Discussion Paper
2001 No. 42

The Quest for Connections: Developing a Research Agenda for Integrated Pest and Nutrient Management

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INTERNATIONAL RICE RESEARCH INSTITUTE

DISCUSSION PAPER

The quest for connections: developing a research agenda for integrated pest and nutrient management[1]

Gary C. Jahn, Elsa Rubia-Sanchez, and Peter G. Cox

Biotic components of the rice ecosystem (i.e., microbes, flora, and fauna) change in response to altered fertilizer regimes and new cultivars. Rice intensification, usually associated with increased fertilizer use, may therefore increase pest problems. Conversely, some rice pest management tactics, such as burning rice stubble or adjusting water levels, affect soil fertility and reduce the yields of certain cultivars. A deeper understanding of the interactions of varieties, nutrients, pests, yields, and production costs will allow us to integrate nutrient and pest management techniques for maximum benefit to rice producers and consumers. New cultivars (e.g., hybrid rice and low-tillering rice) and existing cultivars may interact with pests in different ways. If changes in cultivars and soil nutrient levels create new or more severe pest problems, then the effects of cultivars and fertilizers on natural enemies (of pests) must be considered as a possible cause of changes in pest diversity. Results from greenhouse and field-plot experiments ultimately must be tested at the field and village levels. Depending on soil properties, water availability, and climate, it may be possible to put ecological theories into practice and manage some pest problems by adjusting soil nutrient levels.

The challenge of understanding soil and cultivar interactions with pests and yields (SCIPY) can be approached from different directions. One research strategy, for example, would be to overlay maps of soil types, water availability, cultivar distribution, and pest distribution to characterize the ecosystems. Then, using factorial combinations of fertilizer rates and cultivars in the different ecosystems, we could assess the effects of interactions on pest damage and yield. Another strategy would be to first identify cases in which changes in cultivar and fertilizer interactions have specific effects on the biotic constraints to crops at a particular place and time. Then we could work back to see how widespread the effect is and determine the underlying mechanisms. The advantage of this second approach is that it more rapidly leads to discoveries that can be applied to actual field problems through integrated nutrient and pest management. A third approach might not emphasize characterization or causation, but attempt to solve specific problems on a case-by-case basis through participatory means, that is, with farmers and scientists designing and conducting the research together. This may provide locally relevant answers, but ones that are difficult to generalize and, perhaps, ones that are not grounded in recent scientific insights. A fourth approach might combine deductive and inductive aspects with action research to simultaneously prioritize and solve problems with farmers, build models, and investigate causation.

This paper will discuss the need to investigate SCIPY, the status of this research, and the advantages and disadvantages of various research approaches to this issue.

[1] This Discussion Paper is an expanded and updated version of a keynote address of the same title presented at the International Rice Research Conference (IRRC) in 2000 by G. Jahn. The keynote address by Jahn GC, Cox PG, Rubia-Sanchez E, Cohen M appears in Peng S, Hardy B, editors. 2001. Rice research for food security and poverty alleviation. Proceedings of the IRRC, 31 March–3 April 2000, Los Baños, Philippines. Los Baños (Philippines): International Rice Research Institute. p 413-430.

The interactions among fertilizers, rice cultivars, and pests may have dramatic effects on yield and grain quality, yet these interactions are poorly understood. Unexplained pest outbreaks and declining yields may be the result of these interactions (Boxes 1 to 3). The intensification of rice farming, accompanied by changes in tillage, crop establishment, and irrigation (Doberman and Witt 1999), could alter the spatial and temporal delineation of rice pests. Newly developed cultivars (e.g., hybrid rice, transgenic rice, and low-tillering rice) may not interact with pests (including insects, weeds, and diseases) in the same manner as the cultivars that are currently grown (Box 4). Increasing nitrogen (N), phosphorus (P), and potassium (K) applications may have long-term effects on the ecosystem that result in pest problems. Long-term nitrogen-loading to grassland decreases insect species richness and increases insect abundance (Haddad et al 2000). In irrigated rice fields, herbivores, predators, and parasitoids increase in abundance with nitrogenous fertilization levels (De Kraker et al 2000). High levels of green semilooper *Naranga aenescens* Moore, gall midge *Orseolia oryzae* (Wood-Mason), rice green hairy caterpillar *Rivula atimeta* (Swinhoe), rice leaffolder *Cnaphalocrocis medinalis* (Guenée), and other rice

Box 1. The law of constant final yield.

The "law of constant final yield" states that yield is constant over a wide range of densities for many wild plants (Kira et al 1953). In the case of cultivated plants, fertilizer (e.g., nitrogen, phosphorus, and potassium) is usually added to the soil as plant density is increased, so NPK or other nutrients are not a limiting factor and the "law" does not apply. By adding fertilizer, we raise the carrying capacity (K) of the soil for rice, which in turn raises K of rice for phytophagous insects, pathogens, and weeds. This of course raises K for organisms that parasitize or feed on those phytophagous insects, pathogens, and weeds. However, if the increase in rice pest populations is too rapid for the natural enemy populations to respond, then rice yields may be reduced.

Box 2. Fertilizer affects each component of pest population size.

