RESOURCE USE EFFICIENT AND PRODUCTIVE RICE-BASED SYSTEMS FOR SOUTH ASIA

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ABSTRACT
In South Asia, rice is the topmost, followed by wheat and maize in terms of area, production and yield. While rice and wheat are grown for grain, maize may be grown for grain, green cobs or fodder for animals. Three cereals are cultivated either as a mono crop in irrigated areas or a mixed crop in dryland, mostly in fixed sequences. Maize is cultivated in homesteads in both monsoon and winter seasons on the hills of Nepal and Pakistan and in eastern India. Rice-wheat (R-W) is the predominant cropping system (CS) with 12.6 m ha in the sub-tropical areas of the Indo-Gangetic Plains (IGP); double (R-R) or triple (R-R-R) rice crops with 9.5 and 0.34 m ha, respectively, are common in tropical irrigated or favourable rainfed lowlands of eastern IGP with distinct dry and wet seasons. The intensively cultivated irrigated rice–wheat system is fundamental to employment, income, and livelihoods for hundreds of millions of rural and urban poor of South Asia. However, yield stagnation/decline together with large yield gap; water and labor scarcity; and soil, water, and air pollution are the emerging threats to the sustainability of rice-wheat systems. Therefore, the design and implementation of alternative production systems with increased resource use efficiency, profitability and productivity, and reduced adverse environmental impact, are urgently required. One of the strategies to address emerging problems, specifically shortages of water and labor, is to grow rice and wheat in direct-seeding without tillage utilizing integrated crop and resource management (ICRM) strategies.

Integrated crop and resource management for enhancing productivity and resource use

Two types of trials were conducted to evaluate and refine various technological options. Well-planned on-station research trials were conducted at selected research farms where detailed measurements were made. From on-station trials, successful technologies were introduced to farmers' fields for further evaluation and eventually wider dissemination. Numerous trials were conducted to evaluate various technologies in rice and wheat at various sites of four IGP countries which includes optimal (1) land preparation, (2) water management, (3) crop establishment (time and method of seeding/transplanting, age, number of seedlings, and plant density in the case of rice and seeding rate and depth in the case of upland crops such as wheat), and (4) nutrient, pest, and weed management.

We measured the following four groups of performance indicators in both on-station and on-farm trials: (1) crop productivity, (2) pattern of resource (labor, water, agro-chemicals) use, (3) partial budgeting (various costs and profit), and (4) global-warming potential (GWP). The on-station trials followed proper experimental design and replications; hence, adequate statistical analyses were done. But, for on-farm trials, for which proper experimental designs are often not possible, data were analyzed using SAS mixed model procedure, in which treatment was used as a fixed effect and farmer as a random effect.

On-station technology performance

The productivity of the RW system has been stagnant in recent years because of (1) contrasting tillage requirements for rice and wheat, (2) delayed wheat sowing, (3) poor maintenance of soil structure, and (4) poor management of irrigation water, agro-chemicals, including fertilizer, and crop residues.

On-farm technology performance

Farmers can effectively reduce their yield gaps and enhance farm income by adopting ICRM in rice. ICRM in rice, which also included crop need-based N management with the help of an LCC for transplanted rice (CT-TPR-LCC), increased grain yield by 0.24 to 0.75 t ha^{-1} and net income by \$41 to \$49 ha^{-1} and reduced fertilizer cost because of efficient N use. Likewise, ICRM in zero-till drill-seeded wheat (ZT-DSW-ICRM) increased mean grain yield by 1.06 t ha^{-1}. So far, crop management has largely been developed and promoted in a conventional rice system (CT-TPR). However there is an urgent need for a full package of crop management together with conservation tillage for both rice and wheat. Crop residue is another missing link that should be factored in ICRM. The adoption of a full package of ICRM is essential to maximize system productivity (reduce yield gap) and profit, and save resources.

