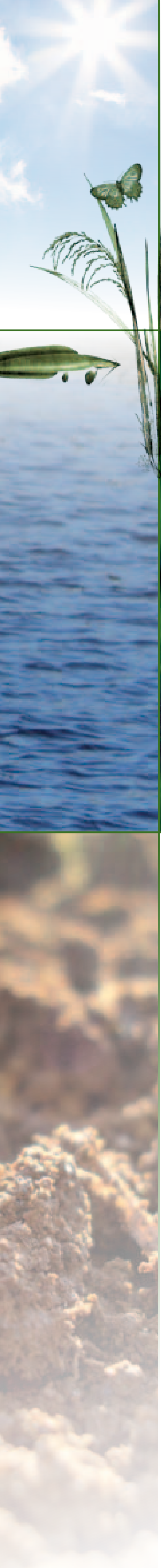
THE ASIA REGIONAL RICE INITIATIVE

BIODIVERSITY, LANDSCAPES & ECOSYSTEM SERVICES *in Rice Production Systems*



THE MULTIPLE GOODS AND SERVICES OF ASIAN RICE PRODUCTION SYSTEMS

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PREFACE TO "THE MULTIPLE GOODS AND SERVICES OF ASIAN RICE PRODUCTION SYSTEMS"

Rice is among the most important cereal crops in the developing world. It is the staple food for at least 33 countries; 15 of these are in Asia and the Pacific. Rice agroecosystems are central to the livelihoods of millions of smallholder farmers, and have the potential to generate multiple benefits for local communities and the public good, at the same time as sustaining rice yields.

Rice cultivation systems are often based on ancient practices that have sustained production, often in steep mountainous terrain, over millennia. Rice fields are some of the most biodiverse ecosystems in the world. Rice paddies often serve as critical conservation areas for migratory waterfowl. Unlike many other production systems, the flooded nature of many rice production practices makes the connection to hydrologically-based ecosystem services and biodiversity particularly acute, and presents the possibility of aquaculture in rice paddies. Rice fields attract many aquatic plants and insects among other organisms that in turn sustain natural fertility in these seasonally flooded systems. The tremendous ecological complexity of rice cultivation systems creates an inherent, seasonal successional process which, if managed properly, supports effective natural control of rice pests and diseases. However, rice production systems around the world face multiple stressors including those of climate change, land degradation, water scarcity, and abuse of chemical pesticides.

As a contribution to the knowledge base on the capacity of rice ecosystems to produce multiple benefits, the present review was undertaken in the context of FAO's Regional Rice Initiative in Asia in 2013. FAO coordinated a process with regional and national experts in Asia to identify emerging holistic systems in rice production, review key integral practices, and assess their documented impacts on both yields and provisioning of ecosystem services. In the majority of cases, from the literature review undertaken it is evident that yields of rice production systems can benefit from the systems that are managed to generate other ecosystem services. Overwhelmingly, in all systems, the predominant outcome has been "win-win": higher yields as well as greater generation of ecosystem services. Different management systems are capable of generating quite different suites of ecosystem services, and show a variety of trade-offs and synergies between these. Under agro-ecological approaches, the capacity of rice systems to sustain natural pest control, maintain soil fertility, provide diet diversity through rice-fish integration, and mitigate greenhouse gas emissions is impressive, to name only some of the services enhanced.

Given the critical importance of rice cultivation in the global and local food economies and livelihoods, we are pleased to contribute with this document as part of the evidence base for decision-makers, as many rice-producing countries revise and reformulate their rice production strategies to sustain yields while enhancing the management of multiple benefits from the agriculture sector. The analysis in this document showcases an example of how FAO's Strategic Framework can be implemented, particularly through its Strategic Objective 2 – to *increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner*.

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CHANGING PARADIGMS OF AGRICULTURE

Increasingly, the global community has recognized that while the last half-century has witnessed striking increases in global food production through intensive use of inputs, such practices may deplete natural resources and impair the ability of agroecosystems to sustain production into the future. In addition, current intensive systems of production and food distribution have not significantly reduced the number of chronically hungry people around the world.

FAO (2011) along with numerous recent reviews (Royal Society 2009; Clay 2011; Foley *et al*. 2011) have highlighted that it is both possible and highly advantageous to address future needs by transitioning to systems of food production that are based on an effective use of ecosystem services and in ways that are regenerative, minimizing negative impacts. Such ecological approaches to food production tend to be knowledge-intensive processes, requiring optimal management of nature's ecological functions and biodiversity to improve agricultural system performance, efficiency and farmers' livelihoods. The stress is thus on knowledge and management skills – of farmers, advisers and researchers- as a major input. In addition to the core desired output of crop productivity from all agricultural systems, there is a growing recognition that farms and farming have central roles for human livelihoods in many respects beyond singular commodity outputs. Farms and farmers are capable of providing multiple goods and services, often beyond farm boundaries. For example, many agricultural zones serve as watersheds for urban areas and users downstream. Agricultural zones occur in biodiversity hotspots, and in centers of crop genetic diversity. Farming systems contribute substantially to the diet diversity of local populations, and may be the repositories for centuries of traditional knowledge and culture, handed down through families. Increasingly, it is recognized that farming practices may contribute - positively or negatively - to the mitigation of greenhouse gases and sequestering of carbon in soils.

YIELD GAPS AND “NATURE GAPS”

In the discussion of how the global agricultural sector may organize itself to feed the world in 2050, there is considerable focus on yield gaps: agricultural systems that produce less food than is possible under optimal management for a given combination of crop and environment are said to exhibit a “yield gap.” A recent review (Garbach *et al.*, *in review*) suggest that we think equally of “nature gaps”: systems that result in lower levels of ecosystem service delivery or ecological integrity than is anticipated for a given combination of environment and agricultural outputs. In this way, it is possible to focus equally on yields and ecosystem services, without losing sight of one or the other.

The spirit of FAO’s Save and Grow calls for moving agricultural development out of a focus on singular focal areas – e.g., improved seed, pest control, water management – to solutions that integrate all components of the farming system. For multiple reasons, there are important present and future incentives to encourage farming systems that build “virtuous circles” – that make careful use of resources, introduce sets of management practices that build on the strengths of each, and facilitate the natural generation and delivery of ecosystem services on-farm. In an increasingly resource-constrained world, more efficient, less wasteful and more self-regenerating agricultural production systems will be of mutual benefit to farmers and to the larger public.

Among the approaches proposed to achieve these aims are holistic systems of agroecology (as opposed to specific individual practices). Core principles of agroecology include maintaining and enhancing soil health; improving recycling of biomass and nutrients; increasing biological diversity and beneficial interactions among species; and optimizing use of water, energy, nutrients and genetic resources (Altieri 1995; Gliessman 1998). Agroecological systems should be farmer-focused, aiding consideration of interactions between the different parts of the farming system, and to create positive synergies- for example, between crop residues and livestock feed, or rice mulch and natural enemy populations (e.g., predators of crop pests).

APPLICATION TO ASIAN RICE PRODUCTION SYSTEMS

Rice production systems in Asia are facing multiple stressors including those of climate change, land degradation and water scarcity. At the same time, many countries in Asia are recognizing a need to revise and reformulate their rice production strategies, to think beyond simple production targets (FAO 2014). Rice agroecosystems are central to the livelihoods of millions of smallholder farmers, and have the potential to generate multiple benefits for local communities and the public good, at the same time as sustaining rice yields. Ecological approaches are embedded in farming systems with holistic approaches. As outlined in FAO's 2011 publication, Save and Grow, such systems seek to integrate ecological principles into agricultural management to reduce dependency on external inputs and increase the productive capacity of biotic and abiotic system components. In this way, ecological approaches aim to increase yield or yield stability and resilience, while maintaining and increasing the provision of on- and off-farm ecosystem services.

Agroecological farming systems have doubters as well as promoters around the world, particularly with respect to their ability to match the yields of conventional agriculture. As a contribution to the development of pathways toward greater sustainability in Asian Rice Production systems, a systematic framework and methodology were developed based in part on an earlier global review (Garbach *et al. in review*) to identify emerging agroecological systems in rice production, review their key integral practices, and assess their documented impacts on both yields and provisioning of ecosystem services.

