Mixing grapes and grain - Scoping the opportunity for selective harvesting in cereals

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Abstract
On-the-go yield and protein sensing was undertaken during harvest of barley over three seasons (2009-11) on South Australian farms in the Lower-North region and on the Eyre and Yorke Peninsulas. Yield data were integrated with high resolution (EM38 and gamma radiometric) soil survey data and remote and proximally sensed crop imagery (~gs31) to identify zones for which selective harvesting might be appropriate. However, these zones did not always align well with 'protein zones' identified in the protein maps. Furthermore, whilst the protein sensor data clearly demonstrated that grain protein is spatially structured, problems with sensor calibration and operation presented severe constraints to the robust use of protein sensing for barley. Nonetheless, production of zone-based 'micro-malts' suggests that selective harvesting is an idea worth pursuing in the grains industry. Successful implementation will require improvements to the technologies used for crop quality assessment, and a likely need for careful re-evaluation of harvest logistics and storage practices.

Key Words
Precision Agriculture, crop quality, protein, value chains, Precision Viticulture

Introduction
The application of Precision Agriculture (PA) to broadacre cereal production has focussed primarily on the variable application of inputs such as fertilizers (Cook and Bramley 1998; Robertson et al. 2012). In contrast, adopters of Precision Viticulture (PV) have been more interested in targeting management with respect to the variable collection of outputs. Thus, selective harvesting has been a major focus for PV in the wine industry. Selective harvesting is defined as the split-picking of fruit at harvest according to different yield/quality criteria and allocating it to different product streams in order to exploit the observed variation (Bramley et al. 2005). This has been shown to be highly profitable whether the selective harvest has focussed on variation within single blocks (Bramley et al. 2005) or where similar parcels have been identified in different blocks and combined so as to deliver a sufficient tonnage for separate processing to be commercially viable (Bramley et al. 2011). Given the availability of on-the-go protein sensing technology and the price premiums paid to Australian cereal growers, we were interested to explore the potential for grain growers and processors to adopt similar selective harvesting strategies and so extract greater value from the process of grain growing.

Methods
This work was focussed in paddocks planted to barley on three farms located in the Lower-North (Giles Corner; LN), Yorke Peninsula (Urania; YP) and Eyre Peninsula (Yeelanna; EP) regions of South Australia. Production at LN and EP was focussed on malting barley, while at YP, the focus was on feed barley for premium pig production. The farmers at each site are leading adopters of PA with several years of yield maps which could be brought to bear in the research. In addition, high resolution soil survey using both EM38 (Geonics, Mississauga, ON, Canada) and gamma-radiometrics (The Soil Company, Groningen, The Netherlands) was undertaken. The data so derived were used in conjunction with the pre-existing yield data to identify 'management zones' (Taylor et al. 2007) which might form the basis for selective harvesting, given our starting assumption that patterns of variation in yield and protein are similar (Norng et al. 2005).

An 'AccuHarvest on-combine grain analyzer' (Zeltex Inc. Hagerstown, Maryland, USA) was fitted to the LN and EP headers for assessment of protein on-the-go during harvest. At YP, a 'Cropscan on header analyser' (NIR Technology Systems, Condell Park, NSW) was used. Both systems use near infrared (NIR) transmission as the basis of protein sensing. Grain samples were also collected immediately prior to harvest and analysed for their protein content (AOAC 2000). In addition, mid-season (~gs31) crop performance data

was collected using remote (Specterra Services, Leederville, WA) and proximal (CropCircle™, Holland Scientific, Lincoln, NE, USA) sensing. At all sites, yield monitors supplied with the headers (LN and EP, Case IH; YP, John Deere) were used as the basis for yield mapping.

Results and Discussion

Figure 1 shows yield data collected pre-project (2006-2010) and in the study year (2011) in a 35 ha LN paddock, EM38 soil survey data collected in March 2011 and the results of clustering these data in various combinations into management zones. As can be seen, the patterns of yield variation are very stable over a six year period and closely match the pattern of soil variation. In turn, the patterns of soil variation closely match topographic variation such that higher EM38 values correspond to lower lying areas where the soils also have higher clay contents (data not shown). Accordingly, presumably due to greater soil water availability, yields tend to be higher in these areas. Discussion with the farmer supported the delineation of two zones rather than some other number (data not shown).

