The “system of rice intensification” (SRI); results from exploratory field research in Ivory Coast: further research requirements and prospects for adaptation to divers agro-ecosystems

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Abstract

The *system of rice intensification* (SRI) evolved in Madagascar during the eighties and nineties, and has been credited with spectacular grain yields ranging from 6 to 15 tons/ha. Subsequently promising on-station and on-farm tests have been conducted in several Asian, Latin American and African countries. This low external input technology for rice is, however, surrounded by many fundamental research questions in the bio-physical and agro-ecological domains that may well be relevant to other crops as well. Because, SRI is not adequately understood by scientists, also its introduction at farmer levels is handicapped.

From 1999 till 2001 WARDA conducted a series of exploratory field experiments on its farm near Bouake in Ivory Coast. Based on the results, this article identifies some of the major crop production factors (time, space, organic materials) and issues related to *synergies* and *synchronies* that merit further research efforts in support of the development of environment-friendly technologies for the small resource-poor farmer target group.

Keywords: rice production systems; low external input technologies

1. Introduction

The “System of Rice Intensification” (SRI) originated in Madagascar (the Antsirabe region at 1500m altitude) in the 1980s. The system was brought to WARDA’s attention by the Cornell International Institute for Food, Agriculture and Development (CIIFAD) in 1997.

In Madagascar the system has been adopted by a fair number of small farmers, who have obtained impressive yields ranging from 6 to 15 tons/ha as compared with the 2 to 3 tons with the regular practices. Also elsewhere, notably in Asia (China, Indonesia, Sri Lanka and Bangladesh: see Uphoff, et al., 2002) the system has been tested with promising results. There are, however, also reports from Madagascar about farmers having recently abandoned the practice (Moser and Barrett, 2002). SRI is still surrounded by fundamental questions, not least in the agro-ecological and bio-physical domains. Therefore, the explanations for adoption and/or dis-adoption are not very convincing; likewise an easy transfer of the technology is handicapped by a lack of knowledge about the processes and mechanisms involved. On the other hand, scientists (national and international) have been rather reluctant to look into the fundamental questions raised by SRI, many of which seem to go counter to conventional knowledge and concepts. So with a few exceptions most testing of SRI has been done primarily through on-farm, participatory methods that logically focus on “grain yield” and “labour requirements” as the key evaluation parameters (see Uphoff, et al., 2002). As a result most of these tests contribute little to the more fundamental understanding of the bio-physical and agro-ecological processes involved.

In Madagascar, the high yields were realised on rather unfertile soils and without large quantities of external inputs like agricultural chemicals. The SRI method presumably compensates for this absence of external inputs through a number of carefully timed and implemented practices: very early transplanting; low plant density of single plants (no clumps); regular weeding/soil cultivation, greatly reduced irrigation rates aimed at keeping the soil moist during the vegetative growth phase instead of flooded, and liberal applications of organic manures (e.g. compost).

An initial review of the SRI method (Stoop, et al., 2001) concluded that the responses might result from synergistic effects between a number of cultivation practices. When carefully implemented and adapted to a particular agro-ecological situation these practices could prove to be of a general and widespread significance notably for rice, but also for other crops, cereals in particular. The method would allow small farmers to economise greatly on the use of irrigation water and other costly, often not even available inputs, including “improved” seeds and agricultural chemicals, and yet obtain high yields. The potential benefits include production as well as economic and environmental aspects in particular for the situations under which resource-poor, small farmers have to operate.

Starting in the 1999 rainy season WARDA initiated several exploratory trials at its experimental farm near Bouake in Ivory Coast to verify the significance of the Madagascar results for the West African rice growing conditions. This exploratory research has led to some unexpected results that question several conventional practices, but also some of the initially identified –presumably critical- components of the SRI practice. Moreover, the preliminary results point to numerous possibilities to grow and to adapt rice cultivation practices in response to local agro-ecological and socio-economic constraints.

2. Background and research hypotheses

The predominant concerns of both international and national agricultural research institutions have tended to be with *intensification* through the increased use of external inputs (mineral fertilisers and pesticides) in combination with high plant densities and improved, high yielding cultivars with wide adaptation. Most of these modern varieties are short cycle, photo-insensitive (100 to 120 days), as compared with the mostly photosensitive (140 to 150 days) local varieties used by many small, resource-poor farmers. Through the early maturing varieties, multiple cropping systems have become possible in some agro-ecologies (e.g. China, Indonesia, etc). For other ecologies (e.g. the semi-arid parts of Western and Eastern Africa) such varieties may help to escape the risks of early and late season droughts associated with the reduced and/or changing rainfall patterns (Mikkelsen and De Datta; 1991). Over the past decade, expectations have been raised further that yields could be increased and/or stabilised through biotechnology by the introduction of genes through genetic manipulation. As a result yield losses from weeds, pests and diseases could be reduced, but also grain quality raised, as for vitamin A in "golden rice", while at the same time the use of environmentally harmful chemicals could be reduced (Charles, 2001).

The resulting modern and intensified cropping systems are highly standardised. At first sight these appear commercially very attractive because of the inherent "scale effects" and the relative ease of dissemination through the common "transfer of technology" extension programs. Certainly in sub-saharan Africa and for resource-poor farmers, such standardised production and transfer systems, however, largely bypass the widespread problem of on-farm diversity and variability in bio-physical and in socio-economic conditions, but also fail to exploit effectively the *Genotype x Environment (G x E) interaction*. This interaction is the backbone of most local farming systems and is based on the wide array of local cultivars that normally have been available to subsistence farmers (Richards, 1985; Tripp, 2001). On the other hand, external inputs are often too costly and/or not even available locally to the majority of small, resource-poor farmers. For this large and widespread group of farmers other practical options are badly required in dealing with the issues of food security and poverty alleviation (see also Stoop, 2002).

The initial review of SRI (Stoop, et al., 2002) concluded that SRI involves all the basic crop production factors: *time, space, water, plant nutrients* and *labour*. Research into SRI therefore requires a holistic perspective instead of the technological component emphasis that prevails in much conventional research. The latter largely bypasses in particular some major synergies between production factors that can be of large practical relevance for small farmers. Obviously this presents some special challenges in terms of research methodology and its field implementation (Giller; 2002).

Two major plant features: *tillering* and *root development* were postulated to be at the basis of the extraordinary yields under SRI. For these two features to express themselves fully, the roles of the two basic production factors: *time* and *space* need to be rethought. These two factors, being to some extent non-commercial, have received inadequate research attention in the past. Both are largely under the control of the individual farmer by his choice "when" to seed and plant his crop(s) and "how" to space the plants in terms of the number of plants per hill and the distances between hills. Also the seed rates for nursery seeding or for direct seeding in the field need to be considered.

