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INTERNATIONAL RICE RESEARCH INSTITUTE

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

Sink regulation in hybrid rice: consequences for breeding programs and crop management

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Hybrid rice: consistently higher grain yield

- **Grain yield advantage: 10 to 15%**
- **Yield components increase: - higher shoot dry weigh**
- **- higher harvest index**

Observations from distinct experiments:

higher or similar grain yield and harvest index of hybrid

Significantly-low relation with shoot dry weight but higher values with hybrid

HI better related to grain yield than shoot dry matter

Year/ Season		GY (t/ha)	ShDW m^{-2}	HI	TilE
2007 DS	H (7)	11.03 a	2108 a	0.54 a	0.52 a
Transplanting	I (6)	9.48 b	1932 b	0.50 b	0.54 a
2006 DS	H (3)	8.45 a	1780 a	0.51 a	0.56 a
Staggered	I (3)	7.53 b	1634 a	0.45 b	0.55 a
2006 DS	H (2)	8.49 a	1587 a	0.55 a	0.63 a
AWD genotypes	I (3)	8.44 a	1611 a	0.52 b	0.62 a
2005 DS	H (2)	7.16 a	1959 a	0.45 a	0.41 b
Broadcasting	I (2)	5.94 b	1820 a	0.42 a	0.55 a
2004 WS	H (5)	5.93 a	1885 a	0.45 a	0.52 a
Wet season	I (7)	5.35 b	1748 b	0.42 b	0.49 a

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Hybrid rice: yield components of plants with same phenology

Comparing yield components of 4 hybrids and 4 inbreds with the same phenology: similar PI, flowering and maturity time, leaf emergence rate and culm elongation

Gen	GY t ha^{-1}	Pan no m^{-2}	FiGr no pan^{-1}	Grain size	ShDW g m^{-2}	HI	Sink size no m^{-2}	Gr Fill rate
H5	**10.45**	**332**	**133**	**23.79**	**2276**	**0.54**	**60028**	**0.74**
H6	**10.77**	**329**	**137**	**23.96**	**2251**	**0.55**	**59424**	**0.72**
H7	**10.63**	**333**	**142**	**22.48**	**2015**	**0.52**	**65157**	**0.71**
H8	**10.73**	**309**	**142**	**24.35**	**2013**	**0.52**	**65118**	**0.68**
I1	**9.73**	**375**	**105**	**24.70**	**2113**	**0.51**	**46473**	**0.85**
I9	**9.17**	**331**	**106**	**26.01**	**1802**	**0.46**	**48448**	**0.71**
I10	**8.38**	**309**	**106**	**23.60**	**1854**	**0.50**	**46115**	**0.77**
I12	**8.72**	**301**	**109**	**26.55**	**2040**	**0.47**	**41621**	**0.74**
Mean-H	**10.65 A**	326 A	**139 A**	23.65 B	**2139 A**	**0.53 A**	**62432 A**	0.73 A
Mean-I	**9.00 B**	329 A	**109 B**	25.22 A	**1952 B**	**0.49 B**	**45664 B**	0.77 A

Hybrid: higher biomass, sink size and harvest index triggered higher filled grain per panicle

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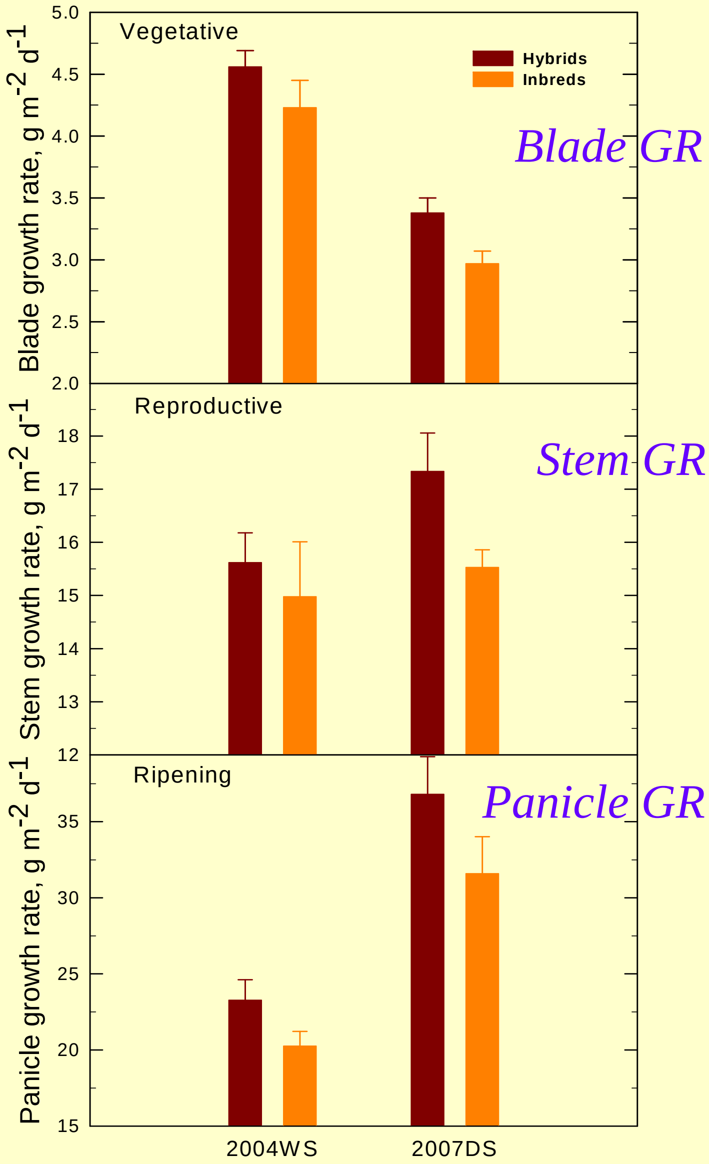
Higher biomass: which phases are involved?



