Understanding models from the ground up: APSIM Modelling in the EGP region

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Introduction

- What is crop modelling? Why would we want to model cropping systems?
- Introduction to the APSIM model
  - What data does it need?
  - What can it do?
- Some examples of how APSIM has been used in the EGP/IGP
- Other useful examples of cropping systems model application
- Crop Yield Gap analysis – new ACIAR-SDIP2 Small Research Activity (SRA)

Group Feedback Session:

- What information would you like to learn from this SRA?

Introduction…..why crop systems modelling?

This presentation is directly about issues facing cereal crop production…..

- Staple food for more most of the world's population
- Grown in lots of different ways, in lots of different places….






But, all over the world, these farming systems are experiencing high levels of adaptive pressure

Due to:

- Changing weather patterns (less/more rainfall, changed temporal distribution of rainfall, less stream-flow, increased temps, CO_2 and evaporation)
- Competition for water between agriculture and other users (industry, growing cities/towns)
- Over-exploitation of resources (or under-exploitation, water)
- Changing market forces, commodity prices, environmental drivers
- The overriding need to produce more food – to feed a growing population

There is a need to evaluate potential new farmer management strategies, under potential new climates and conditions.

(not just rice or wheat or maize crops alone, but as part of diverse farming systems)

Adaptation to all these drivers of change have one thing in common – they are SYSTEMS issues

They are not issues which can be addressed by simply fine-tuning the agronomy of a rice crop or a wheat crop –

They require solutions which integrate a range of options at a cropping systems level….

For example….

• determining how best to share a limited water resource amongst several different cropping enterprises

• optimising the agronomic management of rice in rotation with other non-flooded crops and pastures (maize, legumes, pulses etc..)

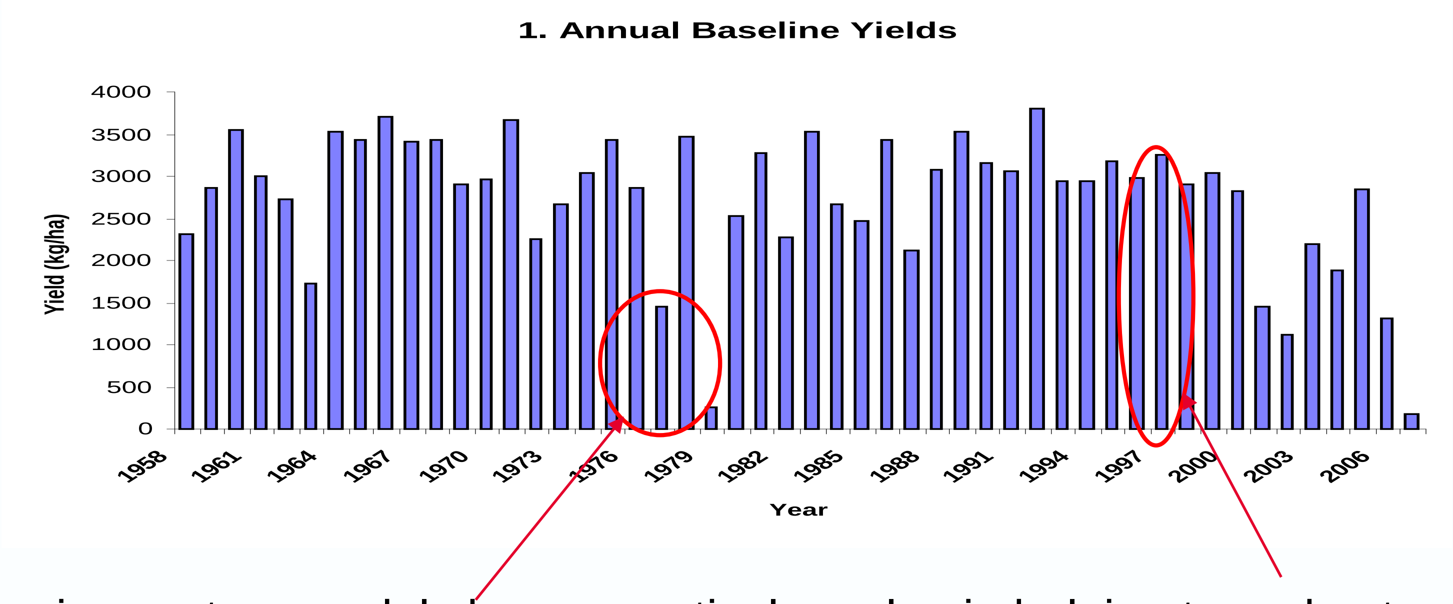
• compare pathways to adapt farmer management in regions with over-exploited water extractions back to sustainable and economic extraction

• how do the range of potential adaptation ideas compare? Between regions, on different soils, different varieties, different managements, a changed climate?

Well-tested **cropping systems models** can play a useful role in developing solutions to these problems,

They are not a replacement for experimentation and local knowledge,
- they supplement and extend the learnings from these….

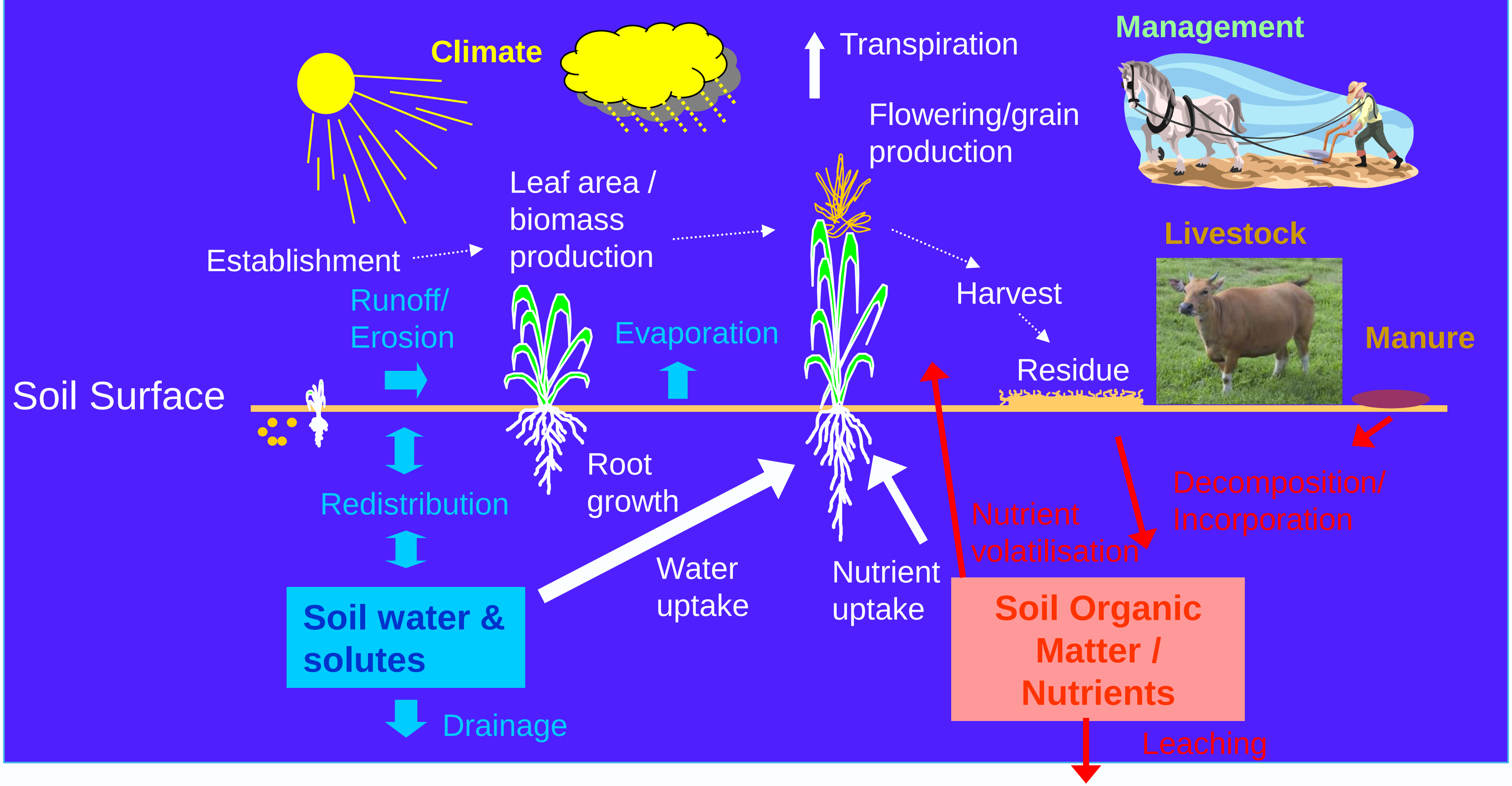
Give information on long-term variability (risk) in the system



Cropping system models have a particular value in helping to understand variability and risk associated with management practices

Introduction to APSIM……

APSIM modelling



APSIM is a cropping systems model……

- **A platform for simulating "cropping system" performance over time**
  - Crop rotations, fallowing, fertiliser and irrigation strategies, crop varieties, weeds etc
  - Daily time-step (requires daily climate data)
  - Point-scale (represents a field or paddock)
  - Can capture the effect of climate changes (CO_2, temperatures)

- **Equal emphasis on crop and soil dimensions of agricultural systems**
  - Simulates crop production, soil water and nutrient dynamics, water-balance terms, resource use

- **Capable of simulating detailed farmer management options**
  - ….and subsequently investigating how other system aspects are affected –yields, water use, runoff, drainage, leaching, GHG emissions etc..
  - Using Gross Margin data (costs, prices etc) we simulate profitability

APSIM's central concept……

The *soil* provides a central focus, *crops*, *seasons* and *managers* come and go, finding the *soil* in one state and leaving it in another.

Crop, pasture and tree modules

- Barley
- Bambatsi
- Canola
- Chickpea
- Cowpea
- E. Grandis[D]
- Faba bean
- Fieldpea
- Grape (VineLogic) [B]
- Lablab
- Lucerne
- Lupin
- Maize
- Millet[C]
- Mucuna
- Mungbean

- Native pasture (GRASP)
- Navybean
- Rice (ORYZA)[A]
- Cotton (OZCOT)[B]
- Peanut
- Pigeonpea[C]
- Sorghum
- Soybean
- Stylo pasture
- Sugarcane
- Sunflower
- Weed
- Wheat
- Hemp

- Mucuna
- Navybean
- Potato
- Brocolli

[A] in association with Uni. Wageningen & IRRI

[B] by arrangement with CSIRO Plant Industry

[C] in association with ICRISAT

[D] In association with CSIRO L&W

APSIM data needs

Daily Climate Data

The essential elements are:

- Year
- Julian Day
- Solar Radiation (MJ/m2) or sunshine hours
- Minimum and maximum daily temperatures (°C)
- Daily rainfall (mm)

APSIM data needs

Soil Data – physical parameters

Soil parameterisation in APSIM is required on a layered basis, the depth and number of layers being arbitrary. Both soil water and soil chemical parameters are required:

- Initial soil moisture content (in volumetric terms, $mm.mm^{-1}$)
- Bulk Density ($g.cm^{-3}$)
- Water-holding contents of each layer (saturation, field capacity, 15 bar lower limit, and air dry) in volumetric terms (mm water.mm^{-1} soil)
- k_{sat} – saturated percolation rate ($mm.day^{-1}$); the rate at which water can pass through a specified soil layer when it is saturated.
- Soil Evaporation parameters
- Soil albedo
- Runoff partitioning parameters
- Maximum ponding height (mm)

APSIM data needs

Soil Data – chemical parameters

Key soil chemical parameters required for each soil layer are:

- Organic carbon (%)
- pH
- Soil organic matter partitioning (% inert, humic, and micro-organism matter)
- Initial fresh organic matter mass and C:N ratio
- Initial NO_3 and NH_4 levels ($kg.ha^{-1}$ or ppm)
- Cation exchange capacity (CEC)
-

Information on the initial amount and type of crop stubble present in the system is required.

APSIM data needs

Crop parameters

For each variety of each crop type and variety to be simulated, detailed phenological information are required:

- Thermal time required (^{o}C days) between key crop stages:
    - Sowing
    - Emergence
    - End of juvenile or vegetative stage
    - Floral initiation
    - Flowering or Anthesis
    - Physiological maturity
- Plant establishment numbers
- Photosynthesis assimilate partitioning ratios between leaves, stems, storage organs and roots at different growth stages

APSIM data needs

Imposed management parameters

Detailed information is required on:

- Sowing windows and/or sowing rules for each crop or pasture in the simulation
- Crop varieties sown
- Amount, type, timing and rates of fertiliser application
- Irrigation schedules and amounts applied
- Residue management practices
- Gross margin – costs and prices

Wherever possible management data are generated (or validated) through focus group discussions and/or farmer interviews

Then, APSIM will predict for you….

(on a daily basis for as many years as you provide climate data)

- Crop biomass and crop development stage
- Grain yield
- Crop water use
- Crop nutrient uptake
- Soil moisture dynamics for each layer
- Soil nutrient dynamics for each layer
- Greenhouse Gas emissions
- Gross Margins (profit)

The model is totally driven by daily climate data – you provide the climate information, APSIM will predict for you:-

- how your crops are growing
- the status of the soil pools (water, C, N, P etc..)

….. according to whatever farmer management you have specified

What questions are answered by the model?

In general terms, what is the outcome for a farmer if they were to change their cropping practices in some way?

- in terms of total production (grain, forage, livestock etc)
- in terms of risk (year-to-year variability in outcomes over lengthy climatic period)
- profit (by incorporating costs and prices into analyses)
- sustainability (long-term effect on soil health, resource use (eg. irrig water, fertiliser), environmental variables (NO3 leaching, deep drainage, GHG emissions, etc.))
- effect of a future changing climate? (on all the above…)

Other more heuristic examples…

- what would the perfect variety look like for a certain agronomical niche – to advise breeders
- understanding the drivers behind grain yield gaps, to focus improvement efforts

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Using APSIM robustly

Four stage process:

1. Parameterisation: measure and collect data (soil, climate, crop, management) to adjust APSIM to local conditions.

2. Calibration: APSIM set up as for experimental trials: simulated and observed results compared. Empirical (estimated) model input parameters (phenology, soil) adjusted until observed and simulated results are similar.

3. Validation: APSIM run against independent data (ideally new season at same site, or other local trials): simulated and observed results compared. (farmer trials or previous experimental data also…..)

