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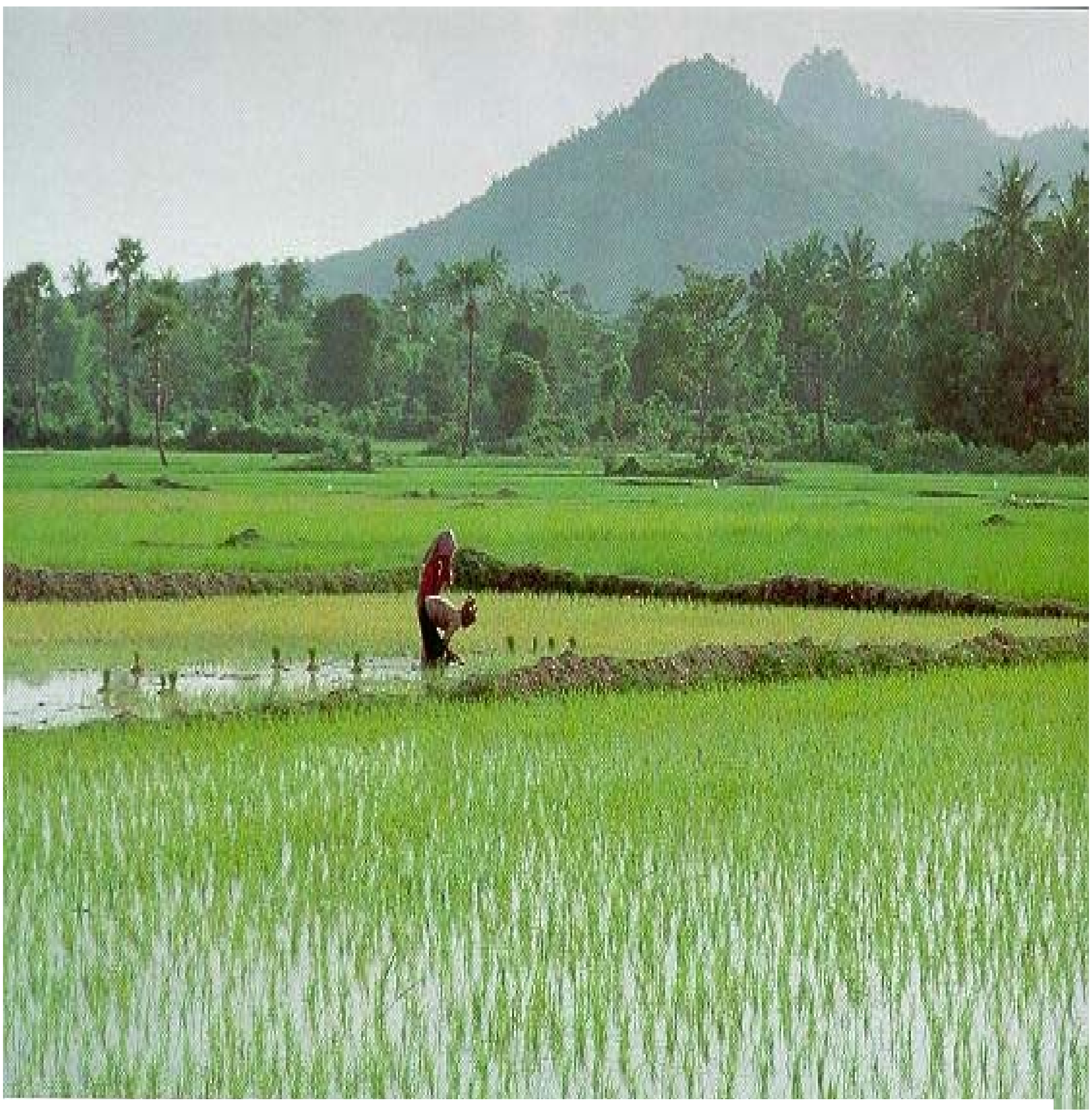

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The Cambodian Society of Agriculture

The Cambodian Society of Agriculture (CSA) provides a forum where members can share information, raise important concerns and identify solutions for agricultural problems facing the people of Cambodia.

The formation of the CSA and the publication of the *Cambodian Journal of Agriculture* come at a crucial time for agricultural development in this country. The scientific community has rapidly expanded and a strong platform has been built from which Cambodia's research community can blossom. The Society now hopes to guide, and encourage agricultural research, extension and education in Cambodia.

The Society advocates the development of economically efficient, ecologically sustainable and socially responsible agriculture in Cambodia, while also providing opportunities for the dissemination of research results and exchange of information.

The importance of sustainable agricultural development to the identity of the CSA is made clear by the Society's logo. Its hexagonal shape represents science and research and the principles of the Society to enhance the environment. This surrounds a tree with three differently coloured leaves: blue (water), green (agronomy and forestry) and red (earth and livestock).

The Society, originally known as the Agricultural Sectoral Meeting, was officially registered as an organization in 1998. It is coordinated by a committee composed of a president, secretary, treasurer and five executive members all elected annually.

In 2001, 60 financial members from eight countries represented government departments, international organizations and non-government organizations at the Society's monthly meetings. The CSA meets on the last Friday of every month and also hosts seminars by a number of guest speakers.

Funding for the Society comes from membership, sponsorship, donations, and particularly with the help of the Australian Agency for International Development (AusAID).

ការកសាងភាពជាដៃគូរ រវាងសង្គមស៊ីវិល និង ស្ថាប័នស្រាវជ្រាវកសិកម្ម

BUILDING COLLABORATION BETWEEN NGOS AND AGRICULTURAL RESEARCH INSTITUTIONS

Peter Cox[1], Numa Shams[2], Gary Jahn[3], Polly Ericksen[4], and Paul Hicks[5]

សេចក្តីសង្ខេប

ក្នុងប្រទេសកម្ពុជាក៏ដូចជាកន្លែងផ្សេងៗដែរនៅក្នុងតំបន់អាស៊ីអគ្នេយ៍ នេះគឺថា អង្គការក្រៅរដ្ឋាភិបាល មានតួនាទីយ៉ាងសំខាន់ ក្នុងកិច្ចអភិវឌ្ឍន៍លើវិស័យកសិកម្ម តាមរយៈការពង្រីក និង បង្កើនសកម្មភាពស្រាវជ្រាវ។ ទោះជា យ៉ាងណាក៏ដោយជាទូទៅ គឺមិនមែនជាតួនាទីរបស់ សង្គមស៊ីវិល ក្នុងការបង្កើតប្រពន្ធ័ផ្សព្វផ្សាយ និងស្រាវជ្រាវឡើយ។ អង្គការក្រៅរដ្ឋាភិបាល អាចសម្របសម្រួល ឱ្យមានលទ្ធផល ដែលអាចទទួលបានដោយក្រុមកសិករ ចំពោះសេវាកម្មជំនួយរបស់រដ្ឋាភិបាល ហើយប្រហែលជាលើកកំពស់ការ ប្តូរផ្លាស់សេវាកម្មទាំងនេះ ដើម្បីឱ្យមានភាពពាក់ពន្ធ័ច្រើន ឆ្លើយតបចំពោះសេចក្តីត្រូវការរបស់សហគមន៍។ នៅក្នុងអត្ថបទនេះយើង ធ្វើការបង្កើតគំរោងការងារដើម្បីជួយដល់សង្គមស៊ីវិល ហើយនិងស្ថាប័នស្រាវជ្រាវផ្នែកកសិកម្ម រួមបញ្ចូលទាំងអង្គការអន្តរជាតិ ដើម្បីទទួលបាននូវការរៀបចំសហការ ដែលពោរពេញដោយផ្លែផ្កា។ យើងអាចបញ្ជាក់អំពីលក្ខណៈរបស់កិច្ចសហការ និង បញ្ហា ដែលកំពុងប្រឈមមុខពេលដែលយើងធ្វើសហការ និង អំពីរបៀប ដែលយើងស្វែងរកឱកាសសំរាប់ធ្វើសហការ ដើម្បីអោយមានប្រសិទ្ធិភាព គំរោងសំណើរពិសេសត្រូវបានធ្វើសំរាប់ការចាត់ចែងកិច្ចការនេះត្រូវទាក់ទង ទាំងការយល់ព្រមរបស់ស្ថាបន័ដើម្បីគាំទ្រភាពជាដៃគូ ហើយ និង ប្រភេទនៃរបៀបស្រាវជ្រាវដែលអាចផ្តល់ការផ្តោតដ៏ ត្រឹមត្រូវសំរាប់សកម្មភាព។

ពាក្យគន្លឹះ: NGO, ប្រពន្ធ័ស្រាវជ្រាវ និង ផ្សព្វផ្សាយ, សង្គមស៊ីវិល

ABSTRACT

In Cambodia, as elsewhere in SE Asia, non-governmental organizations (NGOs) have an important role in agricultural development: through extension and, increasingly, research activities. However, it is generally not their role to set up a parallel research and extension system. NGOs can facilitate access by farmer groups to government support services and, perhaps, promote change in these services so they are more relevant to the needs of local communities. In this paper, we develop a framework to help civil society and agricultural research institutes, including international agencies, enter into more productive collaborative arrangements. We discuss the nature of issues to be faced when entering into collaboration, and how we can exploit opportunities for collaboration more effectively. Specific proposals are made for managing this. These relate both to the institutional arrangements to support partnerships and to the kind of research approach that can provide an appropriate focus for joint activity.

Key words: NGO, research and extension systems, civil society.

INTRODUCTION

There is increasing pressure on agricultural research and extension systems to reach resource-poor farmers. Science can be professionally respectable, and technically satisfying, and yet have little impact on the practical farming issues faced by smallholders who may have little voice in the research and political system (Rukuni, Blackie and Eicher, 1997).

One of the reasons for the increased presence of the NGO sector in agricultural research is a change in donor policy towards greater participation and decentralization. The World Bank claims that the role of the public sector has to be redefined to permit multiple approaches which account for user diversity, and to develop partnerships with farmer organizations, NGOs and the private sector for service delivery (World Bank, 1995). This is driven by the perceived need to increase the return on investment in agricultural R&D.

In the last decade, there has been increased interest, by both development specialists and donors, in fostering collaboration between government research and extension organizations (GOs), including international agricultural research institutes, and NGOs (CGIAR, 1997). The community-organizing skills of NGOs are seen to complement the technical skills of government and international agencies.

The issue is about how the research system can incorporate, and respond to, the voices of smallholders, including priority setting and mobilizing political support for agricultural research (Sands, 1988; Tripp, 1991; Rukuni, Blackie and Eicher, 1997; Ison and Russell, 2000). Smallholders are dispersed and often not confident in dealing with the political and social changes that are now taking place. NGOs could play a more active role as a partner of formal sector research systems and farmer groups to get the issues of small farmers onto the

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research agenda, and in engaging researchers to help small farmers resolve them.

NGOs have been able to identify the needs of the rural poor in ways that GOs have not (Farrington, 1997). They attempt to build within local knowledge systems. They have developed innovative extension methods, e.g. farmer-to-farmer extension, and new technologies, e.g. the System of Rice Intensification (Uphoff *et al*., 2002). They work effectively with farmer groups: to manage some kinds of technology such as seed production or pest management; to manage lumpy assets such as capital equipment and infrastructure; and to manage common property resources such as grazing or forest land. These are all skills that are less clearly evident in the formal research sector.

However, even as NGOs are gaining a more important role in agricultural development, their effectiveness is being challenged by some authors. Kaimowitz (1993) notes that in Latin America, after ten to fifteen years of effort, there are still few documented NGO success stories with agricultural technologies. Others argue that the inherently small size of most NGOs constrains their capacity for technology development and transfer (Eicher, 1989).

The common belief that most NGOs succeed in extending their services to the poor in a cost-effective way is also under challenge (White and Eicher, 1999). Thus, NGOs too are under increasing pressure to show large-scale impact on the livelihoods of resource-poor farmers, and that investing in the NGO sector is more effective than the allocation of resources to rural roads, irrigation infrastructure or institutions for agricultural policy development (White and Eicher, 1999).

There are examples of success e.g. Uphoff, Esman and Krishna (1998). But interest in collaboration between agricultural research institutes and NGOs is in part a response to this shared challenge.

This is not as easy as it may sound. NGOs and GOs have been described as “reluctant partners” (Farrington and Bebbington, 1993). Crewe and Harrison (1998) use ethnographic case material from two different organizations (one an international NGO, the other a multi-lateral agency) to expose some of the conflicts and patterns of behaviour surrounding technology-based (expert-based) development. Participation in ‘partnerships’ could merely be a way to reinforce existing patterns of behaviour, rather than a means to challenge them. Cooke and Kothari (2001) question whether participation has become the new tyranny.

Formal forums are required for certain types of interaction, including the joint planning of research and extension agenda (Farrington, 1997). The task for the coming decade will be to develop these in ways that are non-threatening, both to the organizations involved and to the informal interaction they already undertake. They will first need to develop mutual trust and awareness of each other’s activities because formal interaction will depend on this.

NGOs and formal sector research and extension agencies have different skills, different audiences, different values and different criteria for evaluation. But many of these differences mean that these two kinds of organizations complement each other in important ways, both in what they do and how they do it. The potential for synergy, through collaboration in partnerships, appears considerable.

PARTNERSHIPS

The CGIAR (CGIAR, 1997) sees collaborative partnerships between international agricultural research institutes and NGOs and farmers’ organizations as a key strategy for advancing sustainable agriculture in the developing world.

The International Rice Research Institute (IRRI) is currently working towards an integrated system in which farmers, scientists and extension workers collaborate on research and development, implementation, monitoring and impact assessment of improved rice technologies (Morin *et al*., 2001).

Norris (2000), in her study of the impact of the Cambodia-IRRI-Australia Project (CIAP) (an institutional collaboration between IRRI and the Ministry of Agriculture, Forestry and Fisheries in Cambodia), notes that NGO collaboration was an effective strategy for CIAP to leverage its limited resources and broaden its impact in ways that it could not have achieved alone.

Partnership arrangements of various kinds are widely seen as a way of enhancing the effectiveness of both NGO and formal sector organizations through: the decentralisation of research and extension services, improving cost-effectiveness, and addressing equity concerns through better targeting of programmes; and better management of natural resources, especially of the common property or public access resources on which many farmers depend (Alsop *et al*., 2000). Difficulties in establishing links between government organizations, local membership organizations (such as farmer groups) and NGOs can hamper development programmes. Despite this, these authors note that the ability of NGOs to reach disenfranchised groups and to work effectively in a participatory way has increasingly led government agencies to contract NGOs to undertake rural development work for them.

However, linking with NGOs also presents several limitations. With few exceptions, NGOs have little technical expertise. This has long been recognised as a particular weakness for NGO participation in agricultural technology development (Farrington and Bebbington, 1993). In addition, there are serious questions of scale, efficiency and power in connection with this strategy. Scaling-up an intensive intervention often means doing the same thing at more sites rather than the development of different strategies that match (and exploit) the change of scale better (IIRR, 2000). It is not the role of civil society to set up a parallel research and extension system. The intense support for a small client group raises issues about the efficiency (and equity) of client-driven change processes. And NGO involvement in advocacy, e.g. against genetically modified organisms (GMOs) or in favour of sustainable agriculture or gender equity, may be informed more by an external agenda than that of their client groups.

Tripp and Ali (2001) point put that the introduction of most agricultural technology faces a difficult choice between widespread promotion, with an inevitable sacrifice in the quality of the message, and intensive activities in selected villages in order to focus message delivery and demonstrate impact. An intensive approach may be justified, especially for something as complex as integrated pest management (IPM). But this can quickly absorb most of a programme's attention, leaving few resources for more general diffusion strategies. Tripp and Ali point out that, if a pilot project is successful, this quickly becomes a focus of attention and is seen, in Chambers' (1997) phrase, as an 'island of salvation'. On occasion, research institutes appear to adopt a similar strategy.

Ojha and Morin (2001) suggest that partnerships can be more effective than the efforts of individual agencies in extending agricultural technologies to farmers, but only when the partners fulfil their mutually agreed responsibilities. When any of the partners proves to be uncommitted, separate activities may be more effective than partnerships. They propose that the key to successful partnerships is complementarity of effort. In order to achieve this, there has to be mutual understanding of, and respect for, each other's strengths and weaknesses. Continuous dialogue, resource sharing, local partners, support from local leaders, flexibility, and active involvement of all partners in every stage of the partnership programme are all important.

The concept of committed partnerships as an effective means of extending agricultural technology is new, according to Ojha and Morin (2001), and should be promoted through a series of R&D projects. They recommend that considerable time should be allowed to prepare individual agencies for this new way of working. This applies equally to civil society and institutional partners.

Different kinds of inter-institutional collaboration are often distinguished. Thus, Alsop *et al*. (2000) point out that coalitions are an abstract framework within which interactions occur. Coalitions host particular forms of interaction: consultative relationships; contractual relationships; or collegiate relationships. Collegiate relationships exist when there are few power disparities between parties or if these are irrelevant in that situation. They propose that this is the only form of relationship that is always appropriate in a coalition. In practice, this is often difficult to achieve because of differences in skills and in power. Thus, NGO workers or farmers might not be recognised by scientists as co-researchers. Scientists are often seen by NGOs as excessively academic and out of touch with practical realities. The differences in perceptions and modes of working between research institutions and NGOs can be very deep-rooted (Swiss Commission for Research Partnerships with Developing Countries, 2001).

Catholic Relief Services (CRS), an international NGO, recognises that capacity alone is not a sufficient criterion for selecting partners (CRS, 1999, 2001). In CRS' view, a partnership must be built on three dimensions: there is a need for shared vision; it must be based on 'solidarity' i.e. long-term commitment to promoting justice and peace; and it must have an impact on people's lives. This requires both personal and organizational commitment. CRS recognises that it takes time to cultivate strong partnerships.

It is clear that the cultivation of partnerships is not a trivial matter. Things can go wrong and expectations left unmet. The rewards, however, from successful partnerships can be substantial.

INSTITUTIONAL COLLABORATION FOR AGRICULTURAL R&D

In general, NGOs have close associations with rural people. The comparative advantage of government agencies lies in the provision of technology. There is a division of labour between upstream science-based institutes, and national agricultural research and extension systems (NARES) that are more concerned with adaptive research to fit emerging technologies with local agro-ecosystems. Practical mechanisms are required to bring about change through multiple stakeholder interaction.

Alsop *et al*. (2000) maintain that the key policy shifts needed for this are:

- an increase in the numbers and types of actors and/or organizations;
- a move from research station to field-based research and extension on farmers' fields;
- the use of social science perspectives and skills to support change; and
- a recognition of the need for organisational and human capacity building.

Alsop *et al.* (2000) describe process monitoring as a key tool for building and maintaining coalitions. They argue that process monitoring will:

- rapidly provide current information on events relating to performance, and so facilitate managerial response;
- stimulate modification of objectives and strategies in the light of implementation experience;
- validate new approaches and inform the design of further programmes; and
- facilitate communication and improve collaborative relationships.

Although they were able to show gains in all four of these areas in their case study from Udaipur (India), they also note the need for capacity building to do this effectively and the unanticipated emergence of two additional functions (advocacy and lobbying). These functions are well within the domain of both NGOs and formal sector agencies. The trouble is, the positions advocated by these two kinds of organization may be diametrically opposed, e.g. in the case of GMOs or the requirements for low-input non-genetic solutions to production problems.

Biggs and Smith (1995) argue that coalitions for agricultural research can work if they: focus on a particular issue or interest; have informal, and often diverse, membership; have open boundaries; provide common ground for organizations with different motives; and are time-specific. However, Alsop *et al*. (2000) argue that successful coalitions may be spatially constrained and that time-specificity is not always a feature.

To enhance relationships between NGOs and agricultural research institutes (ARIs), the International Institute for Rural Reconstruction (IIRR, 1999) recommended:

- open communication;
- definition of indicators to evaluate the partnership;
- dissemination of research results in user-friendly format;
- transparency in use and allocation of funds;
- clarification of institutional structures and responsibilities;
- clearly-stated expectations, including strengths and limitations of the partnership;
- consideration and planning of cross-cutting issues;
- phasing of the activities with clearly defined goals and targets for each phase; and
- attitude reversals to do away with biases and stereotypes.

Based on the above discussion, we believe that developing partnerships between NGOs and ARIs requires:

- clear policies/guidelines on how research institutes and NGOs should work with each other and with farm communities (Cox *et al*., 1999).
- clarity about the differences in mandate between research institutes and NGOs while working towards common goals and strategies in the partnership;
- agreement on the areas of collaboration;
- defined roles and responsibilities;
- sharing of credit for research results;
- facilitation of the partnership (McMorland and Piggot-Irvine, 2000); and
- funding to implement these policies/guidelines.

This may require a formal memorandum of understanding at the institutional level.

Partnership can be viewed as a process, in which all projects have permeable boundaries and are influenced by their wider social and institutional environment (Alsop *et al*., 2000). They take into account the unpredictable and idiosyncratic elements in interventions that are central to their success or failure.

If project managers have the freedom to define outputs and activities as part of the process, this can create problems for some participants because it is an unfamiliar way of operating. It can also be a problem for donors because of their concern for accountability, although Cox *et al*. (1999) argue that forced correspondence between actual and planned outputs can hinder development.

Alternative theoretical frameworks for building institutional partnerships are described in the systems literature. For example, Cox *et al*. (2000) argue that partnerships for agricultural development should be self-consciously designed as social systems. Friend and Hickling (1997) present a compatible general framework using the language of strategic choice. Cooperrider *et al*. (2000) describe the use of appreciative inquiry as a positive theory of change. King (2000) points out, however, that systemic learning to facilitate social change is not easy.

RESEARCH COLLABORATION

Building partnerships is one thing; building collaborative research is another. We also need to design a research approach that contributes to, and builds on, the different skills and values of civil society groups and agricultural research institutes.

In the development of a partnership, it should not be assumed that only research institutes conduct the research and that only NGOs and farmers only assist diagnosing problems and extend technology. Nor indeed that farmers are the only ones whose behaviour will change. Each of these groups conducts research, but in different ways, for different purposes, and with different criteria to evaluate the results. A collegiate relationship between NGOs and ARIs will mean building on their complementary skills in the research process just as much as at an institutional level.

Jahn *et al*. (2001) provide an example of how a research issue can be approached in several ways.

They present alternative frameworks for designing a research agenda for integrated pest and nutrient management, where deductive science, inductive science, adaptive management and systems thinking are competing, but complementary, approaches. The systems approach may be appropriate for more complex problems that depend on the differing perceptions, and values of various actors in the system, as well as on technical relationships. These are just the sorts of problems where there is likely to be a common interest between NGOs and research agencies.

In the Wuli Shili Renli (WSR) approach (Gu and Zhu, 2000), *Wuli* denotes knowledge about objective phenomena, *Shili* refers to our ways of seeing, modelling and doing, while *Renli* is concerned with human relationships. This is typical of systems approaches more generally in the way it highlights: multiplicity and difference (rather than conformity and consensus); holistic inquiry about relations in the world, between people and the world, and among people (rather than just about technical relationships in production systems); and human values (Han, 2000) and learning (rather than negating these as somehow outside the system as in objectivist science).

Evaluating on-farm trials is often difficult as farmers adapt technology rather than accepting it as is (‘adoption’) or rejecting it outright. For example, in Cambodia farmers successfully use IR66 as an extra wet season crop in the rainfed lowlands, even though this rice variety was originally designed for irrigated fields and competes poorly with weeds under rainfed conditions (Cox *et al*., 2001; Pheng *et al*., 2001). Within a short project cycle, it is often difficult to measure impact.

The mandate of the NARES is usually to improve the overall productivity (quality as well as quantity) of agriculture at a national scale. In order to do this, they may concentrate their efforts on favourable farm land, giving the poorer, marginal agro-ecosystems less attention. NGOs, on the other hand, often tend to assist farmers living under unfavourable conditions. This difference in targets is a challenge and an opportunity for partnerships. NGOs and ARIs could do the some things together: the entire project is planned, implemented, funded and evaluated as a distinct entity in which both parties are responsible for all activities. This would help each party understand the skills and constraints faced by the other. But it fails to build on the differences between the two kinds of organizations: they are different and these differences are the source of the synergy we are looking for.

