Revising Agronomic and Socio-economic Paradigms for Crop Improvement: Findings from SRI Research Globally

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Most agricultural research aims at making incremental additions to our scientific knowledge. From time to time, however, an accumulation of new knowledge first challenges and then changes the way that phenomena are understood and acted upon. This gets characterized as a '*paradigm shift*'.

Paradigm shifts build upon incremental research findings, but they require both some new vision and some re-conceptualization of phenomena.

Progress in science depends more upon such shifts than upon piecemeal accretions of knowledge.

Keep in mind the advice of Dr. Albert Einstein:
"*Imagination is more important than knowledge*"

Paradigms, for better and worse, represent 'boxes.' Paradigm shifts require thinking outside the box.

We need paradigms to organize knowledge, to make *simplified sense* out of complex, confusing and changing phenomena.

Thus, paradigms ***screen in*** some kinds of information -- and they ***screen out*** other information.

They assign priorities to information; they make simplifying assumptions; they determine what sources of information will be considered as legitimate; they accept some methodologies as being valid, and reject other methodologies.

New knowledge is thus conditioned (and constrained) by whatever constitute the prevailing paradigms.

Research is invariably *limited* and even *biased* by the methods and measurements prescribed by the prevailing paradigms.

After 15 years of research and >400 published articles (http://sri.ciifad.cornell.edu/research/index.html) and with empirical results reported from >50 countries, the System of Rice Intensification (SRI) and its derived/expanded version, the System of Crop Intensification (SCI), are presenting agronomists and policy-makers with a real-time paradigm shift.

SRI methods are now being promoted by governments in **China, India, Indonesia, Cambodia and Vietnam** – where *two-thirds of the world's rice is produced*.

~ 10 million farmers on as many as 4 million hectares in over 50 countries are using some or all SRI methods.

This spread has been led by higher yields, with reduced water and agrochemical inputs, with lower costs of production, and with enhanced resistance to biotic and abiotic stresses.

Researchers and farmers have not expected it to be possible to ‘**produce more output with less input**’ -- the prevailing paradigm **assumes the opposite**.

‘**More from less**’ is ***counter-intuitive***, but explainable:

(a) **Beneficial changes in the morphology and physiology of plants as result of new practices.**

(b) **Visible and measureable changes in the structure and functioning of root systems.**