The "time"(seeding date) factor has been well-documented in terms of its direct effects on the grain yields for many crops; moreover it will influence indirectly the calendar for farm operations (labour) during the entire subsequent season. The "space" factor applies to plant population and plant spacing, and thereby affects the extent of inter- and intra-plant competition. As such the spacing between hills and the number of seedlings per hill are likely to have large implications first for the early as well as late development of individual plants and their root systems, but secondly will also affect the extent to which weeds will be a problem. A basis for this rethinking with respect to rice was provided by two concepts elaborated by Nemeto et al. (1995):

- the *phyllochron* (a periodicity in plant growth expressed as a number of days to complete a unit of growth), and
- the *phytomer* (the unit of plant growth, consisting of a leaf and subtending internode with a tiller bud at its base).

These two concepts contribute considerably in clarifying the dynamics of plant growth and how shortening the phyllochron will accelerate growth, thereby increasing tillering and root development. The implications of these concepts for SRI were discussed in an earlier article (Stoop, et al., 2001), and are particularly relevant in managing the production factors *time* and *space*, starting from the earliest stages of crop establishment and development.

The above considerations have led to the formulation of three hypotheses about the possible mechanisms and processes, that might be responsible for the high yields obtained under SRI:

- the early vegetative development of the rice plant, during the first 4 to 6 weeks following seeding (involving the nursery and transplanting operations) in establishing a rice crop, is of far greater significance to the subsequent grain yield than has been assumed so far,
- there will be large differences between rice cultivars in their specific capabilities to capitalise on the crop growth conditions associated with the conventional production practices as compared with those provided under SRI; it is postulated that to realise the SRI potential, the production factor *"time"* to develop the extensive tillering and the profuse root system is critical, as is the factor *"space"* in optimising the intra-rice plant competition,
- the profuse root system developed under SRI will increase the efficiency with which low concentrations of soil nutrients, derived from the mineralisation of soil organic matter and from the soil biota involved in that process (including possible contributions from increased biological nitrogen fixation) can be absorbed by the rice plant.

The research reported in this paper will deal with the first two hypotheses; the third hypothesis will be discussed in the light of the reported results. Translated into practical agronomic terms this research deals with:

- Seedling development in the nursery under the influence of different seed rates (space factor),
- Seedling age at transplanting and its impact on early plant development, notably tillering (time factor), and
- Spacing between individual seedlings after transplanting and the use of "clumps" of several seedlings/hill versus a single seedling/hill (space factor)

As mentioned already the extensive tillering and root development are crucial elements of SRI. The tillering ability is genetically determined and positively correlated to maturity; it is also greatly affected by agronomic management practices like plant density and spacing (De Datta, 1981). If SRI is to realise its potential, agronomic management must seek to maximise the tillering and rooting process per plant supposedly by optimising the conditions for early plant development through early transplanting, single plants, wide spacing and regular early weeding. These measures -that minimise inter- and intra specific competition- are combined with soil water management practices, that create moist, aerated soil conditions through an irrigation regime of intermittent, greatly reduced rates. In comparison with the continuously flooded situation of conventional systems, the dynamics of organic matter decomposition will be substantially altered. With it, the activity of soil biota, and thereby the nutrient mineralisation processes for nitrogen, but also for other elements (for phosphorus see Turner and Haygarth, 2001) will be changed. Moreover, these conditions will greatly affect the development and functioning of the rice root system.

3. Materials and Methods

The initial research objective of WARDA was to validate, through an exploratory experiment, the results obtained with SRI in Madagascar and compare it with the conventional systems for rice cultivation in West Africa (WARDA, 1999). Experiments were conducted at the WARDA farm in M'be near Bouake in Ivory Coast on typical lowlands and during both the dry (full irrigation) and wet seasons. The climatic conditions at the M'be farm (about 300m above sea level) are presented in table 1 and obviously are very different from those in Madagascar in the Antsirabe region at an elevation of 1500 m. Likewise the soils are very different: very low fertility, sandy soils in Madagascar, and the rather rich lowland clay soils of the M'be farm (40% clay; 1.0% organic carbon; C/N ratio of 12; 10 ppm available P (Olsen); CEC:15 me/100g: Hakkeling, et al., 1989)

Table 1: Climatic data for average monthly rainfall and 75% probability, and mean monthly temperatures (30 year averages) as recorded for Bouake.

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rainf. (av.)	11	47	86	126	134	156	118	98	183	139	32	16	1146
Rainf.(75% prob)	0	11	63	105	105	90	48	57	118	82	9	0	
Av. Temp.(C.)	26.2	27.3	26.9	26.5	25.8	24.4	23.5	23.3	23.7	24.3	24.9	25.1	

After a first, exploratory attempt in 1999, it became obvious that a simple comparison between the conventional irrigated and the SRI practice is hardly viable. The design and implementation of field research -that would permit to confirm or to discount the SRI potential- is complicated by the large number of factors, as well as the wide range of management options for each individual factor. The unavoidable confounding between the many production factors involved in a comparison between two different production systems, but also its confounding with local environmental factors (temperature; rainfall and the resulting flooding or drought) explains the complexity of this type of field research. After the initial attempts during the 1999 and 2000 wet seasons (WS) that compared the conventional, fully irrigated system with SRI (intermittent and reduced rates of irrigation and no nitrogen topdressings), therefore a second series of exploratory trials was designed in 2001 to widen the scope of the investigation. Two complementary types of experiments were conducted:

- *agronomic component* trials in which some of the major factors in SRI are tested using single replications of factorial designs to improve our understanding about the specific adaptation of contrasting varieties and cultural practices under an SRI type system (wide spacing between transplants, reduced irrigation/no flooding)
- *systems trials* contrasting the “conventional package of practices” (as used by WARDA at its M’be farm) with the “SRI package of practices”. The details for both “packages/methods” are summarised in Table 2. In these trials the various agronomic components are necessarily confounded to keep the experiments at a manageable size; the fertiliser regime has been standardised across the two “packages”.

Table 2: Comparison between the major agronomic practices for SRI and conventional irrigated rice used in WARDA trials conducted during the 2001 DS and WS.

