IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

Centre de coopération internationale en recherche agronomique pour le development
CIRAD
Montpellier, France

Enhancing crop performance: the challenge of integrating crop establishment strategies with effective plant traits

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IRRI, 17 November 2005

Outline

- Background
- **Plant response to nursery management**
  - Transplanting age
  - Seed density in the nursery
  - tiller mortality rate
- **Hybrid rice superiority**
  - Dry matter partitioning
  - Plant response to canopy competition
- **Plant response to sparse canopy (early stage)**
- **Prospects**

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Irrigated rice ecosystems

- **Significant yield gap: potential of 10 t ha^{-1} whereas average of 5 t ha^{-1}**
- **Decreasing cultivated land area**
- **Decreasing manpower**
- **Reducing pesticide and fertilizer losses**

→ Need to increase crop efficiency

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Goal

- **Improving rice productivity in favorable production systems by approaching yield potential and increasing resources use efficiency**

Challenge

- **"Heritability for yield under stress is usually higher than heritability for related physiological traits"**

Gary Atlin, 25 August 2005

- **Can we identify effective plant traits to improve the performance and efficiency of the irrigated crop?**

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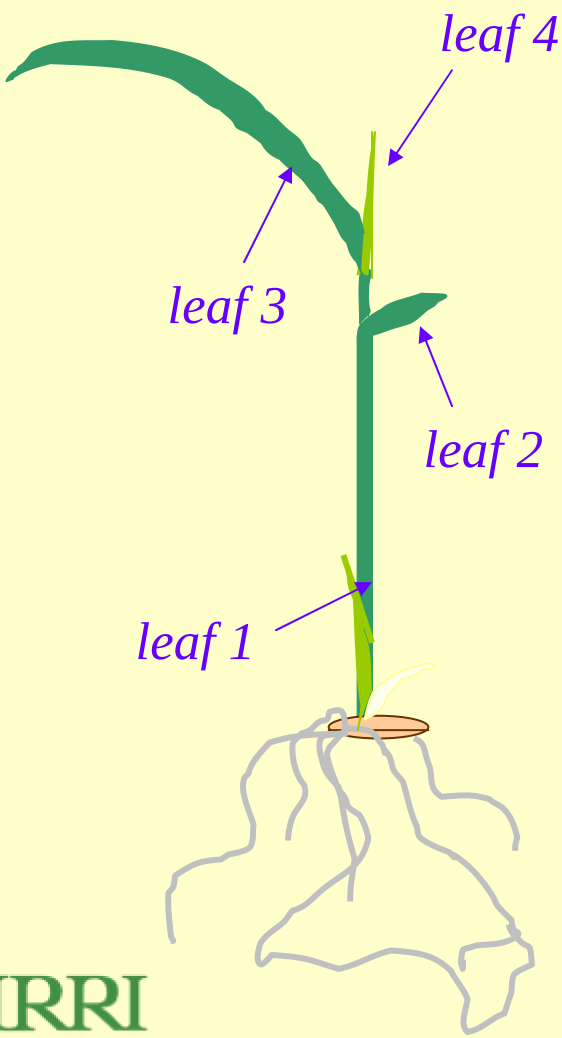
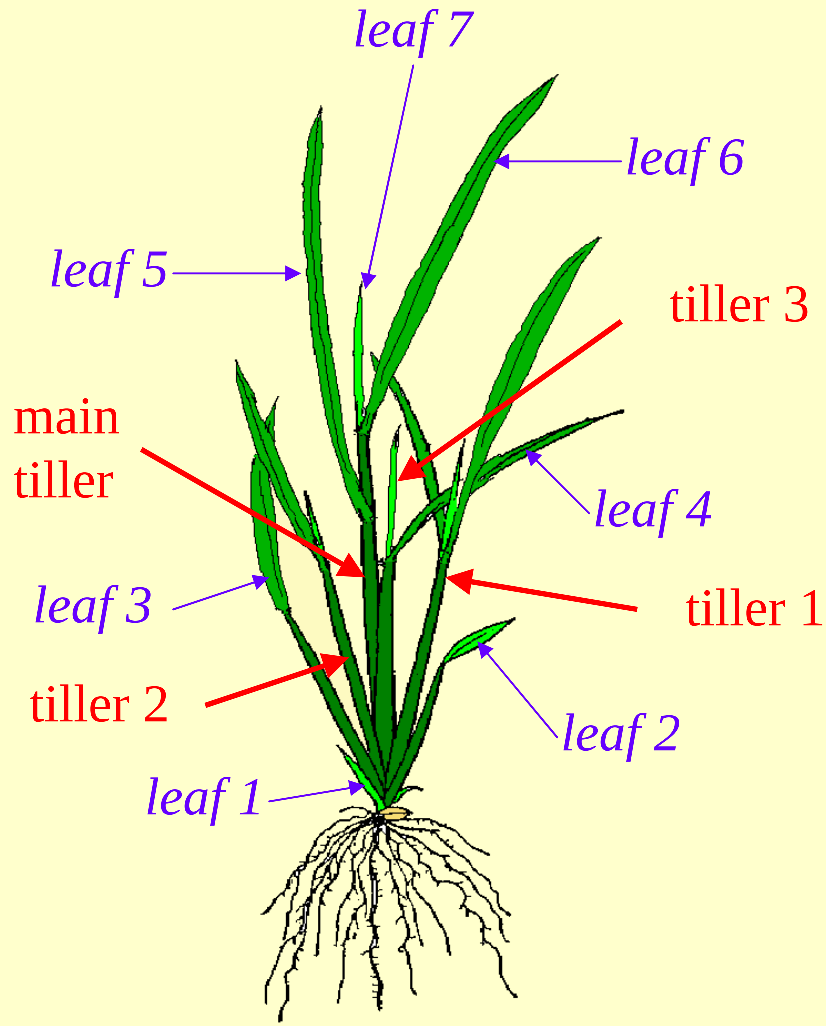
Leaf and tiller count





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Plant response to early transplanting

Common nursery management:

- **Transplanting 20 to 30 days-old seedlings (7 to 10-leaf stage)**
  - Farmers prefer to transplant old seedlings
  - High tiller senescence if early transplanting may induce significant dry matter loss
- **Sowing in the nursery from 3000 to 10000 seeds m^{-2} (75 to 250 g seeds m^{-2})**

Plant response to early transplanting

Crop establishment	Grain yield ($t\ ha^{-1}$)	
	I1	H1
7 days transplanting	**6.99**	**7.75**
14 days transplanting	**6.55**	**7.59**
21 days transplanting	**6.06**	**6.97**

I1: IR72 *H1: IR75217H*

- same sowing date
- same plant density
- same nutrient management

Higher grain yield with early transplanting valid for:

- contrasted genotypes (inbreds, NPTs, hybrids)
- wet and dry seasons (larger gap in the dry season)
- different locations (Philippines, Indonesia,…)

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Plant response to early transplanting

Transplanting, hill spacing 20 x 20 cm

I1 in the main field,
34 days after sowing
for all 3 situations

transplanted 7 days after sowing

transplanted 14 days after sowing

transplanted 21 days after sowing

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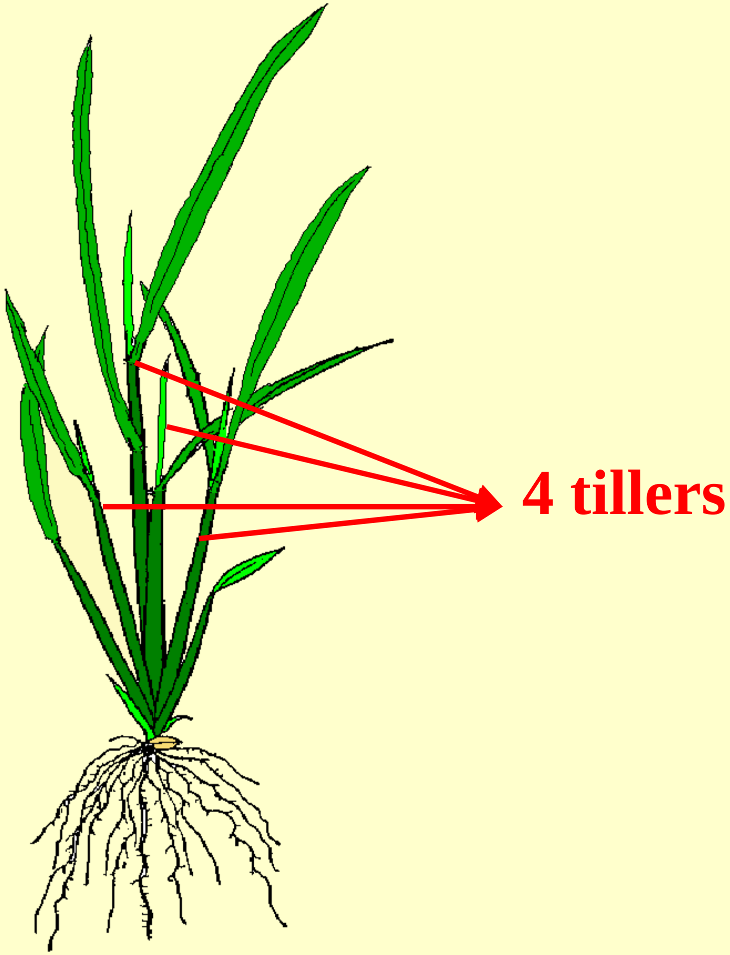
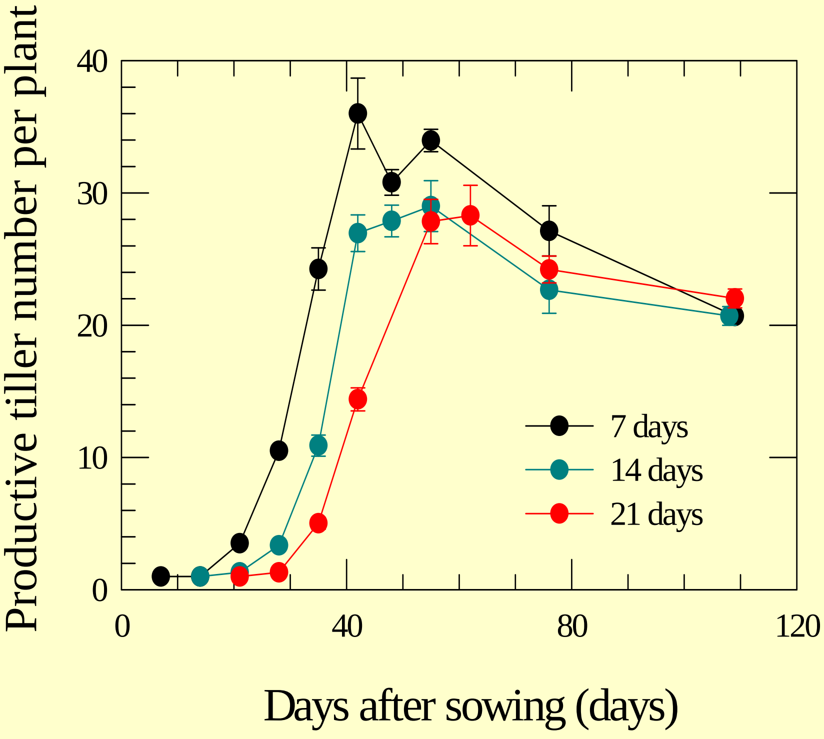
Plant response to early transplanting





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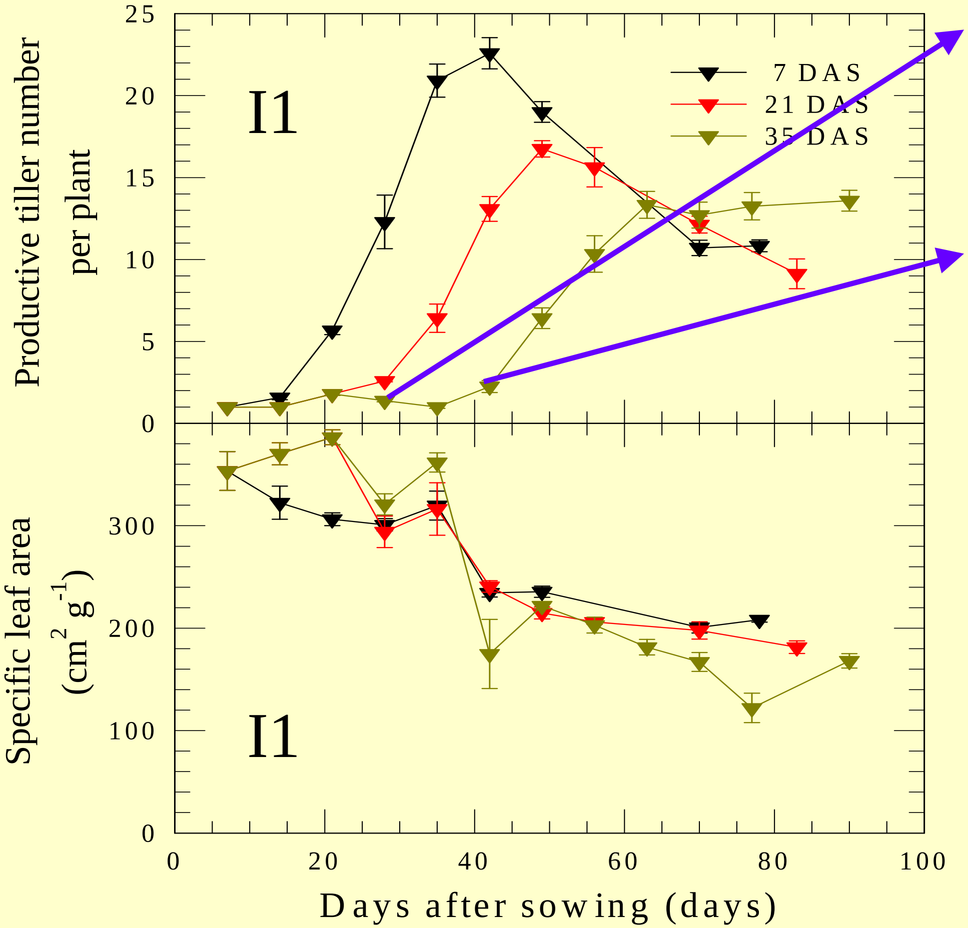
Plant response to early transplanting

