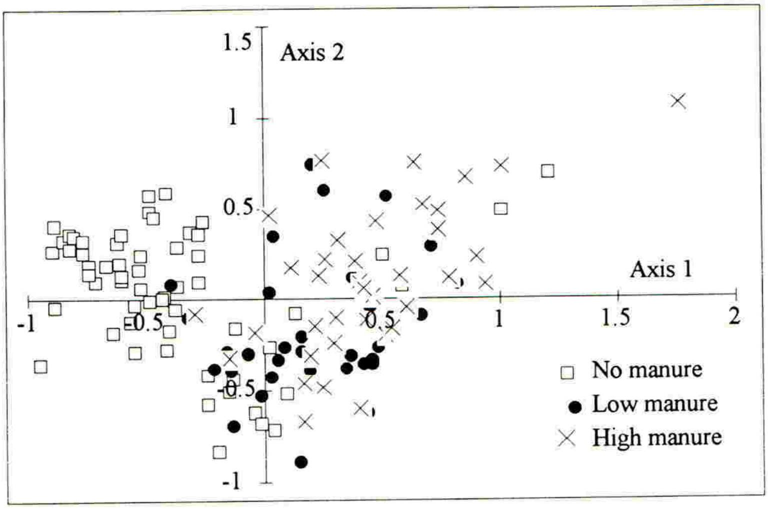
Correspondence Analysis

The first two axes accounted for 20% and 11% of the variation in the data respectively. Fig.1 is a scattergram of the site scores. Fig. 2 illustrates the species scores and the supplementary variables zone and manuring level. Such diagrams provide good visual descriptions of the data. A clear discontinuity is visible in the distribution of sites on Axis 1 (Fig. 1). Those in the negative group were almost all without manure ($p<0.001$). A disproportionate number were from the zones of Nara or Dilli even when the relative manuring levels in the zones were taken into account ($p<0.001$). These two zones are further north and drier, particularly Nara, than the other two. Axis 1 therefore distinguishes the weed communities in bush fallow fields, which rarely receive any manure, from those under continuous cultivation. There is also a zonal component to this axis. The positions of the other supplementary variables on Axis 1 relate to other differences in management between the two types of field and between zones. There was also a tendency for fields in Fallou to be dry sown. Cropping was more variable in bush fields. Souna millet was grown less frequently in bush fallow fields than in the fields under continuous cultivation. Gadiaba sorghum was commoner in fields under bush fallow but rare under continuous cultivation (all $\chi 2$ tests significant at $p<0.001$). The weed flora was more consistent between villages within Mourdiah and Fallou than within Nara and Dilli. *Brachiaria xantholeuca*, *Sesamum alatum*, *Phyllanthus pentandrus*, *Sesamum radiatum*, *Ipomoea cocsinosperma* and bush regrowth were typical of bush fields (Fig. 2). *Acanthospermum hispidum*,*Celosia trigyna*, *Leucas marticinensis*, *S. hermonthica*, *Commelina forskalaei* and *C. rotundus* were typically found in fields under continuous cultivation ($\chi 2$ or 't' tests between manured and unmanured fields significant at $p<0.05$).

TABLE 1. The most abundant weed species identified in a survey of 140 fields in N.W. Mali. The number of fields in which the species was present (Abundance ≥1), abundant with cover >5% (Abundance ≥4), and cover >20% (Abundance ≥6) are given.

Species Name	≥1	≥4	≥6	Species Name	≥1	≥4	≥6
Annual *Digitaria* spp.	119	70	9	*Sesbania pachycarpa*	65	7	1
Mitracarpus scaber	109	55	6	*Corchorus tridens*	57	6	1
Jacquemontia tamnifolia	109	47	2	*Striga hermonthica*	56	32	0
Eragrostis tremula	91	14	1	*Phyllanthus pentandrus*	53	11	0
Cenchrus biflorus	73	19	0	*Centaurea perrottetii*	47	14	0
Cyperus rotundus	72	48	12	*Sesamum radiatum*	46	5	0
Commelina forskalaei	72	22	3	*Leucas marticinensis*	42	10	0

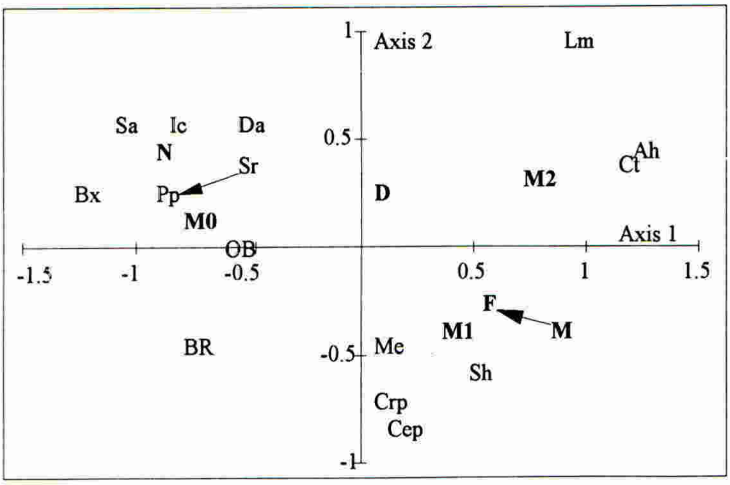
FIGURE 1. Field scores on axes 1 and 2 of the correspondence analysis. Points are labelled according to manuring level.



The interpretation of Axis 2 is more difficult. The axis appears to separate the continuously cultivated fields (Fig. 1) along a gradient which may reflect differences between low and high manured fields combined with further geographical differences. However, very few statistically significant associations were found within the continuously cultivated group of fields. Of the fields in the continuous cultivation group those in Dilli scored higher on Axis 2 ($p<0.01$)than those in Mourdiah or Fallou. Analyses of variance of abundance scores found *S. hermonthica, A. hispidum*, and *Crotolaria podocarpa* to be more abundant in Fallou and Mourdiah ($p<0.05$) and *L. marticinensis* to be more abundant in Dilli ($p<0.05$). *C. podocarpa* was also more abundant on fields with no manure ($p<0.05$). The village of

Makana in Dilli scored particularly high on axis two, 85% of fields contained *L. marticinensis* compared to an average of 42% over all 130 fields.

FIGURE 2. Scores of species, and the supplementary variables, zone and manuring level on Axes 1 and 2 of the correspondence analysis. Zones: Dilli (**D**), Nara (**N**), Mourdiah (**M**), Fallou (**F**). Manuring Levels: No manure (**M0**), Low manure (**M1**), High manure (**M2**). Species: *Brachiaria xantholeuca* (Bx), *Sesamum alatum* (Sa), *Sesamum radiatum* (Sr), *Phyllanthus pentandrus* (Pp), *Ipomoea cocsinosperma* (Ic), *Dactyloctenium aegyptium* (Da), Other Broadleaf (OB), Bush Regrowth (BR), *Merremia* spp. (Me), *Crotolaria podocarpa* (Crp), *Centaurea perrottetii* (Cep), *Striga hermonthica* (Sh), *Celosia trigyna* (Ct), *Acanthospermum hispidum* (Ah), *Leucas marticinensis* (Lm). Only species scoring at least 0.5 on one of the axes are included.



Twinspan

The results from the first two axes of the correspondence analysis agree well with the groupings from the first three TWINSPAN divisions. If the TWINSPAN subgroups are mapped onto the scattergram of sites in Fig. 1 then it is clear that the first TWINSPAN division separates sites around the discontinuity on Axis 1. The second division separates sites according to their position on axis 2. It is to be expected that the results should agree as the techniques used are very closely related. If this was not the case then it would be likely that at least some of the results arose from the data structure. Indicator species for each division are given in Table 2. The first division separated bush fallow and other non manured fields (group a), indicated by *P. pentandrus, S. alatum, S. radiatum*, Bush Regrowth and Other Broadleaf species, from continuously cultivated fields (group b) indicated by *L. marticinensis* and *S. hermonthica*. Within this there were further divisions according to zone and manuring level. The mean diversity of group a, 15.0 species per field, was relatively high compared to that of group b, 12.9 species ($p<0.001$). The diversity of these bush fallow fields was also slightly underestimated since they contained the categories Other Broadleaf and Bush Regrowth which each consisted of more than one species. Group a was divided into groups c, indicated by *Cenchrus biflorus* and *Dactyloctenium aegyptium*, and d, indicated by *Centaurea perrottetii* and *C. podocarpa*. The former contained the bulk of the fields of Nara. Of the fields surveyed from Nara 63% were in group c and 22% in d. Group d contained a relatively high proportion of fields from zones other than Nara, 55%, compared to c with 24% ($p<0.05$). Seven of the 9 fields from Nara which were allocated to group d were from one village, Nyma Koere. Fields of Group c had particularly high weed diversities, mean 15.8 species, even compared to group d, mean 13.9 species ($p<0.05$). The preferential species of c included 5 grass species, far more than for any other group.

TABLE 2: TWINSPAN analysis. Indicator species for the first three divisions. Key to species name abbreviations: *Acanthospermum hispidum* (Ah), *Celosia trigyna* (Cet), *Cenchrus biflorus* (Ceb), *Centurea perrottetii* (Cep), *Commelina forskalaei* (Cof), *Corchorus tridens* (Cot), *Crotolaria podocarpa* (Crp), *Cyperus rotundus* (Cr), *Dactyloctenium aegyptium* (Da), *Ipomoea cocsinosperma* (Ic), *Jacquemontia tamnifolia* (Jt), *Leucas marticinensis* (Lm), *Panicum* spp. (P), *Phyllanthus pentandrus* (Pp), Bush regrowth (BR), *Sesamum alatum* (Sa), *Sesamum radiatum* (Sr), *Sesbania pachycarpa* (Sp), *Striga hermonthica* (Sh), Other broadleaf (OB). Numbers (1),(2), indicate that the weed is an indicator species for the community when present at abundance levels of ≤3 or ≤6 respectively.

Subgroup			Mean No. Species Per Field	No. Fields In Group	Indicator Species
Division 1					
		a	15.0	53	Pp(1), BR(1), Sa(1), Sr(1), OB(1)
		b	12.9	77	Sh(1), Lm(1)
Division 2					
	a	c	15.8	33	Ceb(1), Da(1)
	a	d	13.9	20	Cep(1), Crp(1)
	b	e	13	53	Cep(1), Jt(2), Sh(1)
	b	f	11.4	24	Lm(1)
Division 3					
a	c	g	11.3	3	P(1)
a	c	h	16.2	30	None
a	d	i	13.2	12	Sa(1), Cep(1), Ic(1), Sp(1)
a	d	j	14.9	8	Sh(1), Cof(1), Crp(1)
b	e	k	11.4	18	BR(1)
b	e	l	13.9	35	Ah(1), Cof(2), Cr(1), Sh(2)
b	f	m	11.5	19	None
b	f	n	10.0	5	Ah(1), Cet(1)

Group b was divided into groups e and f. This division was strongly associated with zone ($p<0.001$). 45% and 34% of fields in e were from Mourdiah and Fallou respectively. Fourteen out of 24 fields in f (58%) were from Dilli, and 10 of these were from the village of Makana. *S.hermonthica, C. perrottetii* and *J. tamnifolia* were indicator species for group e. *C. forskalaei* and *M. scaber* at levels of abundance of ≥4 were also preferential to this group. The indicator species for group f was *L. marticinensis.* Preferential species included *Brachiaria ramosa*, *Boerhavia* sp, and *Amaranthus* sp. which are known to prefer village fields or high fertility waste ground. *C. rotundus* at very high abundance was also preferential to this group. Although 81% and 83% respectively of fields in e and f were manured, 48% of manured fields in e received only low levels compared to 26% in f. *S. hermonthica* is known to be more of a problem in continuously cultivated fields which are low in nitrogen (Bebawi 1987). It was observed in 87% of group e fields and at abundance of ≥4 in 34% of sites. However within e it did not appear to be associated with low manured fields.