In the 2011 study year, yield at LN varied from 2.1-5.5 t/ha (mean = 4.2 t/ha), while grain protein varied from 7.0-13.2 % (mean of 150 samples = 9.5%). Unsurprisingly, protein variation was spatially structured. However, and ignoring the issue of sensor calibration, there was a marked difference between the patterns of variation in grain protein when these were determined using sensor data collected on-the-go, compared to when derived from samples collected by hand immediately prior to harvest (Figure 2). Whereas the protein map derived from hand sampling aligned well with our understanding of paddock variation (Figure 1), the same could not be said of the map derived from the sensor data. Thus, when the yield map was clustered with the protein map derived from hand samples, the result (bottom right map in Figure 2) was very similar to the zone maps delineated in Figure 1, with the significantly ($p<0.05$) higher and lower yielding zones also having higher and lower protein. A similar analysis using protein sensor data (not shown) did not match the patterns evident in Figure 1. Similarly disappointing sensor results were obtained at the EP site where the same type of sensor (Accuharvest) was used. In contrast, there was a much better alignment in the patterns of protein variation between sensor-derived and hand sampled data at the YP site (Cropscan sensor), even though grain samples at this site were collected approximately three weeks prior to harvest, immediately prior to the crop being wind-rowed (Figure 3).

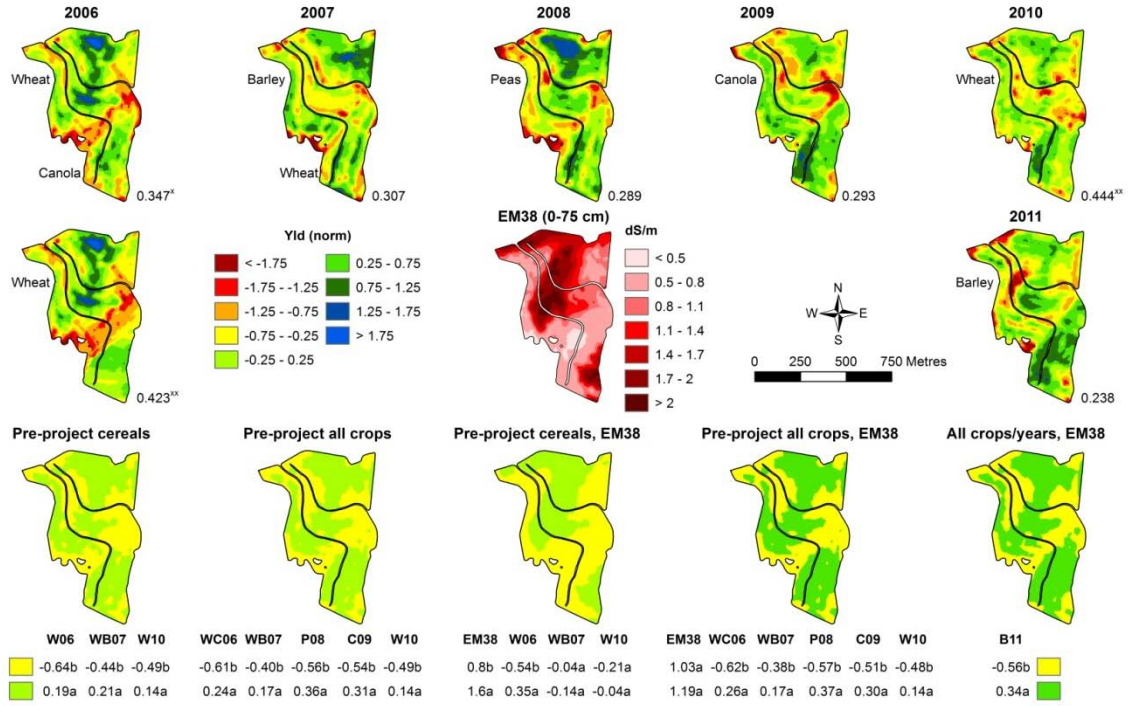

Figure 1. Identification of zones (seasons 2006-2011) in a 35 ha LN paddock growing barley (B), canola (C), peas (P) or wheat (W). Normalised yield data (μ=0, σ=1) were used for this analysis. The number shown at the bottom right of each map is the 95% confidence interval for that map and is used to assess the between zone differences in the zone maps. Higher values in 2006 and 2010 reflect missing data in approximately 10 (^{x}) or 20 % (^{xx}) of the paddock. Zone means followed by different letters are significantly different ($p<0.05$). The legend to the map at bottom right shows 2011 data only; the zone means corresponding to other data layers are very similar to those reported for the map immediately to the left. Zone colours are approximately matched to the yield map legend.

