WHERE DO GREEN MANURES FIT IN ASIAN RICE CROPPING SYSTEMS?*

D.P. Garrity and M. Becker[1]**

ABSTRACT

The mesophytic leguminous species that are suitable as green manures for lowland rice fall into two broad types, as distinguished by their contrasting niches in the cropping system: pre-rice and post-rice green manures. Most prominent in recent research are the pre-rice green manures, due to the recent introduction of waterlogging tolerant, stem-nodulating species such as *Sesbania rostrata*. Post-rice green manures (eg. Astragalus sinica, Indigofera tinctoria) have historically played a much greater role in Asian agriculture, and new forage systems are further expanding the options in these niches. During the 1980s Asian rice farming systems continued to intensify and commercialize. Changing green manure technology is interacting dynamically with cropping systems in rapid flux.

Considerable work has now been done on the soil fertility implications of green manures, but research on the agronomics of green manure systems (plant selection, seed production, crop establishment, and other management factors) has been greatly neglected. It is the agronomic constraints which ultimately determine the feasibility and cost effectiveness of these systems.

This paper reviews the strategies for green manure inclusion in rice farming systems, and develops a qualitative framework for the analysis of the fit of green manures and other soil-improving legumes across the range of ecological niches. Hydrology is the dominant spatial factor controlling green manure adaptation: Waterlogging conditions specifically favor green manures relative to other non-rice species; the comparative productivity of green manures is also strongly favored on sandy soils. Even in intensive irrigated systems there now are several practical pre-rice and post-rice options (eg broadcast relay-cropping). Year-to year performance variability is recognized as a major factor impinging on green manure suitability, particularly in rainfed systems is consistently higher than for inorganic N sources in irrigated systems.

** Former Agronomist/Crop Ecologist, Agronomy, Plant Physiology and Agroecology Division (now Coordinator, International Centre for Research in Agroforestry Southeast Asian Regional Research Program), and Post-doctoral Fellow, Soil Microbiology Division, IRRI.

The prognosis for soil-improving legumes is seen to follow two key trajectories: Toward multiple-use solutions, where they perform simultaneous functions for grain, fodder, and soil fertility enhancement; and greater specificity of species adaption to well-defined cropping systems niches. Emphasis on green manures with a direct economic function will be the key in most situations. Niches where single-purpose soil enhancing green manures fit are limited to stressed conditions, such as waterlogging-prone situations, where alternative crops are not competitive. A practical but comprehensive analytical framework is needed for the recognition of niches with comparative advantage, the holistic evaluation of systems, and the extrapolation of legume alternatives. The complexity and scale of the required work points to the need for an accelerated, sustained international research effort that provides leadership, stimulates coordinated work, and shares priority responsibilities the respective participating research institutions.

INTRODUCTION

The mini-symposium that produced this volume may very well be the first time that a group of scientists has met internationally to review the agronomic issues related to the production systems of green manures. This contrasts with the several meetings (eg. IRRI 1988) and the voluminous work that has gone on for many years on the nutrient contributions of green manures. There are important distinctions between these two areas. This is clarified by a study of the topics that are the subject of the chapters of this proceedings.

This introductory chapter will address two objectives: One general and the other specific. The general objective is to assess the issue of where, when, and how green manures fit into contemporary Asian rice farming systems. The specific objective is to propose an international research effort to stimulate and better coordinate work on the agronomics of green manure production systems. What makes it an appropriate time to deal with these issues? There are three reasons.

First, in the process of coping with sustainability issues, farmers and scientists have historically dealt with such issues of crop yield decline through the mechanisms of crop diversity, crop rotation and inserting legumes in systems. Derrick Byerlee [check speling] (ref--chapter in IRRI 1992 IRRC proceedings--separate volume) elegantly showed sustainability concerns are present throughout Asian rice farming systems. This is the case as most countries have moved into a post-green revolution phase in terms of varieties, nutrient management and production systems

Second, it's been about 12 years now since Sesbania rostrata was introduced into the continent of Asia. This stem nodulating, aquatic legume that fits into waterlogging prone systems. Its introduction caused a great deal of excitement. This newly domesticated 'crop' has now been researched in various countries in the region. It is time we assess what the experience has thoroughly been with pre-rice legumes like S. rostrata.