The division of e into groups k and l was associated with manuring level ($p<0.001$). The indicator and preferential weed species of l were all weeds which are known to be particular problems i.e. *C. forskalaei*, *C. rotundus*, annual *Digitaria* spp., *S. hermonthica*, *L. marticinensis*, and *A. hispidum*. With the exceptions of *A. hispidum* and *L. marticinensis* they were all preferential with abundances ≥4. Of the 35 fields in l, 34 received manure, 20 of these received high applications. Of the 18 sites in k, 9 received no manure and 6 only received low applications. The indicator for k was Bush Regrowth. The subgroup n of l consisted of 5 fields, with indicator species *C. trigyna* and *A. hispidum*. The mean diversity of n was 10, the lowest of the TWINSPAN subdivisions.

DISCUSSION

The analyses highlighted two major causes of variation in weed community composition, geographical location and field type, and also interaction between these factors. The strong effects of location, which were visible to village level, may have masked effects attributable to management practices. The 1990 crop and intercrop did not affect the weed flora, but cropping history is probably far more important than the present crop.The most obvious differences in weed flora were between bush fallow fields in Nara and Dilli (TWINSPAN group a) and the fields of Mourdiah and Fallou and continuously cultivated fields of Dilli (TWINSPAN group b). The bush fallow fields were characterised by a higher species richness and by different species to fields under continuous cultivation. Individual species tended not to reach high levels of abundance. Under continuous cultivation one particular weed sometimes became dominant, particularly annual *Digitaria* spp., *C. rotundus*, *S. hermonthica* and *C. forskalaei*. Within the bush fallow fields further zonal differences between Nara and Dilli were found. Likewise within the continuously cultivated fields there were further differences between fields of Makana in Dilli and those from Mourdiah and Fallou, also between manuring levels within the fields from Mourdiah and Fallou. The first two axes of the correspondence analysis only accounted for 31% of the variation in 26 of the weed species in 130 fields and these axes were difficult to interpret. There is, therefore, a very large proportion of the variation in the weed flora which remains to be explained. Further information on soil characteristics which may be correlated with location,on management history, and of the preferences of individual weed species are also required to improve the interpretation of future surveys. Surveying of more villages in Nara and Dilli, in which there were particularly large variations between villages, would also assist the interpretation of future surveys.

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CONSERVATION TILLAGE/WEED CONTROL SYSTEMS FOR COMMUNAL FARMING AREAS IN SEMI-ARID ZIMBABWE

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ABSTRACT

Soil water is the main factor limiting crop production in semi-arid areas of Zimbabwe. Effective weed control is an essential component of any tillage system which aims to enhance water retention. In order to provide a framework for tillage/weed control research, a rapid rural appraisal and baseline survey were undertaken in two areas. This work indicated a widespread understanding amongst local farmers of the need for timely inter-row mechanical cultivation, both for weed control and for keeping a rough soil surface which can capture subsequent rainfall. On-station trials have demonstrated that conservation tillage involving ridge and furrows may be made when weeding with the farmer's existing animal draught equipment. The labour requirements and concomitant yields of conservation tillage/weeding systems are presented.

INTRODUCTION

Recent conservation tillage work in Zimbabwe has been examining the effect of various tillage practices, notably the use of potholes, ridges and furrows on the conservation of water and concomitant yields of maize and cotton in the marginal semi-arid communal farming areas.

Farming systems analysis (Ellis-Jones and Riches, 1992; Mudhara and Ellis-Jones, 1993) has indicated a widespread understanding amongst local farmers of the need for timely inter-row cultivation for both weed control and for keeping a rough soil surface which can retain subsequent rainfall. Low levels of income from agriculture as well as an acute shortage of labour, especially in female headed households, require that conservation/tillage weed control recommendations are based on low cost labour saving technologies (Lacher and Dikito, 1991).

Weeding is the most labour demanding pre-harvest practice accounting for up to 60% of total labour in crop production (Ellis-Jones and Riches, 1992). It is therefore clear that conservation tillage systems cannot be developed without due consideration for weeding techniques. This paper outlines some of the preliminary findings of a study that is investigating existing farming practices and potential modifications.

TRADITIONAL TILLAGE SYSTEMS

Land preparation is usually undertaken using an ox-drawn mouldboard plough as soon as possible after standing crops have been harvested at the beginning of the dry season (May/June), depending on the availability of draught animal power (DAP) and soil water status. Those households that do not own draught animals will borrow or hire them or else undertake the work by hand if labour resources allow. When prompt post-harvest tillage is not possible ploughing is undertaken at the on-set of the subsequent rainy season.

The most common method of planting is by hand after the first significant rains into a furrow made and covered with a plough. Two to three cultivations primarily for weed control are then undertaken, although many farmers regard breaking the soil cap and the associated water conservation as important.

Data for 1989/90 indicates that 76% of communal area farmers own a mouldboard plough, but only 23% own a cultivator and hence the plough can play an important role in weeding operations (MLARR, 1992). These ploughs, typically have a working width of 0.25 m and given favourable conditions may work as deep as 0.20 m. The cultivators on the other hand, are generally five tined with a maximum working width of 0.90 m and may work as deep as 0.08 m. Intra-row weeds are removed by hand hoeing which is also used for weeding entire fields when DAP is not available.

CONSERVATION TILLAGE

Due to the serious losses of water, soil and nutrients from cultivated lands, the extension service in Zimbabwe strongly recommends the use of the no-till tied ridging system in the marginal communal areas (Elwell and Norton, 1988). Cross ties (small dams) are constructed every 0.70 to 1.00 m along the furrow between crop ridges to form a continuous chain of reservoirs. The ridges are not intended to be destroyed every year, but are maintained at the optimal size and shape; as dictated by inherent soil properties such as texture and fertility, crop type and management practices; using DAP implements or the hand-hoe. The most frequent cycle of ridge construction envisaged was 1 in 4 or 5 years for sandy soils, 1 in 10 years on red clays and permanent on Vertisols. Although there has been considerable success with water catchment ridge and furrows on Vertisols; with the crop planted in the furrow (Nyamudeza *et al.*, 1991); adoption rates by farmers on lighter soils remains very low (Sarapinda, 1989; 1990; Huchu, 1991).

Problems associated with semi-permanent ridges, compared to flat cultivation practices, include a high labour requirement for construction, difficulties in planting and weeding, increased weed problems (particularly *Cynodon dactylon*) and maintenance problems. Vogel (1993) has concluded for the Zimbabwean scenario, that sheet erosion under no-till tied ridging is negligible but the system may generate micro-environments that are adverse to crop production. The major disadvantages are high temperatures and rapid drying in the ridges resulting in poor or delayed crop establishment and therefore poor crop stands. These problems assist in explaining not only low adoption rates, but more importantly modification of the recommendations by farmers. These vary depending on soil type, availability of labour, draught animals and implements, but a typical system is likely to comprise:

- Post harvest dry season ploughing
- Open furrow plough planting where a small furrow is created using the mouldboard plough in which the seed is placed prior to covering by hand/hoe or cross harrowing. This enables early rains to be concentrated into the planting line.
- Ridging or furrowing using a plough at the first weeding depending on rainfall/soil water condition (with or without the mouldboard body attached), modified cultivator with hilling blades for ridging, and more rarely a ridger depending on implement availability and condition of draught animals.

The system is opportunistic in that it allows maximum flexibility in management practices according to local conditions. Research has generally indicated that crops benefit from at least two weeding operations carried out between emergence and six weeks (Weed Research Team, 1987). Systems therefore require investigation that adapt present practices and can be executed with existing implements.

LOW INPUT WEEDING SYSTEMS: DESIGN AND EVALUATION

An examination of labour and DAP requirements is likely to explain some of the reasons for low adoption rates of conservation tillage technologies. Unfortunately little data on the labour profiles in communal farming areas is readily available. Data from various sources (AGRITEX, 1982; Makoholi Experiment Station 1993 and field measurements taken on farm) have been used in the analysis that follows. No attempt has been made to differentiate between different environmental conditions at the time of each tillage operation. Although condition of the animal, the state of repair of implements, soil texture, water content and capping, as well as weed type and cover will effect labour input, emphasis has been placed on establishing average labour requirements in the first instance.

Four weeding systems were tested at Makoholi Experimental Station, Masvingo Province during 1992/93 season (Figure 1). The trial was planted on a coarse grain sand; classified as a *Ferralic Cambisol/ Arensol* under the FAO system; total rainfall for the season was 777 mm, of which 610 mm fell on the growing crop. The trial site was cultivated with a single furrow mouldboard plough pulled by four oxen during the dry season and again at the onset of the rainy season to a depth of 0.18 m. Maize was sown by hand at a 0.30 m in-row spacing, into furrows opened by the plough at a 0.90 m inter-row spacing, and subsequently covered by cross harrowing.

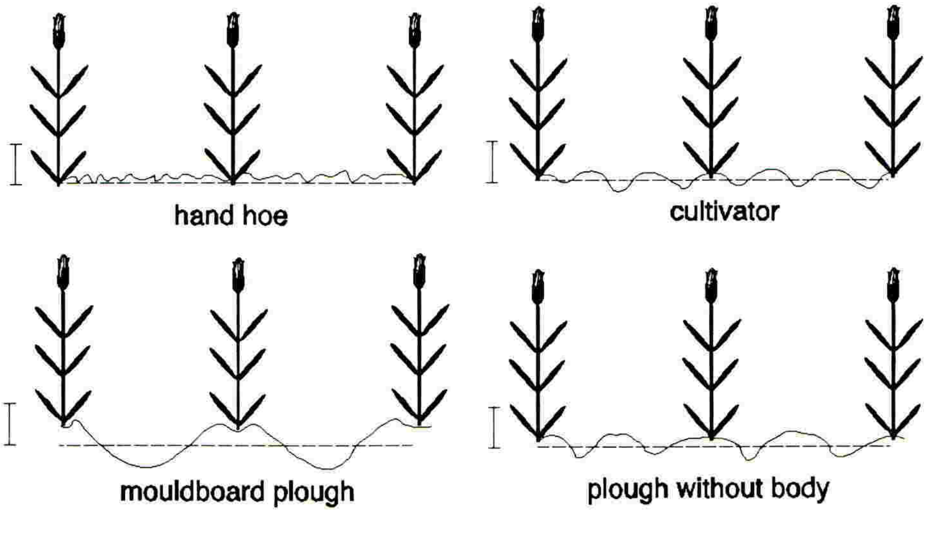

Figure 1 Soil surface relief following four different weeding practices (scale bar represents 0.20m)

The hand hoe weeding system tested assumes that DAP is not available for weeding. This represents households that rely on hiring DAP teams for primary tillage. The cultivator system represents households which have greater access to implements and undertake weeding primarily by cultivator. The two plough weeding systems represent the majority of households who have access to adequate DAP and a mouldboard plough. The plough share is the operational weeding blade and the plough was tested with either the body (mouldboard breast) attached or removed, the latter being the most commonly observed practice in communal farming areas. Weeding by each system was carried out at 21 and 53 days following sowing, supplementary hand weeding of crop rows was done following mechanical weeding if necessary. Traction for each implement was provided by two oxen and two labourers were required to manage the team.