This may include doing different things at the same time or location. There is nothing to exclude researchers from taking other measurements on farmers’ fields in addition to those kept by farmers for their own management purposes. But on-farm experimental designs should consider the resources, constraints, and information requirements of farmers. From the perspective of many NGOs, researchers are needed to contribute to learning by farmers and farmer groups, but scientific criteria take second place.

Much thought has to be given to issues of experimental design and monitoring. In general, joint research projects should build on the complementary skills of NGOs and research agencies and provide research products that are valuable to both, although perhaps in different ways.

Problem identification is also an important activity. What constitutes a scientific problem may not reflect a practical production problem at all. And practical production problems may have no scientific interest because the solutions are already known. The focus of joint research should be on issues that are of common interest. Similarly, not all solutions may be of equal interest to both parties – some solutions may be only of scientific interest but infeasible to apply in practice because of resource constraints of various kinds, e.g. labour or the skill of farm operatives. Other solutions may be so site-specific that ARIs are reluctant to invest resources in their development. In any case, solutions cannot be optimised apart from the social and cultural context of practical farming and local communities. The history of farming systems research (FSR) (Collinson, 2000) provides some guidelines about how to go about collaborative research. In some ways, the implementation of FSR by NGOs (with greater emphasis on facilitating social learning, working with farmer groups, and social activism) has contributed to their strengths but led away from involvement in scientific endeavours. To bring these back together will require new rules of engagement.

Much of this can be thought of in terms of the design of screens for searching an opportunity space. ARIs and NGOs are likely to have very different screen characteristics: contribution to scientific knowledge, statistical validity, generalisability on the one hand; identification and realisation of practical opportunities within existing resource constraints on the other. The role of formal sector science may be to identify novel opportunities for farmers by modifying current practices in ways suggested by scientific understanding of underlying principles. In order to promote and justify investment in partnerships, we need to clarify these values and construct engagement where these different interests overlap.

DISCUSSION

The need for partnerships between NGOs and research institutes (both national and international) is well recognised and widely promoted (e.g. IIRR, 1999; Norris, 2000; Alsop *et al*., 2000; Ojha and Morin, 2001; Morin *et al*., 2001). This is based around the idea of complementarities between the development-intensive site-specific focus of NGOs (providing relevance) and the reliable generalisability of scientific results. There are also some widely recognised problems with setting up these partnerships, maintaining them, and making them work. The problems may be manageable if certain guidelines are followed. We have provided some advice on what these guidelines should look like. The importance of process monitoring to facilitate continuous learning by both partners is stressed.

We have offered less guidance about how to go about developing a shared programme of research and development except for the recognition of the importance of participation by farmers in the development of technology for use by farmers. This emphasis fits with the practical philosophy of NGOs, but less well with research institutes. There is broad recognition of the need for participation in research but less understanding about how to do this. In practice, the formal (research) sector and the informal (farmer) sector are largely parallel paths.

Research is a process of search. Farmers, NGOs, and scientists use different screens to explore the search area. There is no need for complete correspondence, but there must be significant overlap if it is going to be worthwhile for scientists, NGOs and farmers to participate in the same experiments.

Although we recognise that much on-farm experimentation could be done a lot better from a scientific point of view, it can also be done a lot better from a practical (farmers') point of view. We still need to explore novel ways of doing research that are more inclusive of both formal sector research styles and informal styles. This probably means using systems approaches of various sorts (e.g., Chambers, 1997; Jahn *et al*., 2001), including participatory rural appraisal (PRA). PRA is a way of helping farmers and development workers (including researchers!) take part in conversations on a more equitable footing. From a research perspective, PRA techniques are not usually adequate as research tools for exploring complex issues of agro-ecological management. We will need new processes for managing participation.

There may be political difficulties for some NGOs aligning too closely with some research institutes due to different views on controversial issues such as GMOs. However, this should not get in the way of worthwhile collaboration on other issues. Any collaboration would have to give recognition to each other's actions: intellectual property rights, publications, and products.

Successful collaboration will require developing long-term relationships, and trust in each other's commitment and willingness to participate.

CONCLUSIONS AND RECOMMENDATIONS

The processes required for successful partnerships and research collaboration between NGOs and agricultural research institutions should: build on their different sets of skills; recognise and work within their, sometimes contradictory, values; operate on different scales; and support the development of human relationships within the partnership.

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ការចិញ្ចឹមត្រីក្នុងស្រែ ចំរុះនឹងការគ្រប់គ្រងសត្វកកេរ នៅប្រទេសកម្ពុជា

RICE FIELD FISH FARMING INTEGRATED WITH RODENT PEST MANAGEMENT IN CAMBODIA

E.G. Smith[1,3], L. Leung[2], C. Phaloeun[3], U. Sopheap[3]

សង្ខេបអត្ថបទ

ប្រសិទ្ធិភាពនៃការចិញ្ចឹមត្រីក្នុងស្រែ និងការគ្រប់គ្រងពពួកសត្វកកេរ ត្រូវបានធ្វើការសិក្សា។ ការប្រើប្រាស់នូវបច្ចេកទេសក្នុងការចិញ្ចឹមត្រីក្នុងស្រែគួបផ្សំនឹងការគ្រប់គ្រងសត្វកណ្ដុរ គឺមានប្រសិទ្ធិភាពខ្ពស់ ក្នុងការទប់ស្កាត់ពីការបំផ្លាញនៃពពួកសត្វកណ្ដុរទាំងនោះ។ សត្វកណ្ដុរក៏ ជាអាហារដ៏សំខាន់ និងផ្ដល់នូវប្រភពប្រូតេអ៊ីន សំរាប់ជាចំណីត្រី។ ការចិញ្ចឹមត្រីបានចូលរួមវិភាគទានដល់កសិករ ដើម្បីរកប្រាក់ចំណូលបន្ថែមព្រមជាមួយគ្នានេះដែរ ត្រីក៏បានផ្ដល់នូវប្រភពប្រូតេអ៊ីនដល់ការហូបចុកប្រចាំគ្រួសារ។

ការចិញ្ចឹមត្រីអណ្ដែងបង្កាត់រយៈពេលបីខែ បានបង្ហាញអោយឃើញថា បច្ច័យដែលបានផ្ដល់ចំណីមានការលូតលាស់លឿនជាងបច្ច័យ ដែលពុំបានផ្ដល់ចំណី។ ត្រីនៅក្នុងស្រែដែលផ្ដល់ចំណី មានទំងន់ជាមធ្យម ៥១,៥ក្រាម និង មានប្រវែងខ្លួនជាមធ្យម ៧,៨ ស.ម ចំណែកឯត្រីក្នុងស្រែ ដែលមិនផ្ដល់ចំណី មានទំងន់ជាមធ្យម ២៦,៤ ក្រាម និងមាន ប្រវែងខ្លួនជាមធ្យម ៤,៥ ស.ម ។

តាមការវាយតំលៃ លើការភ្លក់រសជាតិសំណាកត្រីចំនួនប្រាំ បានបង្ហាញថា ២៤ភាគរយនៃអ្នកភ្លក់ ពេញចិត្តត្រី ដែលផ្ដល់ចំណី និង ២១ ភាគរយទៀត ពេញចិត្តត្រី ដែលមិនផ្ដល់ចំណី។ នេះបញ្ជាក់ថា ត្រីទាំងពីរប្រភេទ (ផ្ដល់ និង មិនផ្ដល់ចំណី) មានរសជាតិ គួរអោយទទួលយកបានដូចគ្នា។

តាមការសិក្សា និង ការចុះអង្កេតជាលើកដំបូង នៅខេត្តកំពង់ចាម បានបង្ហាញថា បច្ចេកទេសចិញ្ចឹមត្រីក្នុងស្រែ និង ការគ្រប់គ្រងសត្វកណ្ដុរ បានផ្ដល់នូវអត្ថប្រយោជន៍យ៉ាងសំខាន់ដល់កសិករ ក្នុងការអនុវត្តន៍ ហើយថែមទាំងផ្ដល់ប្រាក់ចំណូលបន្ថែមទៀត ដែលបានមកពីការលក់ត្រី។ មិនតែប៉ុណ្ណោះ ត្រីក៏បានផ្ដល់នូវប្រភពប្រូតេអ៊ីនផងដែរ។

ពាក្យគន្លឹះ: *Clarias batrachus, Clarias macrocephalus*, *ការគ្រប់គ្រងសត្វកកេរ, ដំណាំស្រូវចំរុះ*

Abstract

The effect of integrating rice field fish culture with rodent pest management was examined. The use of rodent pest management was effective for controlling rodent pests as well as containing fish within the rice field while potentially providing a free source of dietary protein (captured rats) to feed fish. The growth of fed (captured rats or dried fish) walking catfish hybrids (*Clarias batrachus* ♀ x *Clarias macrocephalus* ♂) in the rice field over 3 months was significantly higher (51.5g, 7.8cm) than a treatment of unfed walking catfish hybrids (26.4g, 4.5cm) in the same rice fields. Fish culture was shown to contribute to a farmer's income (68,800 Riel) and provided a source of protein for the family's consumption. Both the fed and unfed products were found to be palatable and accepted by a test group with 24% of the test group selecting fed fish and 21% selecting unfed fish as their first choice from 5 fish products. This pilot study and a preliminary survey in Kampong Cham province indicate that this technology will be useful for farmers to improve rodent management practices while supplementing income through fish sale and providing a high protein diet for their families.

Keywords; Clarias batrachus, Clarias macrocephalus, rodent management, integrated rice field fish culture, carnivorous, hybrid

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Introduction

Wild fisheries provide the farm household in Cambodia with a free source of dietary protein, equivalent to more than 35% of animal protein consumption (Subasinghe, *et al*., 1998), and are a simple alternative to culturing fish. However in some areas the supply of wild rice field fishes has been degraded to the extent that fish culture is the only alternative for a sustainable fish supply (Bunra and Gregory, 1995). The demise of this natural resource has come about largely because of the intensification of agriculture, population growth, over-harvesting and the use of destructive fishing gear. These problems are likely to worsen with rapidly increasing population (Sihapitakgial, 2000) and increased fish demand for local and export markets (Gregory, 1997).

Rice field fish culture is not a new concept and has been widely trialed and used throughout Cambodia. Not only does the fish harvest add to the rice farmer's income, it provides a source of dietary protein. Dual cropping, rice and fish, helps manage economic uncertainty better, fish are believed to manage insect pests and accelerate nutrient recycling and the simple fact that farmers frequent the rice field more often to manage fish results in improved rice husbandry (Gregory, 1997). Despite these benefits there are many problems that have and continue to inhibit the success of rice field fish culture. The most common problems reported are that natural flooding and drought can result in the loss of an entire fish crop and that fish predators such as carnivorous wild fish can significantly reduce the harvest (Gregory, 1997).

These problems are currently being addressed by CARDI through a novel approach to introduce rice field fish culture to rural Cambodia. This pilot project has been designed to value-add work on the ACIAR funded Farmer-based Adaptive Rodent Management, Extension and Research System (FARMERS) project by linking rice field fish culture with rodent pest management. Implementation of a community-based project has been secured from the AusAID funded Community Development Fund and will be initiated in March 2002.

Materials and Methods

Field design for rice fish culture with rodent pest management

The design of the Trap and Barrier System (TBS) is similar to that used for rodent pest management in the FARMERS project. The trap crop is a 20 x 20m rice plot with a bund and a fence placed around the perimeter. In addition for fish culture, a small pond (4 x 4 m x 1m deep) was incorporated into the corner of the rice field. This was to offer fish a localized site for supplementary feeding and refuge from heat and drought. This study made comparisons between the rates of growth of fish fed a supplementary diet (rats that are trapped or dried fish if no rodents are captured) and those that feed only on what is available in the rice field. To achieve this a division was incorporated into the rice field, rats trapped in the field were euthanised and minced with rice bran to feed fish on one side of the division (Appendix 1). For reproducibility of results two project sites were developed at CARDI. The project was implemented on 1st October 2001 when rice (IR66) was transplanted and hybrids of the walking catfish (average weight 10.93g ± 0.5, average total-length 10.95cm ± 1.52) were released into the rice field on the 22nd October at 1.25 m^{-2}. The catfish had previously been held in a harpa (holding cage) for 7 weeks

Catfish hybrid

The species of fish to be grown is a hybrid of two native catfish species, the walking catfish (*C. batrachus*) and the broad head catfish (*C. macrocephalus*). These fish are a highly regarded table-fish in Cambodia, reaching market prices of 4000 - 5000 Riel kg^{-1} (US\$1- 1.25 kg^{-1}). This group of catfish is very suitable for coupling with the TBS as they are resistant to desiccation, can breath atmospheric air, are highly carnivorous, have fast growth rates (200g in 3 months) and the hybrid has been shown to grow 20% faster (Dunham, *et al*., 1990). Another characteristic of these catfish species is their ability to move across land with their pectoral spines (Pillay, 1990). In the past the mobility of this species has proven to be a problem for rice field culture, however the TBS will act as a barrier to contain these mobile fish. The hybrid cross used for this project was *C. batrachus* ♀ x *C. macrocephalus* ♂. Tarnchalanukit (1986) found that this hybrid cross produces a 5% higher fertilization rate and surviving larvae than the inverse cross. Fish were stocked at 1.25 m^{-2}, or 500 per $400m^2$ trap plot.

Product evaluation

The final issue to be addressed by this study is taste and marketability of the fish product. Preliminary surveys identified that Cambodian's have a preference for wild caught fish compared to cultured fish. Whether this is due to the taste of the fish or common perception that cultured fish are raised on low quality diets in poor water and previous experiences from bad quality products needs to be tested. To test whether there is a difference in taste, a taste test and product evaluation was conducted with CARDI staff to quantify their responses to wild caught versus cultured fish and different catfish species. Staff were asked to sample 5 different fish (wild *C. macrocephalus*, wild *C. batrachus*, fed CARDI hybrid, un-fed CARDI hybrid and hybrid catfish from another farm) and given a survey to record their response to each product.

Project potential

A community project with farmers in the Som Rong Commune, Kampong Cham will be undertaken in March 2002 to further develop the fish culture technique and help scientists target the research to farmers' requirements. The community-based project will be implemented with the arrival of an Australian Youth Ambassador (AYA), Morgan Edwards, and financial support from the AusAID funded Community Development Fund (CDF). To identify the appropriateness of this technology to the community, a preliminary survey of 105 people in the Som Rong Commune and 105 people in Lvea commune, both in Kampong Cham province, was conducted.

Results

Fish production

Hybrid catfish (average weight 1.38g ± 0.1; average length 5.58cm ± 0.1) were raised in a harpa for 7 weeks and reached an average weight of 10.93g ± 0.5 and average total-length of 10.95cm ± 1.52 before being released to the rice field. The average FCR for catfish during this holding period was 2.5.

Fish were on grown in the rice field for a total of 86 days (22nd October - 15th January 2002). Fish were fed on a mixed diet of dried fish and rice bran (30% crude protein), as rodent capture was low due to extensive flooding at CARDI on 15th October. The total volume of fish harvested from the four study sites was 17.2kg. The two study sites (east and west) produced 7.2 and 2.6kg of fed fish respectively. Production of unfed fish from both study sites (east and west) was 1.4 and 2.9kg respectively. A further 2.3kg of wild fish was harvested from both the east and west fed ponds and 0.9kg from the east and west unfed ponds. Wild fish were primarily made up of by Snakehead (Trey raws), Climbing Perch (Trey crang) and minor contributions from Trey chloin, Trey codjoh and Trey changwa. By the end of the culture period the fed fish were significantly larger (62.4g ±3.1, 18.8cm ±0.3) than the unfed group (37.4g ±2.7, 15.5cm ±0.3). The rate of survival was low in both treatments with 31% survival from the fed group and 22% survival from the un-fed group.

The fed treatment was fed at 10% biomass per day for the first 62 days however this was reduced to 5% per day as water quality deteriorated while the other group was not fed for the culture period. Figure 1 shows average weight increase and Figure 2 shows the average length increase of fish fed and unfed in the rice field. The fed fish consumed a total of 32.7kg of supplementary feed in the rice field resulting in an FCR of 1.9.

Water quality deteriorated in the fed ponds over the culture period resulting in an average final pH of 5.93 compared to the unfed ponds that had an average final pH of 6.62.

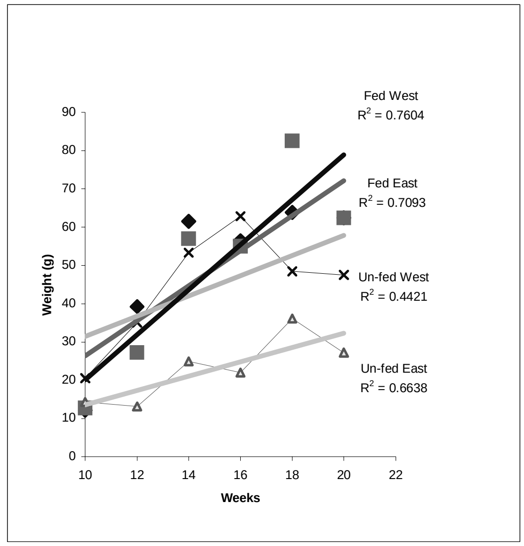

Figure 1: Average weight gain of fed and unfed walking catfish hybrids from two rice field culture sites (east and west).

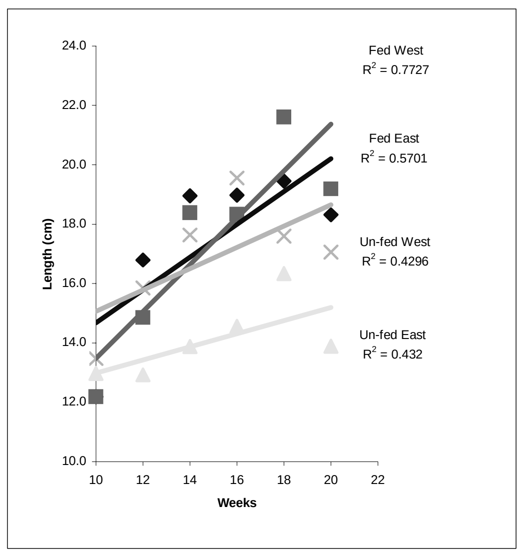

Figure 2: Average length gain of fed and unfed walking catfish hybrids from two rice field culture sites (east and west).

Product taste and acceptability

From a survey of 35 people, 31% selected *C. macrocephalus* as their first choice of fish for overall taste and fish characteristics, 24% of the survey group selected the fed CARDI hybrid as their first choice for taste and fish characteristics, third was the unfed CARDI hybrid (21%), fourth was *C. batrachus* (14%) and the final choice was a hybrid from another farm (10%).

From the survey, 59% of the test group identified that the most desired catfish are light in colour, 36% identified that medium sizes of 200g are preferred and 44% identified that fat fish are preferred (Figure 3).

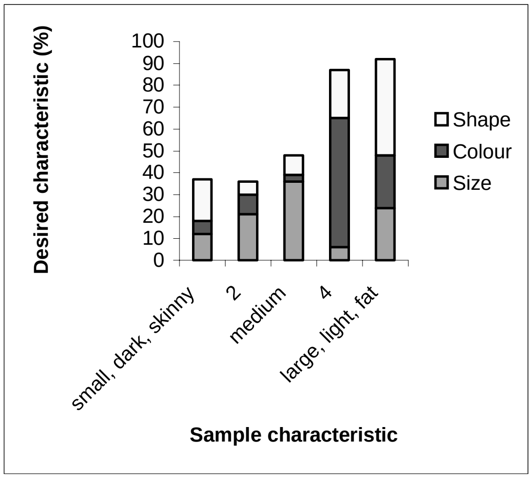

Figure 3: Desired characteristics of catfish identified through a survey of 35 CARDI staff members.

Rat trapping

Rat trapping was very low during the fish culture period due to floods driving rat populations out of the area in mid October. However at the end of December as the rice crop matured rat trapping was more frequent. During the period of fish culture, 22nd October - 15th January, 25 rats were caught. In this period traps also collected a number of snakes and frogs. Rodent capture was still being achieved at the end of the fish culture period and was maintained.

Rice yield

Rice yield was expected to be low due to extensive floods at CARDI 15 days post transplant. Rice did not recover from this early damage and as a result the average yield was 920 kg ha^{-1}. Rice yield from the 200m^2 treatment sites was significantly higher for both east and west fed treatments (26kg and 21.5kg respectively) compared to the east and west unfed treatments (14.5kg and 11.5kg respectively).

Gross margin

Total costs and potential sales for rice and fish are recorded in Table 1.

Table 1: Cost and profit statement related to rice field fish culture.

Item	Unit	Unit price (Riel)	Gross Margin (Riel)
Fingerling	1,000 head	50	-50,000
Fish Food	32.7 kg	1,000	-32,700
Fish	17.2 kg	4,000	+68,800
Rice	73.5 kg	500	+36,750

Preliminary survey

From the 210 people surveyed in Kampong Cham, it was found that 17.6% are growing fish in ponds with an average production of 185kg $year^{-1}$. The main species being cultured is the shark catfish, *Pangasianodon hypophthalmus*, local name Trey Pra. Farmers that were not growing fish clearly indicated that they would like to be able to but are primarily restricted by lack of technology and capital (Table 2).

Table 2: Main problems facing farmers that are not growing fish but would like to be able to. Data presented as a mean percentage of farmers.

Restriction	Som Rong	Lvea
Low protein diet	5.2	0.5
Lack of technology	17.7	15.2
Lack of capital	18.2	23.8
Water restrictions	4.8	4.2
Disease	5.2	1.4
Low market price	3.5	0.0
Other	21.6	27.1

Discussion

1. *Fish production*

FCR of 1.9 is comparable to figures presented by Pillay (1990) of 2.

Water quality was poor in one of the fed ponds therefore the feeding rate was reduced from 10% biomass per day to 5% biomass per day. Water pH was lower in the fed ponds. Fed ponds showed high amount of algal growth while unfed contained little. Future projects will integrate herbivorous species to utilize primary production.

2. *Product taste and acceptability*

The taste test suggests that consumers have a dislike for farmed fish due to inconsistent products reaching the market place as the farmed fish from CARDI were selected as the consumers second preference. The data also identified that consumers are after catfish of a medium size (200g), of light colour and that are fat.

3. Rat trapping

Rodent capture did not begin until late stages of the rice maturity. It is postulated that surrounding crops provided food for the rats but as they were harvested the rats moved into the TBS crop.

4. *Rice yield*

Floods at CARDI on the 15th October caused considerable damage to newly transplanted rice as well as driving out the rodent population. It is estimated that rice yield was affected by 50%. In one case dogs also attacked trap with rats, flattened $2m^2$ of rice.

The agronomic crop benefited from fish culture due to the increased nutrient load to the soil from accumulation of excrement and unconsumed feeds during the fish culture period.

5. Gross margin

This pilot project has identified a new technology that will not only increase the farmer's income and nutritional diversity but will improve rice yield through rodent pest management and nutrient influx from fish culture.

6. Preliminary survey

Farmers identified that lack of capital and technology were the major constraints for them to adapt fish culture.

Acknowledgements

Special thanks must go to Parrah, for his technical assistance in this project. We would also like to thank all of the students from the Royal University of Agriculture who came to CARDI and offered their assistance during this project Orn Por Soeun, Ou Rorthmony, Thov So Thorn and Bun Rim Than.

