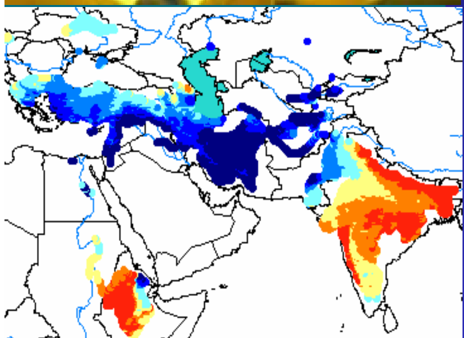


Australia's Growing Future

CSIRO

Genotype by environment studies demonstrate the critical role of phenology in chickpea adaptation to rainfed environments in Australia and India.

CS1/96/07: Traits for yield improvement of chickpea for drought-prone environments of India and Australia

Jens Berger

CSIRO Plant Industry

CLIMA

Department of Agriculture and Food
Government of Western Australia

ACIAR

GRDC
Grains Research & Development Corporation

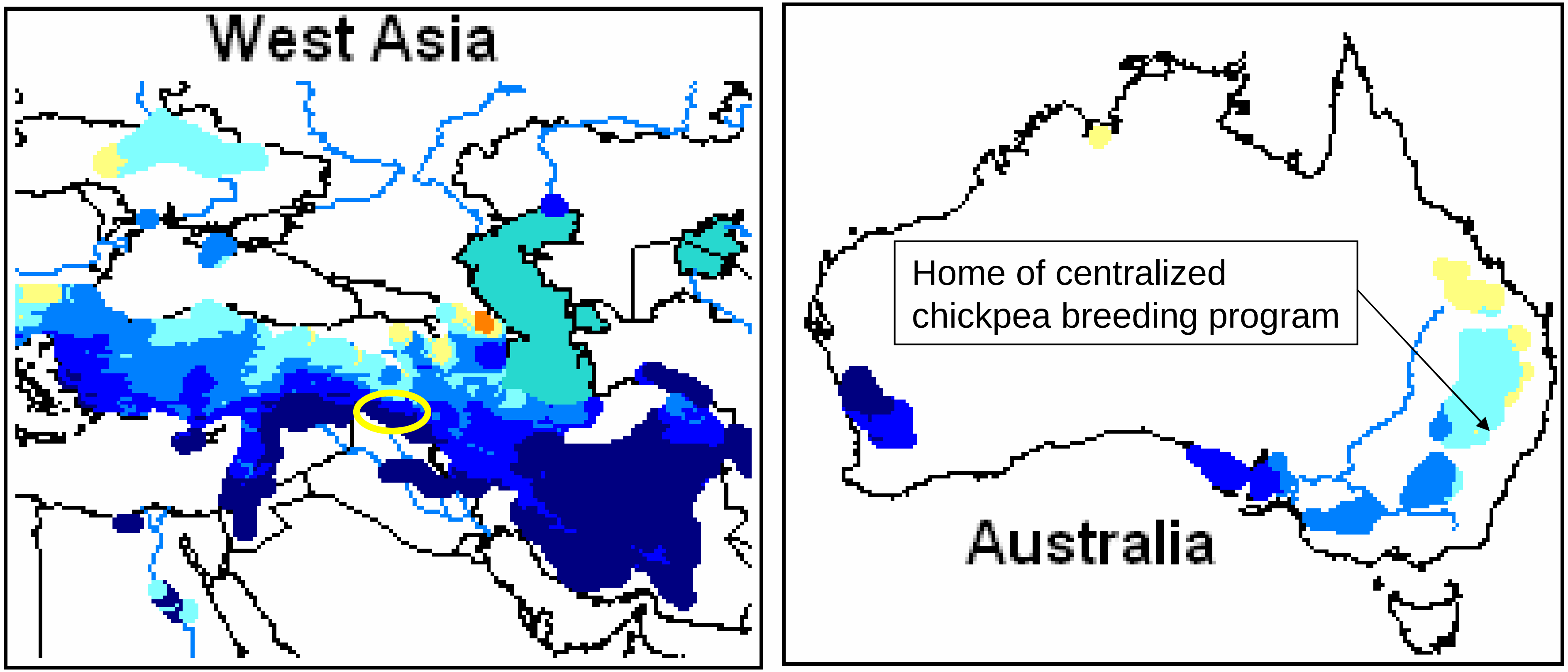
Aims

1. Stimulate a spirit of enquiry among our Iraqi colleagues. Research must question “why is it working/not working?”
2. How? Using ACIAR-funded G*E studies as an example.

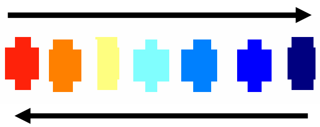
Outline

1. Show the climatic parallels between northern Iraq & southern Australia.
2. Show some pretty pictures.
3. Demonstrate how we used a G*E approach to learn about adaptation of chickpea to southern Australia.

West Asia, southern Australia: Mediterranean climates



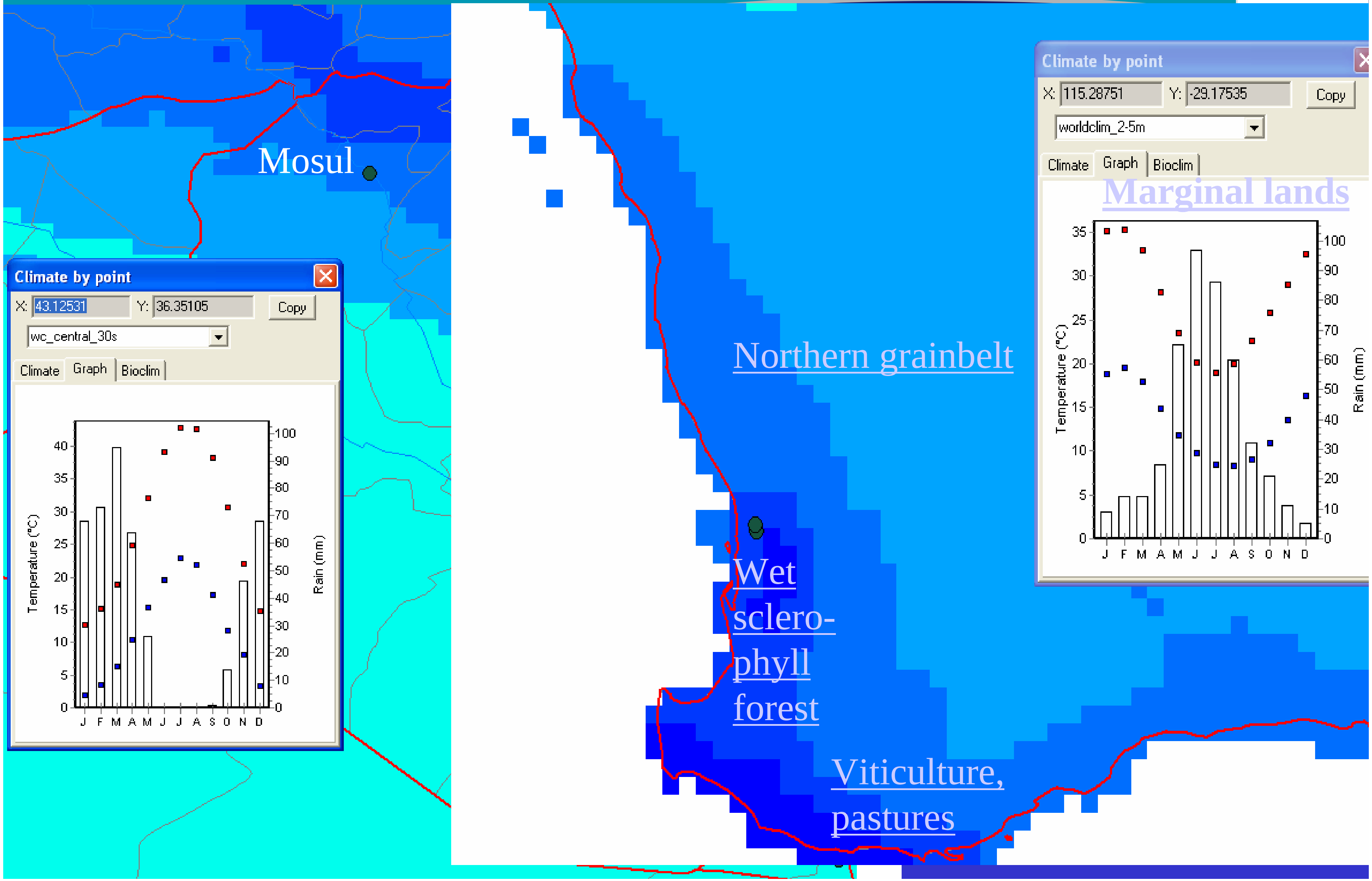
Decreasing winter rain%
Increasing annual rain & summer rain%



Increasing winter rain%
Decreasing annual rain & summer rain%

Climate analysis of global chickpea habitats (Chickpea Breeding and Management, CABI-2006).

West Asia, southern Australia: Mediterranean climates



Using genotype by environment studies to investigate adaptation-motivation

1. G*E studies grow sets of genotypes at different sites.
2. Diverse germplasm + contrasting environments = max info.
3. Most people report only on yield & responsiveness. This is boring, limited and hard to extend! (Chickpea G*E literature recently reviewed in “Chickpea Breeding and Management”, CABI-2006).
4. By characterizing environments & genotypes we can work out how genotypes are adapted to particular environments.
5. This knowledge can be applied to new situations.

