Managing spatial variability of grain yield at the paddock level in southeastern Australia

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Abstract

Spatial variations across a paddock often indicate differences in soil water availability and/or use by the crop. Farmers may be able to manage this spatial variation by manipulating green canopy area, such as by altering nitrogen supply or plant density using variable rate technology, to match the plant available water within specific management zones.

To test the feasibility of this approach, a paddock located in the southern Mallee of Victoria was subdivided into zones based on six management criteria derived from historical yield maps and satellite images. A factorial combination of four rates of nitrogen fertiliser and two sowing densities were applied to the different management zones to produce a range of wheat crop canopies during 2004. In the following year, when barley was grown, four rates of nitrogen were applied. Grain yield in both years differed significantly ($p<0.05$) between these management zones. There were no significant responses to nitrogen fertiliser application by either crop, possibly indicating the high initial nitrogen status of the paddock and the below-average rainfall received during 2004 and 2005. It is concluded that sowing rate and/or stem manipulation may be feasible as an option to manipulate green canopy area to optimise crop growth within specific management zones.

Key Words

Precision agriculture, zoning, wheat, barley

Introduction

The development of geospatial and remote sensing technology has enabled the measurement and/or estimation of variation in grain production within paddocks. Recent advances in remote and proximal sensing of soil properties has also given a new perspective and an increased emphasis to yield variability (Whelan et al. 2002). The challenge facing researchers and growers alike is how knowledge of this variation can be used in a practical way to improve the profitability of cropping.

In rainfed cropping regions the spatial variation in grain yield often indicates differences in soil water availability and/or use by the crop. This variation can be the result of changes in soil texture causing differences in plant available water capacity (PAWC) or physical/chemical constraints that prevent root growth or root water uptake. A potential strategy available to farmers to account for this spatial variation is the manipulation of green canopy area (or canopy structure), by altering nitrogen supply or plant density using variable rate technology, to optimise crop growth to match the quantity of available soil water within specific 'management zones'.

In high rainfall zones around the world, canopy structures in wheat crops have been successfully manipulated by changing sowing densities and more importantly by applying nitrogen at critical stages of plant development. Current research on canopy management in Australia, especially in dryland grain production systems with low to moderate yield potentials, focuses mainly on treating the crop within a paddock uniformly for an individual season, rather than utilising differences in sub-paddock management zones. There is therefore limited data on the potential for managing crop structure through the interaction between sowing rate and nitrogen rate under various sub-paddock production zones.

The objectives of this study were to: (i) quantify yield variation and determine whether zoning methods developed by Abuzar et al. (2004) can be used to sub-divide a paddock; and (ii) quantify influences of nitrogen fertiliser and sowing density on grain yield and yield components of cereals in north Central Victoria. The hypothesis tested in 2004 and 2005 was whether the application of different nitrogen and sowing rates could influence the green area index and thus crop water use in order to maximise yield in different yield zones within a paddock.

Methods

The study site was a 160 ha paddock located near Birchip (35? 47′ S and 142? 58′ E) in the Victorian Mallee. Long-term annual rainfall was 358 mm whilst growing season rainfall was 207mm.. The paddock has had a crop rotation over recent years of: 1995 – medic pasture, 1996 – barley, 1997 – lentil, 1998 – wheat, 1999 – oats / medic pasture, 2000 – wheat, 2001 – oats / medic pasture, 2002 – wheat, and 2003 – fallow. The major soil types of the study area is calcareous clays and calcareous earth …Texture of surface soil varied from loamy sand to sandy clay loam and subsoil varied from sandy loam to sandy clay.

Estimates of standing biomass at flowering (mid August) were derived from satellite imagery Normalized Difference Vegetation Index (NDVI) maps (four years of NDVI data, 1997, 1998, 2000 and 2002) These were combined with crop yield maps (2 years, 1996 and 1998) obtained from the grower's header data to define spatial criteria for different yield potential and inter-year variability (Abuzar et al., 2004) (Figure 1):

1. Low stable (LS) – areas where yield and or/ biomass production was consistently low;

2. Low variable (LV) – areas where yield and or/ biomass production was on average low, but with greater variability between seasons during the majority of years with occasional low yield years;

3. Medium stable (MS) – areas where yield and or/ biomass production was consistently medium;

4. Medium variable (MV) – areas where yield and or/biomass production was on average medium but with greater variability between seasons during the majority of the years with occasional low yield years;

5. High stable (HS) – areas where yield and or / biomass production was consistently high; and

6. High variable (HV) – areas where yield and or/ biomass production was high during the majority of years with occasional low yield years.

