

Infield Spatial Variability of Surface Irrigated Cotton Yields

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1. Introduction

Anecdotal evidence suggests that there is significant infield yield variability within Australian cotton fields. In particular, the design and management of surface irrigation systems appears to have a substantial impact on crop moisture stress. Surface irrigation assessments conducted within the cotton industry have shown that traditional management practices favour allowing the irrigation to run for significantly longer than the furrow advance time to ensure that the bottom end of the field is well watered. However, this may result in waterlogging of the crop at the top end of the field, particularly on long furrows, due to the excessive period of crop inundation at the head ditch end of the field. The recent move towards increasing furrow flow rates and decreasing the period of irrigation application has reduced the potential for water logging but if not well targeted, this practice may result in under-watering at the tail end of the field. Hence, there is the potential for yields to significantly differ between each end of surface irrigated fields with both the size and the nature (ie. either increased or decreased from one end to the other) of the variation a function of the system design and management practice.

Irrigation performance evaluations and optimisations are commonly conducted on a field by field basis for individual irrigation events throughout the season. The recent availability of satellite imagery has also raised interest in evaluating spatial variability in crop stress within cotton fields. However, the cost of satellite imagery acquisition has resulted in this method being used mainly by researchers or for catchment scale analyses and satellite imagery is rarely used at an individual field or farmer level to evaluate irrigation performance.

Many growers and harvest contractors now have yield monitors installed on cotton pickers and are therefore able to generate yield maps on a routine basis. However, the value of yield maps has been questioned as it is often difficult to identify appropriate responses to the observed variations. The advent of variable rate fertiliser technology has provided one notable application of yield monitor data. However, as water is a major source of crop stress, it seems reasonable to expect that the infield variations in crop yield should also be a function of the irrigation design and management practices. Hence, the objective of this work was to investigate the relationships between crop yield and surface irrigation field layout as an indicator of the impact of irrigation management practices.

2. Methodology

This study was conducted in two stages. A preliminary evaluation was conducted using yield monitor data collected during the 2004/05 and 2005/06 growing seasons from 50 fields randomly selected from the Darling Downs region. The second stage involved extending the study across another four cotton growing regions in Queensland by conducting a similar analysis for 25 randomly selected fields from each of the (a) Emerald, (b) Goondiwindi and southern Downs, (c) Mungindi and (d) St George areas over the same seasons. All data used in the study had been collected from commercial yield monitors and collated by DJAS Crop Data Pty Ltd. Data was used on the basis of anonymity for growers. Hence, DJAS Crop Data Pty Ltd removed all identifying details from the data and provided the individual maps only in final analysed form with each map and data set identified only by a unique number (Appendix 1).

The yield maps of the fields (Appendix 2) were plotted using a 20 m x 20 m grid. The average yield for each field was calculated along with the average yield in two zones (i.e. across the head ditch end and across the tail drain end) within the fields. For the Darling Downs fields, the infield zones extended across the entire field width and were 100 metres in length along the rows. A 10 metre buffer strip was omitted at the head ditch end to overcome yield monitor edge effects and a 50 metre buffer was excluded from the tail drain end to account for any water backing up into the field. For the fields from the other regions, the infield zones extended across the whole field width but the length was variable between sites and calculated as 1/5 of the row length. The same buffer strips (i.e. 10 metre head ditch end and 50 metre tail drain end) were imposed as in the Darling Downs fields. This difference in the size of the zone selection was chosen to account for differences in field length and would be expected to produce a more representative measure of the differences between field zones.

3. Results

Significant differences in cotton yields (e.g. Figure 1) were observed between the head ditch and tail drain end of most fields across all regions (Appendix 1). However, the nature of the difference between each end of the field varied greatly between individual sites (Table 1) with a maximum difference of 3.7 bales/ha (i.e. yield at tail drain end higher than head ditch end) to a minimum of -1.8 bales/ha (i.e. yield at tail drain end lower than head ditch end).

There was no significant difference in the trends observed between the regions but the average difference ranged from 0.4 bales/ha for the Emerald region to approximately -0.2 bales/ha in the Goondiwindi and Mungindi regions (Table 1).