Comparing crop growth rate of hybrids and inbreds of same phenology during the three phases of development

$$\text{Blade GR} = \frac{\Delta dw_{\text{blade } 2\rightarrow 1}}{\Delta time_{2\rightarrow 1}}$$

Higher growth rate is observed with the key organ in each of the 3 phases of development in both seasons

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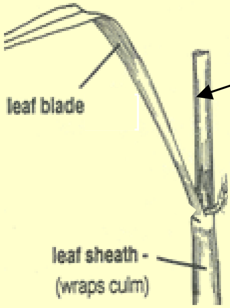
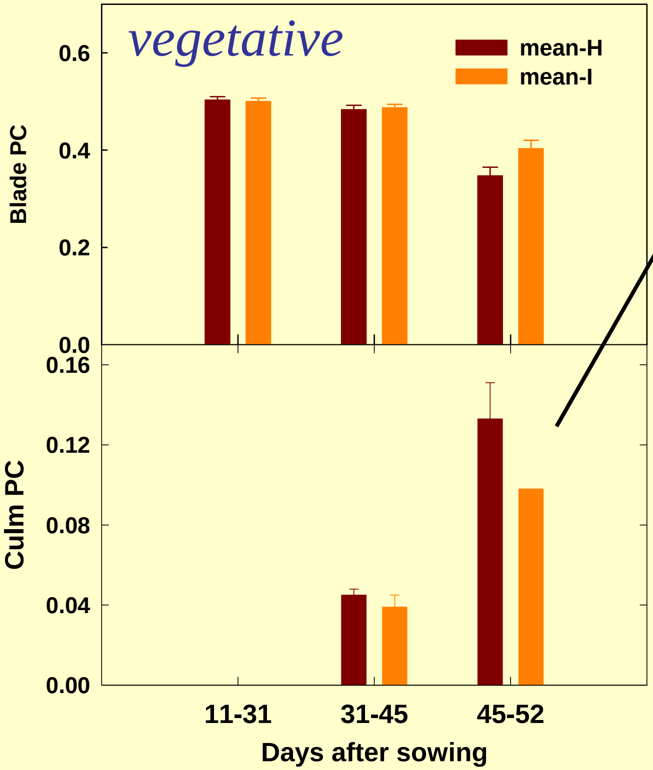
Higher sink size: better sink regulation before grain filling?

Comparing partitioning coefficients of hybrids and inbreds of the same phenology

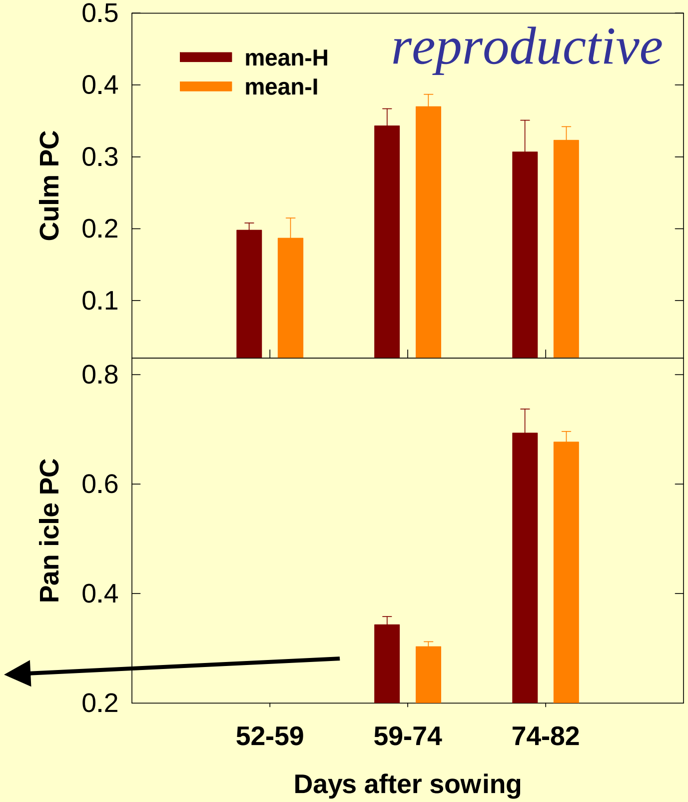


Calculation of blade partitioning coefficient:

$$\text{Blade PC} = \frac{\Delta dw_{\text{blade } 2\rightarrow 1} / \Delta time_{2\rightarrow 1}}{\Delta dw_{\text{shoot } 2\rightarrow 1} / \Delta time_{2\rightarrow 1}}$$