Reduced-till and zero-till drill-seeded wheat either on flat (RT-DSW/ZT-DSW/RT-DSW-PTOS) or raised beds (Bed-DSW) was productive and profitable, with a yield advantage of 0.14 to 0.46 t ha^{-1} and net income from \$76 to \$200 ha^{-1}. Therefore, minimum- or zero-tillage is becoming increasingly popular among farmers in parts of the IGP. Reduced or zero-tillage facilitates timely wheat planting. Reduced- or zero-till wheat is established by tractor-operated drill seeding with or without crop residues in combine-harvested rice fields. Retaining crop residues as mulch would reduce the perceived need to burn rice residues in the northwest IGP and likely enhance the scope of organic matter accumulation in the soil, and move the system toward conservation agriculture.

Conclusions

A number of ICRM modules which encompass following practices were developed and promoted (1) enhance resource- or input-use efficiency; (2) provide immediate, identifiable, and demonstrable economic benefits such as reductions in production costs, and savings in water, fuel, and labor requirements; and (3) ensure timely crop establishment and uniform crop stands, resulting in higher crop yields. Indirect benefits include (1) effective control of *Phalaris minor*, a major weed in wheat by zero-tillage; (2) replacement of residue burning by retention of crop residues, resulting in some improvement in certain soil quality parameters, including short-time accumulation of carbon in surface soil; (3) a reduction in methane emissions from nonpuddled and nonflooded rice fields; (4) buildup of soil fertility over the long term, leading to sustainability of intensive rice-wheat cultivation; and (5) the generation of rural employment by training and empowering local farm machine manufacturers, custom-hire service providers, retailers and traders, and seed producers. Although ICRM with tillage and crop establishment options has been more successful in wheat, the next frontier will be to make similar headway in rice. In short, integrating new RCTs into the portfolio of farmers' current technologies using the framework of ICRM (good agronomy) will continue to be a key to improving productivity and production (thereby reducing yield gap) and eventually attaining national food security.

KEYWORDS
Rice-based cropping system, maize, wheat, integrated crop resource management, tillage, conservation agriculture

Resource Use Efficient and Productive Rice-Based Systems for South Asia

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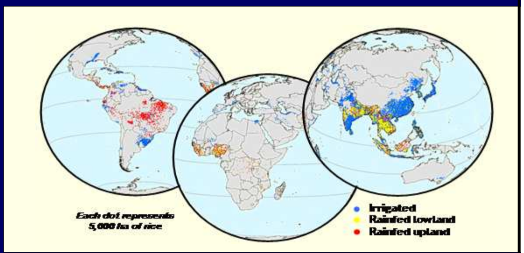
IRRI

Outline

- Food Security and Rice
- GRiSP and CSISA - New Global and Regional Concept for System Research and Delivery
- Rice-Based System – Challenges and Opportunities
- Growing Rice – New Paradigms
- Future Outlook and Likely Changes

A CGIAR Research Program (CRP) in Thematic Area 3: Sustainable crop productivity increase for global food security

Global Rice Science Partnership (GRiSP)



An evolving alliance of IRRI, AfricaRice & CIAT with Cirad, IRD, JIRCAS and hundreds of research and development partners worldwide

Cereal Systems Initiative For South Asia (CSISA) A New Regional Concept for System Research and Delivery

BMGF
USAID (CGIAR)
USAID Missions
Other bilateral donors
Co-investments

IRRI, CIMMYT, IFPRI, ILRI, WFish
NARES (Bangladesh, India, Nepal and Pakistan)
Private sector
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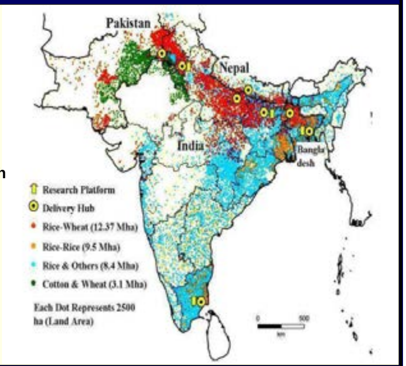
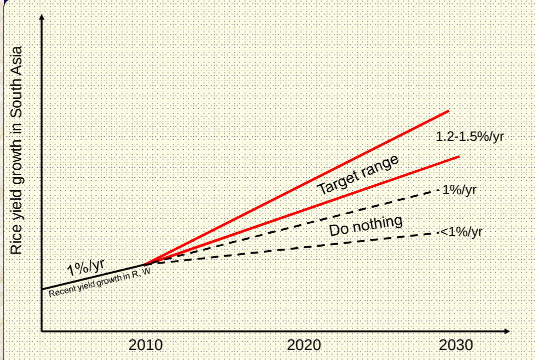