Production system	Age of seedlings	Transplants /hill	Spacing of hills	Transplants per m^2	Water management	Fertility management (kg/ha)	Weed managemen t
Conventional	20-30 days	3	20x20 or 30x15 cm;	80 to 100	Continuous flooding	40N40P40Kbasal + 50Ntop.	2 rounds
SRI	8-15 days	1	30x30 cm	11	Moist soil; intermittent. drying	Same	3 to 4 rounds

The two *agronomic component* trials conducted during the 2001 dry and wet seasons (see table 3) looked at factors that presumably affect the rate of tillering most profoundly: rice varieties, the seed rate used in the nursery, the seedling age at transplanting, and the method of transplanting (as single seedlings or in clumps of three plants/hill). These factorial trials were conducted to clarify the impact of the variables on the vegetative development of the plants under SRI management (see Table 2) For these studies, observations and measurements included: plant height at flowering, number of tillers/hill at various intervals, and productive panicles/hill at harvest.

By contrast the *systems* trials which also used factorial designs, are complicated by the considerable internal confounding between the practices that together make up the “package of practices” factor (conventional and SRI). For the initial exploratory experiments (1999 and 2000 WS) randomised complete blocks with 3 or 4 replications were used. The 2001 DS and WS trials employed a modified design by confounding the “package of practices” (conventional irrigated and SRI) with major blocks to eliminate the substantial border effects that resulted from the water seepage between adjacent plots in the earlier trials. The superimposed factorial treatment combinations (rice varieties, seedling age at transplanting, and plant density/spacing) were replicated four times within each major block using a randomised block design. This set-up permitted separate statistical analyses per major block (= production method: M), as well as a combined statistical analysis, comparing the two production methods (= “packages of practices”) for a single replicate by using the higher order interactions as error term.

All the experiments were conducted with several contrasting varieties that ranged from early maturing (hybrids) to intermediate and late maturing, tall cultivars. Individual plants, representing different treatments in the *systems* trials were uprooted at the critical growth phase near 50% flowering to evaluate root development and the general appearances of the root systems. A summary of the trials conducted is presented in Table 3.

Table 3: Summary of SRI experiments conducted on lowlands at WARDA during the 1999 and 2000 wet seasons (WS) and during the 2001 dry (DS) and wet seasons; all experiments have used factorial designs.

Year	**Season**	**Type of trial**	**Factorial variables[1)] and levels**	**Reps**
1999[1)]	WS	Systems	Methods (2) x Varieties (2) x Seeding dates (2)	4
2000[1)]	WS	Systems	Methods (2) x Varieties (4) x Plant densities (2)	3
2001[2)]	DS	Component	Varieties (9) x Plant densities (2) x Date/age of transplant (2)	1
2001[2)]	WS	Component	Varieties (6) x Nursery seed rate (2) x Date/age of transplant (2)	1
2001[1)]	DS	Systems	Methods (2) x Varieties (4) x Plant densities (2) (modified design)	4 (1)
2001[1)]	WS	Systems	Methods (2) x Varieties (4) x Age of transplant (2) (modified design)	4 (1)

1) The "method" factor in the *systems* trials covers the comparison between the "conventional package of practices" (for lowland irrigated/rainfed rice systems) and the "SRI package of practices"; as a result the "Method" factor involves a considerable degree of internal confounding (see table 2).
2) The two *agronomic component* trials of non-confounded treatments are aimed at clarifying the impact of the early vegetative development in the nursery and following transplanting on the subsequent vegetative development.

4. Results

The results obtained in 1999 from the first exploratory trial indicated that varietal adaptation to either one of the two systems and early crop management would be key issues in determining the number of fertile panicles and thus eventually grain yields. The subsequent investigation was based on a series of trials that were modified and adjusted during the course of the research with respect to the optimum experimental design and the combinations of variables. For the *systems* trials the experimental designs and the field implementation techniques were adjusted to better cope with the confounding problems between the major agronomic management factors (irrigation regime; mineral fertiliser use in particular the N topdressing; transplanting technique and spacing). Also the "spacing" factor in the initial trial was replaced by a "seedling age" factor in the WS 2001 trial (tables 2 and 3).

4.1. Agronomic component studies

In this category two experiments with non-confounded treatments were conducted. The first looked at seedling development in the nursery by recording seedling heights and weights over a 6-week period in combination with the subsequent impact of delayed seedling transplanting (2001 WS) on the vegetative development. The second trial studied the impact of transplanting density (1 or 3 seedlings/hill) in combination with delayed transplanting (2001 DS). Both experiments used the wide spacing and reduced irrigation regime prescribed for the SRI practice. Results for the first trial are presented in figure 1 (seedling development) and in table 4, and for the second trial in table 5.

Table 4: Impact of nursery management (seed rate) on the subsequent plant development following early (10 days) and late (30 days) transplanting.

Treatments	Plant characteristics Tillers/hill at flowering	Panicles/hill at harvest	Plant height (cm)	Days to 50% flowering
Varieties (V)	NS	**	**	**
WAB 450-IBP-65-4	17.4	7.6	109	98
Bouake 189	22.8	14.0	106	115
WITA 12	19.5	12.6	110	118
Suakoko 8	26.3	15.8	145	143
WITA 7	23.8	11.9	104	109
IR 22-107-19-2-1	19.4	14.4	111	116
Nursery Seed Rates (S)	NS	NS	*	NS
S1: (20g/m)	22.7	12.5	111	116
S2: (4g/m)	20.4	13.0	117	116
Seedling age (A)	NS	*	NS	**
A1: 10 days	23.2	11.9	115	111
A2: 30 days	19.9	13.7	113	121
Signif. Interactions	NS	NS	VxA*	NS
C.V.(%)	20.1	12.3	4.8	3.4

Results: the nursery measurements (seedling height; seedling weight) show some consistent differences in response to the seed rate factor over the five weeks monitoring period (fig. 1). While height and weight are always superior for the low seed rate (S2), the major divergence between the two curves only occurs after the first two weeks; it is most pronounced for seedling weights. With an extended period in the nursery, the seedling development rate in the high seed rate plot will be significantly retarded over that of the low seed rate.. Thus it may be postulated that by drastically lowering the nursery seed rate, the early transplanting date (as recommended for SRI), will become less critical. This is a potentially important practical result for farmers who have to cope with unpredictable, early season rainfed conditions that interfere seriously with optimally planning and precisely timing their transplanting operations.