CS1/96/07: Experimental Approach

1. Assemble a wide range of sub-continental, Australian, and Mediterranean genotypes with putative drought resistance. Take the advice of chickpea breeders!
2. Test the genotypes in sites characterizing the major chickpea growing areas in Australia and India over 2-3 years. Assumption: the site/year combinations will provide diverse environments which will select for different trait assemblages.
3. Collect extensive data on plant stand, early vigour, productivity, yield components, and phenology.
4. Use objective methods to detect groups of genotypes with specific or general adaptation in terms of seed yield.
5. Explain adaptation in terms of associated plant traits.

Australia: diverse germplasm across diverse environments

Origin	(n)
Mediterranean	5
Australian	8
North Indian	34
Central Indian	7
Southern Indian	16
Ethiopian	1
Unknown	1
Total	72

2 trial years = 9 site/year combinations

Results: important G x E interaction

***** Analysis of variance *****

Variate: Yield_tha

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.	F pr.
SITE.Rep stratum					
SITE	8	1076.5	134.6	126.0	<.001
Residual	9	9.6	1.1	10.6	
SITE.Rep.*Units*stratum					
Var	71	24.6	0.3	3.4	<.001
SITE.Var	568	95.6	0.2	1.7	<.001
Residual	635(4)	64.1	0.1		
Total	1291(4)	1263.297			

Big effect of sites

Highly significant interaction

REML

*** Estimated Variance Components ***

Random term	Componen	S.e.
SITE	0.93	0.47
SITE.Rep	0.01	0.01
Var	0.01	0.00
SITE.Var	0.03	0.01

REML confirms interaction

var comp >> genotype var comp

...erences in site yield

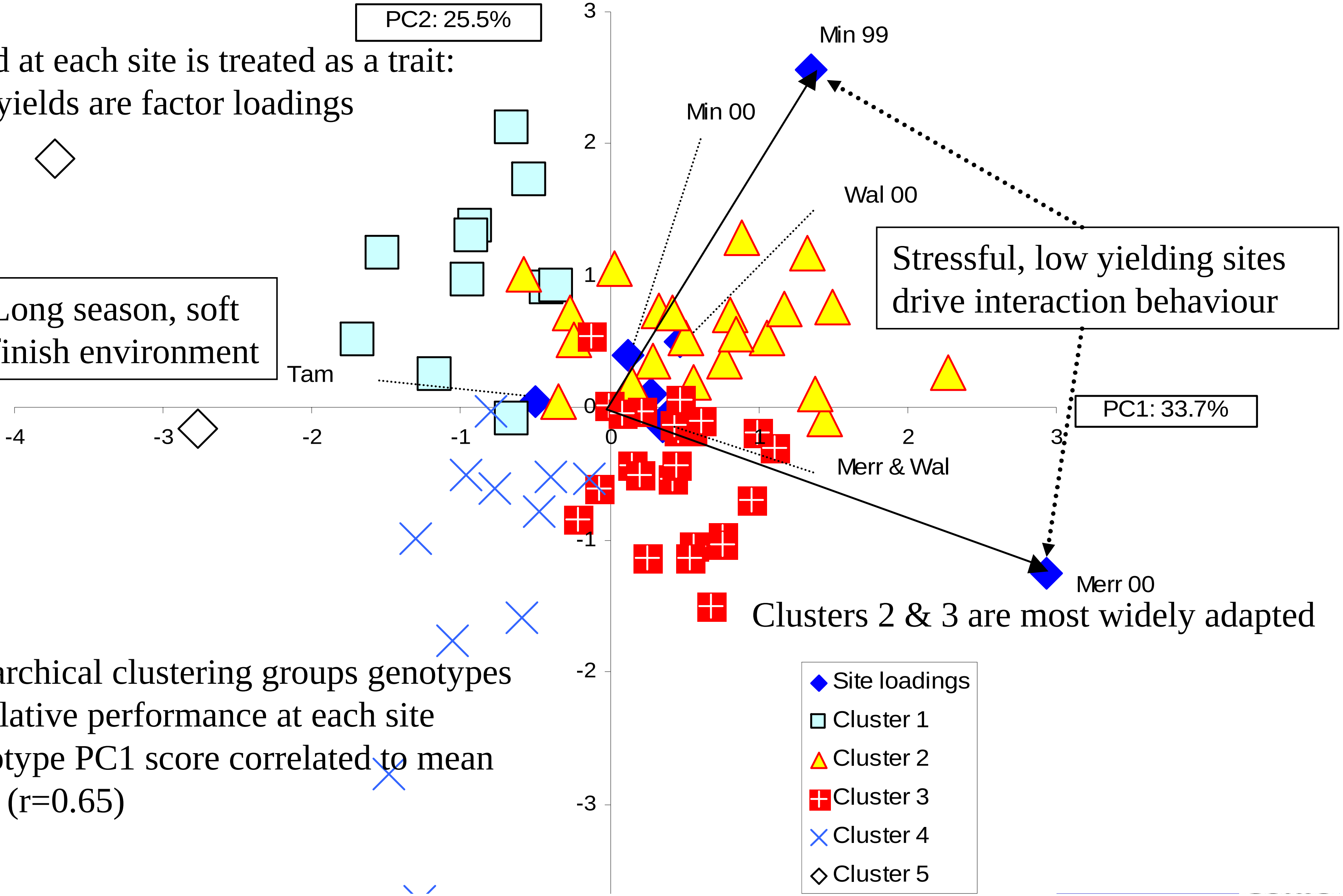
...l associated with terminal drought

	Vegetative	Post -anthesis	Hot days (>32°C) ...nesis (%)
Walpeup			...1
Warwick			...0
Walpeup			...6
Tamwort...			...0
Merredin...			...7
Warwick			...0
LSD			

Productivity associated with pre-...

Multivariate techniques objectively recover the pattern in G x E interaction

Yield at each site is treated as a trait:
Site yields are factor loadings



Clusters 2 & 3 are most widely adapted

Hierarchical clustering groups genotypes by relative performance at each site
Genotype PC1 score correlated to mean yield (r=0.65)

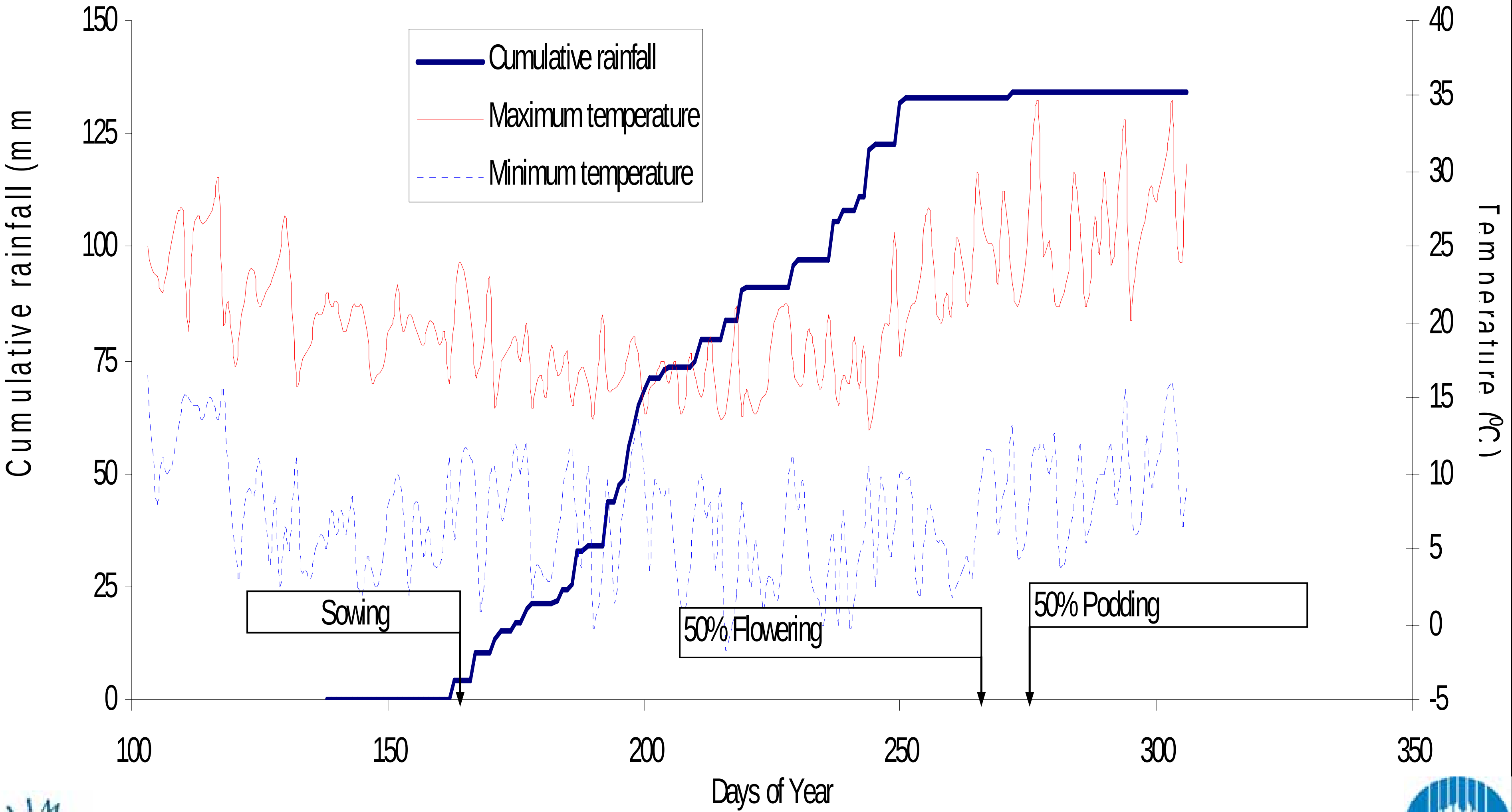
Where are we at?