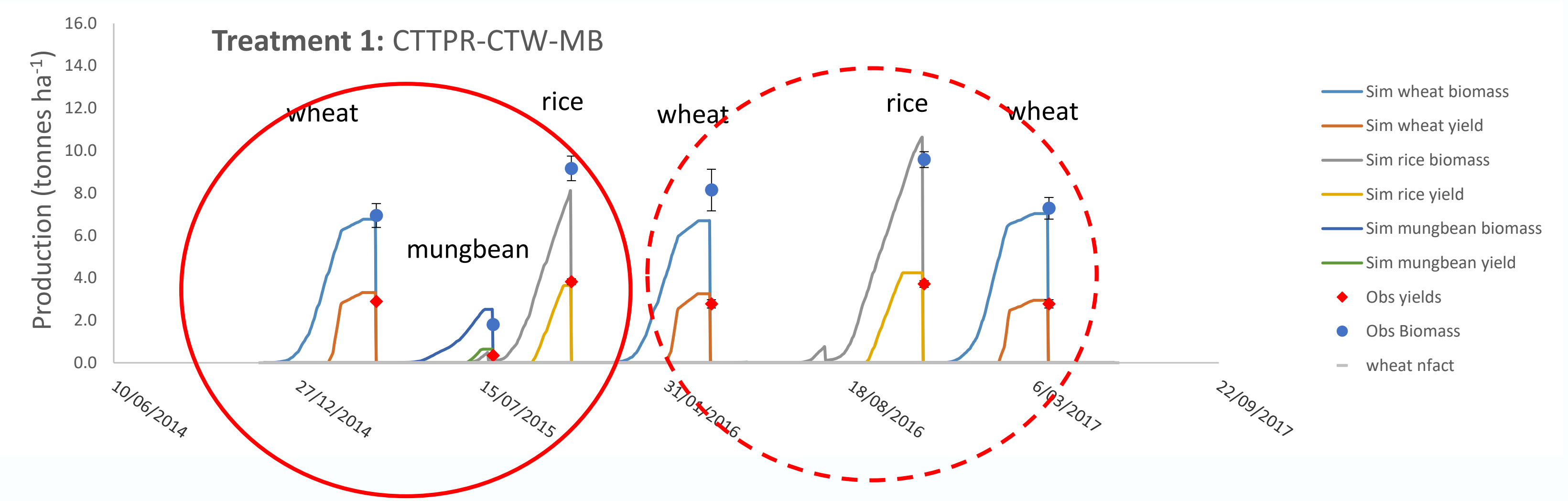
4. Scenario analysis: use validated APSIM as a research tool to gain insight into long term average production and risk under different management options (inputs from social science regarding constraints)

Some examples of how APSIM has been used in the EGP/IGP

- Climate change adaptation studies – (ACIAR-ACCA)
- Evaluating Conservation Agriculture (CA) interventions (ACIAR-SRFSI)
- Strategies for intensifying crop production in saline zones (ACIAR-CSI4CZ)
- Understanding crop yield gaps in the IGP (New SDIP2 SRA - Indus, CIMMYT)

Calibrating and Validating APSIM

ACIAR-SRFSI Project
3 countries (India Bangladesh, Nepal), 8 regions, 40 nodes
350-400 participating farmers (each hosting field trials)



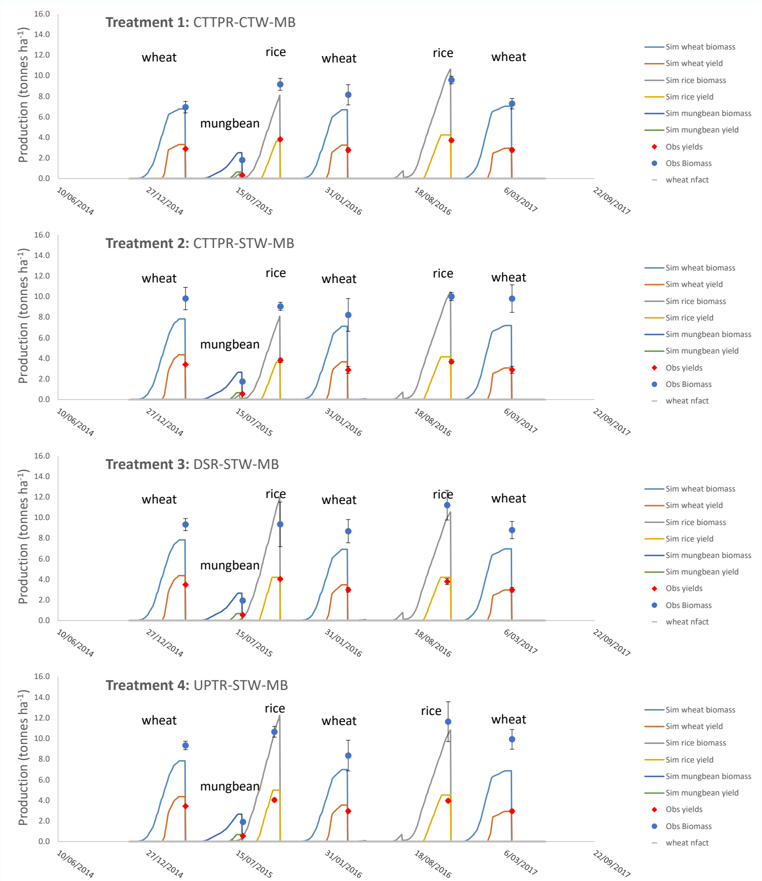
Calibration
(first full season)

Validation

BADURIA – Rajshahi (rice-wheat-mungbean system)

comparing observed vs simulated data

Calibrating and Validating APSIM



BADURIA – Rajshahi (rice-wheat-mungbean system)

RICE-WHEAT-MUNGBEAN SYSTEM

Treatment 1: CTPTR - CTW - MB (Conventional practice)

Initial C & V

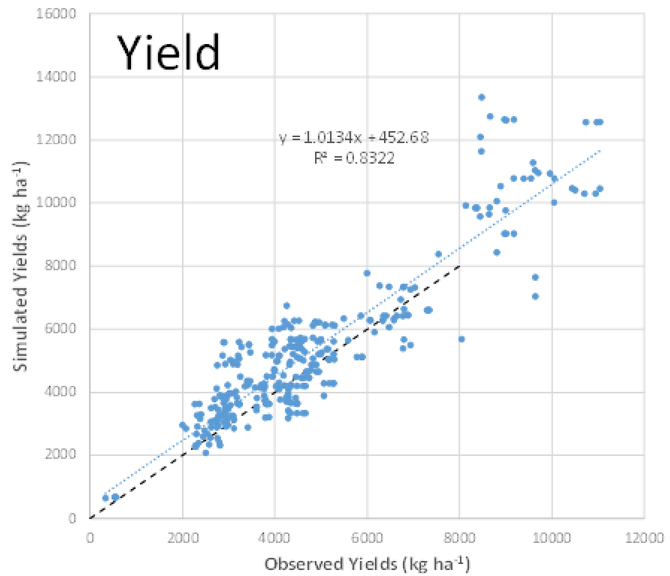
Treatment 2: CTPTR - STW - MB (Partial CA)

Treatment 3: DSR - STW - MB (Full CA)

Treatment 4: UPTR - STW - MB (Full CA)

secondary validation

Calibrating and Validating APSIM



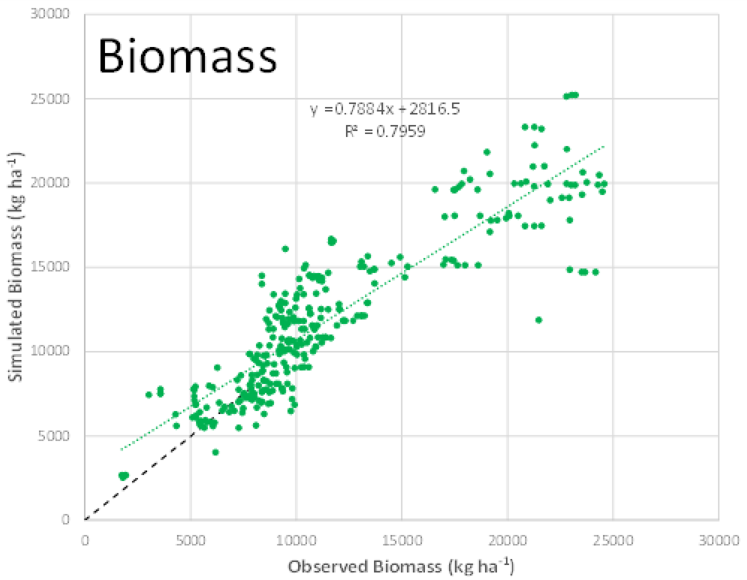


Table 3.3. Statistical analysis of APSIM performance against SRFSI on-farm trials. The units of X_{sim}, X_{obs} and RMSE is kg ha^{-1}.

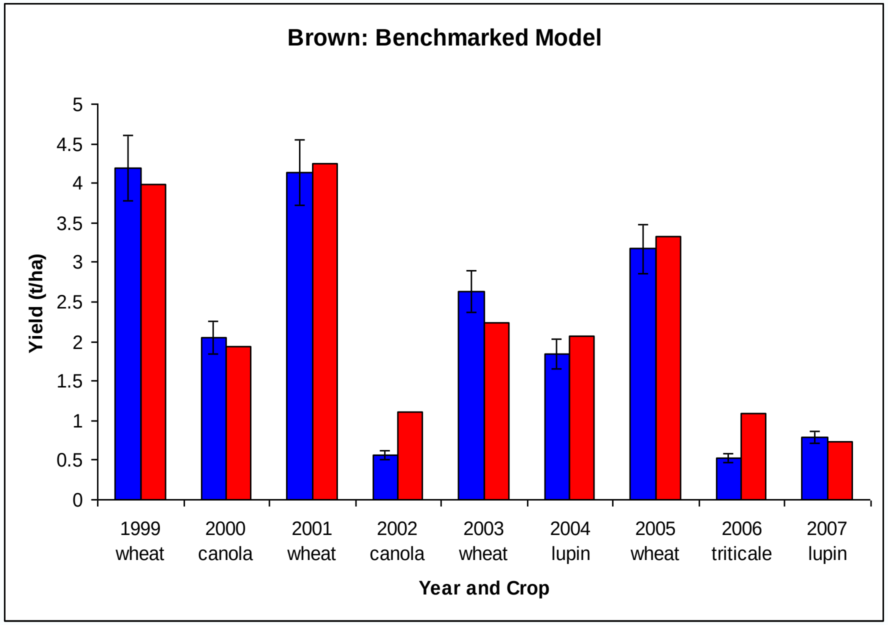
Variable	Treat	n	X_{sim}	X_{obs} (SD)	P(t*)	α	β	R^2	RMSE
Yield	T1	62	4726	4524 (302)	0.92	0.91	824	0.79	1091 (24%)
	T2	62	5076	4700 (267)	0.6	1.03	389	0.83	1131 (24%)
	T3	62	5107	4716 (263)	0.35	1.09	161	0.86	1139 (24%)
	T4	62	5164	4727 (267)	0.27	1.03	439	0.86	1082 (23%)
	Overall	248	5301	4785 (281)	0.09	1.01	453	0.83	1111 (21.9%)
Biomass	Overall	248	11859	11469 (636)	0.44	0.79	2816	0.8	2420 (20.4%)

X_{obs}, mean of observed values; **X_{sim}**, mean of simulated values; **SD**, standard deviation; **n**, number of data pairs; **P(t*)**, significance of Student's paired t-test assuming non-equal variances; **α**, slope of linear regression between simulated and observed values; **β**, y-intercept of linear regression between simulated and observed values; **R^2**, square of linear correlation coefficient between simulated and observed values; **RMSE**, absolute root mean squared error (percentage in brackets of observed mean)

Statistical evaluation of observed versus simulated performance – model validation

What is 'scenario analysis'?

Methods of comparing long-term scenarios…..



Compare two scenarios right next to each other in a time series.

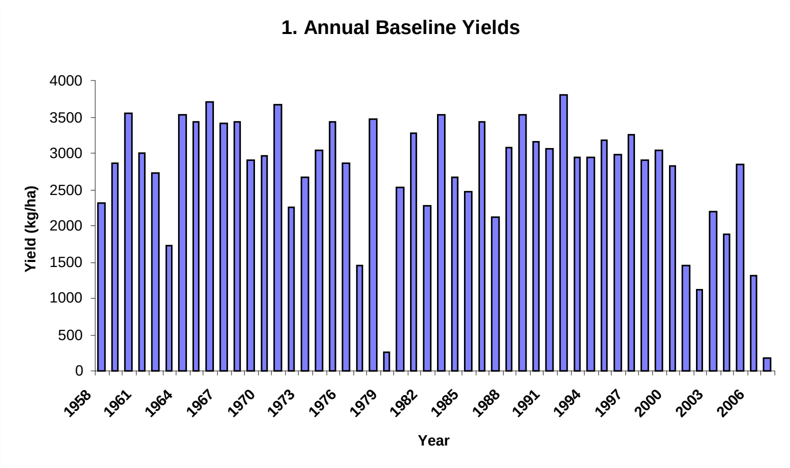
- Can be difficult to get a feeling for the average or the range of returns for each, and hence to compare…..

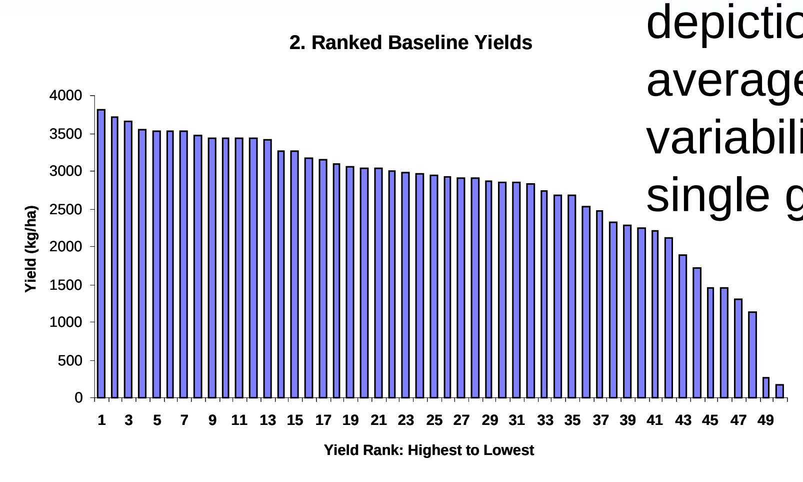
What is 'scenario analysis'?