Weeding by hoe is usually of a 'spot' nature that maintains a weed free flat surface that is not particularly conducive to rainfall capture and retention as the hoed surface is usually walked over and compacted during the operation. In contrast, as is shown in Figure 1, a cultivator produces a rough soil surface with narrow channels remaining where each tine has passed that enhance the surface retention of rain water. Use of the plough without the body is regarded as a substitute for the cultivator by many farmers and results in the formation of low ridges and furrows. However, since the cutting width of the plough share is only 0.20 to 0.25 m, three to four passes are required for weeding in comparison to a single pass by a cultivator and this entails a greater labour input. Unfortunately, the inherent instability of these sandy soils means that the rough soil tilth produced following weeding with a cultivator or a plough without a body readily slumps and a surface cap develops with the first heavy rains. Although this suggests that the retention of rainfall on the soil surface is reduced, complementary studies to this work suggest that mechanical weeding can still have positive benefits in terms of significantly ($P < 0.05$) lower surface bulk density and high infiltration rates up to a month after the last cultivation when compared with hand hoed plots (Twomlow, unpublished data). If the plough body is retained and two passes per inter-row are undertaken a ridged landform (0.15 to 0.20 m) is achieved, providing the greatest opportunity for rainfall capture (Figure 1).

The labour required for weeding by each system is shown in Table 1. This accounted for over 80% of pre-harvest labour input, being greatest for hand-weeding at 132.2 h ha^{-1}. The cultivator and the plough with body attached required similar labour input for weeding. The least labour was required when the plough body was retained. This was 55.2 h ha^{-1}, significantly ($P < 0.001$) less than when the body was removed or weeding was undertaken by hand hoe.

The main weeds on the trial site were *Eleusina indica* and *Richardia scabra*. To ensure a weed free crop after the first inter-row weeding with the cultivator or plough with body removed, hand hoe weeding was required within the crop row. When the plough body was retained no additional hand weeding was required, as in-row weeds were smothered with soil when the crop row was ridged up. The second weeding required hand hoe weeding in-row for all four systems.

TABLE 1: Yields, barren plants, labour requirements and returns to labour for four weeding systems

	Yield kg ha^{-1}	Barren plants ha^{-1}	labour hours spent weeding per ha			returns to weeding kg h^{-1}
			manual	mechanical	total	
hand-weed	5195^a	1000^a	132.5	0	132.2	39.3^b
cultivator	4552^a	222^a	52.15	16.19	68.3^a	66.7^a
mouldboard plough	4345^a	1333^a	26.8	28.3	55.2^a	78.7^a
plough no mouldboard	2766	4000	45.4	40.4	85.8	32.5^b
expt s.e.(df 12)	309.5^{***}	349.7^{***}	-	-	3.16^{***}	4.41^{***}
LSD 0.05	1551	1752	-	-	15.88	22.14

treatment means followed by the same letter do not differ significantly at $P < 0.05$

*** $P < 0.001$

Similar yields were obtained from weeding by hoe, cultivator and plough with body attached (Table 1). Significantly ($P < 0.001$) lower yield was achieved when the plough body was removed for the weeding operation. The lower yield is considered to be due to root pruning during multiple passes close to the crop row, especially at the second weeding. Significantly ($P < 0.001$) more barren plants without cobs resulted on plots weeded by this practice. The returns to labour for weeding demonstrate that use of the plough with body provided the greatest return. This was significantly ($P < 0.001$) greater than hand hoeing or using the plough with body removed. Where labour is a major constraint and only a plough is owned use of this system should be considered.

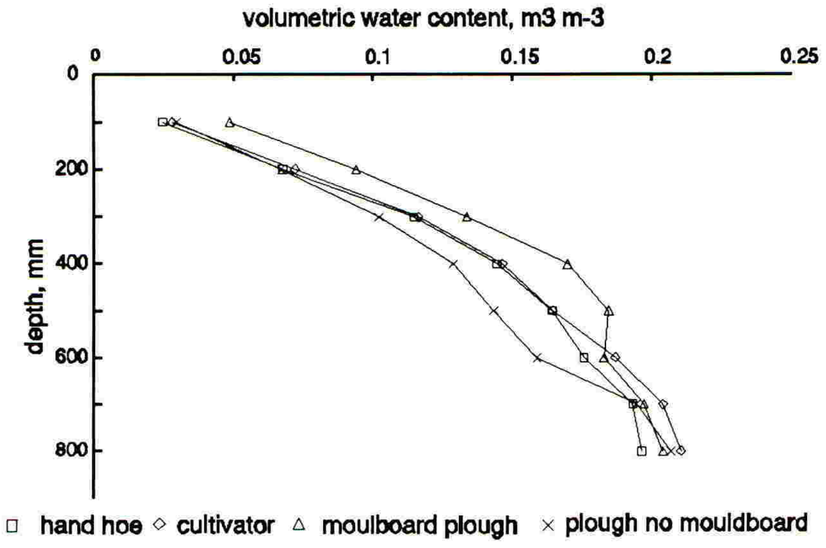

Figure 2 Variation in volumetric water content with depth for four weeding systems for a maize crop at anthesis (15 February 1993).

Figure 2 shows the in situ variation in soil water content with depth for the four weeding systems when the crop was at anthesis. The soil water profiles were measured using a 'Wallingford Neutron Moisture Meter' dynamically calibrated for the soil (Twomlow and Riches, 1991). Statistical analysis of the data presented in Figure 2 revealed that there was a significant ($P < 0.05$) treatment effect on the quantity of water stored within a 800 mm profile. Weeding with the plough body removed resulted in the driest profile, 0.129 m3 m^{-3}, and was significantly drier than the weeding treatment with the plough body attached, which was the wettest at 0.152 m^3 m^{-3}. There was no statistical difference between hand hoeing (0.135 m^3 m^{-3}) and the cultivator (0.141 m^3 m^{-3}).

CONCLUSIONS

From this work it appears that for farmers with adequate DAP the use of the plough with the mouldboard body attached gives a number of advantages over traditional weeding practices, in that labour for weeding can be significantly reduced and a ridge and furrow conservation system is created which has potential for enhancing soil water retention. Further on-farm evaluation of these technology options is desirable to validate these initial conclusions. It is planned that on-farm field observations are continued during the 1993/94 season.

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DISTRIBUTION OF THE RHIZOMES AND ROOTS OF *CYNODON DACTYLON* IN THE SOIL PROFILE AND EFFECT OF DEPTH OF BURIAL ON REGROWTH OF RHIZOME FRAGMENTS

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ABSTRACT

The rhizomatous grass *Cynodon dactylon* is one of the world's worst weeds and the most serious grass weed of Botswana; in a recent survey over half the fields examined were infested. Crops are grown traditionally by broadcasting seed and mouldboard ploughing, a system that perpetuates the problem, whereas ploughing twice before planting can significantly reduce an infestation. To help understand why, soil profiles in a field heavily infested with *C. dactylon* were excavated and rhizomes and roots in 5 cm layers down to 20 cm were removed, separated, dried and weighed. Nearly half the rhizome dry matter was in the top 5 cm layer and 90% within 15 cm of the surface. Roots were evenly distributed through the four layers. In an experiment, segments of rhizome with one, two or three buds were buried at 5, 10, 15 or 20 cm. Few shoots emerged from below 10 cm. The number of buds did not affect the production of shoots. It is proposed that the success of ploughing twice in controlling *C. dactylon* is due to a combination of desiccation and deep burial.

INTRODUCTION

The perennial, rhizomatous grass *Cynodon dactylon* is among the most serious grass weeds world-wide (Holm *et al.*, 1979), and is the commonest and most important grass weed of Botswana (Phillips, 1992). The traditional method of growing crops is to broadcast seed and plough it under to depths of 10 to 20 cm when the soil is moist. This technique perpetuates an established *C. dactylon* weed problem. Fields ploughed twice before planting (double ploughing), have been observed to have less *C. dactylon* regrowth. Double ploughing in spring, with the first pass after the first significant rainfall, is adopted by some farmers as it increases yield even in the absence of grass weeds (Heinrich *et al.*, 1990). Its effect on *C. dactylon* was investigated by Riches (1987), who showed that double ploughing in spring reduced regrowth by up to 90%. In a series of wetter seasons, Phillips (1993) achieved reductions in regrowth of 60% by winter (dry season) and spring ploughing and of 33% by double ploughing in spring compared with traditional single ploughing at planting. Significant increases in sorghum grain yield were recorded from the control of *C. dactylon*. There was continued suppression of rhizome regrowth following double ploughing for between two and four years. To understand why double ploughing achieves good control, the distribution of rhizomes in the soil profile was examined and the depth from which rhizomes could produce shoots was investigated.

MATERIALS AND METHODS

Field study on the distribution of rhizomes and roots in the soil

The study was conducted near Gaborone in a field with a long history of arable cultivation by the traditional method, and where *C. dactylon* was widespread and the dominant weed. The soil

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type was a medium-grained sandy loam with 6.0% clay, 7.4% silt and pH 5.2. The study was undertaken in the latter part of two rainy seasons on 18 February 1988 and 23 March 1989. Both seasons had above average annual rainfall (July-July) of 639 mm and 589 mm respectively recorded at Sebele Research Station 4 km away. A total of eighteen quadrats of 0.25 m² were sampled in areas of the field where the *C. dactylon* ground cover was 90% or more and no crop had established. Each quadrat was laid on the surface and the top growth was clipped at ground level and removed. The profile under the quadrat was then excavated taking four 5 cm layers to a depth of 20 cm, below which few rhizomes could be seen. Rhizomes and roots were taken back to the lab, washed and separated and dried in an oven at 80^{O}C for 24 hours before weighing.

Experiment planting rhizome segments at different depths

Three experiments were conducted at the Sebele Research Station in a field with a soil type similar to that in the study field. Samples of fresh rhizome were cut into segments with one, two or three buds and these were planted at depths of 5, 10, 15, or 20 cm. In the first year the segments were planted on 18 February 1988 in large pots which were kept in a greenhouse. In the two subsequent seasons, the segments were planted in the field on 9 February 1989 and 29 November 1989, in plots 1 m apart in a randomised block design with four replicates. The plots were kept free of other weeds and were irrigated by hosepipe as necessary.