- Genotypes and environments have been objectively classified based only on yield performance.
- PCA shows how cluster behaviour differs at different sites. Visualization is essential!
- Now that genotypes and sites are classified we can ask: “why do certain genotype clusters perform well or poorly in certain environments?”
- How? By interrogating the other data we have collected.

Characteristics of Successful Clusters

- Origin: Clusters 2 & 3 are dominated by Indian material.
- Phenology: Clusters 2 & 3 tended to start and finish flowering, set pods and mature earlier, resulting in shorter vegetative and longer flowering phases at most sites than in the remaining clusters.
- Biomass partitioning: harvest index was consistently higher in Clusters 2 & 3 at all sites except Minnipa 2000.

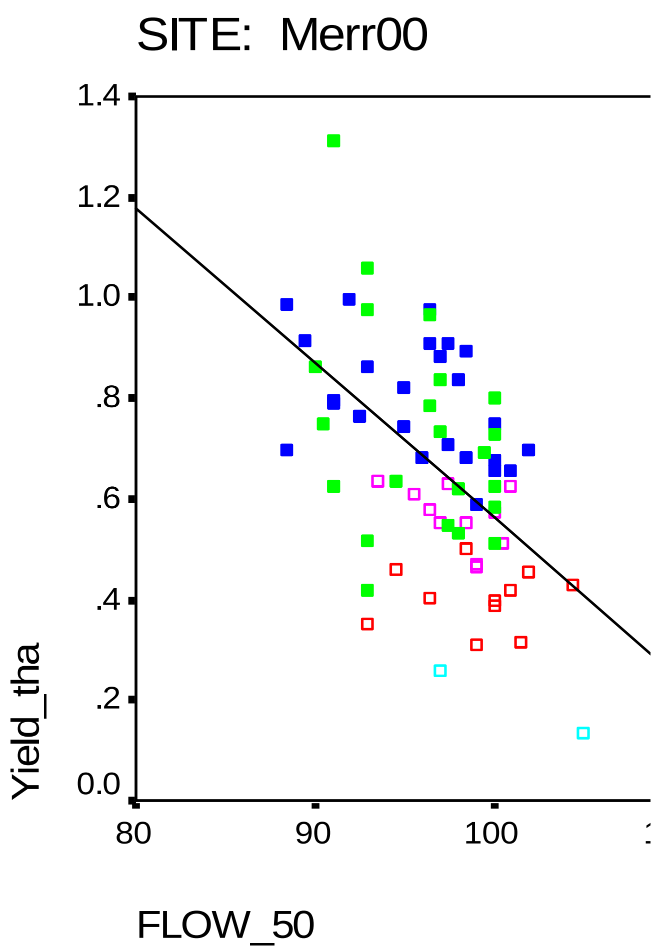
Merredin 2000: a classic terminal drought