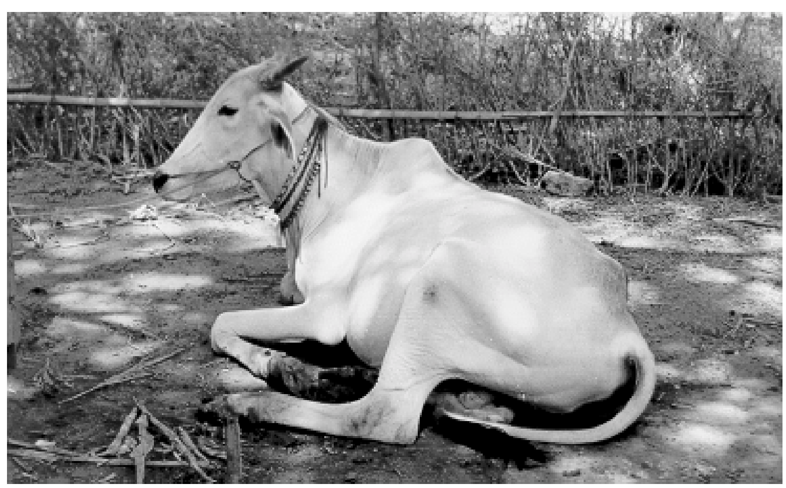
Population size is determined by the size of the previous population and the rates of birth, death, immigration, and emigration, as summarized in the formula (Begon et al 1996)

$$N_n = N_t + B - D + I - E$$

We can use this formula as a handy guide to assess the effect of fertilizer applications on pest populations, N. For example, applications of nitrogen to rice tend to increase the birth rate (i.e., fecundity), reduce the death rate (i.e., mortality), increase immigration, and reduce emigration of phloem-feeding insects such as planthoppers (Preap et al n.d.).

Box 3. Is fertilizer use related to pest outbreaks?

Research on the brown planthopper (*Nilaparvata lugens* Stål) indicates that additions of N, such as urea, to the soil cause *N. lugens* to produce more ovarioles and thereby raise the insect's basic reproductive rate, denoted by $R_o = \sum F_x/a_o$, that is, the total number of fertilized eggs produced in one generation divided by the number of females in the original population (Preap et al n.d.). There is also evidence that certain types of pesticide applications reduce natural enemy populations and thereby reduce brown planthopper mortality (Kenmore 1996). Taken together, these observations raise the possibility that planthopper outbreaks resulting from mass migrations (Zhang and Cheng 2001) may in fact be caused by fertilizer and pesticide use at emigrant sources hundreds of kilometers away.



In traditional farming systems, animal manure was the main source of fertilizer for rice fields. Under these conditions, soil nutrients are a limiting factor for rice production as well as pest and natural enemy populations. *Photo by G.C. Jahn, Takeo, Cambodia, 1995.*

Box. 4. Importance of cultivar in rice/weed competition.

As weed densities increase, different rice cultivars exhibit different competitive abilities under different conditions. In well-fertilized irrigated rice fields, planted with early duration dwarf varieties, weed competition is reduced through continuous flooding. Under rainfed conditions, with no fertilizer, a traditional late-maturing tall rice variety is a better competitor against barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.) than an early maturing dwarf variety (Pheng et al n.d.).

pests are associated with heavy fertilizer applications (Chelliah and Subramanian 1972, Jaswant Singh and Shahi 1984, Reissig et al 1985). Broadcast N applications to flooded rice fields cause a rapid expansion of populations of ostracods, mosquito larvae, and chironomid larvae (Simpson et al 1994a) but a reduction in snail populations (Simpson et al 1994b). Many insect species exhibit higher growth rates and decreased development times when their host plant is fertilized at high N levels (e.g., Fisher and Fiedler 2000, Slansky and Feeny 1977, Tabashnik 1982).

"When we make drastic changes in the agroecosystem without understanding the consequences, the repercussions can be quite serious."

Conversely, some cultural control practices can alter the soil fertility of flooded rice fields, which could potentially reduce the yields of certain cultivars. Examples include plowing fallow land to hinder weeds and the insect pests they harbor; burning stubble to manage the yellow stem borer *Scirpophaga incertulas* (Walker), stem rot (caused by *Helminthosporium sigmoideum*), or the stem nematode *Ditylenchus angustus*; draining fields to control rice leafminer *Hydrellia griseola* Fallen or the caseworm *Nymphula depunctalis* (Guenée); and flooding fields to prevent infestations of thrips *Stenchaetothrips biformis* (Bagnall), mole crickets *Gryllotalpa orientalis* Burmeister, or weeds (Feron and Audemard 1957, Gonzales 1976, Litsinger 1994, Reissig et al 1985, Sison 1938). There is also evidence that certain pesticides can reduce soil fertility (Box 5).

Because these interactions are so poorly understood, there is potential for disaster. When we make drastic changes in the agroecosystem without understanding the consequences, the repercussions can be quite serious. This was the case in the mid-1980s when brown planthopper (*Nilaparvata lugens* Stål) outbreaks in Indonesia were induced and perpetuated through insecticide applications (Kenmore 1996, Kenmore et al 1985).

While it is well known that some types of fertilizer application

Applications of nitrogenous fertilizer increase the fecundity and survival of brown planthoppers. *Photo by A. Barrion*.

Box 5. Effects of pesticides on soil fertility.

Different pesticides will increase or decrease ammonification, nitrification, denitrification, and nitrogen fixation. Some insecticides, such as lindane (HCH) and chlorpyriphos, increase extractable ammonium in flooded soils. Malathion and parathion, organic phosphate insecticides, inhibit the activity of soil urease under flooded conditions. The effects of pesticides on nitrogen transformations can be temperature-dependent. For example, the herbicide butachlor reduces the rate of ammonification of urea in flooded soils at 30 °C but not at 15 °C. HCH applied in combination with carbofuran results in drastic and long-term inhibition of nitrification in flooded soils. Benomyl, a fungicide, inhibits nitrification in flooded soils for up to 30 days at 100 and 1,000 µg g^{-1}. Certain insecticides (e.g., endrin, HCH), fungicides (e.g., metam-sodium, nabam), and herbicides (e.g., propanil, MCPA) inhibit denitrification in irrigated soils. Carbofuran stimuates nitrogen fixation of *Nostoc muscorum* in liquid culture at low concentrations but inhibits N fixation at high concentrations (Ray and Sethunathan 1988).

to rice, particularly of N, tend to increase pest numbers, survival, fecundity, body weight, and damage (e.g., Cook and Denno 1994, Heinrichs 1994, Jaswant Singh and Shahi 1984, Preap et al n.d., Sogawa 1971, 1982, Subramanian et al 1977), this effect varies with soil properties and rice variety. Do fertilizer applications increase pest levels overall (Box 2)? And do such pest increases result in greater crop loss? Do natural enemy populations respond to fertilizer-induced increases in pest populations? Is the natural enemy population response rapid enough to prevent yield loss resulting from insect damage? Would the effect be the same on calcareous soils as on other soil types? Currently, there is simply not enough information available to allow us to predict how changes in rice cultivars and fertilizer regimes will affect pest problems on different soil types at different locations. If such predictions were possible, then in theory some pest problems could be prevented or controlled by manipulating those interactions. Because there are so many genetic, phenotypic, and environmental factors to consider when studying soil and cultivar interactions with pests and yields (SCIPY), a systematic research approach that accounts for multiple components is required.