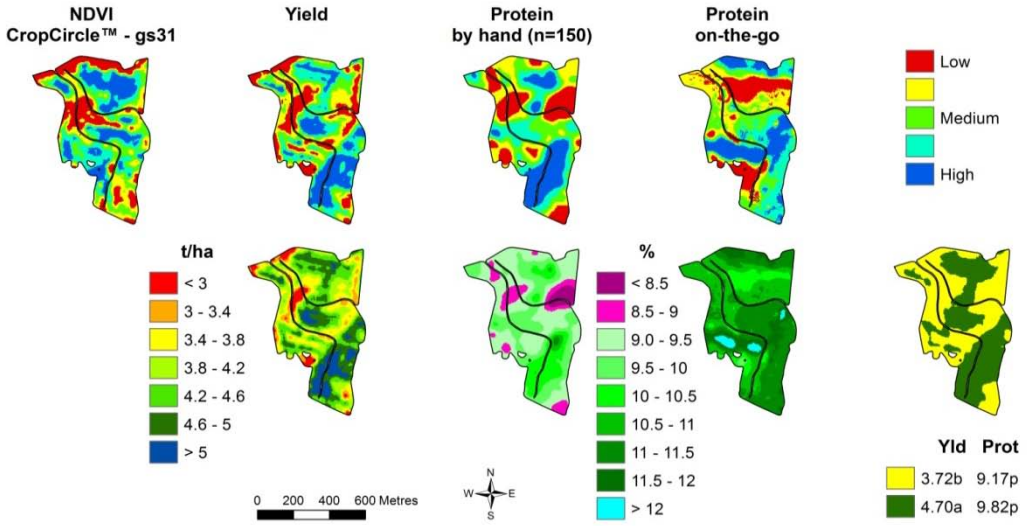

Figure 2. Crop performance at the LN site in 2011 as measured by NDVI (proximal sensing at gs31), yield monitoring and grain protein measured using either laboratory analysis of samples collected by hand or on-the-go sensing using an 'Accuharvest' sensor. In the top row of maps, data have been classified on the basis of 20th percentiles. The bottom row of maps depicts the same data with a more conventional classification. The map at bottom right shows the results of clustering the yield and protein data (hand sampling) – 2 zone solution.

The relatively low protein at this LN site suggests that additional nitrogen may have resulted in a yield response (Kelly et al. 2004), as did an 'N-rich strip' (Raun et al. 2002) which is clearly evident in the yield map close to the northern edge of the paddock (Figure 2). It could also be argued that Figure 2 provides little support for selective harvesting in this paddock in this particular cropping season given that both zones had mean protein levels within the range of the malt segregation (9-12%). However, as Figure 2 shows, even though the paddock made malt grade on average, significant areas had protein below the accepted minimum for malting. Under present practice, this grain would be hidden as a result of it being 'shandied' with that from elsewhere in the paddock, farm or, at the silo, district. However, maltsters are like winemakers in regarding the uniformity of a parcel of grain (or grapes) as a key element of its quality, in addition to attributes such as its protein (or anthocyanin) content. One consequence of a change to selectively harvesting grains may therefore be a narrowing of the segregations to meet demands for greater uniformity, for which greater price premiums may be achieved than are currently on offer at present. It is therefore of interest that at EP in 2010, even though the entire paddock again made malt grade, 'micro-malts' made from samples collected from different yield zones exhibited trends in malt quality attributes that were consistent with trends in yield and protein variation. In further work, the possible economics of this issue must be examined.

