# Do differences in yield components explain poor grain yield responses to Phosphorus fertiliser?

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**Abstract**
Early vegetative responses of wheat to phosphorus (P) fertiliser often diminish by grain maturity but the underlying causes of this change are not well understood. A field trial which was conducted on a Vertosol, with a low available P concentration, in the Victorian Wimmera, examined the growth of wheat (cv. Emu Rock) in response to applications of different P fertilisers. Normalized Difference Vegetation Index (NDVI), a proxy for aboveground biomass, responded to some of the P fertiliser products during stem elongation. A subset of treatments were sub-sampled to investigate whether this early responsiveness of wheat to P fertiliser was maintained through to grain maturity as well as gain more detailed information on changes to yield components. Phosphorus fertiliser had no significant impact on biomass, grain yield or harvest index, despite the early vegetative responses. Changes in the yield components suggest that the increased yield potential resulting from P application was not realised and the cause for this may be inadequate soil water supply during the latter part of the growing season.

**Keywords**
Haying off, nitrogen.

**Introduction**
Early vegetative responses to Phosphorus (P) fertiliser often decline or even disappear as the season progresses. Frequently there is little grain yield response to P application on alkaline soils in south-east Australia despite soil tests indicating low plant available P (Armstrong et al. 2008; Mason et al. 2010; McDonald et al. 2015). These poor grain yield responses are not accompanied by a decrease in harvest index (McDonald et al. 2015), which are typically associated with "haying off" in the presence of excess N (van Herwaarden et al. 1998). This suggests that a different mechanism may be responsible. Few studies reporting these poor yield responses have examined the components of grain yield to understand how they are changing as the response to P declines.

Grain yield potential of wheat is determined early in the growing season by the concurrent development of tillers and spikelets. It is during the tillering phase that many of these early biomass responses have been measured and, these responses are likely related to the increased number of tillers that develop from application of P fertiliser (Elliott et al. 1997). Phosphorus application can also increase the number of spikelets per head (Rahman and Wilson 1977) and therefore the yield potential. Increases in these yield components however may increase competition for other resources (Kirby and Jones 1977), leading to reduced grain number and size.

This study aimed to investigate, firstly whether the early response to P, identified by NDVI, eventuated into a grain yield response, and secondly to examine how yield components were affected, to determine why grain yield responses to P fertiliser are not obtained.

**Methods**
A field trial was sown on the 17$^{th}$ of June 2014 on a moderately P deficient (Colwell P 13 mg/kg 0-10 cm) Vertosol in the Wimmera region of Victoria. The experiment was a randomised block design with 4 replicates and 13 treatments; a control (No P fertiliser) and 4 P fertiliser products applied at 3 rates (3, 6 and 12 kg P/ha). Only one product, Granulock (21.9% P), was sub-sampled and will be reported and discussed in this paper. The wheat variety was Emu Rock, which was sown at 70 kg/ha. Granulock fertiliser was banded with the seed at sowing. Nitrogen (N) application was balanced for all treatments, except the control plots, using UAN. Control plots did not receive any N or P fertiliser. The trial was managed in accordance with district practice.

Normalized Difference Vegetation Index (NDVI) readings were taken during stem elongation using a Crop Circle ® (N Tech industries). Analysis of the results suggested a significant impact of P fertiliser. Granulock P appeared to have the greatest response and was therefore chosen to be subsampled at grain maturity.

Plants were sampled from a 0.6 $m^2$ area (4 rows @ 30 cm spacing, 0.5 m in length) at grain maturity. From this sample, 20 plants were tagged and kept as individual plants; all remaining plants were bulked together. Both samples were dried at 70°C, for 3 days. The remaining sample was weighed and thrashed to obtain grain weight. The individual plants were assessed for tiller number including fertile and non-fertile, number of spikelets and grains per head as well as the weight of grain per head.