Hybrid: quicker increase in allocation to the culm around PI



Hybrid: quicker increase in allocation to the panicle before flowering

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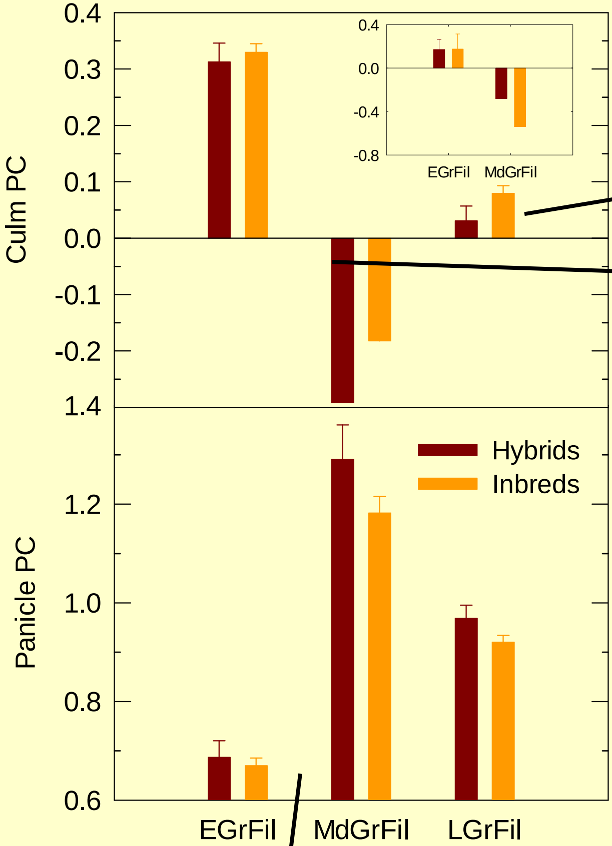
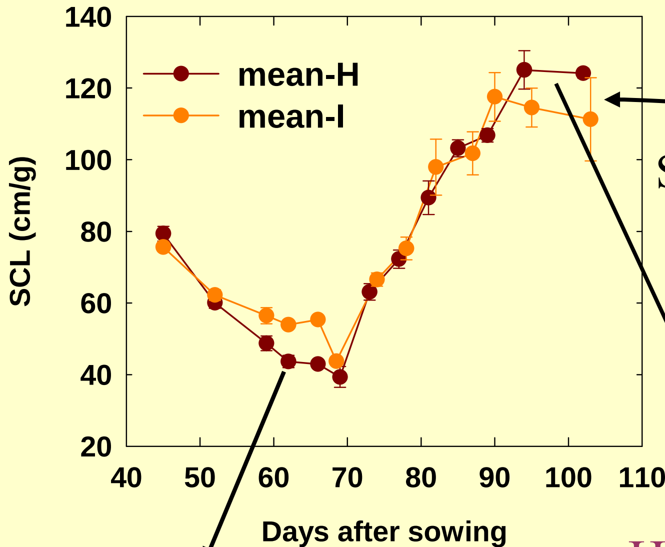
Higher harvest index: better sink regulation during grain filling?

Comparing partitioning coefficients of hybrids and inbreds of same phenology



Inbred: increase in culm biomass at the end of grain filling to bear the panicle

Hybrid: higher remobilization



Specific culm length:

$$SCL = \frac{\text{culm length}}{\text{culm dw}}$$

Hybrid: stronger allocation to the panicle during the whole phase

Hybrid: stronger culm at flowering

Hybrid: weaker culm at maturity

Hybrid: the stronger ability of the culm to store and remobilize biomass is likely to increase grain filling

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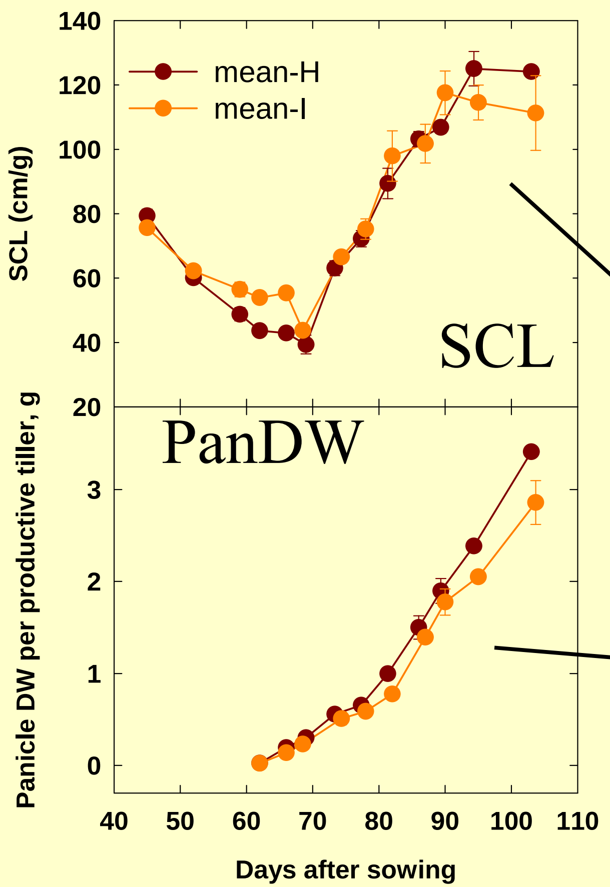
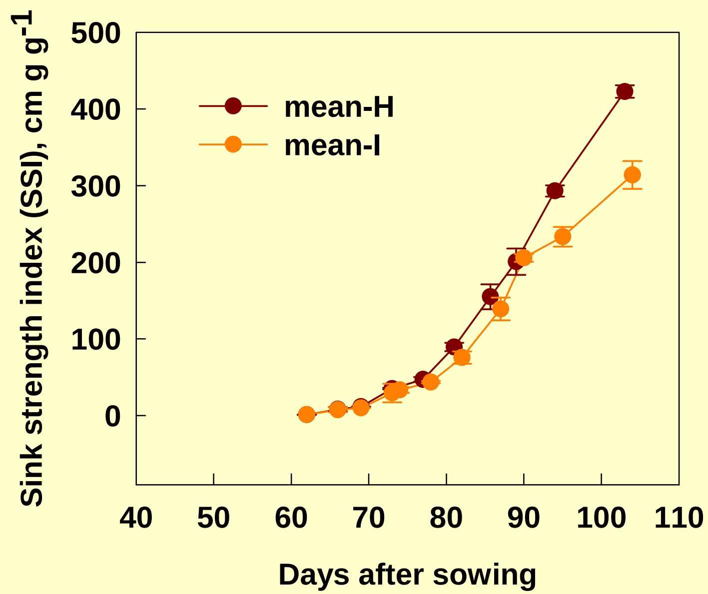
Higher harvest index: designing an improved index



Designing an index that accounts for the efficiency of the partitioning better than the harvest index: that integrates stem vigor (reverse of SCL) together with panicle dry weight without consideration of leaf and sheath dry matter: sink strength index

$$SSI = PaDW \times SCL$$



Correlation of GY with	r
Stem-based SSI	0.95*
HI	0.90*
Shoot DM	0.71*
CGR at maturity	0.86*

Hybrid: a weaker stem bears a heavier panicle however, higher sensitivity to lodging

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Hybrid rice of shorter duration: yield components