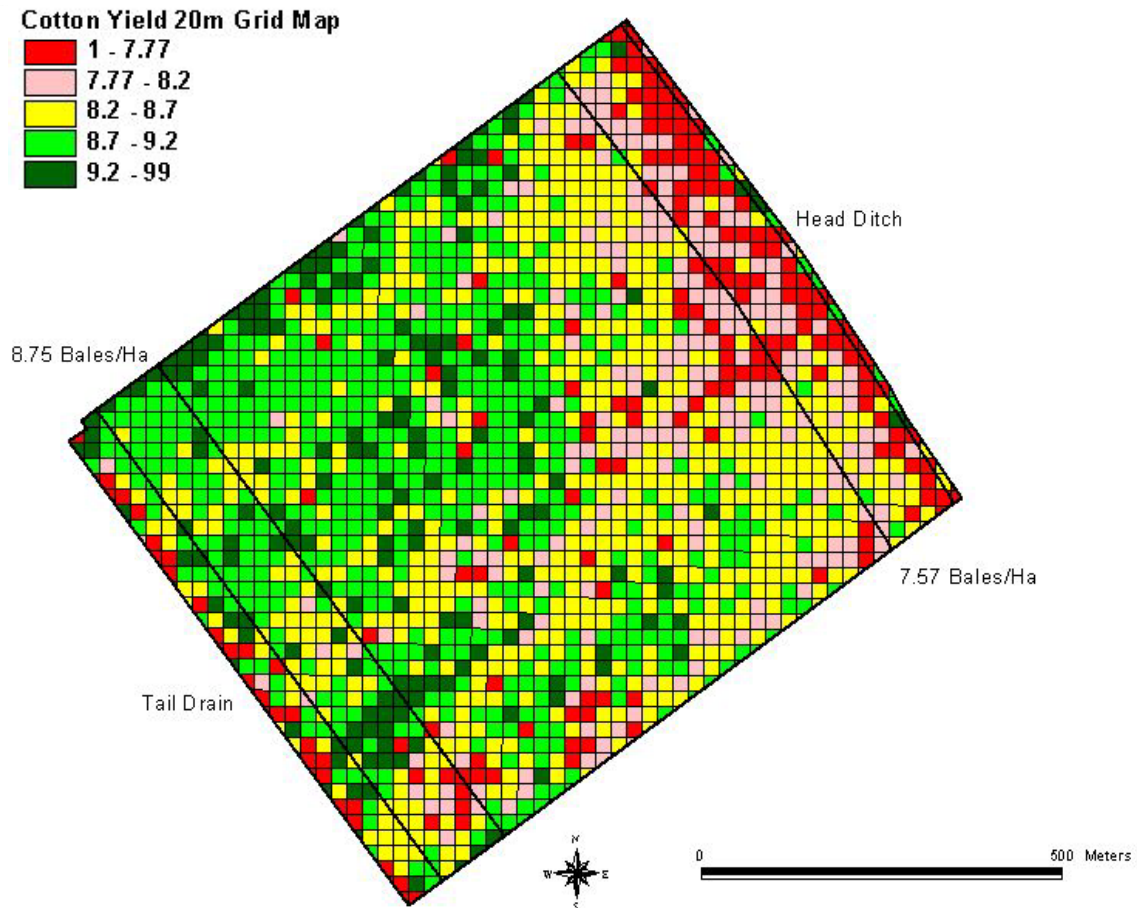


Figure 1. Example of a cotton yield map showing yield differences between the head and tail drain ends of a surface irrigated field

Table 1. Difference in cotton yield between the head ditch and tail drain ends of surface irrigated fields

Region	n	Mean Difference (bales/ha)	Std. Deviation	Minimum Difference	Maximum Difference
Darling_Downs	50	0.225	0.773	-1.84	1.84
Emerald	25	0.410	0.794	-0.68	1.60
Goondiwindi	25	-0.184	1.042	-1.54	3.72
St_George	25	0.383	0.843	-0.99	2.86
Mungindi	25	-0.209	1.065	-1.81	2.19

** positive values indicate that yield at tail drain end is higher than at head ditch end*

The frequency histogram of yield differences between the head ditch and tail drain ends of the fields are shown for both Darling Downs (Figure 2) and the other regions (Figure 3). The distribution appears to be log-normal positively skewed for the Darling Downs (Figure 2) but is not significantly different to a normal distribution for the other regions (Figure 3). This is consistent with observations for many physically measured irrigation related soil variables (e.g. sorptivity and hydraulic conductivity) which appear to be normally distributed at small scales (or with small sample numbers) but which tend to a positive skew with increasing scale and sample size (Sharma et al. 1983).

