Review of prospects for perennial wheat in Australia

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Some key messages

Perennial wheat could.....

- Benefit agricultural sustainability
- Reduce input costs & provide additional forage
- Benefit whole-farm management/risk/flexibility

Major challenges are...

- Domestication/breeding (universal)
- Tolerance of water deficit
- Tolerance of poor soils
- Risk of hosting foliar pathogens over summer

Sources of tolerance of abiotic & biotic stress in several exotic & native perennial Triticeae
Introduction

• Problems with agriculture based on annual crops
  • Soil erosion
  • Hydrological imbalance – salinity & nutrient leaching
  • Soil organic matter & fertility decline
  • Increasing inputs & input costs

• Perennial systems a more sustainable alternative
  • Mimic natural systems
  • But, need to be profitable

• Ongoing work on woody crops & perennial pastures

Is there an opportunity for perennial grain crops?
Microlaena stipoides – native perennial grain?

Study of *Microlaena stipoides* (Davies *et al.* 2005)

Favorable attributes

- Wide distribution
- Large seed size
- Seed yields $\approx 100-500$ kg/ha
- Year-round growth & high forage quality
- Tolerates drought, frost & acid soil

From Davies *et al.* (2005) Perennial Grain Crops for High Water Use - The case for *Microlaena stipoides*. RIRDC Report No 05/024
Which perennial crops in Australia

• Why focus on wheat?
  • Major grain produced in Aust.
  • Immediacy of market & adoption
  • Build on/interact with developments US & elsewhere

• Other immediate possibilities for Australia
  • Sorghum – sub-tropical regions
  • Rye/Triticale
  • Pulses – Chickpea, Soybean
THE BIG QUESTION

To justify effort to develop perennial wheat in Australia the question is:

Would perennial wheat play a potential role in Australian farming systems?

1. What are the potential benefits?
2. What are the probable challenges?
3. What characteristics would be necessary/desirable for adaptation in Australia?
4. How would perennial wheat fit into Australian farming systems?
Unique aspects of Australian agriculture

- Low production levels/yields
- Low external inputs
- Low & erratic rainfall
- Infertile soils
- Low levels of tariff or subsidy protection
- Dominance of mixed crop-livestock systems

Crop ‘ideotype’ will be different from US
Agro-climates of Australia’s cropping zone

Agro-climatic zones:
- Green: Temperate, cool season wet
- Brown: Dry Mediterranean
- Blue: Wet Mediterranean
- Yellow: Temperate, sub-humid
- Red: Sub-tropical, sub-humid
Potential benefits from perennial grains

1. Sustainability & environmental
   • Reduced erosion risk – greater year-round cover
     • *E.g.* Sediment loss < 10% under perennial grasses c.f. conventional crop systems (Silburn et al. 2007)
   • Increased soil carbon & associated soil ‘health’
     • Perennial grasses increase soil carbon (Dalal *et al.* 1995)
   • Improved hydrological balance & water use
     • *E.g.* Drainage halved under temperate perennial grasses (Ridley *et al.* 1997; Dolling 2001)
   • Reduced nitrate leaching and sub-soil acidification
     • *E.g.* N leaching 5-12 kg N/ha/yr lower under perennial grasses (Ridley *et al.* 2001)
Potential benefits from perennial grains

2. Direct production benefits
   • Reduced annual sowing costs
     • Fuel use, weed control
   • Improved nutrient-use-efficiency (Crews 2005)
     • Internal N recycling
     • Reduced losses (leaching/volatilisation)
     • Synchrony of supply
   • Weed management
     • Competition reduce seed set or germination
     • Tactical responses e.g. grazing/cutting
   • Provide forage for livestock
     • Regrowth after harvest
     • Earlier start to growth in autumn
Potential benefits from perennial grains

3. Whole-farm management

• Labour
• Capital investment
• Enterprise flexibility – grain-grazing
• Risk – climate & financial
Challenges – Anti-agronomic traits

Agronomic problems introduced from perennial parents

- Low spikelet fertility
- Self-incompatibility
- Shattering
- Indeterminate ripening
- Awn robustness
- Seed dormancy

- Smaller seed size
  -↓ flour yields
  -↑ bran per kernel,
  -↑ fibre
- Proportional to genome allocation from parents
- Grain chemistry?
  -Unknown in perennial Triticeae
  -E.g. Th. intermedium has no gluten, but higher % protein than wheat (Becker et al. 1992)
  -Novel proteins? (Payne et al. 1984)
Challenges – Grain yield

Grain yield of perennials < annuals

Trade-off between yield & longevity?

