The effect of varietal resistance on the yield loss function of wheat to different foliar diseases

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Key messages

- Disease expression increased with the susceptibility of the varieties, resulting in correspondingly higher yield loss. Losses were between 0.5 and 4 t/ha, depending on the type and severity of disease and the yield potential.
- Partially resistant varieties differed in the extent of their yield loss corresponding with lower disease expression. Partial resistance expressed itself as slower disease development rather than delayed disease appearance on the leaf surface. There was little evidence for foliar disease tolerance associated with lower rates of yield loss.
- Current categories of resistance were generally well reflected in the yield responses observed for various wheat foliar diseases; however yield losses for particular resistance categories varied by disease and disease intensity.
- Partial resistance was effective in reducing losses from all diseases, particularly Septoria tritici blotch, leaf and stripe rusts and yellow spot.

Background and Aims

Western Australia (WA) is the major grain export state producing around 60 per cent of Australia's wheat exports. Foliar diseases remain a concern to the production of wheat and breeding for disease resistance is crucial to reduce yield vulnerability. Many of these diseases can be effectively controlled by growing partially resistant varieties. In some environments avoiding the susceptible and very susceptible varieties may be sufficient. Consequently, there is an ongoing need to understand the contribution of partial resistance to disease management in various environments. This research aims to develop disease response curves indicating potential yield losses associated with various resistance levels for wheat yellow spot (WYS) (syn. yellow leaf spot, tan spot), nodorum blotch (WNB) (syn. Septoria nodorum blotch, stagonospora nodorum blotch, parastagonospora nodorum blotch), Septoria tritici blotch (WST), leaf rust (WLR), stem rust (WSR) and stripe rust (WYR). As a result growers will have improved wheat production and/or system cost efficiency through enhanced knowledge for effective management decisions that consider regional economic thresholds.

Method

The following 12 trials were conducted in each of 2015 and 2016: Four trials for WYS conducted in South Perth WA, Horsham Victoria (VIC), Wagga Wagga New South Wales (NSW) and Hermitage Queensland (QLD); one trial for WNB conducted in South Perth WA; two trials for WST conducted in Inverleigh VIC and Wagga Wagga NSW; three trials for WLR conducted in Carnarvon WA, Inverleigh VIC and Wellcamp QLD; one trial for WSR conducted in Carnarvon WA; and one trial for WYR conducted in Wagga Wagga, NSW. Trials were sown into stubble free paddocks at a sowing time typical of the region. Trials were conducted using five or six varieties representing resistant levels typically in the range of MRMS to VS. Varieties selected were adapted to the particular region, had similar maturities and where possible were resistant to diseases which were potential contaminants. Trial design and disease establishment for the leaf spot diseases (WYS, WNB and WST) differed from that for the three rusts (WLR, WSR and WYR).

Trial design and disease establishment for leaf spot diseases (WYS, WNB and WST)

Trial design

Each trial was sown in a randomised crisscross or split plot design of five disease levels, five or six resistance levels and three replicates. Disease epidemic levels were high disease pressure (HDP), medium disease pressure (MDP), low disease pressure (LDP), very low disease pressure (VLDP) and maximum or total protection (TP). Main plots and replicates were separated by at least 3 m and included a 1 m wide barley buffer. Neighbouring varietal effects were minimised through design. A minimum plot-size of 5 m^2 was used.

Disease establishment and achieving different disease epidemic levels

Mixtures of isolates were used for all three diseases. WNB and WST infection was established using conidial suspensions in conjunction with approaching rain fronts. Four applications starting at eight weeks after sowing (WAS) and after 10 to 14 day intervals, resulted in good disease expression. WYS infection was established using spore suspensions as above in WA and by using infected stubble over east. Epidemics were promoted using sprinkler irrigation at dusk to maintain extended periods of leaf wetness.

Different disease epidemic levels were generated by varying the amount of inoculum exposure or application. Where naturally infested straw was used to establish epidemics, the ratio of infested and non-host straw was varied such that the same total amount of straw was applied to every plot. Non host straw was applied first and the diseased straw was spread over this.