Shoots were recorded as they emerged and harvested on 30 June 1988, 17 May 1989 and 23 April 1990 respectively from the three experiments. The top growth was dried in an oven at 80^{O}C for 24 hours and weighed. Due to the large number of zero values, analysis of variance was not considered appropriate and only mean values are presented.

RESULTS

Field study on the distribution of rhizomes and roots in the soil

The average top growth dry matter harvested from the quadrats was 311.8 g/m² (SD 85.3) which represents a serious infestation of the weed. There were large differences between layers in the amount of rhizome dry matter present (Table 1). Nearly half of the total was in the top 5 cm layer of the soil with only 10% below 15 cm. In contrast, the roots were evenly distributed between the layers. The amount of rhizome varied between quadrats, especially in the bottom layer, which in four quadrats had none. On average, the large majority of rhizomes were in the layer (0-15 cm) normally disturbed by mouldboard ploughing.

TABLE 1. Distribution of rhizomes and roots of *C. dactylon* at four soil depths under a natural infestation.

Depth	Rhizome weight (g/m²)	%	Root weight (g/m²)	%
0-5 cm	160.2 (70.5)	45	21.3 (14.3)	25
5-10 cm	96.3 (43.0)	27	21.9 (12.5)	26
10-15 cm	61.0 (32.3)	17	22.6 (11.6)	26
15-20 cm	36.4 (38.6)	10	20.1 (15.3)	23
Total	353.9	100	85.9	100

(Figures in parentheses are standard deviations)
Data meaned over 18 samples collected in two seasons

Experiment planting rhizome segments at different depths

A short growing period limited growth in the first two seasons, but even under good conditions in the final season, relatively few of the rhizome segments produced shoots that emerged above ground (Table 2). Emergence started 13-25 days after planting and only one or two shoots were produced per plot or pot. Shoot dry matter gave a measure of the vigour of the shoot(s) and this was unaffected by the number of buds on the segment. Planting depth did have an effect on shoot emergence and vigour, only a few emerged from rhizomes placed below 10 cm and most of those that did emerge were small, though in 1990 one large shoot emerged from 20 cm.

TABLE 2. *C. dactylon* shoot dry weight (g) from rhizome segments with 1-3 buds buried at depths from 5-20 cm.

		1988[1]		1989[2]		1990[2]	
No. of buds	Depth (cm)	Reps.[3]	Wt.	Reps.	Wt.	Reps.	Wt.
1	5	2	4.1	3	5.1	2	124.8
	10	1	1.5	1	0.6	1	3.5
	15	1	0.1	1	0.8	0	0.0
	20	1	0.2	0	0.0	1	43.9
2	5	1	0.1	1	0.6	1	18.9
	10	0	0.0	1	2.6	1	27.5
	15	1	0.2	0	0.0	0	0.0
	20	0	0.0	0	0.0	0	0.0
3	5	2	6.6	2	2.6	2	15.0
	10	2	died	2	2.0	1	43.4
	15	1	died	1	1.6	0	0.0
	20	1	died	0	0.0	0	0.0

[1] Pot trial
[2] Field trial
[3] Number of replicates (of 4) producing shoots

DISCUSSION

The field study showed that, in the sandy soils of southern Botswana, *C. dactylon* is a surface growing perennial of which the large majority of rhizomes occur in the plough layer (0-15 cm). These findings are similar to those of Uygur *et al.*, (1985) who found that no sprouting of rhizomes took place in buds from depths greater than 10 cm. Perez & Labroda (1985) found in Cuba that the success of bud growth declined with depth of burial. In a similar field study to the one reported here, they found 80% of the rhizomes in the top 5 cm of soil.

The purpose of our study was to try and find an explanation for the success of double ploughing in controlling *C. dactylon*. The study field was also used by Riches (1987) and Phillips (1993) for experiments comparing time of ploughing for its effect on *C. dactylon* regrowth. In these experiments the depth of ploughing using tractor draught was about 15-20 cm for the first pass and 20-25 cm for the second pass. The depth of a second ploughing is usually greater due to earlier loosening of soil and the retention of more rainfall than on unploughed land, making plough penetration easier in soil that is hard when dry (LWMP, 1990). These depths are likely to be typical of tractor ploughing. The first ploughing inverts the soil containing the majority of rhizomes, exposing a proportion of them to the desiccating effects of the sun and wind. Although the roots are evenly distributed in the soil profile, a proportion of them are likely to suffer desiccation as well. If the first ploughing is done during the dry winter, the rhizomes and roots will be exposed for longer, so increasing the amount of desiccation. The interval between the first and second ploughings of spring double ploughing can vary from a few days to a few weeks depending on the rainfall pattern, the aim being to wait for a storm giving about 15 mm of rain which is adequate for planting. Winter and spring ploughing gave better control of *C. dactylon* regrowth than double spring ploughing (Phillips, 1993), indicating that desiccation is an important factor in control. The results of the experiments comparing shoot production from rhizomes buried to different depths, indicates that rhizomes ploughed below 10 cm will be less successful at producing new shoots than those nearer the surface. A second ploughing is therefore deep enough to bury many of the rhizomes to a depth where production of new shoots will be restricted. The combination of the effects of the two factors, desiccation and deep burial, is proposed as a likely explanation for the observed success of double ploughing in controlling *C. dactylon.*

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HERBICIDE APPLICATIONS: EQUIPMENT DESIGN FOR SMALL-SCALE FARMERS

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ABSTRACT

Weed suppression in the early stages of crop establishment is crucial if optimum yields are to be obtained. If herbicides are used, water for conventional hydraulic spraying is often difficult to obtain during the early part of the season. Intra-row band treatment, very low volume sprays and improved application equipment can reduce the volume of water required and chemical control can be integrated with cultural controls. Narrow-swath band treatment requires specific nozzles and uniform pressure to achieve accurate herbicide placement. 1 bar pressure at the nozzle can be maintained by fitting a spray management valve to either lever-operated or compression sprayers, thus reducing the risk of spray drift. A new dispensing system has also been designed to facilitate accurate metering of pesticide concentrate and thus eliminate mixing of sprays by the operator. Limiting the area to be treated and changes in equipment can reduce the costs of chemical weed control.

INTRODUCTION

Small-scale farmers have traditionally hand-hoed their crops or manually pulled weeds for animal-feed. Manual weeding of tropical crops may require over 50 per cent of the farmer's time thereby restricting time for other activities (Akobundu, 1987). Often manual weeding is delayed until weeds are large enough to pull, but this can cause crop root disturbance, particularly with some crops such as groundnuts (Gworgwor and Lagoke, 1992) and when rhizomatous grass weeds are removed. Careful weeding to avoid crop disturbance, especially in the intra-row, slows down the rate of weeding and on some farms, part of an area sown with crops may be subsequently abandoned because the farmer has insufficient time to weed the area at least twice in the first 6 - 8 weeks of crop development. In consequence, yields attained by many farmers in developing countries are much lower than could be achieved by timely weeding (Akobundu, 1980). Labour which is seasonally employed for weeding is often less available now as people migrate to towns. To avoid the drudgery and back-breaking work of weeding, the need for farmers to use herbicides is increasing as inefficient manual-weeding becomes more expensive. However, the small-scale farmer is faced with a number of problems associated with herbicide application. These include:-

a) unavailability of appropriate products in a small pack.
b) finance to purchase the most appropriate product.
c) equipment to apply herbicides - a separate sprayer to that used for insecticides and fungicides may be advised to avoid subsequent damage to crops, especially cotton, due to traces of herbicide remaining in a sprayer.
d) accurate application as few farmers are trained in proper calibration of their sprayer, and many use the equipment incorrectly.
e) insufficient water for application at the beginning of the rainfall season.
f) poor quality water containing sediment that affects the performance of a herbicide and may block spray nozzles.

g) the risk of spray drift of a herbicide from one area to an adjacent crop, especially in inter-crop farming systems.

This paper describes some recent developments of equipment that can be used by small-scale farmers to increase the efficiency of herbicide application.

INTRA-ROW TREATMENT

Herbicides have often been evaluated as sprays applied in over 200 litres per hectare covering the entire crop area. In many row crops sown in 0.9 - 1.0 metre row spacing, the inter-row soil surface may become very hard with little infiltration of rain water. Cultivation of the inter-row is often necessary, sometimes with tied ridges to improve utilisation of rain, thus in these circumstances there is a need to confine the herbicide treatment to the intra-row area, where hoeing or hand weeding is slower and more prone to cause crop damage. The intra-row treatment requires a spray nozzle with a narrower angle to confine treatment to a swath of 0.2 - 0.3m. This can be achieved by either using a specific fan or deflector nozzle with a narrower angle (40 or 25°) compared to the usual 80 or 110° nozzles, by keeping the nozzle closer to the top of the ridge or by angling a nozzle obliquely across the ridge. Conventional fan nozzles with a reduced dosage along the edge can be used but even-spray nozzles are recommended for these band treatments to ensure more uniform dosage across the intra-row. When combined with mechanical cultivation of the inter-row, spray at the edges of the treated area may be wasted when covered by fresh untreated soil.

In many tropical farms, a considerable amount of time is spent weeding cereal crops, such as maize, in order to avoid yield losses of 40 - 60 per cent which are common when weeding is inadequate (Akobundu, 1987). Where farmers do this to ensure adequate food supplies, the use of an intra-row herbicide treatment would be expected to speed up the cultivation of the inter-row and allow more timely sowing of other crops such as cotton.

VERY-LOW VOLUME SPRAYS

An extremely large range of different nozzles has been designed, but most manually operated sprayers in the tropics are either only fitted with a variable cone nozzle or a high volume deflector nozzle. At the beginning of the season, water supplies are often poor as the levels in local boreholes are at their lowest or a stream may not have started to flow. If the flow rate of a nozzle is too high - say 2 litres per minute, then a 15 litre knapsack would require refilling every 7.5 minutes, and at 300 litres per hectare thirty tankloads would be needed. Ideally the sprayer should be equipped with a standard nozzle body with a set of interchangeable tips. On some sprayers it is not possible to change the nozzle tip, but the farmer needs to have a nozzle of lower output, say 0.5 litres per minute. Unfortunately, the main difficulty with conventional hydraulic nozzles is that the smallest orifices needed to reduce the total volume of spray applied are very prone to blockage by contaminants in the water supply. Small particles of sand are also abrasive and erode nozzle tips very rapidly. Some very-low volume deflector nozzles were designed (Wijewardene, 1982) to apply 50 - 100 litres per hectare, but the smallest was very liable to blockage (Turner, 1985). Nevertheless there are nozzles that can apply 100 litres per hectare which are suitable for herbicide application (Teoh, 1991).

Alternatively, reduced volume herbicide application can also be achieved by using spinning-disc nozzles, but so far most of these used in the tropics have aimed at treating swaths of 1 m or wider, with application rates in the 20-60 litres per hectare range (Teoh *et al.*, 1983). Narrow swaths are possible by shrouding part of the periphery of a spinning disc (Garnett, 1981), but shrouding requires recycling of the spray liquid collected on the shroud. Suitable equipment is available, but not fully evaluated under tropical conditions (Clayton, personal communication).