• Competition for resources

• Seed vs. Perenniating structures
  • Defence mechanisms
  • Stress tolerance

Alternative arguments (DeHaan et al. 2005)

• Grain yield a result of natural selection
  • Perennials dominate in resource-limited environments
  • Survivorship > fecundity

• Grain yield is often SINK-limited → unused resources

• ‘Energetic cost of perenniation’ ≤ extra growth capacity
The breeding challenge

Strategy 1. Perennializing annual wheat

• Perenniality is not a single gene trait
• Need majority of perennial parent genome to be ‘perennial’
• Problems with sterility, chromosomal/genetic stability

Strategy 2. Improve wild perennial

• Use wheat as a donor parent for desired agronomic traits
• Knowledge of ‘genes of interest’ is greater
• Many annual crops have perennial progenitors
  • e.g. Soybean, Sunflower, Rice etc.

• Domestication of annual crops
  • Wild annuals are colonizing species - adapted to disturbance & resource-rich environments
  • ‘our ancestors took the easy route’ (Wagoner 1990)

• Can we ‘re-domesticate’ perennials?
  • Alter our selection pressure
  • Improved ‘selection’ techniques & genetic knowledge
Probable challenges – Pests & diseases

• Longer growing-season – build-up of pathogens
  → ‘green bridge’ over summer
  • Innoculum source for following season
  • Major problems with diseases requiring living tissue
  Rusts – leaf, stripe and stem; Viruses – WSMV, BYDV
• Capacity to manage diseases reduced
  • Tillage & crop rotation reduced
  • Soil & residue pathogens build up
  • Proliferate diseases of continuous, no-till wheat e.g. crown rot

RESPONSE - Breed for genetic resistance
• Many perennial sources of foliar disease resistance
• Less info. on root diseases
## Sources of biotic tolerances in perennial Triteceae

- denotes where tolerance has been documented

<table>
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<tr>
<th>Species</th>
<th>BYDV</th>
<th>WSMV</th>
<th>Leaf rust</th>
<th>Stem rust</th>
<th>Stripe rust</th>
<th>Tan spot</th>
<th>Fusarium head blight (scab)</th>
<th>Powdery mildew</th>
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Tolerance of Australia’s environment

• Require different adaptations from US
  • E.g. Cold/freezing tolerance

• We need
  • Tolerance of water deficit
  • Tolerance of poor & infertile soils
  • Different phenology

• Improved tolerance from perennial parents
  • Occupy niches where annual wheat performance reduced

• Several native & naturalised perennial Triticeae
  • Native – *Elymus* & *Australopyrum*
  • Exotic – *Thinopyrum*, *Leymus*, *Elytrigia*

→ Useful sources for adapted germplasm?
Distribution of perennial Triticeae in Australia

A. Native *Elymus* spp.
Distribution of perennial Triticeae in Australia

B. Introduced *Thinopyrum* spp.

Legend
- Thinopyrum distichum
- Thinopyrum elongatum
- Thinopyrum junceiforme
- Thinopyrum ponticum
Distribution of perennial Triticeae in Australia

C. Native *Australopyrum* and introduced *Leymus/Elytrigia* spp.

Legend:
- △ *Elytrigia repens*
- ◆ *Australopyrum pectinatum*
- ○ *Australopyrum velutinum*
- ■ *Leymus arenarius*
- □ *Leymus multicaulis*
Adaptation to water deficit