(c) **More services of the plant-soil microbiome.**

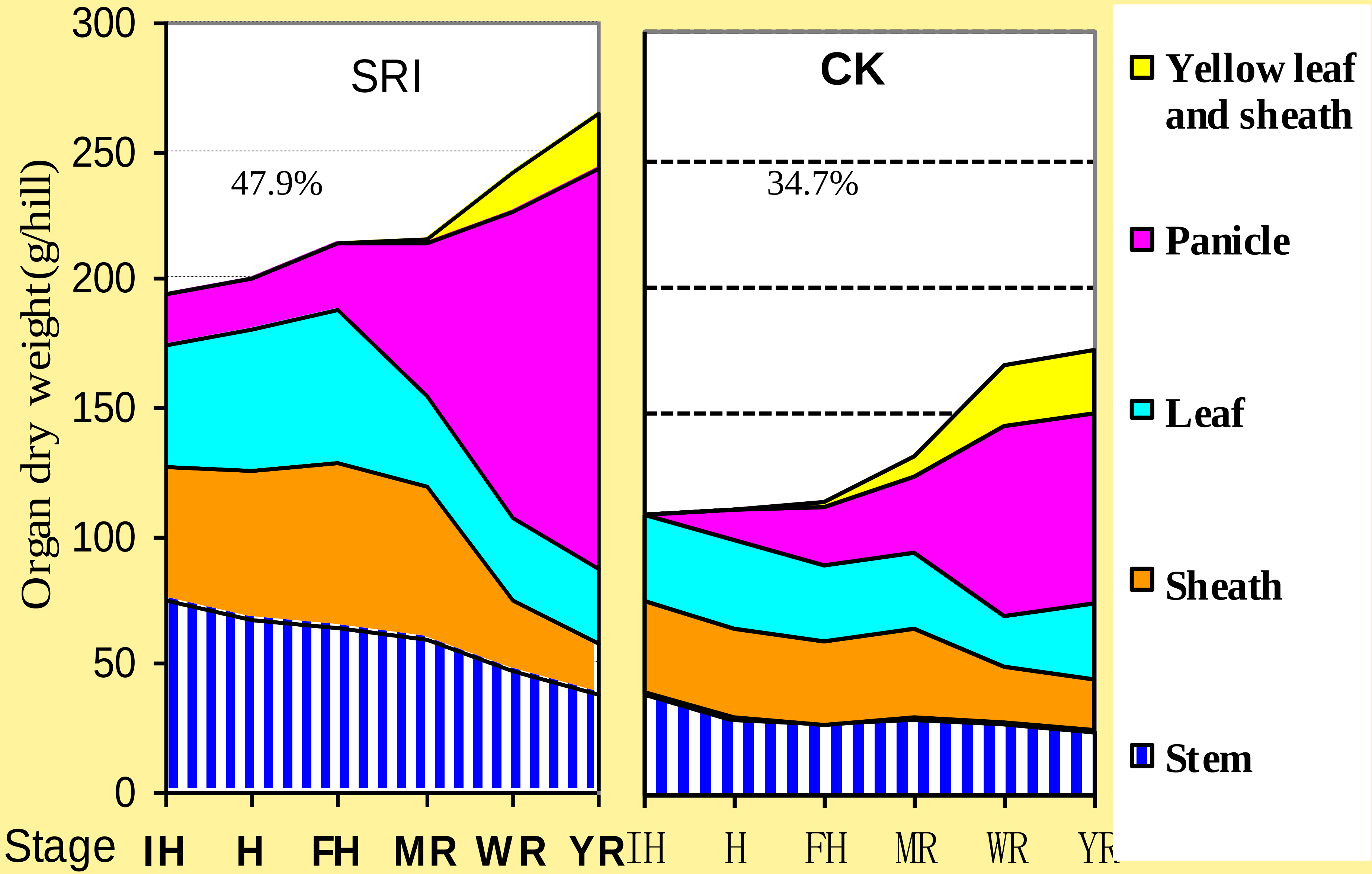
PUNJAB - Irrigated

ODISHA - Rainfed

CUBA

Plants are same age (52 d) and the same variety (VN 2084)

IRAQ: **Comparison trials at Al-Mishkhab Rice Research Station, Najaf**



China National Rice Research Institute paper: *'Non-Flooding Rice Farming Technology in Irrigated Paddy Field,'* Dr. Tao Longxing, 2004

INDONESIA:
Stump of a rice plant (Ciherang cv.) grown with SRI methods -- having 223 tillers and massive root growth from a single seed

Panda'an, E. Java, 2009

Root Growth

SRI hills had better root development (deeper roots, more dry weight, greater root volume and root length) than rice crop grown under RMP.

Effects of rice management practices on root depth, root dry weight, root volume, and root length at early-ripening stage of development (Dr. A.K. Thakur, DWM)

Management practice	Root depth (cm)	Root dry weight (g hill^{-1})	Root dry weight (g m^{-2})	Root volume (ml hill^{-1})	Root volume (ml m^{-2})	Root length (cm hill^{-1})	Root density (cm^{-2})
SRI	33.5	12.3	306.9	53.6	1340.0	9402.5	2.7
RMP	20.6	5.8	291.8	19.1	955.0	4111.9	1.2
$LSD_{.05}$	3.5	1.3	NS	4.9	180.1	712.4	0.2

Canopy structure

SRI plants had higher LAI than RMP.

Greater SLW of leaves under SRI shows greater thickness of leaf.

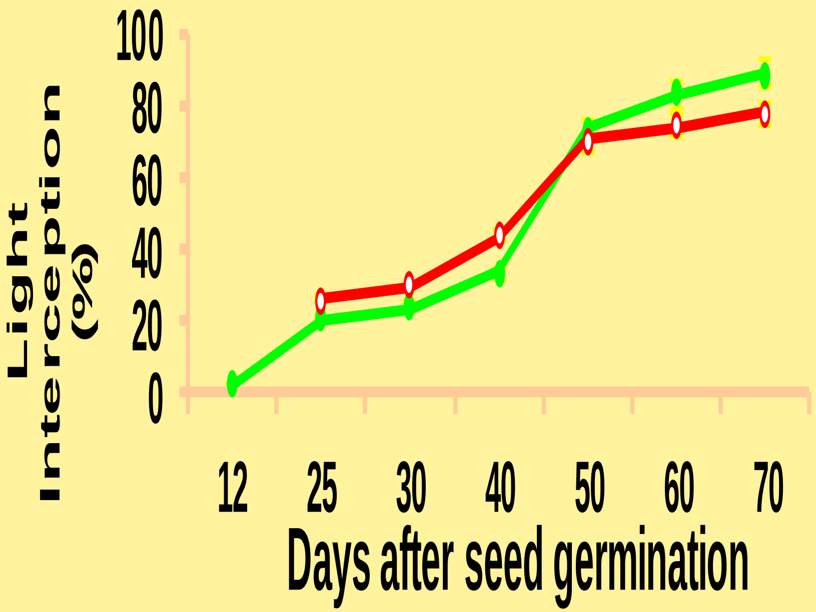
SRI: Open-type canopy structure
RMP: Closed-canopy structure

Effects of rice management practices on leaf area index (LAI), specific leaf weight (SLW), and canopy angle at the flowering stage of development

Mgmt practice	LAI	SLW (mg cm^{-2})	Canopy angle (°)
SRI	3.95	5.50	33.1
RMP	2.60	4.89	17.8
$LSD_{.05}$	0.28	0.34	3.6

<u>Light Interception</u>: SRI plants intercept more light due to less shading of their leaves

RMP plants have a *more closed canopy* so their lower leaves experience more shading