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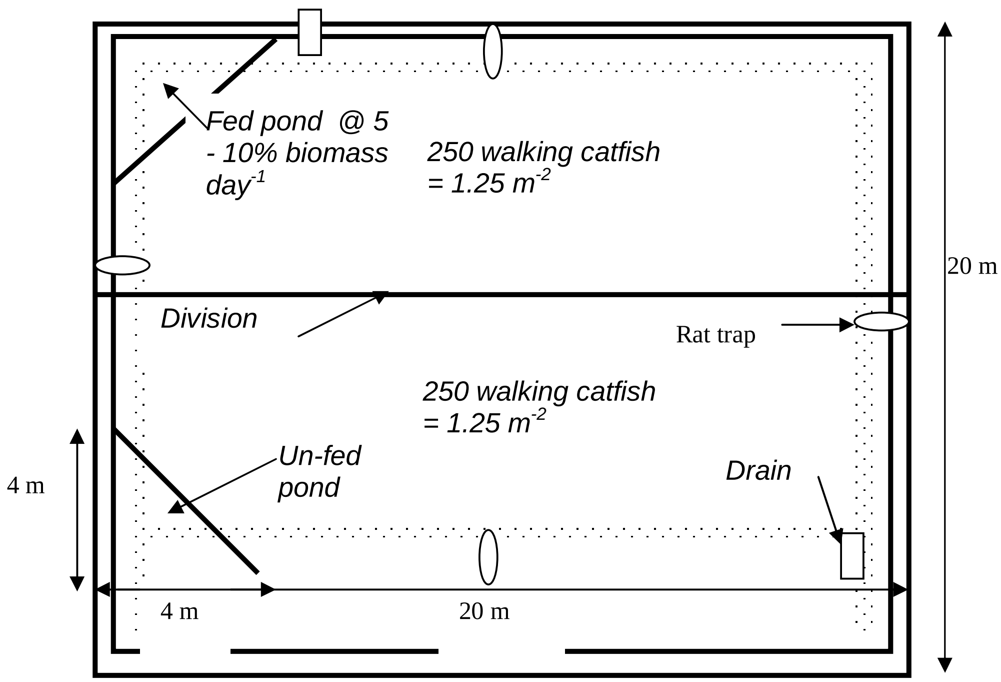
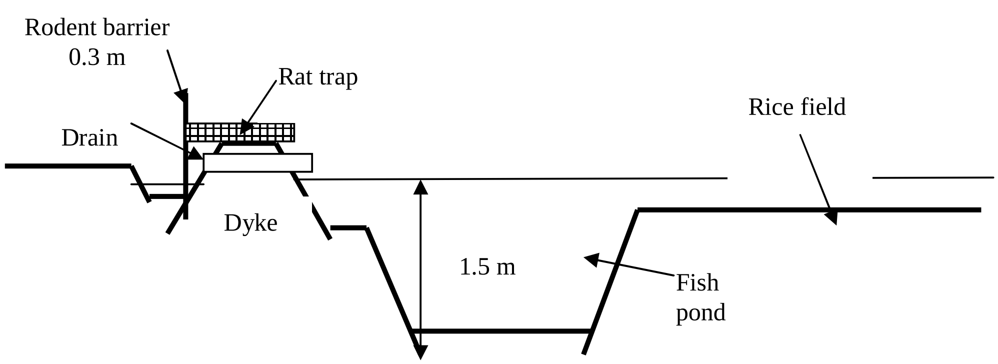
Appendix 1

Integrated rice / fish farming with rodent pest management
System layout





ចំលើយតបនៃដំណាំស្រូវចំការ នៅនឹងការដាក់ជីផូស្វ័រនៅលើដី ដែលបានបញ្ចេញទឹក ក្រោយពេលពន្លិចទឹក ក្នុងរយៈពេលផ្សេងៗគ្នា

RESPONSE OF UPLAND RICE TO PHOSPHORUS ON DRAINED SOILS SUBJECTED TO DIFFERENT PERIODS OF PRIOR FLOODING

Seng Vang[1], R. W. Bell[2], and I. R. Willett[3]

សង្ខេបអត្ថបទ

ការបាត់បង់ភាពឆ្អែតទឹកនៃដីម្តងម្កាល ត្រូវបានគេជឿថា ធ្វើឱ្យទិន្នផលស្រូវធ្លាក់ចុះជារឿយៗ ដោយវាកង្កឱ្យមានកង្វះជីជាតិផូស្វ័រ ប៉ុន្តែយន្តការនេះ មិនទាន់ត្រូវបានសិក្សាឱ្យពិស្តានៅឡើយទេ។ ការពិសោធន៏ក្នុងផ្ទះកញ្ចក់ត្រូវបានធ្វើលើដីអាស៊ីតនៃតំបន់ទំនាបប្រទេសកម្ពុជាចំនួន ២ ប្រភេទ (ក្រុមដីគោកត្រប់-ដីឥដ្ឋខ្មៅ និង ក្រុមដីប្រទះឡាង-ដី ខ្សាច់) ដោយបានដាក់បន្ថែមជីផូស្វាត (P) មុន ឬក្រោយពន្លិចទឹក ដើម្បីតាមដានពីឥទ្ធិពល នៃពេលវេលាដាក់ជី P ទៅលើការលូតលាស់នៃដំណាំស្រូវចំការ។ ដីទាំងពីរប្រភេទត្រូវបានដាក់ជីផូស្វាតក្នុងកំរិត ៤៥ mg P/kg ដី រួចទើបពន្លិចទឹកអស់រយៈពេល ០ ១ ២ និង ៤ សប្តាហ៏ ឬត្រូវបានដាក់បន្ទាប់ពីការពន្លិចទឹករួចរាល់ហើយ។ ក្រោយពីធ្វើការសំងួតនិងបុកដីរួច ដីទាំងនោះត្រូវបានផ្សើមដោយទឹកក្នុងកំរិតសំណើមដីស្រែរួចហើយធ្វើការដាំដុះស្រូវចំការ អស់រយៈពេល ៦ សប្តាហ៏។

ការដាក់ជី P ទៅលើដីខ្សាច់ រួចពន្លិចទឹកអស់រយៈពេល ៤ សប្តាហ៏ បានធ្វើអោយម៉ាស់ស្ងួតនៃដើមស្រូវធ្លាក់ចុះ ចំណែកនៅលើដីឥដ្ឋ ប្រើរយៈពេលតែមួយសប្តាហ៏ប៉ុណ្ណោះ។ ក៏ប៉ុន្តែនៅពេលដែលជី P ត្រូវបានដាក់ក្រោយពេលពន្លិចទឹក នោះម៉ាស់ស្ងួតនៃដើមស្រូវមិនធ្លាក់ចុះទេ ដោយមិនគិតពីរយៈពេលនៃការពន្លិចទឹកជាមុន។ ប៉ូតង់ស្យែលរេដុកម្ម និងតំលៃ pH ដី មានការធ្លាក់ចុះក្នុងពេលពន្លិចទឹក ដែលជាហេតុនាំអោយមានការកើនឡើង នូវតំលៃនីស្សារណកម្ម Fe^{2+} និងសមត្ថភាពស្រូបយក P របស់ដី។ បរិមាណនៃនីស្សារណកម្ម Fe^{2+} អាសេតាត មានទំនាក់ទំនងយ៉ាងជិតស្និទ្ធនឹងបរិមាណ P ដែលដីស្រូបយក (r^2 =0.96-0.98)។ នីស្សារណកម្មនៃ Olsen និង Bray-1 P មានទំនាក់ទំនងយ៉ាងខ្លាំងទៅនឹង ម៉ាស់ដើមស្ងួត និងកំហាប់ P នៅក្នុងដើម ដែលបញ្ជាក់ថាជីជាតិ P ដែលភាពសេរីរបស់វាត្រូវបានកំណត់ដោយរយៈពេលនៃការពន្លិចទឹកជាមុន គឺជាកត្តាដែលកំរិតនូវការលូតលាស់របស់ដំណាំស្រូវ។

រួមសេចក្តីមកការដាក់ជីផូស្វាត មុនពេលពន្លិចទឹក ពុំមានប្រសិទ្ធិភាពល្អ ក្នុងការបង្កើនការលូតលាស់បេស់ដំណាំ ស្រូវចំការឡើយ។ ការនេះបណ្តាលមកពី កំនើននៃការបង្ខាំធាតុ P ជាមួយដែកអុកស៊ី-អ៊ីដ្រុកស៊ីតដែលកើតមានក្នុងកំឡុងពេល ដែលដីធ្វើអុកស៊ីតកម្មនៅពេលវាស្ងួត។ ការធ្លាក់ចុះភាពសេរីរបស់ P ក៏អាចទាក់ទងទៅនឹងកំនើន នៃសមត្ថភាពចាប់យកធាតុ P នៃដីក្នុងពេលពន្លិចទឹក និងបញ្ចេញទឹកផងដែរ។

ពាក្យគន្លឹះ: ដីអាស៊ីត, ដីពន្លិច-បញ្ចេញទឹក, pH ដី, ប៉ូតង់ស្យែលរេដុកម្ម, នីស្សារណកម្មដែក និង ផូស្វ័រ, ការចាប់ធាតុផូស្វ័រ, ការស្រូបធាតុផូស្វ័រ, ដីស្រែទំនាប

ABSTRACT

Low rice yields following intermittent loss of soil-water saturation are believed to involve, on occasions, P deficiency but the possible mechanisms have not been studied in detail. In the present pot experiments, two acid lowland soils from Cambodia (Koktrap -black clay soil and Prateah Lang- sandy soil) were treated with P either before or after flooding to investigate the effect of the timing of P application on its effectiveness for upland rice growth. Phosphate fertiliser (45 mg P/kg soil) was added to both soils before flooding for periods of 0, 1, 2 and 4 weeks, or after drying the flooded soils. After air-drying and crushing, the soils were wet to

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field capacity and the upland rice grown in them for six weeks.

The addition of P 4 weeks before flooding decreased shoot dry matter in the sandy soil and in the black clay soil after only 1 week of flooding. But when P was added after drying the soils, shoot dry matter was not decreased regardless of the period of prior soil flooding. Soil pH increased and redox potential (Eh) decreased during flooding, resulting in an increase in acetate extractable Fe and the phosphate sorption capacity of soils. There was a close relationship between P sorbed and acetate extractable Fe (r^2=0.96–0.98). Olsen and Bray-1 extractable P strongly correlated with shoot dry matter and shoot P concentrations indicating that P, the availability of which was controlled by the period of prior flooding, limited the growth of upland rice.

It was concluded that phosphate fertiliser added before flooding was relatively ineffective in increasing growth in the upland rice. This was attributed to the increase in occlusion of P within ferric oxyhydroxides formed during subsequent oxidation of the soils. Decrease P availability may also have been associated with a greater phosphate sorption capacity of the soils during flooding and drying of soils. The implications of this for P supply to rice in intermittently flooded lowlands, and for P fertilizer requirements of pre- and post-rice upland crops are discussed.

Key words: Acid soils, flooded-drained soils, soil pH, redox potential, extractable P and Fe, P sorption, P uptake, lowland rice soils.

INTRODUCTION

The decrease of growth and grain yield of rainfed rice on the lowlands in southeast Cambodia has been reported to result from a temporary loss of soil-water saturation by apparently inducing phosphorus (P) deficiency in rice (Seng *et al*., 1999). The reason behind the decreased P uptake by rice plants following loss of soil-water saturation was believed to be associated with increased P sorption capacity in the dry soils. While the exact mechanisms involved are not yet fully understood, it was postulated to have been caused by the reactions of phosphate with amorphous iron oxides formed during flooding (Seng *et al*., 1999).

Willett and Higgins (1978) showed that oxidation or drying of previously flooded soils decreased the level of oxalate extractable Fe and phosphate sorption capacity of some Australian soils. Phosphorus added after drying of recently flooded soils was more available to upland crops than if it was added before flooding. But this was dependent on clay content, the level of organic matter, and the level of reducible Fe in the soils. Willett (1982) found that P added after drying the soils was not immobilised if soils were low in reducible Fe and organic matter.

Since the forms and availability of Fe vary between soil types and with the duration of flooding (Ponnamperuma, 1976), the capacity of soils to sorb added P fertiliser following increased duration of flooding may also vary. It was hypothesised that when soils were flooded for lowland rice, then dried to upland conditions this would restrict the availability to upland crops of P added before flooding; and that the availability of P for a subsequent upland crop depends on duration of prior flooding. The objective of this study was to investigate the effect that different periods of flooding had on the effectiveness of applied phosphate fertiliser before flooding relative to P applied after flooding using upland rice growing in two Cambodian lowland rice soils.

MATERIALS AND METHODS

Soils

A Koktrap (black clay soil or Kandic Plinthaquult) and a Prateah Lang (sandy soil or Plinthustalf) (White *et al*., 1997) were sampled to a depth of 0–10 cm from several locations in one field located in Toul Koktrap Rice Research station, southeast Cambodia. The soils had been continuously cultivated once per year during the rainy season for a very long period of time. These soils are known to be infertile, and respond strongly to P fertiliser application (Seng *et al*., 1999). Despite the low P status and the repeated use of the soils for rice cultivation, rice grown on these two soils is generally fertilised with relatively small amounts of P fertiliser (Dubus and Richard, 1997). Samples of each soil were collected during the dry season, bulked, and allowed to air-dry for 72 hours. Crop residues were removed by hand and the samples crushed to pass through a 2 mm sieve. Detailed chemical properties of the soils were reported in Seng *et al*. (2001).

Experimental procedure

Replicate 5 kg portions of soil (air-dried basis) were weighed and placed into plastic pots. There were 4 flooding periods (0, 1, 2, and 4 weeks). Each flooding treatment received either P applied before flooding or P applied after drying of the flooded soils. All potted soils received a complete set of basal nutrients (mg element/kg of soil) after air-drying: N=25 (urea), Ca=20.4 ($CaCl_2.2H_2O$), K=87.3 (K_2SO_4), Mg=21.1 ($MgSO_4.7H_2O$), B=0.1 (H_3BO_3), Zn=0.9 ($ZnSO_4.7H_2O$), Cu=0.3 ($CuSO_4.5H_2O$), Mn=1.4 ($MnSO_4.H_2O$), and Mo=0.1 ($Na_2MoO_4.2H_2O$). Phosphate fertiliser (45 mg P/kg, as KH_2PO_4) was added to half the pots before flooding. The remaining pots received this level of P after drying of the flooded soils. After the addition of nutrients, the soils were thoroughly mixed by shaking end-over-end.

Designated potted soils were flooded and incubated under glasshouse conditions at temperatures ranging from 25–40°C for 0, 1, 2, and 4 weeks by adding sufficient de-ionised water to flood soils to a depth of 2–3 cm. Flooding times were arranged so that all treatments could be dried at the same time. At the end of flooding, soils were air-dried for 48 hours under glasshouse conditions by spreading them thinly on a clean plastic sheet. After air-drying, soils of each pot were crushed and then re-potted. Phosphate fertiliser was applied to those treatments which did not receive P fertiliser before flooding. After P and basal fertiliser addition, the soils were thoroughly mixed by hand. All re-potted soils were then incubated with de-ionised water at field capacity.

Upland rice cultivation

Upland rice was grown as a test crop because of its tolerance to Mn toxicity, and responsiveness to P. Twelve seeds of P-responsive upland rice, *cv.* Sita were sown in each pot to a depth of 2–3 cm. The soils were maintained at field capacity throughout the six-week growing period. After the seedlings were well established (about 9 days after sowing), they were thinned to 8 plants per pot. No additional N was added to the soils after the basal application, and no N deficiency symptoms were evident prior to harvesting at six weeks. Shoot dry matter yields were determined and sub-samples were collected for P concentration analysis.

Soil and plant analyses

Soil pH and redox potentials (Eh) were measured at the end of each flooding and drying period with a portable pH-Eh meter possessing a glass calomel electrode for pH and a platinum electrode for Eh. For dry samples, the pH and Eh values were measured with a 1:5, soil to water ratio with the same meter (Rayment and Higginson, 1992).

Acetate extractable Fe and P were determined by shaking 2 g of wet soil with 50 ml of 1 *M* sodium acetate buffer (pH 3.0) for 5 minutes (TARC, 1973). The concentrations of Fe and P were measured at 490 and 580 nm, respectively, using a Jeneway 6051 colorimeter.

Soil samples of all treatments were taken before planting and at harvest of upland rice for Olsen and Bray-1 extractable P analysis. Bray-1 extractable P was analysed by hand-shaking 2 g of soil with 20 ml of 0.03 *M* NH_4F + 0.025 *M* HCl solution for 1 minute (Kalra and Maynard, 1994). The extracts were filtered immediately through a Whatman 42 filter paper. Olsen extractable P was obtained by shaking 2 g of soil with 40 ml of 0.5 *M* $NaHCO_3$ solution (pH=8.5) for 30 minutes (Rayment and Higginson, 1992; Kalra and Maynard, 1994). After shaking, the extracts were filtered through Whatman 42 filter paper. The concentration of P in the filtrates from each method was determined by the colorimetric procedures described by Kalra and Maynard (1994).

Samples of the soils that had been incubated flooded or dry for 0–4 weeks were air-dried for 48 hours and their P sorption curves determined by the method of Ozanne and Shaw (1967). Two-gram samples were shaken in 40 ml of solutions containing the following P concentrations (mg/l): 0, 10, 15, 20, and 30 for the black clay soil, and 0, 3, 5, and 10 for the sandy soil. The concentrations of P remaining in solution after 17 hours were determined by the colorimetric procedure of Anderson and Ingram (1993).

Shoots samples were milled, and P concentrations determined in concentrated HNO_3 digests (Zarcinas *et al.*, 1987) using an inductively coupled plasma atomic emission spectrometry.

Statistical analysis

For each soil type, analysis of variance was carried out to determine the treatment effects using IRRISTAT 4.0 software (IRRI, 1997).

RESULTS

Response of soil chemical properties

Both soils were strongly acidic when dry, with pH values of about 4.4. Flooding for 4 weeks increased these values to about 5.5 and 6.2 in the black clay and sandy soils, respectively (Fig. 1). At the same time, redox potential (Eh) decreased from about 600 mV to about 300 mV in the black clay, and 100 mV in the sandy soils. Soil reduction was faster in the sandy soil than in the black clay soil, reflecting a poor buffering capacity of the former soil. Soil pH and Eh returned to their pre-flooded values after drying.

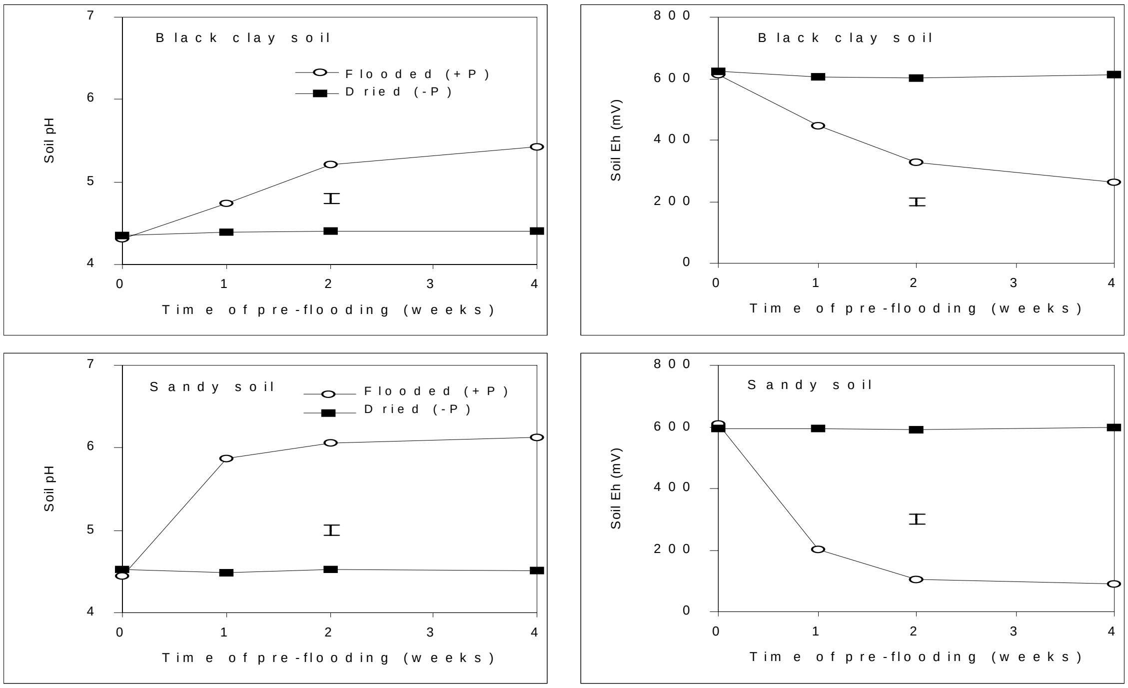

Figure 1. Changes in pH and Eh during flooding. Plotted values are means of 3 replicates. Bars indicate LSD values at $p<0.05$.

Flooding for 4 weeks increased values of acetate extractable Fe from about 30 mg/kg to 300 and 450 mg/kg in the black clay and sandy soils, respectively (Fig. 2). Flooding also increased acetate extractable P from about 1.3 to 5 mg/kg in the black clay soil, and from about 1.5 to 4 mg/kg in the sandy soil. The maximum value of acetate extractable P in the sandy soil was reached after 2 weeks of flooding, but in the black clay soil acetate extractable P values continued to increase until 4 weeks of flooding (Fig. 2). After the soils had dried out, the levels of acetate extractable Fe and P returned to their pre-flooded values.The sorption of P by soils varied markedly with both the period of flooding and soil type. Flooding for 4 weeks increased the P sorption capacity of both soils substantially, but the sandy soil sorbed much less P than the clay soil (Fig. 3). Based on P sorbed at 0.2 mg P/l in the equilibrium solution, the sandy soil under oxidised conditions (0 wk) sorbed about 15 mg P/kg, one-fifth that of the clay soil. There were positive relationships between P sorbed and acetate extractable Fe in both soils suggesting that the forms of Fe associated with increases in acetate extractable Fe during flooding were responsible for or strongly correlated with those causing the increased P sorption capacity of flooded soils (Fig. 4).

Olsen or Bray-1 extractable P values were higher in the sandy soil than in the black clay soil. The Olsen or Bray-1 extractable P values measured on dry soils without P were not significantly different between periods of soil flooding (Table 1). This suggests that duration of flooding did not affect the forms of native soil P measured in the dry soils using the Olsen and Bray-1 extractants. By contrast, flooding for 2 weeks or more significantly ($p<0.05$) depressed the extractability of P fertiliser added before flooding by decreasing levels of Olsen and Bray-1 extractable P in both soils without rice (Table 1) Subsequently, the levels of Olsen or Bray-1 extractable P in both soils decreased significantly with periods of flooding after growing upland rice on these treatments. In addition, the extractability of P fertiliser added after drying of flooded black clay and sandy soils were not diminished by periods of pre-flooding (Table 1). This

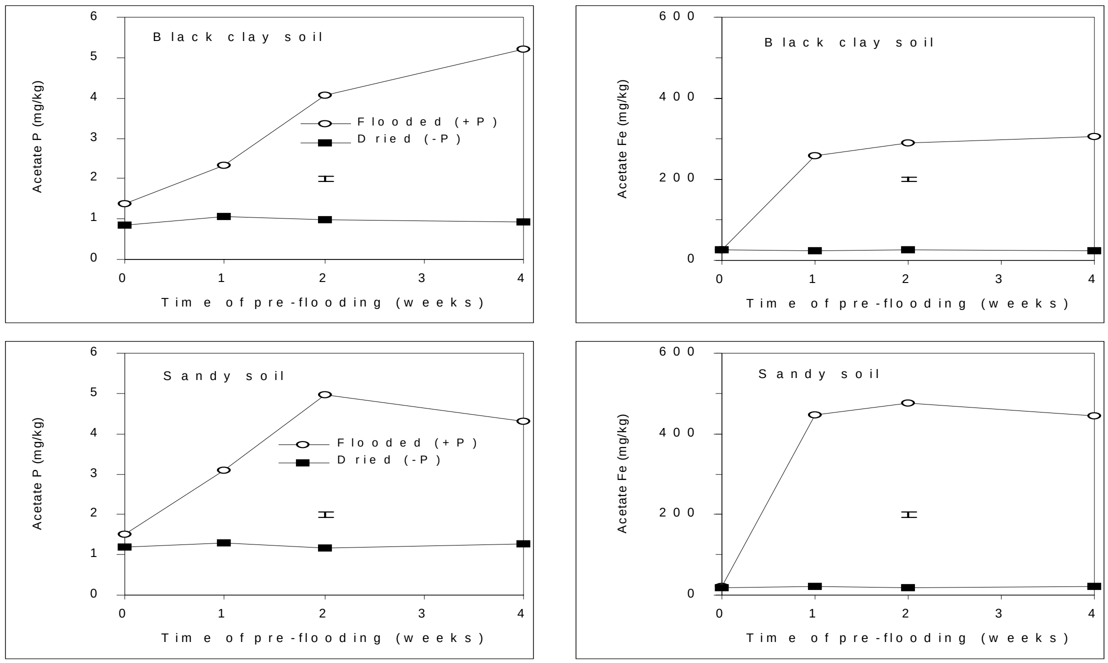

Figure 2. Changes in acetate extractable Fe and P during flooding and after drying of the black clay or sandy soil subjected to 0-4 weeks flooding. Flooded soils received P fertiliser before flooding, whereas dried soils did not receive any P fertiliser at time of measuring. Plotted values are means of 3 replicates. Bars indicate LSD values at $p<0.05$.