Affect potential distribution of perennial wheat

- Desirable attributes for adaptation to arid environments
  - Phenology
  - Summer dormancy
    - Eg. Temperate perennial grasses
  - Deep-rootedness
  - Tolerance traits e.g. osmotic adjustment, …

- Temperate perennial grasses indication of distribution and desirable traits
Water deficit in Australia’s cropping zone

Map showing different agro-climatic zones in Australia, indicating water deficit areas.
Tolerance of soil constraints

Stress tolerance perennials > annual wheat

- Soil acidity & Al/Mn toxicity
- Salinity tolerance
- Waterlogging tolerance

• Longer-lived, larger root system
  • Access deeper soil layers
  • Penetrate hard pans, high soil strength
  • Extract reserves of nutrients
Sources of abiotic tolerances in perennial Triticeae

- denotes where tolerance has been documented

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<th>Species</th>
<th>Drought</th>
<th>Al toxicity</th>
<th>Mn/B/Cu toxicity</th>
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Other perennial cereal alternatives

• Triticale/Rye – *Secale montanum*
  • Drought
  • Heat
  • Soil acidity

• Warm-season cereals – sorghum, pearl millet
  • Subtropical environments

• *Distichlis palmeri*
  • Salt-affected land
Affected greatly by longevity

- Phase rotations – 2-4 year rotations
  - E.g. lucerne
  - Self-regulates by climatic capacity
- Variation on conventional systems
  - Unreliable year-to-year persistence
  - Opportunistically utilise out-of-season rain
- Perennial polyculture - permanent
  - Mixture of warm-, cool-season grasses, legumes
  - Complement spatially, seasonally, or in nutrients
- Companion or relay cropping
  - Increase productivity of low densities
  - Provide N inputs (clover or medic)
Phase rotation with lucerne

Year 1 - Pasture establishment under cover crop

Year 2 - Pasture begins to create a dry soil buffer

Year 3 - Pasture creates large soil buffer

Year 4 - Pasture removal followed by crop

Year 5 - Continue crop rotation

Year 6 - Re-establish pasture under cover crop
Farming systems for perennial wheat

Affected greatly by longevity

• Phase rotations – 2-4 year rotations
  • E.g. lucerne
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Taking perennial wheat forward in Australia

• Potentially a radical change for Australian agriculture
  • Benefits to sustainability & flexibility
  • While maintain grain production

• Key issues for investment cost-benefit payoff
  • Geographical scope
  • Size of applicable area
  • Quantify potential benefits
  • Likely timeline/cost for development
Benefit/Cost Ratio – scale of adoption

Assuming development needed –

- 18 years of development (ie. AU$ 9.8 M)
- 50% likelihood of success

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<th>Max. level of adoption (% of farmers)</th>
<th>% of winter crop area</th>
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Assuming peak adoption 600 000 ha –

- 60% max adoption rate
- 20% farm area across 25% of Aust winter-crop area.

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<tr>
<th>Total years (scoping + breeding)</th>
<th>Research costs (^A) (AU$ M)</th>
<th>Likelihood of success</th>
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<td>3 + 20</td>
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\(^A\) Discounted at 5%
Taking perennial wheat forward in Australia

Verifying the concept

• Evaluate existing germplasm
  • Growth
  • phenology & agronomic suitability
• Pseudo-perennial wheat systems
  • e.g. temp. perennial grasses
  • Desirable adaptive traits (e.g. summer dormancy)
  • Productivity benchmarks
• Role for simulation modelling
  • Climate-yield variation,
  • Adaptation or relative advantage in particular situations
  • Quantify environmental effects
  • Identify important agronomic & physiological traits
Interim products

• Dual-purpose perennial wheat
  • Grazing & opportunistic grain
  • Grazing offsets lower grain yield/poorer quality
  • Modest development to perennial forage grass

• As grain quality & yield increases, imperative for forage reduced
Conclusion

Are ‘perennial grains’ the next revolution in agriculture?

• Undoubtedly there are a range of challenges; and
• A large coordinated effort is required into the future
• Promising progress has been made, albeit slow
• Significant sustainability benefits are possible
• There is excitement about the prospect