The main advantage of the spinning disc nozzle is that by controlling the rotational speed, droplet size is controlled so that there is less risk of downwind drift. This is particularly important in small farmer cropping systems, where a number of different crops are grown in close proximity.

DRIFT CONTROL

Where farmers are using lever-operated sprayers, the pressure of the spray emitted from the nozzles fluctuates to some extent with each stroke of the pump. The pressure is often too high and too many small droplets liable to drift from the intended target are produced. Similarly farmers using a compression sprayer will over-pressurise the spray initially, and then allow it to fall below the optimum pressure.

These problems can be overcome by fitting a pressure control valve. Such valves have been available for many years, but they were expensive and were adjustable. This resulted in few being used and often the pressure was set incorrectly. The new Spray Management Valve (SMV) (Fig. 1) (Craig, *et al.*, 1993a) is a combination of a diaphragm check valve and a small piston in the valve that ensures a constant output pressure irrespective of an input pressure above the minimum pressure needed to open the valve. The SMV can be fitted to any existing manually operated sprayer.

Operational studies in Malaysia have confirmed that as the herbicide spray is maintained at 1 bar pressure, there is less drift, the sprayer tank is emptied over a longer period and efficiency of application is increased by over 30 per cent (Teoh, 1991).

PESTICIDE DISPENSING SYSTEM

The operator is most exposed to contamination by the pesticide when opening the product container, measuring out a required amount and mixing it with water (Craig and Mbevi, 1993). Often when pouring small quantities of the product into a small measure, liquid is spilt over the operator's fingers. Some products are now packaged in a container with a built-in measure (Pfalzer, 1993), but these are not yet readily available in rural areas. However, in recognising the problem of operator contamination, health and safety authorities in many countries are now insisting on the development and use of closed transfer systems. Several different systems have been introduced for tractor-mounted equipment, but little attention has been given to the small-scale farmer using manually operated sprayers. Changes in formulation, with the development of water dispersible granules (Pfalzer, 1993) that can be packaged in small affordable water-soluble plastic sachets enable fixed dosages to be added directly to a spray tank. However the farmer has to use a complete number of tank loads so he may end up with an area that is untreated or with some mixed spray left in his sprayer.

An alternative approach designed for solutions or particulate suspensions of pesticide is to use a disposable container dispenser (Craig *et al.*, 1993b). This has been designed to meter a concentrate liquid into a stream of water at a pre-determined rate. The pesticide is contained in a flexible bag inside a plastic bottle. In the neck of the bottle is a metering and non-return valve. The container is attached to a specially designed trigger valve (Fig. 2) which incorporates a spray management valve as described above. Standard pesticide containers of less than 1 litre capacity are expected to have a neck

Figure 1

Spray Management Valve

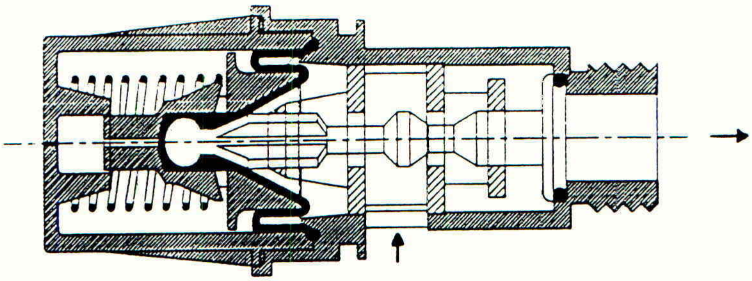
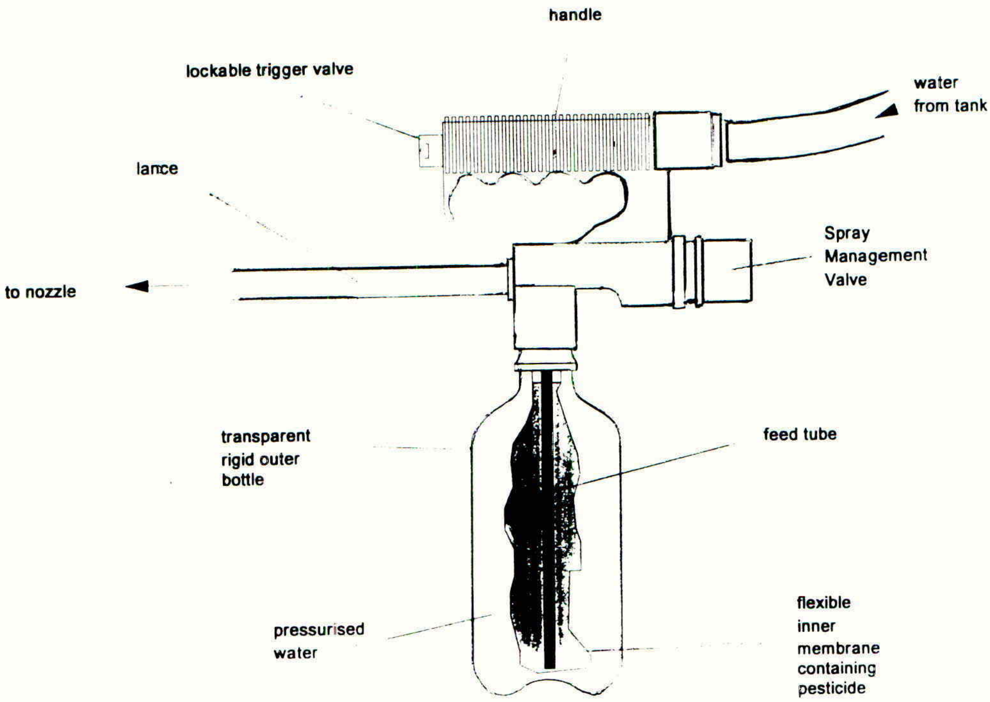


Figure 2

Closed pesticide delivery system for manually operated sprayers



diameter of 45mm. Use of this packaging system eliminates the need for the farmer to calculate how much pesticide is needed for his field as any unused chemical in the container can be retained for a future application. The risk of operator contamination is eliminated and the farmer needs to put only water in the sprayer tank. When the pesticide has been used, the container can be returned to the supplier for disposal or recycling. The modified trigger valve enables the pesticide dispensing system to be fitted to any existing manually operated sprayer. This new design has not yet been accepted by commercial companies, but with increasing legislation controlling the disposal of pesticide waste, the returnable container will increase in importance.

DISCUSSION

If herbicides are to be applied by small-scale farmers in the tropics, the cost of the treatments must be kept as low as possible in relation to labour costs during the period of peak demand when crops are established and with yield increases to justify their use. With fewer resources of casual labour, more farmers will need to consider the use of herbicides, but if they are to be incorporated into their farming system, the farmer will require training and provision of all the inputs needed. As small areas of a farm will have different crops, knowledge on which chemical to use and correct application is particularly important to avoid possible residue problems affecting a subsequent crop. Thus accurate application is more than the supply of chemicals and sprayer. The most appropriate products need to be supplied in a suitable pack with clear instructions in the vernacular and equipment has to have the correct nozzles. The Spray Management Valve and dispensing system would enable farmers to improve their accuracy and safety of application. Limited and careful use of herbicides could significantly improve yields of food crops as well as cash crops and play as important a part as in the large monoculture farming systems.

ACKNOWLEDGEMENTS

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CRITICAL PERIOD OF WEED COMPETITION IN RUBBER SEEDLINGS

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ABSTRACT

Results from a one-year experiment in a nursery showed that the percentage of buddable rubber seedlings was not affected when weeds were allowed to grow for 4 weeks after transplanting, provided that the crop was kept weed-free thereafter, or when the crop was kept weed-free for the first 6 weeks with no subsequent weed removal. Hence, the critical period of weed competition in a rubber nursery appears to be between the 4th and 6th weeks after transplanting the seedling crop.

INTRODUCTION

Weeds are a serious problem in raising rubber (*Hevea brasiliensis*) planting materials in a ground nursery as they can retard the growth of the seedlings. In addition, the cost of weeding is a major component of nursery maintenance.

Weeds are commonly controlled in rubber nurseries by manual weeding. They are removed by hand and/or a hoe at two-weekly intervals for the first four to five months and at monthly intervals thereafter. Post-emergence herbicides can be used when the seedlings are five to six months old and the bark at the base of the stem turns from green to brown. In order to minimize the cost of weeding, it is important to determine when weeds interfere with seedling growth. The time of weed removal may be as important as the removal itself. Weeding at the wrong time can harm the crop or waste resources without benefit to the crop.

Many studies have been made on the critical period of weed competition in crops including, for example, soybean (Horn & Burnside, 1985; Jackson *et al.*, 1985), cucumber (Friesen, 1978), yam (Akobundu, 1981), cassava (Godfrey-Sam-Aggrey, 1978), onion (Roberts, 1976), beans and maize (Nieto *et al.*, 1968). In nursery tree crops, Iremiren (1986) determined optimum weeding times for oil palm seedlings grown in polybags but no reports are known of similar studies in rubber nurseries.

The main objective of our experiment was to define the critical period of natural weed competition on rubber seedlings in a ground nursery.

MATERIALS AND METHODS

A field study was done on the experimental farm at Sembawa Research Institute for Estate Crops (now known as the Sembawa Research Institute) from March until August, 1992. The soil type was a red-yellow podzol with a pH of 4.5.

Pre-germinated rubber seedlings of clone PR 228 were transplanted at the 'jarum' (needle) stage of growth from bed nurseries into plots measuring 3 m x 3 m at a spacing of 50 cm x 30 cm. The seedlings were subsequently maintained for 20 weeks according to the weed treatments described below. Fertilizer was not applied and treatments for disease control were not needed.

The experimental design was a randomized complete block with three replicates. The treatments were two types of weed removal. In the first type (weed-free), plots were kept free of weeds by hand weeding for 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 weeks, after which time weeds were allowed to grow on the plots until the rubber seedlings were 20 weeks old. In the second type (weed-infested), weeds were allowed to develop for periods of 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 weeks; thereafter the plots were hand-weeded and kept free of weeds until the rubber seedlings were 20 weeks old.

At 20 weeks after transplanting, assessments were made of weeds in the experimental area by counting and harvesting weeds in a randomly placed quadrat of 0.25 m^2 in each plot. Crop parameters assessed at the same time included seedling height and stem diameter from 10 randomly selected plants per plot and the percentage of buddable seedlings on the whole plot (excluding border plants), i.e. seedlings with a minimum stem diameter of 8 mm when measured 10 cm above ground level. The data were subsequently subjected to analysis of variance after square root transformation of weed densities, log $x+1$ transformation of weed weights and arcsin transformation of percentage of buddable seedlings.

RESULTS AND DISCUSSION

Weed infestation

Weeds infesting the experimental area were primarily of two types, grasses consisting of *Digitaria* spp., *Ottochloa nodosa* and *Imperata cylindrica* and broadleaf species consisting mainly of *Borreria alata*. Other weed species occurred inconsistently and at low densities. Dry weights and densities of the mixed weed flora at the end of experiment are presented in Table 1.