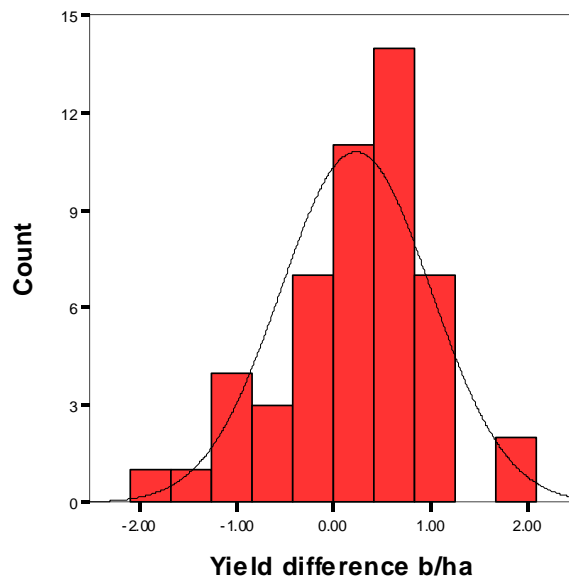


Figure 2. Frequency distribution of cotton yield differences between the head ditch and tail drain ends of fields within the Darling Downs region.

Sixty percent or more of the fields in the Darling Downs, Emerald and St George regions had a higher yield at the tail drain end of the field compared to the head ditch end (Table 2). In each of these regions, more than half of the fields had a yield difference of more than 0.25 bales/ha between these areas of the field while in Emerald, 28% of fields had a difference of more than 1 bale/ha. Goondiwindi and Mungindi had 28% and 40%, respectively, of fields with a higher yield at the tail drain end compared to the head ditch end. All regions except Goondiwindi had approximately $\frac{1}{3}$ of fields producing 0.5 bales/ha more at the tail drain end compared to the head ditch end.