Unfortunately, some sort of unified field theory of crop ecology that accounts for all of the environmental interactions that affect populations of insects, rodents, snails, microbes, weeds, and other pests and their combined effect on yields is not a realistic goal. If we cannot predict rainfall from year to year with any accuracy, what hope do we have of predicting ecological changes and their effect on rice yields? Even if we could predict the effect of all possible cultivar-fertilizer-soil type and pest combinations on yield, these predictions would quickly become outdated as selection occurs for organisms that proliferate under new cultivar and fertilizer combinations. Fortunately, we can address SCIPY without resorting to a unified field theory. One way would be to characterize and map key components of the ecosystem and then model existing interactions so that the biotic yield constraints (BYC) of specific situations could be derived from the model (Ludwig and Reynolds 1988, Savary et al 1996). This deductive approach allows researchers to progressively add components to a model. Another way to study SCIPY would be to discover the underlying mechanisms that cause changes in BYC in specific cases and then generalize these findings to all such cases. This is the classic scientific method, which progresses by devising alternate hypotheses and crucial experiments that exclude one or more of the hypotheses (Platt 1964). A more recent approach to research, known as adaptive management (Cox et al 1996, 2001, Röling and Wagemakers 1998), does not emphasize characterization or causation, but attempts to solve specific problems on a case-by-case basis through participatory means, that is, farmers and scientists design and conduct the research together (Box 6). The lessons of each case study are then applied to the next case study to create learning cycles. A proposed SCIPY research strategy using each of these approaches will be described in this paper. In addition, we will explore the possibility of combining the three research approaches.

Before describing alternative approaches to developing a research agenda for integrated pest and nutrient management, we will give an overview of the status of SCIPY research in rice.

SCIPY
Soil and cultivar interactions with pests and yields

Overview of literature on SCIPY

Since the 1960s, rice production has steadily shifted toward semidwarf, nitrogen-responsive varieties. This change is believed by some to have caused increased pest problems (Nickel 1973, Kiritani 1979, Litsinger 1989, Mew 1992), though the role of fertilizer has not been clearly established or well understood. No simple formula describes how plant recovery from herbivory is related to availability of soil nutrients. The “continuum of responses” model (Maschinski and Whitham 1989), for example, predicts that plants are best able to recover from pest damage when well fertilized, whereas the “growth rate” model (Hilbert et al 1981) predicts that damaged plants will exhibit superior recovery from herbivory when grown under stress, that is, low levels of nutrients. Meta-analysis suggests that basal meristem monocots, such as rice and other grasses, exhibit better recovery from pest damage when the plants are grown under high resource levels, whereas dicots show better recovery when grown under low resource levels (Hawkes and Sullivan 2001). The degree of compensation and recovery from damage also depends on the stage and cultivar of rice (Khiev et al 2000).

Studies by the International Rice Research Institute (IRRI) in Cambodia (CIAP 1996, 1999) indicate that rice fields receiving fertilizer have lower levels of rice bugs *Leptocorisa oratorius* (Fabricius),

Box 6. Adaptive management and the farmer-scientist knowledge matrix.

	What farmers know	What farmers do not know
What scientists know	A	B
What scientists do not know	C	D

Knowledge matrix between scientists and farmers:
A = common knowledge,
B = what is known to scientists but not to farmers,
C = what is known to farmers but not to scientists,
D = what is unknown to both farmers and scientists.

In adaptive management, scientists and farmers build upon their common knowledge base. The interaction helps both parties identify knowledge deficiencies. Neither scientists nor farmers may be aware of the limits of their knowledge until they communicate. Our perception of what we "know," that is, what we believe, continually changes. The flow of ideas is not necessarily from D to A; often it is from C or B to D, but such situations present research opportunities. Sometimes part of a story is in B and part is in C. The complete story is not discovered until farmers and scientists meet. Farmers generally have a poor understanding of ecology and pest life cycles, whereas scientists tend to have a poor understanding of the practical limits of carrying out integrated pest and nutrient management on small rice farms. Neither party is aware of its respective knowledge gaps until they talk and work together.

(Extracted from Jahn GC, Khiev B, Pol C, Chhorn N, Pheng S, Preap V. 1999. Developing sustainable pest management for rice in Cambodia. Paper presented at the AAAS 2nd Asia-Pacific Conference on Sustainable Agriculture, 18-20 October 1999, Phitsanulok, Thailand.)

false smut, and sheath rot than unfertilized fields (Table 1). On the other hand, excess fertilizer can lead to increased pest levels (Litsinger 1994). This is, of course, an oversimplification of the problem. How fertilizer applications affect the severity of pest damage will depend not only on the amount of fertilizer but also on the composition and timing of the applications. The proper balance of nutrients can help keep pest incidence low. Studies in India, China, Indonesia, the Philippines, and Vietnam have found lower pest incidence in fields with site-specific nutrient management compared with the farmers' fertilizer practices (Sta. Cruz et al 2001, Samiayyan et al 2000). The effects of nutrient management on pests are expected to vary with cultivar type, cultivar duration, soil properties, and initial biodiversity. Research on maize suggests that soil management can be used to improve resistance against pests without reducing plant productivity (Phelan et al 1995).

Table 1. Association between fertilizer use and lower than average pest levels in 25 lowland rice fields in Cambodia (CIAP 1996). χ^2 greater than 3.84 are statistically significant at *P* <0.05.