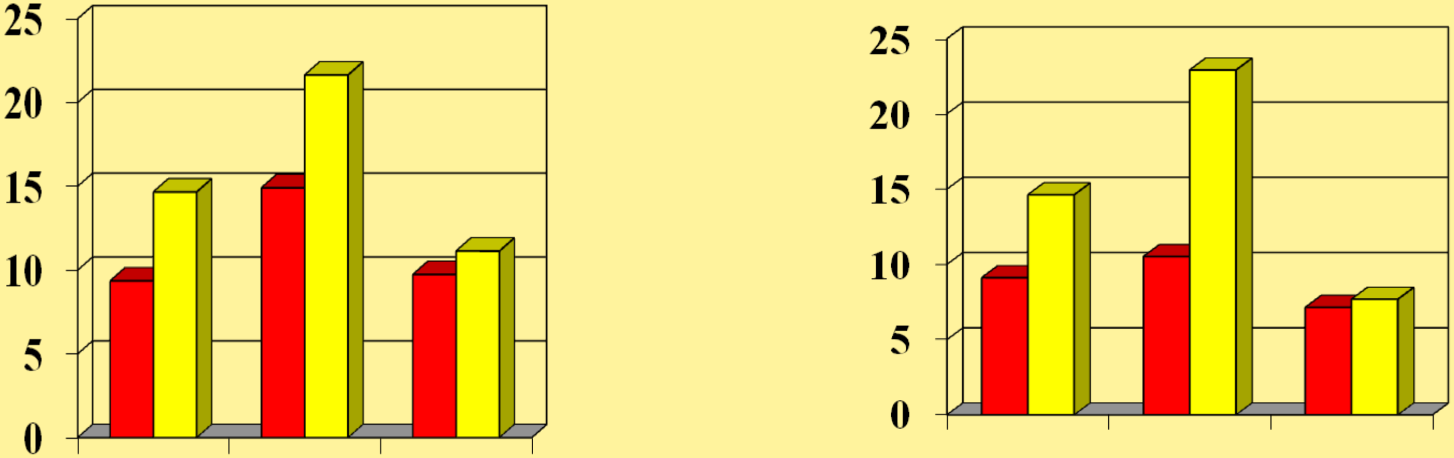


At panicle initiation (PI), <u>light interception</u> in SRI canopies reached 89%, while RMP canopies had only 78% interception -- which gave SRI plants a 15% advantage in the capture of light energy

Xylem Exudation: Effects of rice management practices on exudation rates at early-ripening stage of development, per hill and per area (m^2)

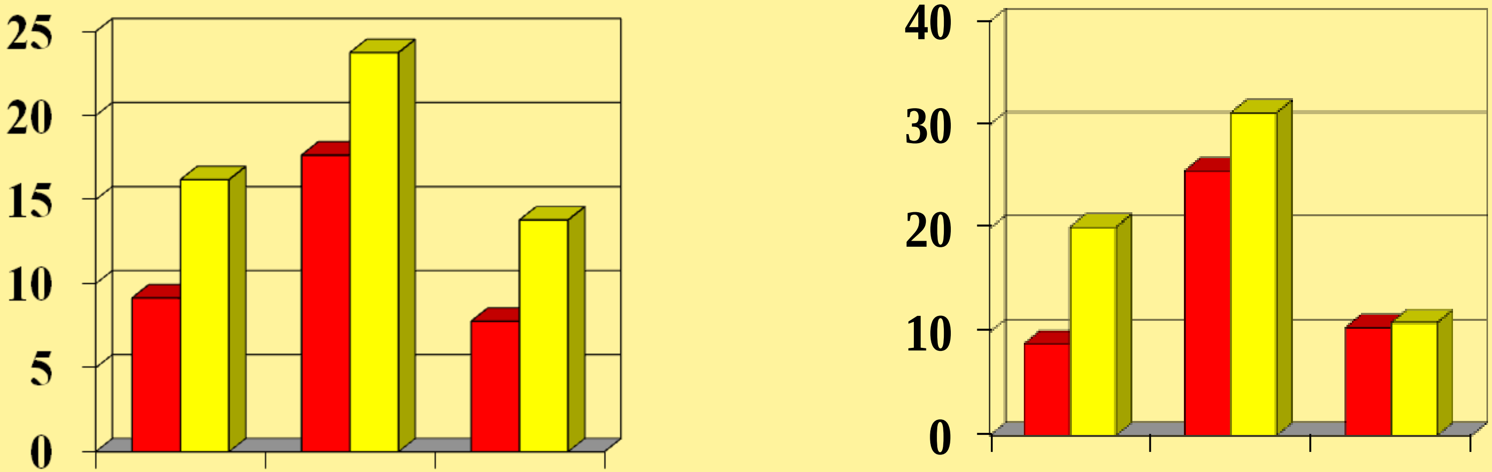
Manage-ment practice	Amount of exudates per hill (g hill^{-1})	Amount of exudates per area (g m^{-2})	Rate per hill (g hill^{-1} h^{-1})	Rate per area (g m^{-2} h^{-1})
SRI	**7.61**	**190.25**	**0.32**	**7.93**
RMP	**2.46**	**122.95**	**0.10**	**5.12**
LSD$_{.05}$	**1.45**	**39.72**	**0.06**	**1.66**