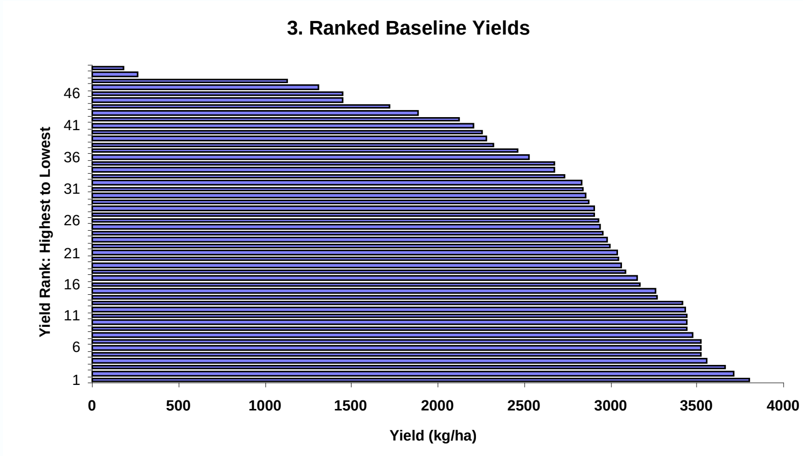
Probability of Exceedance Graph

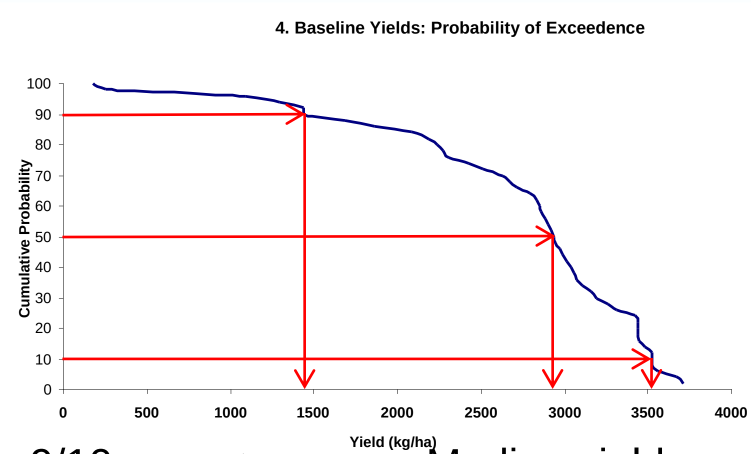
Methods of comparing long-term scenarios…..

Provides an easy depiction of both average and variability in a single glance









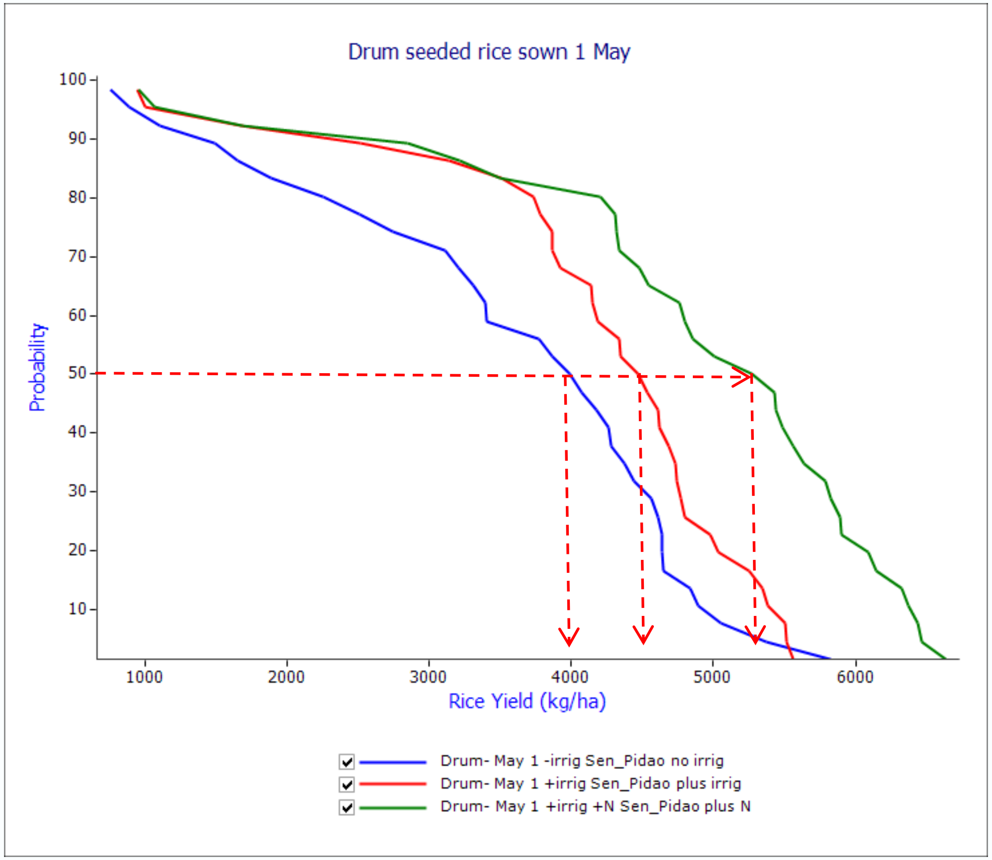
1/10 crops > 3550 kg/ha

9/10 crops > 1500 kg/ha

Median yield = 2900 kg/ha

What is ‘scenario analysis’?

Methods of comparing long-term scenarios…..



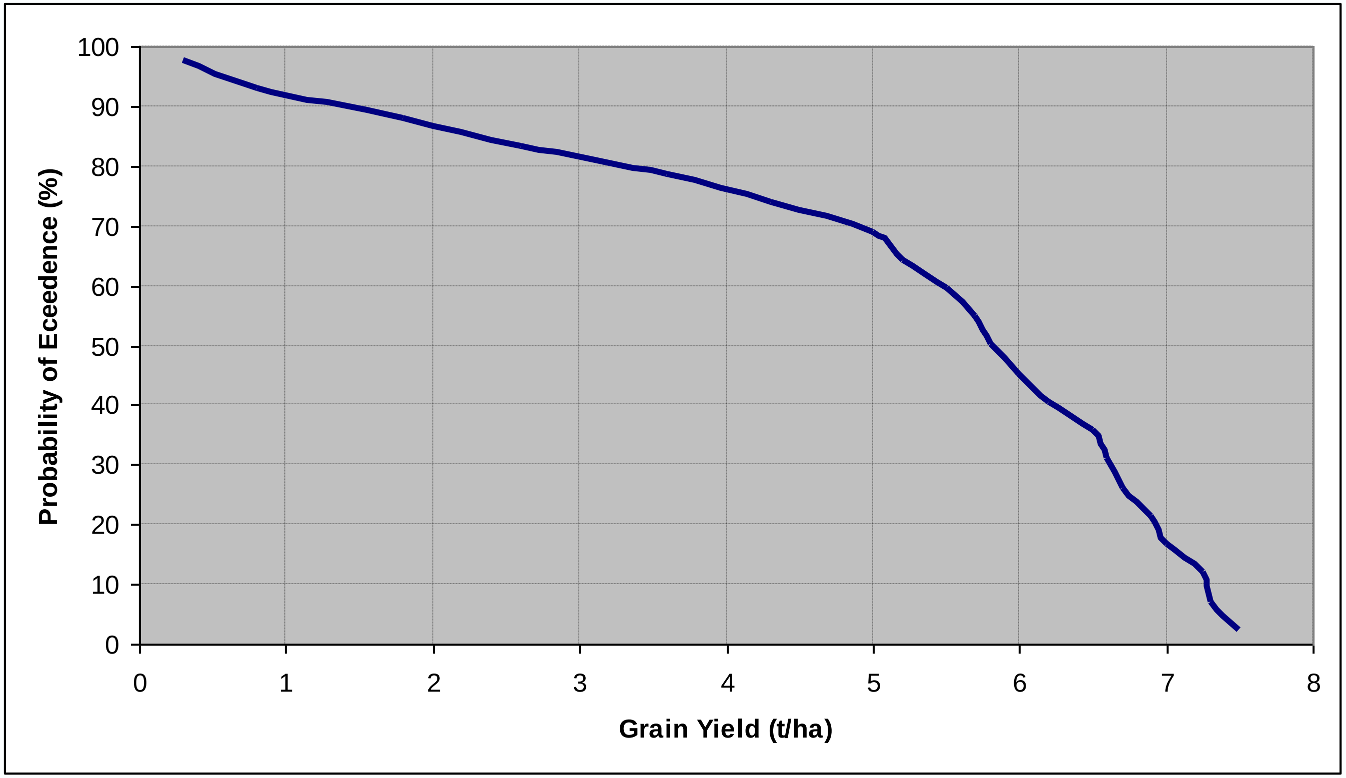
- we can then use this graphical format to compare different adaptation options

ACIAR

Probability of Exceedence at a Glance – Shape of the Graph

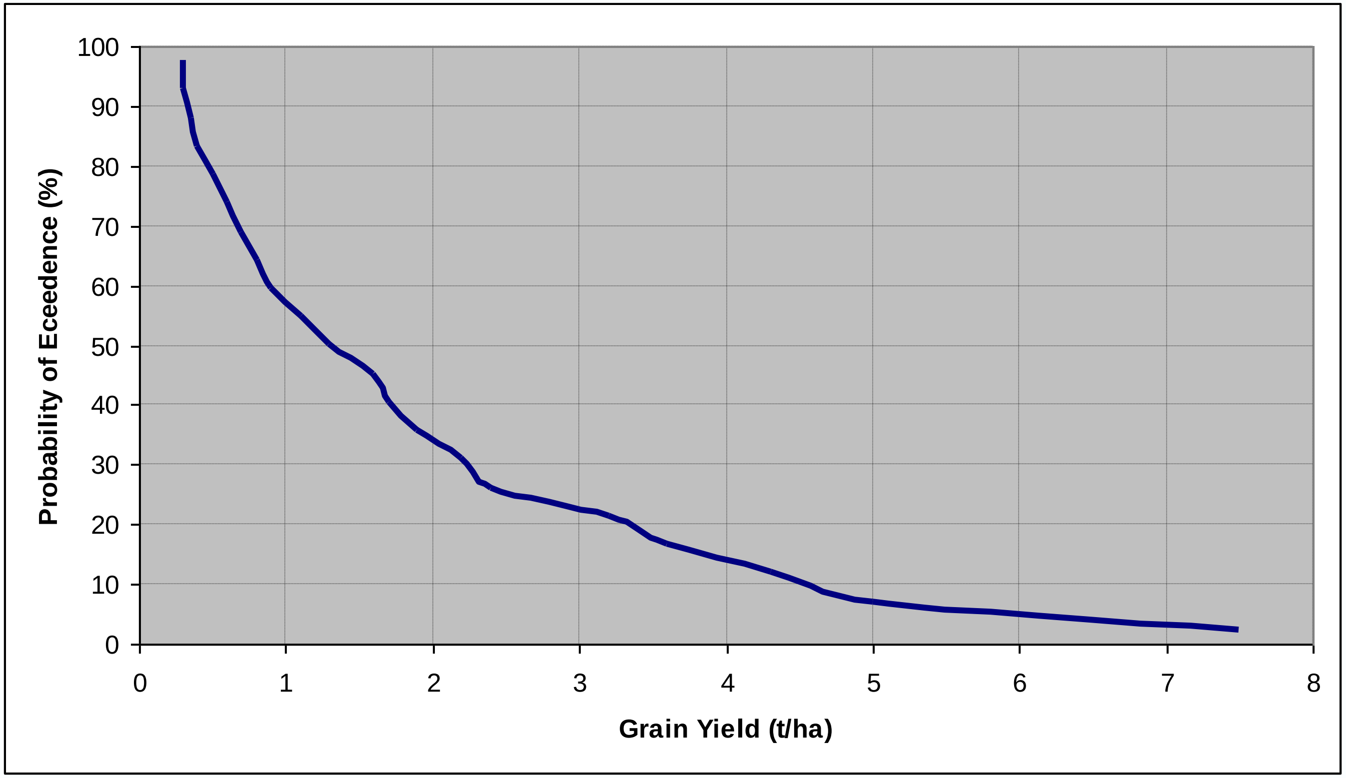
An equal amount of small medium and large yields

Probability of Exceedence at a Glance – Shape of the Graph



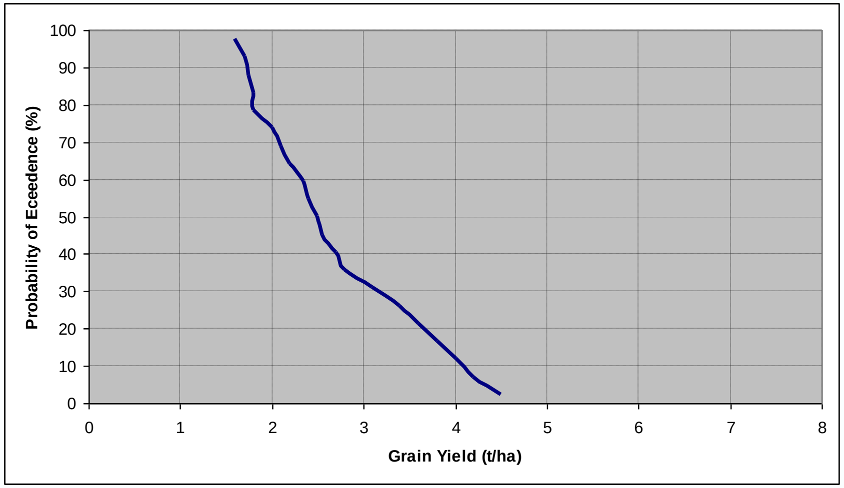
Many large values and fewer small yields

Probability of Exceedence at a Glance – Shape of the Graph



Many small values and fewer large yields

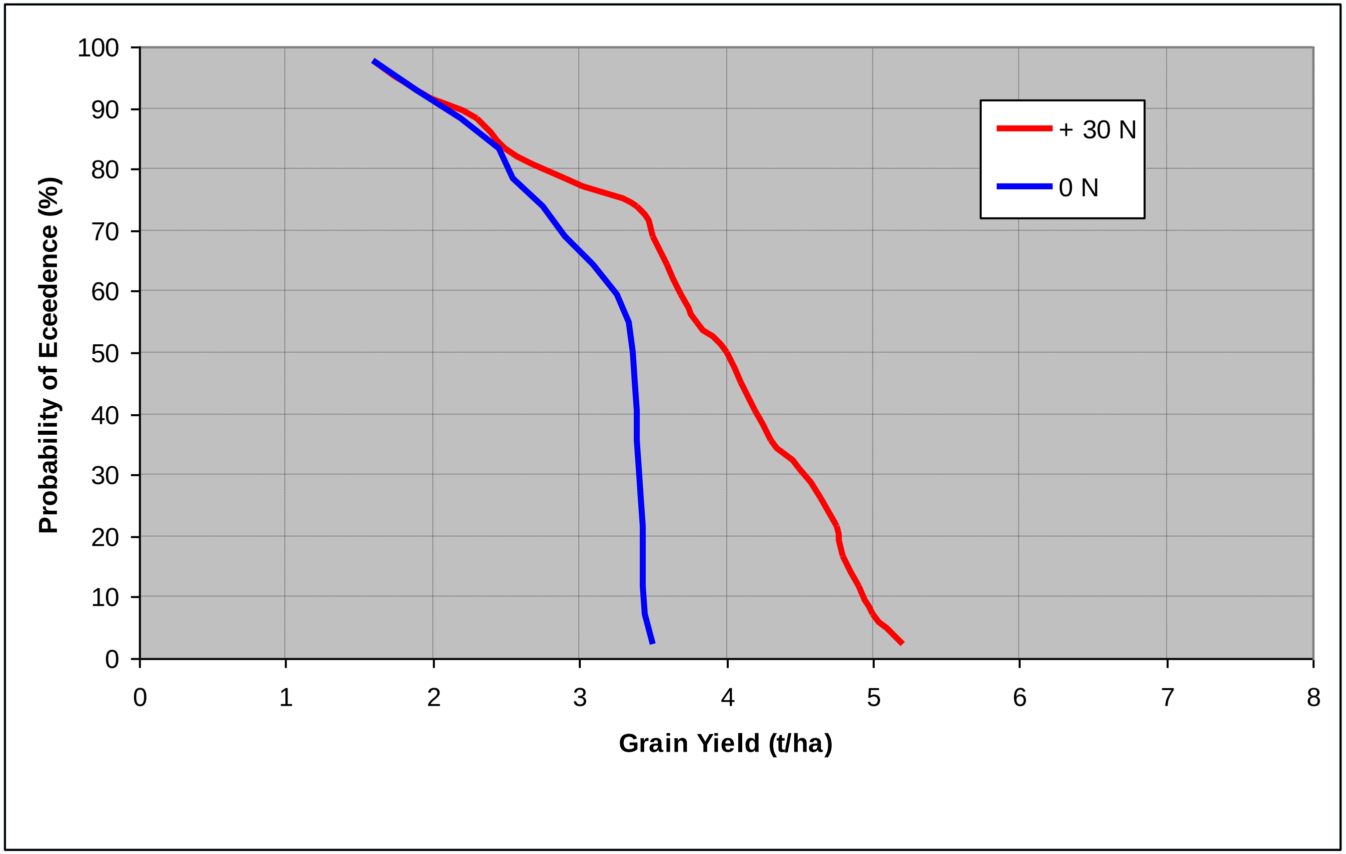
Probability of Exceedence at a Glance – Data Range



How variable or "*risky*" is the yield outcome?