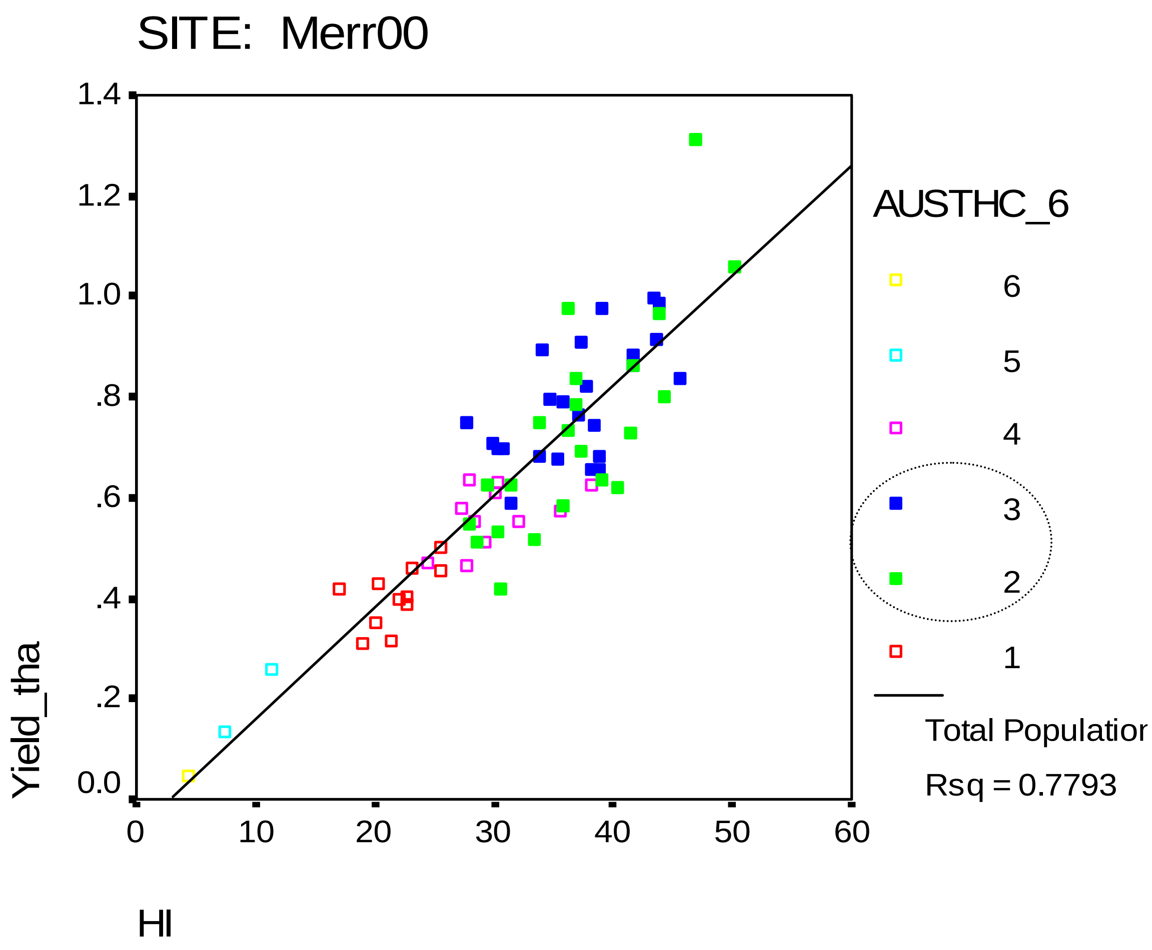


Characteristics of consistently high yielding clusters under terminal drought

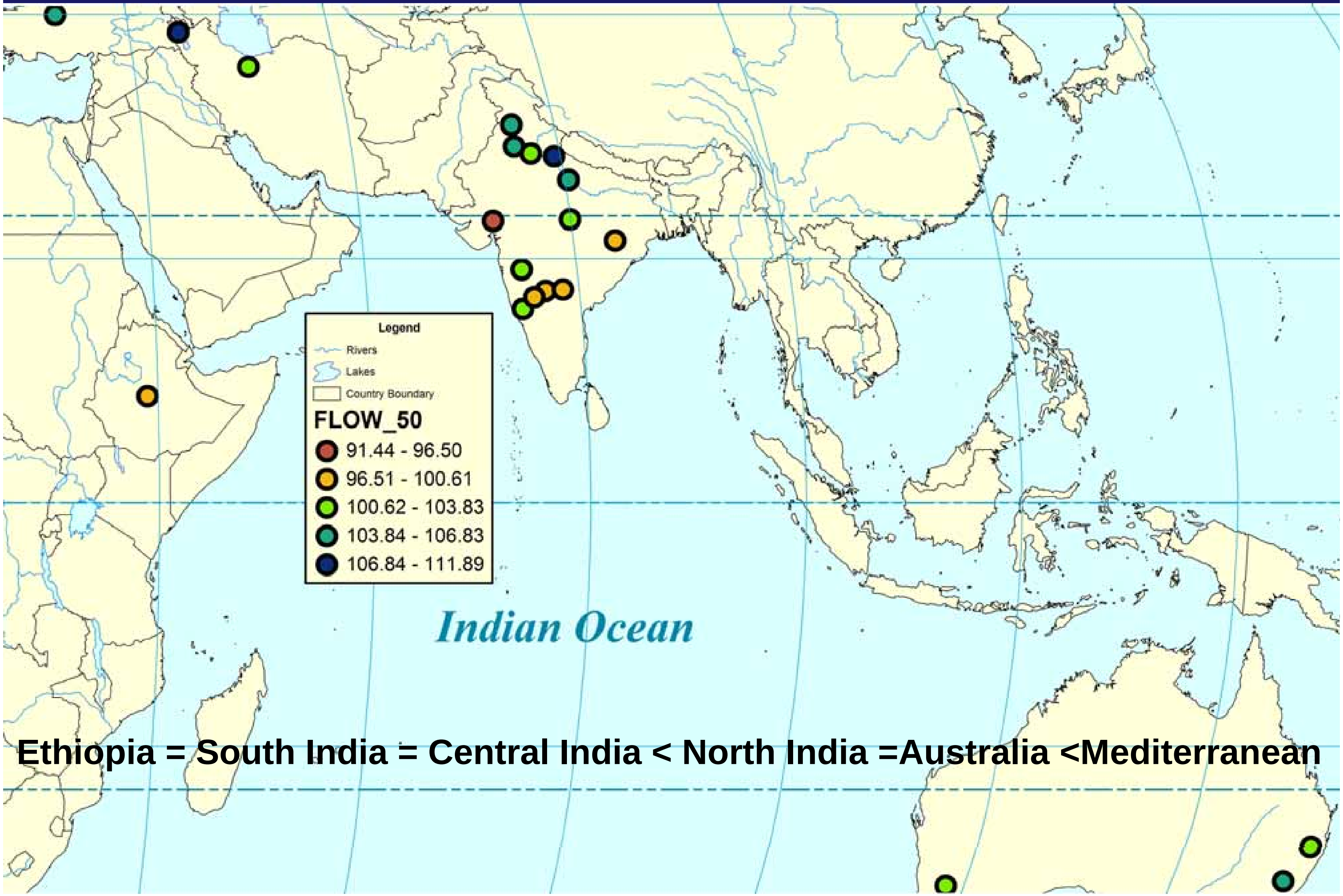
Phenology-early

Harvest Index-high





Origin plays a big role in flowering in chickpea

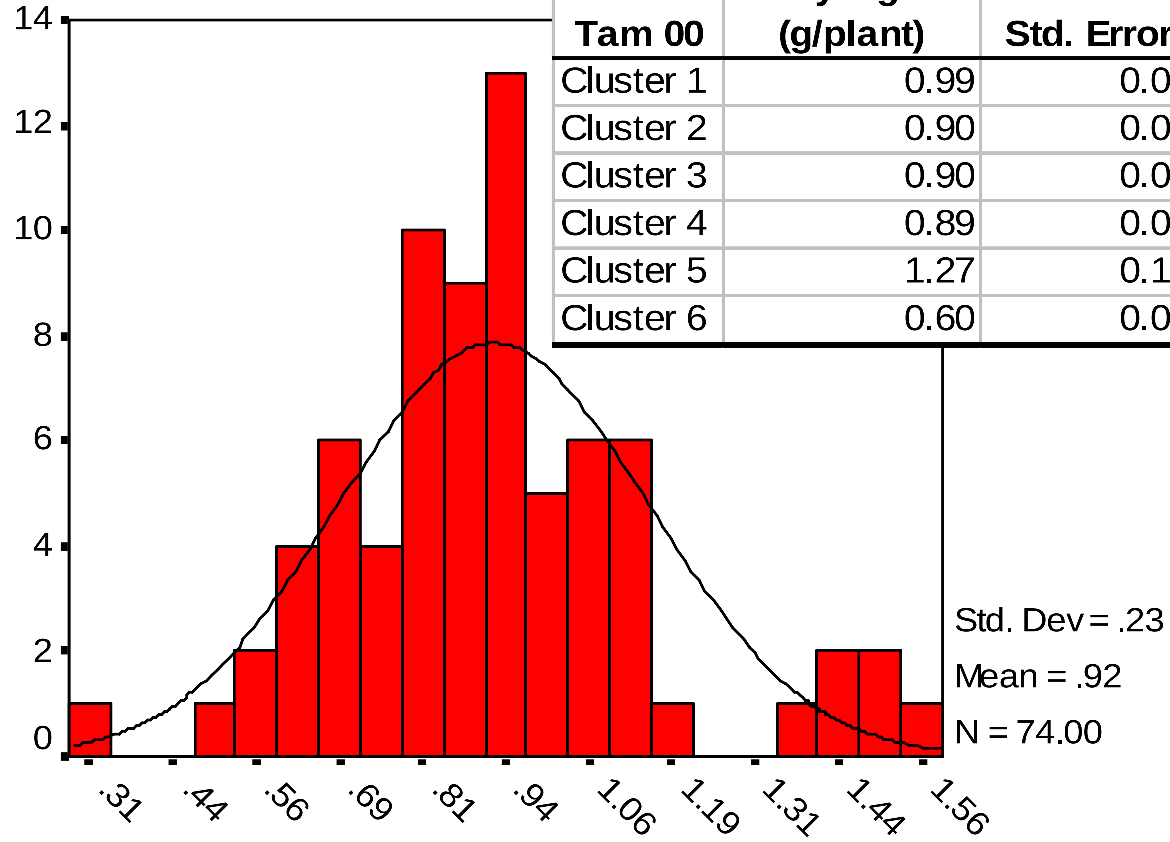


Ethiopia = South India = Central India < North India =Australia <Mediterranean

Characteristics of Successful Clusters- No difference in terms of:

- Early vigour: good range at all sites, but no significant diffs between Clusters 2 & 3 and the rest

SITE: Tam00

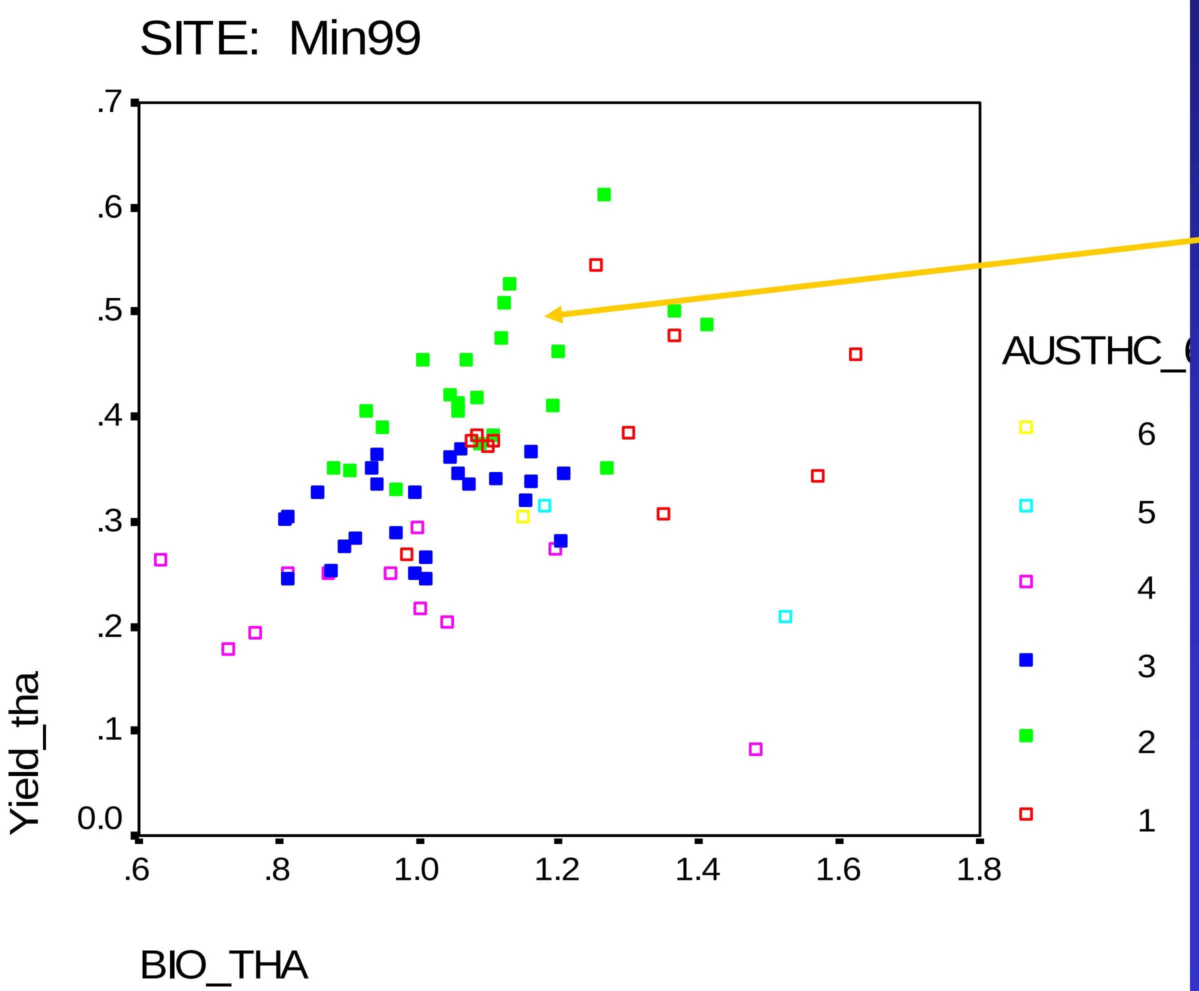


Tam 00	Early vigour (g/plant)	Std. Error
Cluster 1	0.99	0.04
Cluster 2	0.90	0.03
Cluster 3	0.90	0.04
Cluster 4	0.89	0.07
Cluster 5	1.27	0.14
Cluster 6	0.60	0.04

- Early vigour related to seed size (mean *r* = 0.61).
- Trade offs between seed size & number at all sites (mean *r* = -0.40).
- Therefore - **<u>no relationship</u>** between early vigour and seed yield at any site.

Characteristics of Successful Clusters- No difference in terms of:

- Biomass: no significant diffs between Clusters 2 & 3 and the rest at 6 of 9 sites. Clusters 2 & 3 produce **less biomass** at Minnipa 99 & Tamworth 2000, but more at Merredin in 2000.



Cluster 2 is the highest yielder at Minnipa 1999 despite average biomass because of high harvest index.