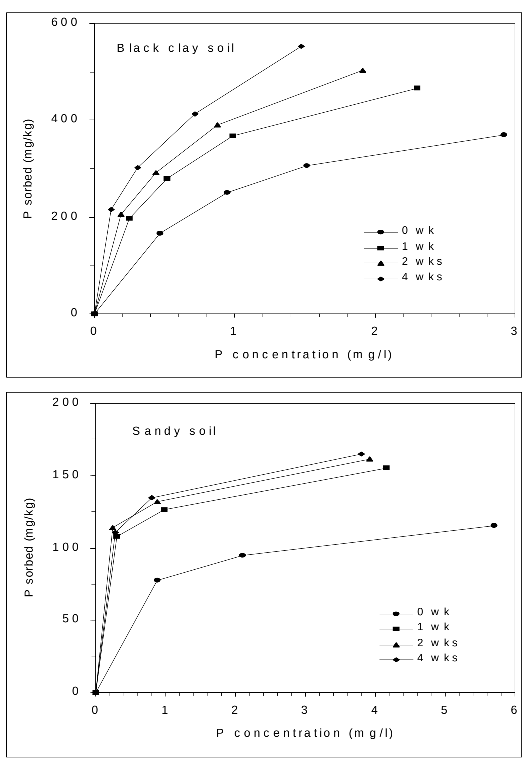

Figure 3. Phosphate adsorption curves of air-dried soils following incubation flooded or dry for the indicated periods.

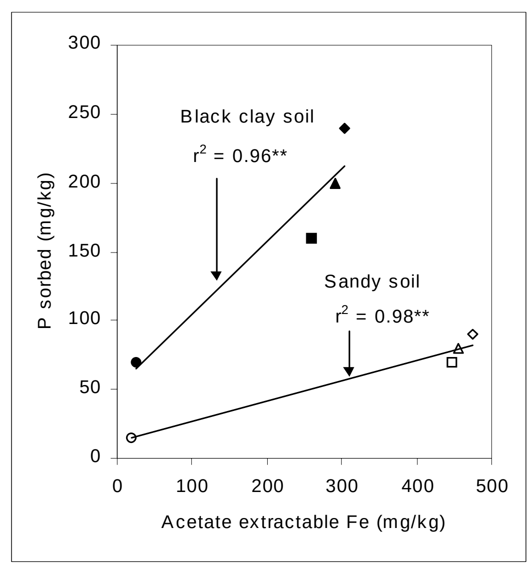

Figure 4. Relationships between P sorbed and acetate extractable Fe in the black clay and sandy soils. Plotted data are means of 3 replicates on each flooded treatment receiving P before flooding at 0 (circles), 1 (squares), 2 (triangles), and 4 (diamonds) weeks. Values of P sorbed were predicted from Figure 6-3, based on P sorbed at 0.2 mg/l in solution.

Table 1. Response of extractable P values in the black clay and sandy soils to flooding and different times of phosphate (P) fertilisation for growing upland rice. Measurements done on oxic soil samples. Presented values are means of 3 replicates.

Addition of P[#]	Time of flooding (weeks)	Extractable P (mg/kg)			
		Black clay soil		Sandy soil	
		Olsen	Bray-1	Olsen	Bray-1
Without P (-Rice)					
	0	1.12	0.70	2.32	1.17
	1	1.11	0.68	2.32	1.13
	2	1.10	0.68	2.31	1.15
	4	1.10	0.69	2.30	1.15
P added before flooding (-Rice)					
	0	1.64	1.18	2.83	1.72
	1	1.59	1.14	2.78	1.68
	2	1.48	1.01	2.69	1.60
	4	1.45	0.96	2.66	1.58
P added before flooding (+Rice)[##]					
	0	1.46	1.10	2.73	1.64
	1	1.42	1.05	2.69	1.61
	2	1.31	0.92	2.59	1.53
	4	1.30	0.85	2.57	1.50
P added after drying (+Rice)[##]					
	0	1.53	1.15	2.75	1.71
	1	1.51	1.14	2.74	1.70
	2	1.50	1.13	2.73	1.68
	4	1.49	1.13	2.72	1.69
LSD (P added x Time of flooding)		*0.08*	*0.08*	*0.12*	*0.08*

suggests that the availability of P to upland rice from added P fertiliser was greater when P was added after drying of flooded soils than when P was added before flooding.

<u>Response of shoot dry matter yields and P uptake</u>

Addition of P fertiliser before flooding depressed the growth of the subsequently planted upland rice provided the period of flooding was ≥1 week on the black clay soil and ≥4weeks on the sandy soil. The reduction in growth of upland rice was greater in the black clay soil than in the sandy soil (Fig. 5). When P fertiliser was applied, after drying of flooded soils, plant growth was similar irrespective of pre-flooding periods.

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Addition of P fertiliser before flooding depressed the growth of the subsequently planted upland rice provided the period of flooding was ≥1 week on the black clay soil and ≥4weeks on the sandy soil. The reduction in growth of upland rice was greater in the black clay soil than in the sandy soil (Fig. 5). When P fertiliser was applied, after drying of flooded soils, plant growth was similar irrespective of pre-flooding periods. In both soils, lower shoot dry matter yields were closely associated with decreasing levels of P uptake by the rice (Fig. 5). This also suggests that decreases in P uptake resulted from a reduced P availability during flooding and subsequent drying of the soils.

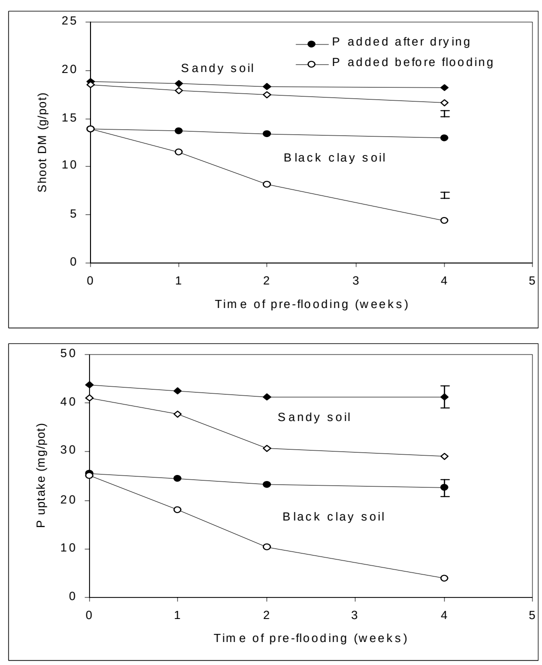

Figure 5. Response of shoot dry matter (DM) and P uptake of upland rice to the addition of P. Plotted values are means of 3 replicates. For each soil type, bars indicate LSD (P added x Time) values at $p<0.05$.

Relationships between shoot dry matter yields and Olsen or Bray-1 extractable P values

In black clay soil both shoot dry matter yield (r^2=0.90–0.92) and shoot P (r^2=0.92–0.96) were positively correlated with soil P concentrations extracted by Olsen or Bray-1 reagents (Fig. 6). In the sandy soil, the relationships were even closer (r^2=0.92–0.99) than for the black clay soil (Fig. 6). The positive relationships suggest that the P extractable by Olsen or Bray-1 reagents was available for the growth of upland rice.

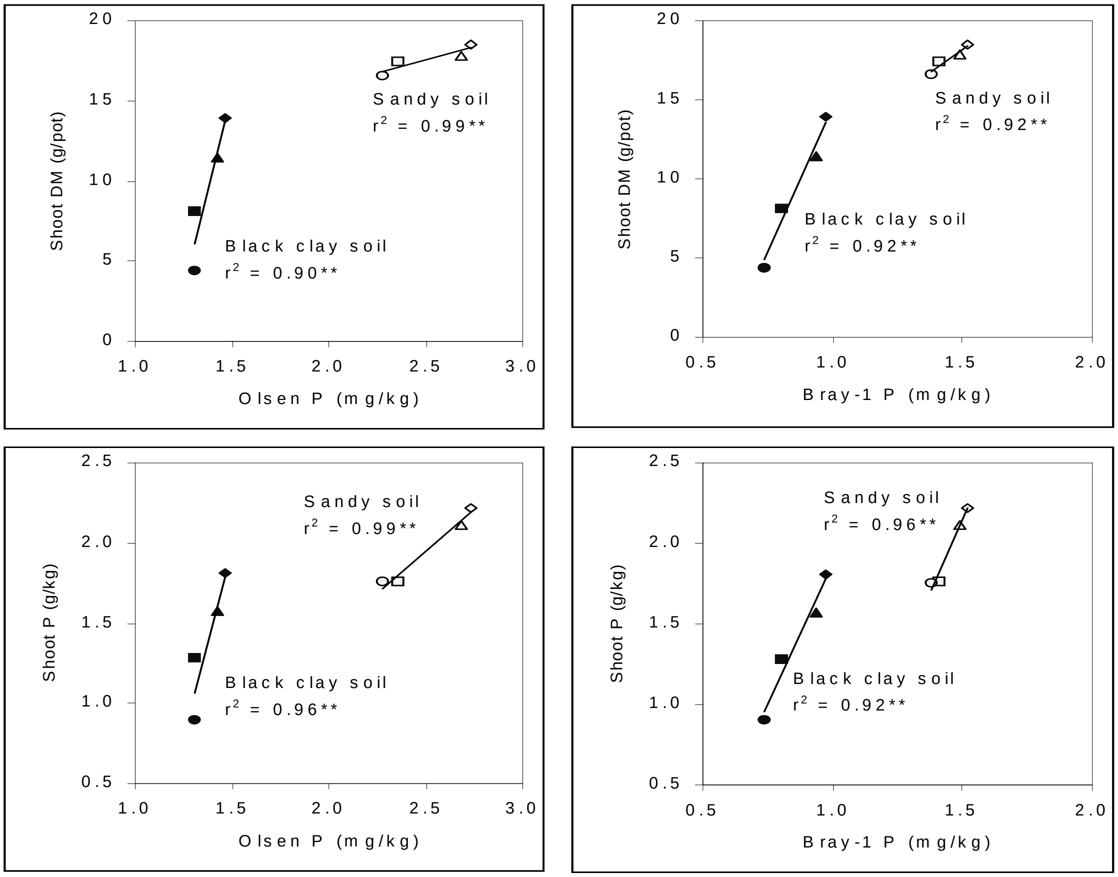

Figure 6. Relationship between shoot dry matter (DM) of upland rice or shoot P concentrations with Olsen and Bray-1 extractable P measured after rice harvested on the black clay and sandy soils subjected to 0 (diamond), 1 (triangle), 2 (square), and 4 (circle) weeks of prior flooding. Plotted values are means of 3 replicates for treatments receiving P fertiliser before flooding.

Discussion

The changes in soil pH, Eh, and acetate extractable Fe and P during flooding were consistent with previous studies on the black clay soil and sandy soils (Seng *et al*., 1996, 2001). The purpose of the present discussion is to explore the mechanism by which temporary loss of soil water saturation in lowland rainfed rice soils may induce P deficiency, as reported by Seng *et al*. (1999).

Effect of flooding periods on the availability to upland rice of P added before flooding

The most significant effect of soil flooding and flooding duration was a decrease in the effectiveness of applied P fertiliser as reflected in decreased rice dry matter. The decrease in effectiveness of applied P was correlated with a marked increase in acetate extractable Fe and in P sorption capacity of the soils albeit after re-drying for analysis. Correspondingly, there was a close relationship between acetate extractable Fe and P sorbed. The greater P sorption of reduced soils has previously been associated with a transformation of less reactive ferric oxyhydroxides to more reactive ferrous compounds in soils with value of oxalate extractable Fe greater than 1 g/kg, pH 4.4–6.4, and organic carbon 5.6–41 g/kg (Khalid *et al.*, 1977). Indeed, since P fertiliser was added before flooding, there was the opportunity for P sorption on reactive ferrous compounds formed during flooding, and acetate extractable Fe appears to correlate closely with the sorption of P on such Fe compounds. On oxidation or drying of the soils, any labile P or P present in the soil solution during flooding had the possibility of co-precipitation with ferrihydrite formed during oxidation as indicated by a significant decline in acetate extractable Fe and P, and this process would markedly restrict the availability of P for the growth of a subsequent upland rice crop (Willett, 1982, Willett, 1991). Further evidence was a marked decline in Olsen or Bray-1 extractable P values measured on each of the oxic treatments of the recently flooded soils where P fertiliser was added before flooding prior to planting rice. This decline may be expected because the occluded P or Fe^{3+} phosphate compound is less readily extractable than the surface-bound P (Willett, 1982). The decreased extractability of added P in these low-P soils with time of flooding could have been associated with increased levels of acetate extractable Fe during flooding, indicating that the greater the amount of Fe reduced during flooding, the greater the amount of P occluded on re-oxidation. Patrick *et al.* (1974) found that in most of the soils of Louisiana USA they tested, a greater proportion of added P was adsorbed in soil that was alternately flooded and dried to field capacity than in soil that was continuously flooded.

The reduction of upland rice growth on the sandy soil was not as marked as that on the black clay soil despite large increases in acetate extractable Fe in the sandy soil. This could be due to the low P sorption capacity in the sandy soil which could have been associated with the effects of its low level of clay, and low organic matter, in addition to levels of oxalate extractable Fe (Seng *et al*., 2001).

<u>Effect of pre-flooding periods on the availability of P added after drying to upland rice</u>

It was found that, after drying, soil pH, Eh, and acetate extractable Fe values of the soils returned to their pre-flooding values regardless of flooding duration. There was a corresponding decrease in P sorption capacity of the dried soils. This indicates that following drying there was a change in soil properties which influence P sorption, and hence P fertiliser added to the dried soils was more effective than if added before flooding. If applied after drying, the Fe^{2+} had presumably already oxidised to ferric oxyhydroxides, and the soils would be less reactive with P. Any decline in the availability of added P in this environment may be attributed to a surface-sorbed P on ferric oxyhydroxides rather than through occlusion. Evidence to support this were the values of Olsen or Bray-1 extractable P measured after growing rice on soils receiving P fertiliser added after drying, which showed no significant difference in values for the respective extractants between prior flooding periods.

Willett (1982) found that P added 16 days after drainage of some flooded alluvial soils rich in reducible Fe (32–62 g/kg) and organic carbon (60–66 g/kg) was strongly immobilised, and subsequently ineffective for increasing wheat growth. In other soils which were low in reducible Fe and organic matter (soil 3, 4, and 5), he found that P added after drying was not immobilised. His latter results (for soil 3, 4, and 5) are consistent with those of this study. The soils used in the present experiment had levels of citrate-dithionite-bicarbonate extractable Fe (cdb-Fe: 1.5–3.3 g/kg) and organic carbon (5–15 g/kg) (Seng *et al*., 2001) lower than those in soil 3, 4, and 5 of the above study (cdb-Fe: 4.5–8.0 g/kg, organic carbon: 10–48.5 g/kg). This clearly shows that on the major rice soils of southeast Cambodia, with low levels of reducible Fe and organic matter, the availability to upland crops, including rice, of P fertiliser added after drying of the flooded soils was not restricted by periods of prior flooding, and hence shoot dry matter weights of rice were not decreased by duration of pre-flooding. This considerably simplifies the P fertilizer strategy for upland crops grown immediately after rice in double cropping patterns. However, the present results also suggest that upland crops grown after rice will obtain only limited benefit from P applied previously to the rice. Further research would be needed to determine whether in double cropping, it was preferable to add most of the P to the upland crop or to the rice in order to optimise P uptake by both.

<u>Conclusion</u>

The availability to upland rice of P fertiliser added before flooding was substantially limited by the duration of flooding as indicated by a substantial decline in extractability of P added before flooding both prior to and after planting rice. This was associated with increases in acetate extractable Fe during flooding, and attributed to sorption of P or/and occlusion of P within ferric oxyhydroxides formed during subsequent oxidation of the soils. As a result, there were substantial decreases in P uptake and shoot dry matter of upland rice growing in these soils. By contrast, P fertiliser added after drying of flooded soils remained highly available to upland rice regardless of the periods of pre-flooding. This was attributed to the fact that phosphate was added after the formation of ferric oxyhydroxides, the form of Fe less reactive with phosphate.

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សំឡឹងមើលអោយលើសពីវិស័យកសិកម្មៈ យេនឌ័រ លំហូរនៃពត៌មាន និង កសិកម្មសមស្រប នៅក្នុងបរិស្ថានក្រខ្សត់ធនធាន

MOVING BEYOND FARMING: GENDER, INFORMATION FLOW, AND SUSTAINABLE AGRICULTURE IN A RESOURCE POOR ENVIRONMENT*

Rebecca F. Catalla[1], Numa Shams[2], and Tuy Samram[3]

សង្ខេបអត្ថបទ

ការចែករំលែកពត៌មានគឺជាដំណើរការទូទៅមួយក្នុងសង្គមស៊ីវិល។ ការផ្ទេរចំណេះដឹងក្នុងបរិយាកាសក្រោយចប់សង្គ្រាម ក្នុងប្រទេសកម្ពុជាក្នុងពេលដែលមានស្ថាប័នផ្លូវការដ៏តិចតួច ធ្វើការផ្សព្វផ្សាយពត៌មាននោះនឹងមានផលវិបាកយូរអង្វែងក្នុងវិស័យអភិវឌ្ឍន៍ជនបទ នៅប្រទេសកម្ពុជា ។

ការសិក្សាអំពីសេដ្ឋកិច្ចសង្គមបានអនុវត្តក្នុងភូមិចំនួនបួនផ្សេងៗគ្នានៅក្នុងខេត្តស្វាយរៀងភាគអាគ្នេយ៍នៃប្រទេសកម្ពុជា ដើម្បីស្វែងយល់អំពីឥទ្ធិពលនៃការអន្តរាគមន៍របស់កសិកម្មសមស្រប អំពីការចូលរួមរបស់យេនឌ័រ និងលំហូរនៃពត៌មាន។ ការសិក្សាក៏បានពិនិត្យផងដែរ អំពីទិដ្ឋភាពវប្បធម៌សង្គមយេនឌ័រនៅក្នុងការងារកសិកម្ម និងអភិវឌ្ឍន៍ជនបទ។ ការវិភាគត្រូវបានធ្វើឡើងលើទិន្នន័យបរិមាណ និងគុណភាព ដែលប្រមូលបានពីការស្ទាបស្ទង់ពីក្រុមតូចៗ ករណីសិក្សា ក្នុងការសំភាសន៍ជាមួយ មនុស្សសំខាន់ៗ និង ការពិភាក្សាជាក្រុម។ ការធ្វើសិក្ខាសាលាថ្នាក់ភូមិ ត្រូវបានរៀបចំឡើង ដើម្បីបញ្ជាក់លើពត៌មានដែលបាន ប្រមូលតាមរយៈការសិក្សាស្រាវជ្រាវ ។

ការសិក្សាស្រាវជ្រាវ បានបង្ហាញដោយផ្អែកលើហេតុផលនៃវប្បធម៌សង្គមថា បុរសបានចូលរួមក្នុងវគ្គបណ្តុះបណ្តាលដែលរៀបចំដោយអង្គការក្រៅរដ្ឋាភិបាលបានជាញឹកញាប់។ តែទោះជាយ៉ាងណាក៏ដោយក៏ ពត៌មានវាមិននៅនឹងថ្កល់សំរាប់តែពួកគេទេ គឺវាក៏បានសាយភាយទៅស្ត្រី និងបុរសជាសមាជិកគ្រួសារ និងទៅមិត្តភ័ក្ររបស់ពួកគេផងដែរ។ ការផ្ទេរចំណេះដឹងកើតឡើងនៅក្នុងស្ថានភាពច្រើនបែប ដូចជា នៅក្នុងវាលស្រែ ក្នុងអំឡុងពេលបាយថ្ងៃត្រង់ ពេលសំរាក ក្នុងពិធីបុណ្យប្រពៃណី និង សាសនា ឬក្នុងការជួបគ្នាដោយចៃដន្យ។ ទោះជាប្រភពពត៌មានទាំងឡាយ អាចមានភាពអព្យាក្រិត្យ មិនប្រកាន់យេនឌ័រក៏ដោយ ក៏នៅមានភាពលំអៀងស្តីអំពីយេនឌ័រលើបុរសដែរដោយសំអាងថាពួកគេជាអ្នកជំនាញ នៅក្នុងភូមិពីព្រោះពួកគេមានកិរិតវប្បធម៌ខ្ពស់ និងដោយមានទស្សនៈចាស់ថាបុរសគួរតែមានតួនាទីខ្ពស់ជាងស្ត្រីក្នុងសង្គម។

ការសិក្សាបានបង្ហាញថា បច្ចេកទេសកសិកម្មសមស្រប បានបង្កើតការងារច្រើនសំរាប់សមាជិកគ្រួសាររបស់ពួកគេ និងកាត់បន្ថយការលំហែរកាយរបស់មនុស្សពេញវ័យ ។ ថ្វីបើការងារកើនច្រើនក៏ដោយក៏ នៅឯថ្នាក់ភូមិមានការយល់ឃើញថា ការងារបច្ចេកទេសកសិកម្មសមស្របកំពុងតែកែលំអមុខងាររបស់ស្ត្រីក្នុងគ្រួសារ និងក្នុងសហគមន៍តាមរយៈបរិយាកាសនៃការពិគ្រោះគ្នាទៅវិញទៅមក។ នេះ គឺជាការកាត់បន្ថយទំនាស់ក្នុងគ្រួសារដោយប្រយោល និង កាត់បន្ថយអំពើហឹង្សាក្នុងគ្រួសារ។ ការសិក្សាស្រាវជ្រាវ បានសន្និដ្ឋានថា ការយកមធ្យោបាយក្នុងស្រុកធ្វើជាមូលដ្ឋាននៃការផ្ទេរចំណេះដឹង ជួយបង្កើតឱ្យមានសហគមន៍ ដ៏រឹងមាំមួយ។

ពាក្យគន្លឹះ: យេនឌ័រ លំហូរនៃពត៌មាន កសិកម្មសមស្រប

ABSTRACT

Knowledge construction is an integral part of the civil society building process. As most of the third world countries lack public institution to support resource poor farmers civil society could help them to establish their rights. The transfer of knowledge in Cambodia's post-war environment, where there are few formal institutions to disseminate information, will have long-term implications for rural development. The majority of Cambodian

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population as well farm community are women. Without empowering them it is not possible to have meaningful rural development.