DEVELOPMENT OF AN ANALYTICAL FRAMEWORK

Agroecological Systems in Rice Production

An important characteristic of agroecological systems is that they address a particular set of management objectives. While it is constructive to recognize the multi-functionality of agricultural systems, no one system can deliver the full range of goods and services that might be envisioned as desirable. And no one system is adaptable to all agroecological zones. Thus, a renewed focus on agroecological systems must encompass a range of production approaches, addressing different, multiple management objectives and agroecological zones.

Through an online conversation carried out in May and June of 2013 with a set of experts in different aspects of rice production[1] a provisional set of agroecological systems applicable to Asian rice production was identified, and further modified through a workshop of national, regional and international experts held in Bali in July 2013[2]. The applicable systems selected and assessed are:

1. Conservation agriculture: cultivation that emphasizes minimum soil disturbance, crop rotation and cover crops
2. Holistic heritage systems of agriculture: cultivation approaches focused on sustainable land use systems and landscapes that have evolved through the dynamic adaptation of farming communities to their environment
3. Integrated farming systems: cultivation integrated with fish, livestock and/or agroforestry
4. Integrated pest management: cultivation with emphasis on integrated control of insect pests and/or enhancement of natural enemies (including practices involving monitoring and site-specific application of inputs)
5. Organic agriculture: cultivation associated with agreed organic practices
6. System of Rice Intensification: cultivation focused on integrated approach to rice production that includes six core practices

We selected these six systems because they are representative of the spectrum of agroecological approaches and include a range of practices that are suited to management of large- as well as small-scale agriculture. These holistic systems of rice production incorporate both traditional knowledge and modern technology; have been the subject of prior research as well as project, program, and/or policy support for agricultural development; and, collectively, are suitable for producing rice and other crops, thus addressing food security needs.

In particular, and in variance with the previous global review of agroecological intensification systems, our team determined that integrated pest management (IPM), with its long history of elaboration in rice ecosystems in Asia, merits recognition as a system, not a practice. In addition, we have recognized the strong contribution of traditional systems to the identification of holistic practices that may have been neglected through conventional intensification.

1 See Annex 1 for list of participants
2 Participants are the authors of this report

Practices Integral to Agroecological Systems of Rice Production

The refinement and uptake of agroecological systems, that are thoughtfully constructed to build on nature's functions, are a proximate goal. Practically, however, it is the set of constituent practices that make up any system, which farmers will need to assess and adapt to their particular circumstances. Thus it is important not to lose sight of specific practices in assessing the provisioning of goods and services from agricultural production systems. Many agroecological systems, indeed, stress the set of "core practices" that are central and essential to the functioning of the system. The prevailing cultivation approaches of each of these six systems, their core practices and related practices are provided in Annex 2.

Practices are also the building blocks of exchange of information, between farmers and between trainers and farmers. They may be the basis of most curricula as offered in farmer training. To a certain extent, practices may be modular, and combined in different ways to meet different management objectives.

Some practices, such as tillage, cover crops and green manures can be used in a variety of rice production systems. It is useful to understand what component practices contribute most to the positive outcomes of different agroecological systems. Thus, the specific practices that might enter into the application of agroecological systems were identified, and it was agreed to note their use in the studies to be reviewed. The practices identified were:

- Minimizing soil disturbance
- Maintaining permanent soil cover
- Crop rotations
- Crop species or varietal diversification
- Cover crops
- Natural pest, disease & weed control
- Water use efficiency
- Integrated nutrient management
- Land preparation
- Seed selection & storage
- Growing healthy crops
- Regular monitoring and informed management
- No external chemical inputs
- Crop-livestock-fish and/or tree integration
- Co-management for energy production
- Specific planting practices
- Strategic water management for soil intermittent aeration
- Conservation of traditional knowledge and management practices
- Safeguarding social and cultural values
- Rational use of seed inputs

Analytical framework for evaluating ecosystem services generated by Asian rice production systems

Ecosystem services have been defined as "the benefits people obtain from ecosystems". The Millennium Ecosystem Assessment has provided a much-utilized framework for identifying the key ecosystem services that we may anticipate to be generated by different ecological systems (Millennium Ecosystem Assessment 2005). These include provisioning services such as food and water; regulating services such as flood and pest population regulation; cultural services such as spiritual, recreational and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth.

We drew upon the analytical framework developed for a global review of agroecological intensification strategies to characterize the observed effects of agroecological systems on yield and thirteen ecosystem services that have been highlighted as key outcomes of multi-functional, rice-based agricultural systems: diet diversity; carbon sequestration; cultural services; energy provision; genetic diversity; mitigation of greenhouse gases; pest control; resilience to climate disturbance; soil structure, fertility, erosion control; water quality; water quantity; weed control; and wild biodiversity and habitat provisioning. These services were selected through the online conversation and workshop activities. We analysed yield (i.e., the service of food provision) separately from the other outcomes in order to assess the relative contribution of each system to closing yield gaps and nature gaps. We present trends in yield plus thirteen ecosystem services.

Link with economic efficiency or livelihoods

The vast majority of current scientific evidence on different agricultural intensification pathways tends to focus on one dimension – such as soil fertility, or pest management, rather than performance across multiple dimensions. Being able to aggregate comparisons within the same study conditions of the outcomes of agroecological systems on both yields and ecosystem services can already help to grasp the complexity and potential convergence of ecological approaches. It would be even more desirable to be able to have a more complete picture of benefits and trade-offs, translated into economic terms or values of importance to human livelihoods. While such documentation is scarce in the literature, our database has noted where such evaluations exist. This aspect awaits further analysis.

Sources of information and criteria for included studies

This review includes both peer-reviewed scientific literature and non-peer reviewed "grey literature" such as project reports and student theses. A wealth of highly localized and detailed information may reside in such documents. This review includes studies that presented observations on at least one of the thirteen focal ecosystem services and a description of the data collection methods. We included review papers only when sufficient data were provided to identify both the comparisons between agroecological systems and contrasting farming systems and observations of indicators of ecosystem service outcomes. We excluded conceptual papers, and studies reporting yield alone. We noted which studies were suitable for quantitative analysis as well as those suitable for qualitative analysis. This report focuses on quantitative data analysis, however qualitative studies were retained in the database to support future analysis.

We identified 155 studies that met these criteria, comprising 21 on conservation agriculture, 32 on integrated farming systems, 20 on integrated pest management, 20 on organic agriculture, 22 on the System of Rice Intensification, and 40 on holistic heritage agricultural systems. These studies contained a total of 676 individual comparisons of agroecological systems (treatments) to a contrasting farming system (controls). Some of the comparisons evaluated multiple ecosystem service outcomes. Of the reviewed comparisons, 602 were suitable for quantitative analysis and this report focuses on these data; 534 comparisons have data on both yield and ecosystem service outcomes, while 68 included data only on ecosystem services.

Literature review and coding protocol

All participants in our expert workshop in July 2013 were trained in the literature search and coding protocol and helped to compile relevant studies, focused on the six agroecological systems and carried out in the Asian region. Internet searches, using Google and the Web of Science were employed. The resources of the IRRI (International Rice Research Institute) library were consulted, and we also included literature recommended by our regional, national and other experts that met our search criteria.

Literature was identified and coded by one of our team and then assigned to a second team member; thus each study included in our analysis was reviewed by two people to help assure consistent coding[3]. The database[4] includes notes on location, type of study, practices noted, scale, type of rice production ecology and scale of uptake. In addition to comparative yields of the baseline versus holistic farming system, the database records information (where available) on varieties used, cover or rotational crops, fertilizer inputs and weed control inputs. For each study comparison, relevant practices were noted, and the outcomes on any of the thirteen ecosystem services as described above.

3 Coding protocol and all data management formats available upon request.

4 The database was developed using Microsoft Excel software for ease of use and sharing among regional experts and collaborators interested in this analysis and its future applications. Our spreadsheet database will be made available on a dedicated website, for further use and update. The first worksheet provides guidance on completing fields and utilizing the scoring system.

Analysis

For each combination of agroecological system and ecosystem service outcome, we summarized the number and proportion of results that reported enhanced, diminished, or not significantly different ecosystem services and yields relative to the contrasting farming system. We used a modified vote-count method (Knowles and Bradshaw 2007; Stanley 2001) in which comparisons with contrasting farming systems are the units of analysis. Contrasting systems included conventionally intensified (high external input) agriculture as well as low-input subsistence or un-intensified farming. For studies that reported both yield and ecosystem service outcomes, we also summarized the proportion of reported win-win outcomes (enhanced yield and ecosystem services), tradeoffs (enhanced outcomes in one metric but diminished outcomes in the other), or lose-lose outcomes (diminished yield and ecosystem services).