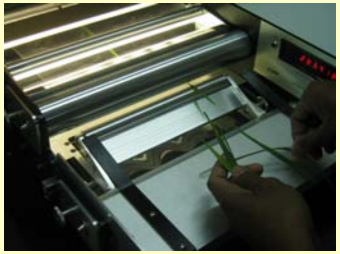
Nursery density: 3000 seeds m^{-2}



- Tiller emergence was delayed if extended stay in the nursery

- Tiller emergence resumed right after transplanting whatever the age

Calculation of specific leaf area



$$SLA = \frac{\text{leaf area}}{\text{leaf dry weight}}$$

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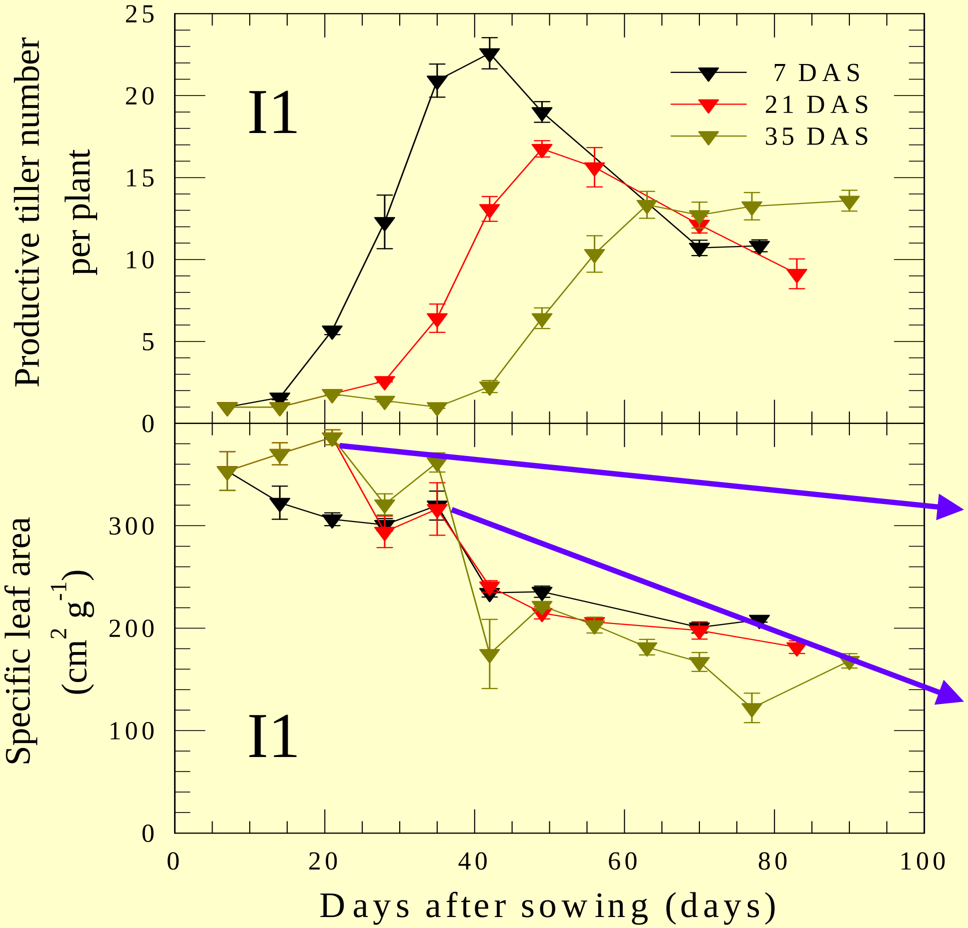
Plant response to early transplanting

Nursery density: 3000 seeds m^{-2}



- **Tiller emergence was delayed if extended stay in the nursery**

- **Tiller emergence resumed right after transplanting whatever the age**

- **SLA increased in the nursery if transplanting was delayed**

- **SLA resumed to the control value right after transplanting**

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No transplanting shock was observed on tiller emergence

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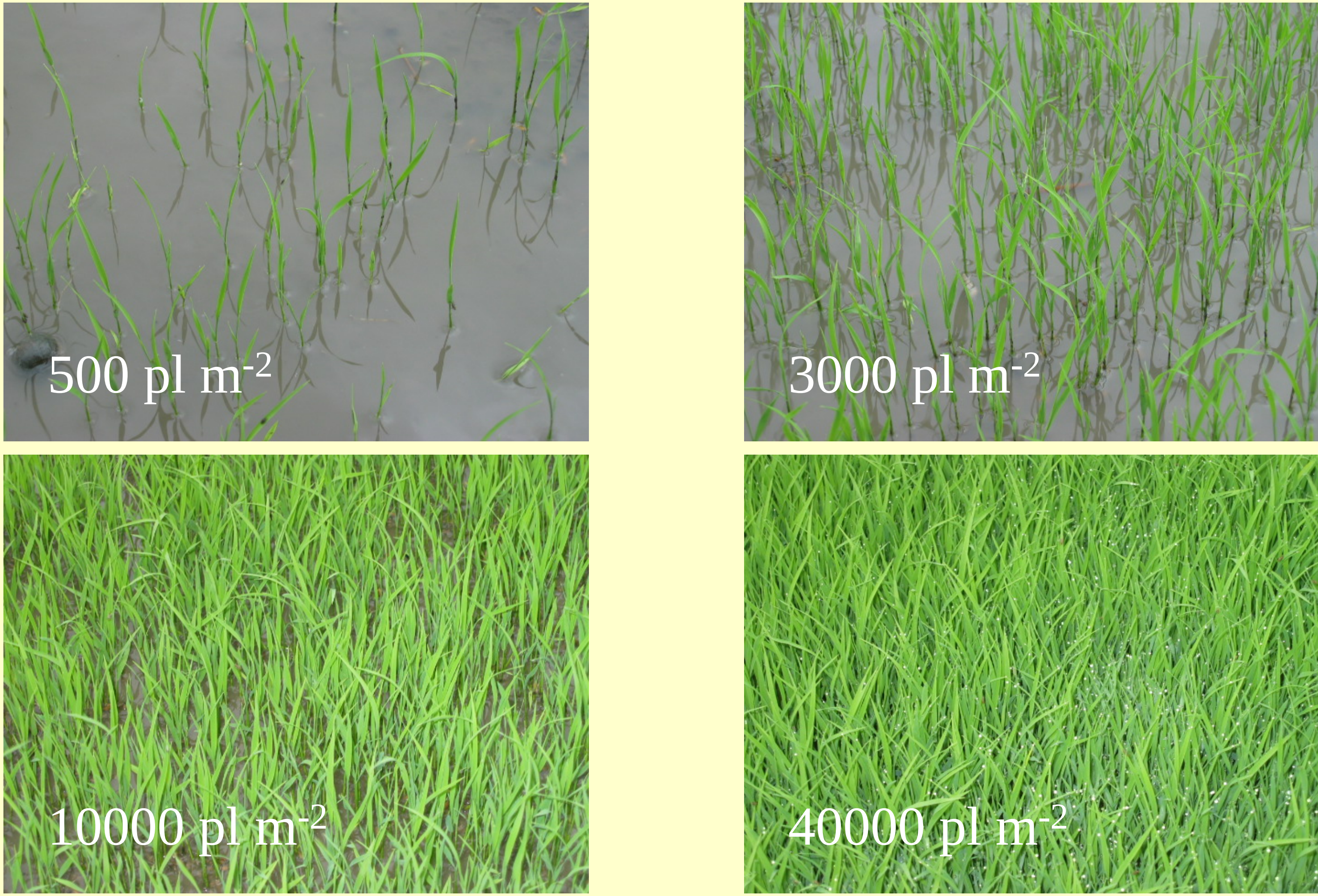
Plant response to seed density



I1 in the nursery, 6 days after sowing

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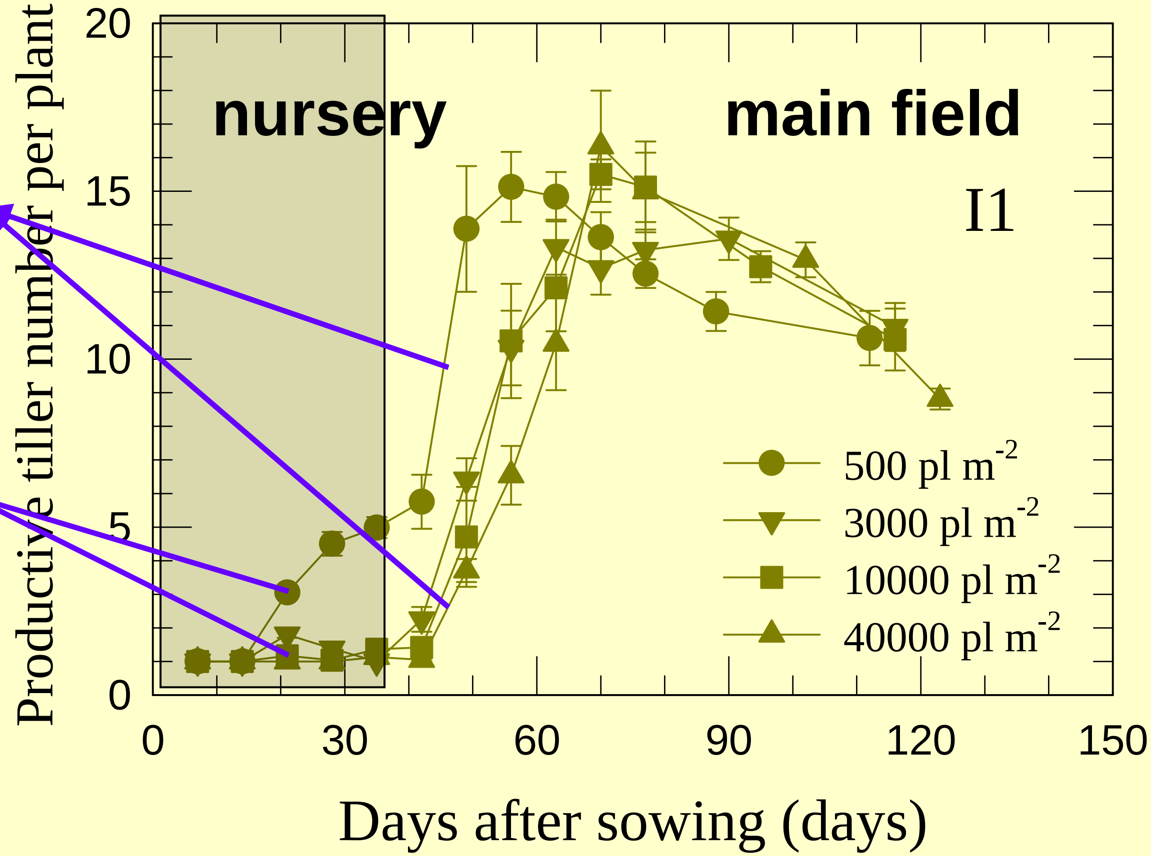
Plant response to seed density