To understand the impact of a sustainable agriculture intervention on gender participation and flow of information, a socio-economic study was carried out in four different villages in Svay Rieng province, Cambodia. The study also looked into socio-cultural aspects of gender in agriculture and rural development. The analysis is built upon quantitative and qualitative data collected through a survey, case studies, key informant interviews, and group discussions. A village level workshop validated the information generated through the research.

The study revealed that, for socio-cultural reasons, men (rather than women) frequently attended the training courses offered by NGOs. However, information does is often disseminated to women and men family members and friends. The transfer of information occurs in a variety of situations: in the rice field, during lunch or resting, in social or religious gatherings, or during incidental meetings. There is a gender bias towards men as para-professional village technicians. This is probably because of their higher educational level, as well as socio-cultural assumptions about the appropriate roles of men and women. The study shows that sustainable agriculture technologies are increasing the workload of all family members and this has meant reduced leisure time for adults and children. Despite the increased workload, there is a perception at the village level that sustainable agriculture technologies are improving the position of women in the family and community through an atmosphere of mutual consultation. This is indirectly reducing family conflict and the incidence of domestic violence. Added work in the rice field, the homestead, and in the home, men and women are crossing gender boundaries as both take on tasks that will make their households more food secure. The study concludes that building on indigenous means of information transfer helps to transform decision-making processes and relationships within the home and the larger community.

Key words: Gender, information flow, sustainable agriculture.

Introduction

Over the past 25 years, gender relations in the context of agricultural production and household food security have been an important focus of studies and discussions in developing countries (Feldstein and Jiggins, 1994). Shaped by an increased appreciation of women's critical yet unrecognised roles in agriculture and in ensuring their household's secure access to food, the discourse greatly contributed to initiatives towards gender mainstreaming and deliberate field-level efforts to incorporate this agenda in program development and analyses. Sustainable agriculture ensures production of food and feed through balance utilization of natural resources without disturbing the natural and social equilibrium. Gender on the other hand looks into socially constructed relationships between men and women. Without having a strong gender approach it is impossible to achieve a sustainable production, as sustainable agriculture deals with not only how the natural resources are being utilized but also who utilizes it and in what ways.

Gender is a development focus in Cambodia that has gained momentum in the last 7 years. This is because the country gradually shifted from post conflict relief and reconstruction phase to development phase with a strong emphasis on sustainable development. Initiatives to generate gender-disaggregated information in different programmatic spheres are fairly recent. A less well-known area, in terms of program development and analyses, is of the relationship between gender and sustainable agriculture (SA). Also a phenomenon of the 90s, SA is a concept and practice that advocates increased agricultural production in an environmentally safe, socially equitable, and economically sound direction (Thrupp, 1996). Its strategy of starting from farmers' requirements and knowledge in experimenting with low input technologies has led its proponents to promote it as a farmer-led process. This, in turn, has been said to enhance the status of women as agriculturists and as members of their communities. Such an improvement in women's status apparently occurs as they take part in SA's attendant livelihood enterprises and frequently labour-intensive technologies (Ingram and Kamp, 1996; Ssennyonga, 1996). The grassroots orientation of the SA approach is also relevant to conventional gender issues in agriculture such as that of food security, access to information and extension services, and decision-making.

Sustainable agriculture has yet to gain wide recognition and application in Cambodia. In a context of predominantly rice-based small-scale farms, poor soils and low yields, a growing population, as well as the lack of rule of law in the importation, production and distribution of agrochemicals (Koma, 1999), external input-based farming practices are replacing traditional low input-based farming activities.

The term gender describes the roles, responsibilities, and characteristics ascribed to men and women because of their sex. These roles are socially constructed rather than biologically determined. In other words, people are born as male or female, but they learn how to be boys and girls, women and men. They are taught what is expected of them by family, culture, media and other social institutions. Studies on gender focus not only on women, but also on the norms that structure the lives and experience of both women and men (Catalla et. al, 2001). Because gender is a social construct, women's and men's role may differ from one place or culture to another and may change over time. Gender analysis help to reveal the source of variation that may be important for agriculture production in a particular location. A gendered approach makes agricultural technologies more relevant for a particular location. It makes agriculture research and extension more efficient and effective; research becomes less biased in favour of men; and the areas where there is greatest need or opportunity for improved technologies are easily identified and their implications for the whole system can be seen (Feldstein and Poats, 1989; Jiggins, 1986, Poats *et al*. 1988; Feldstein, Flora, and Poats, 1989; Russo *et al*., 1989).

Promotion of SA calls for knowledge on the social and cultural context of its implementation. Presently, there is a dearth of knowledge on the extent to which utilization of traditional organic farming activities has upheld the gender division of labour and undermined the contribution of women in agricultural production. As women constitute more than half of farming communities' populations, without their empowerment it is impossible to reach a sustainable development goal. Merged into a "gender-bright"[6] integrated farming systems framework and sustainable livelihoods (Chambers and Conway, 1992) programme, examining these activities can contribute to a good understanding of production ecosystems as well as local resource problems and feasible solutions. Such an analysis also offers opportunities to build upon men and women farmers' local knowledge in technology development and dissemination initiatives. This can help create the space and occasions for women to articulate their own production experiences and knowledge.

One of the central issues that underpin gender in agriculture has been of women's lack of access to extension services (Quisumbing *et al.*, 1998:265; Gorman *et al*., 1999:50). Worldwide, women receive only 5 per cent of all agricultural extension services, implying their lack of access to information and consequently undermining their ability to help maintain environmental quality and the sustainable use of resources (FAO, 1997). Although, in many countries the formal extension services are not that effective, whatever services exist are not reaching women farmers.

The situation is aggravated by two critical concerns: there are few women extension workers compared with men; and these few women extension workers lack training as effective extension workers. In varying contexts where there are women extension workers, their numbers tend to be symbolic rather than substantive (Safilos-Rothschild, 1991). That is, their presence is a 'token', or serves as a concession to having women among the ranks of those in the extension service. This finds evidence in the fact that they have given responsibilities for disseminating limited technical agricultural messages (Safilios-Rothschild and Mahmud, 1989). They are also poorly trained and are therefore ineffective in passing agricultural messages on to women (Halim and Islam, 1988; Safilios-Rothschild and Mahmud, 1989). Existing successes where women have been properly trained for specific extension purposes are few, one being in the Aga Khan Rural Support Program in Pakistan (World Bank, 1990) and another in Rangpur Denajpur Rural Services in Bangladesh (Safilios-Rothschild and Mahmud, 1989).

The situation finds reality in Cambodia where men outnumber women as extension workers. Today, only 16% of the total staff of the Department of Agronomy and Agricultural Land Improvement and 18% of the total staff of the provincial extension offices are female (Norris *et al.*, 2001). In addition, apart from receiving less information, it is uncommon for women as farmers to train other farmers partly as a consequence of social restrictions about the mobility of women in rural areas (Mak, 1999). If the aim of rural development is to alleviate poverty, then development information must be communicated in a way that will not prevent or deter women from actively participating in development activities (Otsyina and Rosenberg, 1998).

Cambodia's experience in agricultural extension is recent and in the process of being systematized (Koma, 1999), with gender awareness programs also being put in place (Gray and Wouters, 1999). A weak revenue and manpower base, as well as lack of research facilities, however, partly prevents the country from experiencing the traditional "technology transfer model" of extension like much of Southeast Asia. Recognition of these potential limitations has led the Royal Government of

[6] The phrase is being adapted from Vlaar and Rhodante, A., (1998) and suggests a critical awareness of the socio-economic issues that underpin differences within and between gender categories (male and female)

Cambodia to accept a farmer-to-farmer extension approach as a national policy for agricultural development, a trend that complements the common NGO focus on farmer-led extension systems. Farmer-led extension is an agricultural extension approach that involves farmers undertaking extension activities, with or without the support of external agents (Scarborough *et al*., 1998). The public sector formal extension services based on technology transfer model have been found not to be appropriate for the need of resource poor farmers.

There is a growing recognition that uniform, hierarchical government bureaucracies are not the best way of providing flexible service tailored to the needs of different categories of farmers and varied agro-ecological conditions (Garforth, 1995). The traditional public sector agriculture is also facing challenge as new agendas are being added to its existing mandate of transfer of technologies to the farmers. Demand has been placed that it should ensure food security (at a national level and within rural communities), conserve environment and alleviate poverty (Jazairy, 1992) and improve the nutritional status particularly for children (Garforth, 1997). To meet this demand farmer led extension either in pure form (meaning without having strong linkage with the public sector) or as a component of public sector extension are being developed in many countries of the world. The farmer led extension gives more power to farmers to determine the public sector agenda for extension (and in some cases research). Farmer led extension do not completely exclude the transfer of technology completely. Rather, through planned technology transfer, it ensures that the technology is appropriate, adaptation rather than straightforward adoption of technologies and the transfer process itself is based on sound principles of adult learning.

Spontaneous dissemination of information is an important component of the farmer-to-farmer extension process. Yet, there is very little understanding on this form of knowledge transfer and how traditional gender relations affect it.

Catholic Relief Services (CRS) is currently implementing a project in Svay Rieng. In this project CRS is trying to build the capacity of farmers trainers who will have ability to solve the ever-changing farm problems through simple experimentation and train other farmers on different improved technologies. CRS is developing a local knowledge network by linking dissemination of information through linkage with farm enterprises owned and operated by farmer trainers. It is also trying to develop a model of low cost community based alternative extension system using farmer led extension methodologies. Therefore, how knowledge transfer could affect the traditional gender roles is important for CRS.

Methods

To understand the impact of sustainable agriculture interventions on gender participation and flow of information, a socio-economic study was carried out in four different villages drawn from 19 project villages of the CRS Cambodia Agriculture Program, in the south-eastern province of Svay Rieng, Cambodia.

The total sample of the study consisted of 95 households representing pre-defined, commonly perceived vulnerable sectors in the localities: female-headed units, widower-headed households, those with disabled members, those representing recent settlers or migrants, old resident households and landless household. The sample was not stratified to weight this different kind of household according to the frequency in the population. A survey, case studies (Yin, 1994a and Yin, 1994b) key informant interviews, and focus groups (Folch-Lyon, 1981) were all employed in this study.

From the total of 95, four to five households per village were re-interviewed to get in-depth information and to serve as case studies. Twenty household case studies were obtained. At the individual level, a village vendor, a market seller, a farmer-trainer and the village chief were selected as key persons to be interviewed in each sample village. Individuals who took part in the focus groups were not selected based on any particular criteria: an open invitation was issued to men and women farmers – including representatives of female-headed units – in each of the four villages. Two focus groups per village were conducted in order to understand variations between men and women in their application of, and experiences with, SA practices (access to agricultural information and technologies and sources and channels of agricultural information and technologies).

Results

Agricultural information and technology transfer

A project can only reach so many farmers in its project area. A positive impact of project interventions partly depends upon informal (and frequently indigenous) 'farmer-to-farmer extension' practices. In agriculture, communication between farmers is a major process by which information about new and improved farm practices is spread. It produces greater effects than any other medium in terms of knowledge gains, attitude formation and changes, and overt behavioural change (Hussain, 1993). This section examines the relevant questions concerning farmer-to-farmer extension and flows of information.

A. Effectiveness of technological information flow

At the core of farmer-led extension and research is the development of location-specific technologies using both indigenous and external knowledge, and the dissemination of these technologies through farmer-to-farmer extension. Understanding the way in which technological information flows between men and women within the home and at the community level can shed light on the impact of NGO-organized training and other development activities on agricultural productivity and farm household income.

1. Access to agricultural information and technologies

The research revealed that, regardless of the type of farm enterprise, male and female heads of household in the study sample have an equal chance of acquiring information about agricultural technologies. In the surveyed villages, these two groups represent two thirds of the population who acquire agricultural information; joint (husband and wife) teams make up the remaining third. In those cases where husband and wife jointly get information, more women learn about production technologies from neighbours and other people, such as the village chief, rather than from attending CRS-organized training activities or from CRS staff. This finding finds support in other studies. In north-western Tanzania for instance, women depend far more on secondary sources of information than men. They learn a lot from gossip, and from their neighbours on their way to farm or riverside (Otsyina and Rosenberg, 1998). Interviewees in this study also reported that, in addition to other factors (e.g. responsibilities in the home, income earning activities), women's lower levels of education contribute to their shyness in participating in training activities.

Findings at the community level across the study villages confirm that technological information on sustainable agricultural practice flow from women to men, and men to women within the home and the community. Information sharing focuses mainly on four farm enterprises: rice production; vegetable growing; fish culture; and micro-animal production (Table 1). Men and women noted several areas of similarity in the information they share in each of the enterprises. It is not known what percentage of male farmers are reluctant to share their newfound agriculture knowledge with their spouses. Norris (2001) reported that this could be the case in some instances.

Differences also characterized the information that women and men disseminate. These seemingly are a function of the particular training courses they attended and/or the gender-specificity of their responsibilities in the enterprises. Women noted rice experiments and rat management in rice production as newly acquired areas about which they share information, indicating their increasing participation in responsibilities that have been traditionally men's. Men, for their part, mentioned seed storage and water management as subjects about which they advise women. In vegetable cultivation, women cited integrated growing of different vegetables while the men spoke of water management as production technologies they transfer to one another.

Interestingly, the women farmers mentioned sharing with their male (and female) counterparts a variety of technological practices on micro-animal production activities, a pattern that lends evidence to their larger involvement in this enterprise. Whether or not women and men advise each other on tasks that have been traditionally within their respective domain of responsibilities (e.g. caring for children chiefly by women or plough-making mainly by men) was not revealed by the women and men in the study. Seemingly, while overlap in responsibilities can occur in farm enterprises, there still are certain areas where men and women maintain their traditional roles or avoid undermining each other's expected responsibilities or knowledge.

2. Sources and channels of agricultural information and technologies

Male and female members of the household who gain access to information on agricultural technologies generally depend on CRS staff and other agricultural experts during training activities as information sources. At the same time, they consider other farmers as information sources when they take part in cross-farmer visits, or engage neighbours in discussions. Women household members additionally noted that the village chief and farmer trainers also provide information on agricultural technologies. Male household members, on the other hand, also consult with government technicians as well as the Village Livestock Agent (VLA) in a neighbouring village for problems relating to their draft or small farm animals. There is some, but not a lot of, variation then between men and women in terms of their information sources across the farm enterprises

– except for fish culture. In this enterprise, the men and women members of the household derive their information mostly from CRS staff.

Also playing a critical role in disseminating farming-related technologies in the village are the village vendors and the farmer trainers. However, the relative importance of village vendors in comparison with other sources is not known.

Farmer trainers as sources of information also figure in the promotion of the information-intensive practices of sustainable agriculture. As key farmer leaders in their villages, they disseminate agricultural information to both women and men representing the poorest to middle socio-economic categories in the village. Their knowledge is frequently based on the training courses they have attended and on their applications of the technologies they learn from training. Only one of the three trainers who had been interviewed goes out of her way to visit the homes of other farmers to keep them abreast of farming practices she learns about. All three – two of whom are female – entertain whomever comes to their homes to ask for advice. They also provide seeds to those expressing interest in growing vegetables or personally help them in preparing the vegetable bed or selecting good seeds. As information sources, this set of farmers reaches out to others in the village who are unable to access CRS staff or who feel they are not actively sought out to participate in the training activities.

Also playing a role in spreading information on agricultural technologies in the village are women's interest groups, members of which disseminate newly acquired knowledge on growing vegetables to other women farmers. The members also distribute planting materials from their gardens to those who express interest in cultivating these crops.

3. Forums of technology dissemination, when these occur, and frequency

Both women and men transfer their knowledge in a variety of situations – while working in the rice fields, while having lunch or resting, while in a social gathering or a religious event, when visiting each other or during incidental meetings, during village meetings. They do this verbally or by demonstrating the technologies in their gardens or by the pond dikes.

Sharing of information within the home between men and women members may occur right after the information has been obtained or upon return from training. How this takes place does not vary greatly from the way sharing is undertaken at the community level.

4. Application of information gained

Application of knowledge gained from the training, from a family member, a CRS staff or a neighbour, is frequently immediate. Very few case study interviewees stated that they were unable to apply what they learned or delayed the use of the information. When this did occur, reasons included not having a piece of land, the timing of application was not right, and/or they did not have the money. It would appear then that technologies being made available at the household levels are generally ones that address the basic concerns of food and income and, as villagers profess, are easy to apply. This is in contradiction to findings from other developing countries. For example, Mehra (1991) found that time limitations resulting from women's economic and home production roles can significantly affect their ability to respond to agriculture reform incentives, especially those that require additional labour inputs; even if women receive information, they have difficulties in implementing it.

TABLE 1. AGRICULTURAL PRODUCTION AND HOW THE TECHNOLOGY IS BEING TRANSFERRED BETWEEN DIFFERENT GENDER

TYPE AND SOURCE OF INFORMATION	**LOCATION AND TIME OF DISSIMINATION OF INFORMATION**
Rice production	
◊ Variety and yielding characteristics ◊ Variety of rice (from Battambang) ◊ Management of rice ◊ Fertilizer use ◊ Quality of fertilizer ◊ Kinds of fertilizer, organic fertilizer ◊ Pesticides, pest management ◊ Rice experiment ◊ Rat management	◊ Telling when asked ◊ Showing at the field ◊ Telling when working in the field: ploughing, broadcasting seeds, uprooting rice seedlings, transplanting, harvesting, ploughing ◊ Telling during free time ◊ Telling at the pagoda, during ceremonies ◊ Telling after getting information ◊ Telling during meetings, discussions ◊ Telling when visiting their house/meet somewhere/ chatting ◊ The neighbours tell
◊ New variety of rice ◊ Seed storage ◊ Fertilizer use, organic fertilizer saving ◊ Water management ◊ Pesticides/Pest management ◊ Maintaining rice transplanted	◊ Telling when asked ◊ Showing at the rice field ◊ Telling when working in the field ◊ Telling at meetings ◊ Telling after training ◊ Cross visiting ◊ Telling when visiting house, chatting, meeting
Vegetable cultivation	
◊ Variety of vegetables ◊ Vegetable seeds ◊ Price of vegetables ◊ Integrated growing of different vegetables/ vegetable cultivation techniques ◊ Fertilizer use (combining organic with inorganic fertilizers to use in the garden); composting ◊ Use of animal manure ◊ How to apply fertilizer ◊ How to grow; circle bed growing	◊ Telling after training or receiving information ◊ Telling when asked / when meeting each other ◊ Telling when working together/at the rice field ◊ Telling during free time ◊ Telling/showing when visiting or working in the garden / visiting / showing at the garden ◊ Telling when there is a meeting ◊ The head of the village tells ◊ Telling at meeting, training ◊ Telling when visiting neighbours
◊ Home garden ◊ Vegetable seeds/variety of vegetables ◊ Fertilizer use/application (organic) ◊ How to prepare bed ◊ How to grow: circle bed ◊ Pest management ◊ Vegetable price ◊ Water management	◊ Telling when visit to the garden/showing at the garden ◊ Telling when working at the rice field – uprooting rice seedlings. Transplanting ◊ Telling after receiving information ◊ Telling at meeting ◊ Telling at ceremony ◊ Telling when they ask/telling when meeting each other/talking (2 villages) ◊ Telling when someone comes to buy at the garden

Table 1 Cont…	
Fish culture ◊ Site selection ◊ Fish species ◊ Pond preparation ◊ How to fertilize the pond ◊ Harvesting method ◊ Integrated culture: pig-fish, duck-fish culture ◊ Polyculture ◊ How to feed; fish feeds ◊ Price of fish	◊ Telling when meet each other on the road or at house/telling during free time or taking a rest ◊ Showing at /visiting the pond ◊ Telling when working in the field /when fishing ◊ Telling/showing at pond dike ◊ Telling when there is a meeting /telling after a training ◊ Telling when eating together/they come to tell at the house ◊ Telling and showing when somebody is visiting home/when asked
◊ Fish species ◊ Pond preparation ◊ Stocking ◊ Feeding ◊ Fertilizing the pond ◊ How to select site ◊ Fish species ◊ Management ◊ How to sterilize the pond (liming/application of lime)	◊ Telling/showing at pond side ◊ Telling after getting information ◊ Visiting the fishpond ◊ Showing/follow up ◊ Telling at meeting ◊ Telling at rice fields and working together ◊ Telling at ceremony ◊ Telling during free time, lunch time ◊ Telling when chatting/when there is a party ◊ Telling when meeting each other or training
Animal Raising ◊ Pig species that grow fast/pig varieties ◊ Pig feeds for fast growing of animals ◊ Variety and price of pig ◊ Chicken variety (Sonaly) – fast growing, producing many eggs ◊ Vaccination of chicken, pigs ◊ Variety of cows ◊ Feeding ◊ Vaccination ◊ Animal diseases ◊ How to treat animal ◊ Medicines	◊ Telling after training/when getting the information ◊ Telling when meeting at/visiting house ◊ Telling when working in the field – transplanting, harvesting ◊ Telling when visiting each other, when asked, during ceremony party/at lunchtime ◊ Telling when someone is asking ◊ Telling when feeding animal ◊ Telling when meeting and chatting ◊ Telling/asking when meeting each other on the road, market
◊ New variety of chicken/chicken seed ◊ Feeding ◊ Management ◊ Vaccination ◊ Disease of draft animals ◊ How to make chicken house	◊ Telling when eating and drinking /when chatting/ visiting house /at ceremony ◊ Telling when working in the field: exchanging labour in transplanting, uprooting rice seedlings ◊ Showing when visiting at the farm/house ◊ Telling after training or receiving information ◊ Telling at meeting, training ◊ Telling when somebody is asking

B. Training as an information source and as a form of technology transfer

A general problem in agricultural training in Cambodia is low participation of women in training organized by NGOs. The study showed that participation of women in training activities depends upon, among other factors, proximity of the village to the market. A close proximity enables the women to engage in various small businesses. While the purpose of the training is mostly to improve income-generating opportunities and increase access to food, some women farmers are not convinced that these purposes can (or should) be achieved at the expense of their business operations. The women who usually participate in the training belong to poorer families.

The general perception at the community level is that the low participation of women in training lies neither in the topic nor in the learning methods or materials. Focus group discussions showed that their lack of participation stems from the following: physical distance from the training venue; they are busy with rice cultivation and income earning activities; house work and having to care for young children; some of them are not invited; the training facilitators come late. Many farmers also believe that the low level of education among the women is a factor contributing to their low attendance in training.

All the women participating in the focus groups recognized the value of training or of sharing information with men. The women observed that when they participate in training activities, men tend to have a higher regard for the women or "do not look down" on them, men listen to the women more when making decisions, and men express satisfaction when women are able to practice their new knowledge successfully. Men participants in the all-male focus groups confirm these assertions. The men indicated they had more confidence in women's abilities, respected the successful women as leaders, and viewed them with admiration.

Beyond the confidence that participation in training creates for them, the women feel that this activity is a good information source. Those who had opportunities to attend were able to apply the new practices they learned, particularly about rice cultivation, vegetable growing, and animal raising. However, women farmers admitted to finding topics such as IPM and pig diseases difficult because these were new to them. Paris (1998) observed that unless women are direct recipients of knowledge-intensive rice production technology training like IPM, we cannot expect productivity gains by women farmers from such knowledge-based systems.

Farmer-to-farmer extension, market information flows and production decisions

A. Women farmers as 'collectors' and 'disseminators' of information and decision-making on technology adoption or adaptation.

Except for those in the smallest and relatively most isolated village of the four study sites, most women in the study sold their produce within the village or in a nearby market. These women predominantly represent poor families. Selling in the market or in the village occurs frequently during the dry season or only when there is a surplus. Engagement in this activity enables women to acquire different kinds of information from fellow sellers in the market or from buyers. This include information about: varieties of vegetable crops and seeds; prices, quality, and availability of agricultural inputs such as fertilizers, pesticides, and vegetable seeds; and prices of consumption items such as white rice, fish, and vegetables. Prevailing prices of farm produce such as vegetables are of particular interest as these partly determine when and what vegetables, for instance, they could sell.