Comparing yield components of hybrids of shorter duration than inbreds with all crop phases affected

Genotype	GY	Biomass at PM	HI	PanNB	FiGrNB.	ToGrNB	1000 seed wt
	$t\ ha^{-1}$	$g\ m^{-2}$		m^{-2}	pan^{-1}	m^{-2}	g
Hybrid							
H6	10.80	2093	0.54	310	145	62490	23.97
H12	10.76	2598	0.46	303	131	55241	27.13
H13	10.70	2149	0.52	290	134	48396	27.48
H14	11.18	1954	0.52	328	135	63142	25.11
Mean	**10.86 a***	**2205 a**	**0.51 a**	**308 b**	**136 a**	**57317 a**	**25.92 a**
Inbred							
I4	10.06	1904	0.52	338	124	57274	23.98
I11	10.18	2243	0.44	406	106	61014	23.69
I13	9.86	1905	0.51	369	121	59698	22.05
Mean	**10.03b**	**2017 a**	**0.49 a**	**371 a**	**117 b**	**59329 a**	**23.24 b**
LSD(0.05)	0.22	202	0.03	18.9	6.1	4457	1.17

Hybrid: higher biomass and harvest index but similar sink size

Individual seed size triggered higher yield

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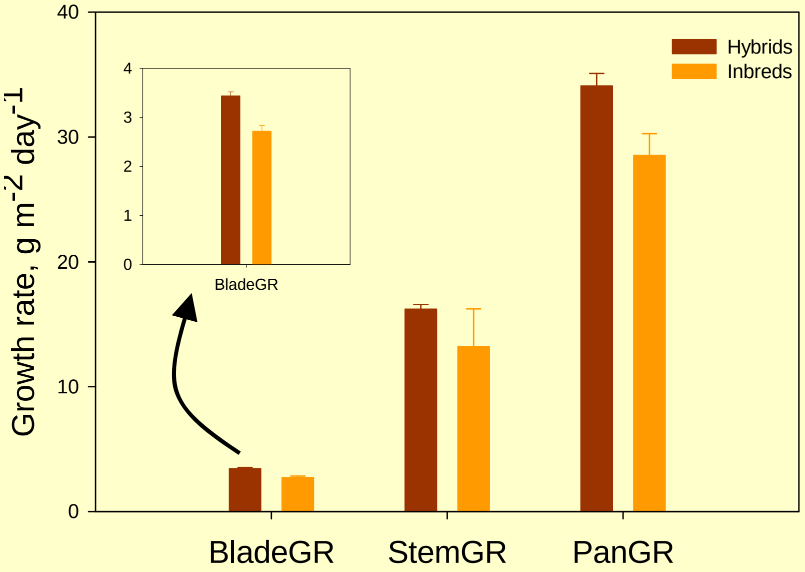
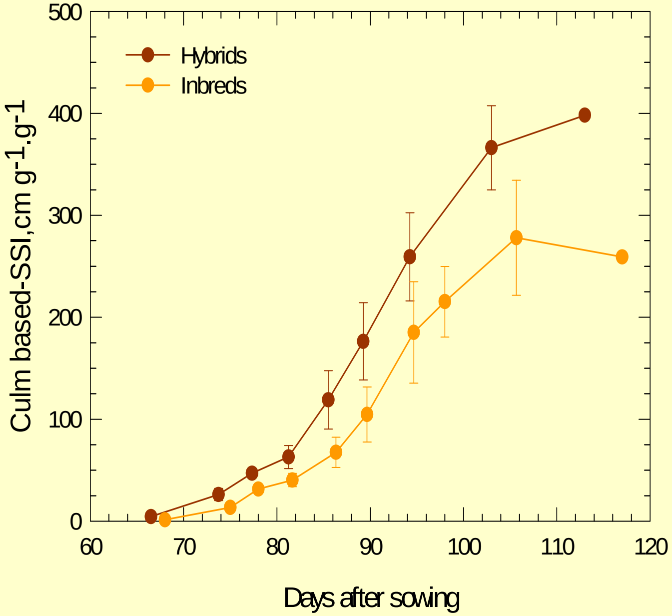
Hybrid rice of shorter duration: biomass accumulation and sink regulation





Hybrid: higher growth rate is observed with the key organ in each of the 3 phases of development in both seasons

Hybrid: more efficient biomass partitioning during the whole grain filling period

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Higher harvest index: designing an improved index

Using the sink strength index (SSI) to compare the efficiency of partitioning between hybrids and inbreds in a large set of situations

Year/ Season		GY (t/ha)	ShDW m^{-2}	HI	SSI ($g\ cm\ g^{-1}$)
2007 DS	H (7)	11.03 a	2108 a	0.54 a	175 a
Transplanting	I (6)	9.48 b	1932 b	0.50 b	145 b
2006 DS	H (3)	8.45 a	1780 a	0.51 a	150 a
Staggered	I (3)	7.53 b	1634 a	0.45 b	102 b
2006 DS	H (2)	8.49 a	1587 a	0.55 a	156 a
AWD genotypes	I (3)	8.44 a	1611 a	0.52 b	133 b
2005 DS	H (2)	7.16 a	1959 a	0.45 a	114 a
Braodcasting	I (2)	5.94 b	1820 a	0.42 a	93 b
2004 WS	H (5)	5.93 a	1885 a	0.45 a	140 a
Wet season	I (7)	5.35 b	1748 b	0.42 b	117b

The difference in SSI between plant types is larger than that in HI, and with consistent significance

SSI at maturity can be used more acurately than harvest index to discriminate plants in their ability to partition dry matter efficiently

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Elements supporting the higher performance of hybrids
observed when comparing hybrids and inbreds of same phenology and of distinct phenology with shorter crop duration for hybrid

- **Higher biomass accumulation in hybrid rice during the whole cycle**
  - Higher key organ growth rate
  - leaf angle during the whole cycle?
  - root and leaf senescence during grain filling?
  - remobilization from senescing tillers and leaves during grain filling?