Rubber seedling growth

Rubber seedling growth, in terms of height and stem diameter, did not differ significantly ($p > 0.05$) between treatments where weed-free periods of 6 to 20 weeks had been maintained after transplanting (Figures 1 and 2). Heights and stem diameters were significantly reduced ($p < 0.05$) where the weed-free period was only 2 to 4 weeks. This indicates that keeping the plots free of weeds for six weeks after planting was as effective in maintaining rubber seedling growth as complete weed removal for 20 weeks.

When weed infestations were allowed to develop for more than six weeks after transplanting, growth of rubber seedlings was considerably retarded. Moreover, when weed-infested periods continued for more than eight weeks, the seedlings showed very little recovery if weeds were then removed; seedling height and stem diameter were not significantly different from those where weeds were not removed (Figures 1 and 2).

The results indicate that the critical period of weed competition for rubber seedlings in the prevailing conditions was between four and six weeks after transplanting. The main limiting factors to growth in this trial were probably water and nutrients. This is because no fertilizer was used during the period of study and rainfall is relatively low at this time of year (1121 mm for the March to July period of the experiment) compared with the November to March period (7-year average rainfall = 1339 mm) when rubber seedlings are also grown. Under different climatic and edaphic conditions or with different weed floras, the critical period of competition may be different. Further work will elucidate variability at the trial site.

Percentage of buddable seedlings

There were notable differences in the percentages of buddable rubber seedlings between the various weed control treatments. When weeds were removed from the plots for the first six weeks or more after transplanting, a high percentage of buddable seedlings (40.4 to 70.7%) was produced

TABLE 1. Densities and dry weights of weeds infesting rubber nursery at 20 weeks after transplanting

Duration of interference (weeks)	Density (plants/0.25 m^2)		Dry weight (g/0.25 m^2)	
	$\sqrt{x}$	Back-transformed mean	$\log_{10} x+1$	Back-transformed mean
Weed free:				
2	16.4	269.0	2.08	119.2
4	12.7	161.3	1.91	80.3
6	13.1	171.6	1.86	71.4
8	12.4	153.8	1.78	59.3
10	12.8	163.8	1.73	52.7
12	9.0	81.0	1.17	13.8
14	7.9	62.4	0.75	4.6
16	4.9	24.0	0.28	0.9
18	3.0	9.0	0.05	0.1
20	3.1	9.6	0.03	0.1
Weed infested:				
2	3.3	10.9	0.05	0.1
4	2.7	7.3	0.02	0.0
6	3.1	9.6	0.02	0.0
8	4.1	16.8	0.04	0.1
10	5.2	27.0	0.09	0.2
12	4.3	18.5	0.06	0.1
14	5.4	29.2	0.10	0.3
16	6.5	42.3	0.18	0.5
18	6.5	42.3	0.20	0.6
20	21.5	462.3	2.11	127.8
LSD ($p = 0.05$)	4.4		1.88	

(Figure 3). However, significantly ($p<0.05$) lower percentages (7.3 to 22.3%) were obtained when the nursery was clean-weeded for only two to four weeks after transplanting.

When the nursery was left unweeded for 10 weeks after transplanting and then kept weed-free, only 19.3% of the rubber seedlings had reached buddable size by the 20th week. Weed-infested periods of 12 or more weeks after planting produced only 17.0 to 2.1% buddable seedlings, not significantly different ($p>0.05$) from the treatment where no weeding was done for 20 weeks (Figure 3).

The practical value of this work is that weed management inputs to rubber nurseries can be rationalized. The product of a rubber seedling nursery is budded stock, so it is important to produce plants of buddable size as quickly and as efficiently as possible. The weed management aspect of this process should ensure that the rubber nursery is free of weeds between the 4th and 6th weeks after transplanting. In practice, this would probably necessitate three weedings at intervals of two weeks after transplanting. Alternatively, a herbicide treatment could be used which suppresses weed growth for at least six weeks.

FIGURE 1. Height of rubber seedlings 20 weeks after transplanting

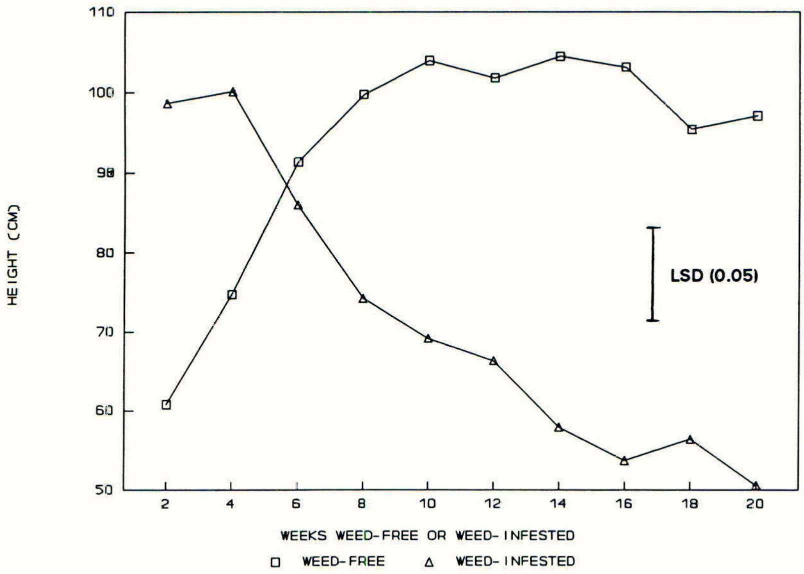


FIGURE 2. Stem diameter of rubber seedlings 20 weeks after transplanting

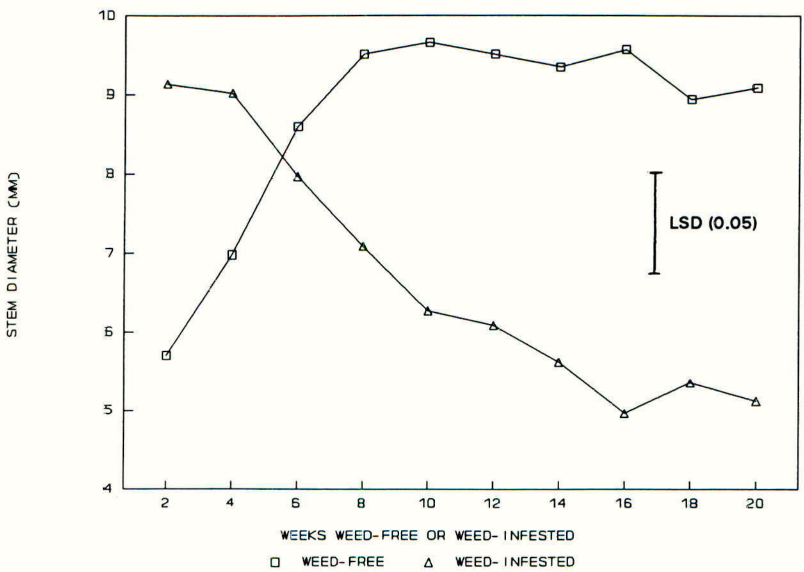
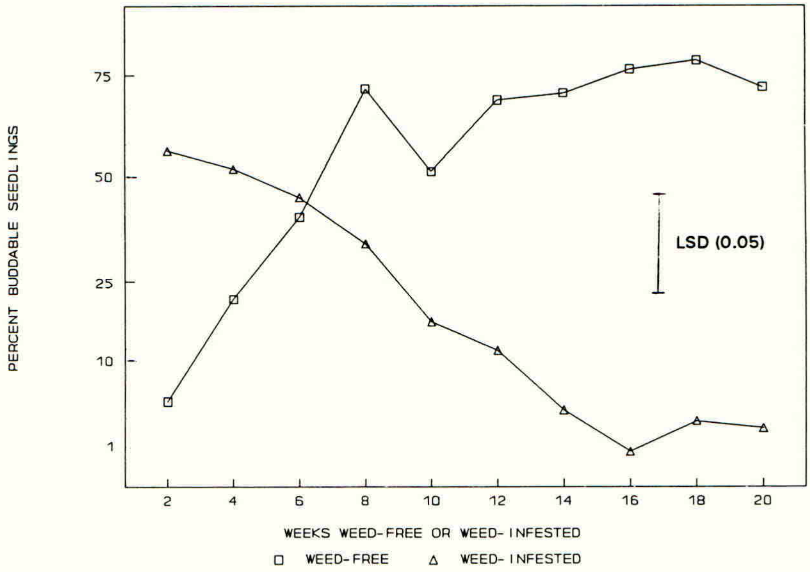


FIGURE 3. Percentage of buddable rubber seedlings 20 weeks after transplanting



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STUDY AND MANAGEMENT OF ITCHGRASS (*Rottboellia cochinchinensis*) IN THE PACIFIC REGION OF COSTA RICA.

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ABSTRACT

Studies of integrated management systems and seed behaviour in the soil for *Rottboellia cochinchinensis* have been conducted in a maize-bean rotation in the seasonally arid area of NW Costa Rica. Seed viability at the soil surface and down to 10 cm was less than 15% after 12 months. The greatest dormancy was found at 20 cm depth (24%). By the second maize cycle, herbicides applied during the cropping season reduced itchgrass populations substantially. Fallow management to eliminate seed production and planting without tillage also caused significant reduction in weed populations.

INTRODUCTION

Rottboellia cochinchinensis is an aggressive and competitive annual grass weed that occurs throughout the tropics and subtropics. Its persistency and noxiousness have been related to its high reproductive capacity (de la Cruz, 1975; Bridgemohan & Brathwaite, 1989). Herrera (1989), mentioned that itchgrass is one of the most serious weeds limiting basic grain production in the seasonally dry Pacific and wet Atlantic regions of Costa Rica. Crop losses and the costs of itchgrass control limit planting areas for small and medium-size farmers.

Seed burial is a primary survival mechanism for many weed species, providing a continuing source of weed seeds in crop lands (Dawson & Bruns, 1975). Bridgemohan & Brathwaite (1989), reported that itchgrass seeds remain viable, regardless of burial depth, for 3 to 4 years. On the other hand, Thomas & Allison (1975) reported that the more deeply situated seed remained viable longer than that near the surface, although there were low numbers of viable seeds at any depth after four years.

Tillage is known to affect the distribution and longevity of weed seeds in the soil profile (Schwerzel & Thomas, 1979). Nester *et al* (1984), reported that the density of itchgrass was 34 seedlings/m^2 following an early cultivation but only 3 seedlings/m^2 on uncultivated treatments. We also suspected that seed production during the fallow period might be an important source of plants for the following cropping season and that this might reduce the impact of other control measures. The objectives of this research were to determine the effects of integrated management practices, consisting of combinations of different tillage practices, chemical controls during the crop cycle and during the fallow, on subsequent itchgrass populations and to estimate seed longevity at different levels in the soil profile.

MATERIALS & METHODS

Experiment 1. Integrated *R. cochinchinensis* management program.