Data was analysed using Genstat V18. The NVDI, biomass and yield data was analysed using a one-way ANOVA. The detailed partitioning of biomass was analysed using a one-way ANOVA, but were unbalanced due to the extra plants recognised during processing. No data transformations were required.

**Results**

The average NDVI readings for each treatment, measured during stem elongation, are shown in Figure 1. P application significantly increased NDVI (F = 0.016), but only at 12 kg P/ha. NDVI is known to be well correlated with biomass and crop yield in wheat (Erdle et al. 2011); however it is not a direct measurement and can be affected by a range of factors which affect plant growth, including differences in crop canopy structure, water stress and crop N status (Verhulst and Govaerts 2010).

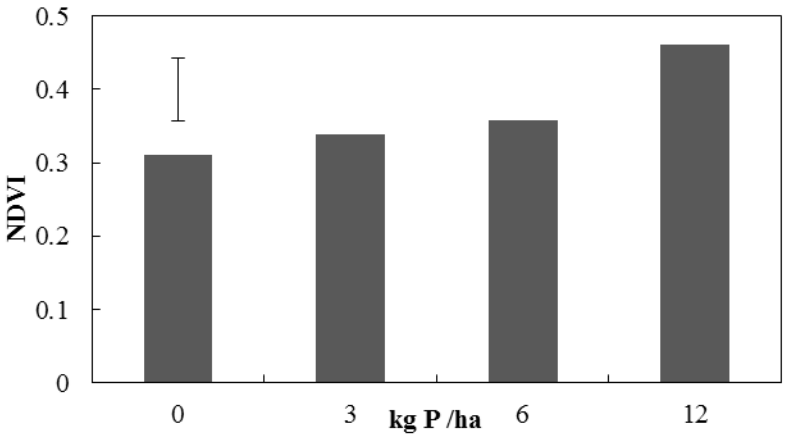


**Figure 1. NDVI results taken during stem elongation for the Control and Granulock (3, 6 and 12 kg P/ha) treatments, averaged over the trial. Vertical line represents LSD for P rate (F = 0.016).**

By grain maturity, the early effect of P application on aboveground biomass had disappeared (F= 0.463) (Table 1). Significant leaf losses where P had been applied or increased relative growth by the control treatment may explain the similar biomass production. Grain yield was not significantly affected by P fertiliser rate (F = 0.44). While van Herwaarden et al. (1998), observed no significant difference in biomass production to applied N at grain maturity, grain yield was reduced.

Increasing P fertiliser application did not affect harvest index (F = 0.252), although there was a non-significant trend for it to decrease as P rate increased. This slight decrease in harvest index could indicate the potential interaction of water. Van Herwaarden et al. (1998) noted that harvest index declined when high N rates lead to excessive water use during early growth (i.e. the crop hayed off).

**Table 1. Biomass, grain yield and harvest index data for the total quadrant (sum of the individual plants plus the remained). Numbers in brackets represent the standard deviation values.**

| P rate (kg P/ha) | Biomass (t/ha) | Grain yield (t/ha) | Harvest Index |
|---|---|---|---|
| **0** | 4.0 (0.49) | 1.7 (0.2) | 0.41 (0.04) |
| **3** | 5.0 (1.42) | 2.0 (0.57) | 0.40 (0.03) |
| **6** | 4.7 (0.49) | 1.8 (0.04) | 0.39 (0.04) |
| **12** | 4.2 (0.66) | 1.6 (0.25) | 0.39 (0.02) |
| | *F= 0.463* | *F= 0.440* | *F = 0.252* |

NDVI values were plotted against the grain yield and biomass of each sub-plot, but no significant correlation was observed ($R^2$= 0.0083 & 0.099 respectively) (data not presented).

The total number of tillers per plant and the number of fertile tillers increased with application of P fertiliser (F <0.001) (Table 2); the addition of 12kg P/ha further increased the number of fertile tillers. The number of non-fertile tillers per plant was not significantly affected by P application (F =0.552).