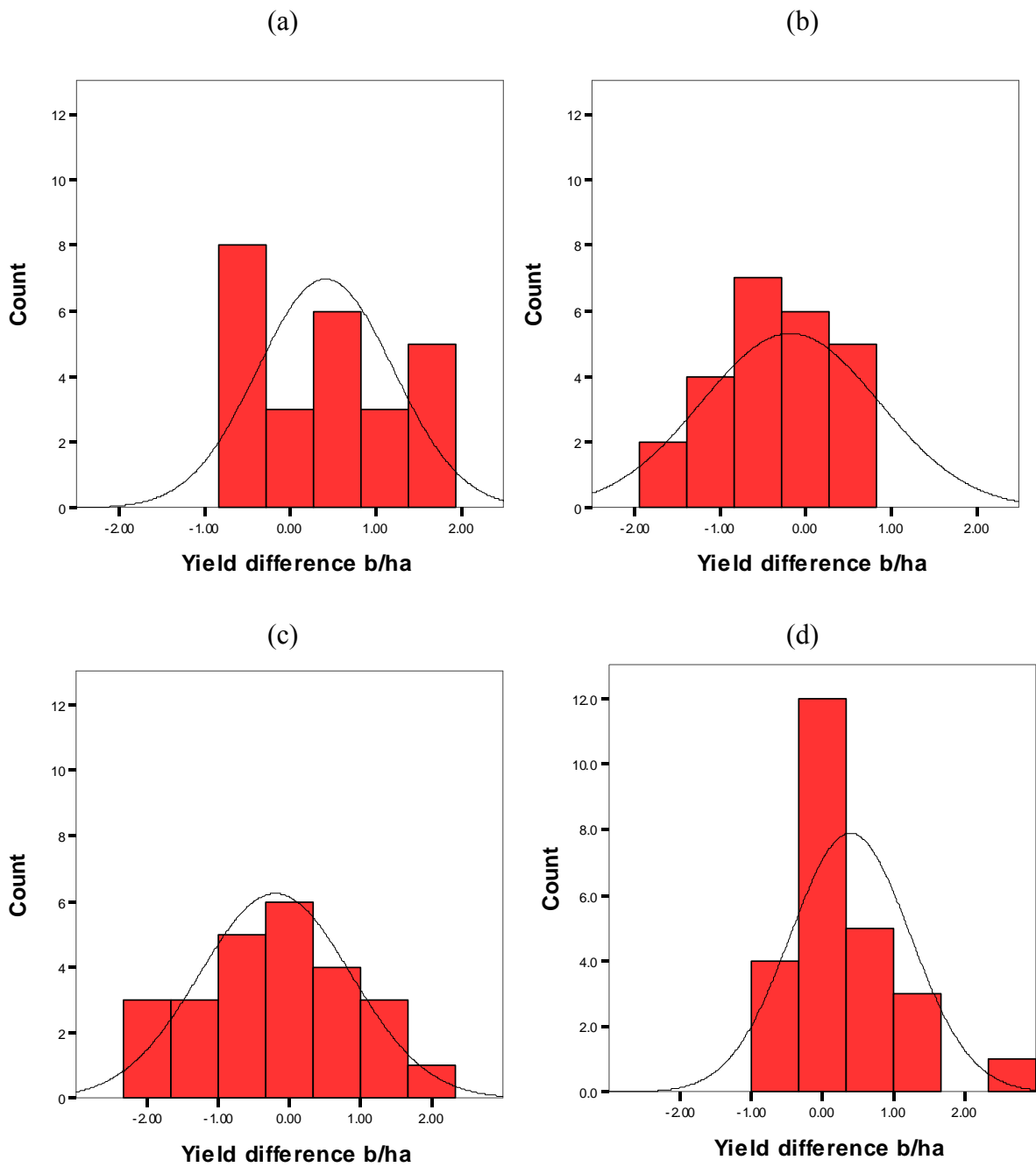


Figure 3. Frequency distributions of the yield differences between the head ditch and tail drain end of the field for the (a) Emerald, (b) Goondiwindi, (c) Mungindi and (d) St George cotton growing regions.

Table 2. Summary of infield cotton yield analysis for each catchment

Region	Darling Downs	Emerald	Goondiwindi	St George	Mungindi
Total number of fields assessed	50	25	25	25	25
No. of fields where tail drain yield > head ditch	34	15	7	17	10
Proportion of fields where tail drain yield is greater than head ditch	68 %	60 %	28 %	60 %	40 %
<i>Proportion of fields showing a tail drain > head ditch yield difference</i>					
> 0.25 bale/ha	60 %	56 %	24 %	56 %	32 %
> 0.5 bale/ha	38 %	40 %	20 %	32 %	32 %
> 1 bale/ha	12 %	28 %	4 %	16 %	16 %

4. Discussion

This work assessed the yield variability between the head ditch and tail drain ends of 150 fields from across the Queensland cotton industry. Large spatial variations in yield were found between individual fields presumably due to the differences in design and irrigation management between locations and managers. However, across four regions (i.e. all except Goondiwindi) approximately $\frac{1}{3}$ of the fields produced 0.5 bales/ha more at the tail drain end compared to the head ditch end. The majority of fields ($\geq 60\%$) in three regions (Darling Downs, Emerald, St George) showed higher yields at the tail drain end compared to the head ditch end of the field. The main mechanisms likely to be responsible for these differences are either waterlogging of the crop the upstream end of the field due to excessive inundation times or lower soil fertility at the head ditch end of the field. The most likely reasons for excessive periods of inundation are either inappropriately long furrows or a preference for running significant volumes of tailwater. However, possible reasons for lower soil fertility at the head ditch end of the field may be either exposure of sub-soils (with lower fertility or higher salinity levels) during land grading or the loss of mobile nutrients (e.g. nitrogen, sulphur) out of the root zone due to higher deep drainage losses in this area.

A substantial number for fields had higher yields at the head ditch end of the field compared to the tail drain. This effect was more prevalent in the Goondiwindi and Mungindi regions

and is most likely associated with water shortages and/or a greater management culture in these regions of pulling furrow siphons earlier resulting in a slight under-irrigation of the tail end of the field.

The individual level of yield variability would also be expected to be influenced by the seasonal weather conditions. Data used in this analysis was acquired from the 2004/05 and 2005/06 seasons which had less than average rainfall during the crop growing period across most regions. If more rain had fallen the trends in yield variation due to irrigation performance would be expected to be smaller. In low rainfall years and under limited water conditions growers often adopt irrigation practices which conserve water such as increasing inflow and reducing over-irrigation at the head ditch end of the field. However, this may have the effect of under irrigating the tail end of the field as observed in the Goondiwindi and Mungindi regions. However, this effect could be due to differences in the soil characteristics, run lengths and/or inflow rates within each the field and region.