- **More efficient sink regulation in hybrid rice during the whole cycle**
  - quicker increase in allocation to the culm before PI
  - quicker increase in allocation to the panicle during culm growth
  - more biomass remobilized from the culm

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Breeding strategy for increasing yield potential

- The potential sink size of tropical high-yielding hybrids and inbreds at IRRI is high enough to meet with the supply (moderate spikelet filling percentage)
- The actual sink size appears as a consequence of the plant's potentialities (sink regulation) and of the environment (source strength)

- The breeding strategies for higher yield potential could consider more direct traits refering to higher sink regulation and higher biomass accumulation. Such traits could be relevant to any phase of the crop cycle
- Higher sink size, as an integrated trait and a consequence of higher sink regulation, still need to be considered

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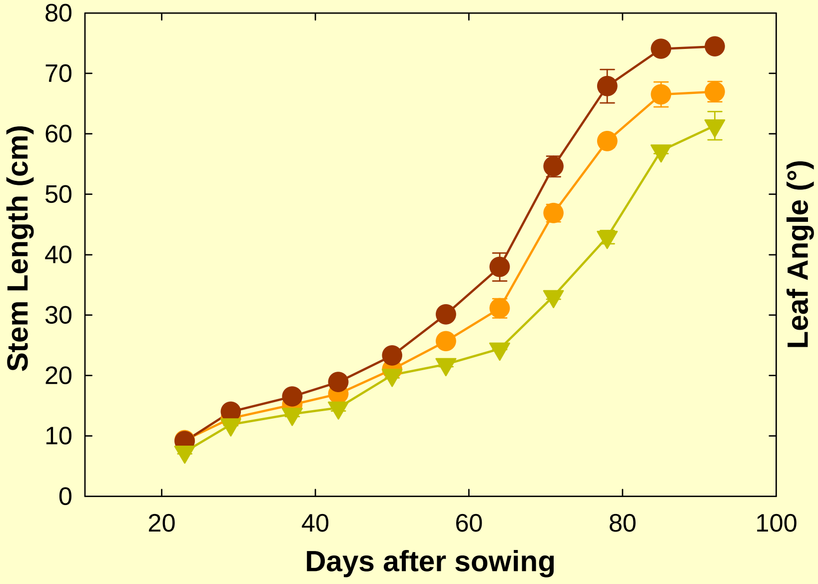
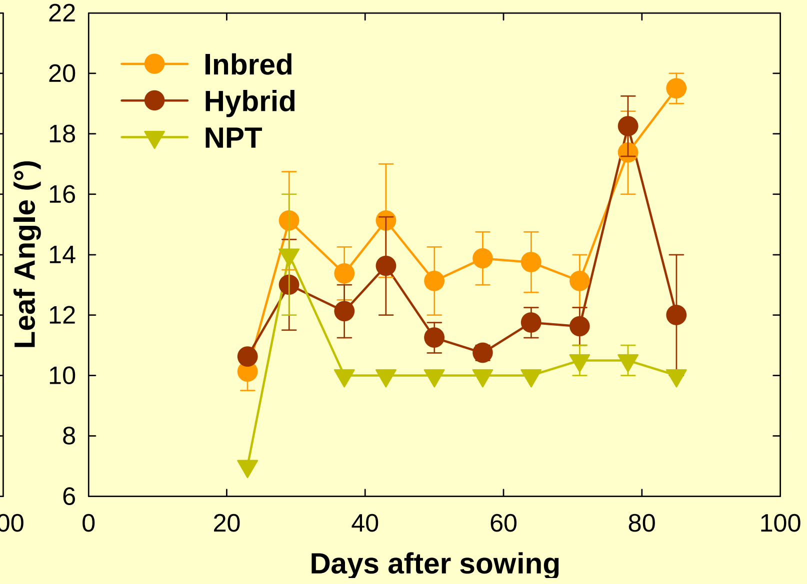
Relevant trait: more efficient plant stand during the whole cycle?

Comparing the plant height and leaf angle of the second youngest mature leaf of 4 inbreds and 4 hybrids and 1 NPT, all of same phenology





Hybrid: characterized with more erect leaves and taller canopy that may trigger higher light interception

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Leaf position and orientation may be candidate traits

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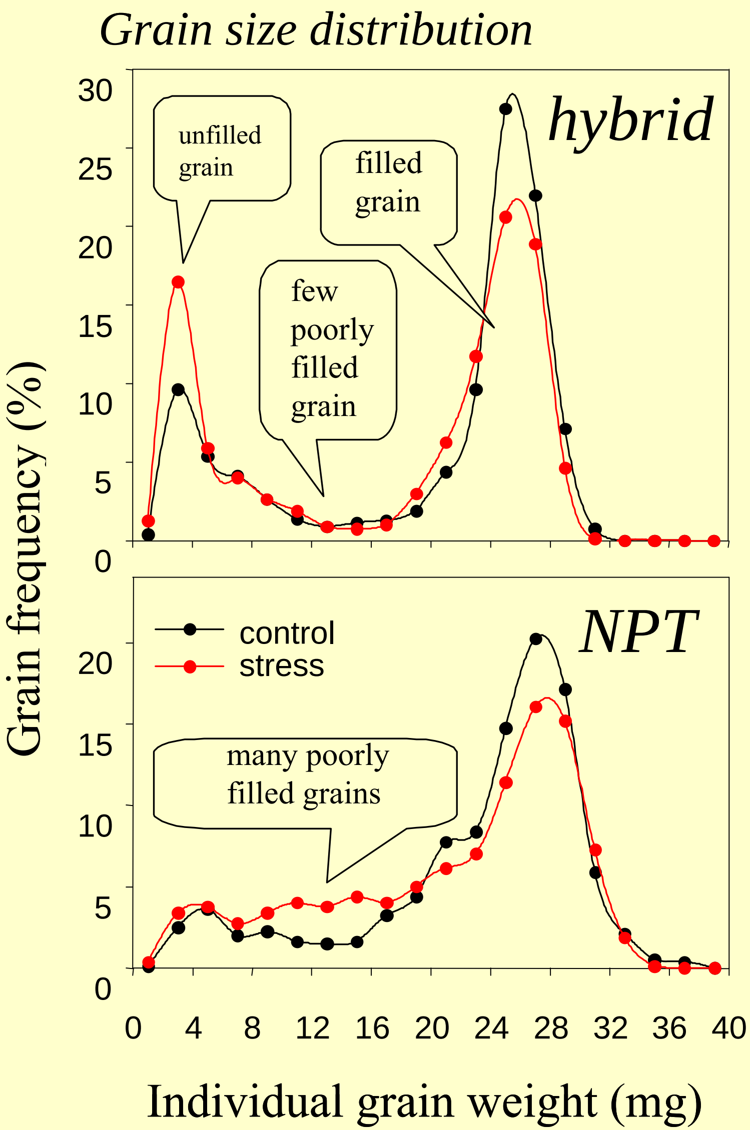
Relevant trait: better sink regulation during grain filling?