Trial design and disease establishment for rust diseases (WLR, WSR and WYR)

Trial design

Each trial was sown in a randomised crisscross or split plot design of four or five disease levels, five resistance levels and three or four replicates. Disease levels included HDP, MDP, LDP, VLDP and TP. Main plots and replicates were separated by at least 3 m and included a 1 m wide susceptible spreader or non-host buffer depending on the method used for disease establishment. Neighbouring varietal effects were minimised through design. A minimum plot-size of 5 m^2 was used.

Disease establishment and achieving different disease epidemic levels

Pathotypes used were Lr 76-1,3,5,7,9,10,12 +Lr37 (“Lr76”) and Sr 34-1,2,7 +Sr38 (“SrVPM”) in WA; Lr 76-1,3,5,7,9,10,12 +Lr37 (“Lr76”) in Victoria and Lr 104-1,3,4,6,7,8,10,12+Lr37 (“new Lr104”) in Queensland. Rust infection was established by introducing infected transplants within pre-sown susceptible spreaders at four WAS or by using urediniospore suspensions on the test plots where non-host buffers were used. Spreaders or test plots were further inoculated with urediniospore suspensions. Epidemics were promoted using sprinkler irrigation at dusk to maintain extended periods of leaf wetness.

Different disease epidemic levels were generated by varying the degree of protection with foliar fungicide or by varying the amount of inoculum exposure or application.

In-season trial management

Appropriate irrigation (where available), weed control and fertilizer regimes were followed to achieve normal plant growth. Selective fungicide sprays were used to exclude non target diseases, e.g. 250 g/ha of Quinoxyfen and 125 g/ha Bupirinate to control powdery mildew.

Assessments

Assessment of development scores/heading dates was made at least once during the season. Disease was assessed at least twice during adult plant stages for all diseases, typically between Z49 to Z59 and Z73 from the top two leaves of 10 random tillers per plot. Stem rust was assessed from two tillers per plant. Glume blotch expression of nodorum blotch was assessed on 10 random heads at Z85 and Z87.

Statistical analysis

For WYS, WNB, WST, WLR and WYR trials, repeated observations on disease expression on sampled leaf layers across time were summarised at the plot level by calculating the relative area under the disease progress curves (rAUDPC) [1] across both leaf layers as an overall measure of disease expression. Where rAUDPC is zero, plant parts remained unaffected by disease throughout the observation period. Where only two disease assessments were made on a trial, disease expression was calculated as the mean proportion of disease across leaf layers and assessment dates. Observations on stems and glumes were similarly summarised using mean proportion of disease for WSR and WNB trials respectively. The mean proportion of disease for the WSR trial was square root transformed.

The yield and disease data were analysed on an individual experiment basis using a random regression approach within a linear mixed model framework. Quadratic terms were included in initial models to allow for non-linearity in yield responses. Fixed terms were included to account for disease expression and random effects to account for variety and its interaction with disease expression, and to describe the blocking structure of the associated trial design. Interaction terms were tested for inclusion using REML log-likelihood ratio tests; fixed quadratic terms were tested for inclusion using approximate Wald-type tests. Where appropriate, terms were included to account for spatial trends in the field and random coefficients were correlated to ensure models remained invariant to translation. Models were fitted using the ASReml-R package [2] in the R statistical computing environment [3].

Results

Yield response curves are presented for the trials conducted in 2016 with the exception of the yellow spot trial at Wagga Wagga which was terminated due to waterlogging, and 2015 results are provided instead. Disease epidemic levels were well achieved for all trials presented and resistance categories were well reflected in the yield response curves (Figs. 1, 2 and 3). Differences in varietal yield potentials within locations were evident from the Y intercept for the variety regression lines, at zero or low disease severity. Total disease (expressed as rAUDPC or mean proportion of disease) increased with the susceptibility of the varieties to the particular pathogen, resulting in correspondingly higher yield loss in various trials (Figs. 1, 2 and 3). Partially resistant varieties showed lower disease and slower disease development rather than delayed disease appearance on the leaf surface. Curves for the partially resistant varieties were shorter than curves for the susceptible varieties reflecting lower levels of disease expression and less yield loss. The slopes of the curves of various varieties in different trials were significantly different from zero but were not significantly different from each other in most trials indicating no differences in disease tolerance (ability of a variety to maintain yield in the presence of infection) among varieties. Slopes were generally higher in the rust trials as compared to the leaf spot trials validating the more damaging nature of rust diseases