The above conclusion appears to be confirmed by the results in the 2nd phase of the experiment: while the impact of nursery seed rate remains non-significant (except for plant height), seedling age at transplanting (10 or 30 days) did affect significantly the number of panicles/hill (see Table 4). More importantly, the effect of a delay in transplanting (by 20 days) on the vegetative development of the plant has caused a significant increase by 10 days in the length of the vegetative growth period, thereby possibly explaining the effect of a significantly increased number of panicles/hill. Similar effects were recorded earlier by Herrera and Zandstra (1980), but also in the subsequent 2001 WS *systems* trial that contrasted in addition the effect of intermittent (SRI) and full irrigation practices (see section 4.2.). While the increase in vegetative growth period has led to an increased number of panicles/hill at harvest, a large proportion of the tillers present at flowering remains non-productive (see also next trial).

Highly significant differences between varieties could already be recorded from the nursery measurements, but also after transplanting and due to the delay in transplanting. In that respect the late maturing Suakoko 8 appears to have the greatest potential to overcome unfavourable early growth conditions.

The second trial compared 9 varieties (early, intermediate and late maturing; rainfed and irrigated types) that were transplanted after 15 or 30 days in the nursery, and as single plants or as clumps of 3 plants/hill. A single replicate of a 9 x 2 x 2 factorial was used to make a preliminary evaluation of the vegetative development features mainly in terms of tillering. Results are presented in table 5.

Table 5: (2000 DS). Exploratory nursery/transplanting trial: summary of results

		Plant characteristics		
Treatments	**Maturity type**	**Tillers/ hill at 45 days**	**Panicles/ hill at harvest**	**Pl height (cm)**
Varieties (V)		**	**	**
WITA7	intermediate	20.6	19.8	99
WAB 326-B-B-2-H5	early	14.0	12.4	110
WAB 176-8-HB	early	8.0	11.7	97
IDSA 78	early	10.6	14.0	85
WITA 12	intermediate	23.0	26.8	131
IDSA 6	early	11.6	13.7	96
WAB 337-B-B-13-H3	late	20.2	19.7	128
FARO 8	late	25.8	16.7	144
IR 22-107-19-2-1	intermediate	20.9	22.5	115
Transplanting method (M)		**	**	NS
3 pl/hill		19.7	18.9	112
1 pl/hill		14.6	16.0	111
Date of transplanting/seedling age (D)		**	**	**
15 days		21.6	20.0	117
30 days		12.7	14.9	107
Interactions				
V x M		NS	NS	NS
V x D		NS	NS	**
M x D		NS	NS	NS
CV (%)		16.6	14.0	1.8

The limited data recorded demonstrate several vegetative plant characteristics and features that are of great relevance to the SRI practice. Notably:

- There are large and highly significant differences between the 9 varieties with respect to “early tillering”, “number of panicles at harvest” and “plant height” (at flowering). Moreover for the early transplanting treatment at 1 plant/hill the number of tillers after 60 days ranged from only 11 and 13 for WAB 176-8-HB and IDSA 78 respectively (early maturing materials) to 54 for the late maturing WAB 337-B-B-13-H3;
- Low tillering rates are associated with early maturing, and short straw varieties; high tillering rates tend to be associated mostly with full-season and tall varieties, although some of the intermediate materials also tiller profusely,
- From the tillers present at flowering only about half tend to produce a panicle at harvest,
- When transplanted early (15 days old) the single seedling/hill manages to catch up with the clump of 3 plants/hill and produce an equal number of larger panicles (see next experiment),
- When transplanting is delayed to 30 days after seeding, the plants will no, longer catch up in tillering, nor in plant height. The highly significant interaction “Variety x Seedling age” for height indicates that some varieties in particular the late and some intermediate materials are better able to compensate for delayed transplanting than are the early varieties.

The overall conclusion from these data is that there exist major differences between varieties in their potential to respond to an SRI type cropping system, i.e. there will be important “variety x system” interactions. Secondly, the rice plant appears to have a considerable capacity through tillering and through an extension of the vegetative growth period, to compensate for delayed transplanting. These features can be exploited in practical ways by increasing the transplanting density and/or the number of seedlings/hill to two as the age of the nursery seedlings increases. A similar effect is reported by Makarim, et al. (2002) and was also observed as commonly practised by farmers in the vicinity of the WARDA M’be station (Defoer; pers. comm.). In addition negative effects of delayed transplanting can be minimised further by using greatly reduced seed rates in the nursery (see previous experiment).

Although this was not studied in the present trials, it is likely that panicle size (grains/panicle), grain size, and the proportion of tillers at flowering that develops a panicle, will be negatively affected by delayed transplanting. Consequently the overall resource use efficiency (for water and nutrients) will be reduced.

4.2. Systems studies

In exploring the SRI potential WARDA has focussed initially on “systems comparisons”. The exploratory (factorial) experiments conducted during the 1999 and 2000 wet seasons (see table 3) permitted to improve the experimental design and layout, and to gain experience in the practicalities of SRI field implementation, as well as to draw some initial conclusions. The initial problems with water management and absence of mineral fertilisation under SRI, resulted in the superiority of the conventional irrigated system, outyielding SRI by 48% and 21% (both HS) in respectively the 1999 and 2000 wet season trials. However, in both cases the effects of *varieties* and of the interactions *varieties x systems* turned out statistically significant for several major plant characteristics. Based on the 1999 and 2000 experiences, the 2000 WS *systems* trial was redesigned and re-run during the 2001 DS; results are presented in table 6, and data summaries are compared with the 2000 WS trial results in table 7.

Table 6: Summary of results from the 2001 DS experiment comparing the conventional Irrigated system with SRI for 4 varieties planted at two spacings

	Crop/grain characteristics									
Treatments	**Grain yield (t/ha)**		**Days to 50 % flowering**		**Height (cm)**		**Panicles/hill**		**1000 grain weigh (g)**	
Method/systems (m):	NS		NS		**		NS		**	
Conv. Irrigated	4.0		114		121		11.4		25.2	
SRI	3.7		115		111		11.3		27.2	
	Conv.Ir.	SRI	Conv.Ir.	SRI	Conv.Ir.	SRI	Conv.Ir.	SRI	Conv.Ir	SRI
Varieties (V)	**	**	**	**	**	**	**	**	**	**
WAB 450-IBP-65-4	3.6	2.6	108	104	110	99	7.4	7.2	26.3	29.3
Bouake 189	6.1	4.1	113	115	111	101	11.0	13.2	27.4	30.1
Wita 12	3.6	4.0	111	114	122	116	11.8	11.2	26.0	27.4
Suakoko 8	2.8	4.1	124	128	141	128	15.2	13.6	21.2	21.3
Hill spacing (S)	NS	NS	NS	NS	NS	NS	**	**	NS	NS
30 x 30	4.0	3.7	114	116	120	111	14.7	14.4	25.1	27.1
30 x 15	4.0	3.7	113	115	121	110	8.0	8.2	25.2	27.2
Interactions										
V x S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V x M	**		**		*		*		NS	
M x S	NS		NS		NS		NS		NS	
VxMxS	NS		NS		NS		NS		NS	
C.V. (%) method blocks	24.3	21.4	4.0	1.8	7.1	3.9	19.3	18.3	6.4	10.4
C.V. (%) Combined analysis	23.0		3.1		5.9		18.8		8.8	