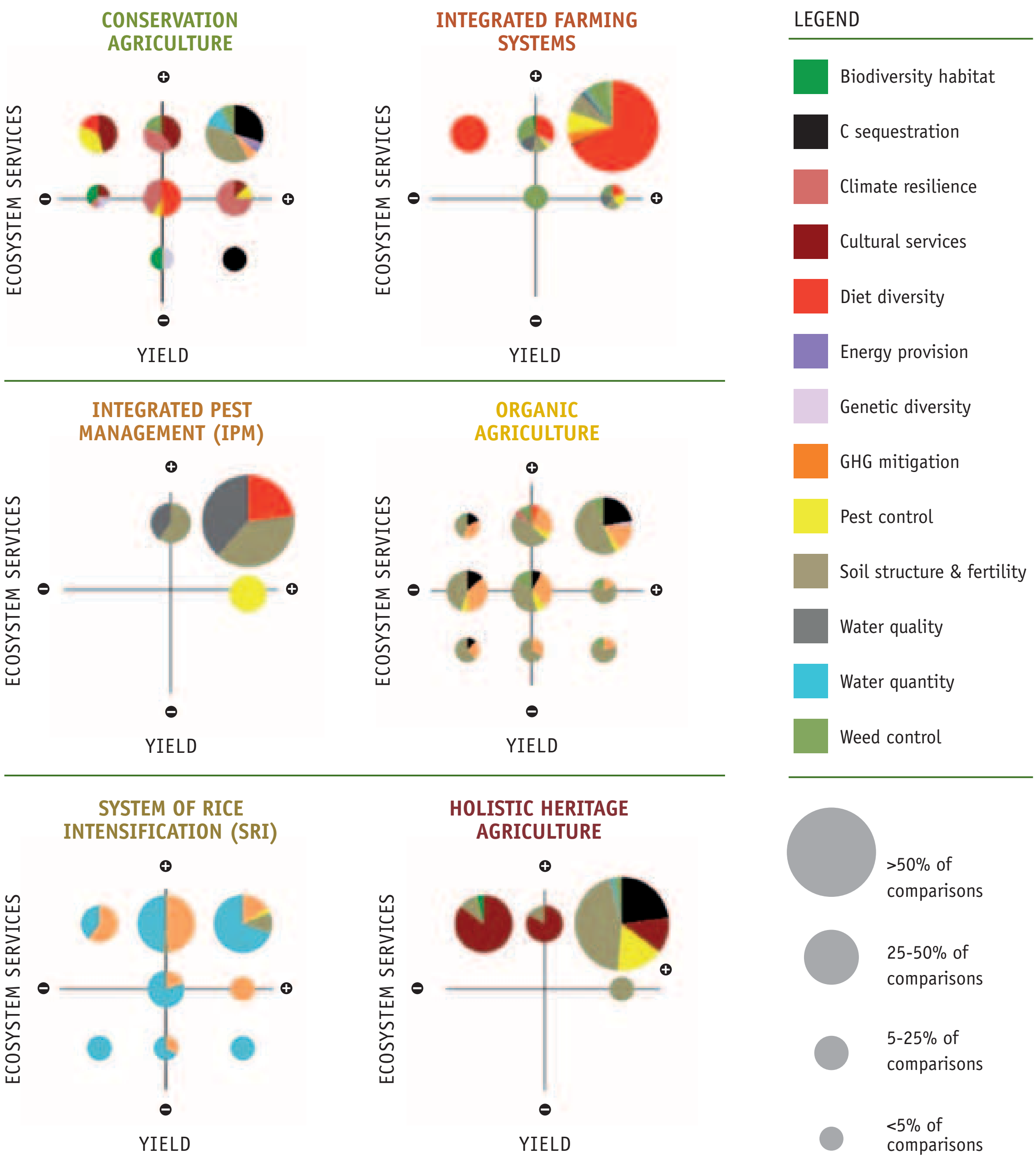
RESULTS

Data Visualization

The results are visualized (Figure 1) from the vote count of ecosystem services and yield outcomes across comparisons to evaluate the number and proportion of studies that reported enhanced, diminished, or not significantly different outcomes relative to the comparison farming system.

FIGURE 1. SYNERGIES AND TRADEOFFS BETWEEN ECOSYSTEM SERVICES AND YIELD IN SIX FOCAL AGROECOLOGICAL SYSTEMS OF RICE PRODUCTION.

Bubble location indicates a specific combination of outcomes for ecosystem services (y-axis: enhanced, upper quadrants; diminished, lower quadrants) and yield (x-axis: enhanced, right quadrants; diminished, left quadrants) relative to comparison farming systems. Bubbles located on the axis itself indicate similar results to comparison systems. Bubble size indicates the percent of reviewed studies reporting each combination of yield and ecosystem service outcomes: largest: >50 percent of comparisons; large: 25-50 percent of comparisons; medium: 5-25 percent of comparisons; small <5 percent of comparisons. Ecosystem services in each outcome are represented by the color ramp below.



The ecosystem services that were identified and documented – whether with positive, negative or no outcomes- in the studies scored are noted in Table 1.

TABLE 1. SUMMARY OF ECOSYSTEM SERVICE OUTCOMES BY SYSTEM.

The tallies represent observations of ecosystem service outcomes reported in agroecological systems versus contrasting farming systems. Tallied observations indicate enhanced services (dark color shading), similar services (light color shading), and diminished services (no shading) relative to contrasting farming systems. The greatest number of observations is listed in boldface for each combination of agroecological system and ecosystem service.

ECOSYSTEM SERVICES	CONSERVATION AGRICULTURE			INTEGRATED FARMING SYSTEMS			INTEGRATED PEST MANAGEMENT			ORGANIC AGRICULTURE			SYSTEM OF RICE INTENSIFICATION			HOLISTIC HERITAGE SYSTEMS		
	↑	↔	↓	↑	↔	↓	↑	↔	↓	↑	↔	↓	↑	↔	↓	↑	↔	↓
Diet diversity	**3**	**3**	0	**90**	0	0				**1**	0	0				**9**	0	0
Carbon sequestration	**35**	11	0	**8**	0	0				**48**	0	2				**22**	0	0
Cultural services				**1**	0	0										**42**	0	0
Energy provision	**3**	**3**	0	**7**	0	1												
Genetic diversity										**4**	0	0				**4**	0	0
Mitigation of GHG	**7**	0	4	2	0	**3**	**1**	0	0	16	8	**30**	**30**	6	2	**6**	0	0
Pest control	**2**	0	0	**8**	2	0	**4**	1	0	**9**	2	0	**12**	0	0	**16**	1	2
Soil structure, fertility, erosion control	21	**23**	2	**12**	2	0	**8**	0	0	**111**	20	16	**11**	1	0	**40**	1	0
Resilience to climate disturbance										**1**	0	0	**5**	0	0	**1**	0	0
Water quality	**1**	0	0	2	**4**	2	**17**	0	0				**1**	0	0	**2**	0	0
Water quantity	**8**	0	0	**1**	0	0	**1**	0	0				**94**	8	5	1	**2**	**2**
Weed control	**7**	3	3	**16**	2	0				**12**	2	4	2	1	**3**	**19**	0	0
Wild biodiversity & habitat provisioning				1	**2**	0										**2**	0	0

TRADEOFFS AND SYNERGIES IN AGROECOLOGICAL SYSTEMS OF RICE PRODUCTION

We review here in more detail the specific outcomes recorded for each farming system, along with discussion of the prevailing trends.

CONSERVATION AGRICULTURE

Conservation agriculture includes three core practices: minimizing soil disturbance, maintaining permanent soil cover and integrating crop rotations (Kassam *et al*. 2009). This review found a total of 83 quantitative comparisons in relation to conservation agriculture. Amongst these studies, there was evidence for enhanced yield and ecosystem services in 33 percent (27 of 83) of comparisons. These 'win-win' outcomes included enhanced services of soil structure and fertility, carbon sequestration, and contributions to weed control, water quantity, energy provision and greenhouse gas emission mitigation.

Yield was enhanced and services not significantly influenced in 8 percent of comparisons, while yield that was similar to contrasting farming systems, but with enhanced ecosystem services were reported in 7 percent of comparisons. Enhanced services included resilience to climate change, cultural services, and weed control. Diminished yield and enhanced services were reported in 11 percent of comparisons; enhanced services comprised pest control, diet diversity, and resilience to climate change. We did not find any published reports of diminished yield and diminished services in conservation agriculture for rice production. Percentages of other outcomes were considerably smaller (5 percent or less).