Pest	χ^2	Association
Narrow brown spot	0.01	None
Gall midge	0.02	None
Whorl maggot	0.45	None
Planthopper	0.65	None
Deadheart	0.65	None
Leafhopper	1.01	None
Brown spot	1.01	None
Bacterial leaf streak	1.14	None
Leaffolder	1.14	None
Hispa	1.39	None
Whitehead	1.70	None
Cutworm/armyworm	1.86	None
Weeds	2.43	None
False smut	4.10	Fertilizer use and low levels of false smut
Sheath rot	4.10	Fertilizer use and low levels of sheath rot
Rice bug	5.22	Fertilizer use and low levels of rice bugs

Most SCIPY research has focused on the effects of specific nutrients on specific pests. N applications apparently decrease thrips populations in rice fields (Ghose et al 1960). Other pests become more abundant if N is applied, such as weeds, sheath blight, leafhoppers, planthoppers (Box 3), and gall midge (Chelliah and Subramanian 1972, Oya and Suzuki 1971, Reissig et al 1985, Savary et al 1995, 2000a,b). Several species of stem borer larvae exhibit significant weight gains when N is applied to the host plant. Heavier stem borer larvae presumably cause more damage to the host plant than lighter larvae (Ishii and Hirano 1958, Ghosh 1962, Rubia 1994, Soejitno 1979). More stem borer (*Chilo suppressalis* (Walker)) eggs are found in fields with high N rates (Hirano 1964). In greenhouse experiments, Alinia et al (2000) found significant interaction effects between fertilizer treatments (NPK, PK, and none) and rice variety on stem borer (*C. suppressalis*) larval survival at the booting stage of aromatic rice: larval survival was highest on plants receiving NPK.

Litsinger (1994) reviewed papers dealing with the effects of fertilizer applications on insect pest damage to rice. In general, what is good for the plant is good for the pest, and this is particularly true of N applications. This is why most pest populations will increase along with rice yields, that is, pest populations are often positively correlated with rice yields (Table 2). Although there are exceptions among rice-feeding insects, N applications tend to promote greater survival, increased tolerance of stress, higher fecundity, increased feeding rates, and higher populations (Uthamasamy et al 1983). N applications also make rice more attractive to many herbivorous insects (Mattson 1980, Maischner 1995). Pathogens and weeds also respond favorably to increased N applications. For example, sheath blight severity tends to increase with N (Reissig et al 1985, Savary et al 1995, 2000b).

> "In general, what is good for the plant is good for the pest . . ."

Table 2. Pest and water incidence as factors related to variation in yields of early duration rice varieties (adjusted $R^2 = 0.84$, $P < 0.05$) (CIAP 1999).

Factors	Coefficient
Nitrogen applied at recommended rate	0.009
Water depth at tillering stage	0.240
Water depth at milk stage	–0.198
Deadheart	0.681
Brown spot	0.378
Rat	–4.623
Hispa	0.313
False smut	1.986
Whorl maggot	–0.677
Leaf blight	0.783

Our understanding of the mechanisms underlying SCIPY is still rudimentary. It is known that N augments rice plant growth and results in softer plant tissues, which presumably allows for easier penetration of the rice plant by insects and pathogens (Nadarajan and Janardhanan Pillai 1985, Oya and Suzuki 1971). But why then do N applications tend to decrease thrips populations? High N rates generally attract ovipositing insects and increase insect fecundity, though it is not known why. Other nutrients, such as P, improve root development and tolerance for root pests, such as the root weevil (*Echinocnemus oryzae* Marshall) (Tirumala Rao 1952). How NPK interactions affect root pests, however, is not understood. Although N applications are usually associated with increased pest problems, K applications may suppress pests by lowering plant sugar and amino acid levels, promoting thicker cell walls, and increasing silicon uptake (Baskaran 1985). Minor plant nutrients, such as silicon and zinc, can also contribute to pest suppression. In the proper quantities, silicon can increase the resistance of rice plants to blast, brown spot, bacterial blight, planthoppers, and stem borers (Chang et al 2001, Kim and Heinrichs 1982, Pathak et al 1971, Prakash 1999). Zinc applications reportedly minimize damage by *Elasmopalpus*, a stem borer of dryland rice (Reddy 1967).

Scant research has been done on how manipulating soil nutrition or cultivars affects communities of natural enemies. Studies suggest that some types of parasitoids concentrate their attacks on insect hosts that feed on leaves with the highest N content (Loader and Damman 1991). Egg production by predaceous mites is higher when they feed on prey reared on citrus trees receiving high fertilizer rates (Grafton-Cardwell and Ouyang 1996). Lycosid spiders (Kartoharjono and Heinrichs 1984) and mirid bugs, *Cyrtorhinus lividipennis* Reuter (Senguttuvan and Gopalan 1990), consume prey at higher rates on pest-resistant rice cultivars than on susceptible ones. Some pest-resistant cultivars appear to be more attractive than susceptible cultivars to certain predators (Sogawa 1982, Rapusas et al 1996).

To date, the application of the science of pest-nutrient interactions on rice consists of simple recommendations to split nitrogen applications, plow straw into the soil to increase silicon uptake, apply K during planthopper outbreaks, or apply N to promote recovery following stem borer and defoliator damage, to give a few examples (Litsinger 1994, Peng 1993). While useful, these sorts of unquantified recommendations fall short of giving farmers the tools necessary to manipulate pest populations through nutrient management. Furthermore, the literature is full of contradictory implications for the manipulation of soil nutrients to manage rice pests. N applications cause at least some rice cultivars to release oryzanone, which makes them more attractive to stem borers (Seko and Kato 1950). On the other hand, the addition of N stimulates tiller production, which helps rice plants compensate for early stem borer damage (Rubia et al 1996). Planthopper incidence is increased by N applications (Cook and Denno 1994, Uthamasamy et al 1983), but plants with high N content have an improved ability to compensate for planthopper feeding (Rubia-Sanchez et al 1999). These apparent contradictions result from several factors: most of the studies are conducted on one or a few cultivars, soil properties are rarely considered, and most of the research is done under artificial conditions in which natural enemies and other contributing variables cannot affect the results. How can farmers strike the balance between applying enough fertilizer to increase yields without increasing pest damage to the point that yields decline? Can increases in fertilizer application raise the risk of sporadic pest damage?