In four yellow spot experiments (Fig. 1A, 1B, 1C and 1D), yields of disease-protected plots were around 3.5 to 6.7 t/ha depending on environment. The yield loss function for this disease was linear. At the highest disease burdens, the most susceptible varieties lost between 0.9 to 2.0 t/ha. In contrast, varieties with the highest levels of partial resistance expressed lower disease and lost between 0.2 to 1.0 t/ha. The results indicate that partial resistance to yellow spot contributes significantly to protecting yield in disease-conducive situations.

In one nodorum blotch experiment (Fig. 2A and 2B), yield of disease-protected plots was around 4 t/ha. The yield loss function for this disease was non-linear. The most susceptible varieties expressed highest burdens of both leaf (Fig. 2A) and glume (Fig. 2B) disease. At the highest disease burdens, highly susceptible varieties lost around 2 t/ha. In contrast, a variety with higher levels of partial resistance expressed lower burdens of total disease and lost around 1.0 t/ha. The result indicates that partial resistance to nodorum blotch can make a significant contribution to protecting yield in disease-conducive situations.

In two Septoria tritici blotch experiments in sNSW (Fig. 2C and 2D), yield of disease-protected plots was typically around 6 t/ha. The yield loss function for this disease was linear. The susceptible varieties expressed highest burdens of disease although the results for variety Revenue at Inverleigh (high rainfall Victoria) (Fig. 2C) suggest the classification of this variety as MS to Septoria tritici blotch may require review. At the highest disease burdens, highly susceptible varieties lost from 0.5 to around 3 t/ha depending on disease burden and yield potential. In contrast, varieties with the highest levels of partial resistance expressed very low burdens of total disease and expressed negligible losses 0-0.2t/ha. The results indicate the high current effectiveness of partial resistance to Septoria tritici blotch.

In three leaf rust experiments (Fig. 3A, 3B and 3C), yield of disease-protected plots ranged from 4.5 to around 8 t/ha. The yield loss functions for this disease were non-linear. At the highest disease burdens, highly susceptible varieties lost from 1.4 to 3.3 t/ha. In contrast, varieties with the highest levels of partial resistance expressed very low burdens of total disease and negligible losses of 0-0.2t/ha. The results indicate the relatively high effectiveness of partial resistance to leaf rust. The effects of leaf rust on yield of two varieties classified as MS appears disproportionately high and warrants further investigation.

In one stem rust experiment (Fig. 3D), disease effects on yield were very severe. Under the disease pressure experienced, partially resistant varieties resulted in only small reductions in overall yield loss.

In one stripe rust experiment (Fig. 3E), the yield loss function was linear and disease levels were very severe. Yield of one highly susceptible variety was reduced from 3.7 t/ha to zero. In contrast, a variety with the highest levels of partial resistance expressed a substantially lower burden of disease with losses limited to around 1.1t/ha.

Conclusions

Wheat expressed different rates of yield loss depending on the type and pressure of the disease. Varieties with different levels of resistance expressed different extents of yield loss. More susceptible varieties expressed higher levels of disease and correspondingly higher yield loss. Partially resistant varieties differed in the extent of their yield loss corresponding with lower disease expression. Partial resistance expressed itself as slower disease development rather than delayed disease appearance on the leaf surface. There was little evidence for foliar disease tolerance associated with lower rates of yield loss.

Partial resistance was effective in reducing losses from all diseases, but most evidently for Septoria tritici blotch, leaf and stripe rusts and yellow spot, for current commercial wheat varieties.

Current categories of resistance were generally well reflected in the yield responses observed for various wheat foliar diseases. However, yield losses for particular resistance categories varied by disease and disease intensity. Further accumulation of yield loss response information across years and environments will support regional benchmarking of resistance categories for yield losses to major wheat diseases.