Australian summary

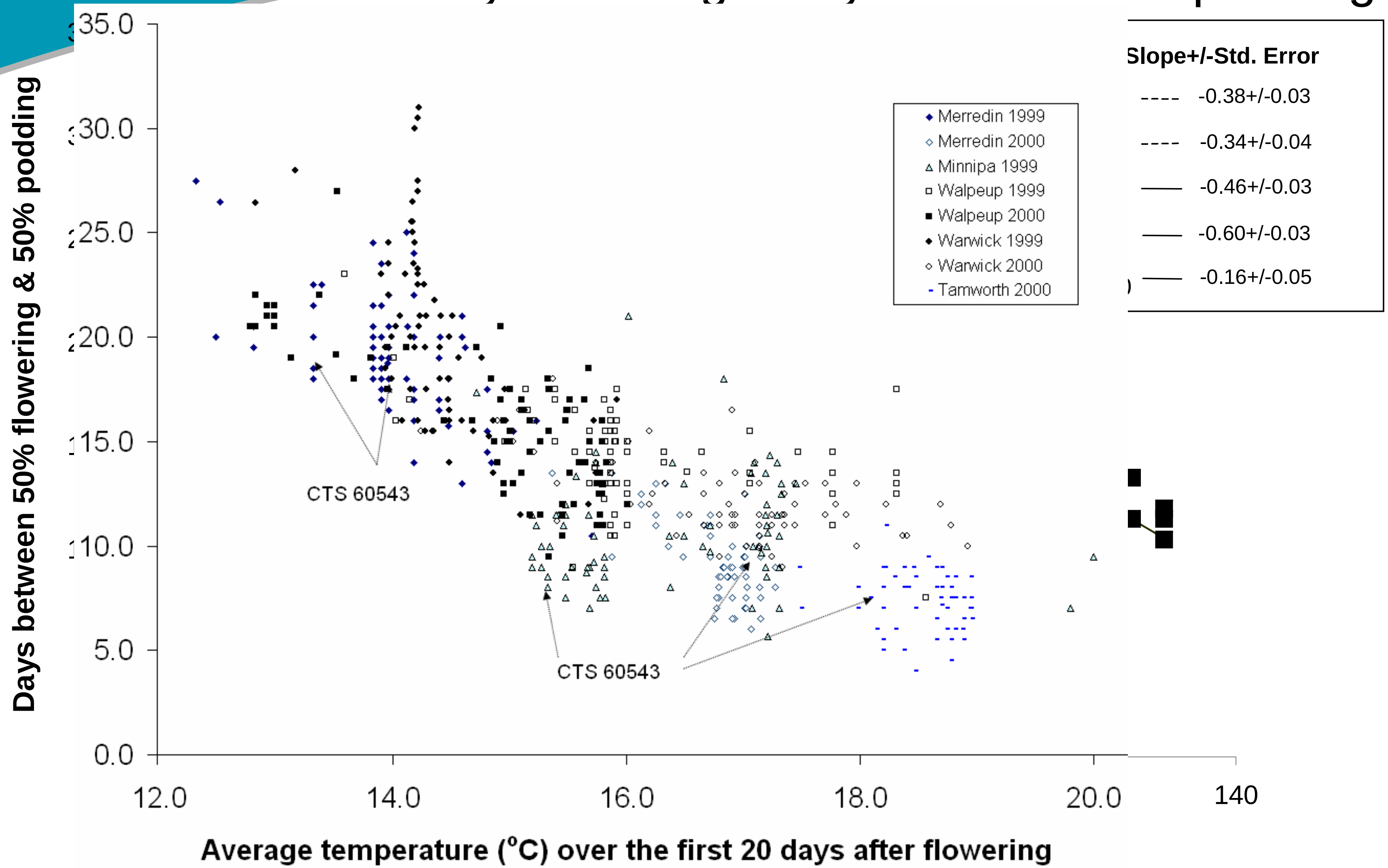
1. Performance under terminal drought is a good predictor for general success across Australia.
2. Central breeding programs located in long season environments are unlikely to produce widely adapted material.
3. Productive clusters: Indian, early phenology + high harvest index = drought escape.
4. Phenology is determined by origin. Photoperiodism, temperature responsiveness at play?
5. High harvest index is more important than high biomass.
6. High early vigour is not important. (Compensated by later growth?)
7. Indian breeders have selected for lower height, higher harvest index.

Chickpea strategy for cool-season Mediterranean farming systems

- Drought escape: avoid terminal drought through early phenology for consistent high yield. (Critical in dry years).
- Select on harvest index.
- Source germplasm from areas where these traits are strongly expressed (southern & central India, Ethiopia, dry areas like Gujurat, Rajasthan?)
- Have solved the problem now? No!

Drought escape is fine, but…

Early flowering delays the onset of podding…



…probably because of the increased exposure to low temperatures

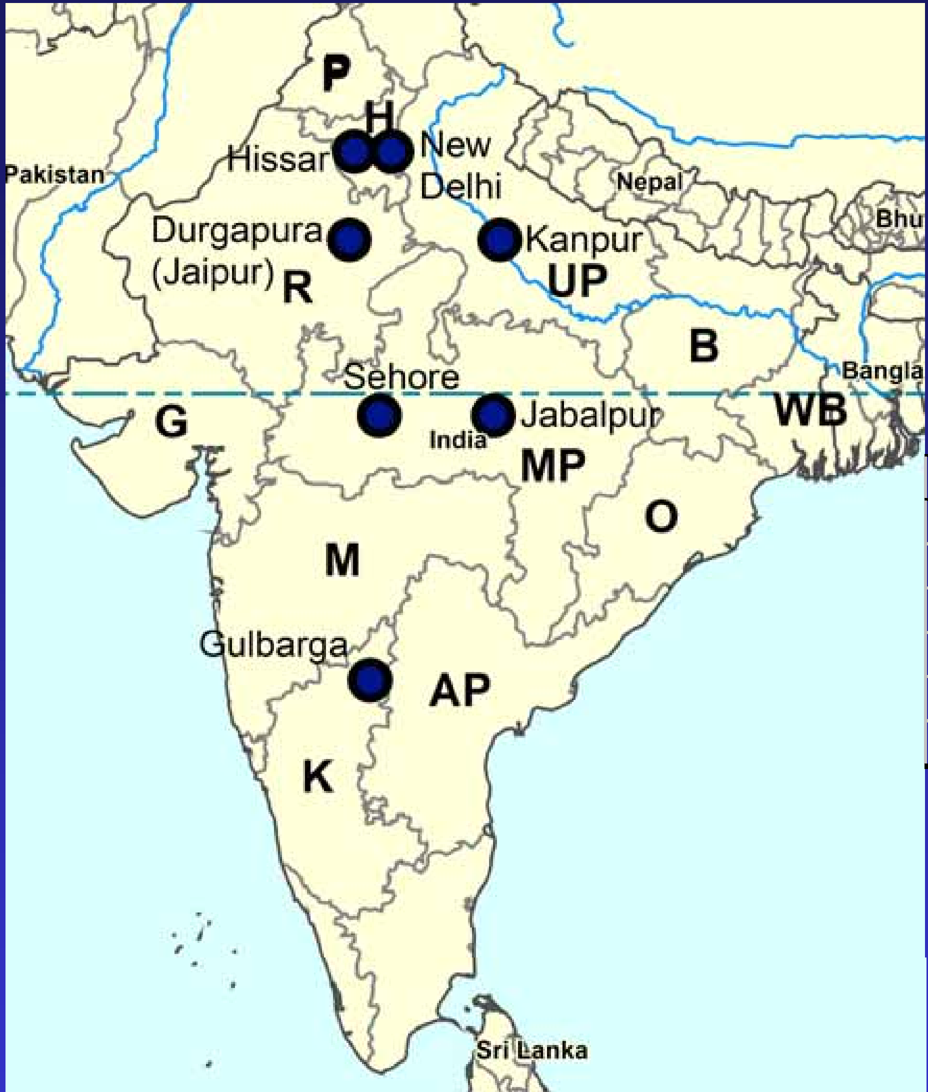
Adapting chickpea to Mediterranean Australia-new directions

- Delayed podset leads to repeated cycles of flowering and subsequent abortion. THIS IS INEFFICIENT!
- Reflects limited cold tolerance at flowering, probably a consequence of the move to spring-sowing early in the evolution of chickpea
- We need more cold tolerance in chickpea to maximize drought escape and stabilize yield.
- This is a focus of my current work as Ecophysiologist at CSIRO. More next week…


Thank you

Chickpea adaptation in India

India: diverse germplasm, diverse environments



Agroecosystem	Total
Autumn sown mediterranean-type (Australia)	3
Autumn sown subcontinental (Central Indian)	5
Autumn sown subcontinental (North Indian)	26
Autumn sown subcontinental (Southern Indian)	7
Spring sown Mediterranean	2
Grand Total	43

3 trial years = 15 site/year combinations

Indian chickpea growing regions

State	Area	Latitude	Longitude	Mean temperature (^oC)		Rainfall (mm)		Daylength	
	(% total production)	(Decimal^o)	(Decimal^o)	Pre-anthesis	Post-anthesis	Preseason	Season	Mean (hrs)	Rate (min/day)
Karnataka	3.6	15.9-17.9	74.5-77.5	24.7	22.6	742.2	126.4	11.3	-0.7
Andhra Pradesh	1.9	16.2-20.0	78.1-83.2	24.7	22.7	820.9	166.1	11.2	-0.7
Maharastra	11.4	16.8-21.1	72.9-77.8	23.3	21.9	808.9	78.2	11.1	-0.7
Orissa	0.3	19.8-21.5	84.0-86.9	22.5	21.8	1515.2	75.4	11	-0.7
Gujarat	0.8	21.2-24.5	69.1-74.9	22.7	20.7	676.8	13.6	10.9	-0.3
Madhya Pradesh	49.1	19.1-26.2	75.8-88.1	19.5	19.3	1307.7	56.2	10.9	-0.3
West Bengal	0.6	22.4-25.0	87.3-88.5	21.2	20.2	1419.3	62.3	10.8	-0.1
Bihar	2.3	23.4-26.7	84.1-87.5	19.1	18.5	1209.7	53.9	10.7	0.4
Rajasthan	13.4	24.5-29.9	71.4-76.2	18.3	19	592	24.8	10.6	0.5
Uttar Pradesh	15.4	25.1-29.9	77.9-83.4	17.9	19.6	949.1	58.7	10.6	0.5
Haryana	1.1	29.2	75.7	16.1	19.3	383	64	10.4	0.7
Punjab	0.1	30.4-31.6	74.9-76.8	15.3	18.1	661.3	118	10.3	1.0