Without further information on the specific soils and irrigation performance it is impossible to identify relationships between the irrigation design and management practices and the trends in yield variation along the field length. However, it seems likely that the most significant factor influencing yield non-uniformity along the furrow length is water infiltration opportunity time which is a function furrow inflow rate, field length and irrigation application time.

5. Conclusions

Significant variations in cotton yield have been found between the head ditch end and tail drain end of surface irrigated fields across five major cotton growing regions of Queensland. It seems reasonable to assume that a substantial proportion of these differences are related to irrigation design and/or management practices. In approximately $\frac{1}{3}$ of the fields evaluated, there was a 0.5 bales/ha higher yield at the tail drain end compared to the head ditch end. This difference is most likely a result of irrigation induced waterlogging of the crop at the head ditch end of the field due to either excessively long furrows (for the flow rates used) or running tail water for too long. However, a substantial number of individual fields (particularly in the Goondiwindi and Mungindi regions) produced a higher yield at the head ditch end compared to the tail drain end. This is most likely associated with growers

attempting to maximise water use efficiency by pulling siphons early and under-irrigating the tail end of the field.

6. References

Sharma, M. L., Barron, R. J. W., and De Boer, E. S. (1983). "Spatial structure and variability of infiltration parameters." *Advances in Infiltration, Proceedings of the National Conference.*, Chicago, IL, USA, 113-121. BN-0-916150-58-5.

Appendix 1: Tabulated Yield Data for Individual Fields in Each Catchment

Summary of analysis

Region	No. Fields TD>HD	Av Yield TD Section	Av Yield HD Section	Av Yield Whole Field	Highest Margin
Emerald	15	5.72 - 10.38	5.43 - 9.67	6.14 - 10.15	E7 & 14 - 1.58
Goondiwindi	7	4.5 - 11.34	5.39 - 10.69	5.33 - 11.2	G5 - 3.72
Mungindi	10	5.7 - 11.91	4.54 - 12.7	5.24 - 11.92	M1 - 2.19
St George	17	6.03 - 11.66	4.52 - 11.36	5.91 - 11.49	SG5 - 2.86

REGION	FIELD CODE	AV YIELD	HD AV YIELD	TD AV YIELD	YLD DIFFERENCE
		Bales/Ha	Bales/Ha	Bales/Ha	BALES/HA
Darling Downs	23		3.31	5.15	1.84
	26		6.73	8.56	1.83
	37		7.72	8.94	1.22
	35		7.57	8.75	1.18
	29		7.67	8.72	1.05
	49		10.73	11.74	1.01
	33		8.48	9.44	0.96
	20		8.3	9.16	0.86
	1		10.89	11.73	0.84
	22		10.52	11.33	0.81
	38		8.02	8.83	0.81
	47		10.29	11.01	0.72
	50		9.6	10.29	0.69
	3		8.05	8.72	0.67
	12		6.09	6.76	0.67
	34		7.72	8.32	0.6
	43		9.71	10.3	0.59
	10		6.5	7.09	0.59
	17		7.37	7.94	0.57
	2		7.82	8.31	0.49
	18		6.84	7.31	0.47
	30		9.02	9.45	0.43
	48		10.27	10.69	0.42
	42		10.24	10.63	0.39
	11		6.06	6.44	0.38
	40		10.64	11.01	0.37
	39		9.9	10.27	0.37
	9		7.59	7.88	0.29
	45		8.58	8.87	0.29
	32		10.88	11.13	0.25
	15		6.22	6.44	0.22
	21		6.52	6.67	0.15
	19		7.36	7.39	0.03
	24		6.25	6.26	0.01
	44		9.92	9.9	-0.02
	36		7.52	7.45	-0.07
	8		6.79	6.55	-0.24
	16		7.95	7.65	-0.3
	5		8.91	8.61	-0.3
	28		8.72	8.38	-0.34
	46		10.79	10.38	-0.41
	25		4.23	3.79	-0.44
	13		7.51	7.03	-0.48
	4		5.22	4.53	-0.69
	31		6	5.05	-0.95
	41		10.6	9.57	-1.03
	6		8.36	7.19	-1.17
	7		9.25	8.06	-1.19
	27		6.94	5.58	-1.36
	14		6.94	5.1	-1.84