* Significance at 5% level
** Significance at 1% level
NS Non-significant

Results

For the WS 2000 trial the grain yield difference has been 21% (both HS) in favour of the "fully irrigated" system; in DS 2001 the difference was reduced to 8% (NS). This narrowing of the yield gap between the two systems undoubtedly should be attributed to the improvements made in the experimental design that permitted a better control over the water management effects, as well as standardising the fertiliser regime. In spite of these adjustments some typical responses to SRI in terms of plant characteristics were recorded in both trials:

- SRI plants have been shorter; the tall cultivar Suakoko 8 therefore lodges only in the "fully irrigated system".
- Total bio-mass produced was reduced under SRI,
- The vegetative growth cycle (till flowering) in WS 2000 was increased by about one week under SRI,
- The total number of panicles harvested/hill tends to be the same for SRI (1 plant/hill) as for the irrigated system (3 plants/hill),
- In neither system does the increase in plant population have significant effects on grain yield or on other major plant and grain characteristics, except for the the number of panicles/hill. Evenso the increased number of harvested panicles/hill under low density compensates almost completely for the reduced number of panicles/hill under a plant density that is twice as high

The significant interactions of "Method x Variety", "Density x Variety" and "Method x Density x Variety" for grain yield reflects the specific adaptation of some varieties, like the cultivars WAB450-IBP-65-4 and WITA 12 (occasionally Bouake 189), to fully irrigated and high plant density conditions of conventional production systems. However, the full-season, tall Suakoko 8 generally favours the SRI conditions.

Table 7a and b: Summary of major results: "Systems comparisons" for WS 2000 and DS 2001

	WS 2000			**DS 2001**		
Grain yields (ton/ha)	**Irrigated**	**SRI**		**Irrigated**	**SRI**	
Varieties (grain yields: ton/ha)						
WAB 450-1BP65-4	3.5	2.9		3.6	2.6	
Bouaké 189	5.2	4.6		6.1	4.1	
WITA12	5.2	3.5		3.6	4.0	
Suakoko 8	3.8	3.7		2.8	4.1	
Crop/plant characteristics						
Grain yield (ton/ha)	4.4	3.7	(HS)	4.0	3.7	(NS)
Bio mass	8.5	7.1	(HS)	6.1	4.6	(HS)
Nb. of days to 50% flowering	84	90	(HS)	114	115	(NS)
Plant height (cm)	122	115	(HS)	121	111	(HS)
Panicles/hill	14.4	11.7	(HS)	11.4	11.5	(NS)
1000 grain weight	25.5	25.1	(S)	25.2	27.2	(HS)
Harvest Index	0.52	0.52	(NS)	0.36	0.45	(S)

The previous trials (WS 2000 and DS 2001) investigated the impact of intra rice plant competition by comparing two plant densities/spacings. The other critical factor in realising the potential of SRI appears to be **the age of the transplanted seedling**. This factor was studied by modifying the previous trial and replacing the density variable by "seedling age"; the interspecific variety (WAB-450-IBP-4-1) was replaced by WITA 7, because of the good early tillering ability of the latter, and the unsatisfactory performance (inappropriate plant characteristics) under SRI conditions of the former. Results are summarised in table 8.

Table 8: Summary of data for the 20001 WS lowland trial

	Grain yield (t/ha)		**Nb of Days to 50% Flowering**		**Height (cm)**		**Panicles/hill**		**Biomass (t/ha)**		**1000 grain weight (g)**	
Method/systems	NS											
SRC (M1)	3.86		98		108		11		6.84			
SRI (M2)	3.98		105		97		15		5.63			
	SRC	**SRI**	**SRC**	**SRI**	**SRC**	**SRI**	**SRC**	**SRI**	**SRC**	**SRI**	**SRC**	**SRI**
Varieties	*	*	**	**	**	**	**	**	**	**	**	**
WITA 7 (V1)	4.5	4.0	90	97	91	76	10	14	5.8	5.4		
Bouake 189 (V2)	3.3	3.8	92	98	93	85	12	14	4.7	4.4		
WITA 12 (V3)	3.8	3.4	96	104	104	92	12	17	4.8	4.9		
Suakoko 5 (V4)	4.4	4.3	114	121	143	134	10	15	12.1	7.9		
Seedling age	NS	*	**	**	NS	NS	NS	NS	NS	NS		
10 days (A1)	4.0	3.6	95	102	108	97	11	15	6.9	5.6		
20 days (A2)	4.0	4.1	101	108	108	97	11	16	6.7	5.7		
Interactions	NS	NS	**	**	NS	NS	NS	NS	NS	NS		
V x A												
M x V												
M x A												
M x V x A												
C.V. (%) method	22.1	14.0	1.7	3.0	1.8	2.3	11.2	11.5	19.6	29.1		
C.V. (%) combined												

The WS 2001 trial has confirmed the major trends signalled for the previous experiments: under SRI plant height and biomass production are reduced, while the grain yields remain the same under either system, leading to an increase in "harvest index". The variety responding most prominently in that way is the late maturing Suakoko 8, which lodges seriously under the conventional irrigated system but not under SRI. In addition the "seedling age" factor has provided important additional information: delayed transplanting had no effect in the conventional system, while significantly increasing yields under SRI. This response is explained by another unexpected result, namely the extended vegetative growth phase (days to 50% flowering), that results under SRI, but also from the delayed transplanting. (the same effect was noticed in the nursery trial reported under section 2.1.). The conclusion here is that under the non-flooded SRI condition, rice plants are able to extend their vegetative growth phase, because their extensive root systems remain active for a longer period (as shown by comparing uprooted plants).

The absence of negative responses from delayed transplanting on plant development (biomass) and grain yield is a potentially very important result, because it indicates *that widely spaced, single transplants* and *non-flooded conditions* are more critical components of the SRI technology, than the very early/young transplants are. While this issue requires still further study, it has important practical ramifications, permitting greater flexibility at transplanting and a much easier weed control situation during the early vegetative development phase.