Probability of Exceedence at a Glance – N limited Yield

Probability of Exceedence at a Glance – N Response



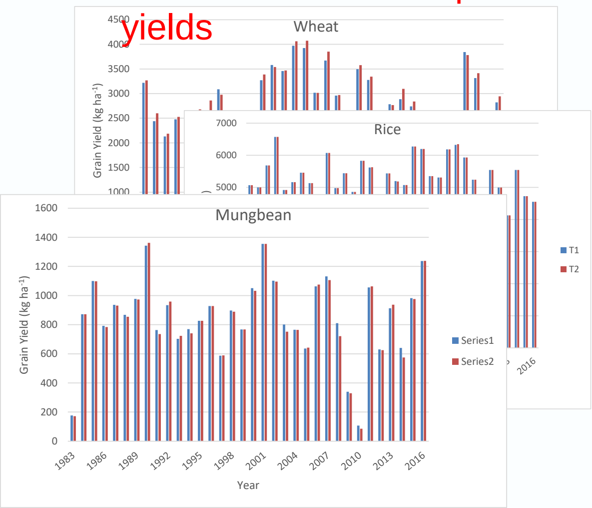
Using APSIM for CASI scenario analysis…

T1: CTTPR-CTW-MB (conventional)
T2: CTTPR-STW-MB (partial CA)
T3: DSR-STW-MB (CA)
T4: UPTPR-STW-MB (CA)

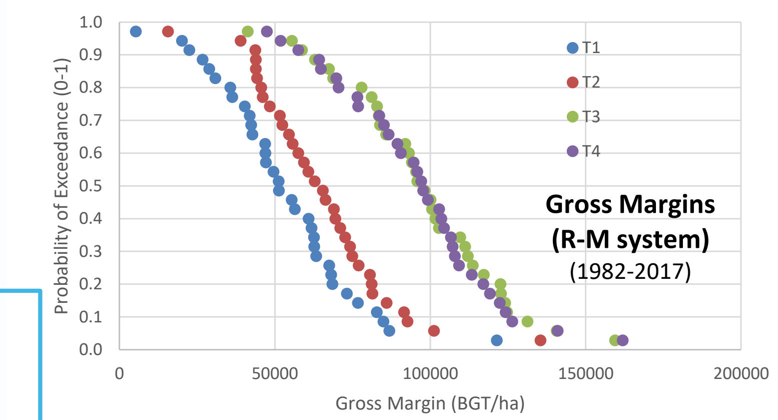
Long-term simulation for Baduria node (Bangladesh)

Rice-Wheat-Mungbean system (1982-2016)

APSIM simulates crop yields

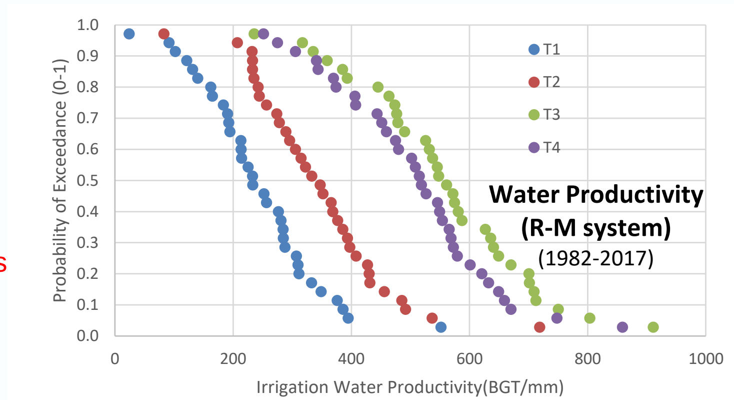


Combine with costs/prices from socio-economic team

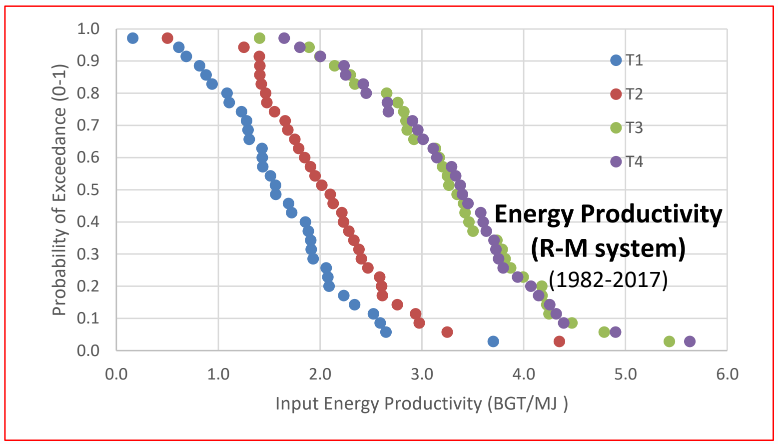


Long-term CASI risk insights through modelling

Combine with APSIM-simulated water use

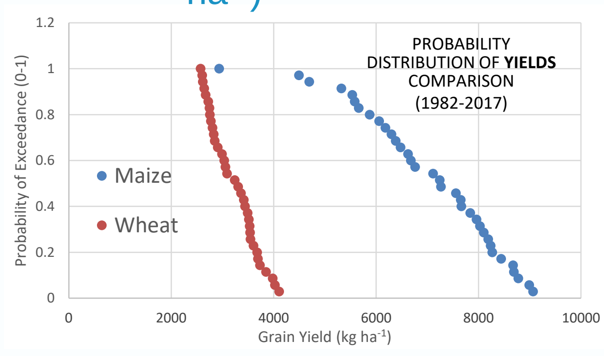


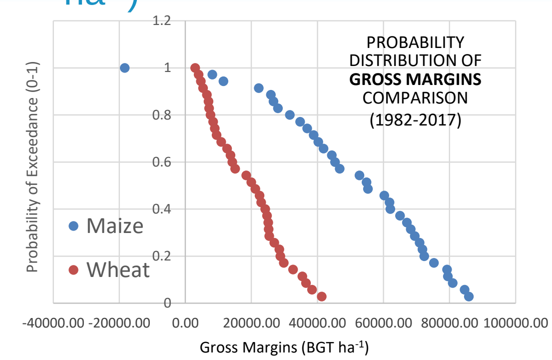
Combine with fuel use measurements from on-farm trials



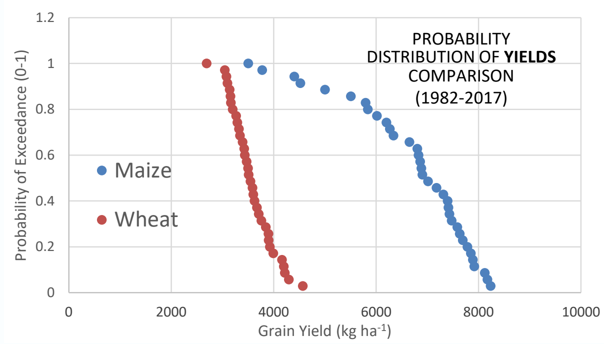
SRFSI Decision Support Tool (DST) Development – rabi crop choice as a function of sowing date opportunity

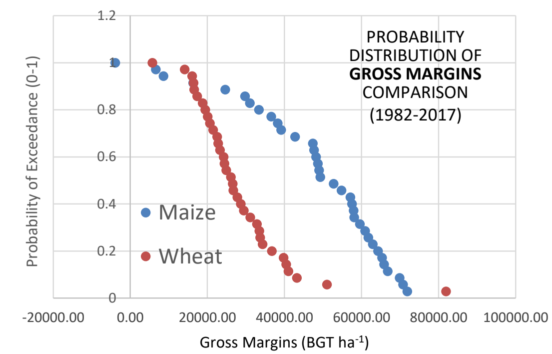
Grain yields (kg ha-1) | **Gross Margins** (BGT ha-1) | **First sowing opportunity**



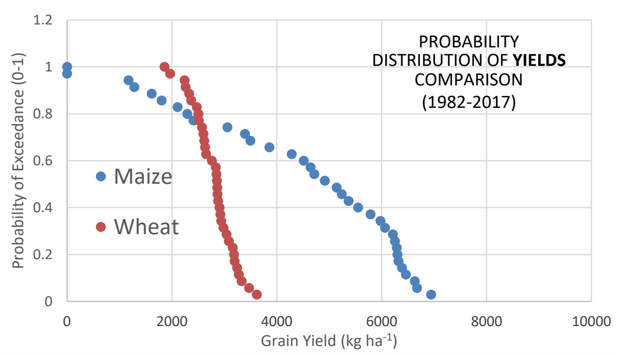


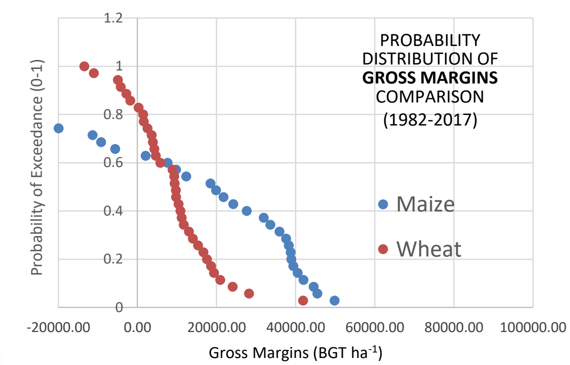
15th Nov





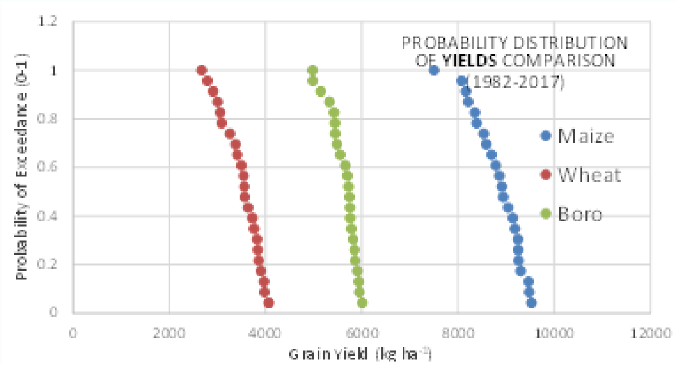
15th Dec

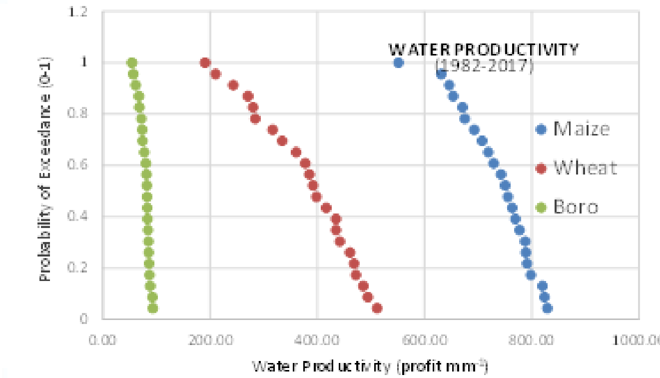


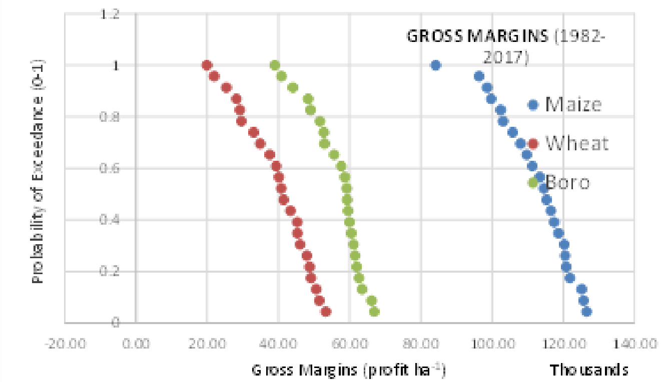


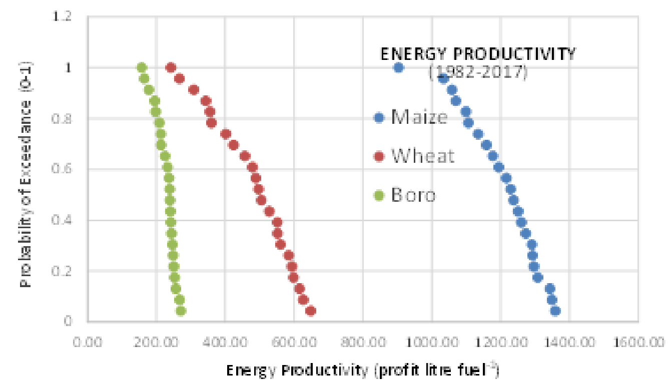
15th Jan

SRFSI Decision Support Tool (DST) Development – rabi crop choice – compared by yields, gross margins, WP, EP, Labour Productivity



