Results

Table 1: Selected soil chemistry details of three trials used in this study before seeding.

Site	Mineral NH_4^+-N & NO_3-N (kg/ha)		Colwell P (kg/ha)		Colwell K (kg/ha)		KCl-40 S (kg/ha)		Organic C (%)	
	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm
WHCAN	21	12	48	58	256	274	70	44	1.5	0.9
WHPAS	37	13	39	29	91	54	16	10	0.8	0.4
Shenton Park	5	5	67	61	59	52	3	2	0.5	0.5

Table 2: Yield of Mace in three trials under different nutrition regimes. Values in bold are significantly different from yields of unfertilised plots.

Treatment	WHCAN Yield (t/ha)	WHPAS Yield (t/ha)	Shenton Park Yield (t/ha)
Background	2.38	1.83	0.11
10 kg N ha	2.28	2.21	0.31
10 kg N ha + 2 kg P ha	2.36	2.08	0.27
10 kg N ha + 8 kg K ha	2.23	2.05	0.32
10 kg N ha + 3 kg S ha	2.30	2.06	0.31
10 kg N ha + 2 kg P ha + 8 kg K ha + 3 kg S ha	2.36	2.30	0.28
30 kg N ha	2.33	2.25	**0.66**
30 kg N ha + 8 kg P ha	2.41	2.05	**0.59**
30 kg N ha + 25 kg K ha	2.38	2.12	**0.62**
30 kg N ha + 10 kg S ha	2.29	2.05	**0.61**
30 kg N ha + 8 kg P ha + 25 kg K ha + 10 kg S ha	2.43	2.06	**0.53**
60 kg N ha	2.26	2.11	**0.74**
60 kg N ha + 16 kg P ha	2.29	2.38	**1.01**
60 kg N ha + 50 kg K ha	2.26	1.89	**0.72**
60 kg N ha + 20 kg S ha	2.29	2.03	**0.91**
60 kg N ha + 16 kg P ha + 50 kg K ha + 20 kg S ha	2.38	2.35	**0.92**
90 kg N ha	2.34	2.11	**0.87**
90 kg N ha + 24 kg P ha	2.35	1.83	**0.91**
90 kg N ha + 75 kg K ha	2.34	1.98	**0.90**
90 kg N ha + 30 kg S ha	2.40	2.29	**0.97**
90 kg N ha + 24 kg P ha + 75 kg K ha + 30 kg S ha	2.28	2.38	**1.12**
Site variability (SE)	0.08	0.11	0.05