Third, as alluded to above, there is has been a substantial distortion in research on green manure crops. Although hundreds of papers have been published on the effects of green manures on soils, and on the succeeding rice crop there is almost no published literature on the agronomic aspects of green manure production systems. This is very unfortunate because we now know alot about the nutrient contribution and dynamics of these crops, but we know very little about how to grow these crops. This imbalance is what we are trying to begin to address in this volume.

One of the major messages that will flow through the chapters in this volume is that regardless of which area of the agronomic aspects of green manure production systems we examine, there is very little established literature. With so little attention to such an major issue, it is perhaps no surprise that the progress in adapting green manures to Asia's changing rice production systems has been so limited.

FITTING GREEN MANURES IN

There are two broad ways in which green manures may fit into rice farming systems. For all of their diversity in terms of the species used and the cropping systems into which they may fit, basically green manures may be defined as either pre-rice or post-rice green manures. The significance is important because there are major differential adaptations and farming systems practices associated with each of these contrasting environments.
Prototype species of pre-rice green manures include examples such as S. rostrata, S. aculeata, other sesbanias, and the Aeschynomenes. These have now been given considerable research attention.

The post-rice situation is exemplified by the massive use of Astrigalus sinica on millions of hectares in the cool tropics of China (Chen, this volume). An example from the warm tropics is the use of Indigofera tinctoria by many farmers in the northern Philippines (Garrity et al, this volume), which is a prototype post-rice green manure for the warm tropics.

The pre-rice green manure systems are suited to rice systems that are permanently wet, or systems with very short periods of non-flooded conditions, which are typical of your year-round irrigated rice culture in the humid tropics. In these situations there is only a short period of time between rice crops in which a green manure may be fit. These fast-growing legumes are then incorporated immediately prior to the transplanting of the successive rice crop. Whether the system includes 2 rice crops, 3 rice crops, or only a single rice crop the pre-rice green manure system is applicable (Chaudhary et al, this volume).

Hydrology is the dominant factor that determines the adaptation of green manures in Asian rice farming systems. The pre-rice system is characterized by waterlogging. This is the situation usually favors a green legume planted prior to rice in the early dry-to-wet transition period. A waterlogging situation tends to eliminate nearly all alternative food crops, as they are not adapted to even short-term waterlogging.

Therefore, there is a landscape ecology of green manures (Alam, 1988--**Glo, cite Alam's thesis**). The topography determines the relative adaptation of green legumes vs. green manures. At higher landscape positions (Figure 1), green legumes such as mungbean, and cowpeas are commonly grown, whereas under waterlogging-prone conditions common at lower landscape positions, waterlogging tolerant green manures find their respective niche. In terms of total area these waterlogging-prone ricelands appear to be much vaster in extent than the well-drained areas, due to the observed frequency of such huge areas of pre-rice fallow lands in most Asian rice-growing countries. This waterlogging-prone landscape may be composed of huge blocks of land that cover whole river flood plains. Or it may be very localized in the elevation drop between successive.

Under conditions where there is a long non-flood period, which is typical of the major rainfed rice ecologies, there are a number of different strategies in which green manures, or other grain legumes that may also serve as green manures, fit into the rice production system. One strategy is the pre-rice green manure option as discussed above. Second is a post-rice legume.

There are major options in terms of inserting a forage legume or other type of non-forage legume into the post-rice system either alone or in intercrop situations with an upland crop (Carangal, this volume). Then whatever portion of the biomass that is unharvested is incorporated at rice establishment. This issue will also be the basis of the paper on legume inter-seeding in wheat-rice systems (Mann, this volume).