Year/ Season	Genotype	1000 FiGrDw	1000 UFiGrDw
2007 DS	H(7)	24.45	4.33
	I(6)	24.40	4.55
2006 DS	H(2)	24.82	5.01
	I(3)	26.84	5.28
2005 WS	H(3)	27.37	4.26
	I(2)	27.00	4.44
2005 DS	H(2)	24.21	4.98
	I(2)	23.41	5.06
2004 WS	H(5)	24.70	4.17
	I(7)	25.23	4.77

Can 'unfilled grain size' be used as a relevant trait?

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Possible candidates traits for increasing yield potential

- **Increasing the source:**
  - Leaf angle and its dynamic during the whole cycle
  - Extended culm growth period vs. vegetative (Slafer et al)?
  - Extended grain filling period?
  - Delayed root senescence in order to delay leaf senescence?

- **Increasing sink regulation**
  - Increased specific leaf area at early stage
  - Low sink strength index at flowering associated with higher reserve storage
  - High sink strength index at maturity associated with high remobilization
  - Low individual unfilled grain size

Crop response to seedling age at transplanting: leaf area growth

Transplanting, hill spacing 20 x 20 cm

Inbred1 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

Is the response respective to plant type contrasted?

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Crop response to seedling age at transplanting: grain yield

In each season: same sowing date, same plant density, same nutrient management

Dry Season			Wet Season		
Genotype	**Seedling age, d**	**Yield, t ha^{-1}**	**Genotype**	**Seedling age, d**	**Yield, t ha^{-1}**
Inbred1	7	**6.99 a**	**Inbred1**	7	**5.32 a**
Inbred1	14	6.34 a	**Inbred1**	14	5.14 b
Inbred1	21	**6.06 b**	**Inbred1**	21	**5.18 b**
Hybrid1	7	**7.75 a**	**Hybrid1**	7	**6.62 a**
Hybrid1	14	6.98 b	**Hybrid1**	14	6.02 b
Hybrid1	21	**6.97 b**	**Hybrid1**	21	**5.89 b**

Grain yield was significantly higher when transplanting 7-day instead of 21-day old seedlings for both plant types in both seasons

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Crop response to seedling age at transplanting: similar behavior for hybrids and inbreds

- **High seedling age at transplanting induced a similar delay in tiller and leaf area production for both plant types by keeping the plants growing longer in the seed bed**

- **High seedling age at transplanting induced a reduction in grain yield (up to 1 t ha^{-1} in some conditions) for both plant types**

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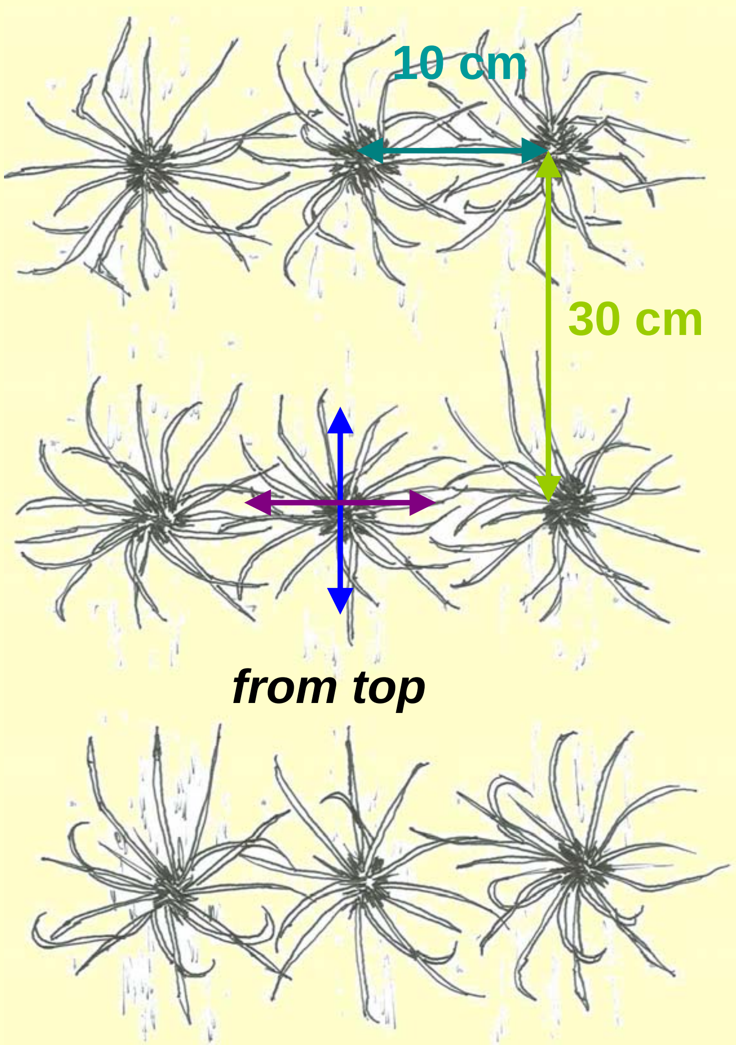
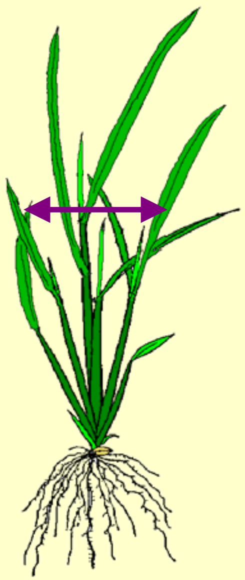
Plant response to uneven canopy: is hybrid rice adapted?