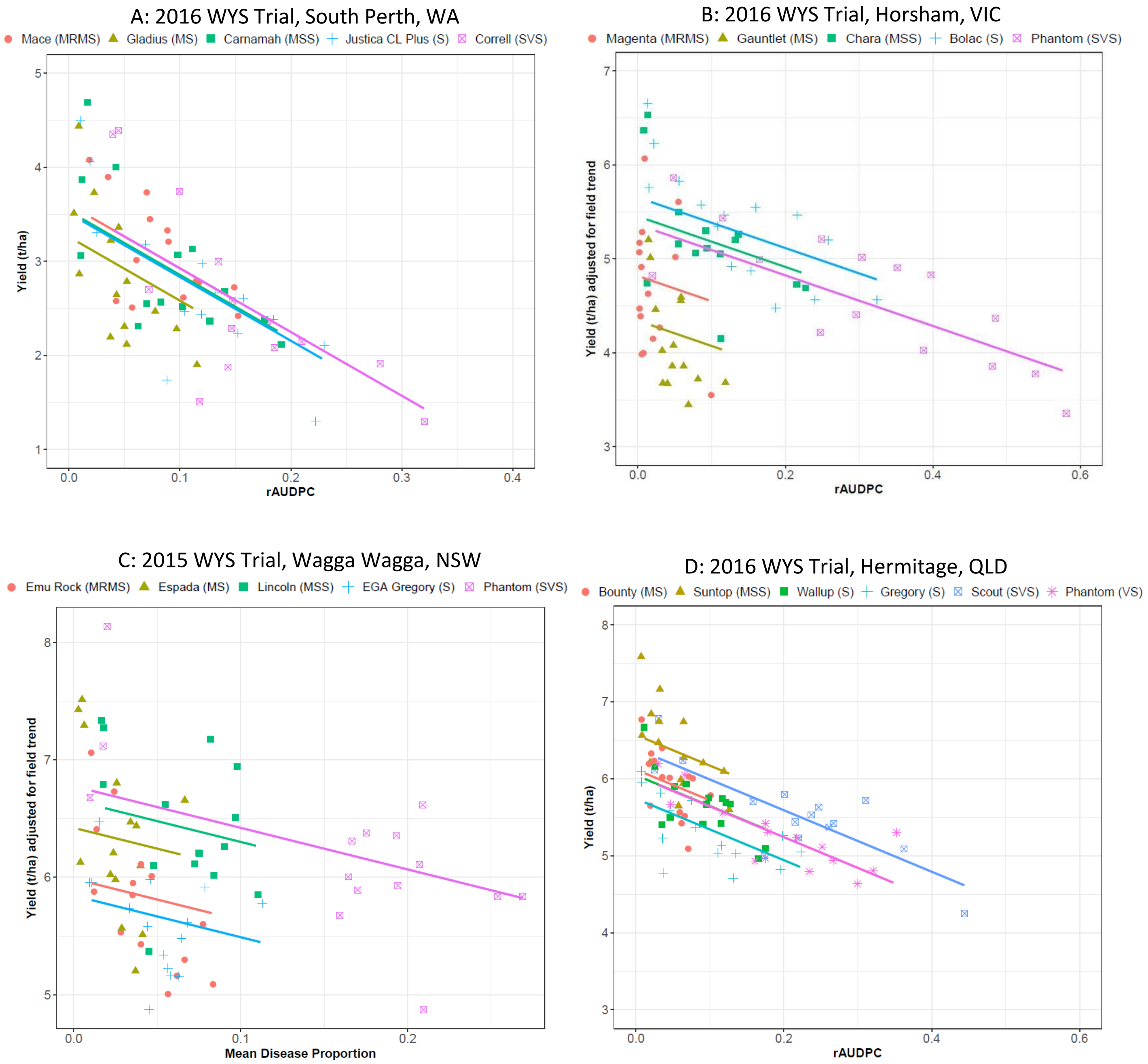

Fig. 1. Yield response curves for wheat yellow spot (WYS) trials conducted at (A) South perth, Western Australia; (B) Horsham, Victoria; (C) Wagga Wagga, New South Wales and (D) Hermitage, Queensland. rAUDPC = Relative Area Under the Disease Progress Curve. Note: The red line for Mace in graph (A) is very short and is not clearly visible as it merges with the pink line for Correl. Similarly, the green line for Carnamah in graph (A) merges with the blue line for Justica CL Plus but is shorter.