Microbial populations in rice crops' rhizosphere soil under conventional crop management (red) and SRI management (yellow) at different stages: active tillering, panicle initiation, and flowering. Units are √ transformed values of population/gram of dry soil (data from IPB, Indonesia)



Total bacteria

Total diazotrophs



Phosphobacteria

Azotobacter

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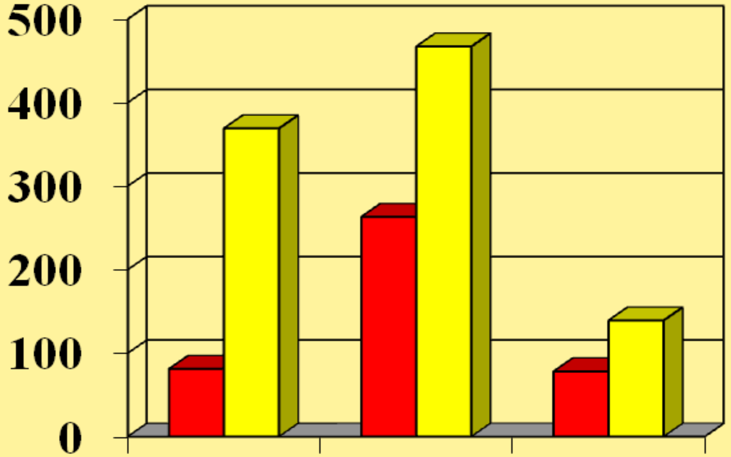
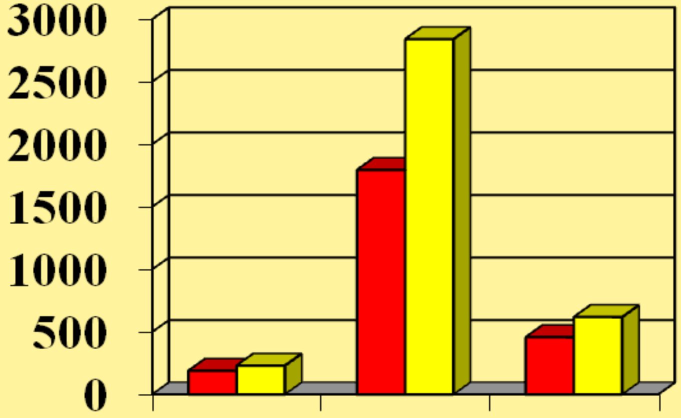
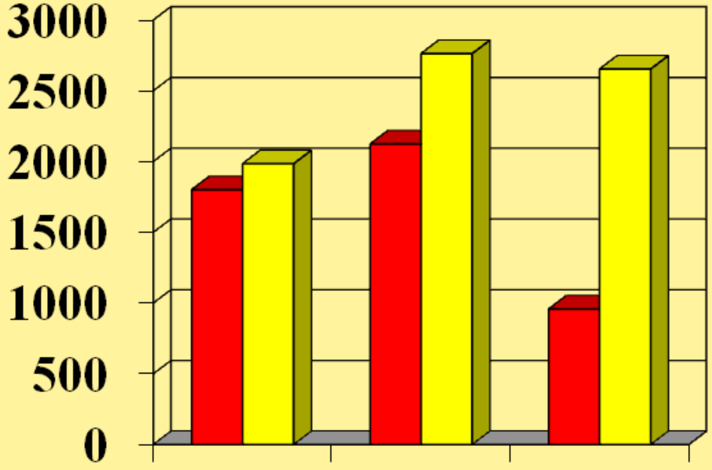
Microbial activity in rice crops' rhizosphere soil under conventional crop management (red) and SRI management (yellow) at different stages: active tillering, panicle initiation, and flowering. Units are √ transformed values of population/gram of dry soil per 24 h



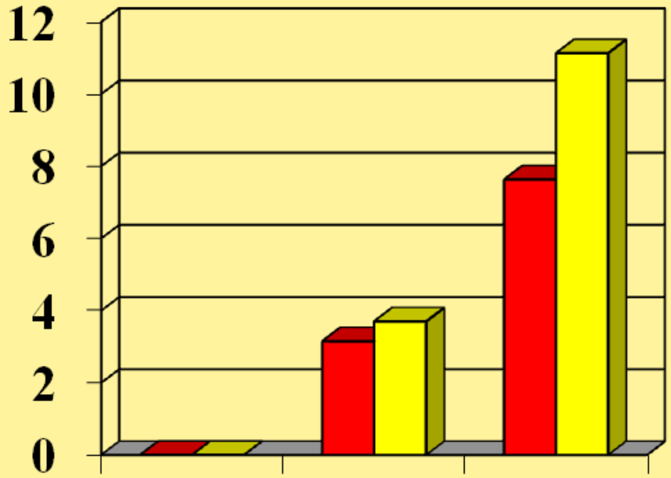
Dehydrogenase activity (µg TPF)



Urease activity (µg NH_4-N))



Acid phosphate activity (µg p-Nitrophenol)



Nitrogenase activity (nano mol C_2H_4)