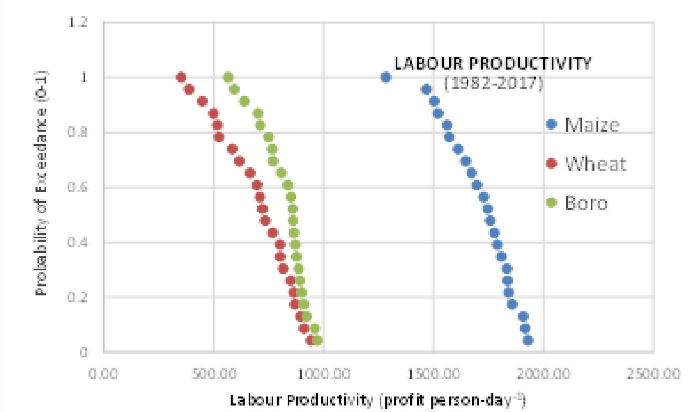






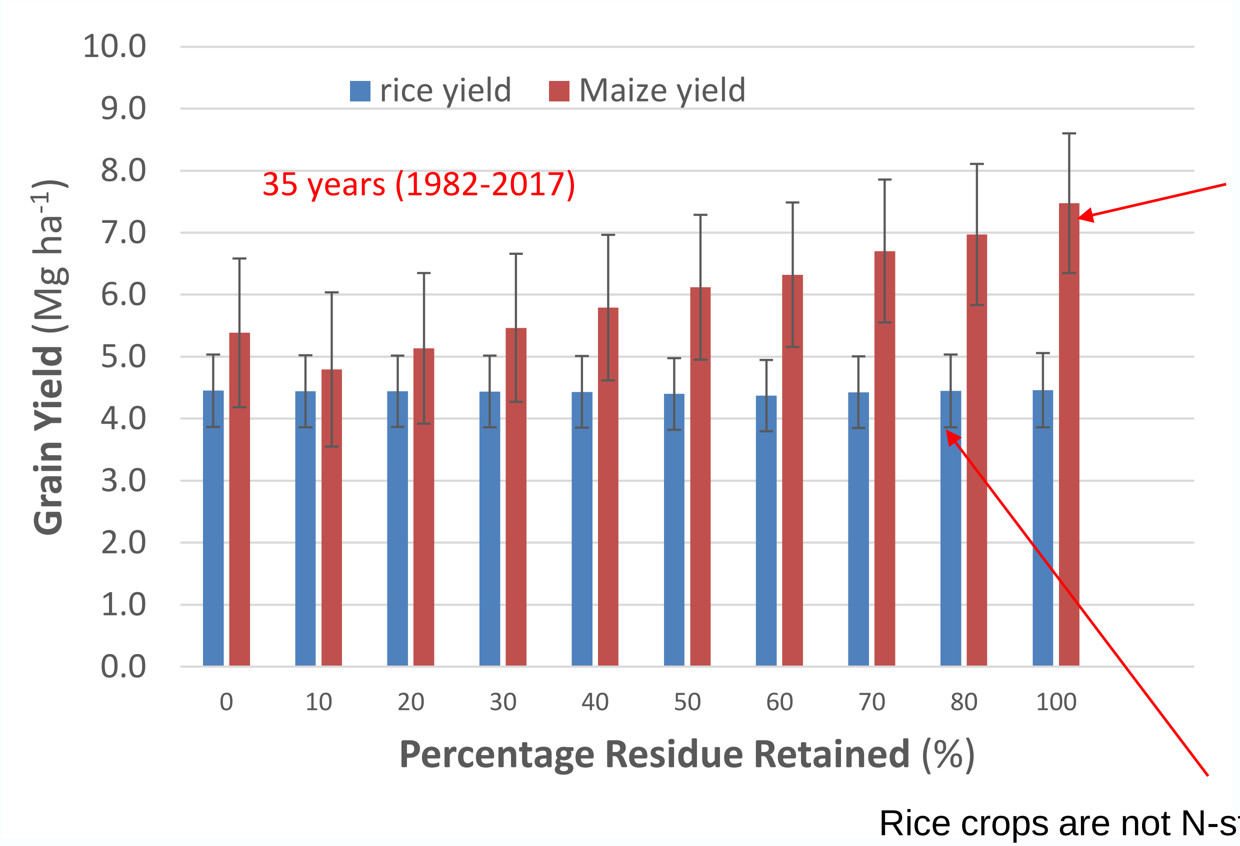
Comparing Maize, Wheat and Boro Rice

(Premtoli, Rajshahi, Bangladesh, for a sowing opportunity on day 319 (15th November))



Scenario Analysis with different residue percentages retained

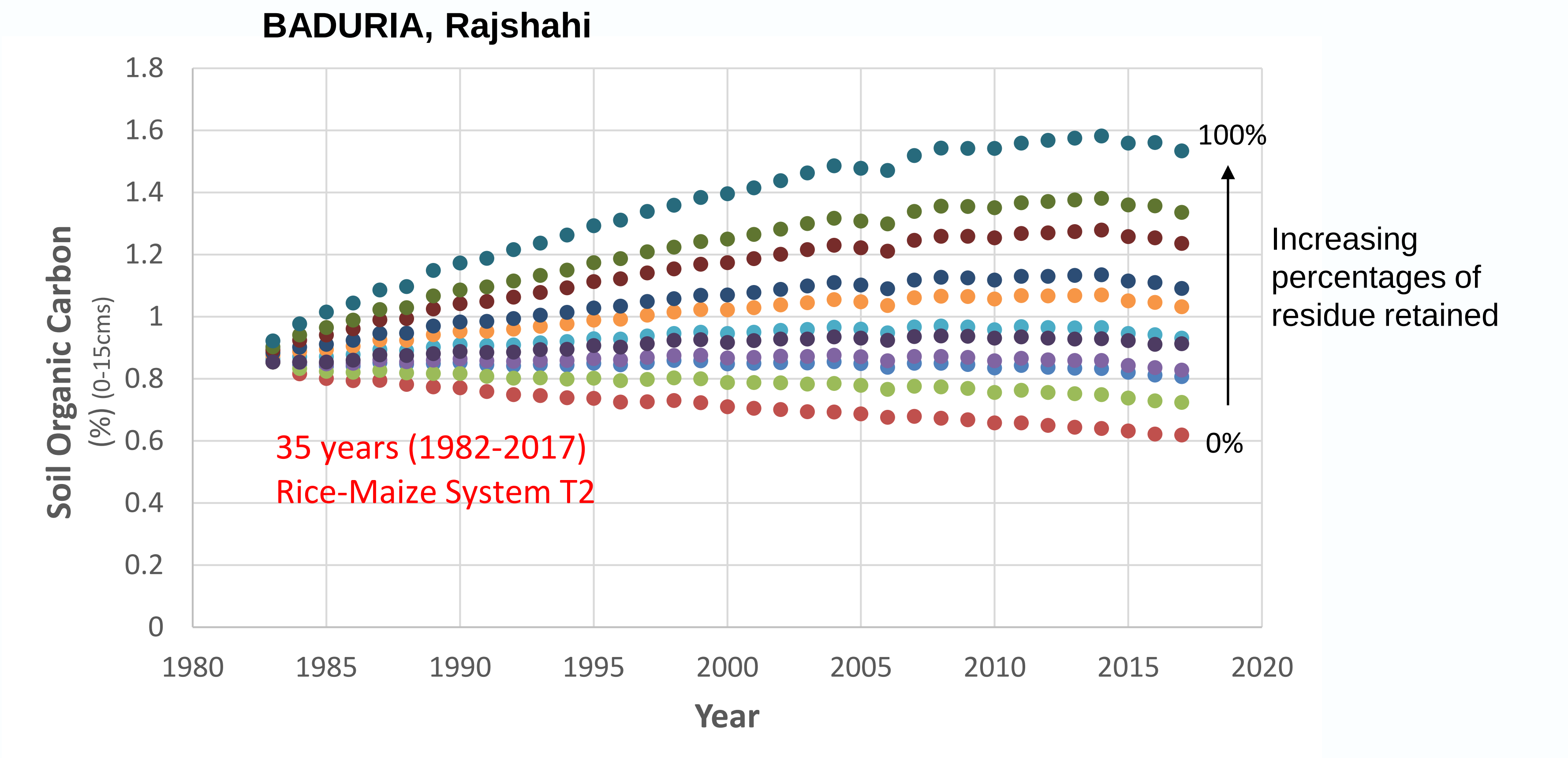
BADURIA, Rajshahi



Modelling suggests significant long-term yield gains may be possible in Maize, but obviously the economic trade-off with less fodder availability not considered in this analysis

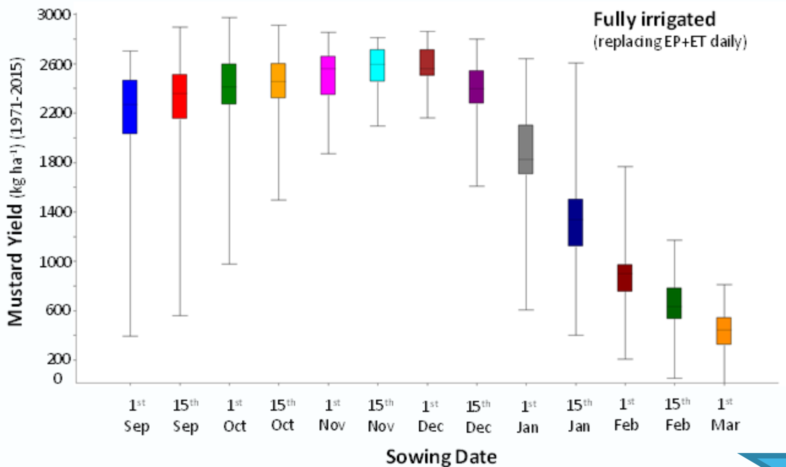
Rice crops are not N-stressed here, hence no gain from added organic material. Slight yield decreases, greater at higher % retention probably driven by N immobilisation