Not all farmers/farmer trainers believe all the information they learn from the market. Some community members have more confidence in NGO development professionals for useful information rather than relying on informal market channels. Except in cases when information being obtained raises questions, the women (and some men) market sellers Whether it is a woman or a man who shares the information obtained from market channels does not appear to matter to the farmer residents in the study villages. The information they learn – whether learned from a woman or a man – creates the same degree of understanding. Male participants to the discussions noted that men-to-men information sharing is easier than men-to-women, suggesting that cultural norms can inhibit the effective dissemination of information. Case study interviewees also noted that the credibility of village-based information sources depends on whether or not the disseminating person is actively engaged in farming, has had many years of experience in this occupation, and/or has a history of providing correct and useful information. One market seller interviewee added that the credibility of persons sharing the information depends as well on the farm micro-enterprise in which they are involved. Women tend to have more credibility than men when they disseminate market-sourced information about vegetables because they spend more time in growing these crops even though men may perform more of the physically demanding tasks in the production process.

Those who receive information from the market sellers use most of what they learn. Some farmer trainers tested the information gathered on the farm before large-scale adaptation and dissemination to others. Making the decision to adopt or adapt a particular technology is frequently the responsibility of both the husband and wife in couple-headed or male-headed households, or of the female head in a female-headed household, unless she has adult children. In couple-headed/male-headed households, whether or not the spouse is involved in farming also has an influence on his/her decision-making capacity.

Whether women farmers can be more effective than men in collecting and disseminating information through informal channels is a function of a number of considerations. For one thing, effective 'collectors' and 'disseminators' of information seem to require an ability to evaluate the advice being received from a variety of market channels, given that such advice are not necessarily accurate and/or applicable. This ability is linked to whether or not the person is a practising farmer and has knowledge of day-to-day operations of the different farm micro-enterprises that other farmers in the village are engaged in. Cultural constraints appear to be critical as well in considering whether women can collect or disseminate information more effectively. This is because women entrusted with this responsibility or men receiving the advice may experience the discomfort that socio-cultural norms create since others in the village may misinterpret and frown on fairly regular one-on-one, male-female/female-male interactions that the responsibility may require.

B Women farmers as micro-enterprise owners and farmer trainers

Findings at the community and individual levels reveal that women farmers can be farm micro-enterprise owners and operators as well as provide quality inputs and technical backstopping to other farmers. At the community level, men and women note that women can be owner-operators of a farm micro-enterprise because of the experience they have gained from applying the knowledge obtained from the NGO- sponsored training courses. Both men and women farmers believe that women can perform the agricultural work that men do, and if they were owner-operators or farmer trainers their farming experience would likely lend them the confidence to train or demonstrate to others their knowledge. Women have been reported to be also "more patient," "more economical than men," and tend to "think first before doing anything" – in effect, to have qualities that qualify them to be effective farm micro-enterprise owner-operators and farmer trainers.

Individual level findings support these observations. Market seller interviewees said that women have the experience to talk about these issues if some of them were designated as farmer trainers, and that being a farmer-trainer is not necessarily a full-time job. Farmer-trainer interviewees noted that women can have the time for the responsibilities that go with being a farm micro-enterprise owner-operator and a farmer-trainer. They added that women already undertake the important tasks of a farm owner-operator and this best qualifies them to take on this additional responsibility.

Despite these possibilities, villagers claimed that women farmers face several difficulties to becoming independent farmer-trainers and owner-operators of micro-enterprises:

- Women are physically not strong enough to perform physically demanding tasks such as vaccinating draft animals, in addition to having a fear of cows and buffaloes
- Women can do "light work" only e.g. grow vegetables
- Women do not have the capital to undertake a farm micro-enterprise that will demonstrate their knowledge
- Women cannot go far from home
- Women may be criticized by neighbours
- This may encourage jealousy between a husband and wife
- They cannot go out at night because they are afraid of ghosts
- Women have a low level of education which discourages them from speaking out or can make them less confident in disseminating to others what they know
- Women may have young or many children who need their time and attention
- Men still have greater credibility than women because of their higher educational levels.

For many of the above reasons, if given a choice on whom they would call first for assistance with production problems in their rice field or micro-enterprises in the homestead, villagers will tend to call on a male farmer-trainer first rather than a female farmer-trainer.

Women farmers – including ones in female-headed households – and women farmer-trainers themselves contend that they can be owner-operators of a farm micro-enterprise, or farmer trainers, even as they recognize the practical constraints to effective performance of these responsibilities, particularly that of being a farmer-trainer. Larger community assertions, however, reflect the larger societal context of a persistent perspective about traditional gender roles that "women can only do light work". The challenge for development practitioner is how to strengthen women's belief in themselves while helping others create a better space for women's contributions to SA practices and integrated farming systems. The confidence building is very important for women farmers to become an effective farmer trainer.

Agricultural technology and gender

A. Agricultural technologies and workloads

Sustainable agricultural practices are frequently labour intensive and can re-orient or reinforce conventional roles and responsibilities in the home and in the farm. Participants to the all-men and all-women focus groups in the four villages revealed that project interventions have contributed to changes in the workload of men and women both in their productive and reproductive activities. Both men and women reported doing work that has been traditionally women's/men's responsibility (Table 2)

Engagement in multiple enterprises on their farms has also entailed more time being spent by men, women, and children in various farm operations and maintaining different farm enterprises. Significant changes appear to be occurring within the home. With the increased workload in the households' productive activities, men reported that they are taking on more responsibilities in caring for children, preparing meals, and doing the family laundry. Additions in the workload in the realm of production activities blur the gender division of labour even in the home.

The overall impact of the changes in technology has been observed by both men and women in several areas (Table 3). At the household level, and regardless of the resource grouping to which they belong, male and female family members alike indicated that their free-time had decreased, and that the time spent on productive work had increased.

TABLE 3. IMPACT OF TECHNOLOGIES ON MALE AND FEMALE HOUSEHOLD MEMBERS (PERCENT OF MEN/WOMEN HOUSEHOLD MEMBERS UPON WHOM IMPACT AREAS ARE OCCURING)

Impact areas	♂			♀		
	↑	↓	—	↑	↓	—
Free time	13	87	-	-	100	-
Child rearing work	23	23	54	14	29	57
Home, family maintenance	57	29	14	33	33	33
Production work	92	-	8	95	-	5
Participation in community activities	92	-	8	83	6	11
Ability to obtain credit	80	10	10	72	7	21
Ability to save	79	-	21	80	-	20

B. Women's and men's perceptions of agricultural technologies

Despite the added workload, men and women in the study villages generally felt positive about the added workload and its attendant changes (Table 4 and 5). Women felt more involved in making decisions in the home, that they are learning more, and that the technologies are helping provide for their household's daily subsistence. Men generally concurred with these assertions.

Beyond the provision for the household's basic needs, women and men claim that SA technologies are fostering better relations within and outside the home. Women's increased roles in the integrated farming system contribute to an atmosphere of mutual consultation in decision-making. The interviewees contended that learning new technologies and sharing information paves the way for better communication and relations in the home and, to an extent, reduces family conflict and the incidence of domestic violence. According to the interviewees, a specific influential factor is that women are discussing with their spouses the concerns that arise from selling their products in local and Vietnam-border markets. In addition to more positive interactions in the home, women and men reported that the onset and spread of the technologies has also helped in building improved relations with others in the village.

TABLE 4. HOW WOMEN, MEN FEEL ABOUT THE TECHNOLOGIES

Women feel.	*Women perceive men to feel…*
✔ they are more involved in making decisions ✔ they can get more income ✔ delighted/happy - **family members help each other** - **more education** - **more vegetables, fish to eat** - husband works more on income earning	happy/glad – ✔ with high yields, more income, income sources ✔ learned more agricultural technologies *… but feel tired when overworked*

Men feel…	***Men perceive women to feel…***
✔ satisfied/delighted/happy – - when family help each other for income - family has vegetable and paddy rice - knowledge, income improved - being encouraged and helped - work harder but family has food, vegetables, more income - family provided with nutrition, income *… but feel tired when overworked*	✔ happy - - knowledge application ➔ food, more income - good relationship with others in village - family living condition improving with more income - better understanding of technologies

TABLE 5. TECHNOLOGIES AND RELATIONS BETWEEN MEN AND WOMEN

women say…

- ✔ Good communication between men and women – husband and wife discuss before making decisions
- ✔ Help each other more
- ✔ Better communication with neighbour, other men, others in village
- ✔ Good understanding in family
- ✔ Women more 'brave', not shy, have better relationship with others

men say…

- ✔ Better respect for each other
- ✔ Friendlier through training and working together
- ✔ Better understanding of relations in family and outside
- ✔ Closer relations, less family conflict

Conclusion and Recommendations

Women farmers can be a force in transferring technologies to other women farmers, particularly among those who rank among the poorest and have less confidence to interact with others at the community level. Such transfer of knowledge and technologies occurs on a one-on-one basis or through groups, and usually at more informal levels. The roles that women play as informal farmer-trainers may be more substantial than is currently recognized.

Traditional communication channels in villages, such as the village chief, market sellers, and village vendors, have central roles in disseminating agricultural information. To date, these channels are being under-utilized as a resource for many villagers, especially women. A critical element to reflect and focus upon is strengthening their abilities to evaluate useful information.

Simply having appropriate technologies will not bring development. The recruitment of women extension workers will not always help. What is needed is the development of systems for developing and transferring technology in its broadest sense, including know-how and technique, in a way that promotes the recipient's own ability to become, him or herself, a technologist (Anderson and Buck, 1980). How does one develop the capacity to invent? Familiarity with existing technologies is certainly part of the answer. This is why issues of access to both knowledge and technologies are so important for longer-term development. Those who do not have access to technological knowledge or experience are never as likely to become developers of their own technological solutions as those who do (Anderson, 1988). To what extent impact of the lack of access to extension services by women farmers is minimized by informal farmer-to-farmer extension, and whether this flow of information is sufficient to encourage women farmers to become innovators, is not yet known.

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លក្ខណៈសំរូបកម្មនិងការផ្តាច់ចេញ និង ចលនការរំដោះចេញនៃសារធាតុផូស្វ័រ នៅលើដីស្រូវស្រែទំនាបបីប្រភេទផ្សេងគ្នា នៅក្នុងប្រទេសកម្ពុជា

PHOSPHATE SORPTION-DESORPTION BEHAVIOUR, AND PHOSPHORUS RELEASE CHARACTERISTICS OF THREE CONTRASTING LOWLAND RICE SOILS OF CAMBODIA

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អត្ថបទសង្ខេប

ការយល់ដឹងនូវលក្ខណៈសំរូបកម្ម **(sorption)** និងការរំដោះចេញ **(release)** នៃសាធាតុផូស្វ័រ **(P)** នៃប្រភេទដីផ្សេងៗ ពិតជាអាចជួយសំរួលបានដល់ការកំណត់នូវតំរូវការសារធាតុផូស្វ័រសំរាប់ការលូតលាស់របស់ដំណាំស្រូវ។ ទាំងពិសោធន៍នៅក្នុងលក្ខខណ្ឌផ្ទះកញ្ចក់ និង នៅក្នុងមន្ទីរពិសោធន៍ ត្រូវបានធ្វើឡើងដើម្បីពិនិត្យមើលនូវយន្តការយូរអង្វែងនៃការរំដោះចេញនៃសារធាតុផូស្វ័រពីដី តាមរយៈការប្រើប្រាស់ ដី ទៅលើវគ្គលូតលាស់ដំបូងរបស់ដំណាំស្រូវ និងធ្វើការកំណត់ផងដែរនូវលក្ខណៈសំរូបកម្ម និង ការផ្តាច់ចេញ **(desorption)** នៃសារធាតុផូស្វ័រនៅលើដីផ្សេងគ្នាបីប្រភេទនៃប្រទេសកម្ពុជា ជាអាទិ៍រួមមានៈ ក្រុមដីប្រទះឡាង គោកត្រប់ និង ក្រុមដីទួលសំរោង។ ចំពោះពិសោធន៍នៅក្នុងផ្ទះកញ្ចក់ គឺដំណាំស្រូវត្រូវបានដាំដុះ ចំនួន ៥ វដ្តជីវិតជាបន្តបន្ទាប់ ដោយក្នុង១វដ្តជីវិតមានរយៈពេលពី ៦ ទៅ ៨ សប្តាហ៍ ដោយប្រើជីផូស្វ័រចំនួន ៤ កំរិត ០, ៥, ១០, និង ២០ មក្រ/គក្រដី។ ចលនការសំរូបកម្ម និង ការផ្តាច់ចេញ **(sorption-desorption isotherms)** នៃសារធាតុផូស្វ័រ ត្រូវបានប្រព្រឹត្តទៅដោយដំបូងឡើយធ្វើអោយដីមានតុល្យភាព **(equilibrate)** ជាមួយកំរិតផូស្វ័រផ្សេងៗ ដូចជា ០, ១០, ២០, និង ៤០មក្រ/គក្រដី ក្នុងសូលុយស្យុងកាល់ស្យូមក្លរួ **($CaCl_2$)** ដែលមានកំហាប់ ០,០១ ម៉ូល នៅសីតុណ្ហភាព ២៥ អង្សាសេ ។

នៅលើប្រភេទដីខ្សាច់ប្រទះឡាង និង ដីឥដ្ឋទួលសំរោង ការដាក់ជីផូស្វ័រក្នុងបរិមាណ ១០មក្រ/កក្រដី មានលក្ខណៈគ្រប់គ្រាន់សំរាប់ អោយដំណាំស្រូវបង្កើតបាននូវបរិមាណអតិបរិមានៃ ចំនួនដើមបែក កំពស់ដើម ទំងន់សារធាតុស្ងួត កំហាប់សារធាតុផូស្វ័រ និង បរិមាណសំរូបផូស្វ័រសរុប **(total P uptake)** ដោយរុក្ខជាតិ។ ផ្ទុយទៅវិញនៅលើក្រុមដីឥដ្ឋអាស៊ីតគោកត្រប់ ដំណាំស្រូវត្រូវការសារធាតុផូស្វ័ររហូត ដល់បរិមាណ ២០មក្រ/គក្រដី ដើម្បីអោយការលូតលាស់ និងបរិមាណសំរូបផូស្វ័រសរុបរបស់វាមានលក្ខណៈអតិបរិមា។ ជារួមយើងសង្កេត ឃើញថានៅលើគ្រប់ប្រភេទដី បន្ទាប់ពីពីរវដ្តដាំដុះរួចមក ការលូតលាស់របស់ដំណាំស្រូវត្រូវថយចុះយ៉ាងខ្លាំងនៅគ្រប់កំរិតជី ដែលបាន ប្រើប្រាស់នៅក្នុងវដ្តដាំដុះទី១ ក៏ប៉ុន្តែការថយចុះខាងផ្នែកទិន្នផល និង បរិមាណសំរូបផូស្វ័រសរុបរបស់ដំណាំស្រូវ ដែលដាំដុះនៅលើប្រភេទដីឥដ្ឋទួលសំរោង និង គោកត្រប់ មានលក្ខណៈតិចតួចជាងដំណាំស្រូវដែលដាំដុះនៅលើដីខ្សាច់ប្រទះឡាង។

ទំរង់ផូស្វ័រអាចស្រូបបានដោយរុក្ខជាតិ **(Resin-P)** គឺជាទំរង់ **(fraction)** មួយដែលមានបរិមាណតិចជាងគេបំផុត បើប្រៀបធៀបទៅនឹងទំរង់ផូស្វ័រចំបងៗនៅក្នុងដីដូចជា **NaOH-Pi, NaOH-Po** និង **Residual-P** នៅលើគ្រប់ប្រភេទដី ។ ក៏ប៉ុន្តែទំរង់ផូស្វ័រ **Resin-P** នេះត្រូវបានគេពិនិត្យឃើញនៅលើដីខ្សាច់ប្រទះឡាង មានបរិមាណច្រើនជាង នៅក្នុងដីឥដ្ឋទួលសំរោង និង គោកត្រប់។ គេកត់សំគាល់ឃើញ ទៀតថា មានការថយចុះខាងបរិមាណនៃគ្រប់ទំរង់ផូស្វ័រ ជាពិសេស ទំរង់ផូស្វ័រចំបងៗ **(NaOH-Pi, NaOH-Po** និង **Residual-P)** នៅគ្រប់វដ្តដាំដុះដំណាំស្រូវ បញ្ហានេះអាចបណ្តាលមកពីប្រតិកម្មជាបន្តបន្ទាប់នៃជីផូស្វ័រដែលបានប្រើជាមួយដី បន្ថែមទៅលើបរិមាណផូស្វ័រ សរុបដែលដំណាំស្រូវស្រូបយកក្នុងវដ្តដាំដុះនិមួយៗ។

នៅក្នុងលក្ខខណ្ឌដីស្ងួត **(oxidized condition)** ប្រភេទដីឥដ្ឋគោកត្រប់ និង ទួលសំរោង ស្រូបសារធាតុផូស្វ័រ ៥ ដងច្រើនជាង ប្រភេទដីខ្សាច់ប្រទះឡាង នៅពេលកំរិតផូស្វ័រប្រមាណជា

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២០មក្រ/គក្រដី ត្រូវបានប្រើប្រាស់។ ការផ្តាច់ចេញនូវសារធាតុផូស្វ័រពីដី ត្រូវបានសង្កេតឃើញដំបូងឡើយមានបរិមាណច្រើននៅលើដីខ្សាច់ប្រទះឡាង ប៉ុន្តែវាក៏បានថយចុះមកវិញឆាប់រហ័សជាងដីឥដ្ឋ ទួលសំរោង និង គោកត្រប់ នៅពេលគេបង្កើនចំនួននិស្សារណកម្ម **(extraction)** នៃដី។ ហើយគេពិនិត្យឃើញទៀតថា បរិមាណសរុបនៃផូស្វ័រដែលផ្តាច់ចេញពីដីឥដ្ឋគោកត្រប់ និង ទួលសំរោង ច្រើនជាងដីខ្សាច់ប្រទះឡាង។ ការស្រូបសារធាតុផូស្វ័រដ៏ច្រើនលើសលប់របស់ដីប្រភេទឥដ្ឋ ក៏បាននាំអោយសំណល់នៃសារធាតុផូស្វ័រ មានប្រសិទ្ធភាពយូរអង្វែងផងដែរ ទៅលើការដាំដុះដំណាំស្រូវ។

ពាក្យគន្លឹះ: ដីស្រូវស្រែទំនាប សារធាតុផូស្វ័រ លក្ខណៈនៃការរំដោះចេញ ប្រសិទ្ធភាពកាកសំណល់ ទំរង់ផូស្វ័រនៃដី សំរូបកម្ម និងការផ្តាច់ចេញ

ABSTRACT

Understanding the P sorption and release characteristics of different soils can help in determining fertiliser P requirements for the growth of rice (*Oryza sativa* L.). Glasshouse and laboratory experiments were undertaken to observe the long-term release characteristics of P from added fertiliser for the early growth of rice, and also to determine P sorption-desorption behaviour of three contrasting lowland soils from Cambodia: Prateah Lang (Plinthustalf), Koktrap (Plinthaquult) and Toul Samroung (Endoaqualf). In the pot experiment, rice was treated with four P rates (0, 5, 10 and 20 mg/kg soil) and grown over five successive cropping cycles, each of six to eight weeks. Phosphorus sorption-desorption isotherms were constructed by equilibrating with 0, 10, 20 and 40 mg P/l in 0.01 M $CaCl_2$ solution at 25 ^oC.

On the sandy Prateah Lang (PL) and clayey Toul Samroung (TS) soils, addition of 10 mg P/kg soil was adequate in the first crop for maximum tiller number, plant height, total dry matter, P concentration, and total P uptake. By contrast, about 20 mg P/kg was needed for the maximum growth and total P uptake on the clayey acid Koktrap (KT) soil. After two crops, plant growth progressively declined at all P levels, but the decrease in yields and total P uptake on the clayey TS and KT soils was slower than for plants grown on the sandy PL soil.

Resin-P extractable was the smallest P fraction compared to other major soil-P (NaOH-Pi, NaOH-Po and Residual-P) pools in all soil groups, but recovery from the Resin-P pool was higher in the sandy PL soil than in the clayey TS and KT soils. The declining amounts recovered from all the extractable soil P fractions, especially major soil P (NaOH-Pi and Po and Residual-P) pools with succeeding rice crops grown on all the soils could be attributed to continued reactions of the added P fertiliser by soils in addition to plant P uptake during each plant-growing cycle.

The clayey KT and TS soils sorbed five-fold more P than the sandy PL soil in oxidized conditions. Phosphorus desorption was initially greatest from the sandy PL soil: but with increasing numbers of soil extractions, the release of sorbed P declined faster than in the clayey KT and TS soils. The cumulative desorbed P was greater from the clayey KT and TS soil than from the sandy PL soil. The greater P sorbed by the clayey soils should ensure a longer duration of the residual P effect.

Keywords: lowland rice soils, phosphorus, release characteristics, residual effect, soil-phosphorus fractions, sorption-desorption

INTRODUCTION

The cause of limiting phosphorus (P) supply for rice crops may be low total P contents and/or a high P sorption capacity of the soil. In Cambodia, the extent to which soil groups identified by White *et al*. (1997a,b) for rice agronomic management differ in their P sorption-desorption behaviour and P release characteristics has yet to be tested. Some studies have been conducted on the short-term crop responses to P fertiliser application (CIAP, 1995, 1996; White and Seng, 1997), and a recent study examined residual value of applied P fertiliser over 5 successive rice crops on the Prateah Lang soil (Pheav *et al*., 2003). Other studies have also examined the dynamics of P availability under alternating reduced and oxidized conditions (Seng *et al*., 1999). It is crucial to determine the long-term P supplying characteristics of a range of important rainfed lowland rice soils in Cambodia.

Understanding of the P sorption-desorption processes of different soils can help in determining comparative P requirements for plants (Kuo *et al*., 1988). The agronomic efficiency of P fertiliser is strongly dependent on the P sorption-desorption capacity of the soils (Singh and Gilkes, 1991). Hence, data on soil chemical properties, including P sorption-desorption reactions in different soils is critical for managing P fertiliser supply and recommendations. Indeed, for further developing soil P management strategies and recommendations, soils may be grouped together on the basis of their ability to release and retain P from fertiliser added, as well as native soil P.

Phosphate sorption characteristics of the soil are important properties in determining fertiliser requirements of crop growth, because adsorbed P equilibrates with P in the soil solution and this P is, in turn, the immediate source of P for plant uptake (Fox and Searle, 1980). Soil properties and environmental conditions affect the P adsorption capacity (Syers *et al*., 1971; Goldberg and Glaubig, 1988; Cristensen, 1989; Sposito, 1989; Zachara *et al*. 1989; Schuster, 1991; Lee *et al*. 1996).

Adsorption capacities typically vary amongst soil types. Some soils have low sorption capacities and hence hold small reserves of P within the soil. The P sorption of soils developed on materials high in quartz was moderate to low, and these soils have modest fertiliser requirements (Mokwunye, 1977). However, other soils have high sorption capacities, and probably, a high capacity to retain P within the soil for an extended period. Fox and Searle (1980) reported that all soils, in which 2:1 and 1:1 type clays predominate, as a general rule, absorb large amounts of P. Sandy soils may have less sorption per unit soil weight, whereas, soils rich in clay minerals and sesquioxides have the greater sorption (Sanyal *et al*., 1993). In a study of P sorption of two soils of southeast Cambodia, Seng (2000) found that a black clayey acidic soil (Koktrap: White *et al*., 1997a, b) sorbed about five-fold greater P concentration than a sandy acid soil (Prateah Lang: White *et al*., 1997a,b) under oxidised conditions.