“Ascending Migration of Endophytic Rhizobia, from Roots and Leaves, inside Rice Plants and Assessment of Benefits to Rice Growth Physiology”

Feng Chi et al., *Applied and Envir. Microbiology* 71: 7271-7278 (2005)

Rhizobium strain	Total plant root vol/pot (cm^3) ± SE	Shoot dry wt/pot (g) ± SE	Net photosynthesis rate (µmol of CO$_2$ m^{-2} s^{-1}) ± SE	Water utilization efficiency ± SE	Grain yield/pot (g) ± SE
Ac-ORS 571	210 ± 36^{A}	63 ± 2^{A}	16.42 ± 1.39^{A}	3.63 ± 0.17^{BC}	86 ± 5^{A}
Sm-1021	180 ± 26^{A}	67 ± 5^{A}	14.99 ± 1.64^{B}	4.02 ± 0.19^{AB}	86 ± 4^{A}
Sm-1002	168 ± 8A^{AB}	52 ± 4^{BC}	13.70 ± 0.73^{B}	4.15 ± 0.32^{A}	61 ± 4^{B}
R1-2370	175 ± 23^{A}	61 ± 8^{AB}	13.85 ± 0.38^{B}	3.36 ± 0.41^{C}	64 ± 9^{B}
Mh-93	193 ± 16^{A}	67 ± 4^{A}	13.86 ± 0.76^{B}	3.18 ± 0.25^{CD}	77 ± 5^{A}
Control	130 ± 10^{B}	47 ± 6^{C}	10.23 ± 1.03^{C}	2.77 ± 0.69^{D}	51 ± 4^{C}

"Proteomic analysis of rice seedlings infected by *Sinorhizobium meliloti* 1021"

Feng Chi et al., *Proteomics* 10: 1861-1874 (2010)

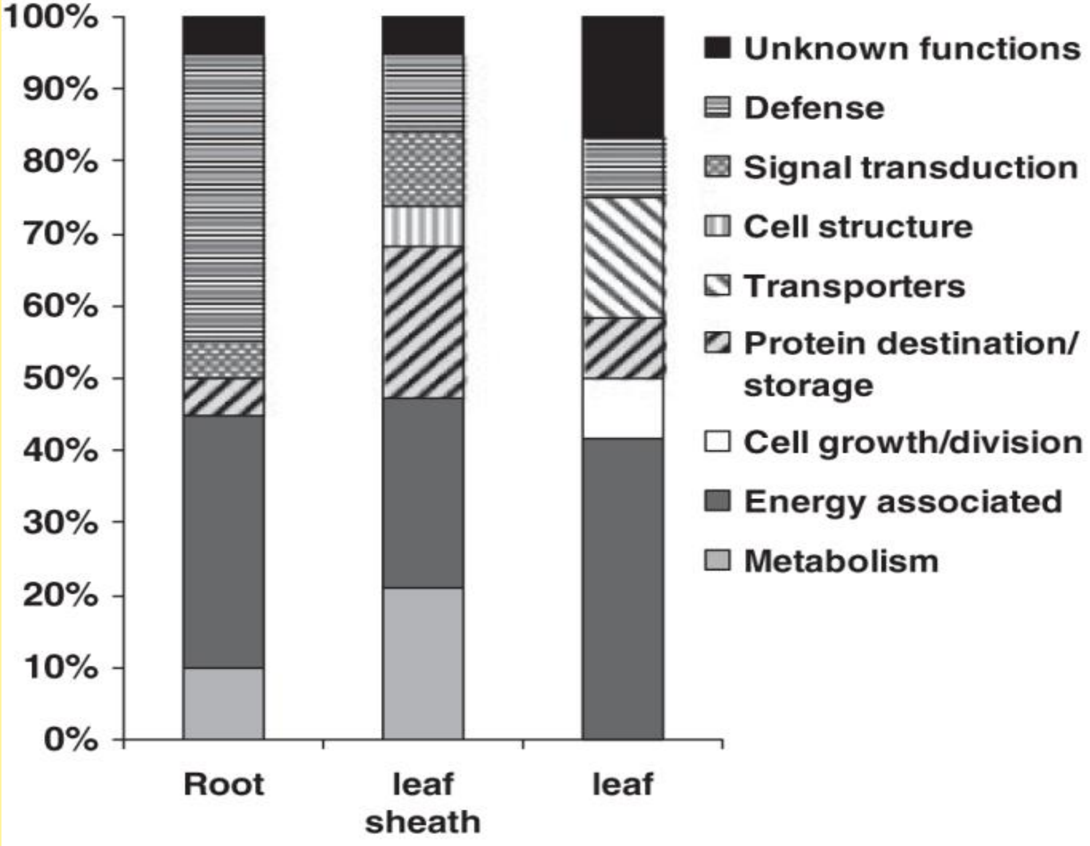
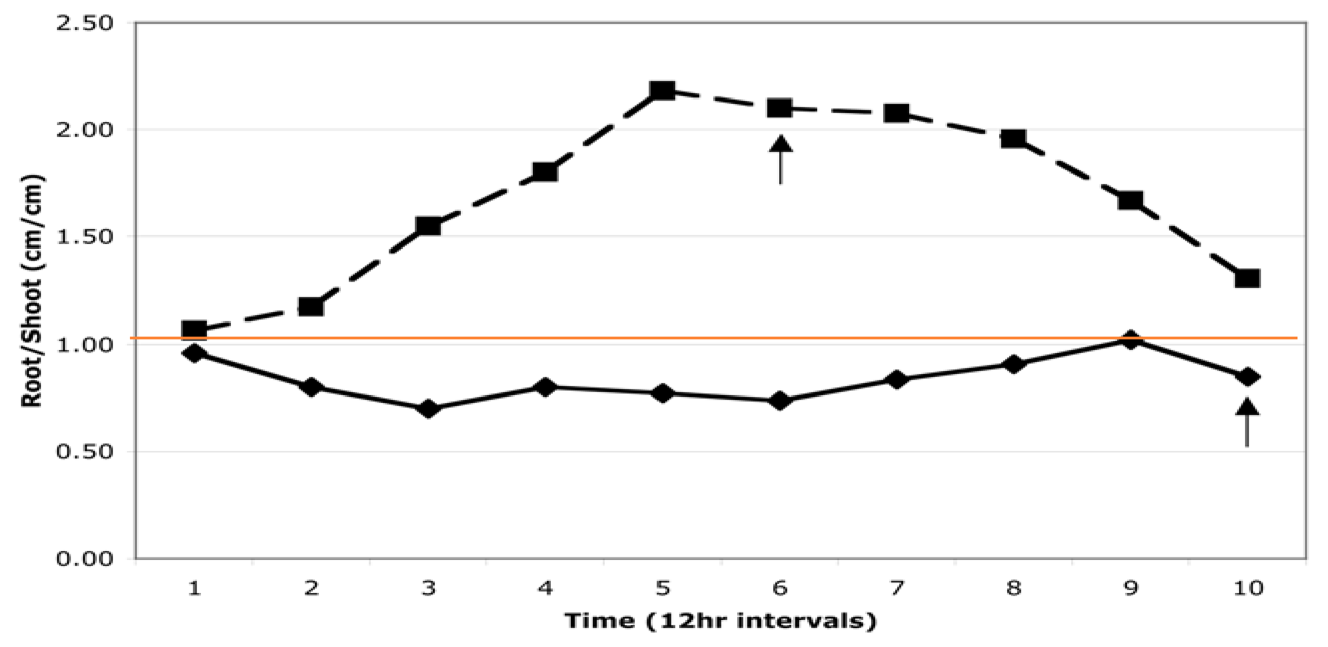