Transplanting 35 days after sowing

-Tiller emergence resumed right after transplanting whatever the density

- Tiller emergence was delayed if high density in the nursery



No transplanting shock was observed on tiller emergence

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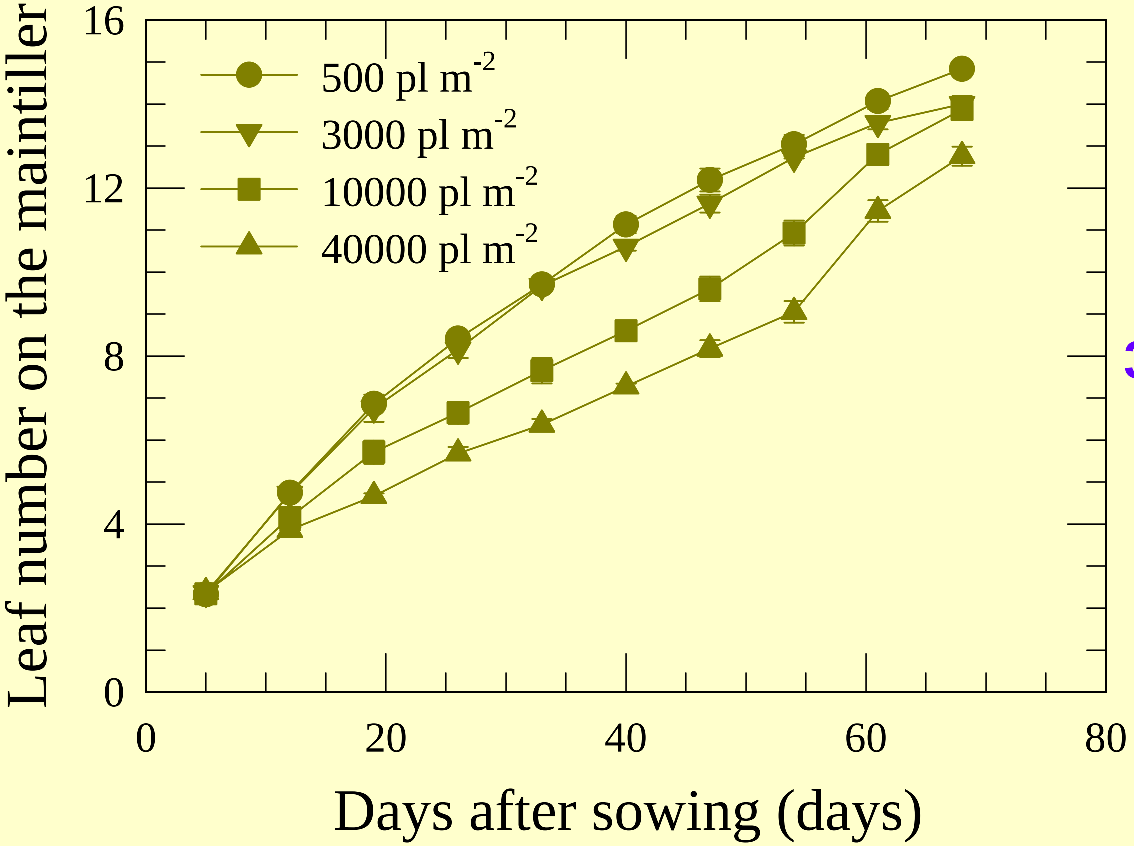
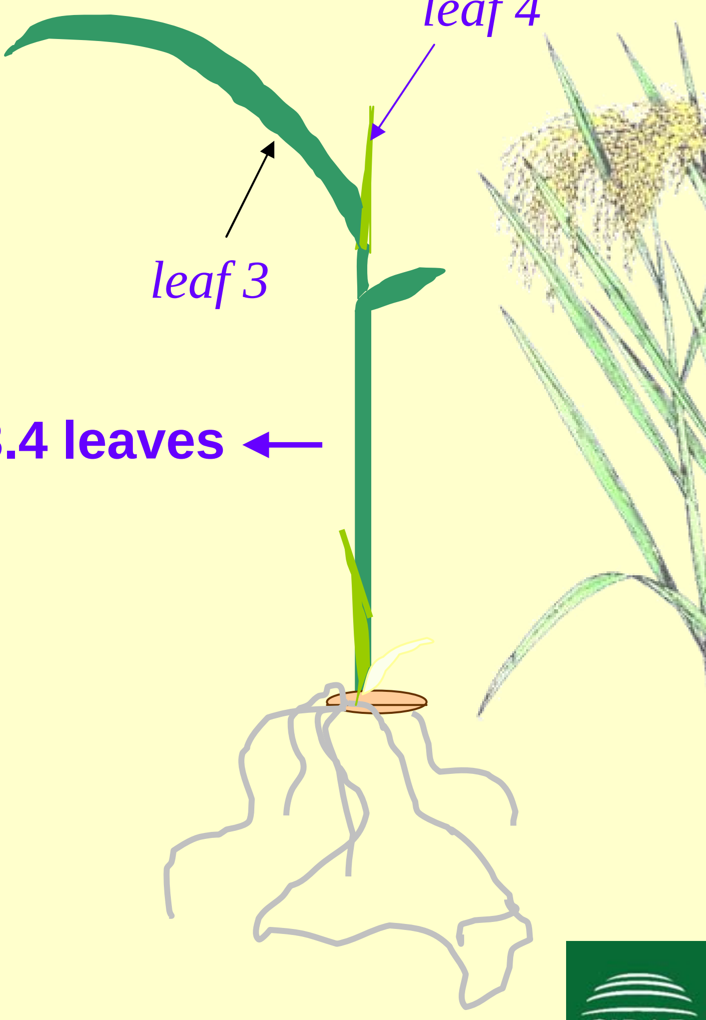
Plant response to seed density

Transplanting 35 days after sowing



3.4 leaves



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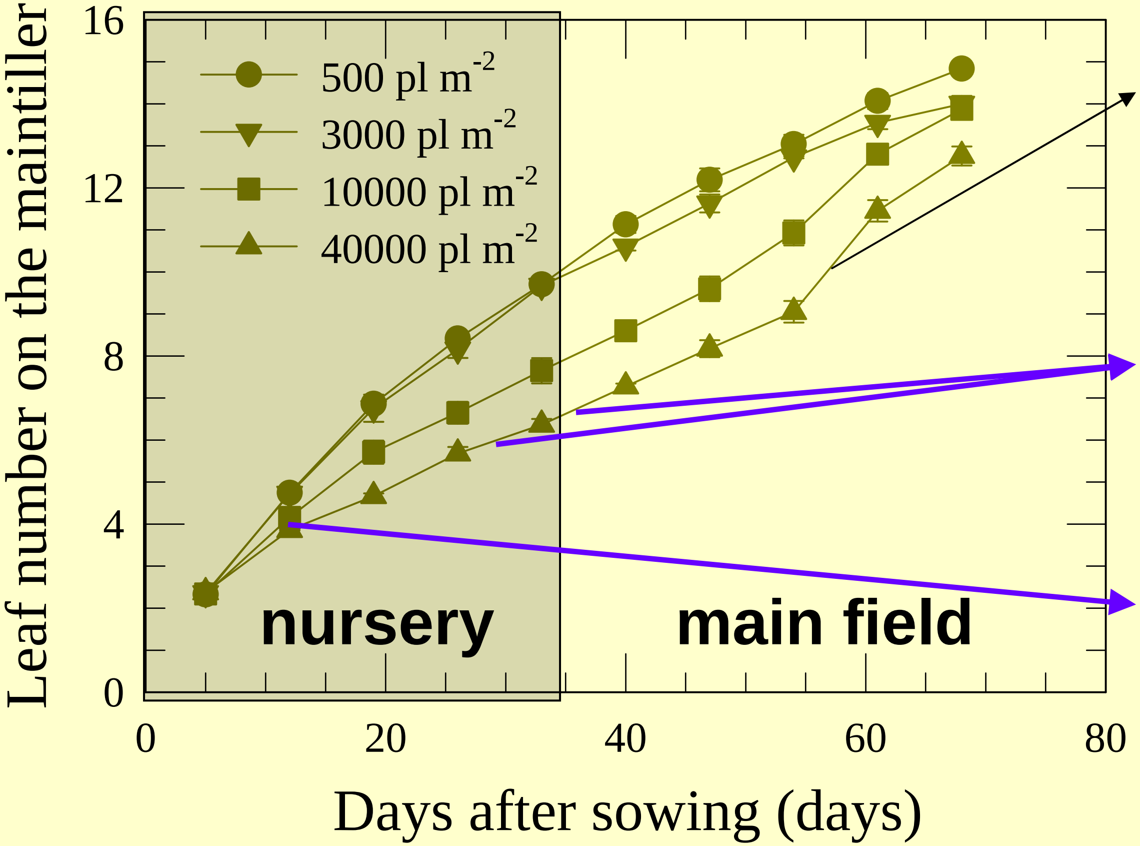
Plant response to seed density

Transplanting 35 days after sowing



- Leaf emergence recovery from competition in the nursery only visible 20 days after transplanting

- **Leaf emergence was similar before and after transplanting whatever the seed density**

- **Leaf emergence was affected in the nursery if high density**

No transplanting shock was observed on leaf emergence

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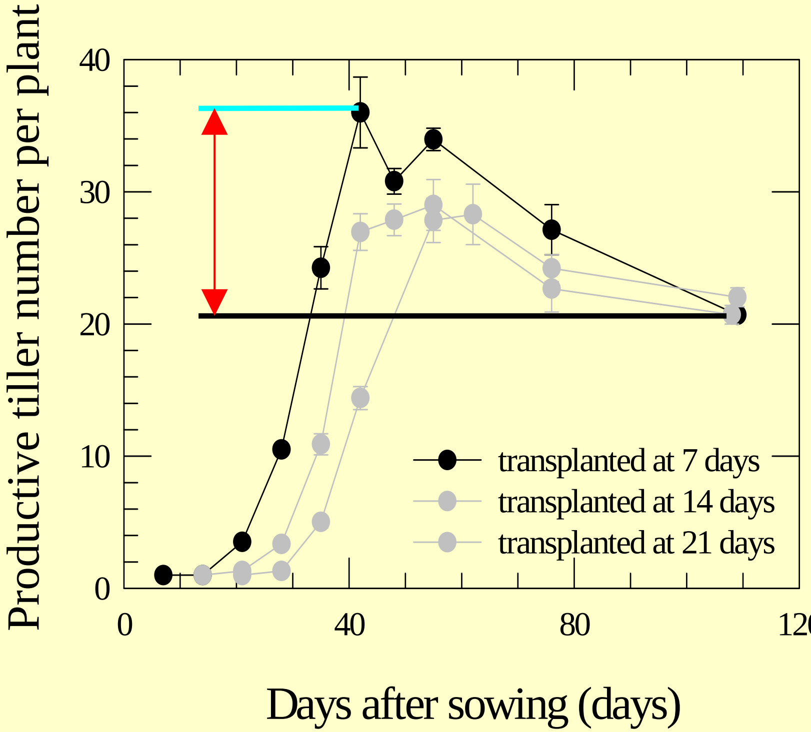
Plant response to nursery management

- **Early transplanting induced an increase in grain yield (up to 1 t ha^{-1} in these conditions)**
- **Early transplanting shall promote a significant reduction in nursery area**
- **No transplanting shock was observed**
  - High seedling density in the nursery induced a delay in leaf and tiller emergence and an increased in SLA
  - Recovery in tiller emergence and SLA was observed right after transplanting, whatever the seed density and transplanting age were
  - Leaf emergence was not affected by transplanting

Impact of tiller mortality rate

Tiller mortality rate:

$$\text{TMR} = \frac{\text{senescent tillers}}{\text{total tillers}}$$



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Impact of tiller mortality rate

Crop establishment	Grain yield (t ha^{-1})		Tiller mortality rate	
	I1	H1	I1	H1
7 days transplanting	**6.99**	**7.75**	**0.53**	**0.50**
14 days transplanting	**6.55**	**7.59**	**0.44**	**0.44**
21 days transplanting	**6.06**	**6.97**	**0.39**	**0.36**

Did high tiller senescence reduce the impact of the positive effect of early tiller emergence on grain yield?

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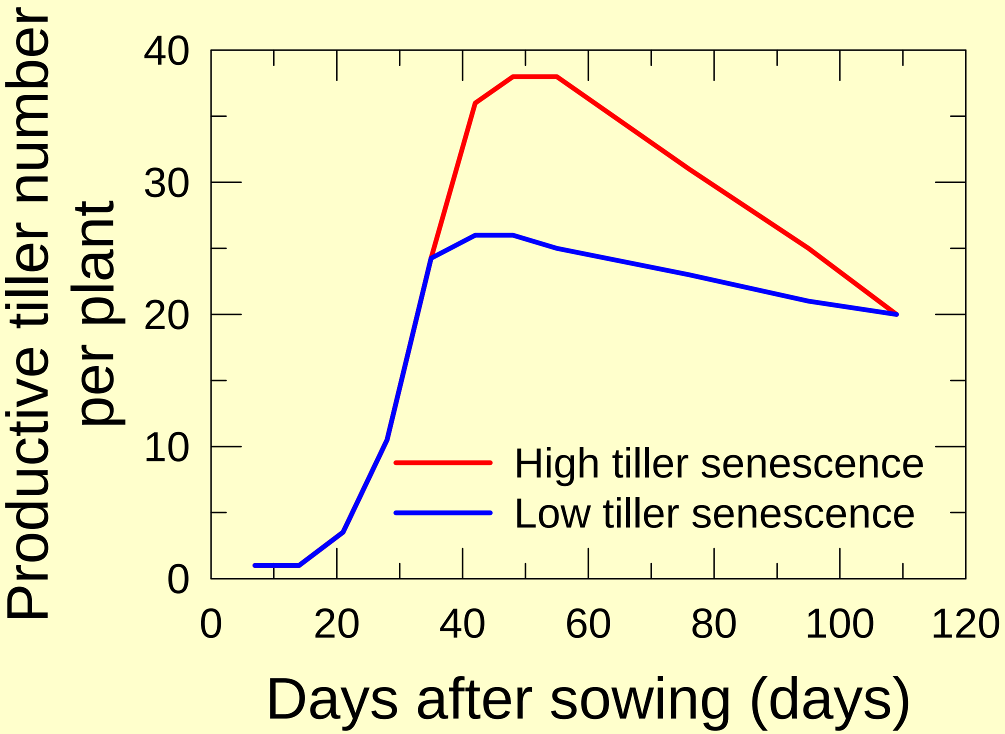
Impact of tiller mortality rate



Conceptual framework:
to achieve similar tiller emergence and tiller fertility but contrasted tiller mortality rate

How to get this contrast in plant response?