In summary, with various soil types in different environments, P sorption-desorption processes have been found to vary with forms of Fe and Al, soil pH, organic carbon, clay and carbonate contents and other soil properties (Saunders, 1965; Hinga, 1973; Ballard and Fiskell, 1974; Holford and Patrick, 1979; Ping and Michaelson, 1986). More details of relevant soil properties and soil-water regimes influencing the P sorption-desorption mechanisms in lowland and upland soils were reviewed by Pheav (2002). However, the factors associated with P sorption-desorption processes in major Cambodian rice soils have not been fully identified. This research was conducted to determine the long-term P release characteristics, and availability of P from fertiliser added to the flooded soils planted to rice over five successive cropping cycles each separated by a 2-week oxidised fallow period. The P sorption-desorption behaviour in three contrasting lowland rainfed rice-growing soils of Cambodia was also examined under the aerobic conditions.

MATERIALS AND METHODS

Soil sampling

Three contrasting soil types were selected for both the pot and P sorption-desorption experiments: Prateah Lang (PL), Koktrap (KT) and Toul Samroung (TS) (White *et al*., 1997a,b); Plinthustalf, Plinthaquult and Endoaqualf (Soil Survey Staff, 1994). Prateah Lang and Koktrap soils both varied from moderately to strongly acidic, whereas, the Toul Samroung soil was closer to neutral. Their main properties are presented in Table 1.

The soils used in both the glasshouse and laboratory experiments originated from farmers' rice paddy fields in Cambodia. Usually, these soils were cultivated with rice during the wet season each year. The top 20-cm layer was collected during the dry season when soil was in fallow. Care was taken to ensure soil samples were collected from fields with no recent history of inorganic P fertiliser application. Soils were sun-dried and crushed, all stones and coarse organic debris removed, and then the soils were sieved to pass through a 2-mm screen.

Table 1. Selected properties of the three major rainfed lowland rice-growing soils of Cambodia used for both pot and laboratory experiments (0-20 cm depth, sieved to < 2.0 mm). Values are means of 249 samples.

Major properties	*Prateah Lang soil*	*Toul Samroung soil*	*Koktrap soil*
pH (1:1 H_2O)	*5.4*	*5.6*	*5.1*
Organic C (g/kg)	*4.0*	*9.0*	*13.0*
Sand (g/kg)	*498*	*355*	*279*
Silt (g/kg)	*370*	*410*	*293*
Clay (g/kg)	*132*	*229*	*416*
CEC [$cmol_c$ (+)/kg]	*3.7*	*15.9*	*8.1*
Exch. Ca [$cmol_c$ (+)/kg]	*1.2*	*7.1*	*1.1*
Exch. Mg [$cmol_c$ (+)/kg]	*0.5*	*3.3*	*0.6*
Exch. K [$cmol_c$ (+)/kg]	*0.1*	*0.2*	*0.1*
Exch. Na [$cmol_c$ (+)/kg]	*0.4*	*0.3*	*0.3*

Data source: Oberthur et al. (2000)

Pot experiment

The P exhaustion pot experiment was conducted in the glasshouse within the compound of the Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, Cambodia. This pot trial was commenced in July 1998 (wet season), and ended in May 1999 (dry season). Five consecutive cropping cycles of rice were examined. Rice plants were grown for six weeks prior to harvest in the first cycle and for eight weeks during the second to fifth cycles. The experiment was arranged as a randomized complete block (RCB) design with factorial combinations of three soil types (PL, KT and TS) and four levels of P fertiliser (0, 5, 10 and 20 mg P/kg soil) with four replicates, giving a total of 48 pots.

Phosphate fertiliser was supplied as potassium dihydrogen orthophosphate (KH_2PO_4). In addition to P fertiliser, other nutrients in solution were applied basally to the soil during the first cycle at the following rates (mg/kg soil): NH_4NO_3: 200; K_2SO_4: 142; $CaCl_2.2H_2O$: 71; $MgSO_4.7H_2O$: 21; $MnSO_4.H_2O$: 15; $ZnSO_4.7H_2O$: 10; $CuSO_4.5H_2O$: 5; H_3BO_3: 0.71 and Na_2MoO_4: 0.6. From one week after planting, 4 ml of NH_4NO_3 solution (28 mg N/kg soil) was also top-dressed weekly to ensure that plants did not experience N deficiency at any stage. Phosphorus fertiliser was only added at the beginning of the first cycle, whereas N, K, S and Mg fertilisers were applied in every cropping cycle. Based on symptoms of N, K, S and Mg deficiencies that appeared in plants in the first cropping cycle, these fertilisers were increased in subsequent cycles to equal rates (mg/kg) used by Lor *et al*. (1996): NH_4NO_3: 479; KNO_3: 230; Na_2SO_4: 110; and $MgCl_2.2H_2O$: 137. The application of complete micronutrients (as shown above) was repeated at the beginning of the fifth cropping cycle.

The soil was mixed thoroughly before 10-kg portions were placed in double plastic lined bags into undrained PVC pots. All nutrients were firstly applied to the soil surface, allowed to sun dry and then mixed by shaking to distribute the nutrients evenly throughout the soil. The soil was then wetted with deionised water (DI) to field capacity one week before germinated rice seeds were planted. Thereafter, all pots were flooded to a depth of 4-5 cm and maintained at this level throughout the rice-growth cycle by daily watering. Between cycles dry soils for two weeks.

Rice (*Oryza sativa* L.), cv. IR64 seeds were germinated for 48 to 72 h in Petri-dishes on a filter paper moistened with a combination of 1.0 mM $CaSO_4$ and 10 μM H_3BO_3 solution at room temperature (modified from De Datta, 1981). Ten germinated rice seeds per pot were sown at 0.5 to 1.0 cm depth. One week after emergence, healthy plants with similar physical appearance were selected and thinned to five plants per pot. All pots were re-positioned every three days to avoid positional effects on plant growth.

Six to eight weeks after sowing, when rice was at the maximum tillering stage, shoot and roots were harvested to determine dry matter (DM) and the P content of plants. Shoots were cut at ground level, and roots gently pulled up by hand and recovered after careful washing with DI water to remove soil. Both shoot and roots were oven-dried at 75 ^oC for 48 h until reaching constant weight. Fresh and dry weights of plant samples were recorded. Plant height and tiller number per pot were also measured. After oven drying, plant materials were chopped and finely milled by an electrical grinder, then a sub-sample of about 10 g/sample was packed in a sealed plastic bag and stored at 4 ^oC prior to utilisation. Phosphorus concentrations were determined with inductively coupled plasma atomic emission spectrometry (ICP-AES) after samples were digested with concentrated nitric acid (HNO_3) at 140 ^oC (Zarcinas *et al*., 1987).

In each cropping cycle, soils were sampled at harvest from those pots that received nil-P and the highest P (20 mg/kg soil) levels. The flooded soil was stirred thoroughly and 50 g/pot removed from 0-10 cm depth. The soil samples were oven-dried at 50 ^oC, and then crushed, their coarse organic debris was removed and samples were packed (20 g/sample) for subsequent nutrient analyses. A sequential soil P fractionation method was used, involving modifications to the procedure of Hedley *et al*. (1994) to make it suitable for highly weathered sandy soils of Cambodia as described in Pheav *et al.* (2003).

Phosphorus sorption-desorption experiment

All soil samples were incubated in aerobic conditions at constant temperature of 25 ^oC for 2 weeks prior to the soil P sorption-desorption analyses. Phosphorus sorption-desorption experiments used the procedures of Ozanne and Shaw (1967).

For P sorption: triplicate 1.0 g samples of the air-dry soil were placed in 50-ml centrifuge tubes and suspended in 20 ml of 0.01 M $CaCl_2$ solution containing 0, 10, 20 and 40 mg P/l as KH_2PO_4. In each tube, two drops of ethanol-free chloroform were added to minimize microbial activity. Equilibration was carried out in an end-over-end shaker for 17 h with temperature at 21-25 ^oC. The samples were then centrifuged for 10 minutes at 2000 rpm, and filtered through Whatman # 42 filter paper. Phosphorus in the solution was determined by the method of Murphy and Riley (1962). The amount of P sorbed was calculated from the difference between initial and final P concentrations.

Phosphorus desorption was quantified by initially equilibrating air-dried soil samples, that were pre-treated with the same P levels as above, with 20 ml of 0.01 M $CaCl_2$. The amount of P sorbed by the soil after a 17-h equilibration represented the starting value for absorbed P. The soils were subjected to sequential desorption with 20 ml of 0.01 M $CaCl_2$ (P-free), re-equilibrated in the end-over-end shaker for 17 h at 21-25 ^oC. Phosphorus in the extracts after centrifugation and filtration was analysed as described above. This cycle was repeated until P recovery in the extracts approached zero (below detection) or a constant value. Normally, a total of 8 to 18 extractable steps are required, depending on soil types and P concentrations added (Rhue *et al*., 1994; Harris *et al*., 1996; Villapando and Graetz, 2001). Desorbable P was determined by summing the total P desorbed after successive extractions.

Statistical analysis

For every cropping cycle of the pot experiment, an analysis of variance (Two-way ANOVA) for each of the growth parameters was undertaken to determine treatment effects using the IRRISTAT software package for Windows, version 4.03 (IRRI, 1997). When the treatment effects were significant, the least significant difference (LSD) was used for mean comparisons.

RESULTS

Growth and P uptake response to phosphorus fertiliser

Plants grown on all the soils responded strongly to the application of P fertiliser for all the characters measured. With 10 mg P/kg added to soils, plant height, tiller number (Table 2), shoot and root dry matter (DM) (Figure 1), and total plant P uptake (data not shown) significantly (p<0.01) increased. About 10 mg P/kg applied to Prateah Lang (PL) and Toul Samroung (TS) soils was required for maximum shoot DM of rice in crop one, and 20 mg P/kg soil was required for the maximum shoot DM on Koktrap (KT) soil.

Table 2. Response of maximum tiller number and plant height of rice to single application of P fertilisers 6 to 8 weeks after sowing on three contrasting lowland rice soils of Cambodia over five successive cropping cycles. The values are means of four replicates. Data of the nil-P treatment is not presented here because of other basal nutrients than P were applied different levels from the P treated plots, and varied from one crop to another.

Treatment		Crop 1		Crop 2		Crop 3		Crop 4		Crop 5	
Soil	P level (mg/kg)	Tiller (no/pot)	Height (cm)	Tiller (no/pot)	Height (cm)	Tiller (no/poi)	Height (cm)	Tiller (no/pot)	Height (cm)	Tiller (no/pot)	Height (cm)
PL	5	65	73	17	49	17	40	11	43	10	32
	10	76	64	24	54	37	47	19	48	10	31
	20	86	74	60	66	42	50	21	53	10	33
KT	5	35	62	14	48	11	43	10	38	13	38
	10	40	67	13	47	22	47	14	44	18	40
	20	53	68	53	67	59	57	43	66	28	48
TS	5	32	67	31	61	10	44	10	35	10	32
	10	53	72	33	59	16	45	12	31	10	28
	20	54	78	46	65	42	58	17	53	21	41
F (PL)		**	*	**	**	**	ns	**	ns	ns	ns
F (KT)		**	**	**	**	**	**	**	**	**	**
F (TS)		**	**	**	*	**	*	**	**	**	**
F (S x P)		**	**	**	**	**	*	**	**	**	**

* Indicates statistical significance amongst P treatments: ns: not significant,* $p \leq 0.05$, ** p<0.01.

A four-fold increase in shoot DM was recorded with the application of P at 20 mg/kg on the PL soil, more than six-fold on the KT soil, and up to eight-fold on the TS soil, compared to pots receiving no P fertiliser (Figure 1). Root dry weights showed similar responses to those of the shoot DM in the first crop. The greatest increase in the root growth was obtained for the plants growing on the PL soil with 10-20 mg P/kg soil treatment (Figure1).

Phosphorus concentrations in shoots increased sharply ($p<0.01$) with P fertiliser application. The P concentrations of the shoots were 2.6, 2.0 and 1.8 g P/kg for the PL, TS and KT soils, respectively, at 20 mg P/kg treatment (data not shown) in the first crop in each treatment (data not shown). By contrast, from the second crop, P concentrations in the shoots of the plants grown on the TS and KT soils were greater than in those plants grown on the PL soil (data not shown).

The shoot dry weight was positively correlated with P concentrations in plants grown on all the soil groups over five successive rice crops (Figure 2). Indeed, total P uptake increased with P fertiliser application on all the soils. The highest P uptake by rice grown on the PL soil was about two-fold greater than for the plants grown on both the KT and TS soils at the 20 mg P/kg soil (Figure 2). The reduction of total P uptake over successive cropping cycles was closely related with decreasing shoot DM, especially with lower P supply (Figures 1, 2). The decline in rice growth was greater for plants growing on the PL soil than for those plants growing on the KT and TS soils (Figure 1).

Soil P fractions

Resin-extractable P was the smallest (< 0.2 mg P/kg) amongst all P fractions of all soil types (Figure 3). The Resin-P extractable fraction, however, was higher in the sandy PL soil than in the clayey KT and TS soils. After one crop, both labile P (NaOH-Pi and NaOH-Po) and occluded P (Residual-P) fractions were the largest pools of extracted P from all the soils (Figure 3). The size of extractable P pools decreased on all the soils in succeeding cropping cycles. The decline in labile NaOH-P pools was greater in the clayey KT and TS soils than in the sandy PL soil (Figure 3).

The total P uptake of rice was almost equally well correlated with the soil P levels in each of the fractions for all three soil groups (Figure 4). Plant P uptake was much more responsive in the PL soil to increases in each of the P fractions than in other soils.

Phosphorus sorption-desorption levels

The sandy PL soil adsorbed about one-fifth of the P adsorbed by clayey KT and TS soils when P in the initial solution was 20 mg P/l (Figure 5). Amongst the three soil groups, KT adsorbed almost 100 % of P applied even when the addition of P was up to 40 mg P/l, whereas, only about 75 % and 26 % of the added P fertiliser in solution were sorbed by the clayey TS and PL soils, respectively (data not shown).

The desorption of P was much greater in the sandy PL soil than the clayey TS and KT soils after the first soil extraction with all added P levels (Figure 6)
. Phosphorus released from the PL soil after one desorption cycle was about two-fold and six-fold higher than the clayey TS and KT soils, respectively. However, after two extractions the desorbed P from the TS and KT soils decreased only slightly or remained constant at about 5 and 3 mg P/kg for more than eight soil extractions, unlike the sandy PL soil, on which the desorbed P level dropped quickly and levelled off at close to zero at the fifth soil extraction (Figure 6).

There was a negative relationship between P sorption and total P uptake of rice grown on different soil types (data not shown). For example, with P added at 20 mg/l, the soils sorbed about 81, 384 and 395 mg P/kg, corresponding with the total uptake of 127, 64 and 57 mg P/pot by rice plants growing on the PL, TS and KT soils, respectively (Figure 4). This suggested that the more P that was sorbed by the soil, the less available the P was for plant uptake.

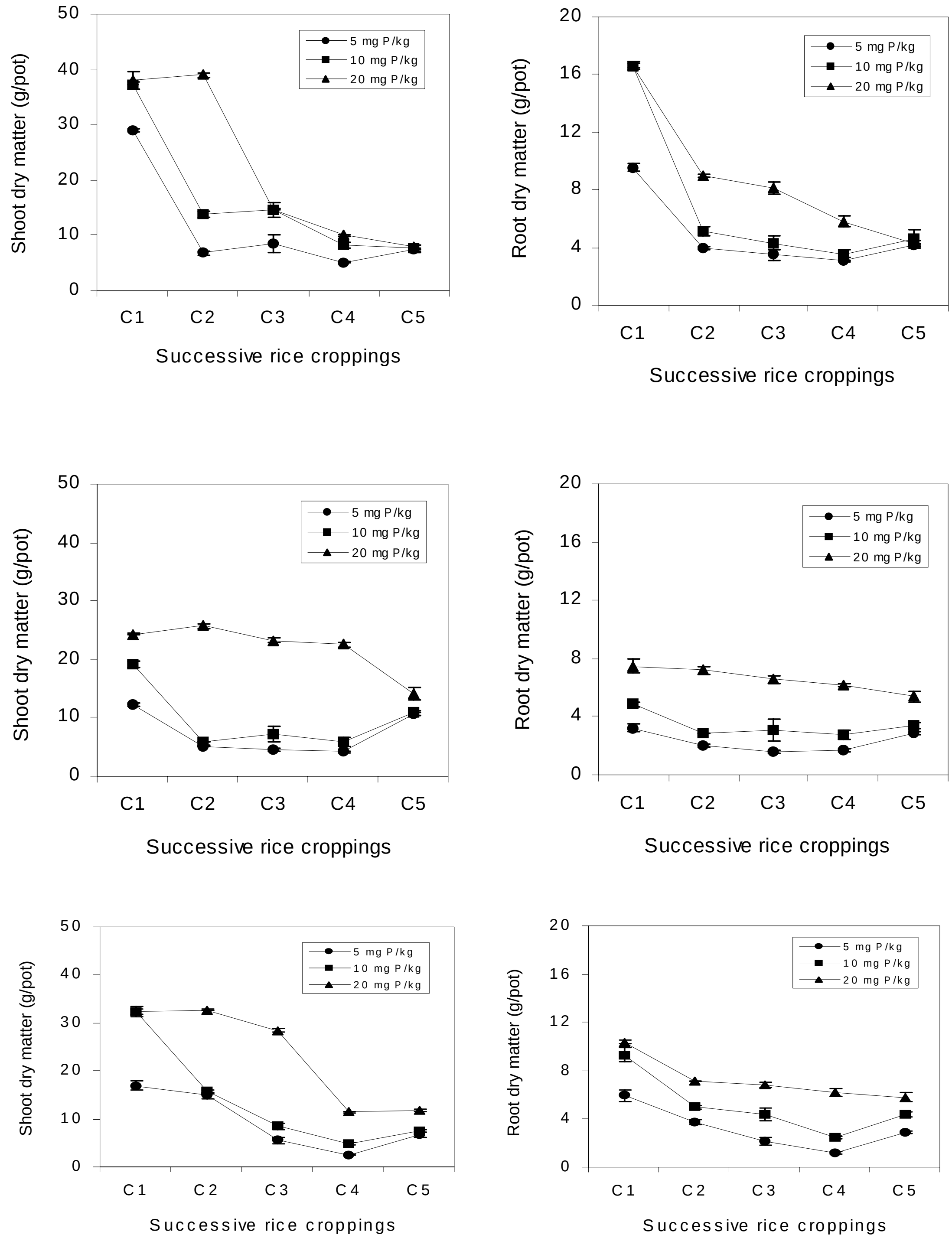

Figure 1. Shoot and root dry matter of rice in response to single applications of different P levels on the three contrasting lowland rice soils of Cambodia over five successive cropping cycles. Plotted values are means of four replicates. Vertical bars represent standard errors of four replicates. Data of the nil-P treatment is not presented here because of other basal nutrients than P were applied different levels from the P treated plots, and varied from one crop to another.

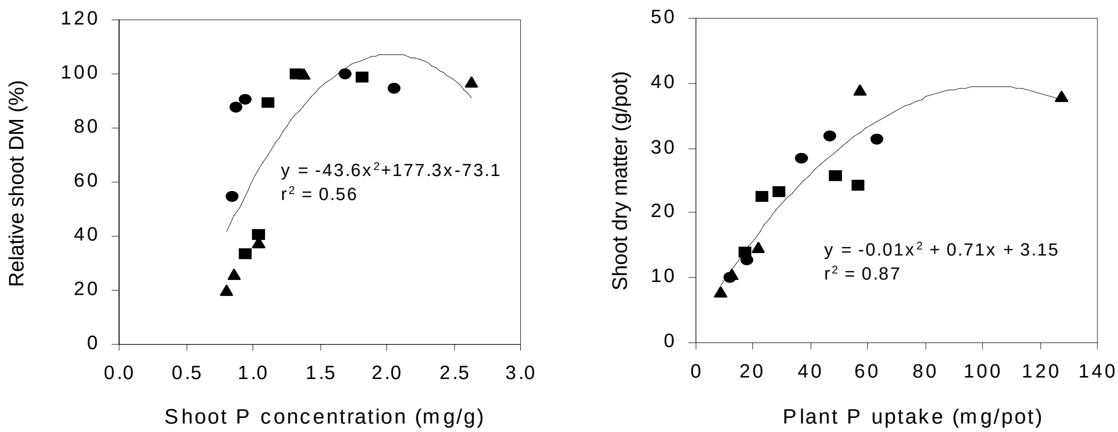

Figure 2. The relationship between the relative shoot DM and shoot-P concentration, and total plant P uptake (shoot and root) of rice grown with the high-P (20 mg P/kg) on the three contrasting lowland rice soils of Cambodia (¡¶: Prateah Lang; ¡´: Koktrap; ¡½: Toul Samroung) over five successive cropping cycles. Plotted values are means of four replicates.

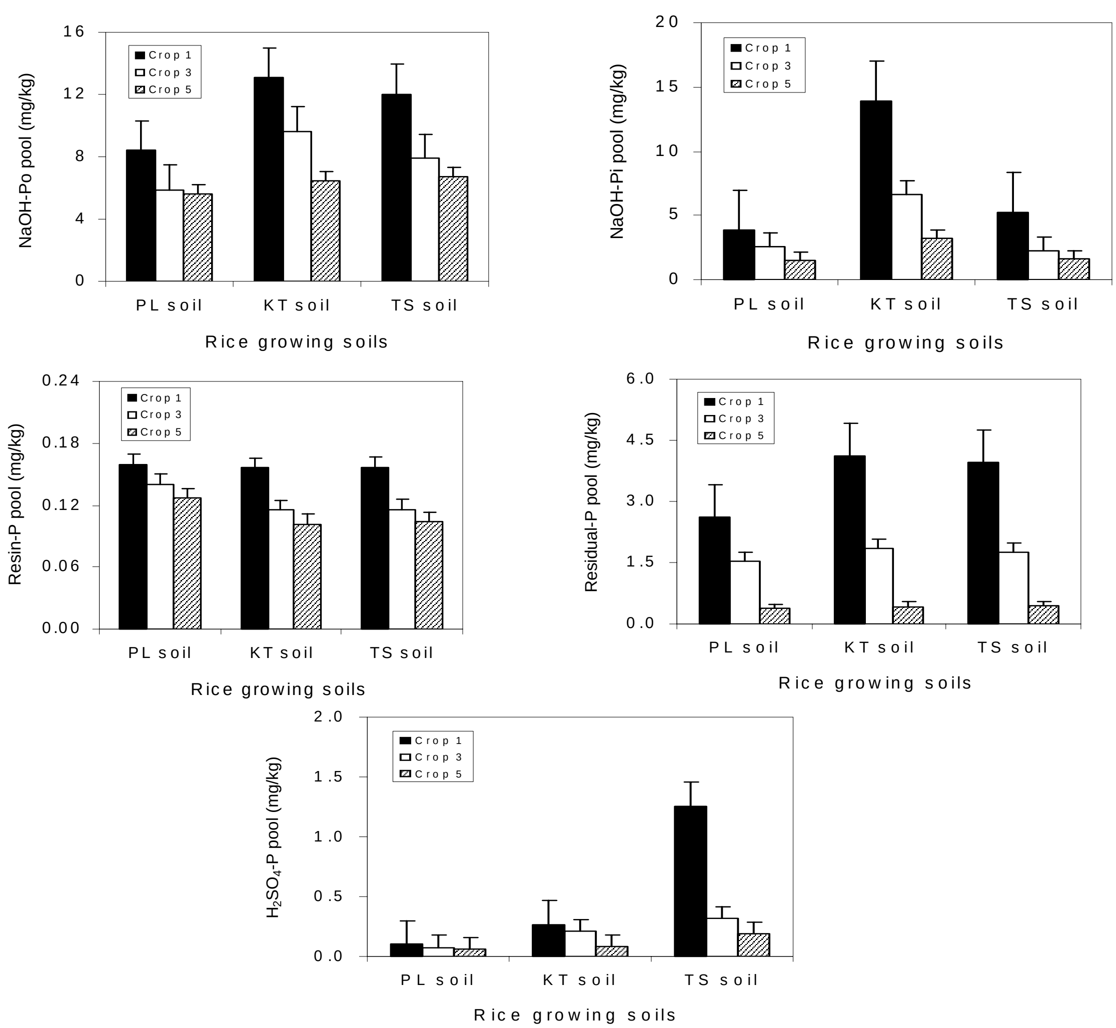

Figure.3 Extractable P fractions of the Pateah Lang (PL), Koktrap (KT), and Toul Samroung (TS) soils with the high-P (20 mg/kg) treated soil over five successive cropping cycles. Plotted values are means in the first, third and fifth crops. Vertical bars denote standard errors of four replicates.