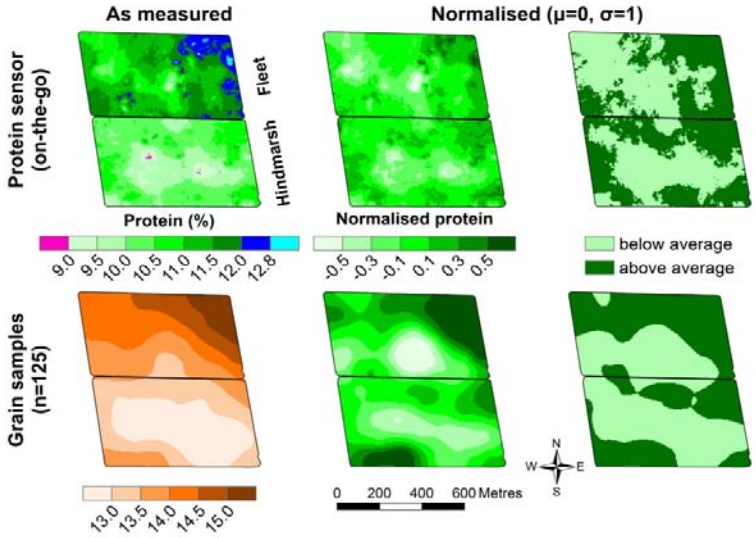

Figure 3. Protein variation (2011) in two YP paddocks of feed barley (60.6 ha in total), assessed using on-the-go sensing during harvest (Cropscan sensor) or laboratory analysis of samples collected immediately prior to wind-rowing, three weeks earlier. As the paddocks were sown to different varieties, the data underpinning the maps in the centre and right columns were normalised on a per paddock basis to remove variety-specific effects.

A key learning during this work has been that protein sensing is substantially less robust than yield monitoring. Instrument calibration is an area needing particular attention. Even after factory reconditioning following the 2010 harvest, it still took over a week of careful work in the laboratory before we were confident that the Accuharvest sensors were sufficiently well calibrated to be used in the field. Figures 2 and 3 raise concerns as to the temporal stability of the calibrations, and there were times during the 2011 season when a lack of faith in the numbers being logged led to the sensors being switched off by harvester drivers. A further problem concerns the density of the data set collected and its impact on 95% map confidence intervals (CI). Assuming that the sensor takes a 'good' reading on its first attempt, the process of filling the sensor chamber, taking the reading and then emptying the chamber takes around 6-7 seconds. Thus, when operating optimally, data are logged at approximately 7 second intervals, although logging intervals are often considerably longer. In contrast, a yield monitor which typically logs yield every 1 or 2 seconds. Given what the protein sensor has to do, one could argue that its performance is impressive. However, this low data density contributes to high CI values; in the protein maps shown in Figures 2 and 3, CI was greater than 1% protein. Such high CIs are the reason why zone mean protein contents in this work have generally not been significantly different. Since the malt segregation is only 3% protein wide (9-12%), it is clearly problematic for a protein map CI to approach half the tolerable range. Clearly, without marked improvements to sensing technology, it will not be possible to stream grain to narrower segregations.

Conclusion

Given the availability of on-the-go protein sensing and the desire of processors for grain lots with minimal variation, selective harvesting makes good philosophical sense for both growers and processors. However, successful implementation will depend on an ability to robustly define zones with respect to both yield and protein (or other quality attributes), changes to harvest and storage logistics, improvements to on-the-go protein sensing technology, especially in terms of calibration and sampling frequency and sufficient price premiums to make selective harvesting profitable.

Acknowledgments

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