"... unquantified recommendations fall short of giving farmers the tools necessary to manipulate pest populations through nutrient management."

In traditional farming systems, grain pests are managed by winnowing and other simple techniques. Will such simple pest management techniques be adequate as traditional farmers increase fertilizer use in an effort to improve yields? *Photo by G.C. Jahn, Koh Kong, Cambodia, 1997.*

Currently, nutrient and pest management recommendations are woefully inadequate for predicting edaphic effects on multiple pests and different cultivars. Add to this the issues of how the pests of new cultivars will respond to integrated nutrient management (INM); how INM affects natural enemies, symbionts, and the ecological community; and how grain quality is affected by pest-nutrient interactions, and it becomes clear that we have barely scratched the surface of understanding SCIPY. A better understanding of SCIPY could lead to INM practices that facilitate integrated pest management (IPM). For instance, we might be able to manage soil nutrients to attract more ovipositing herbivorous insects to weeds, or to improve the allelopathic properties of certain rice cultivars (Pheng et al 1999a,b). Perhaps strategies to manage host-plant resistance (HPR) in rice cultivars (e.g., Cohen et al 1998, 2000) could be improved by incorporating INM. Basal applications of fertilizer have been found to reduce golden apple snail populations (de la Cruz et al 2001), which are serious rice pests throughout Asia (e.g., Halwart 1994, Jahn et al 1998).

Objectives of SCIPY research

A SCIPY research program would strive to improve INM and IPM by understanding how variability in soil properties and rice cultivars influences BYC and how IPM strategies impinge on soil nutrition. An objective of such research would be to predict the consequences of intensified production on BYC. This would lead to the following outputs:

- Identifying situations in which pest outbreaks are likely to occur

- Predicting the effectiveness of IPM under different edaphic conditions
- Integrating pest and nutrient management strategies by
  - Improving the match between INM and IPM recommendations for rice by avoiding contradictory recommendations.
  - Describing the combinations of soil nutrient management and cultivar choices that encourage or discourage yield loss from damage by key rice pests.
  - Enhancing the biological control of rice pests through appropriate cultivar and fertilizer combinations.
  - Developing nutrient management recommendations that promote better compensation for and better HPR against pest damage in new and popular rice cultivars.

SCIPY research could be a means to progress toward integrated natural resource management (INRM), which is the broad-based management of land, water, and biological resources for sustainable agricultural productivity. By managing soil nutrition and populations of beneficial organisms as natural resources, INRM could sustain rice productivity. The alternative to INRM is to control insect pests with insecticides if pest populations exceed economic thresholds as a result of fertilizer applications. The problem with such a nonintegrated chemical approach is that natural enemy levels are reduced through insecticide use (e.g., Jahn 1992). Over time, the populations of predators and parasitoids are reduced to levels at which secondary pest outbreaks occur (Dent 1995).

Possible approaches

The challenge of meeting these objectives could be approached deductively (Sta. Cruz et al 2001, Ludwig and Reynolds 1988), inductively (Platt 1964), or adaptively (Checkland 1985, Cox et al 1999a, Röling and Wagemakers 1998). Each of these approaches has advantages (Table 3). The three approaches could also be combined, as in the *Wuli, Shili, Renli* (WSR) systems methodology of Gu and Zhu (1995).

> "It is quite possible to correctly ascertain the association of events without knowing the mechanism for it."

The deductive approach is typically used for modeling complex systems. It consists of describing the general situation and then (based on patterns, associations, or correlations) deducing the expected

Table 3. Relative advantages of different research approaches, where 1 indicates the greatest advantage and 3 indicates the lowest advantage.

Approach	Deductive	Inductive	Adaptive
Has multiple components	1	3	2
Is predictive	1	2	3
Reveals mechanisms	2	1	3
Increases understanding	2	1	3
Has rapid application	3	2	1
Has rapid adoption	2	3	1

outcome of specific interactions. By characterizing multiple components of a system, modeling can highlight which areas are poorly understood and which components dominate the outcome (Norton et al 1991). This is not the same thing as prioritizing research, however, which requires drawing boundaries and deciding which components are more likely than others to contribute to the desired objective. In fact, thorough characterization may actually be an impediment to producing practical outputs. In an effort to make a model more predictive, it is tempting to continually add components until the model becomes so complex that it can never be applied in a real-world situation (Cox 1996). Or worse, model building can become an end unto itself.

Research agendas often begin with characterization studies (e.g., Jahn et al 2000a, Savary et al 1994, 2000a) so that the ecogeographical distribution of problems can be better understood and the likelihood that a species or event will occur can be predicted. The predictive nature of deduction should not be confused with determining causation. It is quite possible to correctly ascertain the association of events without knowing the mechanism for it. It is also possible to describe spurious associations in the mistaken notion that they are somehow causally linked. For instance, studying the coincidence of certain historical events with the appearance of celestial bodies led to the development of astrology. Begon et al (1996) described mathematical modeling as "a form of simplicity that is essential to seek, but equally essential to distrust." Applied to SCIPY, a deductive approach might begin with the spatial delineation of the environment (McLaren and Wade 2000), soil properties, and rice pests at landscape or regional scales (Fig. 1). Then the interactions of these factors could be characterized, including BYC for different cropping situations (Savary et al 1996, Jahn et al 2000b), through nonparametric techniques (e.g.,