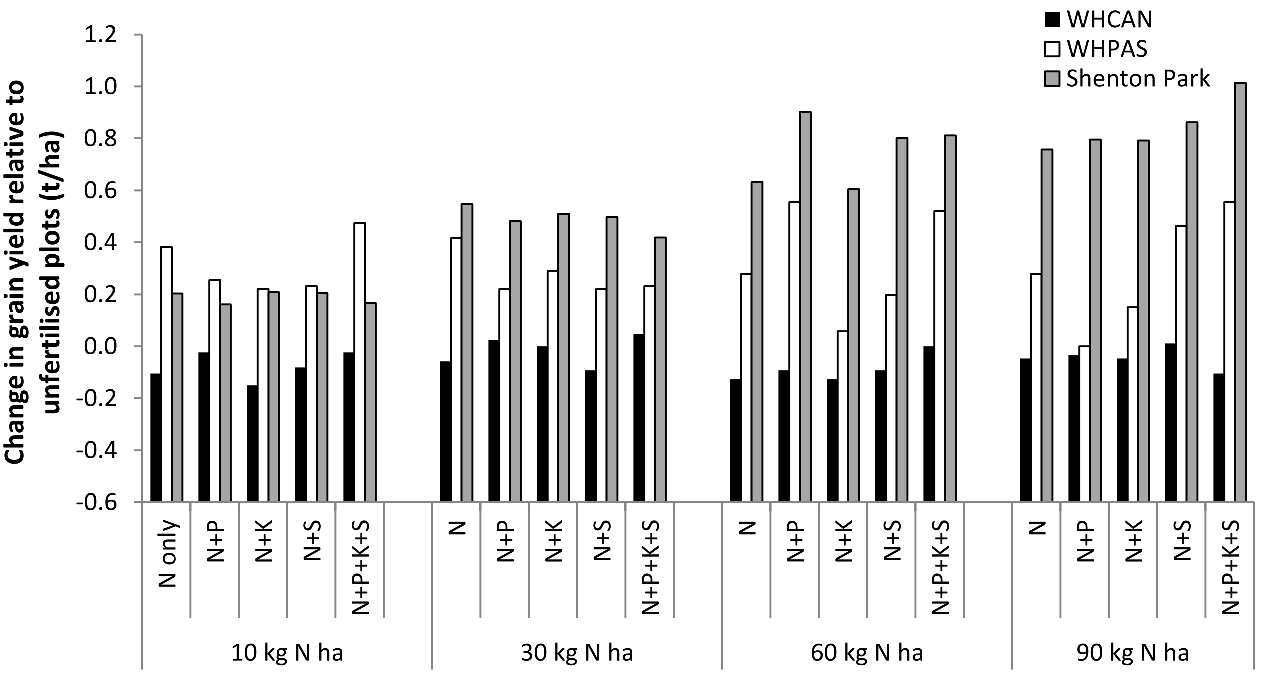

Figure 1: Change in Mace yield relative to yield from unfertilised plots across all three trials. WHCAN background yield 2.38 ± 0.08 t/ha; WHPAS background yield 1.83 ± 0.02 t/ha; Shenton Park background yield 0.11 ± 0.03t/ha. Mean error (SE) for each site - WHCAN = 0.08 t/ha; WHPAS = 0.11 t/ha; Shenton Park = 0.05 t/ha.

Economic Analysis

Table 3: Economic Analysis ($/ha) of Mace grown in three trials under different nutrition regimes. Values in bold are significantly different from gross margins of unfertilised plots.

Treatment	Fertiliser Costs	WHCAN Gross Margin	WHPAS Gross Margin	Shenton Park Gross Margin
	($/ha)	($/ha)	($/ha)	($/ha)
Background	0.00	762.96	585.19	35.41
10 kg N ha	13.22	716.41	694.19	87.05
10 kg N ha + 2 kg P ha	16.71	738.85	649.96	70.27
10 kg N ha + 8 kg K ha	25.25	689.56	630.30	76.59
10 kg N ha + 3 kg S ha	14.97	722.07	644.29	85.66
10 kg N ha + 2 kg P ha + 8 kg K ha + 3 kg S ha	30.49	725.07	706.55	58.26
30 kg N ha	39.65	704.79	678.87	**170.58**
30 kg N ha + 8 kg P ha	53.60	716.77	601.95	**135.97**
30 kg N ha + 25 kg K ha	77.26	685.70	600.52	**121.36**
30 kg N ha + 10 kg S ha	45.49	687.85	610.07	**149.24**
30 kg N ha + 8 kg P ha + 25 kg K ha + 10 kg S ha	97.05	680.73	562.21	72.19
60 kg N ha	79.30	**642.92**	594.77	**158.27**
60 kg N ha + 16 kg P ha	107.21	**626.12**	655.75	**216.62**
60 kg N ha + 50 kg K ha	154.52	**567.70**	449.18	74.38
60 kg N ha + 20 kg S ha	90.97	**642.36**	557.18	**200.89**
60 kg N ha + 16 kg P ha + 50 kg K ha + 20 kg S ha	194.09	**568.87**	557.76	101.18
90 kg N ha	118.96	**629.19**	555.12	**158.93**
90 kg N ha + 24 kg P ha	160.81	**591.04**	424.37	**129.26**
90 kg N ha + 75 kg K ha	231.78	**516.37**	401.55	57.04
90 kg N ha + 30 kg S ha	136.46	**630.21**	596.88	**174.79**
90 kg N ha + 24 kg P ha + 75 kg K ha + 30 kg S ha	291.14	**438.49**	471.82	68.49

Based on EPR for 12/12/14 AH Base Price $320/tonne; Fertiliser prices based on 2012-13 ABARES average prices Urea $608 tonne; TSP $802 tonne; KCl $692 tonne; Gypsum $140 tonne.