Temperature decreases with latitude

Monsoon increases with longitude

Daylength decreases with latitude, rate of change increases with latitude

Results: important G x E interaction

Big effect of sites

*** Estimated Variance Components ***		
Random term	**Component**	**Std. Error**
SITE	0.62	0.24
Var	0.09	0.02
SITE.Var	0.10	0.01
SITE.Rep	0.02	0.01

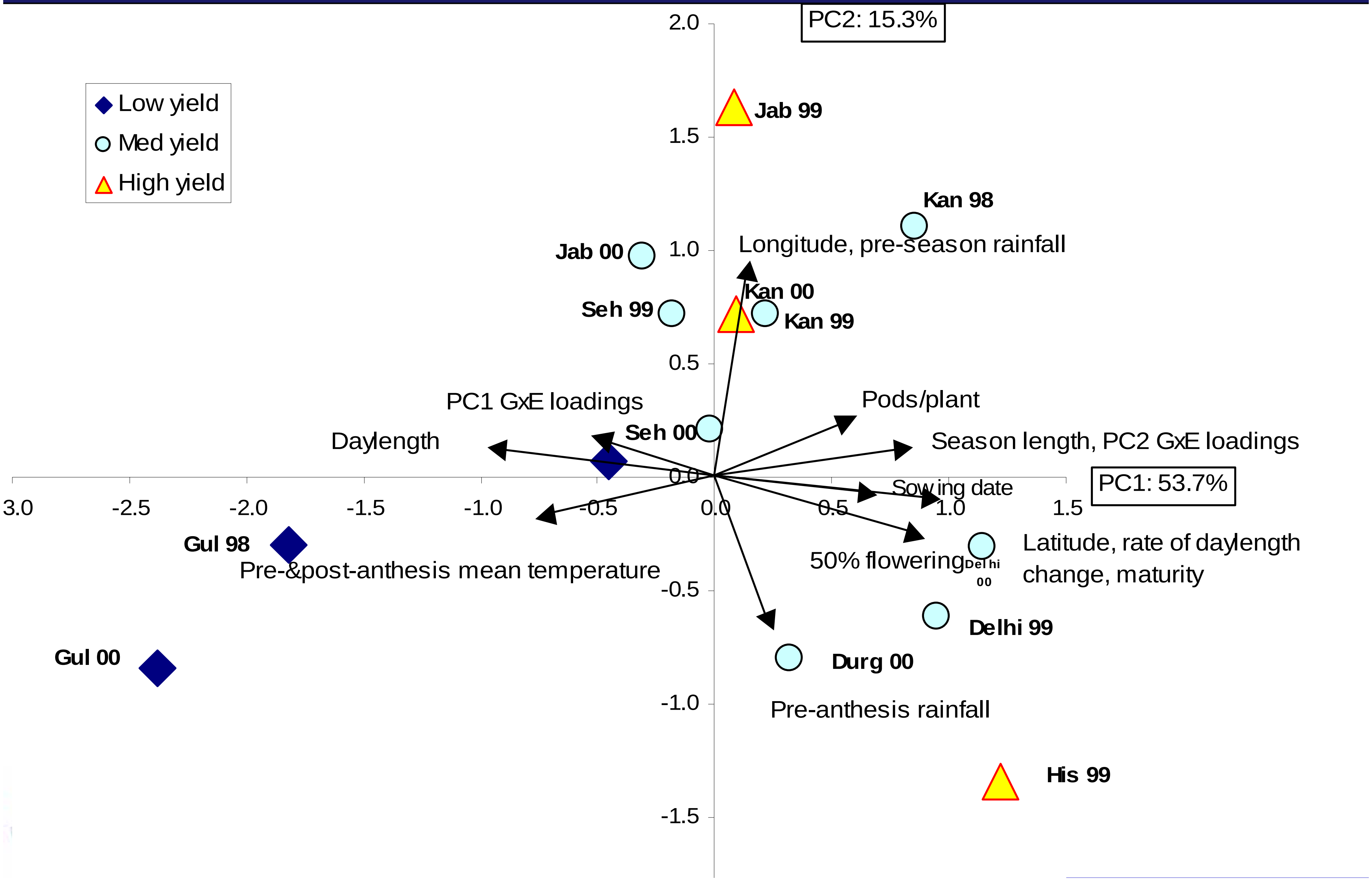
Smaller, but still significant effects of G, and interaction with site

Variance of G, and G x E similar (unlike Australia).
Suggests G x E pattern should be simpler, more explainable?

Results: 10 fold differences in site yield

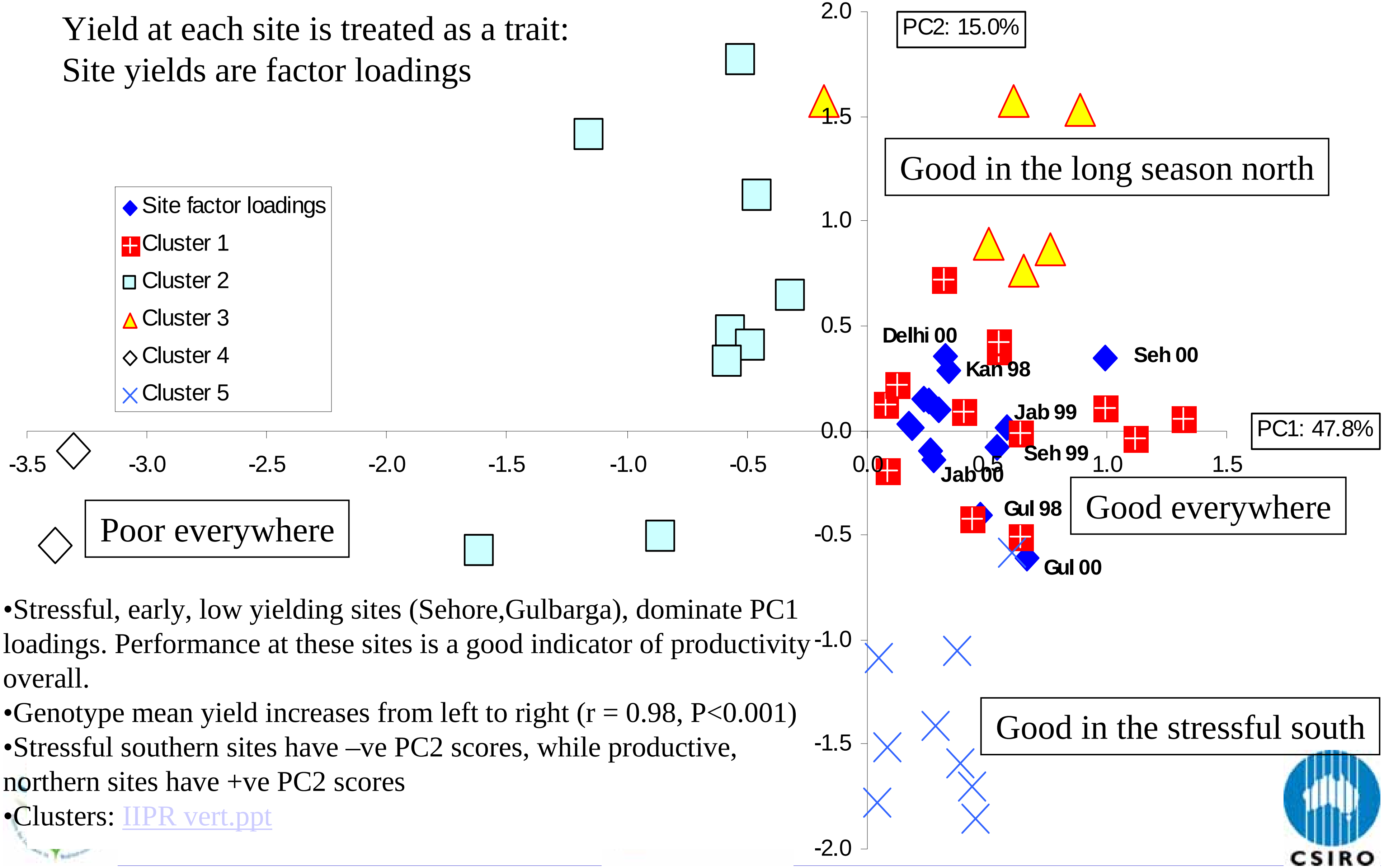
Site	Mean yield
Sehore 2000	-0.60 (0.3)
Gulbarga 2000	-0.39 (0.4)
Gulbarga 1998	-0.15 (0.7)
Sehore 1999	0.05 (1.1)
Delhi 1999	0.07 (1.2)
Durgapura 1999	0.17 (1.5)
Delhi 2000	0.17 (1.5)
Durgapura 2000	0.17 (1.5)
Jabalpur 1998	0.22 (1.7)
Kanpur 1998	0.24 (1.7)
Jabalpur 2000	0.29 (1.9)
Kanpur 1999	0.29 (1.9)
Jabalpur 1999	0.33 (2.1)
Kanpur 2000	0.39 (2.4)
Hisar 1999	0.41 (2.6)