Thus synergies between yields and ecosystem services were the most common characteristic of conservation agriculture systems in rice production. The range of ecosystem services generated by conservation agriculture was quite diverse as compared to other systems, with soil structure and fertility and carbon sequestration featuring prominently; all but four services were included (genetic diversity, cultural services, resilience to climate disturbance, and wild biodiversity and habitat provisioning).

It is reasonable to expect that studies will focus on the outcomes that are most likely to be associated with core practices—such as enhanced soil structure and fertility that are often expected to be associated with minimizing soil disturbance and maintaining soil cover in conservation agriculture. It bears mentioning that we found nearly equal observations for enhanced soil structure and fertility in conservation agriculture as we did soil structure and fertility that was similar to contrasting farming systems (21 and 23 observations respectively, Table 1).

The literature reviewed stressed that conservation agriculture rice systems can have positive and negative effects depending on regional conditions (Farooq 2011). Climate, soil type, farming system, farmer knowledge and availability of resources can have major impact on yield, conservation agriculture adoption, and generation of ecosystem services.

HOLISTIC HERITAGE AGRICULTURAL SYSTEMS

As the product of indigenous agricultural innovations and communal decisions and customs, smallholder rice production systems provide a living testament to the possibilities of a harmonious relationship between human and nature. Holistic heritage systems of agriculture as defined here references the “cultural landscape” that was originally shaped by the restrictions posed by local resources, and activities developed by respecting the biophysical boundaries of the landscape (Silfwerbrand 2012). The years of practices have coevolved with the environment, and the resulting interactions brought forth local wisdom in rice farming practices that has also influenced and shaped the cultural heritage of the society (Norgaard 1984).

Within the 97 quantitative comparisons identified by this review, win-win outcomes of enhanced services relative to contrasting farming systems were reported in 56 percent of quantitative comparisons. The service that was measured most frequently was soil structure and fertility. The other services that were reported frequently in win-win outcomes were carbon sequestration, pest control, and cultural services.

Enhanced ecosystem services and diminished yield were reported in 26 percent of comparisons (27 of the 97 comparisons). These findings were driven predominantly by one publication with many observations, focusing on the production of rice and associated crops in deeply flooded areas of the Chao Phraya delta (Puckridge no date). Ecosystem services that were enhanced encompassed three services: enhanced cultural services, soil structure and fertility, and wild biodiversity and habitat provisioning.

With respect to win-neutral outcomes, enhanced ecosystem services and no significant difference for yield relative to contrasting farming systems were reported in 12 percent of comparisons.

In one study, five comparisons with respect to ecosystem services alone were documented, reporting an overall trend towards enhanced ecosystem services, including genetic diversity (measured as "varietal diversity of more than nine rice types") and enhanced mitigation of greenhouse gas emissions in heritage organic farming approaches (Kediyal 2009).

One of the most important outcomes from Holistic Heritage agricultural practices is the evolution of genetic diversity of different plant cultivars and their conservation. The interactions

between the environment and traditional practices have resulted in the richness of germplasms for rice and another 264 species of endemic plants useful to humans, found in rice paddies (FAO 2013). The Ifugao rice terraces and the subak system of Bali has been shown to form unique clusters of micro-watersheds that are connected to the whole mountain ecology, thus conserving water and acting as a filtration system at the same time. The so-called "biorhythm" technology, in which cultural activities are harmonized with the rhythm of climate and hydrology management, has been the primary drivers for the growth and development of the society in the area (FAO 2013). This interaction, between culture and nature has created "biocultural diversity" that forms an important part of the landscape (Mathez-Stiefel *et al.*, 2007) and preserves the ecosystem.

INTEGRATED FARMING SYSTEMS

Integrated farming systems, in the present scope, includes production systems that integrate rice with the generation of other goods, such as fish, or livestock (often ducks) or services such as those provided by agroforestry. Rice-fish systems are particularly well elaborated throughout the region.

In the 105 comparisons that were identified focusing on integrated farming systems, 'win-win' outcomes of enhanced services and enhanced yield were represented in 67 percent. This synergistic outcome had strong evidence for enhanced diet diversity. All but two ecosystem services were documented in comparisons reporting synergies, suggesting that integrated farming systems can support beneficial, multifunctional outcomes. Enhanced ecosystem services with yields similar to contrasting farming systems were reported in 14 percent of comparisons; enhanced services were reported for diet diversity, weed control, soil structure and fertility, biodiversity habitat and pest control. Percentages of other comparison outcomes were considerably smaller (5 percent or less).

As rice fields resemble naturally occurring marshes and ponds, they have inherited an aquatic fauna from wild ecosystems that is often very rich and well adapted to the drastic environmental changes occurring in a paddy over a growing season. In recognition of this, the Ramsar Wetlands Convention recognizes paddy field as the biggest and largest human-made wetlands in the world, with important inter-connectivity for delivery of ecosystem services between paddy field and extended natural wetlands, in a resolution adopted in 2012 on Agriculture-wetland interactions: rice paddy and pest control (Ramsar 2012).

Integrated farming systems capitalize on this inherent biodiversity, and take advantage of the different ecological niches in rich paddies, by producing both rice and high-quality animal products (Bombaradeniya 2003; Mirhaj 2013) of vital importance to food and nutrition security throughout Asia. Managing rice landscapes for fish, with additional needs for ditches and dyking have, in some instance, opened up greater areas for vegetable and fruit production which in turn have provided opportunities that may reduce the amount of migration by young women (Little 1996).

To a lesser but possibly growing extent, integrated farming systems recognize the contribution of trees located near rice fields, both as sources of watershed protection, nutrient inputs and tree products (Kosaka 2006).

A few studies touched on the emission of methane and the release of N_2O, two important gases with global warming potential. The results, however, were contradictory and inconclusive.

INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) developed from the concept of integrating control tactics into an effective and cost efficient crop protection system, with optimal use of natural biological control and varietal resistance, with minimal reliance on chemical pesticides. It is sometimes defined as the farmers' 'best mix' of control tactics based on crop yield, profit, and safety for human health as well as for the environment. Since IPM advocates the conservation of natural enemy populations in rice fields, basic knowledge on pest and natural enemy species, population dynamics and trophic linkages is fundamental, as is a commitment to regular observation and monitoring before deciding to apply any inputs. In the evolution of the concept of IPM, given the link between nitrogen applications and pest outbreaks, thus, we have included studies that document site-specific nutrient management strategies that hinge on collecting localized data to determine needed inputs.

It should be noted that there is a disparity in the number of comparisons, with IPM being much lower than other systems, having only 22 quantitative comparisons. This form of analysis is quite subject to included studies, and thus there is greater uncertainty in the results with underrepresented systems having few comparisons, as with IPM.

Amongst the observed comparisons, win-win outcomes of enhanced yield and enhanced services relative to contrasting farming systems were reported in 59 percent of comparisons. Enhanced services were reported for diet diversity, water quality, and soil structure and fertility. Yield was similar, and ecosystem services enhanced in 23 percent of comparisons reviewed; enhanced services were documented for soil structure and fertility (measured as increased uptake of nutrients, or indices of agronomic efficiency) and water quality (based primarily on reduced pesticide applications).

Somewhat unexpectedly, very few of the IPM studies reported outcomes on natural pest control; perhaps this ecosystem service is taken for granted in documenting the outcomes of integrated pest management. One landmark study on the provisioning of natural pest control in rice production systems in Indonesia (Settle 1996) however provided a detailed description of the dynamics of natural pest control in rice. This study showed that abundant populations of generalist predators can be found in most early-season tropical rice fields. These generalist predators are likely to be supported, in the early season, by feeding on abundant populations of detritus- feeding and plankton-feeding insects, whose populations consistently peak and decline in the first third of the season.

The abundance of alternative prey gives the predator populations a "head start" on later-developing pest populations, thus enabling them to strongly suppress pest populations and generally lend stability to rice ecosystems by decoupling predator populations from a strict dependence on herbivore populations. Should herbicides be applied early in the season as a measure to control weeds, these applications will impact negatively on detritus-plankton feeding insects, thus denying general predators the 'head start' on later-developing pest populations. These and other observations support management strategies that promote the conservation of existing natural biological control through a major reduction in insecticide and herbicide use, and the corresponding increase in habitat heterogeneity.