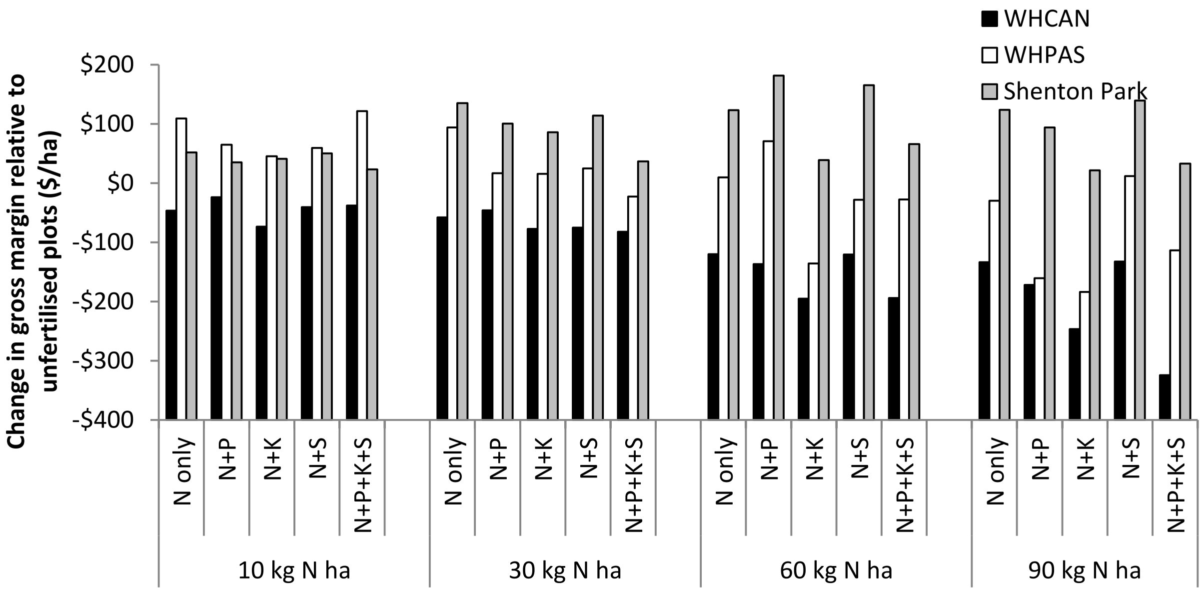

Figure 2: Change in gross margins relative to gross margins from unfertilised plots across all three trials. WHCAN background margin $762.96/ha; WHPAS background margin $585.19/ha; Shenton Park background margin $35.41/ha.

Comments

Yields, responsiveness to fertiliser N applications and economic assessments of trials

Mace yields were highest at the WHCAN site (average 2.33 ± 0.08 t/ha), followed by WHPAS site (2.11 ± 0.11 t/ha) and the, much lower Shenton Park (0.63 ± 0.05 t/ha) (Table 2). At the WHCAN site there was no yield response to fertiliser N applications, with yields in unfertilised plots (2.38 ± 0.08 t/ha) similar or higher than most other nutrition treatments. Economically, the application of fertilisers was deleterious at this site as gross margins were highest in unfertilised plots ($762.92/ha) with gross margins statistically decreasing when 60 kg N ha or more was applied (Table 3; Figure 2).

Yields at the WHPAS site responded to N applications with average yields of N fertilised plots (2.13 ± 0.08 t/ha) higher than yields of unfertilised plots (1.83 ± 0.02 t/ha) (Table 2). Mace responded to an N application of 10 kg N ha (0.3-0.5 t/ha increase), however, there were limited yield increases when N applications were increased to 30, 60 or 90 kg N ha (Table 2). Economically, most nutrition regimes which applied less than 30 kg N ha increased the gross margin by up to $120/ha (Table 3; Figure 2).

At Shenton Park, yields were responsive to N applications with increasing with fertiliser N application (Table 2). Economically, some nutrition regimes resulted in a $182/ha increase in gross margin relative to unfertilised plots with margins greater than $120/ha statistically higher than in unfertilised plots. The extremely low yields at the Shenton Park site (despite having ideal pH and high in season rainfall, see Trial Details) can be explained by very poor nutrient retaining capacity and severe leaching of the deep coarse sands. These properties were only made worse by high in season rainfall. This site was chosen to give an extreme scenario of how the nutrients would interact and perform on a deep coarse sand that was unable to hold any nutrients due to its physical make up.

Role of fertiliser P, K and/or S on wheat yield under varying N concentrations

Across the three trials, yields were increased by applications of P, K and/or S, however, only under certain situations (Table 2; Figure 1). At the WHCAN site applications of P, K and/or S had no influence on yields of Mace under varying fertiliser N applications. This is not surprising given the high background P, K and S concentrations present at this site (Table 1) and that no N response was observed.

At WHPAS and Shenton Park yield increases were observed when N was applied at 60 kg N ha or 90 kg N ha with either P, S or P, K and S also applied (Table 2; Figure 1). These yield increases typically fell in the range of 0.2-0.3 t/ha and in some cases, particularly when 60 kg N ha + 16 kg P ha was applied, they were economically beneficial increasing gross margins by between $60-70/ha (Table 3; Figure 2).