The concept of establishing a legume by inter-seeding into a cereal stand is little known or used in tropical agriculture, although it has been common for centuries in temperate farming systems. Mann reviews the prospects for using this practice as a low cost method for green manuring, building on the prototype of Indigofera tinctoria and other crops of that nature that may be broadcast seeded in a wheat crop and plowed in for the successive rice crop.

The Indigofera system is indigenous in the Philippines (Garrity et al, this volume). As practiced by Ilocano farmers in northern Luzon, the indigo is broadcast into a dry season maize crop. It occupies the field only after the maize is harvested. Thus, establishment costs are low, and the green manure does not compete with other crops for field time. At incorporation 100 or 200 kg may be contributed to the following rice crop.

Forage legumes may be extremely useful as potential green manures, as they provide a valuable sourced of fodder during the dry season forage scarcity period that most Asian lowland rice farmers experience annually

SOILS AND GREEN MANURE ADAPTATION

In addition to the hydrological factors, we find that soil factors are extremely important in determining the adaptation of green manures. An analysis of the literature on the performance of green manures related to soil quality variation has indicated some interesting relationships, particularly related to green nitrogen yield and soil properties. As the percentage sand content increased among experimental sites compared from various studies, there was a distinct tendency for the green manure nitrogen accumulation to increase (Figure 2). The data were taken from a wide range of soils around the region. Among the datasets that were examined, the only case that deviated substantially from the general trend was that of Ubon, Thailand. There the response on a very sandy soil (>90%) was much lower than predicted, presumably because of extreme soil infertility.

The nitrogen use efficiency of both organic and inorganic N sources declined as sand content of the soil increased (Figure 3). However, the nature of the relationship contrasted between the two sources. Urea N-use efficiency tended to decline more drastically than in the case of green manure use. The efficiency of the two sources was similar on clay-textured soils. On sandy soils the green manure N-use efficiency tended to be substantially greater. This was at least partially due to increased green manure N accumulation on these soils (Figure 4).

[Matthias--would you want to add more details here?]

Another interesting observation from this dataset was that whereas as we expect urea nitrogen fertilizer efficiency to decline as the amount of urea applied increases, it tends to be higher at all levels of urea application under irrigated compared to rainfed conditions (Figure 5A). However, when the situation of nitrogen supplied by green manures is examined, the nitrogen efficiency tended to be very similar between irrigated and rainfed conditions (Figure 5B). The application of green manures would appear to be as efficient in stimulating rice yields when applied in rainfed or irrigated situations.

[Matthias--more ??]

The third major factor that we wanted to emphasize was risk and variability in green manure production. The data tend to reveal quite vast differences among rainfed sites in the riskiness associated with green manure crop success in the pre-rice season, and in the amount of nitrogen accumulation that would be expected each year (Garrity and Flinn, this volume). Uncertainty of outcome in investment in green manure is undoubtedly a serious dis-incentive in the farmers' mind in many situations where the average potential is favorable, particularly for the pre-rice green manures.

NEGLECTED AREAS OF RESEARCH

What are the neglected areas of green manure research? We wish to highlight four particular areas: Plant selection, seed production, crop establishment and pest management. This presentation will be limited to an overview of these issues as several of the succeeding chapters will concentrate on them in more detail.

Most current and prospective green manure species have received virtually no formal plant improvement. Many are so recently introduced that they are actually undomesticated species. Other than the ad hoc efforts of the farmers who have cultivated them, plant improvement in the green manures has been almost totally neglected. Cultivar differentiation is nearly unknown.

There are many characters that are important in the adaptation of a green manure, not only the nitrogen contribution of the species (Figure 6). These other characters have been entirely ignored by researchers. Yet they are crucial to the agronomic feasibility and cost effectiveness of the species.

[Mathias--discuss the comparative features of a few of the species in Figure 6 to illustrate the points above and below.]