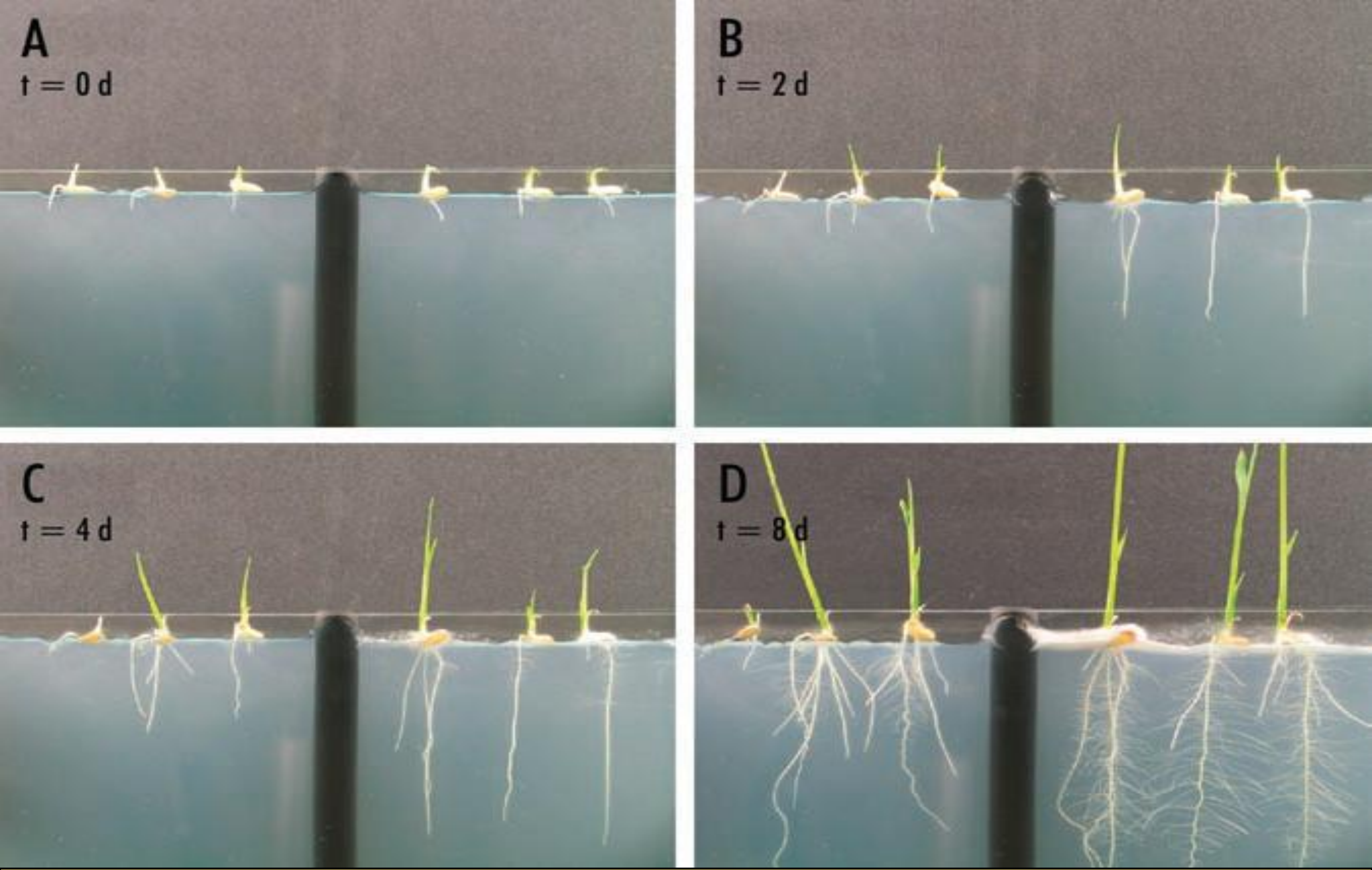
Figure 4. Functional categorization of the differentially expressed proteins in different tissues.