Challenges Facing the Rice-Based System

- Growing cereal demand vis-à-vis declining harvest area
- Declining/stagnating productivity
- Rising agro-chemical use and declining use efficiency
- Degrading soil and water resource base
- Adverse changes in micro-climate.
- Growing labor shortage
- Non-reliability of irrigation water
- Food security vis-a-vis increased income

Required Yield Growth



Source: A. Dobermann

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Sustainable Agriculture
Ecological Intensification/Conservation Ag

Green Revolution → Yield Maximization
- Variety
- Water
- Fertilizer
- ...or
- Energy

Post Green Revolution → Yield wi... ...iency ...n
- ...mum soil disturbance and drill seeding
- Residue mulch
- Efficient use of inputs
- Nutrition
- Diversification
- Adaptation to climate change

What is for the farmers ?

Food Security, Environmental Quality, Economic Viability on a Sustainable Basis

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Best Management Practices for Rice: An Analysis

Component	Best practice	Benefit	Farmers outlook
Land leveling	Laser	Increase overall farm efficiency	Yes
Land preparation	Minimum soil disturbance or no puddling	Labor, energy and water saving and soil health imp...	
Water	Dry seeding or aerobic culture with smart water management (i.e. AWD)	Water saving	
Crop/seed establishment	Drill seeding with certified, treated and optimal se...	...ng, and ...zer placement	Yes
Crop variety	High-yielding ...	... improvement and value addition	Yes
Residue	...	Environment and soil health improvement	No
Nutrient		Crop, environment and soil health improvement	No
Pests	IPM/IWM	Crop and environment improvement	No
Diversification/ intensification	Other crops (replacement of main crop and/or integration of fallow crop)	Value addition	Yes/No
Post harvest	Storage (super bag)	Reduce crop loss	Yes
Market linkages	Linking farmers to reliable stakeholders	Overall farm support	Yes

Positive contribution to ecosystem services

What are the Yardsticks ?

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System Monitoring and Performance Target Indicators

S. No	Indicator	Rice		Wheat		Maize (Spring)	
		Conventional Rice	BMP	Conventional Wheat	BMP	Conventional Maize	BMP
1	Cropping intensity (%)	200	>200				
2	Tillage	Intensive (dry and wet tillage	Minimal (reduced or no tillage)	Intensive tillage	No-tillage	Intensive tillage	No-tillage
3	Planting (Labor use efficiency)	Transplanting	Drill seeding	Broadcasted	Drill seeding	Dibbled	Drill seeding
4	Grain yield (% of climatic potential)	40-60	70-80	60-70	80-90	40-50	60-70
5	WUE (kg grain m^3 water)	0.25-0.30	0.32-0.35	1.00-1.10	1.40-1.50	2.0-2.5	3.0-3.5
6	Irrigation water application (l/kg grain)	3000-4000	2000-3000	600-800	400-600	500-700	400-500
7	NUE AE_N RE_N	18-24 30-40	>25 >50	20-24 30-40	>27 >50	18-23 35-40	>26 >50
8	Biocide residue index	70-80	70-80	1.0-1.5	0.5-1.0		
9	Specific energy (Mj/kg)	2.52	2.0	0.70-0.60	0.20	0.70-0.60	0.20
10	Crop health index	L-M	M-H	L-M	M-H	L-M	M-H
11	Soil health index	L-M	M-H	L-M	M-H	L-M	M-H
12	GWP (Kg CO_2 equi/ha)	3000-4000	2500-3500	580-610	530-550		
13	Net income (US $/ha)	200-250	300-350	350-360	390-400	250-350	350-400
14	By product (straw) use • livestock • Energy	Yes No	Yes Yes	Yes No	Yes Yes	Yes No	Yes Yes

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Growing Rice – New Paradigms

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Requires water, labor, and time; and about 30% of total cost