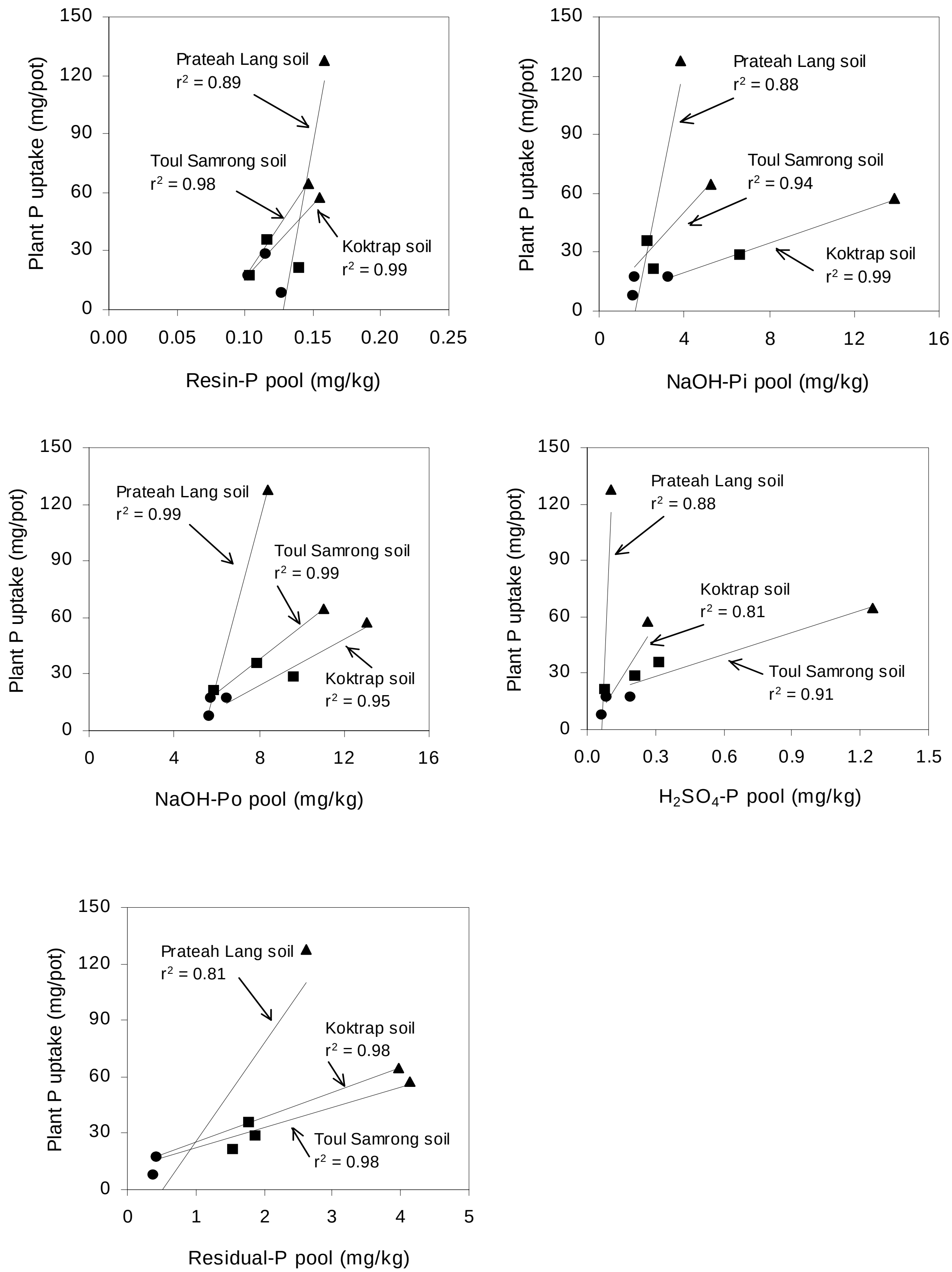

Figure 4. The relationship between soil-P fractions and total P uptake of rice grown with the high-P (20 mg/kg) treatment on the three contrasting lowland soils over five successive rice cycles. Values are the means of P fertiliser treatments in the first (¡¶), third (¡´), and fifth (¡½) crops. Note the change in scales of X-axis.

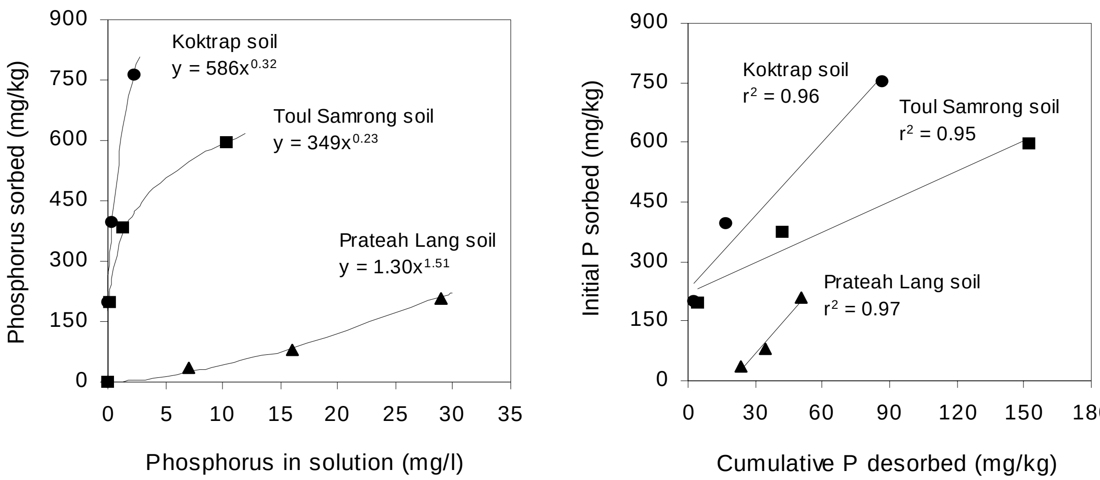

Figure 5. Phosphate sorption isotherms fitted by the Freundlich model, and the relationship between the initial P sorbed, and cumulative P-desorbed after eight successive soil extractions of the three contrasting rainfed lowland rice-growing soils of Cambodia. Plotted values are means of three replicates.

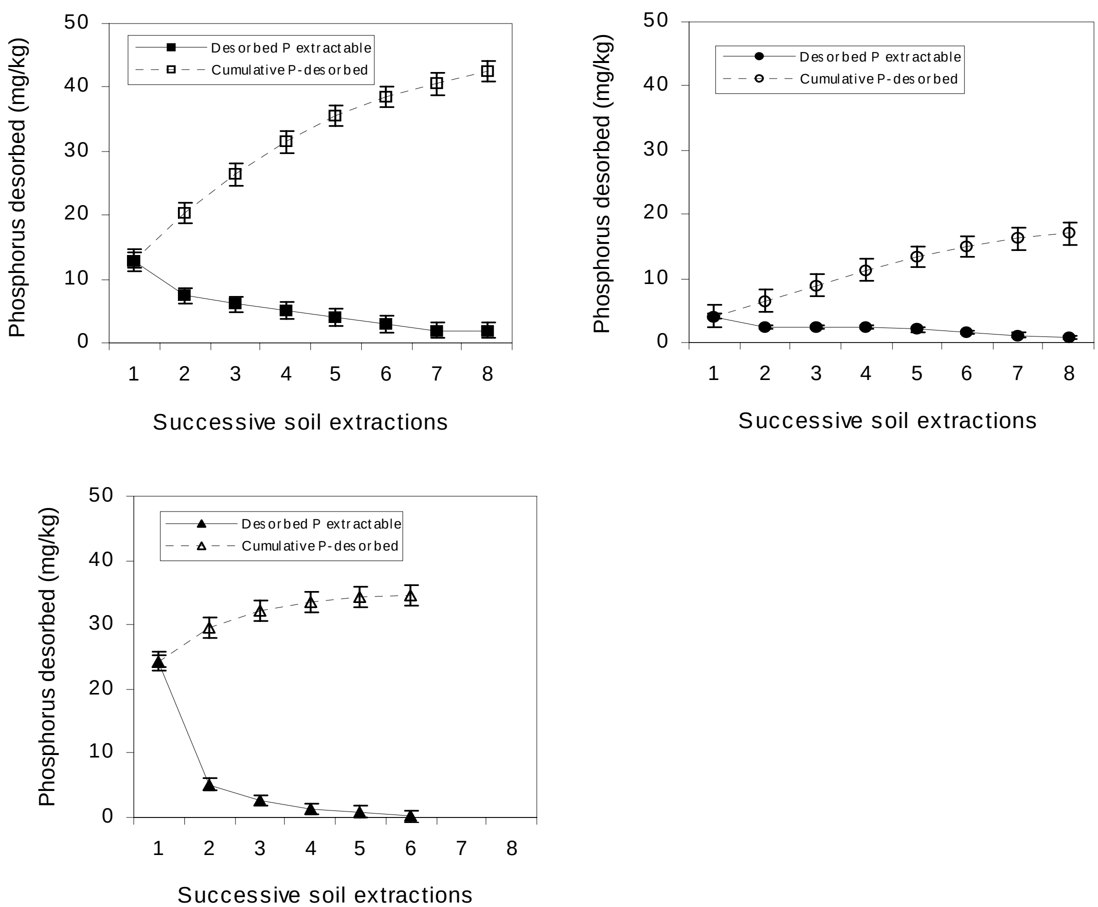

Figure 6. Sequential P desorption and cumulative P desorption of three rainfed lowland rice soils of Cambodia equilibrated over six to eight successive soil extractions after initial loading with 20 mg P/l added in solution. Plotted values are means of three replicates. Vertical bars represent standard errors of three replicates.

Table 3. Phosphorus uptake and efficiency of phosphorus recovery of rice plants from single applications of P fertiliser on three contrasting lowland rice soils of Cambodia over five successive cropping cycles. The values are means of four replicates.

Soil type	Rice cropping cycle	Plant P uptake (mg/pot) Shoot	Root	Total plant	†Recovery of P fertiliser (%)
Prateah Lang	Crop 1	96.6	29.4	126.1	56
	Crop 2	49.6	5.6	55.2	20
	Crop 3	17.6	3.8	21.4	4
	Crop 4	9.6	2.5	12.1	-1
	Crop 5	7.1	1.4	8.4	-2
	‡Cumulative P	180.5	42.6	223.1	77
Koktrap	Crop 1	49.5	7.7	57.2	20
	Crop 2	45.2	4.7	49.9	16
	Crop 3	25.8	2.7	28.5	6
	Crop 4	20.2	3.1	23.3	2
	Crop 5	15.1	2.5	17.6	1
	‡Cumulative P	155.8	20.7	176.4	45
Toul Samroung	Crop 1	56.1	7.3	63.3	25
	Crop 2	42.6	3.9	46.5	17
	Crop 3	33.2	2.9	36.7	12
	Crop 4	11.5	1.7	13.2	1
	Crop 5	12.9	3.6	16.4	2
	‡Cumulative P	156.2	19.4	175.6	57

† Recovery of P fertilizer for each crop was calculated by subtracting values of the nil-P treatment.
‡ Cumulative P uptake of plants from fertilizer: values are the sum from crop 1 to crop 5.
Crop 1: means that rice plants received 20 mg P/kg soil in that crop; Crop 2: indicates the second crop after P applied, i.e. the first crop using residual P, and so on for Crop 3, Crop 4 and Crop 5.

DISCUSSION

Growth and P uptake in response to P supply, and its relationship to P sorption-desorption processes

The maximum vegetative growth of rice was obtained for up to two successive crops with the high-P (20 mg/kg) treated soils. However, from the second cropping cycle onwards all other aspects of growth and P uptake declined progressively at all added-P levels (Table 2; Figure 1). This decrease could be attributed largely to the removal by the plants of the most readily available P from fertiliser P application in the previous cropping cycle. Other factors involved in the decline in growth of rice are discussed in following sections.

The shoot and root dry matter of rice growing in the sandy PL soil was greater than that for plants grown on the clayey TS and KT soils with all levels of applied P fertiliser in the first crop (Figure 1). This result is consistent with the findings of Seng *et al*. (1999) that rice dry matter in the KT soil, were less than those of plants grown in the sandy PL soil. The greater shoot growth of plants in the PL soil for a given P addition may be attributed to the low P sorption capacity of this sandy soil. Available P as reflected in Resin-P level in the sandy PL soil was greater than in the clayey TS and KT soils (Figure 5), suggesting that the greater P availability in the PL soil increased shoot and root dry matter. This hypothesis was further supported by the shoot/root ratios, which decreased more strongly in the clay TS and KT soils compared to the sandy PL soil (data not shown) as is typical of P limitations (Asher and Loneragan, 1967).

In the first crop, maximum shoot DM was received with the application of 10 mg P/kg soil on the sandy PL soil, whilst rice shoot dry weight responded up to the highest P (20 mg/kg) fertiliser application on the clayey TS and KT soils (Figure1). This result clearly indicates that rice crops respond differently to P fertiliser application on the three soils types due to their various P sorption capacities, suggesting different levels of P fertiliser should be applied on each of the soils in order to achieve a target rice yield. The following are recommended P fertiliser rates (kg P/ha) for rice production: for PL soil (10-23); TS soil (15-40); and for KT soil (15-46) (White *et al*., 1997b; Dobermann and White, 1998; Seng *et al*., 2001). The high rate is generally recommended for modern-high-yielding rice varieties grown with favourable conditions (e.g. good crop management and rainfall or supplementary irrigation), whereas, the low rate is suggested for traditional rice varieties grown with less favourable growing conditions.

There are various kinds of P fertilizers commonly used in lowland rice production (Sanyal and De Datta, 1991). Apart from phosphate rock (PR), they supply similar available P to rice in most lowland soils, except on very strongly acid or alkaline soils in which sorption or precipitation processes of P are the major concern (De Datta, 1981). The results from previous studies of Pheav (2002) demonstrated that application of either TSP or KH_2PO_4 increased yield and P uptake of rice on the sandy PL soil. Based on more rapid dissolution of PR in low pH soil (Hammond *et al*., 1986), and the high P sorption capacity of the KT soil as discussed below, it is suggested that PR would be an effective P fertilizer source for the clayey acidic KT soil. This is supported by the results of a glasshouse experiment by White *et al*. (1999), who reported that P from TSP was more available to plants than P from other sources on the coarse-textured Prey Khmer and Prateah Lang soils, whereas, P from PR was more available than TSP on the clayey KT and TS soils. There remains a need for both short- and long-term research under field conditions on lowland rice soils to determine the effectiveness of different P fertilizers including PR, particularly, when loss of soil-water saturation occurs.

The greater total P content in rice plants grown on the PL soil after one crop corresponded with a greater initial rate of P released from the soil after the first extraction of the P desorption experiment (Figures 2, 6). However, a greater decline in P desorption was observed from the sandy PL soil than from the clayey TS and KT soils after one soil extraction. The cumulative P released from the clayey TS soil was greater than from the sandy PL soil after five successive extractions (Figure 6). Even after eight successive extractions, total desorbed P on KT soil was only 50 % of that on PL soil. This suggests that total P uptake would be reduced when rice plants were grown on the sandy PL soil, after most of easily desorbable P was removed in the first and second crops. These results are similar to those in a field experiment on the same soil type reported in Pheav *et al*. (2003).

The P sorption of the soil may be a good predictor of residual effects of P fertiliser on different soils. Sanchez (1980) reported that the duration of residual effects of different rates of applied P fertiliser varied considerably with soil properties. For example, with P fertiliser application at 20 mg P/kg, the maximum shoot DM was maintained for two crops on the PL soil, a result that is consistent with the findings in the field experiment on the same soil type (Pheav *et al*., 2003). On the sandy PL soil after crop 2, the shoot DM declined sharply. This contrasts with the plants grown with residual P fertiliser on the clayey TS and KT soils. The shoot dry weight of these plants decreased steadily with each cropping cycle, but the values after crop 2 exceeded those of the plants growing on the sandy PL soil (Figure 1). This suggests that a higher residual P value can be obtained on the clayey KT and TS soils than the sandy PL soil. This was also supported by the P desorption experiment (Figure 6). Soils that have high P sorption rates may release P into soil solution spread over a longer period of time.

The amount of P recovered in succeeding rice cropping cycles was less than the total amount of fertiliser P applied. Approximately, 25, 45 and 55 % (Table 3) of the P applied at 20 mg/kg were retained in the sandy PL, clayey TS and KT soils, respectively, as residual P after five successive rice cropping cycles. The amount of P (75 %) removed from the sandy PL soil in this pot experiment was greater than that removed by rice plants (55 %) on the same soil in the field experiment of Pheav *et al*. (2003). This could be due to removal of both roots and shoots from the pot experiment in each cropping cycle, whereas, some P in the form of rice stubble and roots was potentially available for return to the soil in the field condition. The greater amount of P retained in the clayey KT and TS soils than that in the sandy PL soil could be the result of high P sorption capacity of these clayey soils, and to reactions of added P with mineral fractions in the soil that remove a significant portion of P from plant available pools. The greater aggregation of the clayey soils may also contribute to increased P sorption (see below).

Phosphorus fractionation in relation to crop growth

That resin extracted the least amongst all soil P pools, is consistent with the findings reported on the sandy PL soil for field conditions (Pheav, 2002; Pheav *et al*., 2003). However, the level of the Resin-P pool was greater in the sandy PL soil than in the clayey TS and KT soils (Figure 3). The sandy PL soil had the lowest P sorption capacity, and consequently, more of the added P remained free in the soil solution. However, after three consecutive crops, resin-extractable P had declined in all soil types, and this was reflected in decreased plant growth.

The amounts recovered from all the soil P pools, especially from major fractions (NaOH-Pi, NaOH-Po and Residual-P) declined with succeeding rice crops grown on all the soils, but the decline in these labile NaOH-extractable pools was greatest in the clayey KT and TS soils. This decrease can be explained by the occurrence of continuous sorption of the added P fertiliser by soils during each the plant-growing periods in addition to plant uptake. Indeed, NaOH-Pi was the fraction that declined most rapidly amongst the major soil P pools over five successive rice-cropping cycles (Figure 3). This is consistent with the results of the field experiment reported in Pheav (2002); and Pheav *et al*. (2003), and the significance was also discussed in those publications. The reason for the decline in labile inorganic NaOH-Pi pool could be the biological immobilization of the soil inorganic P fraction (Zhang and MacKenzie, 1997), as well as depletion due to plant uptake in every crop. In addition to plant uptake, McLauglin *et al*. (1988) demonstrated that some of the inorganic P pool was taken up by microorganisms, which eventually was incorporated into the organic P pool as microbial detritus.

Phosphorus sorption-desorption processes of lowland rice soils

Phosphorus sorption-desorption processes vary with soil types and soil-water conditions (oxidation and reduction). Each of the soils differed significantly in physico-chemical characteristics, including clay content, pH, organic matter, hydrous oxides of Fe and Al (Oberthur *et al*., 2000; Seng, 2000). The lower P sorption capacity of the sandy PL soil could be due to a low level of clay, organic matter, and oxalate extractable Fe contents of the soil (Pheav *et al*., 1996; Oberthur *et al*., 2000; Seng, 2000). In other oxidised rice soils, the P sorptivity generally correlated well with the clay content and oxalate extractable Fe (Fox and Kamprath, 1970; Willett and Higgins, 1978; Loganathan *et al*., 1987; Willett and Cunningham, 1983; Bennoah and Acquaye, 1989; Seng, 2000). The low oxalate extractability of Fe in the sandy PL soil indicates that ferric hydrous oxides present were generally well crystallised (McKeague and Day, 1966; Willett and Cunningham, 1983). Crystalline Fe oxides are relatively inactive in P sorption under the aerobic soil conditions (Henry, 1961; Willett and Higgins, 1978).

Variable charge clays, especially Fe and Al hydrous oxides contribute significantly to P sorption capacities in tropical acidic rice soils, particularly at low pH when surface positive charge is increased (Fox and Searle, 1980). Amongst the two clayey acidic soils reported in this study, P sorption appeared to be greater in the KT soil with lower pH and a higher organic matter content than the clayey TS soil (Pheav *et al*., 1996; Oberthur *et al*., 2000). Sorption of freshly added P by highly weathered soils was shown by Hartikainen (1983) and Barrow (1984) to increase as soil pH level decreased. However, a decrease in pH may also favour desorption of P already in the soil (Kirk *et al*., 1990). In the variable-charge soils, this may be because the increase in surface positive charge as the pH decreases favours diffusion of P out of the soil particles along the electro-chemical gradient (Barrow, 1984). A positive correlation between the soil organic matter and P sorption of the soil has been found by several workers (Kanabo *et al*., 1978; Mizota *et al*., 1982; Bennoah and Acquaye, 1989; Niskanen, 1990). The role of organic matter in P sorption in acid soils has often been attributed to the association of the soil organic matter with hydrous sesquioxides forming Fe and Al chelates, which provide more active surfaces for P sorption (Saunders, 1965; Fox and Searle, 1980; Sanyal *et al*., 1993).

The decrease in P desorption with successive extractions was observed to be greater from the sandy PL soil than from the clayey TS and KT soils (Figure 6). The greater value of initial P desorption was possibly influenced by the pH of the soil: increasing the pH positively affected the desorption rate (De Smet *et al*., 1998). When the soil was equilibrated with 20 mg P/l, the sandy PL soil adsorbed 87 mg P/kg, and subsequent cumulative desorbable-P over six repeated soil extractions was about one-third of the initial amount of sorbed P. This is consistent with the results of vander Zee and van Riemsdijk (1991); and De Smet *et al*. (1998), who estimated that, in acidic sandy loam or loamy sand soils, the amount of reversibly adsorbed P to be one-third of the total sorbed P. The same authors found further that the total amount of the reversibly adsorbed-P was highly correlated to the oxalate extractable P and Fe of the soil.

Although our study did not measure soil-aggregation, other researchers demonstrated that soil aggregates, particularly in clay soils, had a strong influence on P sorption-desorption processes. Cornforth (1968); Nye and Stauton (1994); and Linquist *et al*. (1997) suggested further that diffusion of P into the interior of soil aggregates may be the cause of the declining plant P availability with time on well structured soil. With depletion of P around the soil aggregates, P diffusion from the inside of aggregates to the outside, and the accessibility of rice roots to this P within the soil aggregates, could become important influences on residual P supplying capacity of the soil (Wang *et al*., 2001). Soil descriptions of White *et al*. (1997a, b) indicated that TS and KT soil had more aggregate development than the sandy PL soil, but longer residual effect of P fertiliser application.

Conclusions

Availability of P fertiliser to plants depends, to a large degree, on the sorption and subsequent release of P from the soil surfaces. The vegetative growth of rice on the sandy PL soil was much greater than on the clayey TS and KT soils after equal amounts of P fertiliser were added. The increase in P concentration and total P uptake of rice plants growing on the PL soil was attributed to increased available P in the Resin-P extractable fraction because of the lower P sorption capacity of this sandy soil. However, sandy PL soil had less residual P than the clayey KT and TS soils due to its lower P sorption capacity. This may imply the need for more intense management of P supplied to the sandy PL soil to ensure adequate residual P value, and for maintaining the maximum growth of rice plants on this soil. By contrast the present results predict a longer residual value for P in the KT and KS soils.

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