Tiller emergence is affected by water depth

⇒ Increase in water depth at mid-tillering

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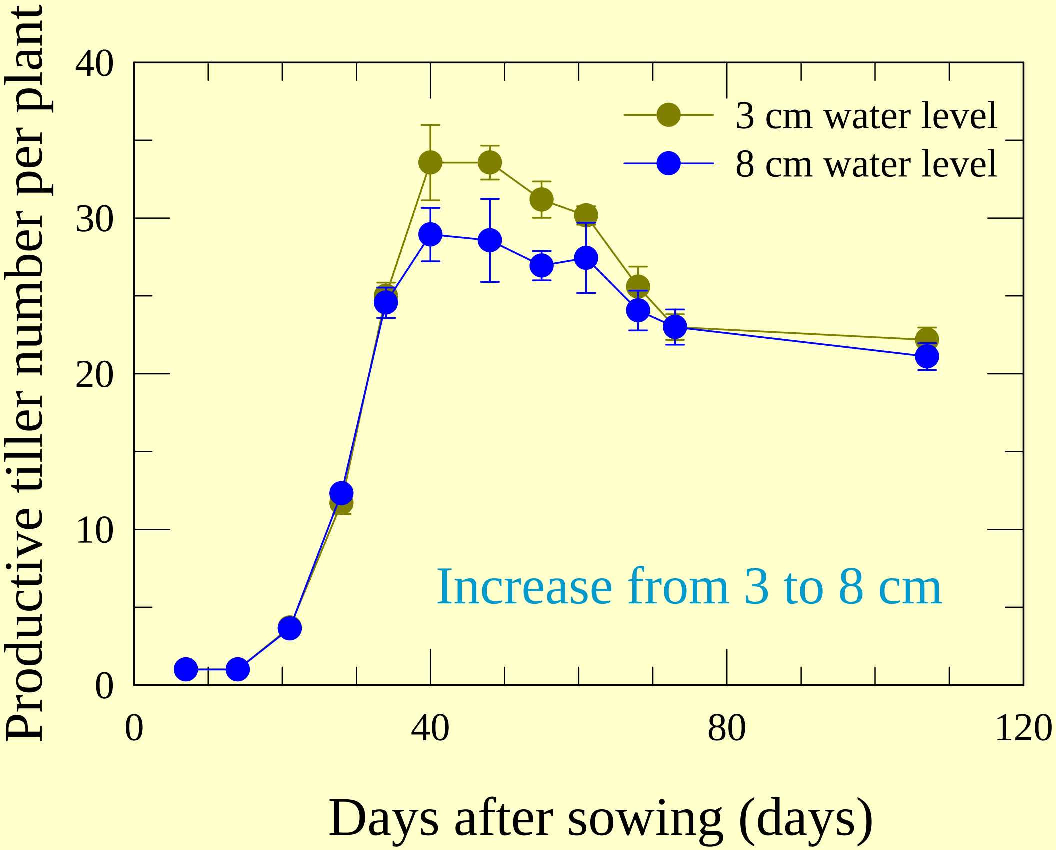
Impact of tiller mortality rate

Transplanting, hill spacing 20 x 20 cm

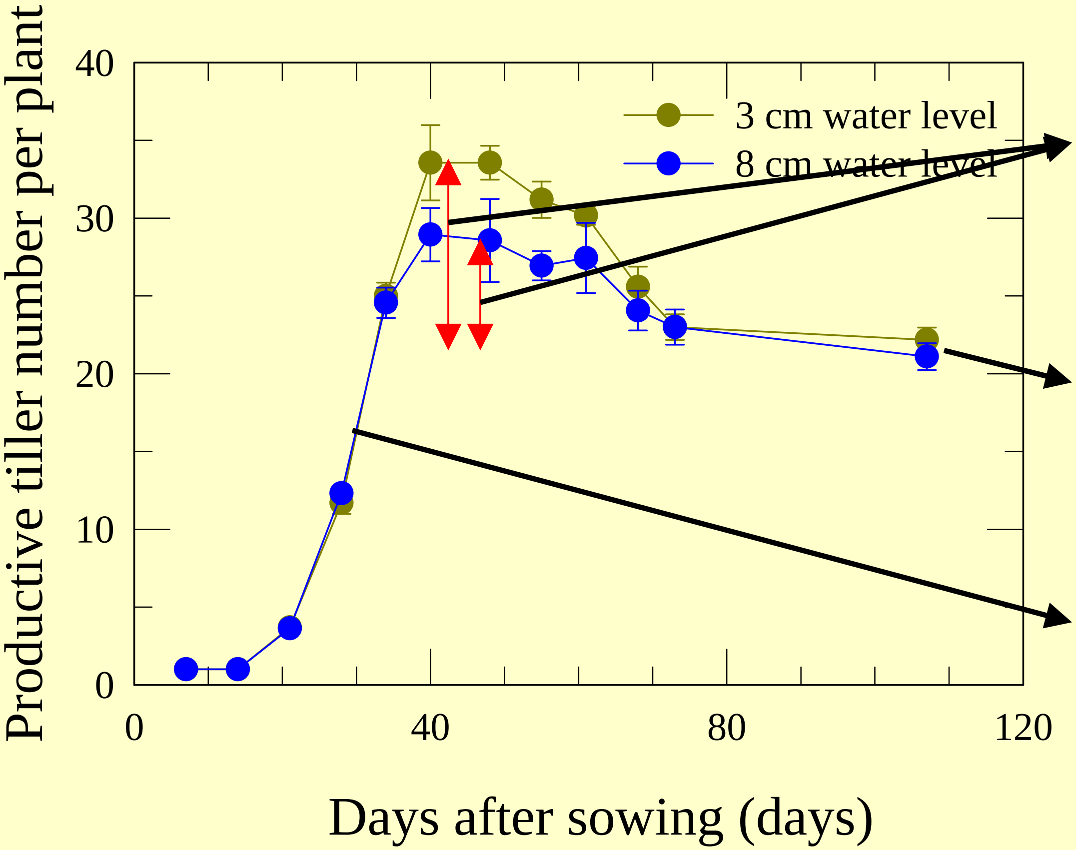


Tiller emergence is affected by water depth

⇒ Increase in water depth at mid-tillering

Impact of tiller mortality rate

Transplanting, hill spacing 20 x 20 cm



- **Decrease in TMR from 0.33 to 0.24**

- **Similar productive tiller number**

-**Similar rate in tiller emergence**

Has grain yield increased?

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Impact of tiller mortality rate

Genotypes	Water management	Tiller mortality rate	Grain yield (t/ha)	Tiller density (m^{-2})	Per productive tiller		Grain size (g)
					Filled grain dry weight (g)	Filled grain number	
I1	3 cm water level	**0.33**	**6.89**	554	1.60	72.2	22.2
	8 cm water level	**0.24**	**6.61**	527	1.45	64.5	22.6
H1	3 cm water level	**0.33**	**9.08**	473	2.17	91.8	23.6
	8 cm water level	**0.25**	**9.08**	465	2.20	92.3	23.8

Grain yield was unchanged for both genotypes

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Plant response to nursery management

- **Early transplanting increased tiller mortality rate (for contrasted genotypes and seasons)**
- **High tiller mortality rate did not affect yield**
  - Tiller senescence:
    - concerned small tillers then low plant dry matter
    - concerned non-competitive tillers for access to light because inside the canopy
    - may have contributed to higher dry matter accumulation in productive tillers through efficient remobilization

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Hybrid rice superiority

- **Higher grain yield of hybrid rice in the tropics:**
  - Higher early biomass accumulation (greater leaf area production but similar tiller production) during the dry season
  - Higher harvest index during the wet season

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Hybrid rice superiority

***Dry season**, hill spacing 20 x 20 cm, same crop duration*

Season	Seedling age	Variety	Grain yield *t ha^{-1}*	Harvest index
2003	7 days	I1	6.99	0.43
		H1	7.75	0.53
	14 days	I1	6.34	0.46
		H1	6.98	0.55
2004	7 days	I1	6.89	0.46
		H1	9.08	0.53

Higher grain yield
and higher harvest index
for H1 compared to I1
in the dry season

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Hybrid rice superiority

***Wet season**, hill spacing 20 x 20 cm, same crop duration*

Season	Seedling age	Variety	Grain yield *t ha⁻¹*	Harvest index
2003	7 days	I1	5.18	0.34
		H1	6.68	0.38
	14 days	I1	5.10	0.34
		H1	5.98	0.41
2004	7 days	I1	5.22	0.41
		H1	6.13	0.45

Higher grain yield
and higher harvest index
for H1 compared to I1
in the wet season

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Any hypothesis to explain the difference in HI?

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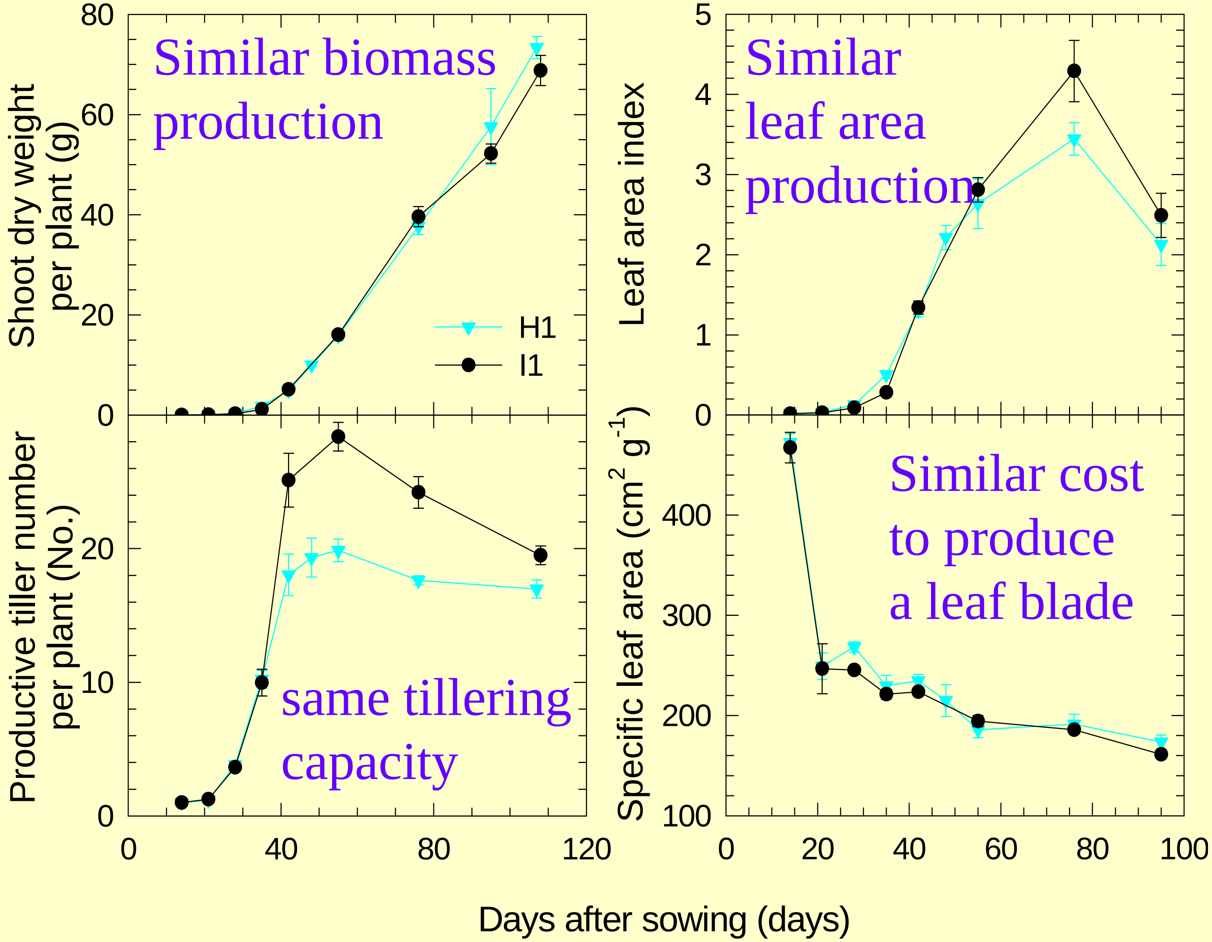
Dry matter partitioning

Dry season, hill spacing 20 x 20 cm, same crop duration



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Similar early vigor in the dry season

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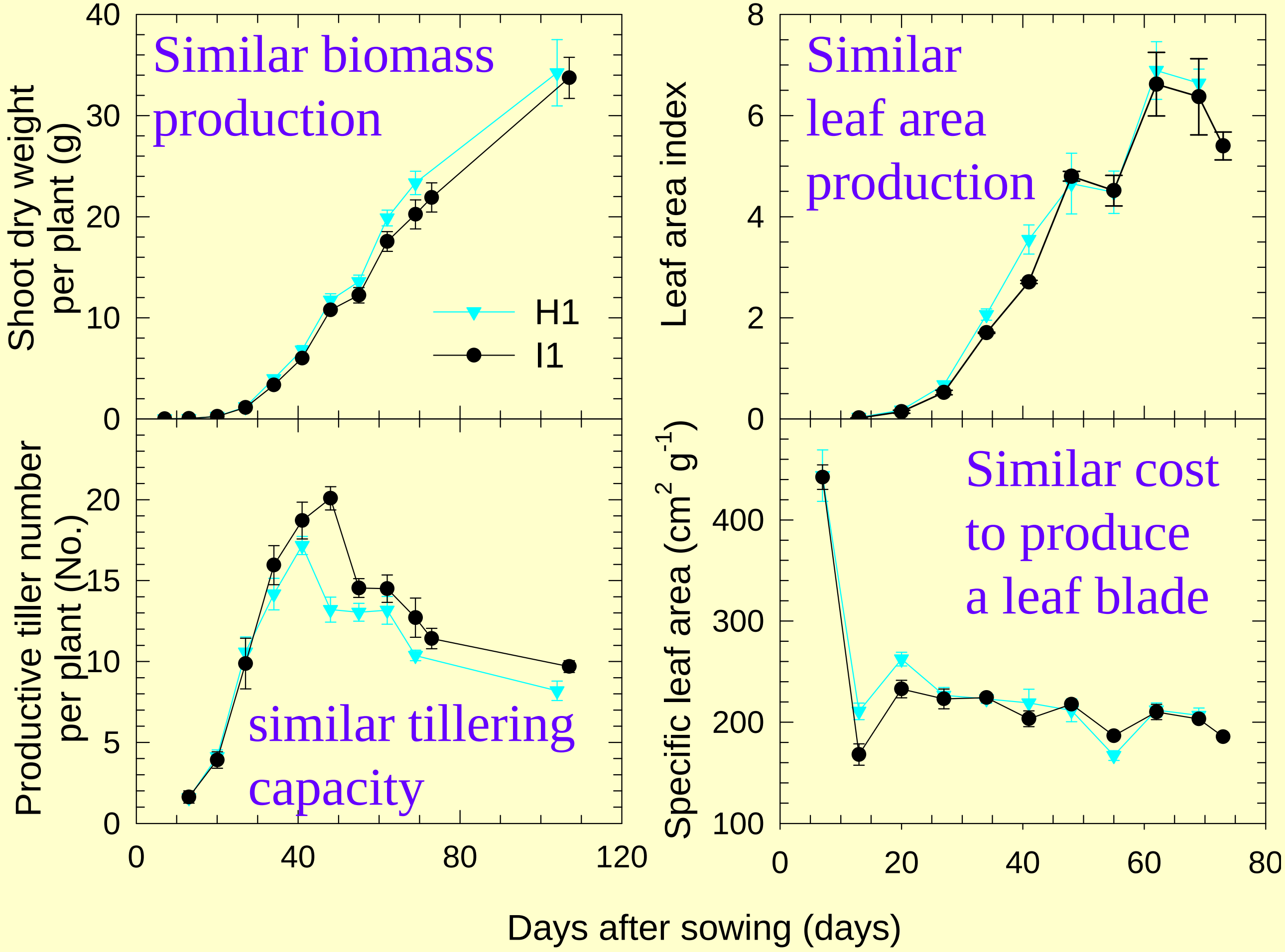
Dry matter partitioning