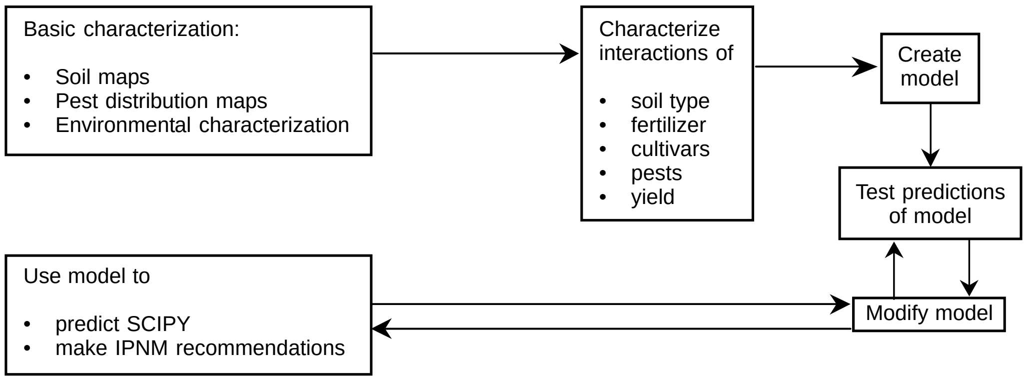


Fig. 1. Example of the deductive approach to the SCIPY (soil and cultivar interactions with pests and yields) research agenda. IPNM = integrated pest and nutrient management.

correspondence analysis). The relative contribution of components of BYC to variation in yield can be deduced using step-wise regression techniques (Adipala et al 1993, Karungi et al 2000, Ludwig and Reynolds 1988). The predictions of the model must then be rigorously tested and the model modified based on the test results.

In contrast to the deductive approach, the inductive approach moves from specific discoveries to generalizations about the way nature works. This is the classic scientific method, aptly described by Platt (1964) as "strong inference." In this approach, the scientist seeks to simplify the system to the point that variation is controlled in all components except one. The disadvantage to this approach is that a highly simplified system may not reflect the reality of farmers' fields. Using an inductive approach, researchers might first identify suspected cases of SCIPY dominating the production situation and then conduct experiments to show that the phenomena can be reproduced in repeatable ways (Fig. 2). Unlike the deductive approach, the inductive approach has an aspect of research prioritization already built into the research process. Only experimentally repeatable SCIPY effects would merit further investigation. The mechanisms for the observed phenomena would then be identified by eliminating alternative hypotheses

". . . the scientist seeks to simplify the system to the point that variation is controlled in all components except one."

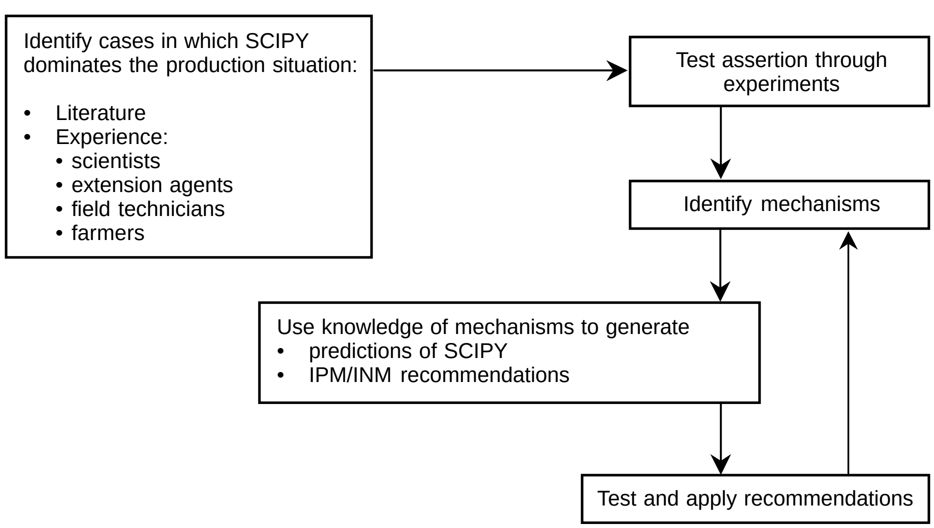


Fig. 2. Example of the inductive approach to the SCIPY (soil and cultivar interactions with pests and yields) research agenda. IPM = integrated pest management, INM = integrated nutrient management.

through decisive experimentation. The mechanisms for SCIPY effects could range from chemical and physiological causes to behavioral or ecological causes, thus requiring interdisciplinary investigations. By revealing the fundamental causes of SCIPY effects, it should be possible to predict SCIPY and make integrated pest and nutrient management (IPNM) recommendations. If these predictions and recommendations are incorrect in some cases, then investigators would return to studying causation in more detail.

The most recent addition to developing research agendas is action research or adaptive management (Flood 2000). Through this approach, neither characterization nor causation is sought (Checkland 1985). Rather, the emphasis is on creating case studies of situations in which farmers and scientists have worked together to solve practical problems (e.g., Jahn et al 1999). Each case study serves as a basis for the next intervention, creating learning cycles. While traditional science may use farmers as a source of information, the adaptive approach includes farmers and other stakeholders as collaborators and colleagues, so that adoption of existing technology and adaptation to the farm situation are relatively rapid (Cox et al 1999b). Modeling may form an important part of the adaptive approach, but with the end user in mind. In the deductive approach of system dynamics, modeling is a means for researchers to describe the universe in sufficient detail to predict events (Lane 2000). In contrast, adaptive research models are tools that farmers use to support their decisions. An adaptive model, for instance, could include crop calendars that aid IPNM interventions. Because action research fosters a high degree of farmer participation, it tends to have a relatively high impact on farmers' livelihoods. The very process of conducting the research with farmers tends to ensure the relevance of research results to farmers' problems. Unfortunately, the adaptive approach is so tailored to specific circumstances that replication and, therefore, verification are often quite difficult. When an adaptive approach solves a problem, it may not be clear why since the objectives and methods of adaptive research are constantly shifting, resulting in messy data. To the degree that farmers are involved in the research, the treatments and results become increasingly

Interviewing farmers to identify key constraints to rice production is often the first step in a research project, regardless of the research approach that is ultimately used. *Photo by G.C. Jahn, Battambang, Cambodia, 1996.*

heterogeneous and difficult to analyze (Petch and Pleasant 1994), although the relevance and sustainability of those results are usually increased (Chambers and Jiggins 1987, Cox 1998). Another concern is the evaluation of new technology with farmers. Should resource-poor farmers be exposed to the risks of unproven technology so that they can evaluate it? Perhaps the adaptive approach is better suited for developing solutions than for evaluating new technology. An adaptive approach to SCIPY research could begin by identifying SCIPY-related production problems with farmers (Fig. 3). After finding out how farmers are dealing with the problem, scientists and farmers could discuss new ways to solve the problem and then test solutions together. The results are documented and then applied to the next case study.