Evaluation in a transplanted field with a rectangular spacing 30 x 10 cm

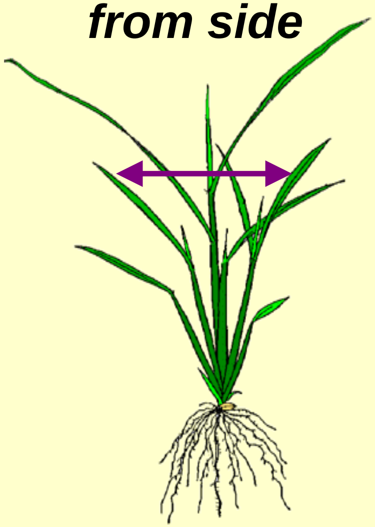


Is the plant able to adapt its tiller orientation according to access for light?



Is the clump diameter in the 30 cm spacing different from that in the 10 cm spacing?

from side



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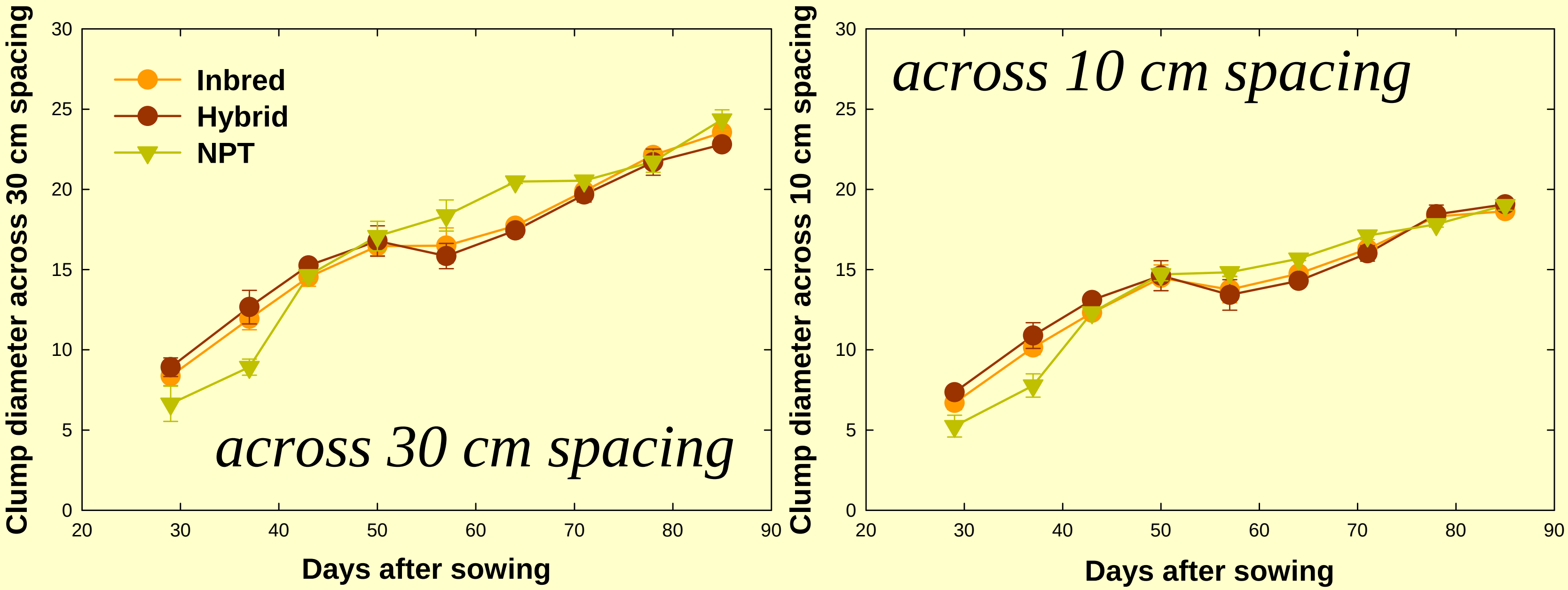
Plant response to uneven canopy: plasticity of plant architecture?

Comparing the clump plasticity of 4 inbreds and 4 hybrids (both plant types represented as an average) and 1 NPT, all of same leaf emergence rate (same phenology)



Same and weak sensitivity of hybrids and inbreds to intra-plant competition:

- similar dynamics in clump size was observed regardless of spaces between plants
- slight difference in clump diameter between the 2 spacings

Same clump plasticity:
same trend in adaptation to direct-seeding?

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Crop response to uneven canopy: difference in yield variation?

Transplanting at 100 plants m^{-2} and row seeding at 320 seeds m^{-2} (80 kg ha^{-1}), early wet season, IRRI

Different plant density

Genotype	Treatment	Yield t ha^{-1}
Inbred4	TP100	6.89b
Inbred4	SR80	8.65a
Inbred1	TP100	6.60b
Inbred1	SR80	7.84a
Hybrid4	TP100	6.93b
Hybrid4	SR80	8.04ab

Transplanting at 150 plants m^{-2} and direct seeding at 200 seeds m^{-2} (50 kg ha^{-1}), late wet season, IRRI

Same plant density

Genotype	Treatment	Yield t ha^{-1}
Hybrid1	TP150	6.78a
Hybrid1	SB50	5.90b
Inbred1	TP150	6.41a
Inbred1	SB50	5.66b
Inbred3	TP150	6.89a
Inbred3	SB50	6.10b

Gap in grain yield between hybrid and inbred was maintained regardless of crop establishment

Crop response to uneven canopy: difference in yield variation?