Wet season, hill spacing 20 x 10 cm, same crop duration



Similar early vigor in the wet season

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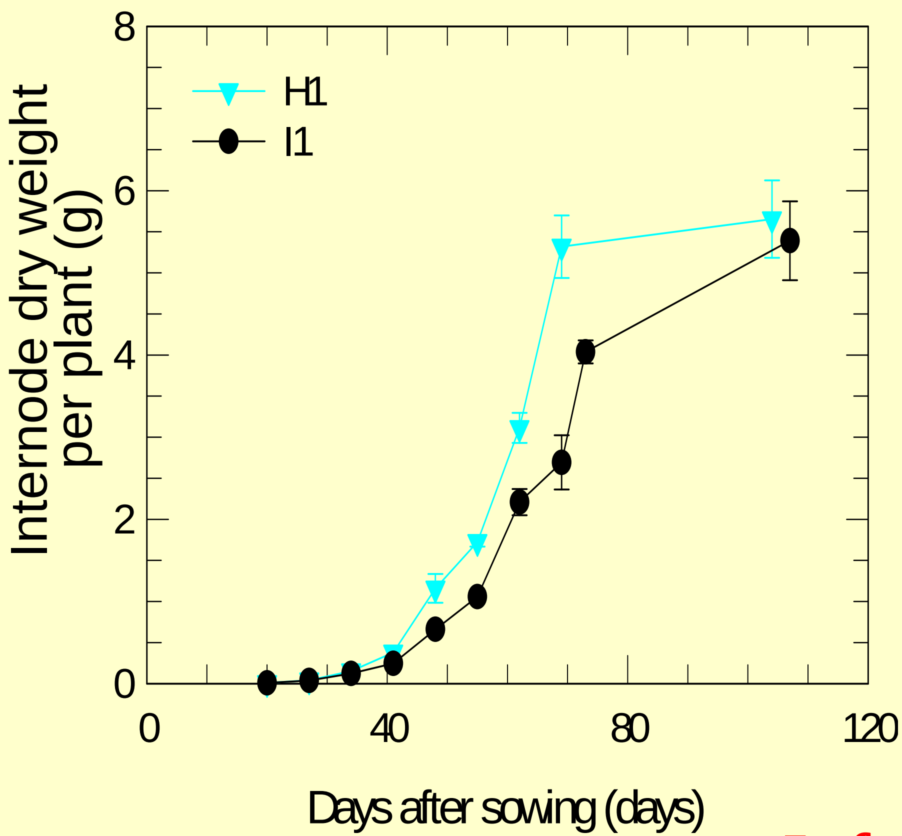
Dry matter partitioning

Wet season, hill spacing 20 x 10 cm, same crop duration



Faster internode elongation for H1 compared to I1

No increase in H1 internode dry weight during grain filling

Is faster internode elongation increasing grain filling?

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Hybrid rice superiority

***Wet season**, hill spacing 20 x 10 cm, same crop duration*

What about
other genotypes?

H5 and I1: 107 days
H6 and I13: 113 days

I1: IR72
H5: IR78386H
I13: IR77186-122-2-2-3
H6: IR79118H

Season	Seedling age	Variety	Grain yield *t ha⁻¹*	Harvest index
2004	7 days	I1	5.22	0.41
		H5	6.24	0.46
		I13	5.95	0.42
		H6	5.66	0.45

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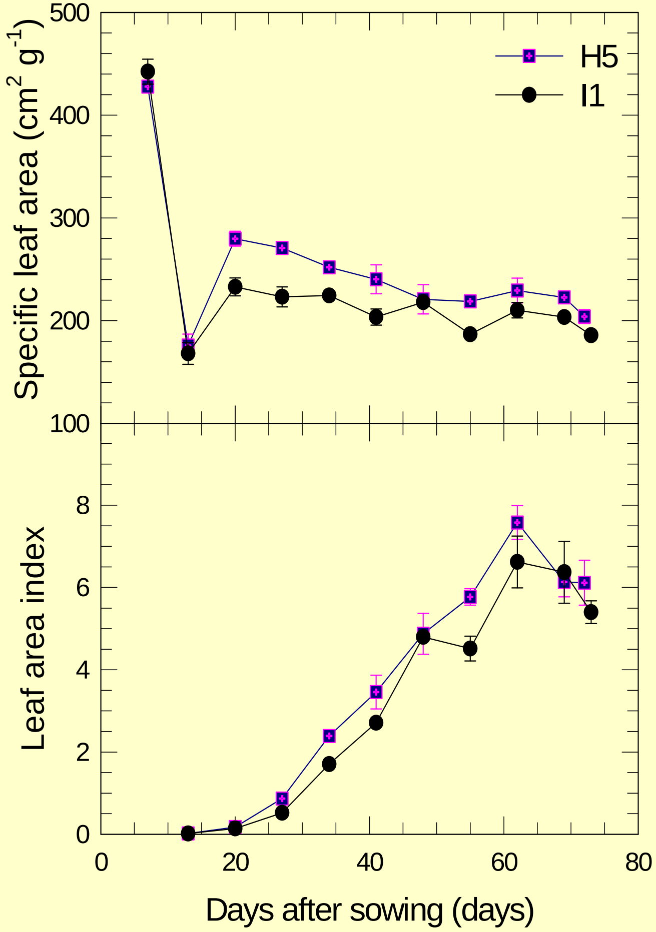
Dry matter partitioning

Wet season, hill spacing 20 x 10 cm, same crop duration



Lower cost for leaf blade production for H5 compared to I1

Higher leaf area production for H5 compared to I1

Is the smooth higher vigor of H5 having a significant impact?

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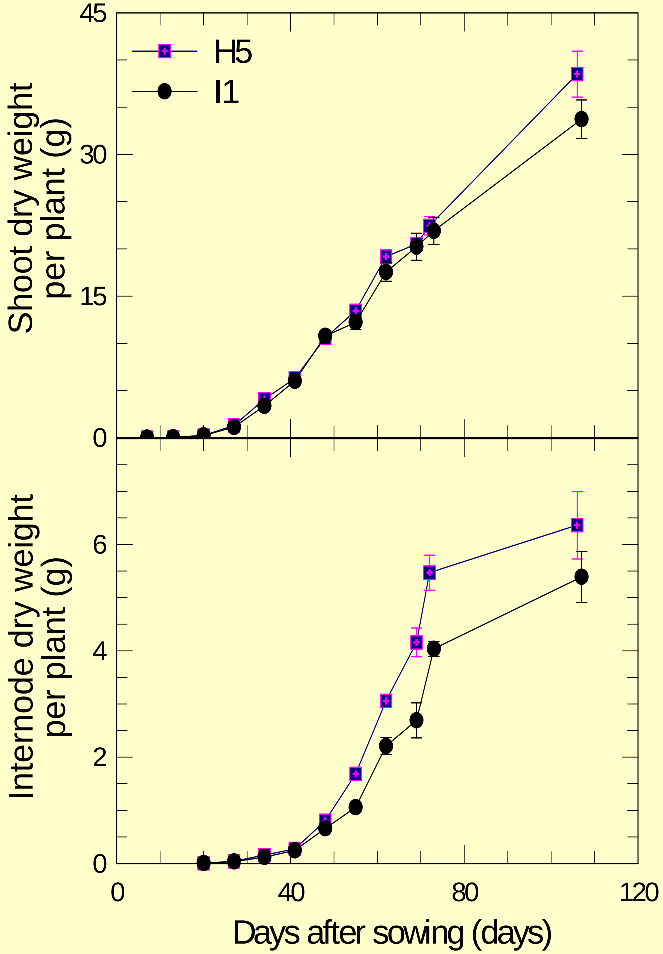
Dry matter partitioning

Wet season, hill spacing 20 x 10 cm, same crop duration



Similar biomass production for H5 compared to I1

No significant impact of higher LAI on early dry matter accumulation

Faster internode elongation for H5 compared to I1

Is faster internode elongation increasing grain filling?

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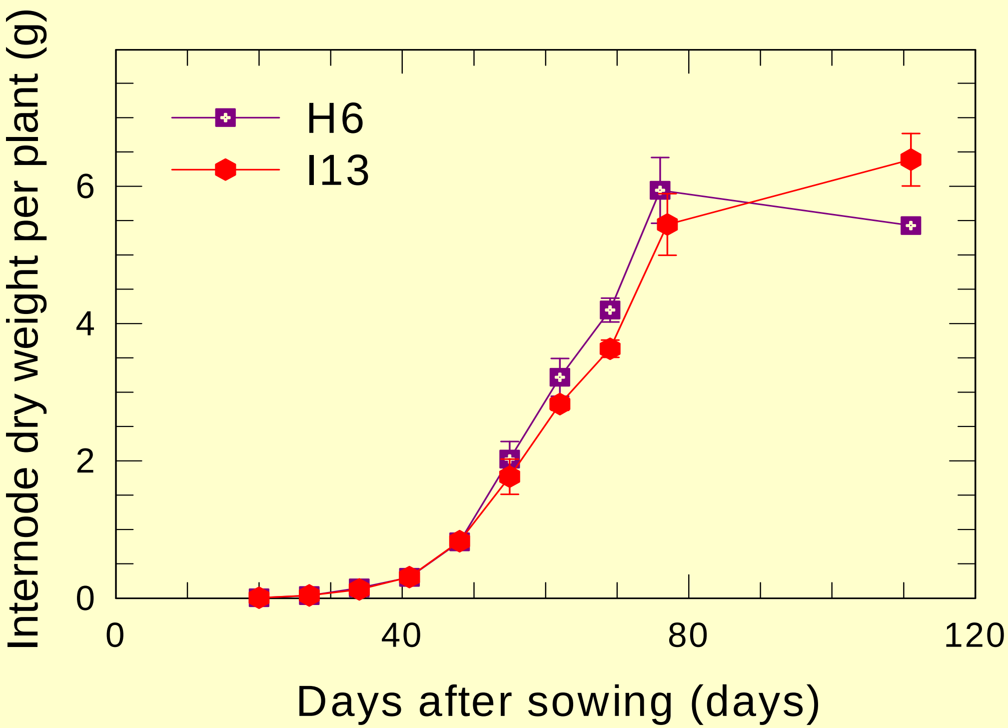
Dry matter partitioning

Wet season, hill spacing 20 x 10 cm, same crop duration

Grain yield of I13: 5.95 kg ha^{-1} grain yield of H6: 5.66 kg ha^{-1}



Similar internode elongation rate for H6 and I13
and
no yield superiority for H6

Internode elongation rate appears to be one major plant trait for achieving high grain yield

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Hybrid rice superiority

- **Higher grain yield of hybrid rice in the tropics:**
  – No increase in early vigor in the dry and wet seasons
    - similar early biomass accumulation
    - no impact of greater leaf area production
  – Systematically higher harvest index

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Hybrid rice superiority

- **Faster internode elongation and earlier mature stem length:**
  - increase in partitioning priority for grain right after flowering (less competition with stem)**?**
  - increase in carbohydrates accumulation due to a better light distribution in the canopy**?**
  - higher request for nitrogen supply around panicle initiation but not at early stage**?**

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Hybrid rice superiority

***Broadcast**, 25 kg seeds ha^{-1}, dry season*

	Crop maturity		Stem elongation		
				per square meter	
Genotype	Grain yield (t ha^{-1})	Harvest index	Crop stage	Shoot dry weight (g)	Dry matter increase (g)
I1	5.93	0.41	PI	**486**	**656**
			Flowering	1142	
H3	8.21	0.46	PI	**425**	**909**
			Flowering	1334	