References

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Key words

Wheat foliar diseases, yield loss, yield response curves, disease levels, yellow spot, nodorum blotch, Septoria tritici blotch, leaf rust, stem rust, stripe rust

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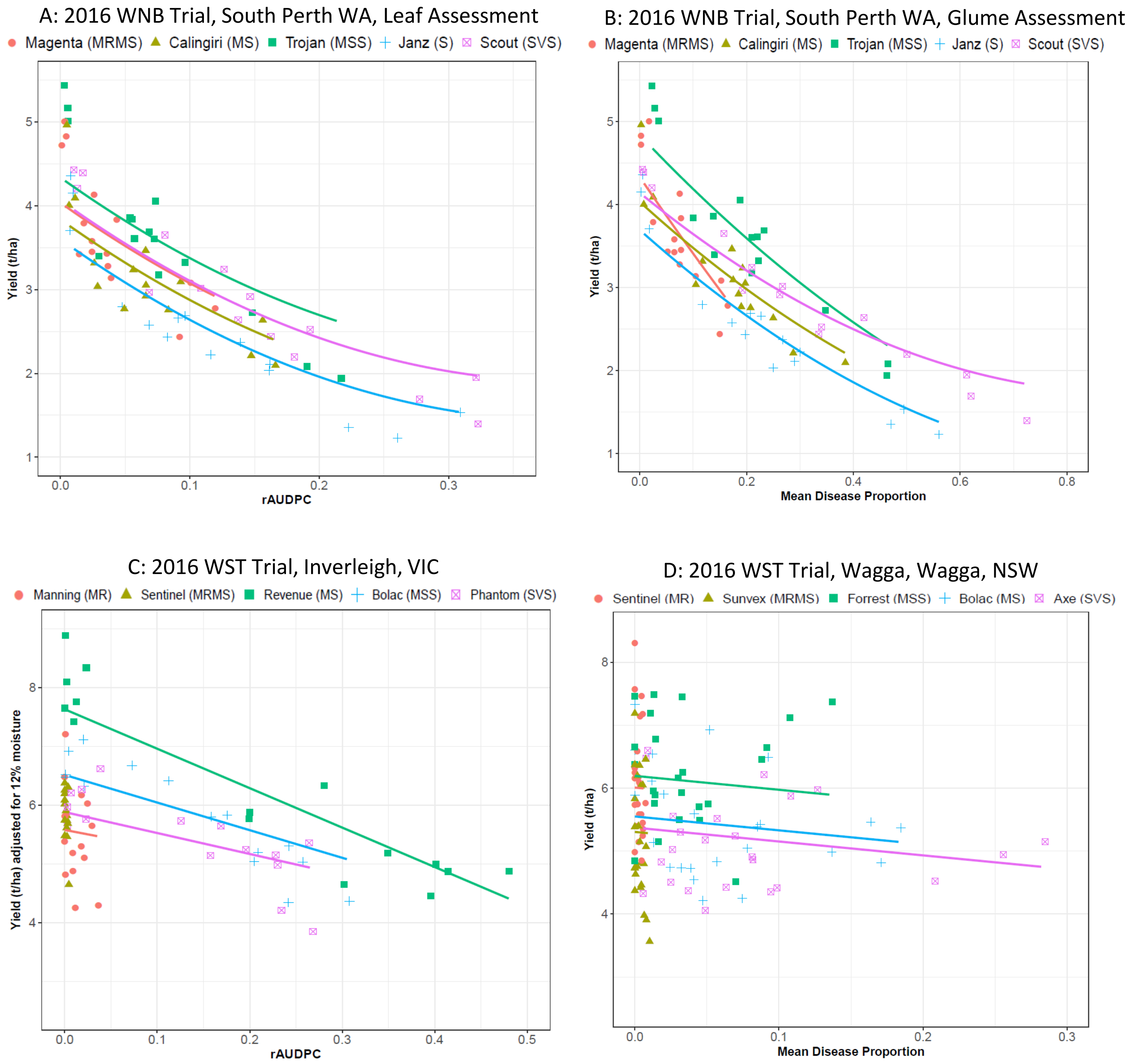
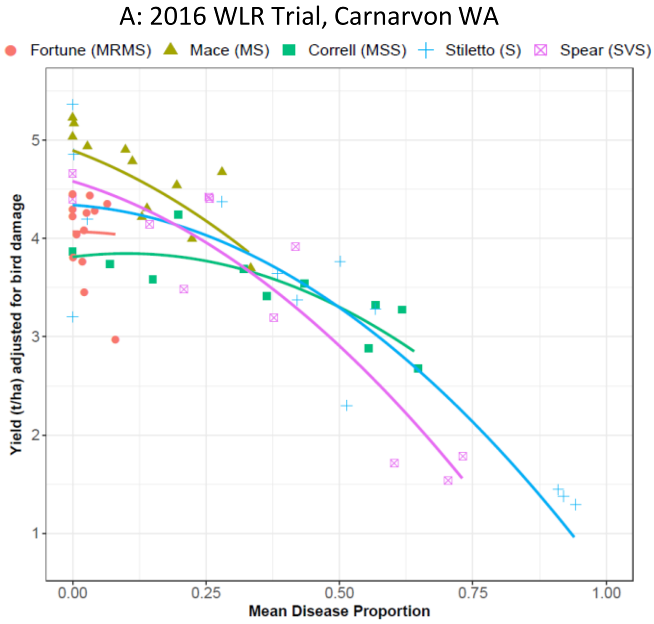
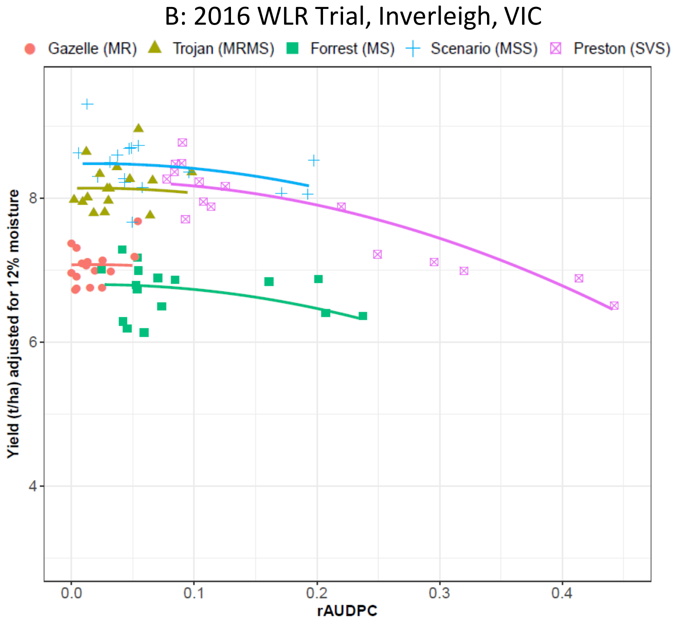
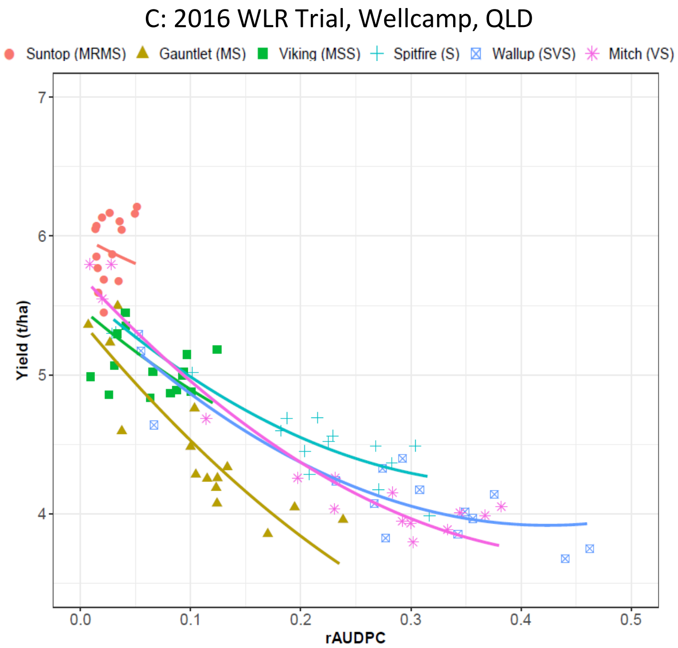
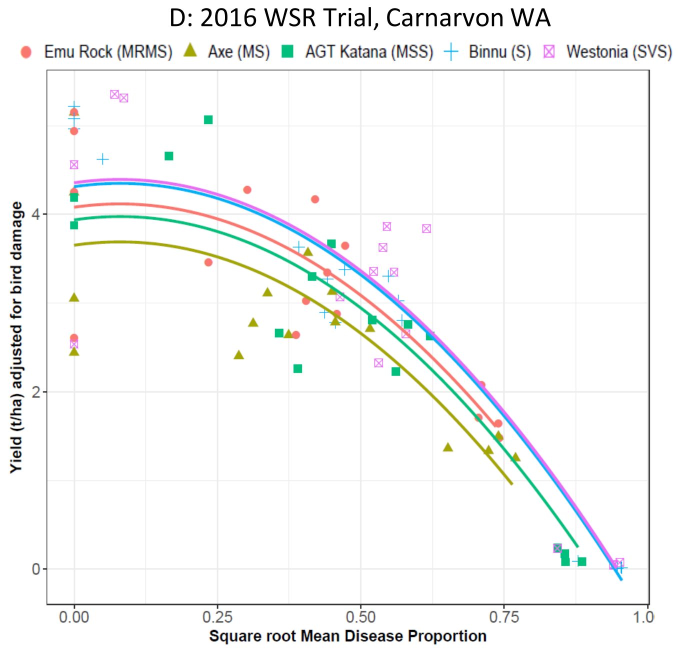