4.3. Phenological analysis and observations

Observations on uprooted SRI plants show large numbers of tillers with each tiller developing its own system of adventitious roots to support it. There are sharp contrasts between plants from the irrigated / flooded and the SRI condition: the former have predominantly brown, suberous roots, while the latter have many new, still actively growing young roots at flowering. Moreover, the root mass produced by a single plant grown under SRI practices exceeds that from a clump of three plants grown under the conventional, fully irrigated practice. As a logical consequence the sizes of the individual panicles from SRI plants become larger.

The results of the phenological analysis indicate roughly two types of varieties: early maturing ones that emphasise above ground development from the start and late maturing ones that first appear to emphasise root development before progressively starting the above ground development. Next the latter catch up and overtake the early materials in terms of total biomass production.

5. Discussion:

This article attempts to give an initial justification and explanation of the SRI practices, but there remain many aspects that still require further investigation. SRI field research is complicated by large variations in agro-ecological conditions between locations and in weather conditions between seasons at the same location. All of these will affect the outcome of different experiments and will cause variations in the results. Against this background the WARDA experiments recorded repeatedly a number of typical responses. These underscore a need for further research that eventually may lead even to the development of new, more resource-use, efficient rice production systems.

5.1. Implications for further research

At the basis of this article are a number of exploratory (factorial) field experiments that combined some of the factors judged to be most critical in achieving the extraordinary rice grain yields reported for small, resource-poor farms in Madagascar and elsewhere. A number of critical responses could be confirmed in different experiments conducted in different seasons (dry: fully irrigated, or wet: rainfed supplemented by irrigation) and over a three year period. For the first trial -conducted during the WS 1999- the “conventional irrigated system” outyielded the “SRI” by 48%. This difference was reduced to 21% in the WS 2000. By DS 2001 the difference was further reduced to 8% (NS), and finally in the WS 2001 it was +3% (NS) in favour of SRI. This trend reflects a progressive mastering of the SRI practices at the station by scientists, farm supervisors and daily labourers. Among the specific effects recorded repeatedly were:

- significant interactions between rice varieties and production system (fully irrigated/flooded or intermittent, non-flooded irrigation) for grain yield and several other plant characteristics of which an intermediate to late maturity and profuse tillering appear crucial to SRI type systems,
- huge and highly significant increases in tillers/plant and panicles/plant, and a reduction in plant height, leading to an absence of lodging even for tall varieties under SRI practices,
- a significant extension of the vegetative growth period under SRI (water management) practices, expressed as a delay in the onset of flowering, probably resulting from more active and more profuse root systems,
- the above features have contributed to a lower total bio-mass production that resulted into a significantly increased “harvest index”; this effect was accentuated further in the 2001 DS systems trial by a significant increase in grain size under SRI practices.

De Datta (1981) mentions some similar effects, but he attributed these to the absence of flooding. He also showed for a wide range of irrigated varieties that the dry season crop always had a higher harvest index than during the wet season. This feature is commonly attributed to the more favourable radiation and temperature regimes during the dry season. The present responses indicate, however, that the soil water / irrigation regime can cause similar effects and can be interpreted as an increase in resource use efficiency for water and plant nutrients under SRI practices. This also provides an illustration of the complexity of research on irrigated rice production systems due to unavoidable confounding between production and environmental (including soil) variables.

Based on these results it was concluded that SRI type practices still offer ample scope for further increasing the efficiency of resource use (water, nutrients, land and labour), as well as the total grain yield. However, two crucial pre-conditions would need to be met:

a) the identification and use of SRI-adapted varieties, in combination with

b) an adjusted, non-conventional, form of soil nutrient management

From the experiments several preliminary conclusions can be drawn about a number of desirable plant characteristics for SRI-adapted varieties. The identification of such varieties is crucial to exploiting this system successfully in the future. Among other features, adapted varieties are characterised primarily by large tillering abilities, which as noted also by de Datta (1981) is associated mostly with materials of intermediate and/or full-season maturity. Thus very early maturing varieties (like the WAB450-IBP65-4), as well as some intermediate ones (like WITA 12) selected for conventional intensified rainfed and/or irrigated systems will miss the inherent potential to respond. The WITA 12 develops a dense bunch of erect tillers for each individual plant, whereas varieties like Suakoko 8 and to a lesser extent Bouake 189 will show an unfurled bunch of tillers for each plant. Together with the wide spacing between plants this leads to a prolonged open crop canopy and a delay in canopy closure. Many scientists object to this, because it diminishes the initial rate of radiation utilisation by the crop as compared with the conventional practices. Chinese research (Longxing, et al.; 2002) suggests, that this might be compensated for by continued photosynthetic activity by the older leaves, since these are not shaded out. Moreover, the Chinese scientists recorded more profuse and deeper root systems. These two features that resulted from the use of single, widely-spaced plants will greatly affect competition both above ground for radiation and below ground for plant nutrients and thereby the combined efficiency of resource use. These aspects would require further fundamental investigations that eventually may even lead to adjustments in the standard cropping models for rice.

While all rice varieties will respond to SRI practices in terms of increased tillering per plant, it is obvious that very early maturing, short-statured cultivars -a major output of many ongoing breeding programs- will have a lower capability to respond simply for lack of “time”. As a result the *phyllochron* concept may need to take into account the “time” factor with respect to various maturity classes.

Makarim et al. (2002) rightly point out that in a SRI system, the modern, early varieties will be increasingly sensitive to very early transplanting (< 15 days), because their short overall vegetative growth phase leaves limited time for recuperation from the transplanting shock. Therefore to capitalise on a positive SRI effect these early materials would require a closer spacing (e.g. 20 x 20 cm). By contrast the intermediate and late maturing varieties have an important additional practical advantage of making the system more robust (i.e. less sensitive to precise timing of field operations like very early transplanting, precise land levelling, strict control over water, etc.). Moreover, the present results also indicate that these latter varieties offer many more opportunities to compensate for non-ideal growing conditions and field implementation practices that are common for the diverse agricultural production systems of small resource-poor farmers. The most important compensation characteristics identified have been the extension of the vegetative phase (till the onset of flowering) when transplanting was delayed. Moreover, the reduction in tillering and subsequently number of panicles/plant at harvest due to a delay in transplanting could be effectively compensated for by reducing the spacing between hills and by increasing the number of transplants/hill. These results also re-emphasise the considerable importance of *genotype x environment* (G x E) interactions in particular under SRI conditions.