I1: IR72 *H3: SL-8*

Higher dry matter accumulation during stem elongation

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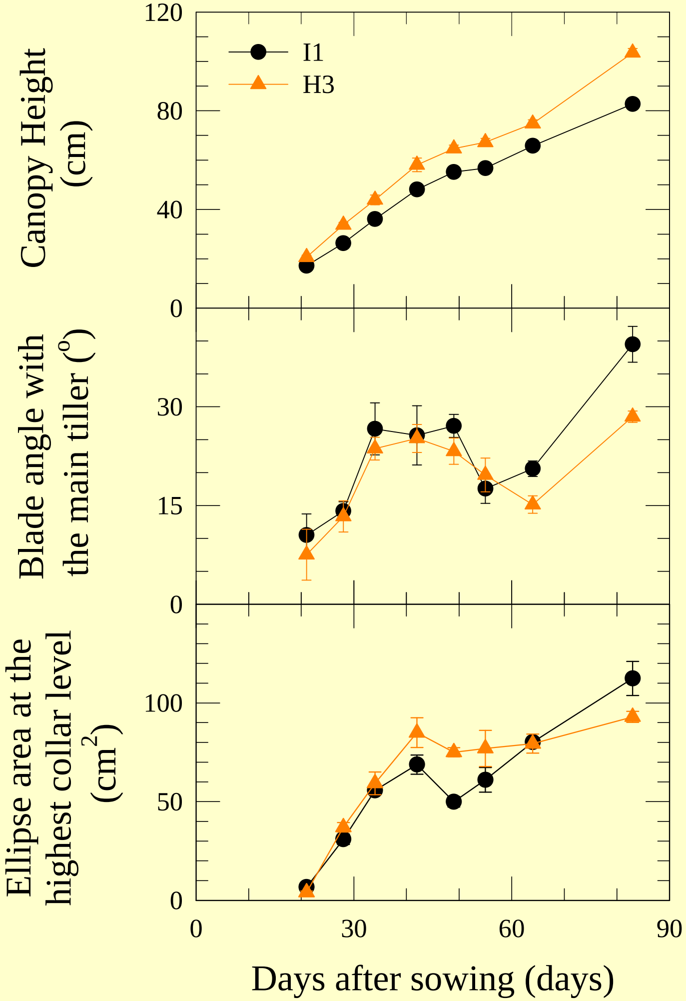
Plant response to canopy competition



canopy

height

How these plants are adapting to competition?

***Transplanting**, hill spacing 20 x 10 cm*

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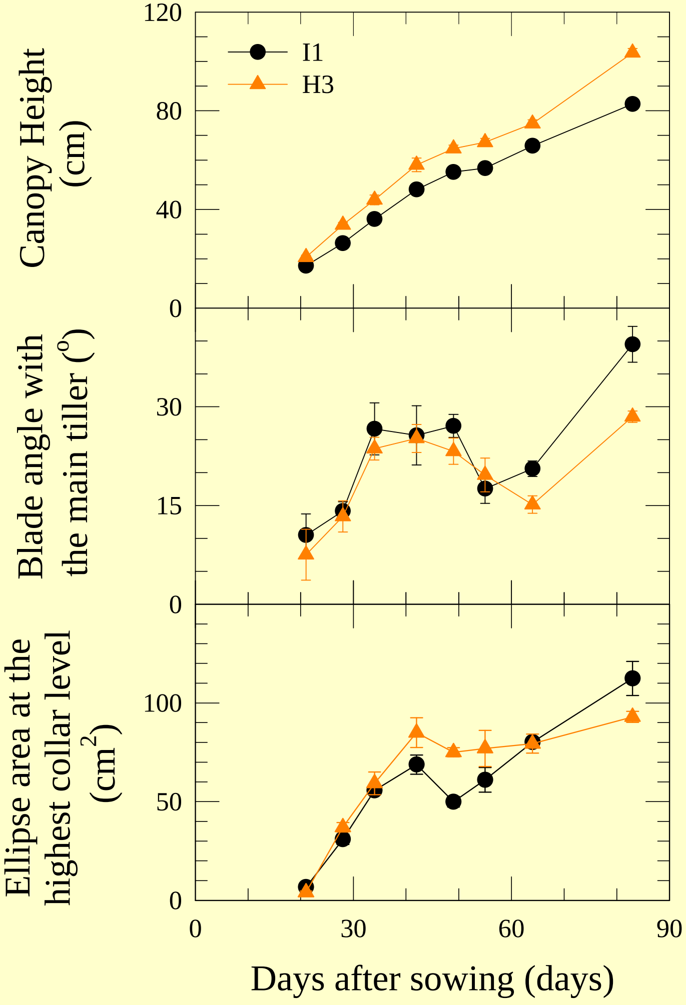
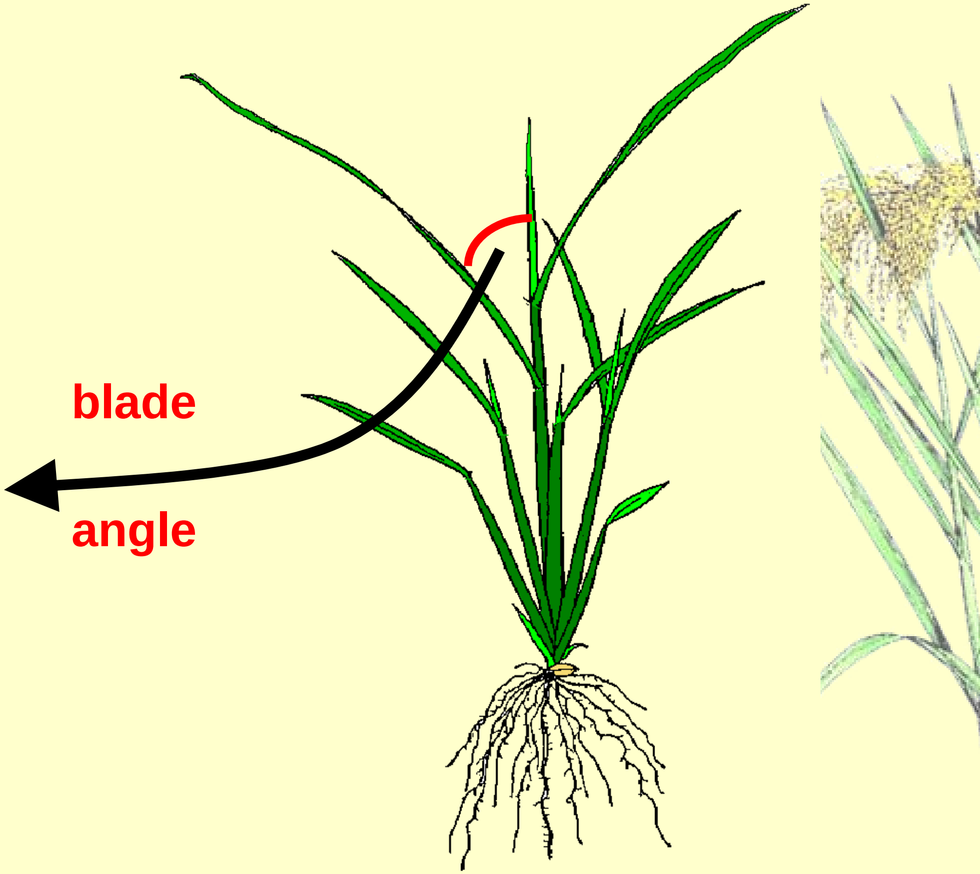
Plant response to canopy competition





Transplanting, hill spacing 20 x 10 cm

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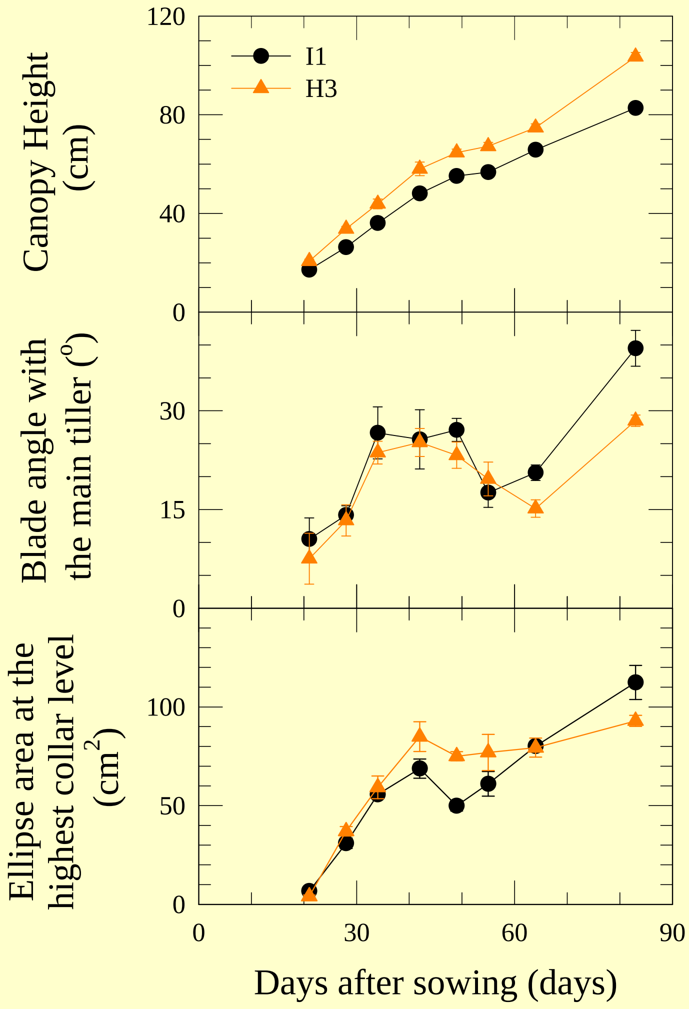
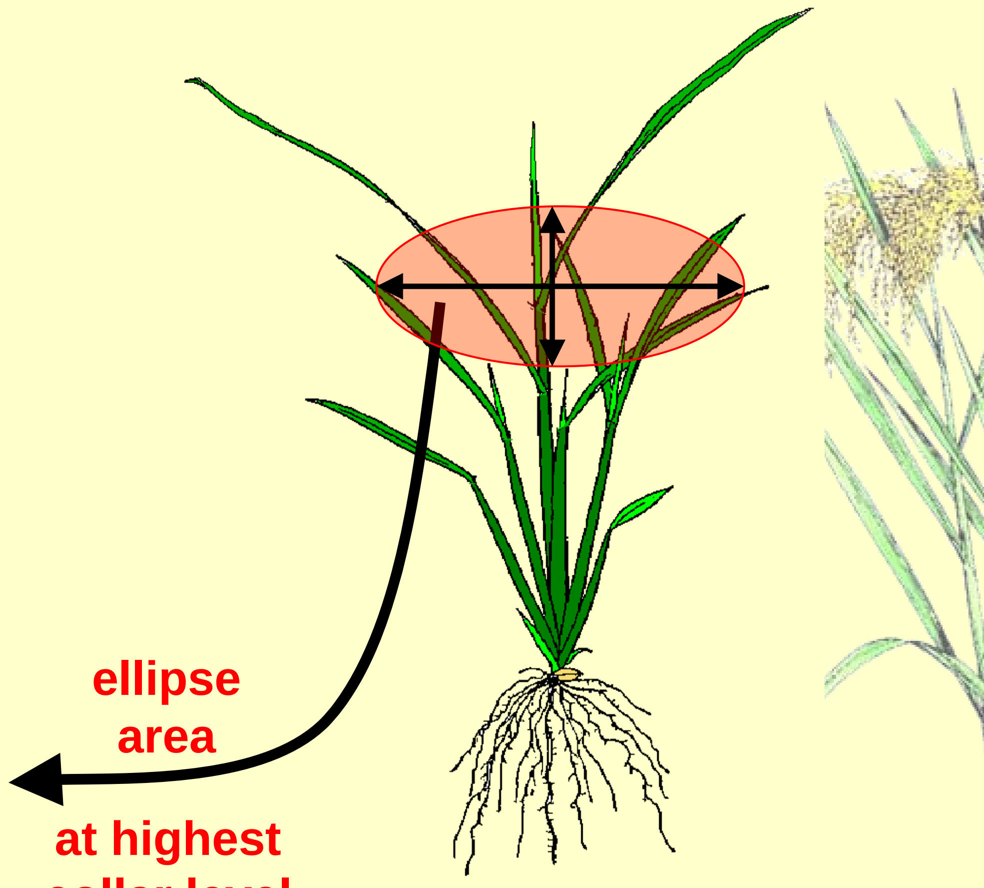
Plant response to canopy competition





Transplanting, hill spacing 20 x 10 cm

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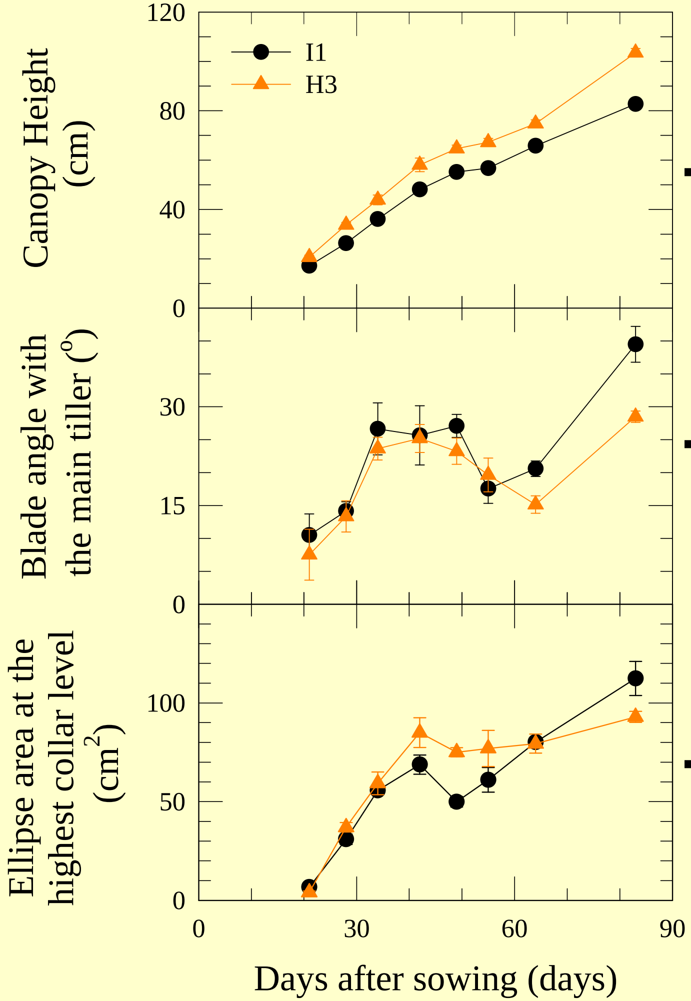
Plant response to canopy competition