Overuse of chemical fertilizer, nitrogen-based urea in particular, is also known to favor pest reproductive potential, most notably plant hoppers. Particularly in nitrogen-rich hybrid rice plantings, conditions for Brown Plant Hopper (BPH) outbreaks are favorable, particularly also due to the complete lack or low level of genetic crop diversity (Bottrell & Schoenly, 2012).

It should be noted that the distinction between IPM and some of the other production systems described in this paper is of course rather artificial and in reality much more blurred. In fact, most, if not all, integrated farming systems would have to include IPM one way or another. As prominently featured in the ongoing work of FAO's Regional Rice Initiative, there clearly is no point in trying to raise fish or shrimp in a paddy field if a farmer does not also reduce and/or eliminate pesticides from the paddy production system.

ORGANIC AGRICULTURE

Organic agriculture (OA) systems actively manage soil organic matter, plant nutrients, and pests and weeds through practices such as crop rotations with legumes, crop residue management, use of animal manure and green manure, mechanical weeding, application of mineral-bearing rocks, and biological pest control. Organic certification standards prohibit the use of synthetic fertilizers, pesticides, growth regulators, and feed additives.

Within the 161 quantitative comparisons identified by this review, win-win outcomes were reported in 48 percent of comparisons; ecosystem services enhanced included soil structure and fertility, weed control, mitigation of greenhouse gas emissions, genetic diversity, and pest control.

Other relationships between yields and ecosystem services in organic rice production systems were reported in much smaller percentages of studies: Win-neutral of enhanced yield and similar ecosystem service outcomes were reported in 3 percent (5 of 161) comparisons; win-lose (yield up and ecosystem services down) reported in 3 percent (5 of 161); win-lose (yield down and ecosystem services down) reported in 2 percent (2 of 161) comparisons; lose-lose outcomes were reported in 3 percent (5 of 161) comparisons; lose-neutral outcomes of diminished yield and similar ecosystem service to contrasting farming systems were reported in 6 percent (9 of 161) comparisons; and lose neutral outcomes of similar yield and diminished ecosystem services to

contrasting farming systems were reported in 1 percent (1 of 161) comparisons; while win-neutral outcomes of similar yield and enhanced ecosystems to contrasting farming systems were reported in 5 percent of comparisons. The only outcome of somewhat greater occurrence was in neutral outcomes (no significant differences in yields and generation of ecosystem services) reported in 16 percent of comparisons; these studies measured services of soil structure & fertility, mitigation of greenhouse gases, carbon sequestration, pest control, and weed control.

Certainly one of the unique strengths of rice paddy production systems is their inherent ability to generate fertility; a feature that organic production systems can be seen to enhance. In general, biological nitrogen fixation by associated organisms in rice paddies are a major source of nitrogen for lowland rice (George 1992). The efficiency of nitrogen uptake by rice for which chemical fertilizers are applied is typically low, due to large losses of nitrogen from flooded soils (De Datta and Buresh, 1989), although this may be mitigated through precision placement of fertilizers. Nonetheless, the ability of organic production systems to favor biological forms of nutrient inputs is to their advantage.

The relationship between organic rice production, carbon sequestration and greenhouse gas emissions is a delicate balance. The addition of organic materials such as straw and manure enhances soil organic carbon (Komatsuzaki 2009), replacing the practice of burning straw after harvest – and thus emitting green house gases – still common across Asia. Some studies have shown that greater methane emissions may result from application of organic materials, while nitrous oxide emissions may be significantly reduced (Zou *et al.*, 2003). Means of mitigating emissions by tailored watering regimes has been one avenue that has been explored, through systems of rice intensification discussed below.

Studies examined in the context of this review pointed also to the impacts of organic production on pest control. In some studies, the reproductive rate of insect pests, and thus their damage levels, was suppressed under organic treatments as opposed to conventional applications of chemical fertilizer (Kajimura 1995).

SYSTEM OF RICE INTENSIFICATION

System of Rice Intensification (SRI) is an integrated approach to rice cultivation that includes six key elements: 1) transplanting of seedlings at a young age; 2) low seedling density with shallow root placement; 3) wider plant spacing, in a square grid; 4) intermittent application of water, as opposed to continuous flooding; 5) frequent weeding, preferably with a mechanical weeder; and 6) incorporation of organic matter into the soil, complemented by synthetic fertilizer if needed (http://sri.ciifad.cornell.edu). It is applicable to irrigated systems and equally relevant for rainfed production – albeit more challenging in terms of implementation.

134 quantitative comparisons between SRI and conventional or traditional (subsistence or low-input, but not holistic heritage) systems were identified, showing strong evidence for win-win and win-neutral outcomes. Win-win outcomes were reported in 46 percent of comparisons. Enhanced ecosystem services were water quantity, mitigation of greenhouse gases, soil structure and fertility, and pest control. Win-neutral outcomes of enhanced ecosystem services and similar yields to baseline systems were reported in 23 percent of comparisons. Neutral-neutral outcomes were reported in 7 percent of comparisons: these studies focused on water quality and greenhouse gas mitigation. Percentages of other comparison outcomes were below 5 percent.

Enhancement of water quantity in SRI was predominantly reported among the ecosystem services provided by SRI, and was achieved through reduction of irrigation water and water use at transplanting and during some rice plant growth stages (Belder 2002; Thiyagarajan 2002; Sato 2006; Choudhury 2007; Satyanarayana 2007; Adhikari 2010; Zhao 2010; Sharif 2011), improvement of soil capacity to absorb and retain water (Adhikari 2010), and higher water use efficiency (Zhao 2010; Lin 2011; Veeraputhiran 2012) and productivity (Belder 2002; Thiyagarajan 2002; Satyanarayana 2007; Ginigaddara 2009; Susi 2010; Thakur 2011). SRI was reported in a study to increase water use efficiency by 91.3 percent and irrigation water use efficiency by 194.9 percent compared with traditional flooding (Zhao 2010).

Methane gas (CH4) mitigation was observed in 30 out of 38 comparisons in two SRI studies (Wassmann 2000; Susi 2010). However, both studies reported higher emission of nitrous oxide (N_2O) that, according to Wassmann (2000), limits the application of certain crop management practices for reducing emissions only to rice systems with high baseline emissions of CH_4. The author therefore recommended that rice systems with high methane emission levels should be identified, and site-specific technology packages should be identified that mitigate methane emissions while taking N_2O emissions into consideration.

DISCUSSION

SYSTEMS AND PRACTICES, OUTCOMES, SYNERGIES AND TRADEOFFS

While the review carried out here is subject to a number of limitations (in that its conclusions are entirely linked to the quality and coverage of holistic rice farming systems and their outcomes on ecosystem services), our results present some strong conclusions. The foremost among these is that, in the majority of cases, yields of rice production systems do not need to be sacrificed when the systems are managed to generate other ecosystem services. Overwhelmingly, in all systems, the predominant outcome has been “win-win”: higher yields as well as greater generation of ecosystem services.

Perhaps of even more practical use, however, may be that our examination has shown that different management systems are capable of generating quite different suites of ecosystem services, and show different kinds of trade-offs and synergies between these. While we would not suggest that this review is definitive, we would suggest that the results can form a very useful basis for discussion, of how management systems may be modified and elaborated to build further synergies and minimize key trade-offs, according to management objectives. There is clearly considerable scope for looking at how, for instance, organic practices may be modified to enhance carbon sequestration, or how water can be managed to minimize greenhouse gas emissions. The delicate interplay between natural pest control, fertility management, and production of aquaculture products in rice paddies is another area meriting considerable future attention.

POLICY CONSIDERATIONS

Many studies that were examined in the course of this review point to the need for favorable policy environments to support the growth and uptake of holistic farming systems. For example, better regulation and enforcement of certain pesticides currently used in paddy production could greatly enhance vital ecosystem services for natural biological control and for food and nutrition security. In another example: it was stressed that in Laos, the many benefits from Conservation

Agriculture were clear: integrating grasses and legumes in diversified rotations and as relay crops permitted not only additional fodder and grain production, but also contributed to nutrient recycling, pest management and weed control (Lestrelin 2011). But in an environment in which staple crops are prioritized above all others, there are limited market opportunities for a more diversified farming system.