PCA shows site yield & biology is driven by geography and climate



Multivariate techniques recover the pattern in G x E interaction objectively

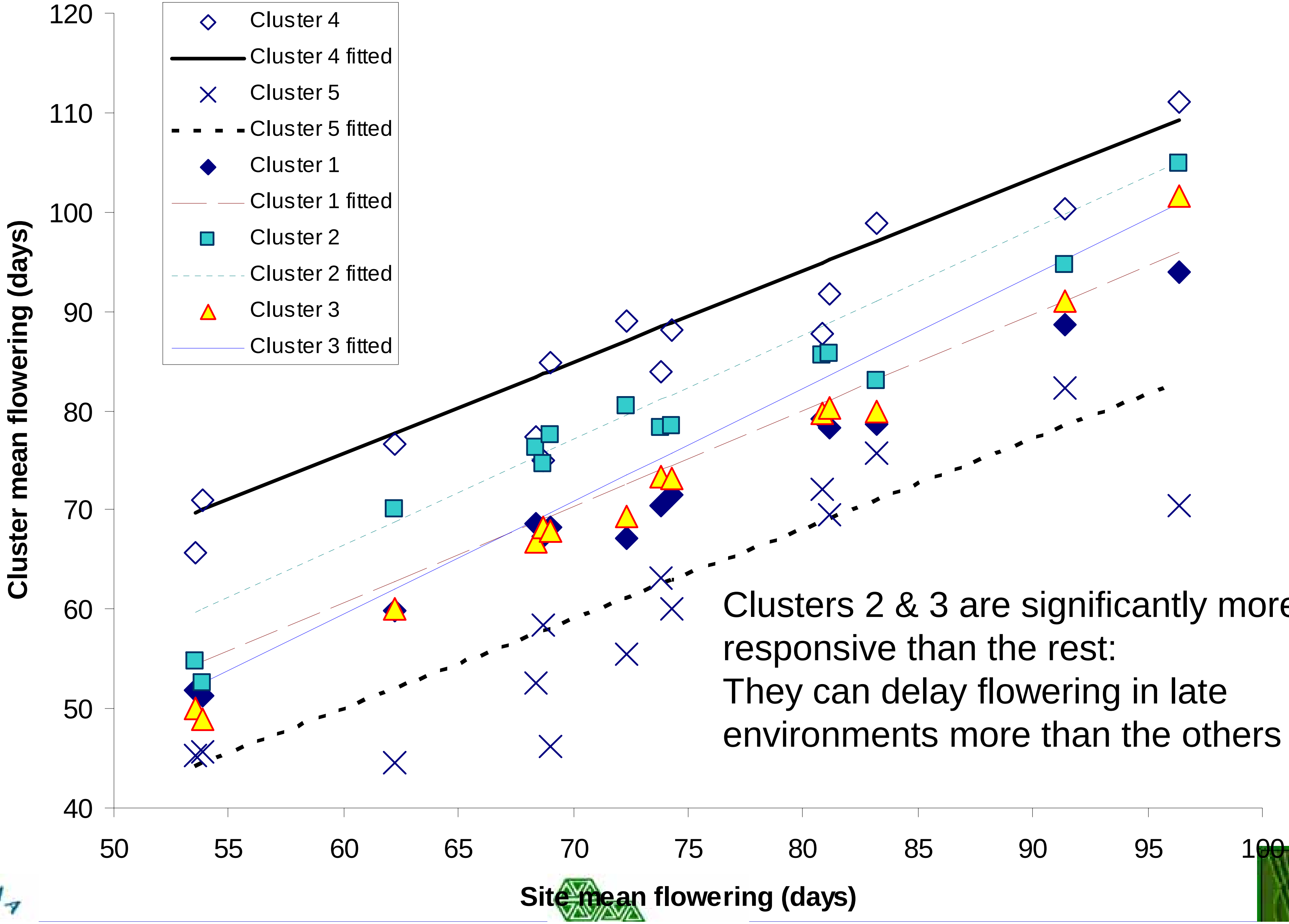
Yield at each site is treated as a trait:
Site yields are factor loadings



- Stressful, early, low yielding sites (Sehore, Gulbarga), dominate PC1 loadings. Performance at these sites is a good indicator of productivity overall.
- Genotype mean yield increases from left to right (r = 0.98, P<0.001)
- Stressful southern sites have –ve PC2 scores, while productive, northern sites have +ve PC2 scores
- Clusters: IIPR vert.ppt

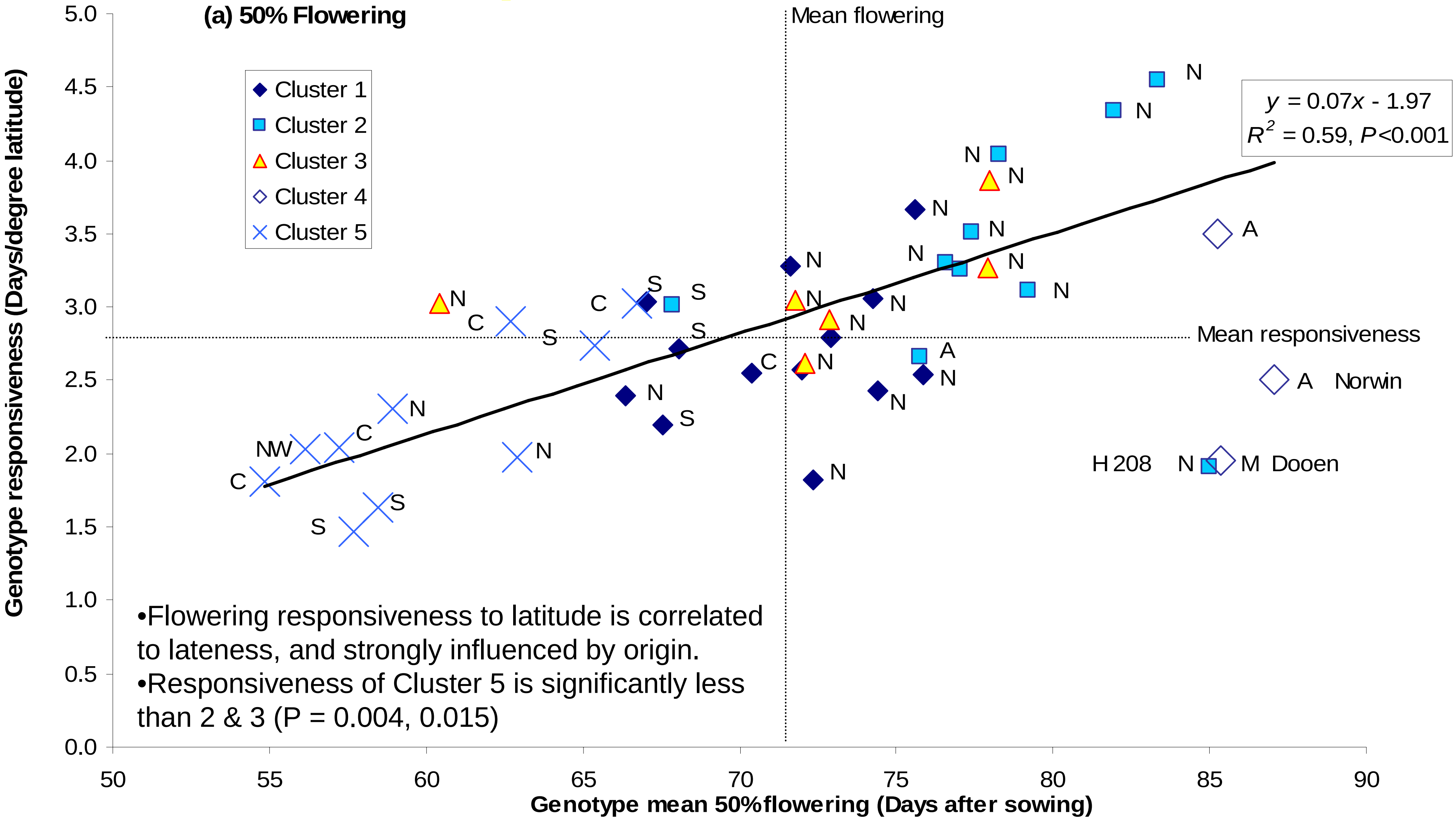
CSIRO

Cluster characteristics: 50% Flowering



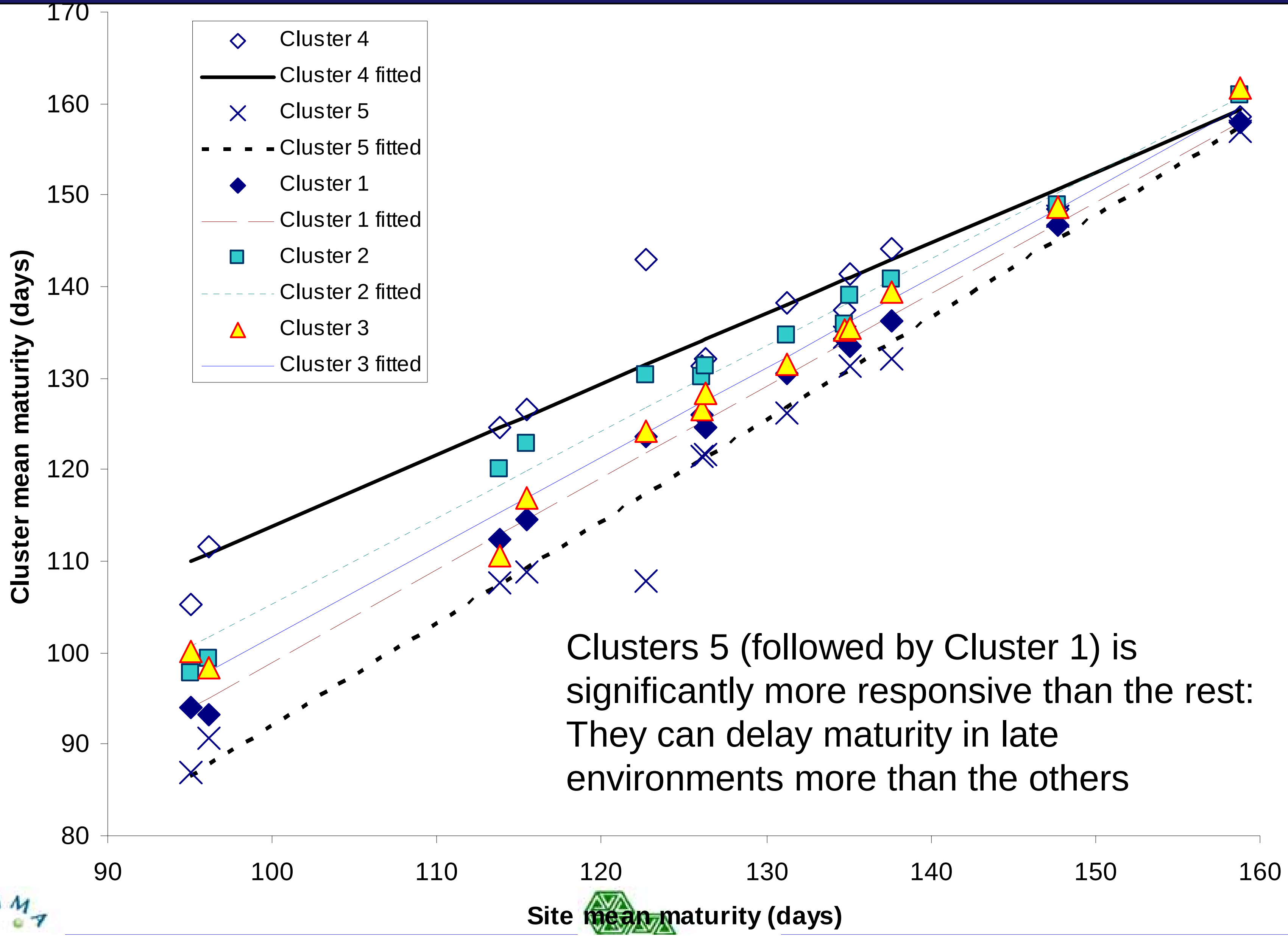
Clusters 2 & 3 are significantly more responsive than the rest:
They can delay flowering in late environments more than the others