Ratio of root and shoot growth in symbiotic and nonsymbiotic rice plants -- seeds inoculated with the fungus *Fusarium culmorum* vs. controls

R. J. Rodriguez et al., ‘Symbiotic regulation of plant growth, development and reproduction” ***Communicative and Integrative Biology***, 2:3 (2009).



Data are based on the average linear root and shoot growth of three symbiotic (dashed line) and three nonsymbiotic (solid line) plants. Arrows indicate the times when root hair development started.



Growth of nonsymbiotic (on left) and symbiotic (on right) rice seedlings.
On the growth of endophyte (F. culmorum) and plant inoculation procedures, see Rodriguez et al., ***Communicative and Integrative Biology***, 2:3 (2009).

Higher ***in-plant water-use efficiency*** from more productive plant phenotypes as measured by the ratio of **photosynthesis** to **transpiration**

For each 1 millimol of water lost by transpiration:

3.6 μ mols of CO_2 are fixed in SRI plants,

1.6 μ mols of CO_2 are fixed in RMP plants

Such physiological modifications become more important with climate change

"An assessment of physiological effects of the System of Rice Intensification (SRI) compared with recommended rice cultivation practices in India," A.K. Thakur, N. Uphoff and E. Antony
Experimental Agriculture, *46(1), 77-98 (2010)*

A Life Cycle Assessment (LCA) of Greenhouse Gas Emissions from SRI and Flooded Rice Production in SE India

Alfred Gathorne-Hardy, with D. Narasimha Reddy, M. Venkatanarayana, and
Barbara Harriss-White, Oxford University, UK, and NIRD, Hyderabad
Taiwan Water Conservancy, 61:4 (2013), 100-125.

Considering both CH_4 and N_2O from total production cycle, **SRI paddies emitted >25% less GHG** per ha (in CO_2-eq), and **>60% less net GHG emissions per kg of paddy rice** given the 58% higher yield per hectare with SRI management.