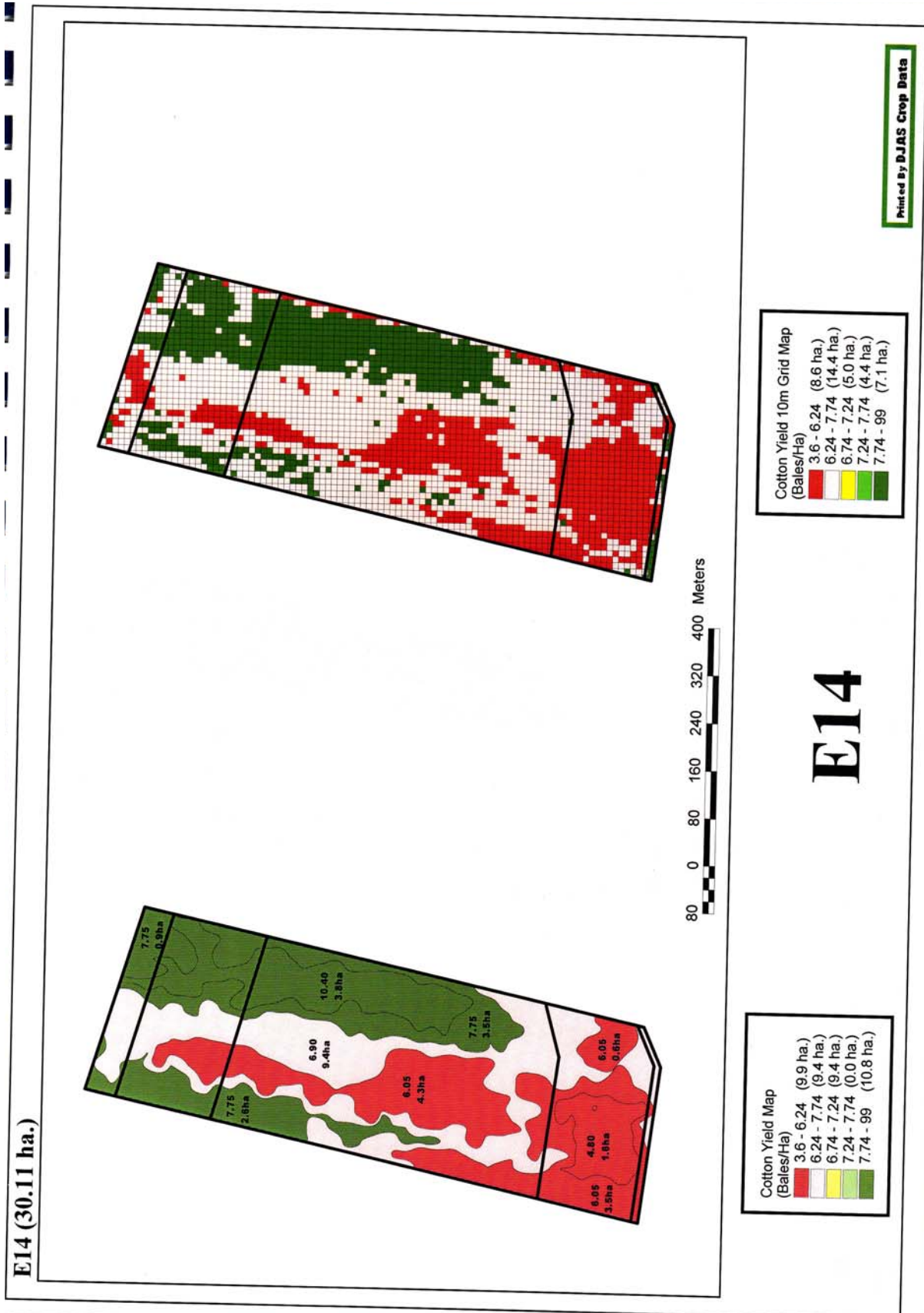
REGION	FIELD CODE	AV YIELD	HD AV YIELD	TD AV YIELD	YLD DIFFERENCE
		Bales/Ha	Bales/Ha	Bales/Ha	BALES/HA
Emerald	E7	7.3	6.4	8	1.6
	E14	6.99	5.93	7.51	1.58
	E13	8.25	7.38	8.9	1.52
	E6	6.72	6.03	7.54	1.51
	E8	6.31	5.43	6.93	1.5
	E10	9.51	8.82	10.19	1.37
	E12	9.32	8.76	9.83	1.07
	E9	9.96	9.38	10.31	0.93
	E11	10.15	9.67	10.38	0.71
	E4	8.58	8.07	8.74	0.67
	E5	8.7	8.6	9.07	0.47
	E2	9.69	9.44	9.87	0.43
	E3	9.66	9.01	9.41	0.4
	E15	8.66	8.49	8.77	0.28
	E1	9.74	9.54	9.7	0.16
	E18	8.09	8.42	8.38	-0.04
	E22	8.46	8.49	8.36	-0.13
	E21	8.63	8.72	8.42	-0.3
	E23	7.23	7.26	6.95	-0.31
	E25	8.53	8.8	8.45	-0.35
	E24	8.63	8.9	8.42	-0.48
	E20	8.16	8.1	7.58	-0.52
	E19	6.14	6.26	5.72	-0.54
	E17	6.75	7.12	6.52	-0.6
	E16	6.45	6.65	5.97	-0.68