**Table 2. The effect of P rate on the number of tillers per plant. Data from the individual plants analysis. Values presented as treatment averages. NS = not significant.**

| P rate (kg P/ ha) | Total tillers | Fertile | Non-fertile |
|---|---|---|---|
| **0** | 3.6 *a* | 2.6 *a* | 1.0 |
| **3** | 4.2 *b* | 3.0 a*b* | 1.3 |
| **6** | 4.4 *b* | 3.2 *b* | 1.2 |
| **12** | 4.9 *c* | 3.6 *c* | 1.3 |
| | *F <0.001* | *F =0.006* | *F = 0.55* |
| | *Ave LSD =0.41* | *Ave LSD =0.49* | *NS* |

The number of spikelets per head was not affected by the addition of P fertiliser (F = 0.90); all heads produced approximately 17 spikelets (Table 3). The total number of spikelets per plant increased with P application (F = 0.01), which is related to the increased number of fertile tillers with the addition of P. Phosphorus application did not significantly affect the number of grains per head (F = 0.42). On a per plant basis, grain number increased with P addition; again reflecting more fertile heads.

Grain weight was not significantly affected by P rate (F = 0.24). Phosphorus nutrition generally has little impact on final grain size (Grant et al. 2001). Other factors such as assimilate supply, through the impact of temperature and water supply, are likely to have a much greater impact (Kobata et al. 2012). While not significant there appeared to be a decline in weight per grain and per head as P fertiliser increased. Unfortunately, the number of plants per quadrant was not recorded.

**Table 3. Yield components from the individual plants analysis. Values presented as treatment averages. NS = not significant.**

| P rate (kgP/ha) | Number of Spikelets per head | per plant | Number of Grains per head | per plant | Grain weight per grain (mg) | per head (g) | per plant (g) |
|---|---|---|---|---|---|---|---|
| **0** | 16.7 | 43 a | 25 | 63 a | 34 | 0.86 | 2.2 |
| **3** | 16.8 | 50 ab | 25 | 73 ab | 33 | 0.83 | 2.4 |
| **6** | 16.9 | 54 bc | 25 | 79 b | 32 | 0.81 | 2.6 |
| **12** | 16.8 | 61 c | 23 | 85 b | 30 | 0.70 | 2.6 |
| | *F =0.90* | *F =0.01* | *F = 0.42* | *F = 0.04* | *F = 0.24* | *F = 0.09* | *F = 0.25* |
| | *NS* | *LSD =9.2* | *NS* | *LSD = 14.0* | *NS* | *NS* | *NS* |

Table 4 shows the long term average (LTA) rainfall for the local BOM weather station (located near the trial site). In 2014 the annual rainfall was 256mm, 114 mm less than the LTA. Growing season rainfall (GSR) was only 194 mm; 78% of the LTA. In April rainfall far exceeded the LTA. For the May-July period rainfall was average, but between August and October recorded values were well below.

**Table 4. Monthly and annual rainfall (mm), including Long term average (LTA) and 2014. GSR = Growing season rainfall from April to October (inclusive).**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | *Total* | *GSR* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LTA** | 30 | 23 | 14 | 26 | 32 | 40 | 42 | 37 | 40 | 32 | 29 | 25 | 370 | 248 |
| **2014** | 16 | 4 | 14 | 51 | 33 | 45 | 36 | 10 | 15 | 5 | 16 | 12 | 256 | 194 |

Unfortunately, a lack of soil water data prevents investigation into the pattern and amount of water used by the different P treatments. The pattern of rainfall observed during 2014 suggests the early yield potential set up by the 12 kg P/ha may not have been fulfilled due to inadequate water in the late stages of growth. The trend of some yield components, suggests the wheat was unable to fulfil the extra yield potential established during early growth stages. The level of water stress however was not so significant as to lead to a reduction in harvest index or significant decline in grain weight.

## Conclusion

Despite the early crop response (as measured by NDVI), there was no yield response to P application at this site in this season. We hypothesise that if adequate water had been available throughout the season, P fertiliser may have had a positive impact on yield.


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