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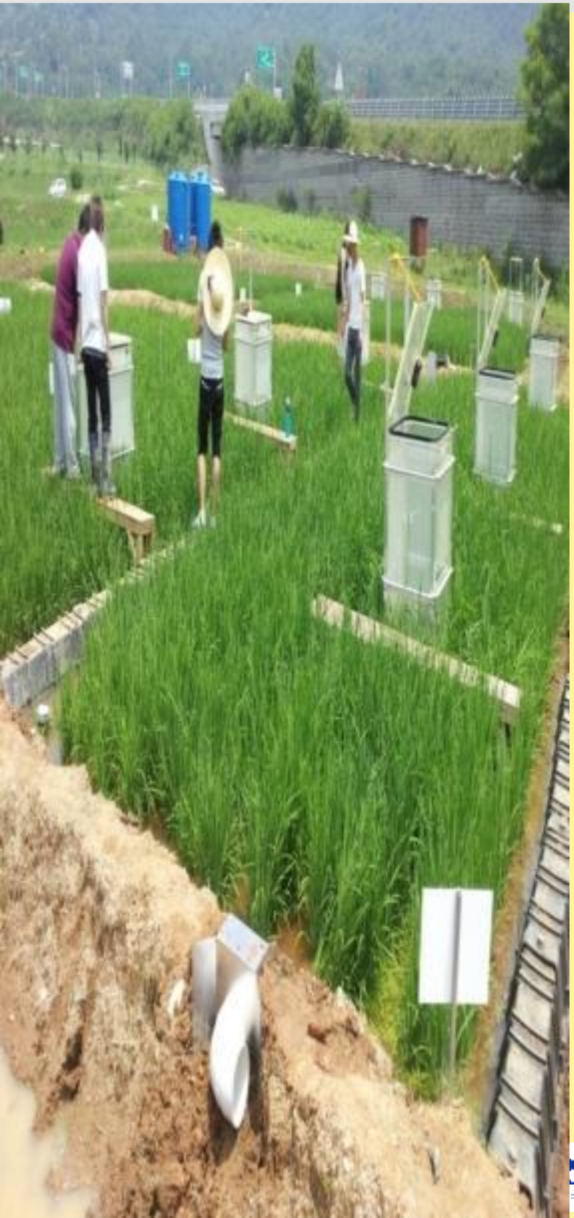
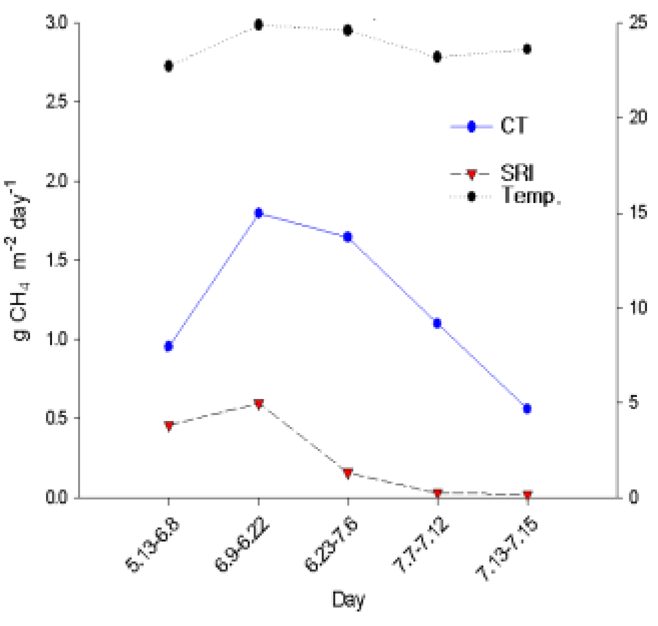
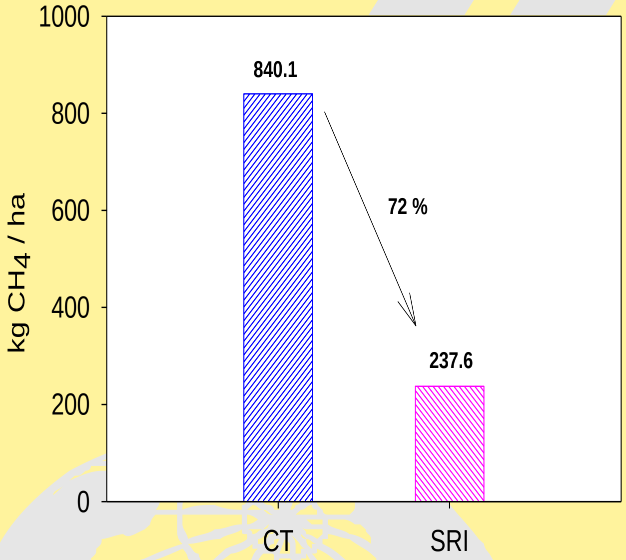
* A study in Vietnam found **significant 20% reduction in CH_4**, and a **non-significant reduction of 1.5% in N_2O** (*Promoting the System of Rice Intensification: Lessons Learned from Trà Vinh Province, Vietnam*, GIZ/IFAD, Hanoi, 2013.

* Korean study found **65-73% reduction in GHG emissions** (CO_2- eq) compared to conventional flooded rice production (J.D. Choi, et al., *Irrigation and Drainage*, 63:263-270 (2014).

Comparison of methane gas emission







Treatment	Emission (kg/ha)		CO_2 ton/ha equivalent
	CH_4	N_2O	
CT	840.1	0	17.6
SRI	237.6	0.074	5.0

Much more remains to be researched and to become known – SRI is still ‘a work in progress’

An **agronomic paradigm shift** is already underway:

1. Focus in genetics is moving to **epigenetics**
2. Research on the **plant-soil microbiome** needs to catch up with work on the ***human microbiome***
3. We need much more research on **root systems**
4. Also we need more research on **soil ecology**!

The SRI approach to agriculture has succeeded not only because it has worked 'outside the box' of the current agronomic paradigm of the GR.

SRI also is shifting the prevailing paradigm for research and extension, which privileges *formal scientific knowledge and training* over *farmer observation and experimentation*.

SRI could not have gotten this much acceptance within a decade if it had been nurtured within the 'bosom' of our present research and extension modalities, institutions and thinking.

SRI introduces a more farmer-centered strategy for making further agricultural improvements.

This *will not displace or derogate* formal science-based research

But SRI's emergence suggests need for synthesis between formal and farmer knowledge, especially

*** To cope with hard-core challenges of continuing hunger and poverty, on the one hand, and**

*** To buffer against the effects of adverse climatic changes, on the other.**

We thus need to achieve a parallel paradigm shift for socio-economics, institutions and poilicy.

THANK YOU

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