While the present study does not extend to economic valuations, there are sufficient indications in the studies reviewed that the social and economic benefits of holistic farming systems will depend on supportive policy environments. In West Java, under organic rice production yields were lower than conventional farming, while the prices were twice as high, resulting in comparable returns (Komatsuzaki 2009). Wages per working hour were considerably lower in the organic systems, however. This suggests that while there is scope for land owners and farmers to increase profits by converting to organic cultivation, workers receive little added benefit. While there are societal benefits from improved environmental quality, social justice considerations remain to be addressed in policy.

WAY FORWARD

Historically, agroecological approaches have come from farmer communities, later to be taken up in science and in policy (Altieri and Toledo 2011). In rice production systems in Asia, the many manifestations of holistic farming systems have come from farming communities, adapting to local conditions with often tremendous ingenuity. As noted by Dey (2012), "in the absence of sufficient policy support from government, farmers nonetheless experiment and innovate—often in unexpected ways—to improve their livelihoods."

We suggest that the strength and value of agroecological farming systems are evident in this review. The many questions it may raise would greatly benefit to be taken up and addressed in more scientific research, identifying specific ways in which trade-offs between environment and production may be minimized, and greater synergies built. A reinforcing policy environment and substantial investments in ecology-literacy education for rice farmers for more effective management of ecosystem services - respecting the need for building on farmer knowledge - would ensure that future developments lead to improved livelihoods, sustained production from rice systems, and a regenerative natural environment.

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ANNEX 1.
PARTICIPATING EXPERTS IN DIFFERENT ASPECTS OF RICE PRODUCTION, IN ONLINE DISCUSSION

Participants in online conversation carried out in May and June of 2013 with a set of experts in different aspects of rice production: Sarah Beebout, IRRI; Chanthakhone Boualaphanh , National Agriculture and Forestry Research Institute, Lao PDR; Damayanti Buchori, Bogor Agricultural University, Indonesia; Fabrice de Clerck, Bioversity; Kelly Garbach, Loyola University Chicago, USA; Barbara Gemmill-Herren: FAO, Rome, Italy; K.L. Heong: IRRI; Jan Willem Ketelaar, FAO Regional Office for Asia and the Pacific; Matthew McCartney: IWMI, Laos; Jeff Milder: Rainforest Alliance; Abha Mishra: Asian Center of Innovation for Sustainable Agriculture Intensification ; MaryJane RamosdelaCruz: FAO, Rome, Italy; Roel Ravanera, Xavier University, Philippines; Bill Settle: FAO, Rome, Italy; Kimanh Tempelman: Norwegian Forest and Landscape Institute; Tu Anh Vu Thanh, Universiti Malaysia Terengganu.

ANNEX 2.
COMPARATIVE SYSTEM DESCRIPTIONS, CORE AND RELATED PRACTICES

RICE FARMING SYSTEM	DESCRIPTION	ANTICIPATED CORE PRACTICES	ANTICIPATED RELATED PRACTICES
CONSERVATION AGRICULTURE	Cultivation that emphasizes minimum soil disturbance	• Minimum soil disturbance • Permanent soil cover • Crop rotations	• Mulching
ORGANIC RICE PRODUCTION	Cultivation associated with certified organic practices	• 'Permitted' soil amendments • Natural pest control, including biological control and biological pesticides • Mechanical weed control	• Crop rotations with legumes • Mulching • Green manure
SYSTEM OF RICE INTENSIFICATION (SRI)	Cultivation focused on integrated approach to rice production that includes six core practices	• Transplant young seedlings • Low seedling density with shallow placement • Wide plant spacing, square grid • Intermittent water application • Frequent weeding • Incorporation of organic matter	• Water use monitoring
HOLISTIC HERITAGE AGRICULTURAL SYSTEMS ALSO CALLED GLOBALLY-IMPORTANT AGRICULTURAL HERITAGE SYSTEMS (GIAHS)*	Cultivation approaches focused on sustainable land use systems and landscapes that have evolved through the dynamic adaptation of farming communities to their environment		• Floating/deepwater rice
INTEGRATED PEST MANAGEMENT (IPM)	Cultivation with emphasis on integrated control of insect pests and/or enhancement of natural enemies	• Cultural control • Biological control • Physical control • Resistant plant varieties • Site specific management zones (SSMZs)	
INTEGRATED FARMING SYSTEMS, I.E. RICE-FISH SYSTEMS	Cultivation integrated with fish, livestock and/or agroforestry		

ANNEX 3.
FULL STUDY LIST

SYSTEM	TITLE	FIRST AUTHOR	YEAR	JOURNAL OR SOURCE
CONSERVATION AGRICULTURE	Greenhouse gas emission from direct seeding paddy field under different rice tillage systems in central China	Ahmad *et al.*	2009	Soil and Tillage Research
CONSERVATION AGRICULTURE	Silicate fertilization in no-tillage rice farming for mitigation of methane emission and increasing rice productivity	Ali *et al.*	2009	Agriculture, Ecosystems & Environment
CONSERVATION AGRICULTURE	Zero tillage impacts in India's rice–wheat systems: A review	Erenstein *et al.*	2008	Soil and Tillage Research
CONSERVATION AGRICULTURE	Managing native and legume-fixed N in lowland rice-based cropping systems	George *et al.*	1992	Plant and Soil
CONSERVATION AGRICULTURE	Soil organic carbon sequestration as affected by tillage, crop residue, and nitrogen application in rice–wheat rotation system	Ghimire *et al.*	2011	Paddy and Water Environment
CONSERVATION AGRICULTURE	No-tillage and direct seeding for super hybrid rice production in rice-oilseed rape cropping system	Huang *et al.*	2011	European Journal of Agronomy
CONSERVATION AGRICULTURE	Evaluation of precision land leveling and double zero-till systems in the rice–wheat rotation: Water use, productivity, profitability and soil physical properties	Jat *et al.*	2009	Soil and Tillage Research
CONSERVATION AGRICULTURE	Conservation Agriculture in cereal systems of South Asia: effect on crop productivity and carbon-based sustainability index	Jat *et al.*	2011	NR
CONSERVATION AGRICULTURE	Experiences and research perspectives on sustainable development of rice-wheat cropping systems in Chengdu Plain, China	Jia-guo *et al.*	2010	Agricultural Sciences in China
CONSERVATION AGRICULTURE	Considering winter cover crop selection as green manure to control methane emission during rice cultivation in paddy soil	Kim *et al.*	2012	Agriculture, Ecosystems & Environment
CONSERVATION AGRICULTURE	Tillage in lowland rice-based cropping systems	Lal	1985	Soil Physics in Rice (IRRI book)
CONSERVATION AGRICULTURE	Conservation agriculture in Laos: Diffusion and determinants for adoption of direct seeding mulch-based cropping systems in small-holder agriculture	Lestrelin *et al.*	2011	Renewable Agriculture and Food Systems
CONSERVATION AGRICULTURE	Tillage and weed control effects on productivity of a dry seeded rice–wheat	Mishra *et al.*	2012	Soil and Tillage Research