A field experiment is being conducted in a maize-beans-fallow rotation at the University of Costa Rica Regional Center in Santa Cruz, Guanacaste, in NW Costa Rica. The trial evaluates combinations of tactics for their ability to reduce itchgrass plant populations to a manageable level. The tactics being evaluated are fallow management (during the dry season from November to May): handweeding, paraquat application (applied at 0.5 kg AI/ha, 250 l/ha) and no weeding; tillage practices: zero tillage and conventional tillage (one pass of a disk plow to 20 cm depth plus two passes of a disk harrow); in-crop control (pendimethalin plus alachlor 1.0 Kg + 2.4 Kg AI/ha (H1); pendimethalin at 1.25 (H2) and 1.5 Kg AI/ha (H3); no control (H4)). The herbicides were applied pre-emergence following planting in both crops, using a four nozzle knapsack sprayer pressurized with compressed CO_2 with a calibrating volume rate of 285 l/ha at 207Kpa. The nozzles were even flat spray tips 8002 stainless steel (50 mesh). Fallow management practices were initiated during the dry season of September 1991, prior to the maize planting of a maize-bean rotation in May 1992. Maize was planted at the beginning of the rainy season in May and beans was planted immediately after maize harvest in September. Average itchgrass population on the trial site in September 1991 was 58 plants/m^2. Itchgrass populations have been evaluated in 0.25 m^2 quadrants at 15 and 45 days after planting of each crop. The maize planting of the second cycle of the rotation was made in May 1993, with weed management practices applied as described for the first season.

Itchgrass population estimates during the May 1993 maize crop, made at 15 and 45 days after planting, were subjected to analysis of variance using a split-split-plot model with sampling dates as repeated measures. Fallow management was the main plot factor, tillage system was the subplot factor, and control practices during the crop cycle were the sub-subplot factor. All weed densities were transformed to $\sqrt{x}$+ 0.5 prior to analysis.

Maize was harvested in September 22, 1992 and August 31, 1993 from 12 m^2/plot. Yields were converted to kg/ha at 12 % moisture and subjected to analysis of variance using the same model.

Experiment 2: Itchgrass (*R. cochinchinensis*) seed bank behaviour.

Mature spikelets of *R. cochinchinensis* were hand harvested from plants infesting maize at Santa Cruz, Guanacaste, in October 1991. Samples of 100 seeds were placed in 10 by 10 cm, 140-105 mesh, water permeable, polypropylene packets. Packets were buried in the field in a clay soil for different burial times (1, 2, 4, 6, 8, 10 and 12 months) at 0, 5, 10 and 20 cm depths in February 1992, during the dry season. The experimental design was a split-plot replicated in three blocks. Main plots were burial times and sub-plots were burial depths. The experimental area was not cultivated and was kept weed-free by hand weeding. Rainfall during the 12 months was 1457 mm. Seed packets were collected after the planned burial durations and analyzed after air-drying for 48 hours. A modified Schafer & Chilcote (1969) model was followed for partitioning of recovered seed: $S = P_{ex} + P_{end} + D_g + D_n$, where S is the total number of itchgrass seed initially buried, P is the population's persistent portion, and D is the non-persistent portion. The non-persistent population (D) was separated into two parts, seeds germinating in situ (D_g) and seeds losing viability (D_n); separation between D_g and D_n was done by counting emerged radicles. Seeds that did not germinate were placed under screenhouse conditions and germination counts made after 15 days. Seeds that germinated were considered as seeds undergoing enforced dormancy (P_{ex}) at recovery time. A tetrazolium test was conducted on seeds that failed to germinate to differentiate between non-viable (D_n) and innate dormancy (P_{end}). Data for the 12 month samples were transformed to arc-sin $\sqrt{\%}$ and analyzed by analysis of variance.

RESULTS AND DISCUSSION

Experiment 1. Integrated *R. cochinchinensis* management program.

Population density.

In the May 1993 maize crop, the third planting since the trial was initiated, there were significant effects due to the management practices ($P<0.05$) (Table 1). There was a higher itchgrass population in plots without fallow management compared to those with fallow management (Table 1). Also there were lower itchgrass population in zero tillage than in conventional tillage plots ($P<0.05$).

However, use of any of the herbicides had the largest effect on itchgrass populations during the crop cycle ($P\leq0.0001$). This was greater than the effect of either tillage or fallow management (Table 1). There were only small differences in itchgrass populations among the herbicide programs used for in-crop control and between the manual and herbicidal methods used for fallow management. There were no significant interactions between the main management practices, so the combination of zero tillage with the best available methods of fallow management and in-crop controls is likely to provide the best integrated program for itchgrass control.

TABLE 1. Mean population density of *R. cochinchinensis* as affected by fallow period management, tillage and in-crop control in maize planted May 1993 (plants/0.25m^2).

Component	Transformed overall mean[1]	Mean plants 15DAP[2]	45DAP
FALLOW MANAGEMENT			
Manual weeding	1.40	1.59	2.73
Paraquat	1.55	1.89	3.23
No weeding	1.81	3.09	4.50
SED (6)	0.15		
TILLAGE			
Zero	1.49	1.83	3.11
Conventional	1.68	2.55	3.86
SED (9)	0.11		
IN-CROP CONTROL			
Pend+alachlor (H1)	1.24	0.77	1.75
Pendimethalin (H2)	1.16	0.60	1.54
Pendimethalin (H3)	1.02	0.27	1.13
No control (H4)	2.94	7.13	9.54
SED (54)	0.10		

[1]from ANOVA of $\sqrt{x+0.5}$ transformed data with 15 and 45 days after planting as repeated measures.
[2]days after planting.

Similar conclusions can be drawn when selected control programs are followed throughout the trial period (Table 2). These can be contrasted with two programs that include no measures specifically directed against the weed and can thus be considered as controls. The lowest itchgrass populations were observed with a management program that included pre-emergence control with herbicides, weed elimination during the fallow period and zero tillage.

Crop production.

In 1992 and 1993, only herbicide use as in-crop treatment had a significant effect on yields ($P \leq .0001$). No other single factors significantly affected yields. However, in 1993, the high rate of pendimethalin (H3) gave a higher yield in conventional tillage than in zero tillage, whereas for all the other in-crop treatments the reverse was true. The interaction was significant ($P<0.05$). An indication of the main factor effects can be observed in Table 2 in which maize yields in selected control programs are followed throughout the experimental period. Yields in 1992 were higher overall than in 1993, probably due to low rainfall in July (124 mm), just after flowering. This was probably also the explanation for the larger differences between the no control and herbicide control treatments in 1993. Itchgrass plants in the no control treatments were very vigorous and competed more strongly with maize than in 1992 when maize growth was not held back by poor soil moisture.

TABLE 2. Effect of selected integrated control programs on *R. cochinchinensis* populations (untransformed mean plants/ $0.25m^2$) and crop yield (kg/ha) at 12 % moisture over three sowing cycles.

Practice	Itchgrass population 5-92 45[1]	9-92 45	5-93 45	Crop yield 5-92 Maize	5-93 Maize
WITH IN-CROP CONTROL BY HERBICIDES[2]					
Fallow management					
Zero tillage	3.5	1.2	1.0	3525	2908
Conventional tillage	4.1	2.5	1.5	3688	2917
No Fallow management					
Zero tillage	3.2	1.3	2.0	3708	2617
Conventional tillage	4.5	2.9	2.1	3618	2158
NO IN-CROP CONTROL					
No fallow management					
Zero tillage	18.9	6.5	10.4	2396	650
Conventional tillage	18.5	11.1	13.5	2146	700

[1]days after planting.
[2]data are means for the three herbicide treatments H1-H3.

Experiment 2. Itchgrass (*R. cochinchinensis*) seed bank behaviour.

Seeds losing viability (D_n) at soil surface (due to rotting) were 48% of the initial population after 12 months ($P<0.05$) (Table 3). The most seeds that germinated in situ (D_g) was at

TABLE 3. Effect of depth of burial for 12 months on depletion (D) and persistence (P) of a *R. cochinchinensis* seed population, data are transformed (arc-sin $\sqrt{\%}$) means.

	Depths (cm) 0	5	10	20	SED	df
FATE OF SEED						
Persistence	0.362	0.383	0.334	0.509	0.240	(6)
In situ germination	0.063	0.073	0.068	0.067	0.015	(6)
Viability loss	0.069	0.057	0.065	0.055	0.012	(6)

5 cm depth (53%). For depths greater than 5 cm in situ germination decreased to 46%.

The greatest dormancy ($P_{ex}+P_{end}$) after 12 months was observed at 20 cm depth (24%). If itchgrass seed set is prevented, it seems likely that it could be possible to greatly reduce itchgrass seed populations in arable lands within 1 year, particularly if zero tillage is applied. These results are similar to those of Bridgemohan *et al* (1991).

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FIELD-EVOLVED IMAZAPYR RESISTANCE IN *IXOPHORUS UNISETUS* AND *ELEUSINE INDICA* IN COSTA RICA

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ABSTRACT

Field-evolved resistance to acetolactate synthase inhibitors has been previously documented for sulfonylurea herbicides but not for imidazolinones. The first confirmation of imazapyr resistance, found in populations of *Ixophorus unisetus* growing along ditchbanks in rice producing areas in the Northern Pacific region of Costa Rica, is described. These populations were subjected to imazapyr applications for over five years before becoming resistant. A second case was detected in the Central Valley of Costa Rica in a poultry operation, where goosegrass (*Eleusine indica*) became the most prevalent weed after continuous overuse of imazapyr for more than 4 years. Screenhouse studies indicate that selected biotypes of *I. unisetus* are 5 to 80 times more resistant to imazapyr than the most susceptible biotype. The resistant biotype of goosegrass required 14 times more imazapyr for a 50% growth reduction. There was some degree of cross resistance to other imidazolinones and some sulfonylureas.

INTRODUCTION

Weed populations that have evolved resistance to sulfonylurea herbicides, which inhibit acetolactate synthase (ALS), have been previously characterized. Sulfonylurea-resistant biotypes of four broadleaf weeds species (*Lactuca serriola*, *Kochia scoparia*, *Salsola iberica*, and *Stellaria media*) were selected in North America by this class of herbicides (Thill *et al.*, 1991). In Australia and in England, two grasses (*Lolium rigidum* and *Alopecurus myosuroides*, respectively) evolved cross-resistance to sulfonylureas after being selected with other non-related herbicide families (Thill *et al.*, 1991).

Imidazolinone herbicides also inhibit ALS but no field- evolved resistance has been documented until now. Some sulfonylurea-resistant biotypes of *L. serriola* and *K. scoparia* exhibit cross-resistance to imidazolinones (Mallory-Smith *et al.*, 1990; Primiani *et al.*, 1990). Imidazolinone-resistant maize is being commercially developed (Newhouse *et al.*, 1991).