REGION	FIELD CODE	AV YIELD	HD AV YIELD	TD AV YIELD	YLD DIFFERENCE
		Bales/Ha	Bales/Ha	Bales/Ha	BALES/HA
Goondiwindi	G1	8.36	8.28	8.58	0.3
Sth Downs	G2	9.62	9.17	9.83	0.66
	G3	9.65	9.5	9.7	0.2
	G4	7.5	7.03	7.76	0.73
	G5	8.53	5.45	9.17	3.72
	G6	11.2	10.69	11.34	0.65
	G7	9.1	8.4	9.15	0.75
	G8	8.25	8.47	8.17	0.3
	G9	7.38	7.47	6.02	1.45
	G10	7.99	8.57	7.38	1.19
	G11	6.6	7.6	6.06	1.54
	G12	5.33	5.39	4.5	0.89
	G13	7.08	7.57	6.68	0.89
	G14	7.57	8.01	7.18	0.83
	G15	9.16	9.05	8.75	0.3
	G16	8.71	9.19	8.44	0.75
	G17	7.72	8.01	7.51	0.5
	G18	8.62	8.8	8.17	0.63
	G19	8.07	8.72	7.98	0.74
	G20	8.6	8.62	8.48	0.14
	G21	8.52	8.48	8.4	0.08
	G22	8.55	9.08	8.2	0.88
	G23	6.67	6.8	6.71	0.09
	G24	8.73	9.02	8.75	0.27
	G25	8.88	8.91	8.76	0.15