"Should resource-poor farmers be exposed to the risks of unproven technology so that they can evaluate it?"

As each approach has it own advantages and disadvantages, might it be possible to apply the best of each approach toward a SCIPY research agenda that includes prioritization? Combining inductive, deductive, and adaptive methods is the essence of the *Wuli, Shili, Renli* (WSR) approach first proposed by Gu and Zhu (1995). In the WSR approach, sociotechnical systems are seen as constituted by the Chinese words *wu* (objective existence), *shi* (subjective modeling), and *ren* (intersubjective human relations) (Gu and Zhu

物理	事理	人理
Wuli	*Shili*	*Renli*

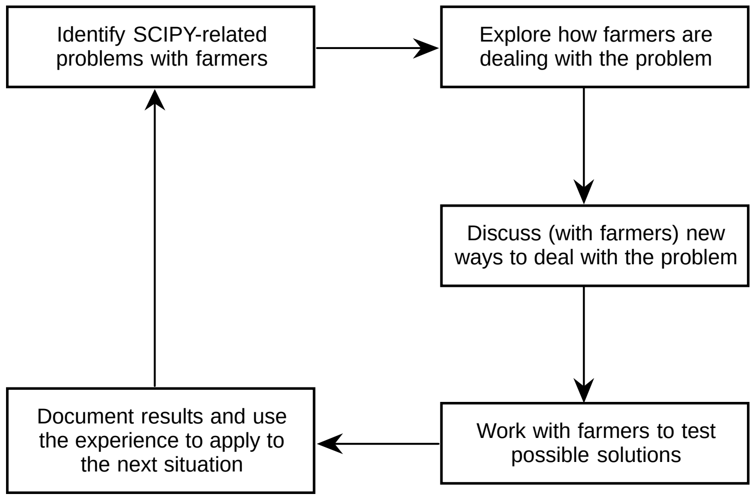


Fig. 3. Example of the adaptive approach to the SCIPY (soil and cultivar interactions with pests and yields) research agenda.

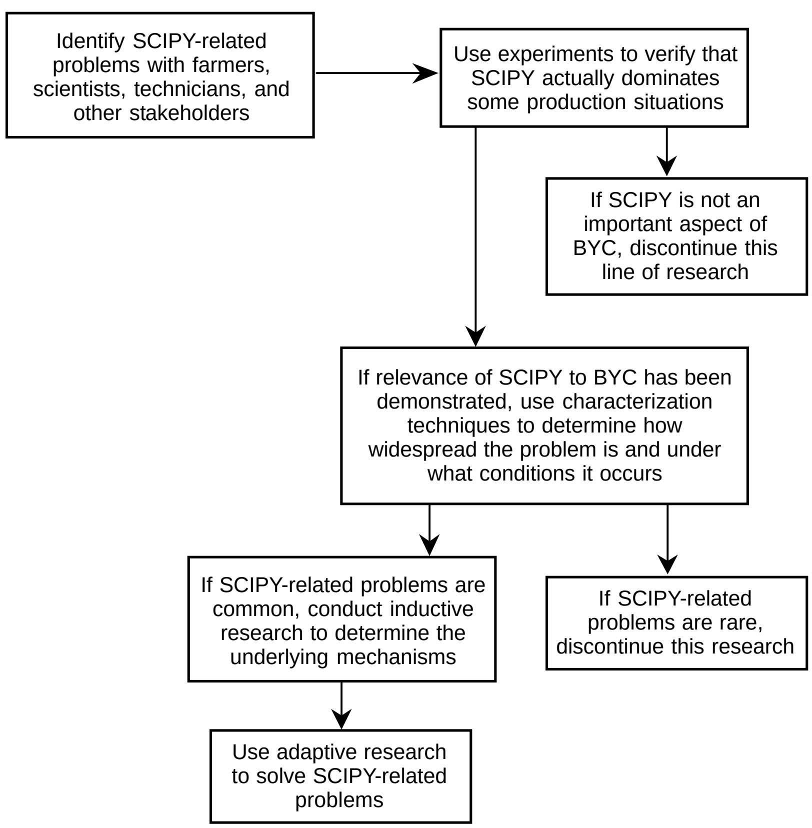


Fig. 4. Example of combined adaptive, inductive, and deductive approaches to a SCIPY (soil and cultivar interactions with pests and yields) research agenda to address existing crop problems. BYC = biotic yield constraints.

2000)[2]. The WSR aim is dynamic unification of knowledge of the physical world, system organization, and human relations to achieve a feasible result (Gu and Tang 2000).

Regardless of the research approach taken later, it would seem prudent to begin by verifying that SCIPY is actually an economically important (and widespread) part of the existing BYC to rice, or that it is likely to become an important aspect of BYC in the new cultivars being developed. In the first instance (i.e., SCIPY is already an important part of BYC), an adaptive approach could be used to identify situations in which SCIPY dominates the constraints to rice production (Fig. 4). Experiments (i.e., an inductive approach) could be used to verify whether SCIPY is an important part of BYC. If it is not, then SCIPY research on existing problems can be discontinued. On the other hand, if the relevance of SCIPY to BYC has been demonstrated, then characterization techniques (i.e., a deductive approach) could be used to determine how widespread SCIPY-related problems are and under what conditions they are expected. If characterization indicates that the problems are not widespread, then SCIPY research on the currently used cultivars can be discontinued. If, however, such problems are widespread, then experiments could be conducted to determine the underlying mechanisms. Knowing the conditions and causes of SCIPY should then enable researchers to move into an adaptive phase and work with farmers to solve SCIPY-related problems. In this adaptive phase,

[2] *li* is added to each component to denote "the nature of . . .". Zhu (2000) explores the philosophical basis for WSR, including discussion of the meaning of *li*.

farmers and researchers would agree on the indicators used to measure the impact of IPNM or INRM on rural livelihoods.