Scenario Analysis with different residue percentages retained

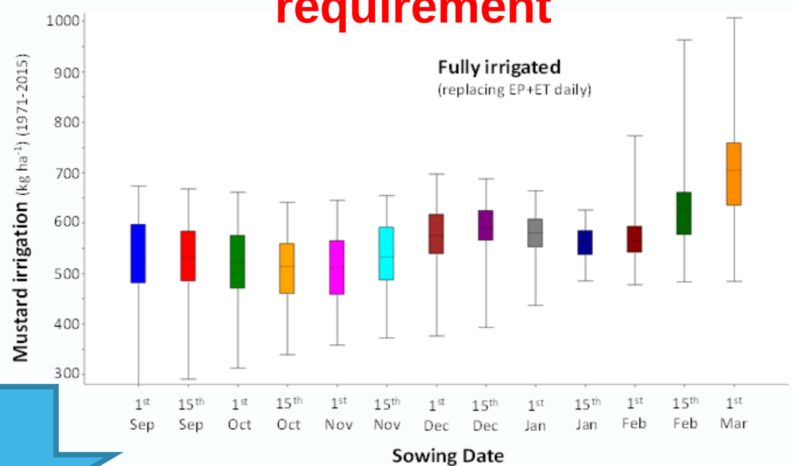


Optimal sowing dates for Mustard

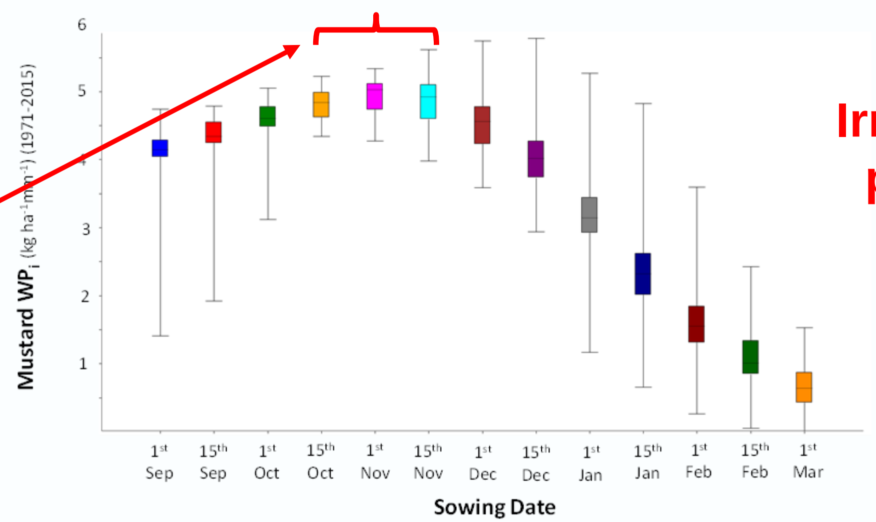
Grain Yield



Irrigation requirement

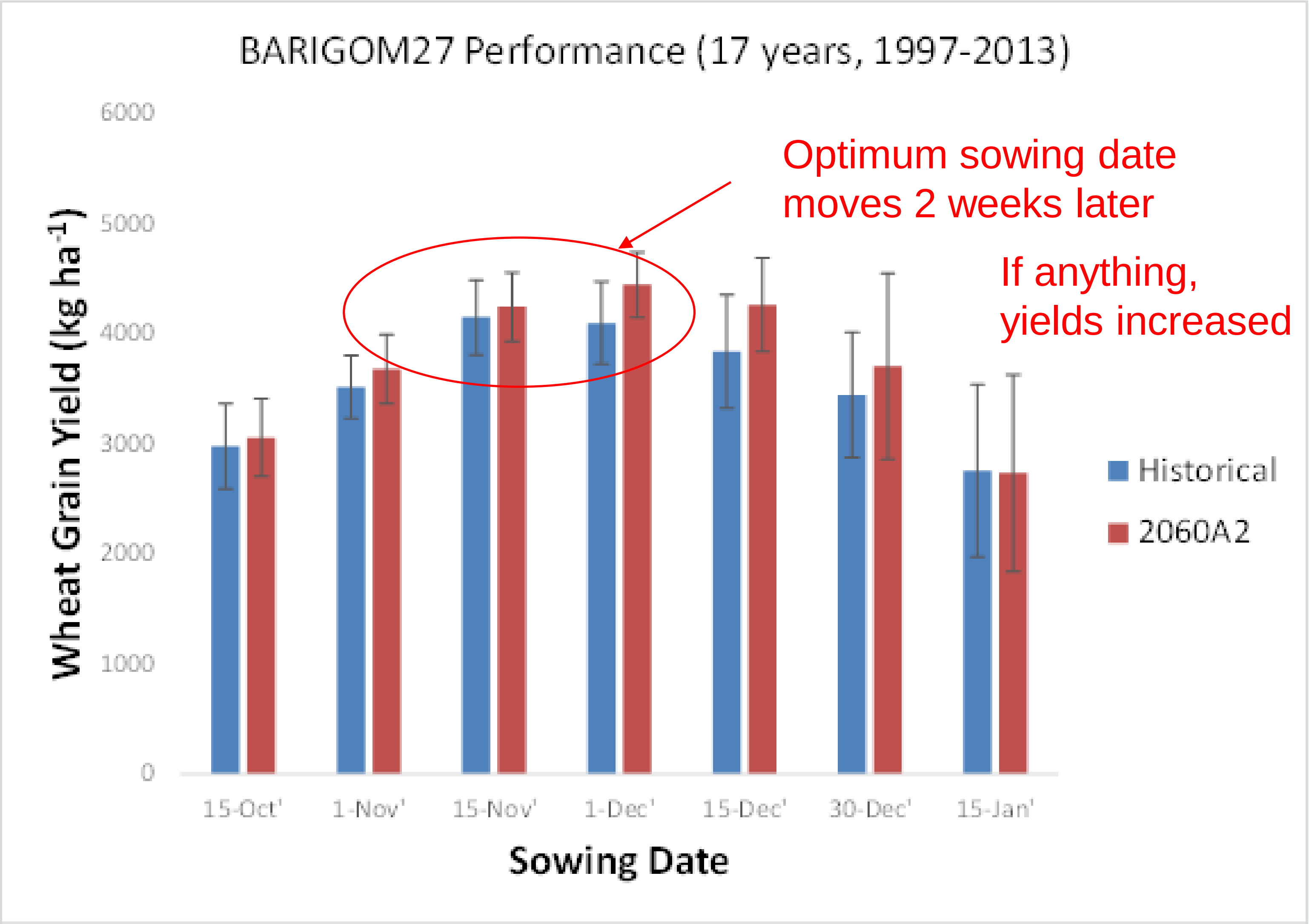


Fairly narrow range for optimal WP and low risk



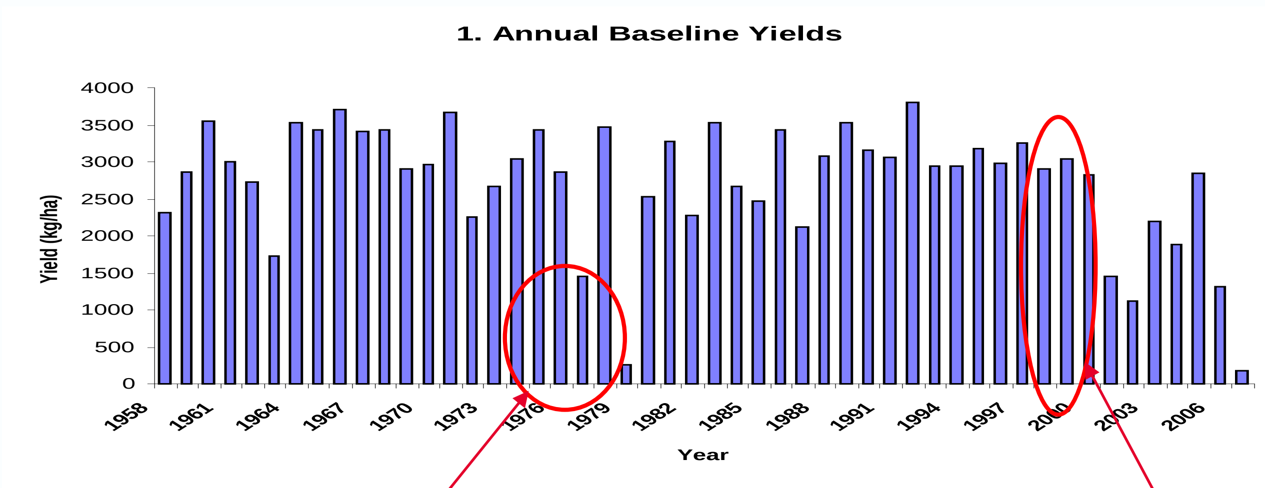
Irrigated water productivity

Scenario Analysis – the impact of future climate on optimum sowing date and risk (BARIGOM27 wheat at Dinajpur, Bangladesh)

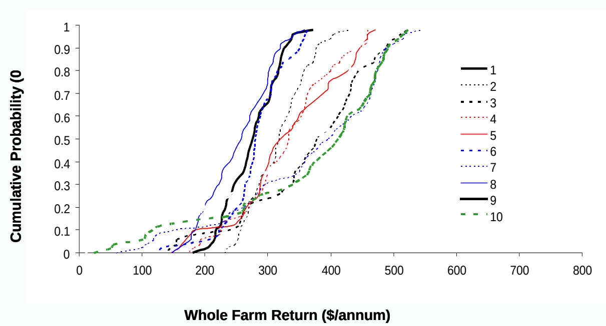


Some other useful applications of cropping systems modelling……

Extending experimental learnings – gaining more value



Cropping system models have a particular value in helping to understand variability and risk associated with management practices



- turining 1 or 2 year experiments into probability distributions covering 50+ years

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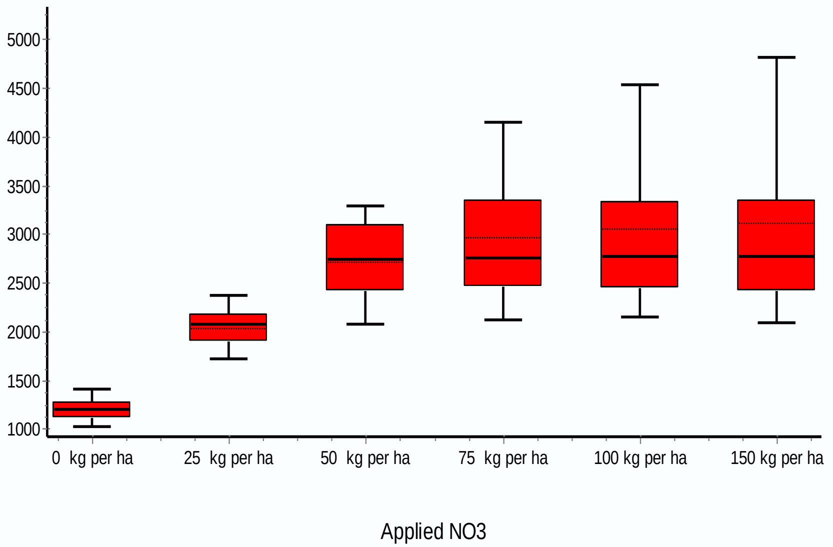
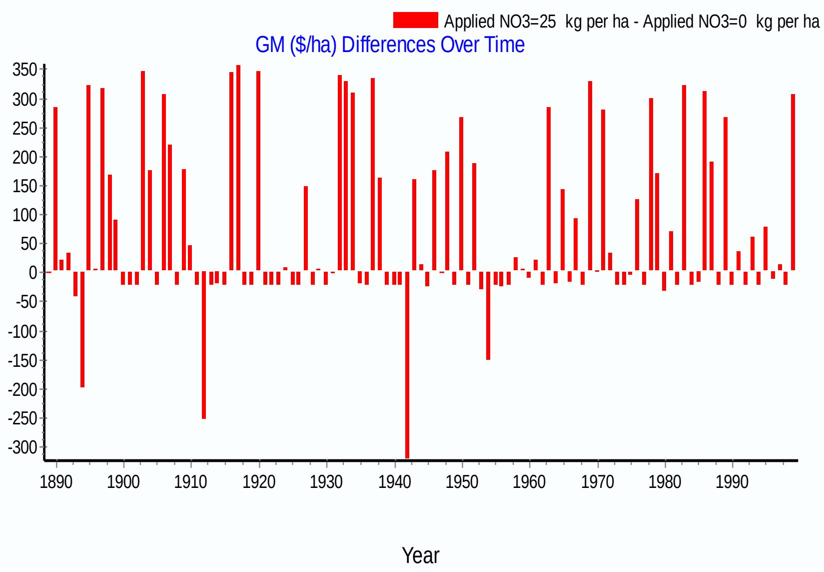
Exploring "What if?" questions – scenario analyses





- Which crop to sow?
- When to sow?
- How much N fertiliser to apply?
- Optimum maturity length?
- Optimum planting population?
- Effect of amount of soil water at sowing?
- Effect of soil water-holding capacity?
- Effect of different SOI phases prior to planting?

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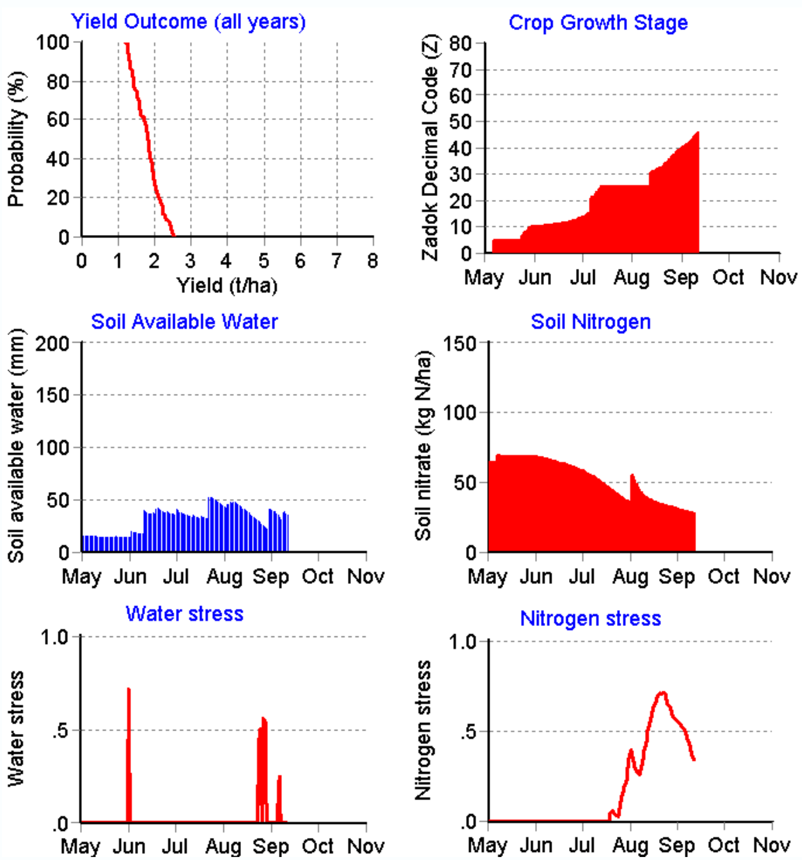
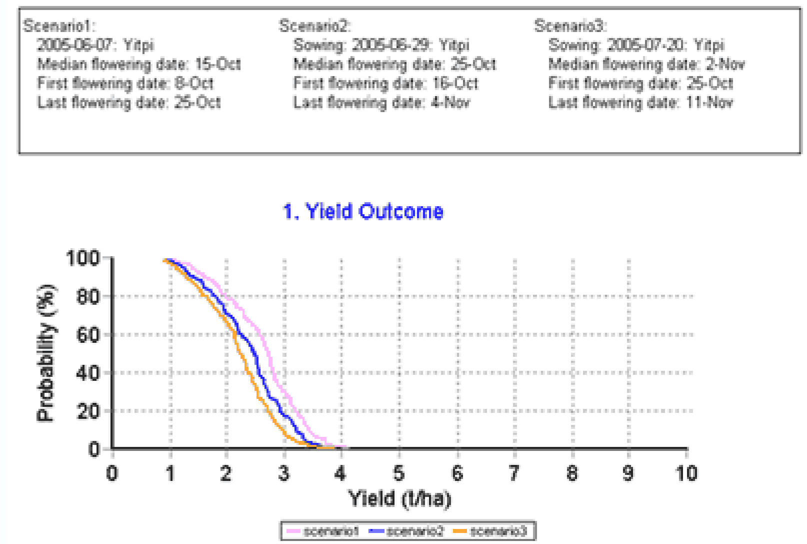
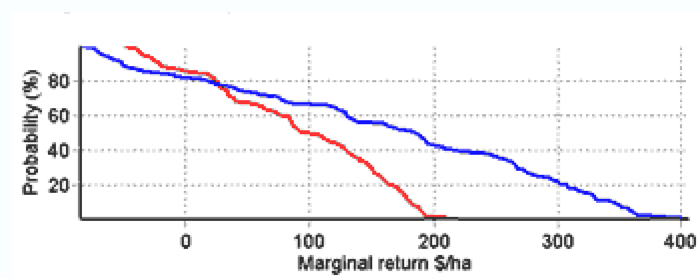
Decision Support for farmers

YIELD PROFIT – w/ Birchip Cropping Group (Victoria, Australia)







▪ gives farmers updated simulated probabilities for yield outcomes as the season progresses

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Minimizing time to adoption for new technologies

→ *we can evaluate management options through 'virtual experiments' in computer simulation models, using scenario analysis*

→ *We can use models help prioritise which options to test in the field and conduct more targeted experimental research*

→ *Models are tools to provide time efficient learning experiences, which can minimise the time to adoption for new technologies, and allow easy assessment across different locations and environments*

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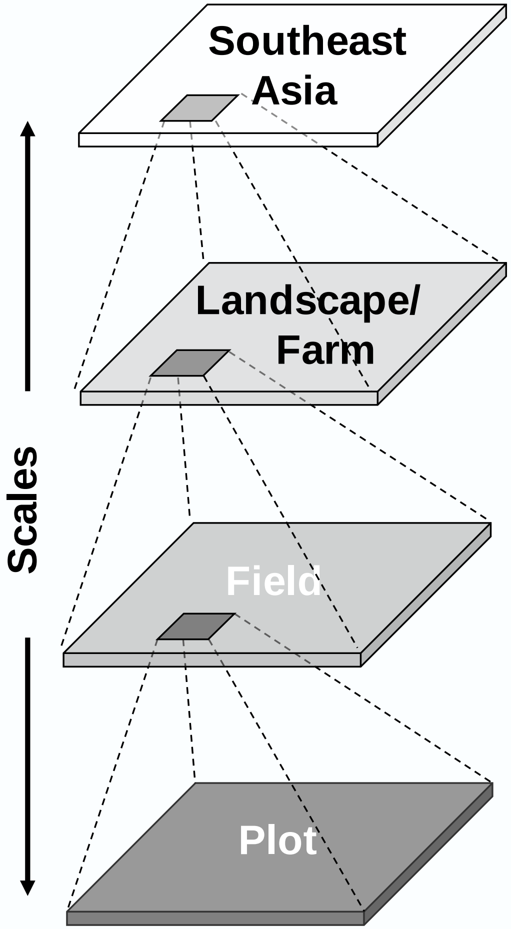
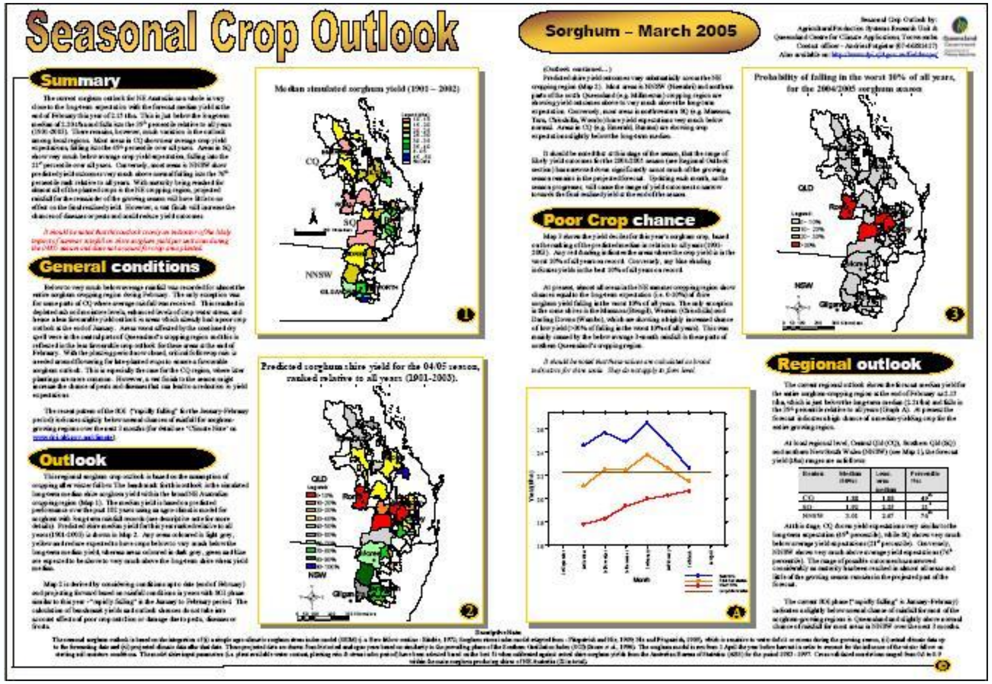
Up-scaling experiments and regional yield forecasting