Herbicide resistance in grasses is less common than resistance in broadleaves, accounting for about 30% of all reported cases (LeBaron, 1991). *Eleusine indica* (goosegrass), an important weed with worldwide distribution, evolved resistance to dinitroanilines after repeated use of trifluralin in cotton over a period of 10 years in South Carolina, USA (Mudge *et al.*, 1984). *Ixophorus unisetus* (Panicoideae) is not considered a major weed, except along ditchbanks in rice and sugar cane in some areas of Central America. In a few instances, it invades rice fields outcompeting the crop and reducing yields. However, crop losses due to this weed have not been quantified. In Costa Rica, *I. unisetus* is reported at elevations from sea level to 1,200 m. It is also present in Mexico and the rest of Central America, as well as in Colombia, Venezuela, and Cuba (Pohl, 1980).

The objective of the bioassay studies reported here was to determine if field populations of both *I. unisetus* and *E. indica* from Costa Rica have evolved resistance to imazapyr and other ALS inhibitors.

MATERIALS AND METHODS

Plant material

Seed of the allegedly resistant (R) populations of *I. unisetus* were collected from plants growing along ditchbanks on a rice-producing farm in Puntarenas province. These populations (identified as Tijo Blanco and Escuadra) had been subjected to imazapyr applications at commercial rates (0.5-0.7 kg a.e./ha) for over five years. Other populations where imazapyr failed to control this weed after repeated applications were those named Taboga and CATSA-2, collected from sugar cane farms in Guanacaste province. Susceptible (S) populations, probably treated at least once with imazapyr, also came from Guanacaste (El Viejo, CATSA-1, and Palmira); the Carrillos biotype, never treated with imidazolinones, was used as the unexposed control for all biotype comparisons.

R-goosegrass seed was collected from a poultry farm located in the Central Valley, where this weed became prevalent after continuous overuse of imazapyr for more than four years. The S-biotype of goosegrass was obtained from a roadside about 3 km away from the poultry farm.

None of the populations studied of either species had been treated with other imidazolinones or any sulfonylurea herbicide.

Herbicides

I. unisetus was treated postemergence with nine dose rates of imazapyr, sulfometuron-methyl, triasulfuron, and preemergence with chlorsulfuron, imazethapyr, and imazaquin. Goosegrass was sprayed early postemergence with imazapyr, imazethapyr, imazaquin, sulfometuron-methyl, chlorimuron-ethyl, and metsulfuron methyl. Rates used are indicated in Table 1. Commercial formulations of the herbicides were applied in a spray booth (R & D Sprayers, Opelousas, Louisiana, USA) or by a portable CO_2-operated sprayer, both equipped with a flat fan nozzle delivering 200 l/ha.

Experimental procedures

For postemergence treatments, *I. unisetus* seed was germinated in soil at room temperature and seedlings transplanted 10-12 days after emergence to pots containing approximately 0.5 kg of soil. Goosegrass seed was mechanically dehulled and caryopses were germinated in Petri dishes containing Whatman No. 2 filter paper moistened with 0.2% KNO_3. Dishes were placed in a growth chamber at 30°C/20°C day/night temperatures (12 h photoperiod). Seedlings (2-3 cm long) were individually transplanted to pots. Pots were maintained in a screenhouse or outside before and after herbicide treatment. Plants (10 per pot) were sprayed with the corresponding herbicide at the 5-6 leaf stage for *I. unisetus* or at the 2-3 leaf stage for goosegrass. Above-ground tissue of *I. unisetus* plants treated with imazapyr was harvested 7 days after application (DAA); and those treated with triasulfuron or sulfometuron-methyl, at 15 DAA to determine both fresh and dry weights. Goosegrass plants were harvested 15 DAA. Two weeks after initial harvesting, clipped plants that resprouted were counted and weighed.

TABLE 1. Rates of herbicides for bioassays with *I. unisetus* and *E. indica*[1].

Herbicide	Dose range (g/ha)[2]	Species	Biotype
Imazapyr	0 - 2400	Ei, Iu	S
	0 - 19200	Ei, Iu	R
Imazaquin	0 - 640	Ei, Iu	S
	0 - 2560	Ei, Iu	R
Imazethapyr	0 - 1200	Ei, Iu	S
	0 - 9600	Ei, Iu	R
Chlorsulfuron	0 - 60	Iu	S
	0 - 240	Iu	R
Chlorimuron-ethyl	0 - 40	Ei	S
	0 - 160	Ei	R
Metsulfuron-methyl	0 - 40	Ei	S
	0 - 160	Ei	R
Sulfometuron-methyl	0 - 300	Ei	S
	0 - 1200	Ei	R
	0 - 75	Iu[3]	S
	0 - 150	Iu	R
Triasulfuron	0 - 200	Iu	S
	0 - 800	Iu	R

1 Abbreviations: Ei: *Eleusine indica*, Iu: *Ixophorus unisetus*, S: susceptible, R: resistant.

2 Rates for imidazolinone herbicides are given in acid equivalent; for sulfonylureas, in active ingredient.

3 El Viejo, S-biotype of Iu, was treated with the same rates used for S-Ei.

For preemergence herbicides, *I. unisetus* seed was germinated in a 50:50 mixture of soil:sand and transplanted (10 each) into pots with soil, when the radicles were about 1-3 mm long. The following day, pots were sprayed as before and surviving plants were counted and weighed 30 DAA. The response of biotypes CATSA-1 and Taboga to imazethapyr and chlorsulfuron could not be determined because seed failed to germinate.

A completely randomized design with four replications was used for the bioassays, unless initial plant growth differences were noticeable when a randomized complete block design was more suitable. Data were analyzed by regression using appropriate transformations when needed and GR_{50} (herbicide rate required to reduce fresh weight by 50%) or LD_{50} values were calculated from regression equations. Most responses were described by exponential or polynomial functions. Data presented here correspond to fresh weight evaluations and regrowth counts.

RESULTS AND DISCUSSION

A wide range of responses to ALS inhibitors was observed among *I. unisetus* biotypes. GR_{50} values and resistance indexes (RI: ratio of GR_{50} of each biotype over Carrillos biotype) are presented in Tables 2 and 3. Biotypes originally considered as susceptible were affected by imazapyr similarly to the control (Carrillos) biotype as indicated by GR_{50} values. Taboga, a biotype collected from a sugar cane farm with imazapyr-use history was susceptible. The most resistant biotypes (Tijo Blanco and Escuadra) came from the farm (Hacienda San Agustín) where imidazolinone resistance was originally suspected. Escuadra is almost 80 times more resistant than Carrillos and plant regrowth could be inhibited only after spraying a rate 32 times higher than that required for the same effect in the susceptible biotype. Only Tijo Blanco and Escuadra exhibited cross-resistance to other imidazolinones (Table 3). El Viejo and Palmira had negative cross-resistance (greater sensitivity) to imazethapyr. All biotypes were equally or more susceptible to sulfometuron-methyl and chlorsulfuron than the control biotype. It was not possible to calculate a GR_{50} value for triasulfuron because plants were only slightly affected by this herbicide. However, Tijo Blanco was relatively more susceptible to triasulfuron than the other biotypes (data not shown). Lack of efficacy of sulfonylureas against *I. unisetus* was expected since these herbicides are commercially used to control broadleaves and show selectivity to grass crops and weeds.

Primiani et al. (1990) found a resistance index of 30 by visually comparing a chlorsulfuron-resistant biotype of *K. scoparia* with a susceptible one, and observed different degrees of cross-resistance to other sulfonylureas and imazapyr.

TABLE 2. Relative response of *I. unisetus* biotypes to postemergence application of imazapyr and sulfometuron-methyl.

Biotype	Imazapyr			Sulfometuron-methyl		
	GR_{50} (g/ha)	RI[1]	RIAR	GR_{50} (g/ha)	RI	RIAR
Carrillos	22.0	1.00	300	10.5	1.00	>75
El Viejo	22.8	1.04	75	1.9	0.18	150
CATSA-1	33.9	1.54	150	0.6	0.06	>75
Palmira	47.4	2.15	38	17.7	1.69	>75
CATSA-2	<150.0	<6.82	150	1.0	0.09	150
Tijo Blanco	117.6	5.35	4800	0.5	0.05	>150
Taboga	45.6	2.11	300	2.6	0.25	>150
Escuadra	1725.0	78.80	9600	12.0	1.15	>150

[1] Abbreviations: RI: Resistance index, RIAR: Lowest regrowth-inhibiting applied rate in g/ha.

TABLE 3. Relative response of *I. unisetus* biotypes to preemergence application of chlorsulfuron, imazaquin and imazethapyr.

Biotype	Chlorsulfuron		Imazaquin		Imazethapyr	
	GR_{50} (g/ha)	RI[1]	GR_{50} (g/ha)	RI	GR_{50} (g/ha)	RI
Carrillos	14.04	1.00	10.5	1.00	53.2	1.00
El Viejo	<1.47	<0.03	7.6	0.72	6.5	0.12
CATSA-1	-	-	14.4	1.37	-	-
Palmira	3.01	0.21	9.1	0.86	11.6	0.22
CATSA-2	1.08	0.08	15.6	1.48	66.9	1.26
Tijo Blanco	6.13	0.44	155.7	14.83	475.2	8.93
Taboga	-	-	14.0	1.33	-	-
Escuadra	21.28	1.52	151.9	14.47	628.0	11.80

[1] RI: Resistance index.

Imazapyr-resistant goosegrass showed cross-resistance to imazaquin, sulfometuron-methyl, chlorimuron-ethyl and, especially, to imazethapyr (Table 4). Metsulfuron-methyl had little effect on goosegrass growth; this herbicide is commonly used for selective broadleaf weed control in rice and other crops. The level of resistance to imazapyr in goosegrass (RI = 14-21) is moderate in comparison to that observed with the most resistant biotype of *I. unisetus* (RI = 79).

TABLE 4. Response of two *E. indica* biotypes from Costa Rica to imidazolinone and sulfonylurea herbicides.

Herbicide[1]	--------- GR_{50} (g/ha) --------- S-Biotype		R-Biotype		RI		Regrowth LD_{50} (g/ha)		
	PFW	RFW	PFW	RFW	PFW	RFW	R	S	RI
IPR	34	49	460	1030	14	21	1460	46	32
ITR	150	210	>9600	>9600	>64	>46	>9600	390	>25
IQN	525	592	>2560	>2560	>5	>4	LI	LI	-
SFM	10	9	62	156	6	18	921	21	43
CME	28	30	>160	>160	>6	>5	LI	LI	-
MSM	ND	LI	ND	LI	-	-	LI	LI	-

[1] Abbreviations: IPR: imazapyr, ITR: imazethapyr, IQN: imazaquin, SFM: sulfometuron-methyl, CME: chlorimuron-ethyl, MSM: metsulfuron-methyl, PFW: plant fresh weight, RFW: regrowth fresh weight, RI: Resistance index (R/S), S: susceptible, R: resistant, ND: not determined (data did not allow calculation), LI: Low growth inhibition even at highest rates precluded calculation.

The mechanism of resistance to imidazolinones in *I. unisetus* and goosegrass has not been studied. Resistance to sulfonylureas in resistant broadleaf weeds is due to decreased sensitivity of the ALS enzyme to these herbicides (Thill *et al.*, 1991). The discovery of imazapyr resistance in these two weeds offers the opportunity to further study physiological aspects of ALS-inhibiting herbicides.

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