Hill sowing (HS), broadcasting (SB) and row seeding (SR) sown at 25, 50 and 100 kg ha^{-1}, dry season, PhilRice

Gap in grain yield between hybrid and inbred was maintained regardless of crop establishment

Genotype	Treatment	Grain Yield (t ha^{-1})
Hybrid	HS50	8.25 a
	SB25	8.19 a
	SB50	7.63 a
	SR25	8.03 a
	SR50	7.71 a
Inbred	HS50	6.70 a
	SB50	6.72 a
	SB100	6.85 a
	SR50	6.71 a
	SR100	7.08 a

Same response to plant arrangement of hybrids and inbreds

High performance with seed rate as low as 25 kg ha^{-1}
(*as long as water and weed are properly managed)*

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Crop response to uneven canopy: lack of adaptation of hybrid rice

- **No adaptation of IRRI hybrids and inbreds to direct-seeding**
  - All the genotypes evaluated here were bred under transplanted conditions and were not supposed to be adapted to direct-seeding
  - Higher performance of hybrids compared to inbreds were mainly due to higher hybrid potential: in most cases, the best genotypes selected under transplanting conditions were also the best under direct-seeding conditions

- **High performance of hybrid with seed rate as low as 25 kg ha^{-1}**

- **Developing a breeding program in Asia entirely devoted to uneven plant arrangement conditions would have a significant impact on the delivery of promising genotypes for direct-seeding: substantial benefits in grain yield should be observed from a plastic plant stand at early stage**

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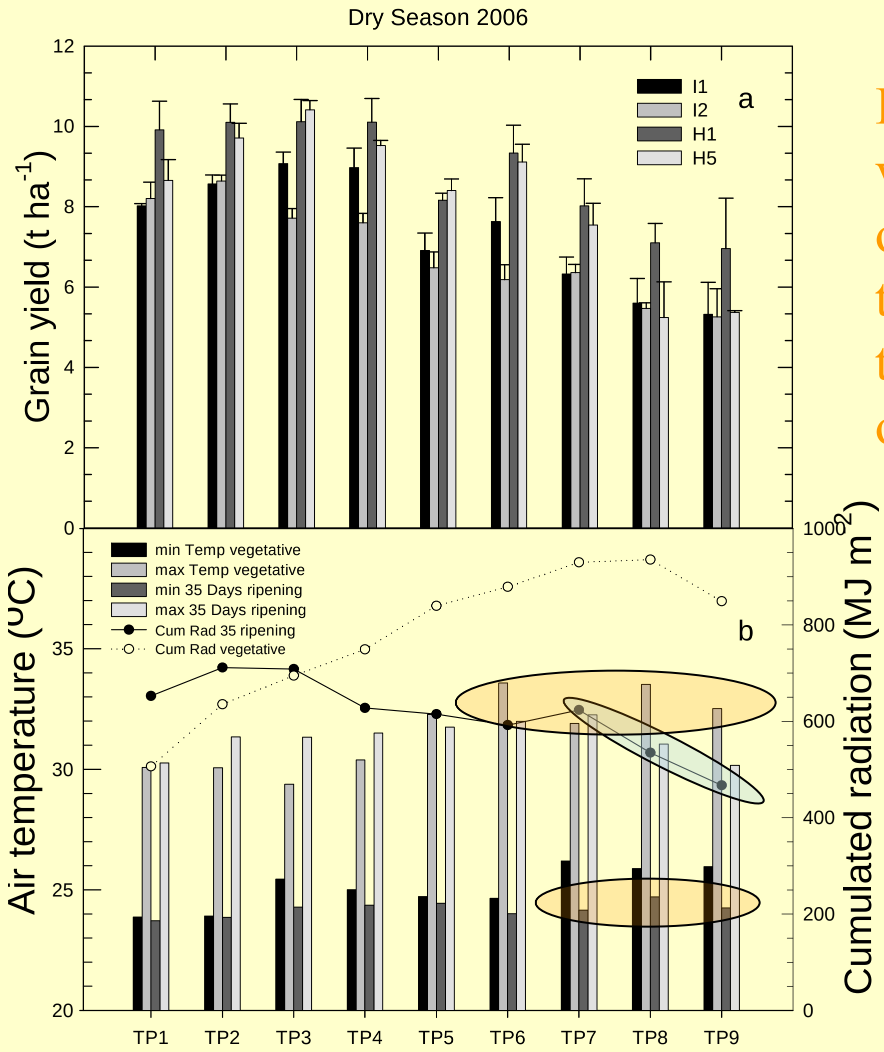
Crop response to weather conditions: optimum sowing date?

Staggered sowing dates from late December (TP1) to early April (TP9) of 2 inbreds and 2 hybrids



Increase in day temperature during vegetative (reduced crop growth because of detrimental values) and in night temperature during ripening (biomass loss through respiration) shall have reduced overall biomass accumulation

Grain filling rate of late sowings was most probably limited by the reduction in cumulative daily radiation that decreased from 700 to 500 MJ m^{-2} with sowing dates

Pattern of variation in grain yield with sowing date was similar across genotypes

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Crop response to cultural practices: lessons learnt

- Nitrogen management needs to be adjusted to plant type demand (Peng et al)
- **Cultural practices other than nitrogen management do not need to be specifically adapted to hybrid rice:** hybrids and inbreds respond similarly to seedling age at transplanting, to direct-seeding conditions and to sowing date
- **Transplanting young seedlings to avoid high competition in the seed bed shall substantially increase grain yield of hybrids**
- **Direct seeding at seed rate as low as 25 kg ha^{-1}, or even lower, is very encouraging**

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