Under SRI, the individual plants develop profuse root systems, because each new tiller continues to generate new adventitious roots to support it. Consequently, the total soil volume tapped by each individual plant is greatly increased, having direct implications for nutrient uptake and utilisation efficiency. The field measurements of reductions in biomass production and in plant height under SRI (causing a total absence of lodging), while grain yields were unchanged (fertiliser levels being the same), likewise point to increased resource use efficiency. It is postulated that the profuse root system is a feature with major implications for plant nutrient management. Such root system will be particularly effective in tapping the low soil nutrient concentrations that are released through the gradual decomposition of soil organic materials through the activities of the associated soil biota.

By contrast high plant densities as used in conventional fully irrigated systems, lead to increased competition and reduced root development. This increased plant density is essential, however, to capitalise on mineral fertiliser applications, N topdressings in particular. Obviously, the resulting high nutrient concentrations in the soil, will at the same time lead to increased losses, and therefore pollution of the environment. In that respect the judicious use of organic sources of nutrients as practised by the resource-poor farmers in Madagascar, will introduce a very different soil nutrient dynamics.

The efficiency of plant nutrient uptake by rice plants grown under SRI practices, is not only a matter of soil nutrient availability and nutrient budgets (Smaling, 1997; Smaling, et al., 1998). The latter lead to recommending unrealistically high application rates (5-10 ton/ha) for organic manures to arrive at comparable nutrient levels as in mineral fertilisers. It is also more complex than combining the use of mineral with organic fertilisers (Sanchez and Jama; 2000). It will be necessary therefore to explicitly introduce the *quality* of organic materials and its impact on the associated (soil) biota ranging from earthworms to fungi and bacteria. It will be these organisms that will determine the rate, effectiveness and pathways of the decomposition/mineralisation, but also N fixation processes. Therefore the *quality* features of organic manures/materials (ranging from composts, green manures, animal manures, crop residues, household refuse etc), will ultimately determine the optimum *quantity* of organic manures (compost) and the appropriate mixtures with mineral fertilisers. Results obtained in Senegal on groundnut and millet by Diop (2002), consequently suggest that compost application rates could be substantially reduced.

The *"quality"* of organic manures will be first and foremost determined by the physical and chemical properties of the initial materials, and by the type (conditions and duration) of the *"preparation"* process (e.g. composting method; storage of farmyard manure; etc.). Quality criteria should include the C/N ratio, and thus the N content of the materials, but also the lignin and possibly tannin contents as well as the presence of common toxic substances like polyphenols. On that basis, Palm, et al. (1997) arrived at a useful grouping of organic materials in four major quality categories, which subsequently were translated into practical farm management options by Giller (2000). A further characterisation of organic materials (nutrient contents; soluble polyphenols, etc.) can be found in a recently created database (Palm, et al., 2001).

The nitrogen content and the various organic substances of the materials in combination with the physical conditions (humidity, aeration and temperature) will affect the rate of mineralisation by influencing the effectiveness and efficiency of the biota. The same conditions will also greatly affect the growth and nutrient uptake processes by the plant roots. As reported by McGrath and Giller (???), very low concentrations of heavy metals in the soil led to massive yield losses of white clover, simply because the N fixing capacity of micro-organisms was suppressed. It is postulated that toxic organic substances liberated during organic matter decomposition would have similar effects –though less persistent than heavy metals- on the soil biota and that such a process could be far more widespread than anticipated so far. Such indications are also provided by the results of Vityakon et al. (2000), who compared the effects of lowland and upland conditions using mixtures of organic materials (e.g. rice straw mixed with groundnut and/or Sesbania residues) on both the N-mineralisation and nutrient uptake processes. The results underscore the logical effects of soil aeration and soil moisture (and thus the irrigation regime). Through the mixtures of organic materials, its overall quality could be significantly improved and thereby the rate of N mineralisation. Finally, with an abundant presence of soil micro-organisms (as under the lowland condition), these will become another, non-negligible source of nutrients for nitrogen and phosphorus that becomes available under a wetting-drying regime (Turner and Haygarth, 2001).

High quality organic matter and optimum soil conditions for its decomposition, in combination with the reported profuse root systems under SRI, will supposedly lead to both a greater access and a more balanced, overall nutrient supply and uptake at low soil nutrient levels. This is supported by Toomsan, et al. (2000) who suggested a greater synchronisation between rice N demand and the N release from organic residues, than would be possible through N-topdressings. The potential practical importance is related to the recognition that large proportions (up to 70%) of applied fertiliser nitrogen are being lost commonly in rice production systems in Africa (Wopereis et al.; 1999) and in Asia (Ladha, et al.; 1998).

The research required to clarify SRI –and for that matter also other low external input/organic systems- will require fundamental studies. So far research on SRI has been based mostly on simple comparisons between various cultural practices and between mineral and organic types of fertilisers, conducted through on-farm, participatory approaches. These have often led to inconclusive and/or conflicting results, a major reason being the array of different types of organic manures of very different sources, origins and qualities in terms of their respective nutrient compositions and the make up of the organic components. Moreover, the soil fertility dynamics (for organic manures obviously related to the activity of the soil biota) will be greatly affected by the soil moisture condition (intermittent wetting and drying as opposed to continuous flooding) apart from the huge and very location specific diversity in soils.

A most striking outcome of the trials has been that agronomic management –in particular with respect to water- had fundamental impacts on rice plant characteristics such as plant height, maturity and total biomass production, but also on key features like grain and panicle size. These results imply an important increase in the efficiency of resource use (in particular for water and nutrients). While the improvement of these types of plant features have normally been the prerogative of plant breeders, the present results suggest that more rapid, and substantial progress can be made simply by adjusting agronomic management practices. The latter constitutes in many cases and certainly in the short term, a far more effective and efficient research approach, leading to environmental-friendly results. In that respect the breeding and selection efforts for N-use efficiency (Ladha, et al.; 1998) and for certain, presumably superior plant types / characteristics (the new rice plant type: Holmes, 1994) are unlikely to lead to production systems that are radically different from the present ones. Consequently such approaches will not resolve the major concerns about losses in bio-diversity and environmental pollution commonly associated with modern agriculture.

5.2. Prospects for adoption and adaptation to divers agro-eco systems

The SRI practices as initially developed and described by de Laulanie (1993), are extremely delicate like the transplanting of very young, 10-day old, seedlings, and very sensitive to timely implementation and planning (for transplanting, as well as for the management of irrigation water, land levelling and weeding). Therefore scientists have often objected that SRI constitutes more of a *small-scale horticultural* than of a modern, *large-scale agricultural* operation. The results presented in this paper suggest that the delicacy features of SRI may have been overemphasised. The results of the agronomy component/nursery trial in combination with the 2001WS *systems* trial, indicate that the use of very young seedlings for transplanting may be less critical provided that the seed rates used in the nursery are drastically reduced. Moreover, suitable, SRI adapted, varieties -predominantly of the intermediate and late maturity types known for their profuse tillering- (see table 5) should be preferred over early varieties. Only with strict control (in terms of labour, water, plant nutrients and know-how) over the entire production process, as for instance in parts of China, are the very early maturing varieties likely to perform satisfactory.