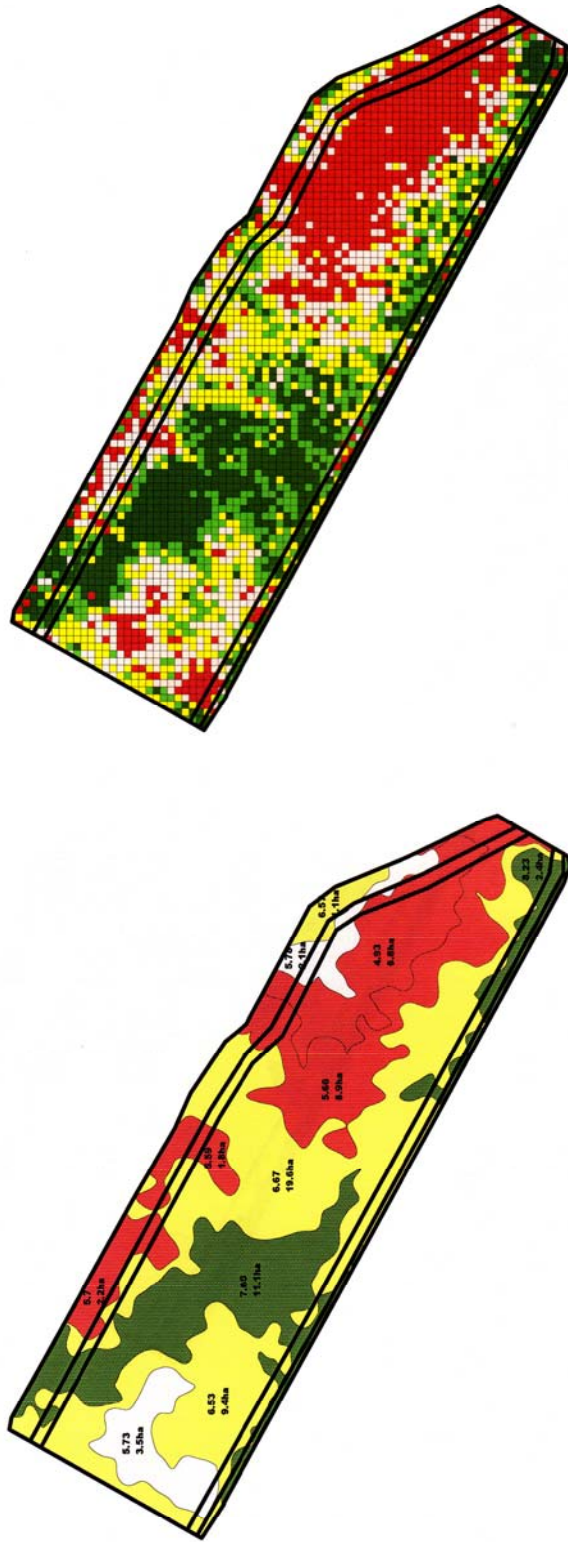
REGION	FIELD CODE	AV YIELD Bales/Ha	HD AV YIELD Bales/Ha	TD AV YIELD Bales/Ha	YLD DIFFERENCE BALES/HA
Mungindi	M1	8.72	7.41	9.6	2.19
	M2	7.35	6.49	7.55	1.06
	M3	11.86	11.69	11.91	0.22
	M4	11.38	10.94	11.54	0.6
	M5	10.03	9.82	9.98	0.16
	M6	8.97	8.26	8.94	0.68
	M7	8.18	7.6	8.44	0.84
	M8	5.24	4.54	5.7	1.16
	M9	7.78	7.14	8.14	1
	M10	7.72	7.68	8.19	0.51
	M11	7.72	7.79	7.34	0.45
	M12	6.73	6.95	6.54	0.41
	M13	7.33	7.25	7.02	0.23
	M14	7.8	7.66	7.65	0.01
	M15	10.29	10.85	10.38	0.47
	M16	11.92	12.7	10.89	1.81
	M17	9.76	10.05	9.05	1
	M18	10.03	10.05	9.83	0.22
	M19	11.24	11.72	10.81	0.91
	M20	11.49	11.82	11.49	0.33
	M21	9.14	9.2	7.86	1.34
	M22	8.03	8.59	7.06	1.53
	M23	8.87	9.27	7.74	1.53
	M24	9.02	9.56	7.85	1.71
	M25	8.55	9.42	7.72	1.7

REGION	FIELD CODE	AV YIELD	HD AV YIELD	TD AV YIELD	YLD DIFFERENCE
		Bales/Ha	Bales/Ha	Bales/Ha	BALES/HA
St George	SG1	9.9	9.68	9.96	0.28
	SG2	9.19	8.88	9.2	0.32
	SG3	8.88	8.15	9.7	1.55
	SG4	8.87	8.01	9.62	1.61
	SG5	5.91	4.52	7.38	2.86
	SG6	10.02	9.87	10.23	0.36
	SG7	10.67	9.48	11.14	1.66
	SG8	10.88	10.89	11.11	0.22
	SG9	10.78	10.4	11.07	0.67
	SG10	11.25	10.57	11.41	0.84
	SG11	11	10.9	11.2	0.3
	SG12	11.49	11.36	11.66	0.3
	SG13	10.44	10.23	10.43	0.2
	SG14	8.18	8.12	8.28	0.16
	SG15	8.88	8.77	9.02	0.25
	SG16	9	8.54	9.14	0.6
	SG17	8.17	7.78	8.48	0.7
	SG18	8.81	8.94	8.89	0.05
	SG19	8.48	8.63	8.35	0.28
	SG20	7.75	8.23	7.48	0.75
	SG21	9.14	9.42	8.88	0.54
	SG22	6.44	6.41	6.03	0.38
	SG23	7.54	7.57	7.43	0.14
	SG24	7.62	7.36	7.18	0.18
	SG25	10.69	11.07	10.08	0.99

Appendix 2. Individual Yield Maps of the Fields Analysed in Each Catchment



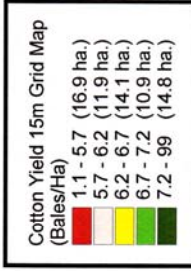
E16 (68.64 ha.)



300 0 300 600 900 Meters



E16



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