This hybrid rice expressed:

- **higher canopy height**, particularly from panicle initiation (50 days)

- **more erect leaves** from panicle initiation

- **constant ellipse area** from maximum tillering (40 days)

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Plant response to canopy competition

Thanks to rapid internode elongation, H3 crop seemed to express:

- **a better light distribution in the canopy**
  - larger space between leaves (taller plants)
  - less mutual shading (more erect leaves)
  - less intra-specific competition (smaller ellipse)
- **a higher dry matter accumulation**

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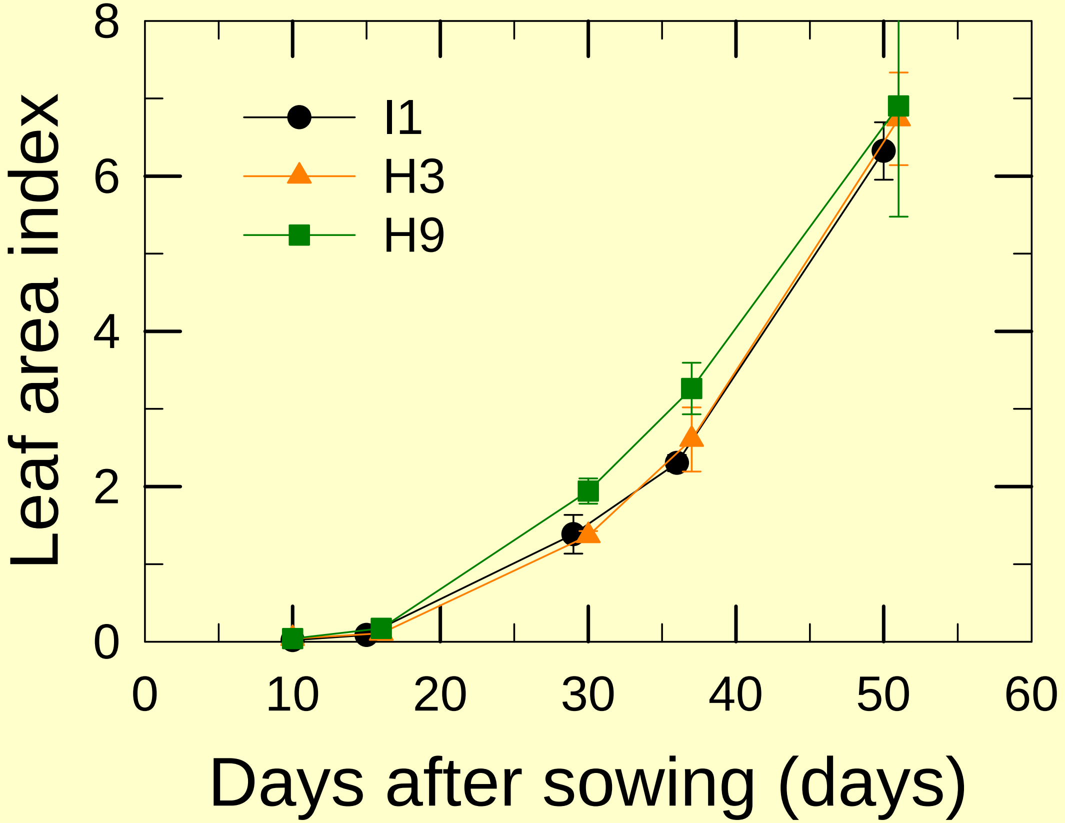
Plant response to uneven canopy

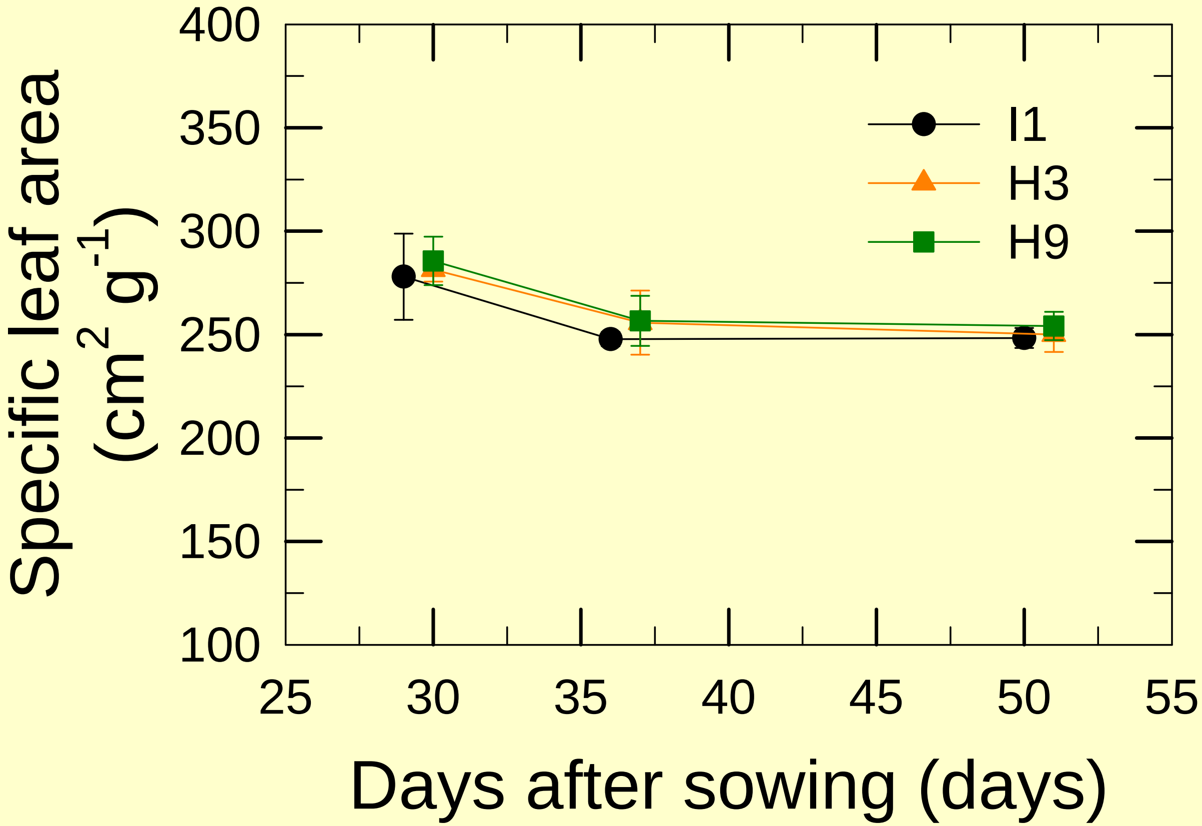
Broadcast, 50 kg seeds ha^{-1}



What may be the cause of this contrasted capacity to produce leaf area between 20 and 40 DAS?

Plant response to uneven canopy

Broadcast, 50 kg seeds ha^{-1}



The specific leaf area is apparently not the cause

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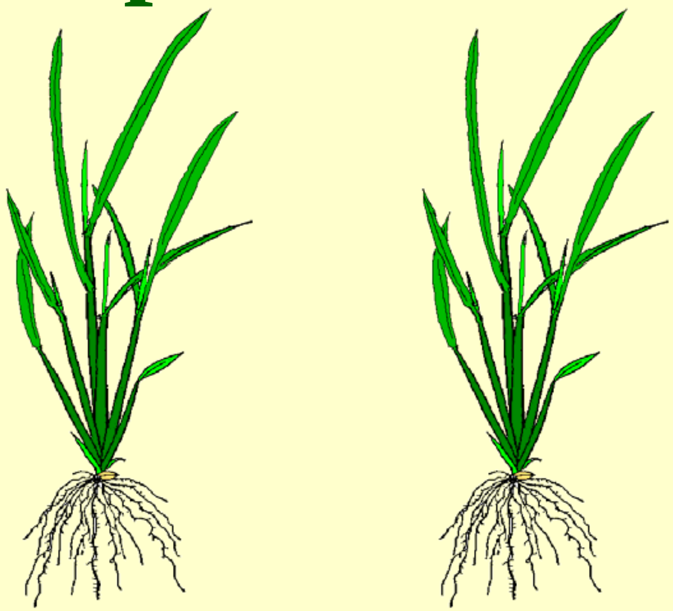
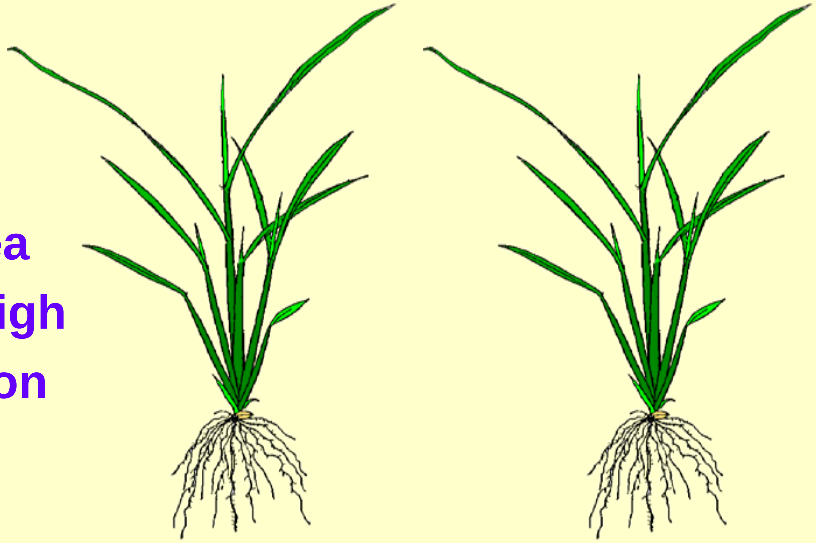
Plant response to uneven canopy

At early stage:



Situation 1:
Canopy with erect leaf area and possible low light interception



Situation 2:
Canopy with droopy leaf area and possible high light interception

Is the plant able to adapt its tiller and leaf orientation according to access for light?

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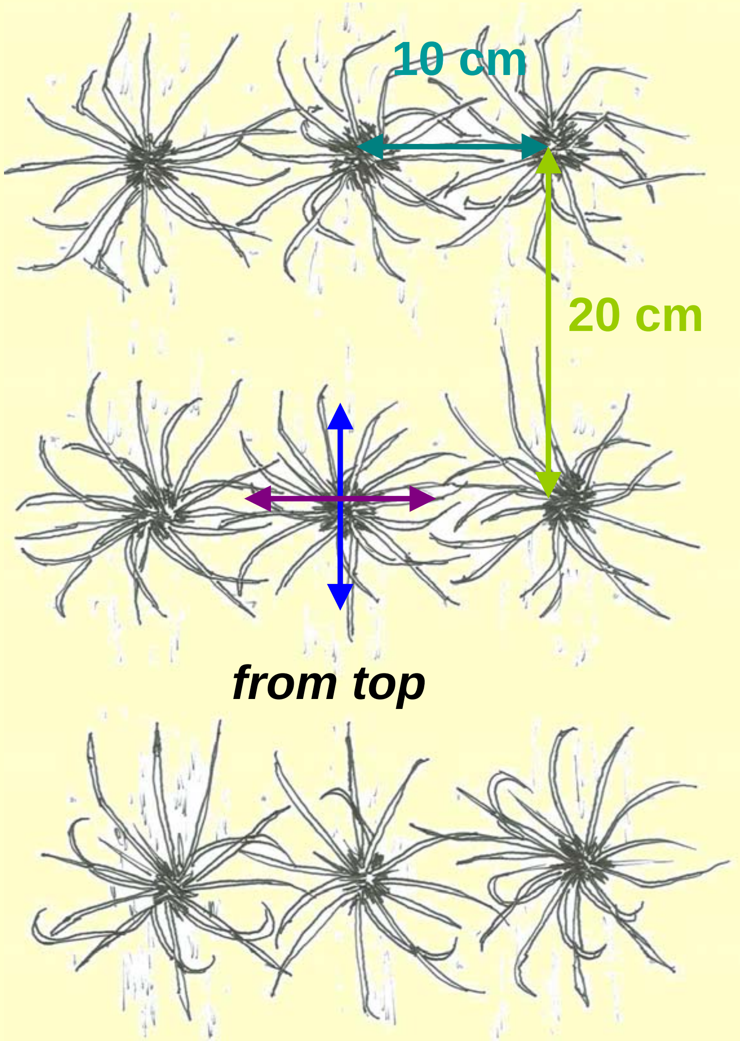
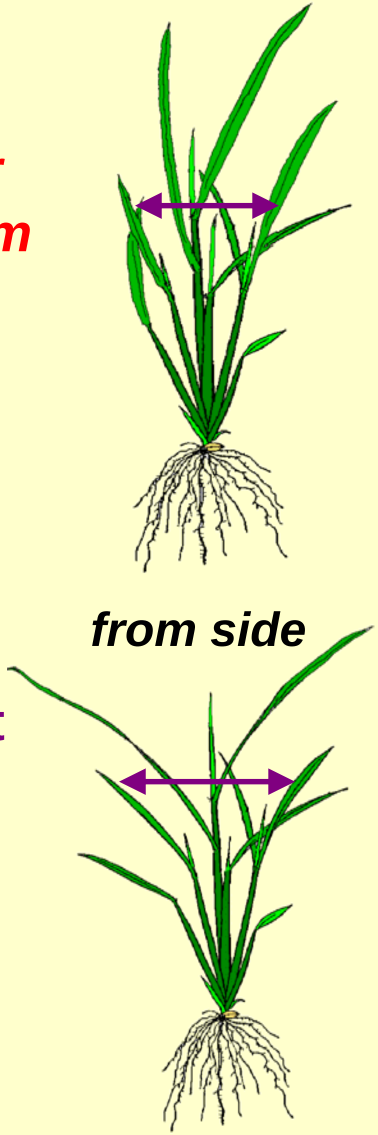
Plant response to uneven canopy



Evaluation in a transplanted field with a rectangular spacing 20 x 10 cm

Is the clump diameter in the 20 cm spacing different from that in the 10 cm spacing?