The relatively disappointing performance of the early maturing varieties/hybrids in the systems trials is undoubtedly associated with their reduced tillering; the agronomic component trials on the other hand underscore the genetic diversity in rice with respect to this feature. The diversity of rice growing environments – certainly under rainfed conditions – as encountered in West Africa, but also in Madagascar and in Asia, is huge. With it the location specific problems –be it for water or soil fertility management as well as for the often, associated outbreaks of pests and diseases- will always remain divers. Fortunately the genetic variation in rice to meet this environmental diversity is also huge and therefore the number of options for implementing and adapting SRI to local bio-physical and socio-economic conditions are numerous as well. A consequence is that the practice requires considerable “farmer” experimentation in gaining the required knowledge and experience. This farmer experience involves many different production aspects like the incidence and severity of pests and diseases, as well as weed control and weed management.

These often highly location-specific constraints can be crucially affected through agronomic management (in terms of plant population, the soil nutrient and soil water regimes). Only through experience will farmers be able to eventually minimise the labour requirements involved, for instance during the initial stages of crop establishment when adequate weed control will be crucial. Correct planning and timely implementing the cultural practices –land preparation, levelling, timing and rate of irrigation in relation to the seeding/transplanting operations- are all of importance in reducing the subsequent labour inputs. Failure by farmers (but also by research and development personnel) to appreciate the complexities of SRI practices, will obviously have been a factor in the non-adoption and dis-adoption by farmers in Madagascar, as reported by Moser and Barrett (2001). As they point out, seasonal liquidity problems in combination with labour constraints –most common and most sever among the poorest producers- interfere seriously with a widespread adoption of SRI. In other words, for the major low-income target group, a different appreciation of risks and seasonal opportunity costs (earning essential short term cash as hired labour, versus a long term investment in mastering a new practice) plays a major role in the adoption process.

The social and economic acceptability of SRI will depend first and foremost on the extent to which farmers can:

a) develop a proper understanding of the plant growth and development features under SRI, and
b) master the labour requirements in particular during the early stages of crop development.

Pretty and Uphoff (2002) underscore that development is basically a social process in which opportunities for learning through trial-and-error are fundamental requirements. The consistent support by knowledgeable development workers will be another critical element in that process. With these conditions met, there are no reasons why the SRI practices could not be adjusted eventually to suit also a larger-scale, possibly mechanised, type of rice farming.

6. Conclusions

The present results have confirmed some of the key plant features and crop responses that are at the basis of the potentially very high SRI yields. However, the grain yields from the experiments conducted in Ivory Coast fell far short of those reported from Madagascar and elsewhere. This leaves the issue of soil fertility and plant nutrient dynamics (not directly addressed by the current trials) as a major topic requiring much further and fundamental clarification by agricultural scientists. Such research is best conducted at the experiment station level, requiring also laboratory facilities. However, there has been a rather widespread reluctance by the formal (international) agricultural research establishments to undertake this work. Hence, SRI presents many examples today where on-farm, participatory research has been used for the wrong reasons. Mostly "inconclusive" results have been the outcome of extensive and time-consuming (for researchers and farmers) experimentation, that to a large extent has lacked scientific rigour.

As concluded in a recent study (Stoop, 2002) for West and Central Africa, the huge agro-ecological diversity of the region can not be addressed successfully through general, mostly standardised technologies (like improved varieties, mineral fertilisers, pesticides). Moreover, agricultural research and development in support of the *poor* may require a shift in the respective research agendas to adapt these to those means that are relatively most easily available to the target group. These would include organic materials (as compared to the external agricultural inputs that are often unavailable and/or too costly), but also the production factors "time" and "space". As this paper claims there is important evidence that the efficiency of resource-use for agricultural production in tropical areas with its generally impoverished soils (characterised by their low soil organic matter contents and low cation exchange capacities) can still be greatly increased. Likewise there are numerous options (through the choice of varieties and through adjustments in cultural practices) to adapt production systems to local conditions.

The extremely high rice yields obtained by some small farmers using SRI type practices in Madagascar, can only be possible through greatly increased resource-use efficiency in which organic matter quality and management (in their case compost) play key roles. The yield response will be the combined effects of optimising the soil nutrient mineralisation and the biological N fixation processes in which the soil biota are key agents. Both these processes favour moist and aerated soil conditions that at the same time, however, will also enhance root development. Extensive root systems are essential to allow the plant to trap low soil nutrient concentrations in sufficient quantities to make very high grain yields a reality. It is postulated that these low nutrient concentrations will offer both a more balanced and a better synchronised nutrient supply to meet the evolving demands by plants, than is possible through mineral fertiliser applications with the added benefit of both reduced nutrient losses and therefore reduced environmental pollution.

The required research and the resulting insights would improve our knowledge about the overall functioning of agro-ecosystems and the role of bio-diversity. The results from the present study suggest a need for reconsidering the basic production factors of "space" and "time". The former will involve the use of optimum plant population levels in the competition for radiation and plant nutrients as affected by the major source of soil fertility: mineral or organic. The latter involves the use of appropriate varieties in terms of their maturity cycles in combination with an optimum timing of the implementation of essential cultural practices. An interesting illustration of this feature is the observation by Ladha, et al. (1998), that early and late maturing rice varieties achieved maximum grain yields at 150 to 200 and 100 to 150 kg N/ha respectively. It is postulated that the combined effects will allow large improvements in resource use efficiency. While this should eventually permit resource-poor farmers to raise their production, and economise on the use of external inputs, it would also require farmers to experiment (informally) to realise the essential adaptation of these principles and practices to their respective location-specific constraints.

Many agricultural research (breeding/agronomy) and development efforts tend to bypass the issues of diversity and variability in the rural environment (location specificity in socio-economic and agro-ecologic conditions). As a result they lack the strategies to capitalise adequately on it (e.g. through G x E interactions) and to guide producers in making essential adaptations in their production systems.

The final conclusion from this paper is that the widespread adoption of SRI type practices (and for that matter other low external input technologies), are currently constrained equally by inadequate theoretical knowledge and research, and by inappropriate development and extension approaches. Both fail to appreciate the diversity of and the limitations under which resource-poor communities are operating.

Acknowledgements

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