Species differ dramatically in the amount of nitrogen and biomass they contribute to a system depending on the hydrology (Figure 7) or soil properties (Figure 8).

[Mathias--more discussion here ??]

There has been very little attention paid to the plant breeding issues. High nitrogen yield is important, but photoperiod insensitivity and a range of other characteristics are extremely valuable. Without these characteristics high nitrogen yield gives us very little payoff within a very intensive cropping system.

The degree of photoperiod sensitivity varies greatly among green manure species (Figure 9). Manipulation of this character has great implications in seasonal adaptation and seed production potential.

[Discuss further?]

IRRI has been assembling a collection of as many accessions as possible of the major green manures from around the world, particularly the aquatic and semi-aquatic species. The collection is beginning to represent a fairly substantial reservoir of genetic variability in these crops. But there are no plant breeders possibly in the entire world who are working on selecting better architecture and seed production for these crops.

Seed production is one of the most costly and labor intensive aspects of green manure production. Plant architecture and seed yields are crucial determinants of these costs. Without attention to these aspects green manure seed production, farmers strain to produce seed on plants that are too tall and rangy, clasp their seed pods too tightly, or is subject to seed shattering, and may flower nonsynchronously. These constraints are typical of the semi-domesticated nature of most green manure species.

Sesbania is a clear example. It was only introduced to agriculture within the last two decades. It has a growth habit that is inconvenient for harvesting seeds that increases the seed production costs substantially. Without the selection of better plant types we cannot drastically reduce seed production costs. Plant breeders will need to be involved, looking at the germplasm within species and examining better plant types for harvesting conditions.

The third neglected factor mentioned above was crop establishment. It is one of the most crucial factors as far as farmers are concerned. As with any crop plant, intensive tillage tends to insure good plant populations and favorable early growth conditions for rapid establishment. These are necessary conditions for a green manure crop that often must fit into a narrow time window. But such practices are seldom justified for a crop that bears no direct economic yield. The only viable option is to move toward to minimum or zero tillage methods of green manure crop establishment.

How do we reduce the establishment cost of green manure and so we get them at or below cost for nitrogen fertilizer? Agronomists must develop or refine production practices so as to minimize labor and draft power requirements, yet obtain reasonable green manure stands and performance. Chapters by Palaniappan et al (this volume) and Pradhan and Garrity (this volume) will be deal with these issues.

Pest management in green manures is an especially problematic issue. We may wish to ignore the possibility that pests are indeed a significant constraint, but in fact leguminous green manures are crops. As legumes, they are often particularly desirable food sources to pests and pathogens (Figure 7). They may be subject to severe pest attacks. There are a number of species of pests that are important. We shall have to keep in mind and provide more pest management for these species. This is particularly cogent with regard to seed production. The seed producing capacity of the crop is often the weakest link in the chain of constraints. If the seed yield is uncertain or low due to heavy pest pressure, the entire production system is questionable. This is highlighted by Herrera and Garrity (this volume) with respect to sesbania seed production systems in northeast Thailand.

THE PROGNOSIS FOR GREEN MANURES

This chapter was a qualitative treatment of the factors that govern green manure performance, and how they tend to vary in different ecologies. The discussion highlighted the basic contrast between the pre-rice green manures (typified by sesbania) and the post-rice green manures (typified by Indigofera). The agronomic issues are a dominant concern in the pre-rice sesbania green manures, whereas in the post-rice situation many of these factors are of lesser importance.

What is the prognosis for green manures in Asia? This remains a hot topic for debate. There is a spectrum of viewpoints ranging from the conclusion that they will be never a significant factor, to the viewpoint that in future they will be much more important than they are now.

We see two trajectories that will vastly influence the outcome: First, Asian rice production systems have tremendously commercialized and intensified in a last couple of decades. Therefore, we see the tendency that green manure species and systems must provide multiple use solutions to be acceptable. That is, any green manure must be something else besides, whether food, fodder, fuel, or industrial product. Since farmers are looking for multiple benefits and our work should address these prospects vigorously.