To evaluate the extreme responses, treatments were only applied to zones in the high or low criteria.

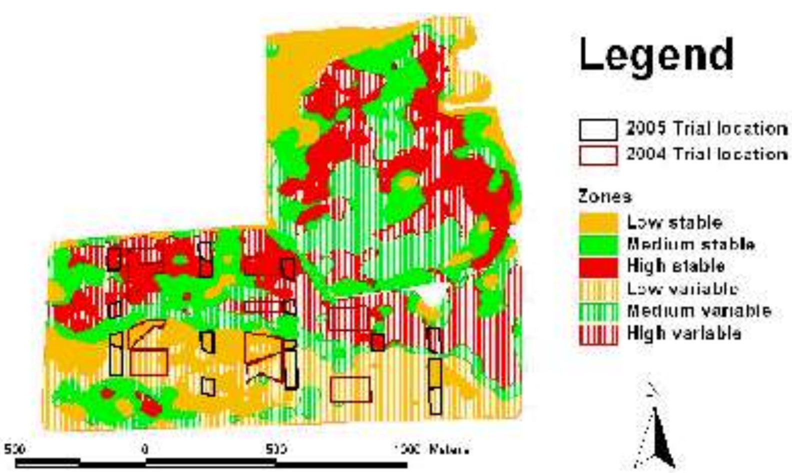

Figure 1: Paddock zones showing biomass variability and layout for the sowing rate and nitrogen treatments during 2004 and 2005 (from Abuzar et al. 2004).

During 2004, a factorial combination of 2 sowing rates and 4 nitrogen fertiliser treatments were replicated 3 times on a wheat crop (Yitpi). During 2005, just four nitrogen treatments were applied on a barley crop (Vicsloop) (see Fig 1). The sowing densities were: (a) low sowing rate @ 30 seed kg/ha; and (b) normal sowing @ 80 kg seed /ha. The nitrogen treatments were applied by topdressing different amounts according to a range of seasonal forecasts: (i) zero N; (ii) amount to match a poor rainfall in remainder of season (low risk - 30% chance of not receiving at least this amount of rainfall); (iii) amount to match an average rainfall in remainder of season (medium risk - 50% chance of not receiving at least this amount of rainfall); and (iv) amount to match a good rainfall in remainder of season (high risk - 80% chance of not receiving at least this amount of rainfall). These equated in 2004 to nitrogen applications (applied as urea) of 0, 14, 26 and 50 kg N/ha respectively (applied on 13 August 2004) and in 2005 to rates of 0, 25, 33 and 50 kg N/ha applied as foliar UAN on the 13th September (mid-tillering).

Statistical analysis of data was performed using GENSTAT (Payne et al., 1989). In 2004 a split-split-strip-plot design was used with half-blocks corresponding to sowing rate, columns within half-blocks corresponding to nitrogen level and strips within half-blocks corresponding to yield zones. In 2005, a strip-plot design was used with columns within blocks corresponding to nitrogen level and strips within blocks corresponding to yield zones. Analysis of variance was performed using both ANOVA and linear mixed models (REML) incorporating variance structure for zones.

Results

Total rainfall during 2004 and 2005 were 265 and 327 mm respectively, or 25% and 8% lower than long-term averages, respectively. The distributions of rainfall during both growing seasons were highly variable. During the 2004 growing season the paddock received 164 mm rain between sowing and anthesis while only 61 mm between anthesis and grain maturity. In 2005 the barley crop received 134 mm rain between sowing and anthesis while only 27 mm between anthesis and grain maturity.