Importance of background nutrition on fertiliser responsiveness

All three trials contained very different soil nutrient profiles before seeding (Table 1). At WHCAN Colwell K concentrations were approximately 5 times higher than critical values for wheat (≈40 mg K kg) and around seven times higher for S (≈10 mg S kg) (Table 1). In addition, WHCAN also had P concentrations in excess of critical values (≈30 mg P kg) and the highest organic C content (1.5%) of all three trials. WHPAS contained available P, K and S and organic C concentrations that were considerably lower than in WHCAN (Table 1). Colwell K concentrations although far lower than at WHCAN were still approximately 2.5 times higher than critical values, whilst available P and S concentrations were similar to critical values thus explaining why P and S responses were observed.

Background nutrition levels at Shenton Park were low, with N and S limiting, K concentrations at critical levels and very low organic C content (Table 1) due to the gutless sand being prone to leaching. Available P concentrations were, however, higher than in both of the Wongan Hills sites (Table 1).

Grain yields at WHCAN > WHPAS > Shenton Park (Table 2), which is the same pattern present in pre-sowing soil tests for available K, S and organic C, whilst pH was the inverse pattern (i.e. lowest at WHCAN; highest at Shenton Park) (Table 1). The combination of high residual P, K and S concentrations plus organic C may have facilitated N mineralisation, thus explaining why yields were highest at WHCAN despite limited fertiliser N response. Decreases in both the background nutrition and organic C content resulted in the WHPAS and Shenton Park sites being more fertiliser responsive and therefore fertiliser dependent in terms of increasing yields (Table 2). Future research is needed to determine if background nutrition levels, organic carbon content, pH or interactions between background nutrition, organic C and soil pH regulate crop responsiveness to fertiliser applications.

Do nutrient concentrations or ratios between nutrients govern yield responses?

At both WHPAS and Shenton Park yield responses were observed when N+P; N+S or N+P+K+S fertiliser regimes were applied (Table 2; Figure 1). The yield responses were, however, not constant across different concentration levels (Table 2; Figure 1). For example at WHPAS a yield decrease of approximately 0.5 t/ha was observed when 90 kg N ha + 24 kg P ha applied instead of 60 kg N ha + 16 kg P ha, whilst the same scenario resulted in a 0.1 t/ha yield decrease at Shenton Park (Table 2). The ratio between N: P added in these regimes was constant (1: 0.26) however, the ratios between P: K changed from 0.47:1 (when 16 kg P ha applied) to 0.81:1 (when 24 kg P ha applied). When P: K ratios were kept constant (i.e. when 60 kg N ha + 16 kg P ha + 50 kg K ha + 20 kg S ha or 90 kg N ha + 24 kg P ha + 75 kg K ha + 30 kg S ha were applied) yields increased by about 0.2-0.3 t/ha (Table 2). This finding implies that the application of N, P, K and S are all required to increase yields when N concentration of 60 kg N ha is applied. Whether this is a result of plants requiring strict ratios between nutrients remains uncertain and requires further research, however, based on the data presented here it would appear more likely that ratios between nutrients govern yield responses rather than absolute nutrient inputs.

Major Findings and Implications

1. Ensuring a nutrient balance between N, P, K and S concentrations is key to yield increases and thus careful attention to pre-season soil tests can be economically beneficial. In some scenarios the use of targeted N+P, N+S or N+P+K+S fertiliser regimes can stimulate grain yield to be economically viable. This is, however, heavily regulated by background nutrient concentrations.
2. Interactions between background nutrients, soil organic contents and soil pH are likely to dictate whether a soil will be fertiliser responsive. Further understanding of these interactions and management of these resources has the potential to maximise grain yields and could provide economic benefits by limiting fertiliser applications.
3. On nutrient responsive sites the only way to ensure grain yield increases was through the application of fertiliser regimes encompassing targeted N+P+K+S applications. This is not always the most economically viable approach, however, it highlights that ratios between nutrients govern yield responses rather than absolute nutrient inputs. Future research highlighting critical ratios between nutrients (i.e. N:P, N:P:K etc.) may be as important as current research addressing critical nutrient concentrations.

Acknowledgements
Margaret Roper, Cathryn Sullivan and Kelley Whisson - CSIRO Agriculture Flagship, Floreat, WA
Shari Dougall - DAFWA Wongan Hills Field Station
Michael Blair and Rohan Hungerford - UWA Shenton Park Research Station
Summit Fertilizers
InterGrain

Paper reviewed by: Dr Cathryn O'Sullivan and Dr Margaret Roper (CSIRO Agriculture Flagship)

Contact
Elliot Duncan, CSIRO
elliot.duncan@csiro.au
(08) 9333 6615