Second, green manure systems will increasingly have to adapt to a wider range of specific production systems. We have to consider this growing specificity. We may analyze in broad terms, but what really matters is specifically adapting species to production systems, and that means attention to local-level agronomy and extension. They are going to be the key people involved in this effort, and practical solutions are what they need.

We judge there to be a wide range of species or ecotypes of green manures available that allow the fitting of green manure crops into most rice-based systems. Hydrology is the dominant factor determining the type and duration of green manure crop in any given situation. Green manure crops have given the highest nitrogen yields and N use-efficiency on light-textured soils in rainfed environments. Finally, major agronomic constraints are the year-to-year variability of green manure performance and the inavailability of seeds.

The increased use of inorganic nitrogen is inescapable. But biological nitrogen fixation systems are still responsible for providing more than 60% of the new nitrogen in the biosphere. Thus it seems but common sense to maintain a parallel effort to exploit wherever possible the latent sources of biological N that can be tapped on-farm. To do this more pressure needs to be directed toward public research and development institutions to take up this work more vigorously as one of the areas of their distinct comparative advantage.

Whereas there is tremendous private research investment in the development of inorganic fertilizers and their usage. To balance this effort, long-term public research funding on soil-improving legumes is essential to create integrated soil fertility solutions providing superior income and environmental benefits. Currently there is very little investment on the exploitation of nitrogen fixation, which would rely overwhelmingly on public sector research investment. This represents a distortion, and this is the probably one area in which we public sector research institutions should be much more aware of their role.

The national policy environment vis-a-vis green manures differs drastically among Asian countries: Countries with little public support for bio-fertilizer use (Philippines); countries with strong government support (China; Myanmar); countries where green manure use is stimulated by non-availability of inorganic fertilizers (Bhutan); countries where green manures are promoted as a means to reduce the rice area (Taiwan).

INTERNATIONAL INITIATIVE ON GREEN MANURE AGRONOMICS

Due to the large gaps in knowledge and technology on green manure productions systems, we propose a targeted international research initiative on green manures that focusses on the agronomic issues in a systems framework. Such an initiative will be needed to tackle these issues. Nothing on this scale has been done in the past.

The INSURF network has been doing some work on the nutrient management issues relevant to green manures in a coordinated way for several years. But no such attention has ever been given to the practical agronomic issues of green manure production systems. The ad hoc nature of the very limited research translates into inadequate output. Could we better collaborate and develop a program in which we feel that each researcher is a part of something bigger, and something that really has momentum.

How could such an international strategy be formulated and carried out? Figure 4 is a framework for examining our relative priorities in agronomic systems research.

In green manure systems evaluation, farmer participation is critical. There is probably little debate about that. But for that effort, anthropologists and agronomists, backed by economic evaluation need to work in teams. The systems evaluation efforts will provide constant feedback to component technology development efforts. The critical issues of species selection, seed production, crop establishment and pest management are shown as the four major areas of concentration.

Within species selection, plant breeders need to get involved. There are many legume breeders in the Asia. Why not envision a program in which legume breeders could take a part-time role in a soil improving legume program in which they could get involved in green manure plant improvement, and collaborate with agronomists in the testing of their plant selections in systems.

Seed production methods is a research area where there may be some confusion. The issues is how do you produce seeds, and how do you reduce the cost of producing seeds? This is a research issue, but one finds that no one is engaged in this as it doesn't conveniently fall within conventional areas of disciplinary responsibility. It falls between them.

Crop establishment and pest management, of course, are areas in which agronomists and pest management specialists, respectively, can rapidly mobilize.

The complexity and scale of the required work points to the need for an accelerated, sustained international research effort that provides leadership, stimulates coordinated work, and shares priority responsibilities among the respective participating research institutions. A determined effort on improving the agronomics of green manure systems is needed, and it needs to begin now.