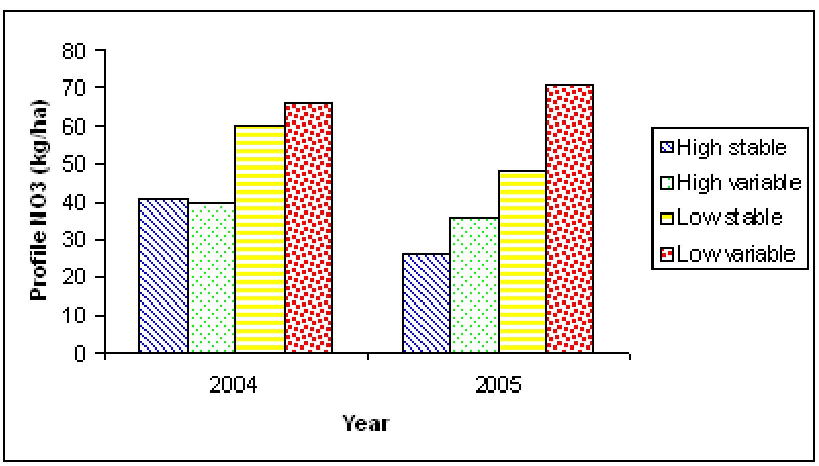

Figure 2. Profile mineral N at sowing during two growing seasons at Birchip

Soil nitrogen content at sowing was significantly different between zones (Figure 2). The LV zones had the highest mineral N while HV zone had the lowest.

Grain yield and above ground dry matter of wheat varied significantly ($p<0.05$) between zones (Table 1). The ‘High Stable’ zone produced the highest dry matter at anthesis as well as grain yield, while the ‘Low Variable’ zone recorded the lowest grain yield. This yield difference was not attributable to any differences in plant numbers between the zones but was mainly due to the number of grains per ear and the 1000-

grain weight. The 'Low Stable' zone had the lowest anthesis dry matter. Grain yield results were significantly different between the HS and HV zones compared to the LS and LV zones for both the yield and dry matter. However, no significant differences in grain yield and yield components were found between variable and stable zones for both the low and high yielding zones. Grain protein differ significantly between zones (Table 1).

Sowing rate significantly ($p<0.05$) influenced grain yield and most of the yield components of wheat during 2004 (Table 2). Low sowing rate produced greater amounts of dry matter at anthesis and final grain yield compared to normal sowing rate. However, the increase was only 22% compared to approximately 300% between High and Low zones. Harvest index was also significantly ($p<0.05$) higher in the low sowing rate than the normal sowing rate. There was no significant difference in total nitrogen uptake between sowing rates (Table 2).

Results from both the ANOVA and REML analyses show that influence of nitrogen on wheat grain yield or yield components was not significant in all zones. The interaction terms, sowing rate X zone, sowing rate X nitrogen, nitrogen X zone and sowing rate X nitrogen were also not significant ($P>0.05$).

Grain yield and dry matter of barley were significantly different between zones (Table 3). The HV zone produced the greatest anthesis dry matter as well as the highest grain yield, while the LV zone had the lowest grain yield and the LS zone had the lowest dry matter. Total dry matter at harvest and grain yield were significantly greater in the HS and HV zones compared to the LS and LV zones. The HS and HV zones had highest 1000-grain weight, number of grains per ear and number grains unit area.

Grain protein did not differ significantly between zones (Table 3). Grain protein levels exceeded the level required for malting classification (9 – 12%) regardless of zone. Nitrogen fertiliser application did not significantly affect dry matter, grain yield or quality regardless of zone.

Table 1. Dry matter, yield components and quality data of wheat during 2004 at Birchip.

Yield components	Paddock zones				Chi prob.
	High stable	High variable	Low stable	Low variable	
Plants per m^2	60.0	57.2	63.9	61.4	0.443
Total dry matter at anthesis (t/ha)	2.41	2.39	2.02	1.81	<0.001
Grain yield (t/ha)	0.686	0.675	0.239	0.157	<0.001
Total dry matter at harvest (t/ha)	2.765	2.704	2.170	1.974	<0.001
Harvest index	0.25	0.24	0.11	0.08	<0.001
Ears per m^2	174	174	154	141	<0.001
Grains per ear	15.02	15.51	8.50	7.75	<0.001

Grains per m^2	2,602	2,655	1,338	1.080	<0.001
1000-grain weight (g)	25.47	25.42	16.79	13.64	<0.001
Screening (%)	10.5	9.1	43.1	61.9	<0.001
Grain >2.0 mm in diameter (t/ha)	0.644	0.614	0.155	0.073	<0.001
Grain protein (%)	14.7	15.2	15.4	16.3	<0.001
Total N uptake (%)	3.6	3.8	4.4	4.6	<0.001

Table 2. Dry matter, yield components and quality data of wheat for two sowing rate treatments during 2004 at Birchip.