- using cropping systems models linked with GIS systems



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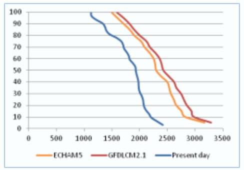
Climate Change studies

Adaptation options are being examined that have the potential to help farmers better manage current climate variability and risk, as well as providing immediate livelihood benefits to them (in each country). Overlaid on top of these are three climate scenarios:



1. Historical climate
2. Project future climate 2030-2060 (Echam5) (milder future climate changes)
3. Project future climate 2030-2060 (GFDLCM2.1) (more extreme, harsher future climate)

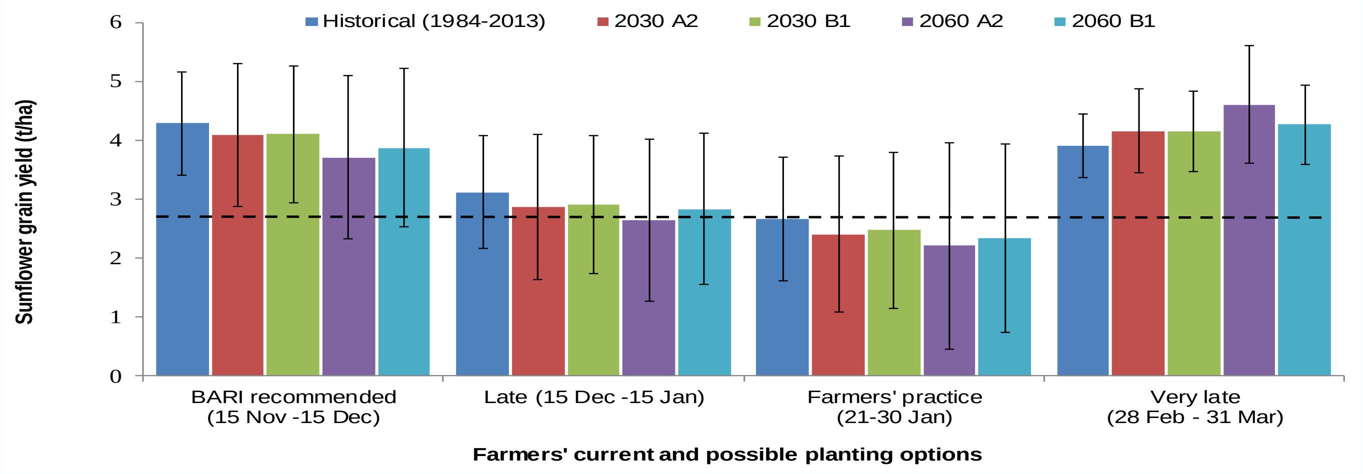


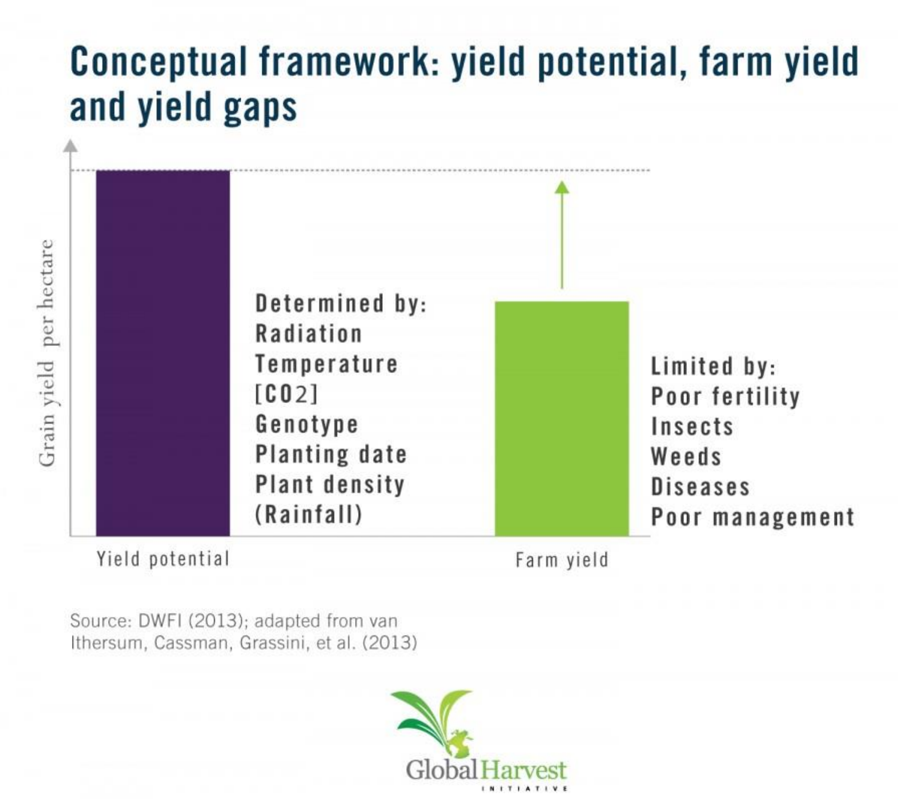
Figure 1: APSIM simulated yields of sunflower with salinity under farmers’ current and possible sowing options across the five climate scenarios. **Note:** Error bars show seasonal grain yield variability around the mean (30 years). Dotted line shows yield difference between farmers' sowing historically and other scenarios, BARI = Bangladesh Agriculture Research Institute.

Kabir et al., 2017

Crop Yield Gap Studies

New ACIAR SDIP2 Small Research Activity (SRA) for 2019

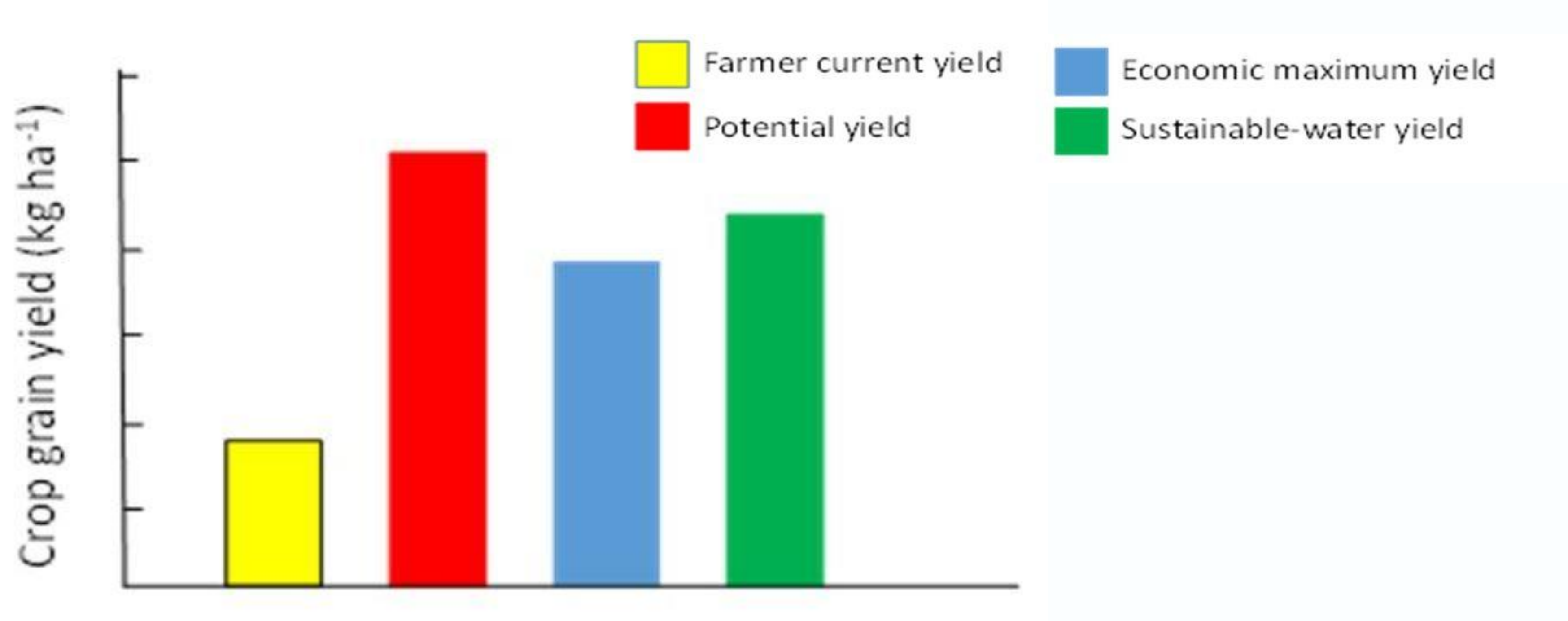
- ‘Bridging crop yield gaps’ is an active research field globally (difference between what farmers are achieving and what is possible)



Crop Yield Gap Studies

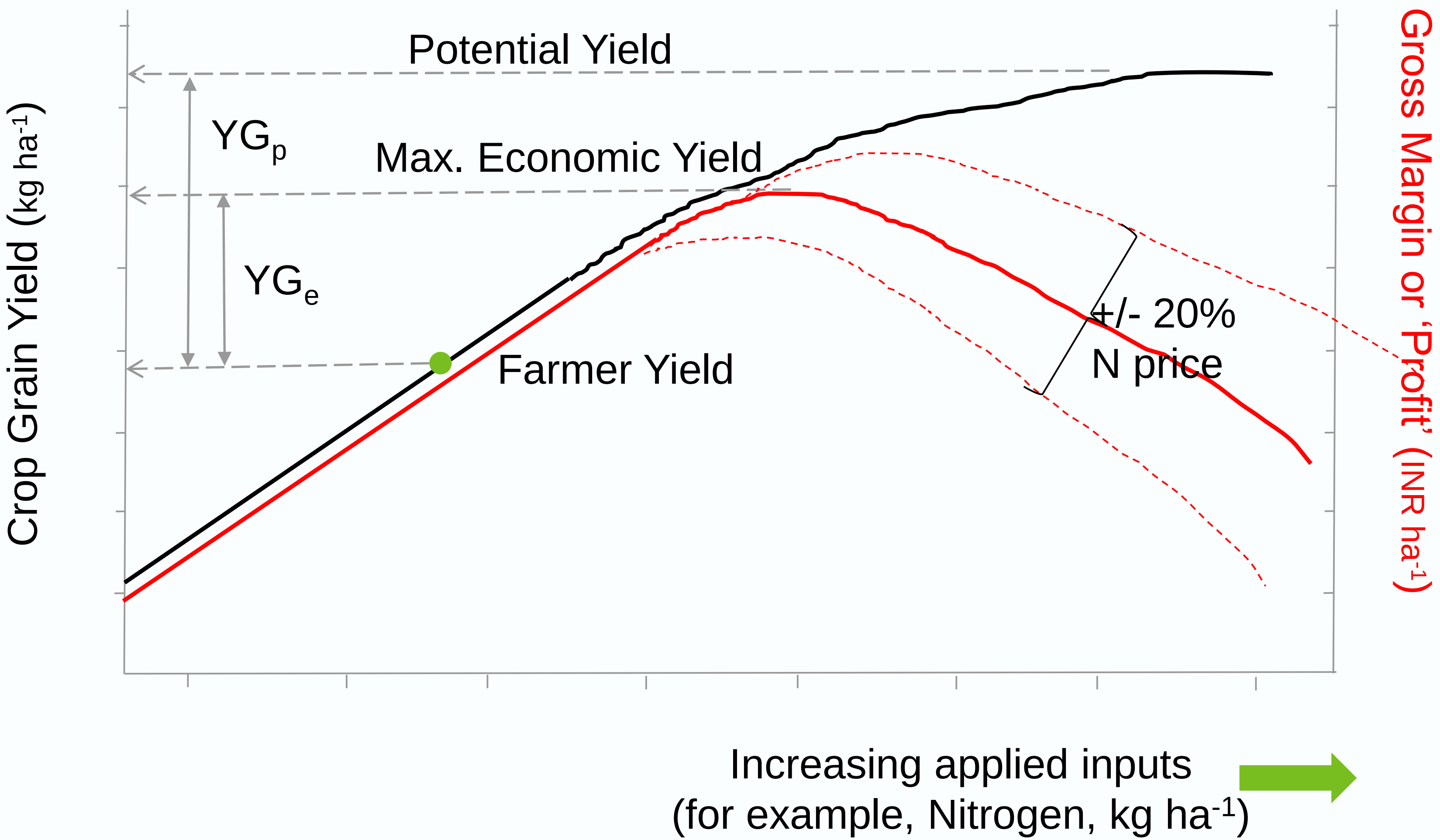
New ACIAR SDIP2 Small Research Activity (SRA) for 2019

- Different types of ‘yield gap’ are likely to be of interest to different parties, but poorly understood in the EGP
    1. Physiological Yield Gap
    2. Economic Yield Gap
    3. Sustainable Water-Use Yield Gap