SYSTEM	TITLE	FIRST AUTHOR	YEAR	JOURNAL OR SOURCE
CONSERVATION AGRICULTURE	Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice-wheat system in Indo Gangetic Plains of India	Nayak *et al.*	2012	Field Crops Research
CONSERVATION AGRICULTURE	Conservation agriculture on sloping lands in northern mountainous regions of Vietnam	Quoc Doanh	2008	Regional Workshop on Conservation Agriculture, Laos
CONSERVATION AGRICULTURE	Effect size and duration of recommended management practices on carbon sequestration in paddy field in Yangtze Delta Plain of China: A meta-analysis	Rui & Zhang	2010	Agriculture, Ecosystems & Environment
CONSERVATION AGRICULTURE	Perennial grasses for controlling soil erosion and run-off in rice (Oryza sativa)-greengram (Phaseolus radiatus) cropping systems	Sarma *et al.*	1995	Indian Journal of Agricultural Sciences
CONSERVATION AGRICULTURE	Effect of Interplanting with Zero Tillage and Straw Manure on Rice Growth and Rice Quality	Shi-Ping *et al.*	2007	Rice Science
HOLISTIC HERITAGE AGRICULTURE	Adoption of sustainable agricultural practices by traditional rice growers	Bonny *et al.*	2001	Journal of Tropical Agriculture
HOLISTIC HERITAGE AGRICULTURE	Integrating Fish and Azolla into Rice-Duck Farming in Asia	Cagauan *et al.*	2000	Naga, The ICLARM Quarterly
HOLISTIC HERITAGE AGRICULTURE	Traditional Rice Farming in Sri Lanka Still Viable with Climate Change	Dharmasena *et al.*	2012	IPS CLIMATEnet Blog (Climate Change Policy Network of Sri Lanka)
HOLISTIC HERITAGE AGRICULTURE	Traditional and Modern Matters on Rice Cultivation Associated with Duck	Furuno *et al.*	2009	6th International Rice-Ducks Conference
HOLISTIC HERITAGE AGRICULTURE	Effect of Integrated Rice-Duck Farming on Rice Yield, Farm Productivity, and Rice-Provisioning Ability of Farmers	Hossain *et al.*	NR	Asian Journal of Agriculture and Development
HOLISTIC HERITAGE AGRICULTURE	Traditional methods of rice cultivation and SRI in Uttarakhand Hills	Kediyal *et al.*	2009	NR
HOLISTIC HERITAGE AGRICULTURE	Production of rice and associated crops in deeply flooded areas of the Chao Phraya delta	Puckridge *et al.*	NR	NR
HOLISTIC HERITAGE AGRICULTURE	Comparative study of organic and traditional farming for sustainable rice production	Quyen *et al.*	2002	Omonrice
HOLISTIC HERITAGE AGRICULTURE	Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos	Roder *et al.*	1995	Plant and Soil
HOLISTIC HERITAGE AGRICULTURE	Response of traditional and improved upland rice cultivars to N and P fertilizer in northern Laos	Saito *et al.*	2006	Field Crops Research
HOLISTIC HERITAGE AGRICULTURE	Boro Rice: An Opportunity for Intensification	Singh *et al.*	NR	NR
HOLISTIC HERITAGE AGRICULTURE	Lowlands development in Indonesia, in the past, present, and future	Suryadi *et al.*	NR	NR

SYSTEM	TITLE	FIRST AUTHOR	YEAR	JOURNAL OR SOURCE
INTEGRATED FARMING SYSTEMS	Rice monoculture and integrated rice-fish farming in the Mekong Delta, Vietnam- economic and ecological considerations	Berg	2002	Ecological Economics
INTEGRATED FARMING SYSTEMS	Carbon sequestration and soil carbon pools in a rice–wheat cropping system: Effect of long-term use of inorganic fertilizers and organic manure	Brar *et al.*	2013	Soil and Tillage Research
INTEGRATED FARMING SYSTEMS	Soil Carbon Dynamics in Different Cropping Systems in Principal Ecoregions of Asia	Bronson *et al.*	1997	Management of Carbon Sequestration in Soil (edited book)
INTEGRATED FARMING SYSTEMS	Methane and nitrous oxide emissions from an integrated rice-fish farming system of Eastern India	Datta *et al.*	2009	Agriculture, Ecosystems & Environment
INTEGRATED FARMING SYSTEMS	Change and diversity in smallholder rice-fish systems	Dey	2012	IFPRI Discussion Paper
INTEGRATED FARMING SYSTEMS	Methane emissions and related physicochemical soil and water parameters in rice-fish systems in Bangladesh	Frei *et al.*	2007	Agriculture, Ecosystems & Environment
INTEGRATED FARMING SYSTEMS	Potentials of agroforestry and plantation systems in Indonesia for carbon stocks: an economic perspective	Ginoga	2002	ACIAR Project Working Paper
INTEGRATED FARMING SYSTEMS	Culture of fish in rice fields	Halwart & Gupta	2004	FAO Publication
INTEGRATED FARMING SYSTEMS	Rice-fish culture: feeding, growth and yield of two size classes of P. gonionotus and Oreochromis spp. In Bangladesh	Haroon & Pittman	1997	Aquaculture
INTEGRATED FARMING SYSTEMS	Rice-fish culture in China: a review	Kangmin	1988	Aquaculture
INTEGRATED FARMING SYSTEMS	Integration of elements of a farming system for sustainable weed and pest management in the tropics	Kathiresan	2007	Crop Protection
INTEGRATED FARMING SYSTEMS	Species composition, distribution and management of trees in rice paddy fields	Kosaka *et al.*	2006	Agroforestry Systems
INTEGRATED FARMING SYSTEMS	Yield performance comparison between cultures of rice cum prawn (Macrobrachium rosenbergii) and rice cum fish (Cyprinus carpio, Oreochromis niloticus) in North-Eastern Bangladesh	Mirhaj *et al.*	2013	Aquaculture
INTEGRATED FARMING SYSTEMS	Productivity enhancement through rice–fish farming using a two-stage rainwater conservation technique	Mishra & Mohanty	2004	Agricultural Water Management
INTEGRATED FARMING SYSTEMS	Studies on nitrogen cycling under different nitrogen inputs in integrated rice-fish culture in Bangladesh	Oehme *et al.*	2007	Nutrient Cycling in Agroecosystems
INTEGRATED FARMING SYSTEMS	Community-based fish culture in seasonal flood plains	Prein *et al.*	2006	in Integrated Irrigation and Aquaculture in West Africa: Concepts, Practices and Potential

SYSTEM	TITLE	FIRST AUTHOR	YEAR	JOURNAL OR SOURCE
INTEGRATED FARMING SYSTEMS	Economics of rice-fish Integrated system under organic management	Prema	2003	FAO document repository
INTEGRATED FARMING SYSTEMS	Traditional integrated farming systems and rural development: the example of rice field fisheries in Southeast Asia	Ruddle	1982	Agricultural Administration
INTEGRATED FARMING SYSTEMS	Overall effect of rice biomass and fish on the aquatic ecology of experimental rice plots	Vromant & Chau	2005	Agriculture, Ecosystems & Environment
INTEGRATED FARMING SYSTEMS	Emergy evaluation of organic rice-duck mutualism system	Xi & Qin	2009	Ecological Engineering
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in intensive irrigated rice systems of West Java, Indonesia	Abdulrachman *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in irrigated rice systems of Central Luzon, Philippines	Gines *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in irrigated rice systems of Zhejiang Province, China	Guanghuo *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	Changes in rice farmers' pest management in the Mekong Delta, Vietnam	Huan *et al.*	1999	Crop Protection
INTEGRATED PEST MANAGEMENT	Using IPM, farm incomes are boosted by growing potatoes in lowland rice	Ketelaar & Shoji	NR	FAO publication series: Stories from the field
INTEGRATED PEST MANAGEMENT	A farming systems approach to insect pest management for upland and lowland rice farmers in tropical Asia	Litsinger *et al.*	1993	NR
INTEGRATED PEST MANAGEMENT	An analysis of the labor-intensive continuous rice production system at IRRI	Morooka *et al.*	1979	IRRI Publication
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in irrigated rice systems of Tamil Nadu, India	Nagarajan *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in irrigated rice systems of Central Thailand	Satawathananont *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	Integrated management to reduce rodent damage to lowland rice crops in Indonesia	Singleton *et al.*	2005	Agriculture, Ecosystems & Environment
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in irrigated rice systems of the Red River Delta of Vietnam	Son *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	Site-specific nutrient management in irrigated rice systems of the Mekong Delta of Vietnam	Tan *et al.*	2004	IRRI Publication
INTEGRATED PEST MANAGEMENT	IPM Farmer Field Schools: A synthesis of 25 impact evaluations	van den Berg	2004	FAO Publication
INTEGRATED PEST MANAGEMENT	Managing Tropical Rice Pests Through Conservation of Generalist Natural Enemies and Alternative Prey	Settle *et al.*	1996	Ecology