In the second instance—the likelihood that SCIPY will become an important component of BYC in the future—one could begin with an experimental approach to document SCIPY effects (Fig. 5). If increased SCIPY is not an important aspect of the BYC on new cultivars under increased fertilizer use, the research can be discontinued. However, if the importance of SCIPY to BYC is shown, characterization studies could indicate where and under what conditions SCIPY would contribute to the BYC of new cultivars. If these studies suggest that the problem will be rare, the research can be discontinued. But if SCIPY-related problems are expected to be widespread and dominate the production situation, experiments could proceed to discover the underlying mechanisms and develop IPNM as part of INRM. IPNM would have to be evaluated and further developed as new cultivars are tested in field trials. Finally, as cultivars are released, the IPNM and INRM techniques would be evaluated and improved with farmers using an adaptive approach.

Strategic vs diagnostic IPNM

In developing IPNM (or INRM) to address present or future crop problems, researchers can choose between a strategic and diagnostic approach. In strategic IPNM or INRM, characterization would

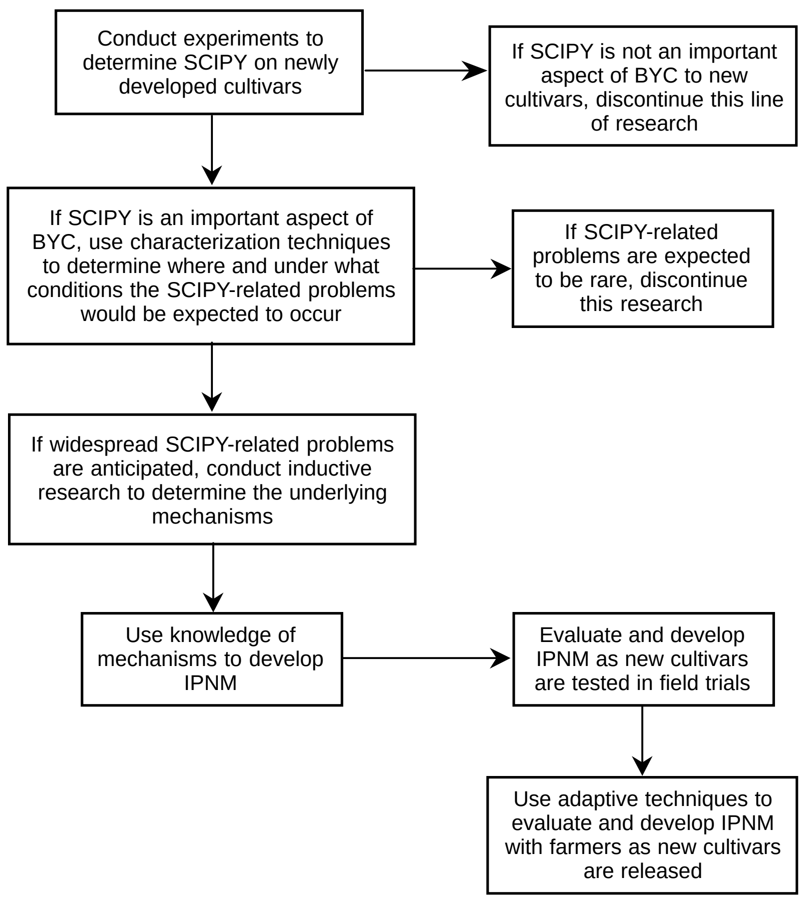


Fig. 5. Example of combined adaptive, inductive, and deductive approaches to a SCIPY (soil and cultivar interactions with pests and yields) research agenda to address potential crop problems related to the release of new cultivars and increased fertilizer use. BYC = biotic yield constraints, IPNM = integrated pest and nutrient management.

reveal the potential problems in rice fields that fit into particular categories and recommendations could be made for each category. In the diagnostic approach, the problems of each rice field would be diagnosed separately and the solutions tailored to that field. A strategic approach would be preferable, if possible. But at some point we may have to accept that the ecosystem is too complex to allow the development of strategic IPNM or INRM. Otherwise, we could be left modifying impossible models indefinitely.

"...we could be left modifying impossible models indefinitely."

Conclusions

Although a great deal is known about single interactions between particular nutrients and pests, little is known about complex interactions of soil nutrients, rice cultivars, pests, and grain yield. To date, our recommendations on fertilizer applications and their effects on pests have been simple and unquantified. A clear, prioritized research agenda for SCIPY should lead to practical solutions to practical problems that farmers face now and in the probable future. If SCIPY is shown to be an important factor in rice production, we need to develop IPNM as part of INRM and the ability to predict SCIPY effects in farmers' fields, either strategically or diagnostically. Ultimately, it is in farmers' fields that all our research efforts must be applied.

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Notes

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Acknowledgments: Thanks go to Michael Cohen for helpful comments and suggestions and to Bill Hardy for editorial suggestions. We also thank Zeng Rong Zhu and Zhichang Zhu for providing the Chinese characters for *Wuli, Shili, Renli*.

Appendix 1. Acronyms.

BPH	brown planthopper
BYC	biotic yield constraints
CIAP	Cambodia-IRRI-Australia Project
HPR	host-plant resistance
INM	integrated nutrient management
INRM	integrated natural resource management
IPM	integrated pest management
IPNM	integrated pest and nutrient management
IRRI	International Rice Research Institute
K	potassium
K	carrying capacity
N	population size
N	nitrogen
P	phosphorus
R_o	basic reproductive rate
SCIPY	soil and cultivar interactions with pests and yields
WSR	*Wuli*, *Shili*, and *Renli*