Fig. 2. Yield response curves for wheat nodorum blotch (WNB) trial conducted at South Perth, WA with (A) leaf assessments and (B) glume assessments; wheat septoria tritici blotch (WST) trials conducted at (C) Inverleigh, Victoria; and (D) Wagga Wagga, New South Wales. rAUDPC = Relative Area Under the Disease Progress Curve. Note: The red line for Magenta in graph (A) is not clearly visible as it merges with the pink line for Scout but is much shorter. Line for Sentinel in graph (C) is almost zero and lines for Sentinel and Sunvex in graph (D) are extremely short.









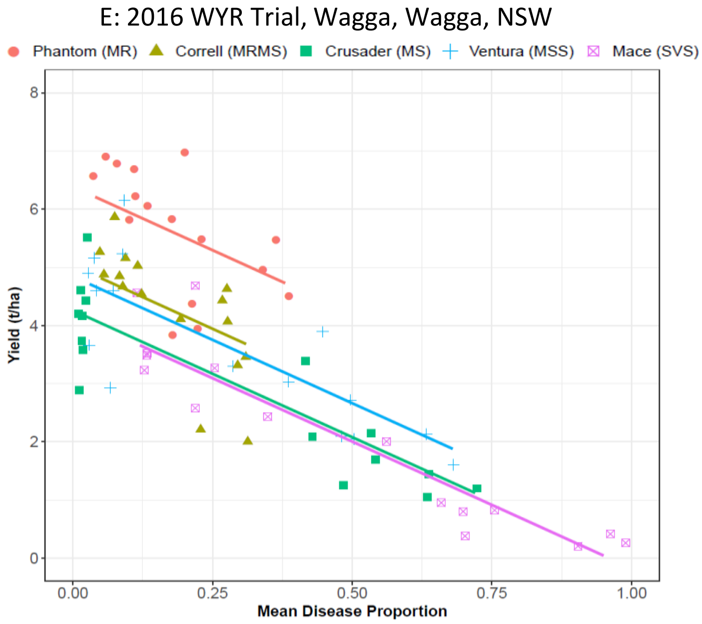


Fig. 3. Yield response curves for wheat leaf rust (WLR) trials conducted at (A) Carnarvon, WA; (B) Inverleigh, Victoria; and (C) Wellcamp, Queensland; wheat stem rust (WSR) trial conducted at (D) Carnarvon WA; and wheat stripe rust (WYR) trial conducted at (E) Wagga Wagga, New South Wales. rAUDPC = Relative Area Under the Disease Progress Curve.