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Effects of Puddling in Rice-Wheat Cropping

Advantages
- Reduces water permeability
- Eases transplanting of rice
- Controls weeds
- Enhances soil nutrient availability

Disadvantages
- Requires large volume of water
- Longer turn around time, leading to delayed sowing of next crop
- Labor intensive
- Destruction of soil structure leading to higher bulk density, soil penetration resistance, and surface cracking adversely affecting following upland crop

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Drivers of Shift

Labor shortage | Water Shortage | Soil health issues | Economics

Puddled transplanting

Unpuddled direct seeding

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Pre-Requisites for Success of Unpuddled Direct-Seeding

- Precise land leveling
- Good initial crop establishment (optimal seed rate and seeding depth)
- Precise water management
- Efficient and economical weed management
- Suitable rice variety

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Laser Assisted Leveling

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Crop Establishment - Seed Metering System

Fluted roller type

Traditional seed metering (fluted roller)- Higher seed rate, seed breakage & poor establishment (particularly in rice)

Inclined plate type

Inclined plate/ cup/roller system- *towards precision seeding*

Cup type

Roller type

- Optimum seed rate
- Primed seed can be used
- Better crop establish-ment

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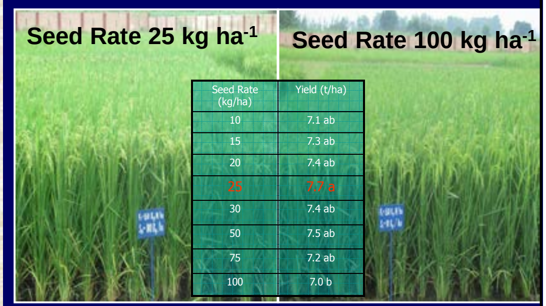
Optimization of Seed Rate for Dry-DSR



Seed Rate (kg/ha)	Yield (t/ha)
10	7.1 ab
15	7.3 ab
20	7.4 ab
25	7.7 a
30	7.4 ab
50	7.5 ab
75	7.2 ab
100	7.0 b

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Weed Management Issues in DSR

- Higher and more diverse weed flora
- Changes in weed population dynamics
- Lack of viable weed management practices

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Integrated Weed Management

Many little hammers

- Stale seed bed
- Mulching and zero-tillage
- Use of suitable herbicides
- Crop rotation
- Intercropping of cover crops
- Hand weeding/mechanical weeding
- Competitive rice cultivars
- Water management
- Herbicide resistant Rice

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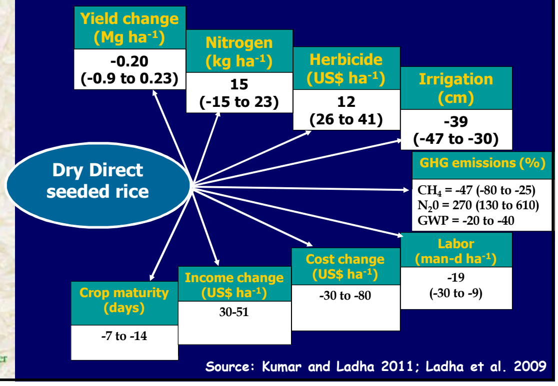
Dry-DSR Performance and Input-use Efficiency Compared to CT-TPR



Source: Kumar and Ladha 2011; Ladha et al. 2009

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Likely Change

- Substantial increase in mechanization specially for land leveling, reduced tillage and drill-seeding (and fertilizer applications?)
- Significant increase in agro-chemical usages
- Land consolidation
- Increasing involvement of private sector
- Improved access to the market for inputs and outputs
- High productivity growth through better land and crop management practices
- Diversification and more hybrid crops
- Farming more attractive

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Areas of Mutual Interest

- Modifying rooting pattern for early vigor and rapid establishment of DSR
- Optimizing panicle architecture during reproductive phase in DSR
- GHG dynamics from flooding to aerobic rice culture
- Improving rice residue quality for animal feed

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Challenge

Meeting rising food demand under resource constraints while maintaining ecosystem services–reduce agriculture's Ecological footprint

J. Lynam, draft, CGIAR Alliance, 2007

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THANK YOU

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