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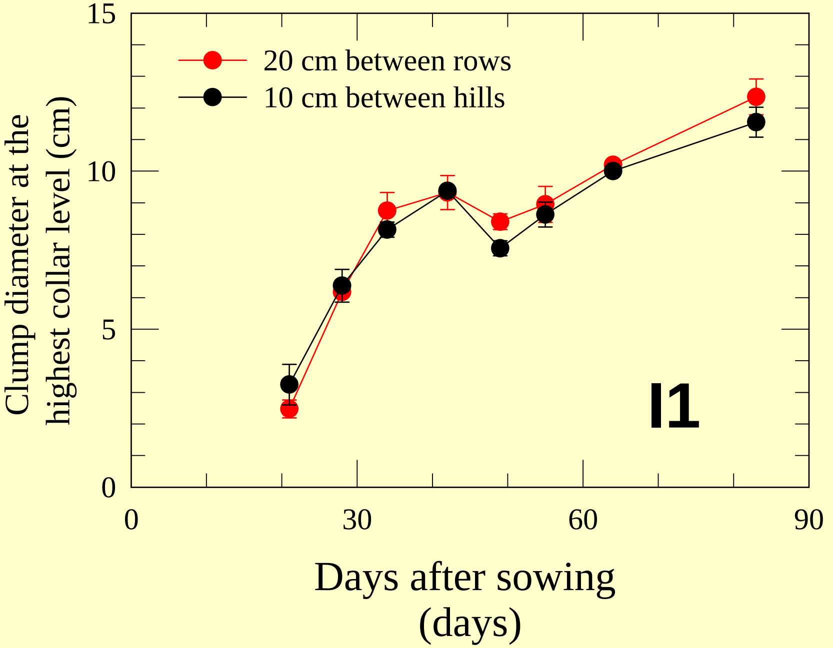
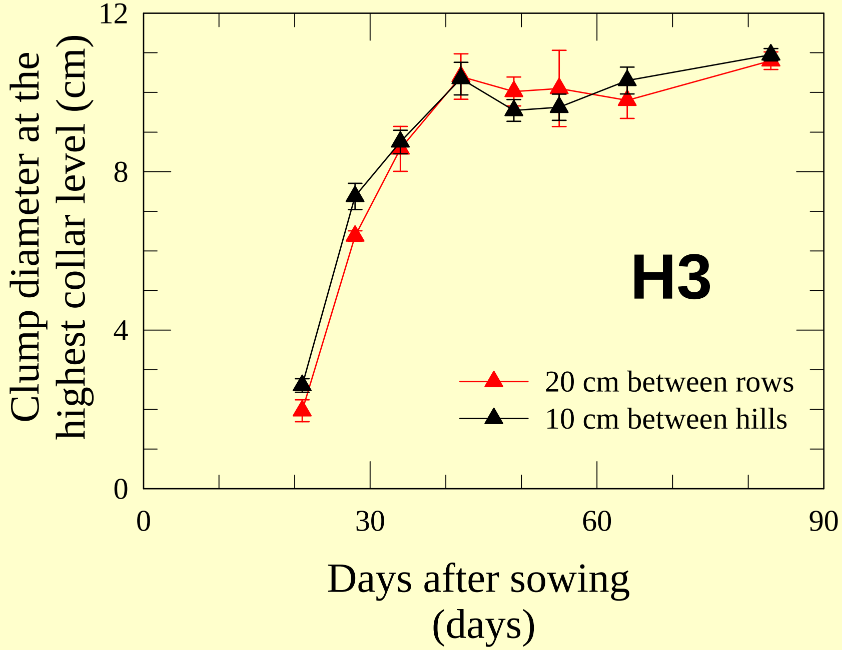
Plant response to uneven canopy

Transplanting, hill spacing 20 x 10 cm





I1: IR72 *H3: SL-8*

I1 and H3 do not appear to be sensitive to neighboring plants at early stage

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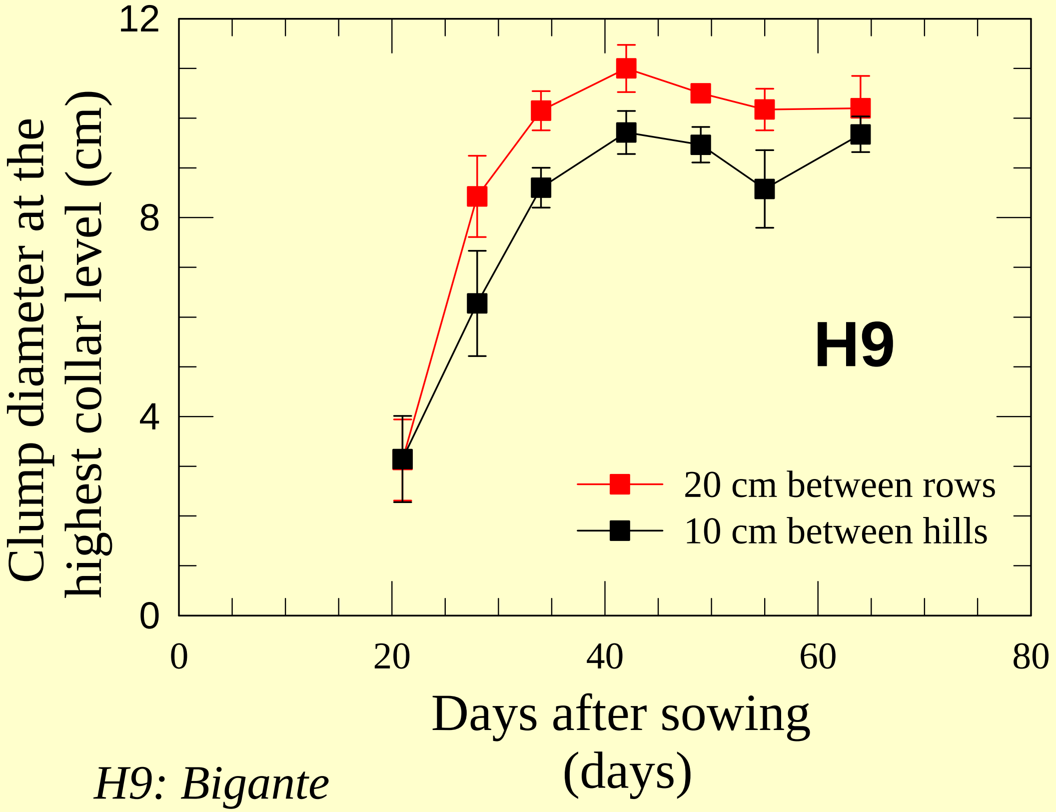
Plant response to uneven canopy

Transplanting, hill spacing 20 x 10 cm



H9: Bigante

H9 appears more sensitive to the access for light at early stage

This may explain the better ability of H9 to produce leaf area in an uneven canopy

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Plant response to uneven canopy

During tiller emergence, hybrid rice crop H9 had:

- **a likely better sensitivity to free space to access light**
  - Clump leaf area occupied preferably the open space between rows (20 cm spacing) than the closed space between hills (10 cm spacing)
- **an appreciably higher leaf area production in uneven canopy (broadcast 50 kg seeds ha^{-1})**

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Outline

- **Background**
- **Plant response to nursery management**
  - Transplanting age
  - Seed density in the nursery
  - tiller mortality rate
- **Hybrid rice superiority**
  - Dry matter partitioning
  - Plant response to canopy competition
- **Plant response to sparse canopy (early stage)**
- **Prospects**

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General perspectives

- **Achieving higher crop productivity through crop traits of interests**
  - Limits in increasing sink strength
    - Failure of New Plant Type and Low Tiller Gene introgressed lines (few tillers, big panicles)
    - High initiated grain number in improved adopted varieties: grain fertility rate between 0.6 and 0.8
    - Possible role of reserve storage

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General perspectives # 2

- **Achieving higher crop productivity through crop traits of interests**
  - Assimilate partitioning strategy (leaf area production, internode elongation, duration in grain filling)
  - Remobilization from senescent to productive tillers, from stems and leaves to panicles
  - Spatial leaf and tiller disposition for access to light

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General perspectives # 3

- **Analyzing dry matter partitioning strategy and remobilization during internode elongation and early grain filling**
- **Analyzing genotypic variability in response of plant architecture to canopy competition and its impact on crop performance**

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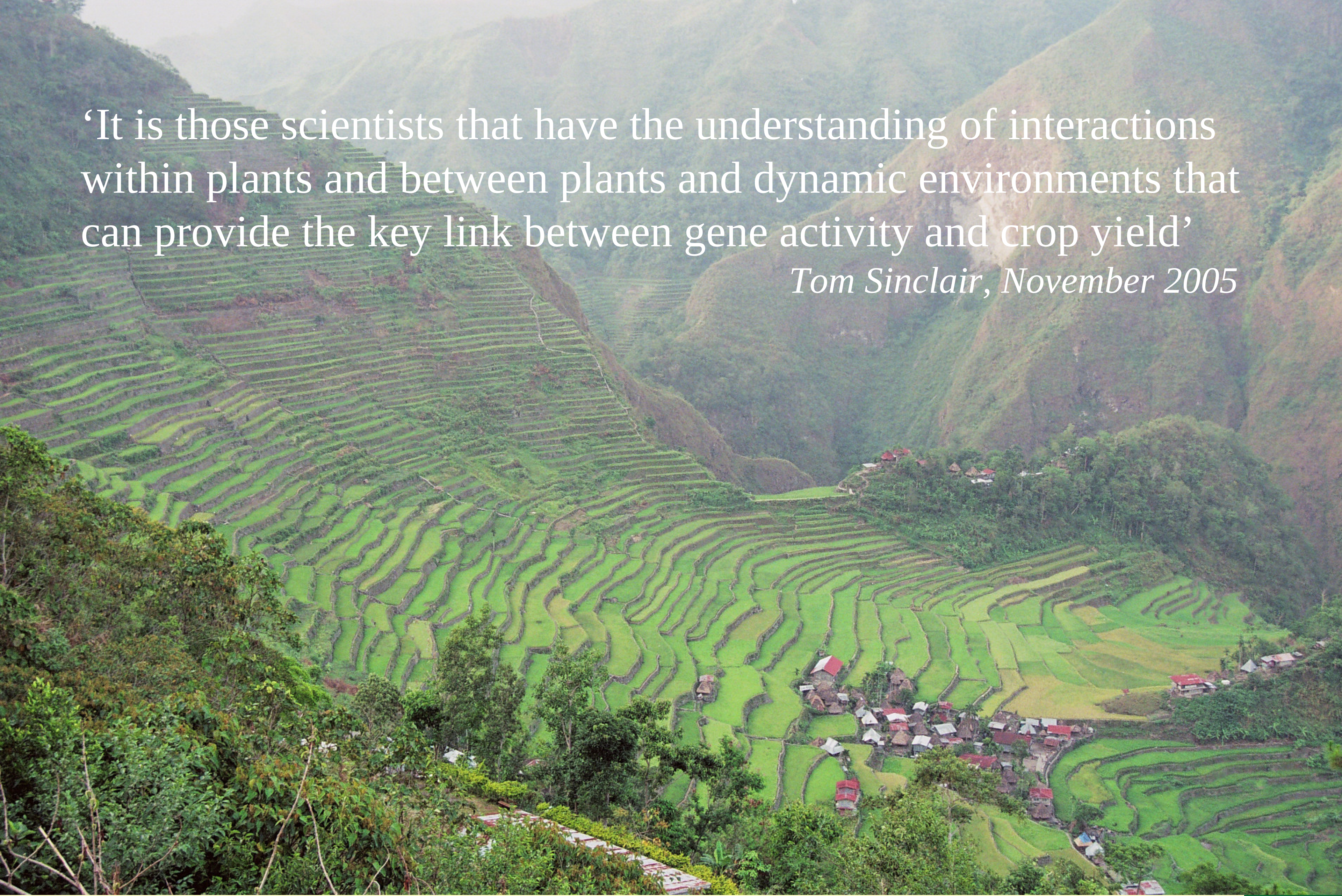

‘It is those scientists that have the understanding of interactions within plants and between plants and dynamic environments that can provide the key link between gene activity and crop yield’

Tom Sinclair, November 2005

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