Cluster characteristics- genotype flowering response to latitude



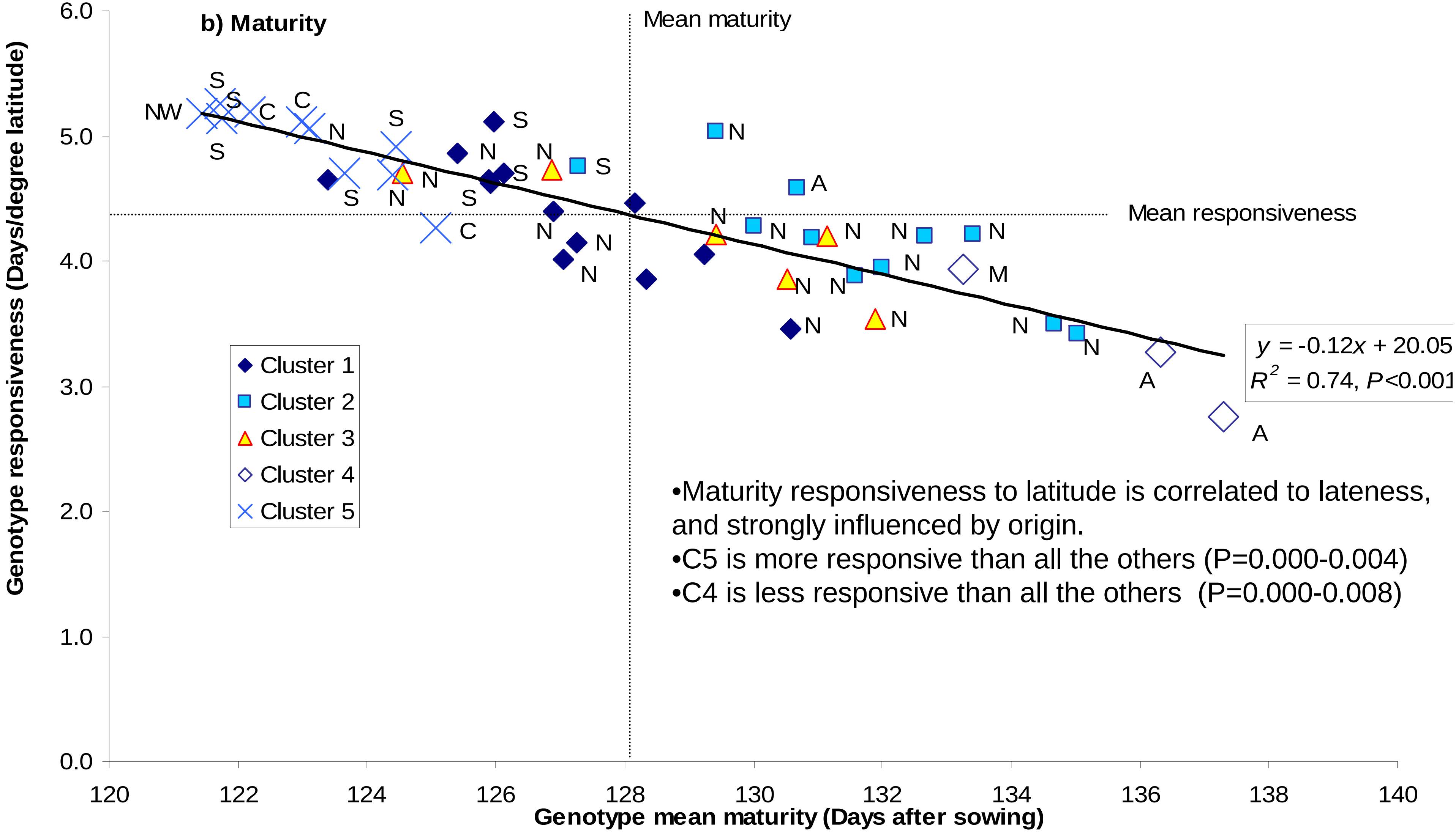
- Flowering responsiveness to latitude is correlated to lateness, and strongly influenced by origin.
- Responsiveness of Cluster 5 is significantly less than 2 & 3 (P = 0.004, 0.015)

Cluster characteristics: Maturity



Clusters 5 (followed by Cluster 1) is significantly more responsive than the rest: They can delay maturity in late environments more than the others

Cluster characteristics- genotype maturity response to latitude



•Maturity responsiveness to latitude is correlated to lateness, and strongly influenced by origin.

•C5 is more responsive than all the others (P=0.000-0.004)

•C4 is less responsive than all the others (P=0.000-0.008)

Other traits related to specific adaptation

- Gulbarga excepted, Cluster 3 generally accumulated more biomass by maturity than Cluster 5 (P<0.001 to P<0.062).
- Cluster 3 was significantly taller than Cluster 5 at most sites (P<0.001 to P<0.049), and had a higher number of seeds per pod (P<0.001 to P<0.056), regardless of latitude or productivity.
- Cluster 5 had a significantly higher harvest index (P<0.001 to P<0.034) at most central and southern sites.
- The interval between flowering and podding was significantly (P<0.05) greater in Cluster 5 than in 3 at Delhi (both years), and particularly Hissar (50 versus 21 days), but also in Jabalpur and Durgapura in 2000.

Discussion: phenology & specific adaptation

- Indian environments are more stable than Australian: because of the large latitudinal range and role of stored soil moisture.
- Phenology plays a critical, *dynamic* role in specific and general adaptation.
- Germplasm specifically adapted to the north is able to delay flowering at later flowering sites or higher latitudes *more* than non-adapted material: increases both source *and* sink potential and reduces the time interval between flowering and podding.
- Southern adaptation: early phenology = drought escape. Low flowering plasticity, but can extend growing season length under favourable conditions. This allows germplasm specifically adapted to the south to partially compensate for excessively early flowering in the north, and explains why yield differences between adapted and non adapted germplasm are smaller at Hissar than at Hyderabad.

Discussion: phenology & wide adaptation

- The combination of intermediate flowering and relatively early, responsive maturity (Cluster 1), is a phenological compromise that leads to wide adaptation, with high yields both north and south.
- In the south, intermediate flowering and early maturity in Cluster 1 provides sufficient drought escape to match Cluster 5 yields at all but 1 site, whereas a relatively delayed maturity in the north gives rise to a similar yield as Cluster 3 at all higher yielding sites.
- Phenological responses to latitude will be elucidated in terms of temperature/photoperiod effects in a 3rd paper which will also include the Australian data. Why can the northern material modify its flowering date, whereas the southern material can't?

Discussion- Implications for Breeding

- The dynamic role of phenology in specific and wide adaptation has important implications on site choice for evaluation.
- While there is a wide range of flowering dates at all sites, maturity becomes compressed with increasing latitude. Southern India (Gulbarga) is the best place to evaluate maturity.
- Evaluating in the north and south enables you to quantify genotype flowering responsiveness and model the effects of photoperiod and temperature.

Output

CSIRO PUBLISHING

www.publish.csiro.au/journals/ajar *Australian Journal of Agricultural Research*, 2004, 55, 1071–1084

Genotype by environment studies across Australia reveal the importance of phenology for chickpea (*Cicer arietinum* L.) improvement

J. D. Berger[A,H], *N. C. Turner*[A,B], *K. H. M. Siddique*[A], *E. J. Knights*[C], *R. B. Brinsmead*[D], *I. Mock*[E], *C. Edmondson*[F], *and T. N. Khan*[A,G]

2. Berger J. D. M. Ali, P. S. Basu, B.D. Chaudhary, S. K. Chaturvedi, P.S. Deshmukh , P.S. Dharmaraj, S.K. Dwivedi, G. C. Gangadhar, P.M. Gaur, G, J. Kumar, R. K. Pannu, K. H. M. Siddique , D. P. Singh, S. J. Singh, N. C. Turner, H. S. Yadava, S. S. Yadav (2005) Genotype by environment studies demonstrate the critical role of phenology in adaptation of chickpea (*Cicer arietinum* L.) to high and low yielding environments of India. Field Crop Research *in preparation.*


Thanks very much for all your efforts.
Working together was great.