Yield components	Sowing treatments		Chi prob.
	Normal sowing rate	Low sowing rate	
Plants per m^2	75.4	45.81	<0.001
Dry matter at anthesis (t/ha)	2.06	2.25	0.004
Grain yield (t/ha)	0.392	0.482	0.047
Dry matter at harvest (t/ha)	2.41	2.36	0.482
Harvest index	0.15	0.20	0.025
Ears per m^2	175	144	<0.001
Grains per ear	9.72	14.11	<0.001
Grains per m^2	1,770	2,074	0.047
1000-grain weight (g)	19.48	21.47	<0.001
Screening (%)	33.9	27.3	0.009

Grain >2.0 mm in diameter (t/ha)	0.340	0.403	0.073
Grain protein (%)	15.2	15.6	0.085
Total N uptake (%)	4.04	4.17	0.080

Table 3. Dry matter, yield components and quality of barley for the four paddock zones during 2005 at Birchip.

Yield components	Paddock zones				Chi prob.
	High stable	High variable	Low stable	Low variable	
Plants per m^2	135.7	141.0	144.8	122.9	0.03
Total dry matter at anthesis (t/ha)	5.09	4.96	3.68	3.90	<0.001
Grain yield (t/ha)	1.543	1.555	1.108	1.138	<0.001
Total dry matter at harvest (t/ha)	2.780	2.805	2.147	2.331	0.006
Harvest index	0.55	0.56	0.51	0.48	<0.001
Ears per m^2	220	227	208	224	0.377
Grains per ear	15.95	15.83	13.88	13.75	0.015
Grains per m^2	3,514	3,540	2,903	3,125	0.067
1000-grain weight (g)	43.95	43.93	37.94	35.74	<0.001
Screening (<2.5 mm) (%)	12.4	14.1	42.8	52.6	<0.001
Grain >2.5 mm in diameter (t/ha)	1.355	1.347	0.662	0.580	<0.001
Grain protein (%)	12.6	12.6	15.7	15.9	<0.001
Total N uptake (%)	2.61	2.61	3.63	3.75	<0.001

Discussion

For some yield zones, grain yield was significantly higher in areas with low plant density compared to areas with high plant density with a 23% yield increase for the low sowing rate across all zones. However, there were no significant differences in harvest biomass production between low and normal sowing rate treatments. This indicates that although the low sowing rate treatment started with a lower number of plants per unit area, tillering compensated and the number of heads per unit area was not affected during the 2004 trial. The growing season rainfall during 2004 was significantly lower than the long-term average growing season rainfall with very low rainfall in October 2004. Despite the fact that the number of stems per unit area was only reduced by 18%, the harvest index was improved by 33% and this resulted in a 23% yield increase. The question arises, what might have happened to the soil water use at grain filling if the low sowing treatment had maintained a very different number of stems per unit area? The conclusion by McDonald (1990) that detillering in malting barley is a useful attribute under restricted water conditions is still valid. A trial conducted at Birchip, Victoria during 2005 showed that reducing the amount of tillering increased grain yield per plant (data not shown) but not per unit area. This has implications for breeding for reduced tiller plants. Clearly, further research is needed to understand how green area index can be better matched to spatial variability in plant available water.

Conclusions

Grain yield and yield components of both wheat and barley varied considerably between paddock zones, confirming the ability of the zoning technique developed by Abuzar et al (2004) to separate yield in different areas of yield potential. Farmers may need to account for this variability in order to maximise crop production

However the lack of any significant response to nitrogen fertiliser application by either the wheat crop in 2004 or the barley crop in 2005 highlights the overriding effect of residual soil N in this paddock (derived from medic pasture in 2003) and poor seasonal rainfall conditions that limited yield potential. This suggests that nitrogen may not always be a good option in this environment for manipulating green canopy area to optimise crop growth within specific management zones.

It is concluded that sowing rate and/or stem manipulation may be feasible as an option to manipulate green canopy area to optimise crop growth within specific management zones.

Acknowledgements

The authors are grateful Colin Aumann, Tony Fay, Ashley Waite (DPI Victoria) and Bobby Liston (from BCG) for providing technical and logistic support; GRDC and DPI for funding and Ian and Warrick McClelland for allowing access to their paddock and providing assistance; and Michael Wash for reviewing the manuscript.

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