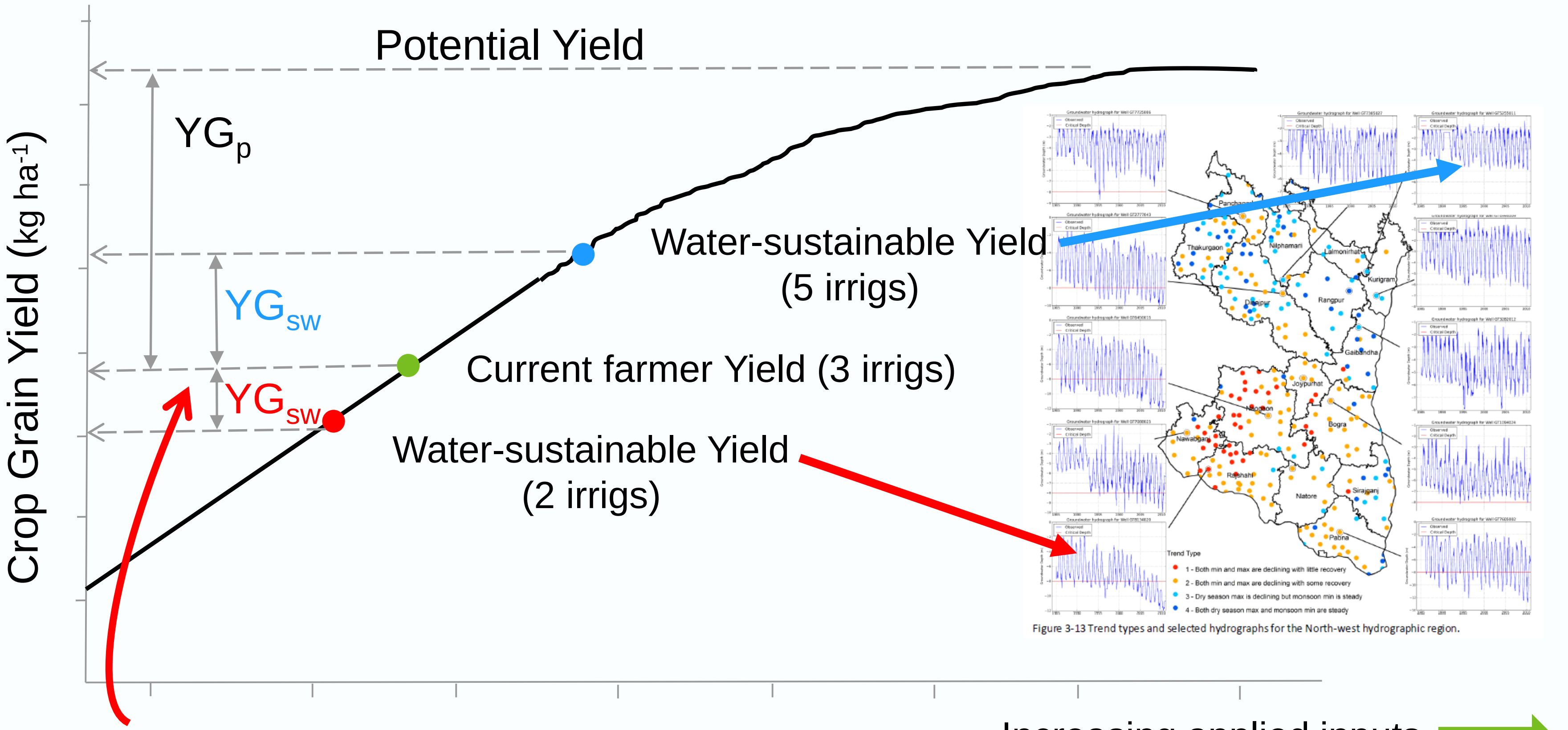
Crop Yield Gap Studies

The difference between potential yield and maximum economic yield



Crop Yield Gap Studies

The sustainable water yield (YG_{sw})

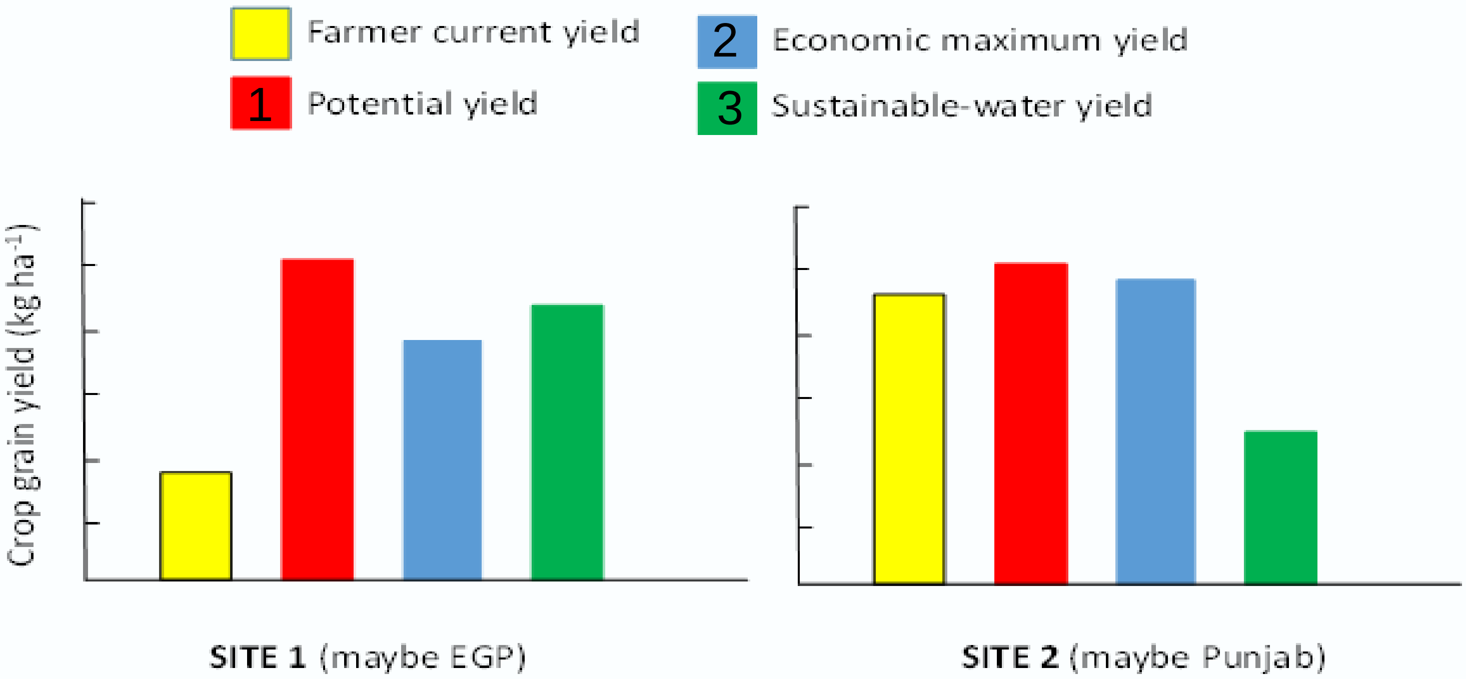


NB. The sustainable-water yield gap may be $^{+}$ve or $^{-}$ve, depending on degree of under- or over-extraction of water currently occuring

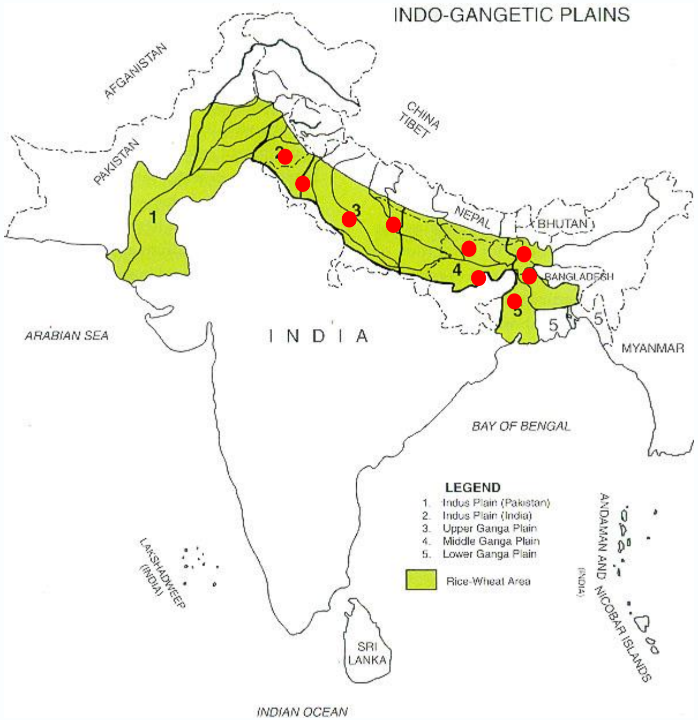
Crop Yield Gap Studies

New ACIAR SDIP2 Small Research Activity (SRA) for 2019

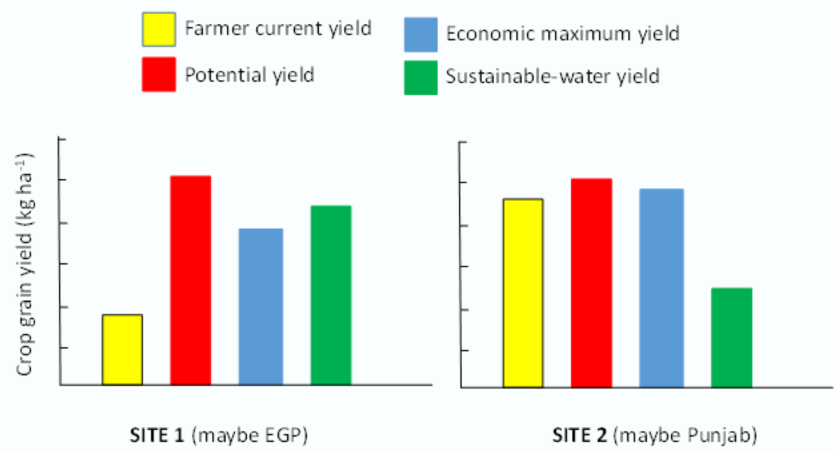
- Crop yield gaps are likely to vary widely across the whole IGP, as well as the comparison between 1-3 at any given location (and this knowledge is very relevant to good policy development (economic and environmental settings/levers))



Aims



- To provide a 'Proof of Concept'
- Define and compare the 3 crop yield gaps at 8-10 sites across IGP (rice and wheat only)
- Starting with data-rich, well-modelled sites in EGP (SRFSI)
- Including other IGP sites for comparison (which have been well modelled by CIMMYT (partner))
- Impact of CA, climate change
- We will employ a combination of cropping systems modelling, economic analysis, farmer engagement, and data-sourcing.



- Defining where farmers are currently at physiologically, economically and environmentally
- Identify scope to sustainably increase food production in future
- Identify areas for policy intervention (levers to facilitate increased production, or maybe reduced production, to achieve national goals, SDG's)

Synergies

- Agronomy and cropping systems modelling
- Socio-economics
- Hydrological modelling – both surface and groundwater

Partnerships

- **CIMMYT** – crop modelling and socioeconomic skills and experience throughout the IGP, particularly in the 'comparison' sites in Western and Central Gangetic Plains

- The **Global Yield Gap Atlas (GYGA) Project** (http://www.yieldgap.org/ ; funded by Bill and Melinda Gates Foundation, USAid and others). Lead by Wageningen University and University of Nebraska, Lincoln. Global leaders

- Key hydrological modelling groups, and socio-economic research groups in region.

Expected Outcomes

- Better informed policy across the EGP. Provision of answers to questions like:
    - what crop yields are physiologically possible?
    - what crop yields are economically desirable for farmers (under both current and alternative economic settings)
    - How do limitations on sustainable use of water resources impact on optimum target yields?
    - How do Conservation Agriculture and climate change impact the above?
    - How do all of these answers vary across the IGP/EGP?

- Informed farmers extension services

- Better informed and targeted researchers

(if demonstrated to be useful, the methodologies and protocols developed during this 12 month project will potentially facilitate a much broader analysis of the whole region in a subsequent project, bringing in the latest GIS, satellite and remote-sensing technologies, together with the latest economic and climate forecasts, to provide robust insights for regional policy-makers and other stakeholders).

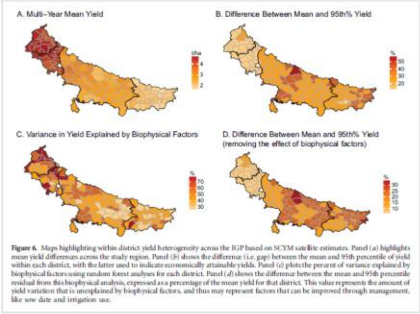


Figure 6. Maps highlighting within district yield heterogeneity across the IGP based on SCYM satellite estimates. Panel (*a*) highlights mean yield differences across the study region. Panel (*b*) shows the difference (i.e. gap) between the mean and 95th percentile of yield within each district, with the latter used to indicate economically attainable yields. Panel (*c*) plots the percent of variance explained by biophysical factors using random forest analyses for each district. Panel (*d*) shows the difference between the mean and 95th percentile residual from this biophysical analysis, expressed as a percentage of the mean yield for that district. This value represents the amount of yield variation that is unexplained by biophysical factors, and thus may represent factors that can be improved through management, like sow date and irrigation use.

Audience Feedback…….

Which are highest research priorities?

1. Physiological Yield Gap
2. Economic Yield Gap under current economic settings
3. Economic Yield Gap sensitivity to changed economic settings
4. Sustainable-water yield gap
5. Any other suggestions?

CSIRO

Thank you

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What questions are answered by the model?

Some examples……

•how best to share a limited water resource amongst several different cropping enterprises? To maximise production? Profit? WP? Minimise NO3 leaching?

•assessing different crop residue management practices (between and within crops) to find desired trade-off point between conserving water, increasing soil fertility and maximising livestock grazing from field

• optimising the management and timing of one crop to facilitate enhanced performance of another crop in the rotation

• how do a range of potential adaptation ideas compare? Between regions, on different soils, different varieties, different managements?

•how do any of the above effect the water-balance terms? ET, runoff, drainage?? How do they effect long-term soil carbon?

Who are the stakeholders?

- Agricultural Scientists - APSIM is a researcher tool, not a farmer tool
- Farmers – who both contribute to and benefit from research findings
- Agricultural Consultants –use decision-support tools developed using APSIM (for example Yield Prophet)
- CSIRO, Government Departments, Universities, funding bodies (ACIAR, GRDC, RIRDC etc) who have contributed to APSIM development
- Economists (who use biophysical outputs from APSIM in their calculations)
- Hydrologists (APSIM outputs used as point-source inputs to SW/GW models)
- Universities (PhD students, teaching tool, etc)
- Policy developers (estimates for future production, water needs, fert needs etc)
- International Agricultural Research Institutes (strong demand for skills in cropping systems modelling)

Underpinning Work

- ACIAR has undertaken little targeted 'yield gaps' work, per se, however many projects have generated vital data which can be used for APSIM-based research in this area, including:-
  - ACCA (LWR-2008-019),
  - SAARC-Australia Project (LWR/2010/033),
  - SRFSI (CSE-2011-077),
  - LWR/2009/046, LWR/2010/081, and also on regional water resources (LWR/2003/026, LWR/2001/001, LWR/2001/014).

- SRFSI and other project socio-economic learnings (particularly regarding CA)

- Also the CSIRO-SDIP-Indus project (lead by Dr Mobin Ahmad) has gained significant insights into drivers for yield gaps in the Pakistani Punjab rice-wheat system, and a paper recently published (Field Crops Research)
- CSIRO-SDIP-Bangladesh project (lead by Dr Mohammed Mainuddin) linking hydrology and cropping systems modelling