SYSTEM	TITLE	FIRST AUTHOR	YEAR	JOURNAL OR SOURCE
ORGANIC AGRICULTURE	Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield	Asai *et al.*	2009	Field Crops Research
ORGANIC AGRICULTURE	Greenhouse gas emission in relation to labile soil C, N pools and functional microbial diversity as influenced by 39 years long-term fertilizer management in tropical rice	Bhattacharyya *et al.*	2013	Soil and Tillage Research
ORGANIC AGRICULTURE	Evaluation of different organic manures on soil properties, growth and yield of rice and maize under rice/maize crop rotation	De Silva	2005	Annals of the Sri Lanka Department of Agriculture
ORGANIC AGRICULTURE	Organic amendments influence soil quality and carbon sequestration in the Indo-Gangetic plains of India	Ghosh *et al.*	2012	Agriculture, Ecosystems & Environment
ORGANIC AGRICULTURE	Effect of different fertilizer treatments on quantity of soil microbes and structure of ammonium oxidizing bacterial community in a calcareous purple paddy soil	Gu *et al.*	2008	Agricultural Sciences in China
ORGANIC AGRICULTURE	Organic carbon fractions affected by long-term fertilization in a subtropical paddy soil	Huang *et al.*	2010	Nutrient Cycling in Agroecosystems
ORGANIC AGRICULTURE	Effect of organic rice farming on planthoppers 4. Reproduction of the white backed planthopper, Sogatella furcifera Horvath (Homoptera: Deiphacidae)	Kajimura *et al.*	1995	Research on Population Ecology
ORGANIC AGRICULTURE	A case study of organic rice production system and soil carbon storage in West Java, Indonesia	Komatsuzaki	2009	Japanese Journal of Farm Work Research
ORGANIC AGRICULTURE	Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice–wheat and maize–wheat systems	Kukal & Benbi	2009	Soil and Tillage Research
ORGANIC AGRICULTURE	Rice husk biochar for rice based cropping system in acid soil 1. The characteristics of rice husk biochar and Its Influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia	Masulili & Utomo	2010	Journal of Agriculture Science
ORGANIC AGRICULTURE	Evaluating the benefits of organic farming in rice agroecosystems in the Philippines	Mendoza	2004	Journal of Sustainable Agriculture
ORGANIC AGRICULTURE	Combined inorganic/organic fertilization enhances N efficiency and increases rice productivity through organic carbon accumulation in a rice paddy from the Tai Lake region, China	Pan *et al.*	2009	Agriculture, Ecosystems & Environment
ORGANIC AGRICULTURE	Planted legume fallows reduce weeds and increase soil N and P contents but not upland rice yields	Saito *et al.*	2008	Agroforestry Systems
ORGANIC AGRICULTURE	Trends in productivity and nutrient dynamics under improved soil nutrient management techniques for rice in the rainfed lowlands of Cambodia	Seng *et al.*	2010	World Congress of Soil Science

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ORGANIC AGRICULTURE	Integrated use of organic manures and inorganic fertilizers for the cultivation of lowland rice in Pakistan	Zia *et al.*	1992	Soil Science and Plant Nutrition
ORGANIC AGRICULTURE	Soil aggregation and distribution of carbon and nitrogen in different fractions under long-term application of compost in rice–wheat system	Sodhi *et al.*	2009	Soil and Tillage Research
ORGANIC AGRICULTURE	Effect of organic farming on management of rice brown planthopper	Sujeetha *et al.*	2003	International Rice Research Notes
ORGANIC AGRICULTURE	Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China	Zhang *et al.*	2010	Agriculture, Ecosystems & Environment
ORGANIC AGRICULTURE	Organic amendments influence soil organic carbon pools and rice–wheat productivity	Majumder *et al.*	2008	Soil Science Society of America Journal
ORGANIC AGRICULTURE	Seasonal variation of methane flux from coastal saline rice field with the application of different organic manures	Datta *et al.*	2013	Atmospheric Environment
SYSTEM OF RICE INTENSIFICATION (SRI)	System of Rice Intensification as a resource-conserving methodology: Contributing to food security in an era of climate change	Adhikari *et al.*	2010	SATSA Mukhapatra - Annual Technical Issue
SYSTEM OF RICE INTENSIFICATION (SRI)	A review of studies on SRI effects on beneficial organisms in rice soil rhizospheres	Anas *et al.*	2011	Paddy and Water Environment
SYSTEM OF RICE INTENSIFICATION (SRI)	Adaptation of the System of Rice Intensification in Sri Lanka	Batuwitage *et al.*	2002	Cornell International Institute for Food, Agriculture and Development
SYSTEM OF RICE INTENSIFICATION (SRI)	Water use of alternately submerged and nonsubmerged irrigated lowland rice	Belder *et al.*	2002	Water-wise rice production (Bouman *et al.*, eds)
SYSTEM OF RICE INTENSIFICATION (SRI)	Assessment of System of Rice Intensification (SRI) and conventional practices under organic and inorganic management in Japan	Champagain *et al.*	2011	Rice Science
SYSTEM OF RICE INTENSIFICATION (SRI)	Yield and water productivity of rice–wheat on raised beds at New Delhi, India	Choudhury *et al.*	2007	Field Crops Research
SYSTEM OF RICE INTENSIFICATION (SRI)	System of Rice Intensification and Irrigated transplanted rice: Effect on crop water productivity	Choudhury *et al.*	2007	Journal of the Indian Society of Soil Science
SYSTEM OF RICE INTENSIFICATION (SRI)	System of Rice Intensification and conventional rice culture: A demonstration trial at VSU campus, Baybay city, Leyte, Philippines	de la Rosa *et al.*	2006	NR
SYSTEM OF RICE INTENSIFICATION (SRI)	Effect of conventional, SRI and modified water management on growth, yield and water productivity of direct-seeded and transplanted rice in central Thailand	Ginigaddara *et al.*	2009	Australian Journal of Crop Science
SYSTEM OF RICE INTENSIFICATION (SRI)	SRI on-farm trials in Eastern Visayas	Leyte State University, Cornell University	NR	NR

SYSTEM	TITLE	FIRST AUTHOR	YEAR	JOURNAL OR SOURCE
SYSTEM OF RICE INTENSIFICATION (SRI)	Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics	Lin *et al.*	2011	Paddy and Water Environment
SYSTEM OF RICE INTENSIFICATION (SRI)	Effect of mechanical planting and weeding on yield, water-use efficiency and cost of production under modified system of rice intensification	Mohapatra *et al.*	2012	Indian Journal of Agricultural Sciences
SYSTEM OF RICE INTENSIFICATION (SRI)	An evaluation of the system of rice intensification (SRI) in Eastern Indonesia for its potential to save water while increasing productivity and profitability	Sato *et al.*	2006	Paper for International Dialogue on Rice and Water
SYSTEM OF RICE INTENSIFICATION (SRI)	Opportunities for water saving with higher yield from the system of rice intensification	Satyanarayana *et al.*	2007	Irrigation Science
SYSTEM OF RICE INTENSIFICATION (SRI)	Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan	Sharif *et al.*	2011	Paddy and Water Environment
SYSTEM OF RICE INTENSIFICATION (SRI)	SRI in Laos	Shimazaki *et al.*	2011	NR
SYSTEM OF RICE INTENSIFICATION (SRI)	Intermittent irrigation in system of rice intensification potential as an adaptation and mitigation option of negative impacts of rice cultivation in irrigated paddy fields	Susi *et al.*	2010	Proceedings of the 6th Asian Regional Conference of International Commission on Irrigation and Drainage
SYSTEM OF RICE INTENSIFICATION (SRI)	Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance	Thakur *et al.*	2011	Paddy and Water Environment
SYSTEM OF RICE INTENSIFICATION (SRI)	Effects of SRI practices on hybrid rice performance in Tamil Nadu, India	Thiyagarajan *et al.*	2002	Water-wise rice production (Bouman *et al.*, eds)
SYSTEM OF RICE INTENSIFICATION (SRI)	Influence of System of Rice Intensification on yield, water use and economics through farmers' participatory approach	Veeraputhiran *et al.*	2012	Madras Agricultural Journal
SYSTEM OF RICE INTENSIFICATION (SRI)	Characterization of methane emissions from rice fields in Asia. III. Mitigation options and future research needs	Wassman *et al.*	2000	Nutrient Cycling in Agroecosystems
SYSTEM OF RICE INTENSIFICATION (SRI)	Comparisons of yield, water use efficiency, and soil microbial biomass as affected by the System of Rice Intensification	Zhao *et al.*	2010	Communications in Soil Science and Plant Analysis

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THE MULTIPLE GOODS AND SERVICES
OF ASIAN RICE PRODUCTION SYSTEMS

As a contribution to the knowledge base on the capacity of rice ecosystems to produce multiple benefits, the present review was undertaken in the context of FAO's Regional Rice Initiative in Asia in 2013. FAO coordinated a process with regional and national experts in Asia to identify emerging holistic systems in rice production, review key integral practices, and assess their documented impacts on both yields and provisioning of ecosystem services. In the majority of cases, from the literature review undertaken it is evident that yields of rice production systems can benefit from the systems that are managed to generate other ecosystem services. The analysis in this document showcases an example of how FAO's Strategic Framework can be implemented, particularly through its Strategic Objective 2 – to *increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner*.

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