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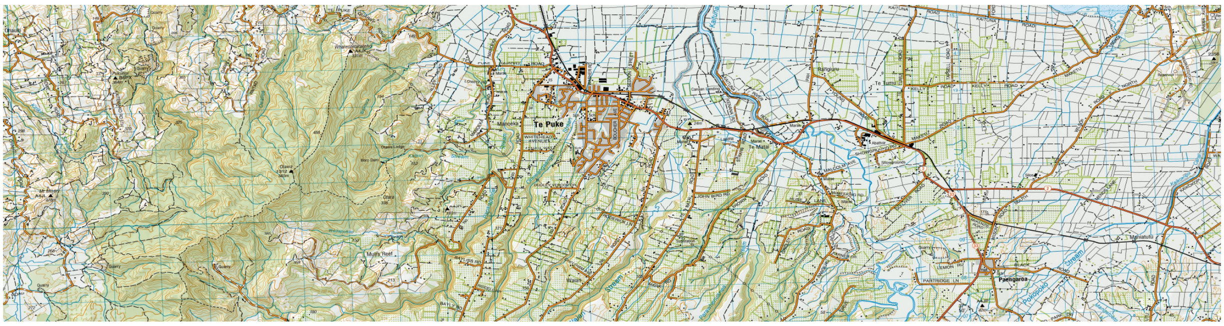

How important is Location in determining Kiwifruit Orchard Returns?

Spatial Variation in ‘Hayward’ Kiwifruit Orchard Gross Revenue within a Growing Region across Seasons

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Abstract:
Between-orchard variation in approximated average gross revenue per hectare of 341 conventionally managed commercial ‘Hayward’ (HWCK) kiwifruit orchards was spatially modelled across Te Puke, the main production region of New Zealand, over six consecutive growing seasons (2003-2008). Variation between orchards in average gross revenue within seasons (of which spatial variation is a component) was greater than variation between seasons (~temporal variation). Within seasons there were spatial patterns to the distribution of approximated gross revenues per hectare between orchards. The temporal consistency of the spatial variation enabled segregation of the Te Puke growing region into three geographic zones which contained orchards that consistently earned distinctly different returns both within and across seasons.

Despite the differences in orchard revenues between the geographic zones identified being statistically significant and the location of an orchard within the Te Puke growing region having an effect on orchard revenue, orchard location was not predictive of orchard revenue. Therefore it is concluded that the spatial component of between-orchard variation in revenue was exceeded by that of non-spatial site-to-site variation. This we attribute to differences in individual management practices between orchards. As orchard revenue is determined (in order of decreasing influence) by fruit numbers, fruit size and fruit dry matter content - the same hierarchy of responsiveness to orchard management practices - then it follows that orchard revenue is very open to manipulation by orchard management practices.

Therefore geographic zonation between orchards should not be where the effort in managing variation in Hayward kiwifruit and/or land values is concentrated.

Introduction:

I want to buy a kiwifruit orchard.
Where are the best performing orchards located?
Are there geographic areas containing orchards which consistently earn higher returns across seasons?

Orchards are businesses, and orchardists grow fruit to make money. In the New Zealand kiwifruit industry the standard metric of orchard return is Orchard Gate Return (OGR) which is typically reported at both an OGR/tray level and an OGR/hec level (where 'tray' refers to a tray of export grade kiwifruit, which in New Zealand equates to approx 3.5kg of fruit). OGR refers to the net fruit revenues less postharvest processing and cool-storage costs, and is the total amount of money coming back to the 'Orchard Gate' from which harvesting, transport and production costs need to be deducted to arrive at the net orchard return.

Historical national industry average returns for conventionally produced Hayward (HWCK) kiwifruit orchards are presented in Figure 1. Over the last eight seasons there has been a trend of increasing HWCK orchard returns from a low of $24,051/hec in the 2007/08 season up to the current season's forecast high of $47,876/hec (Figure 1).

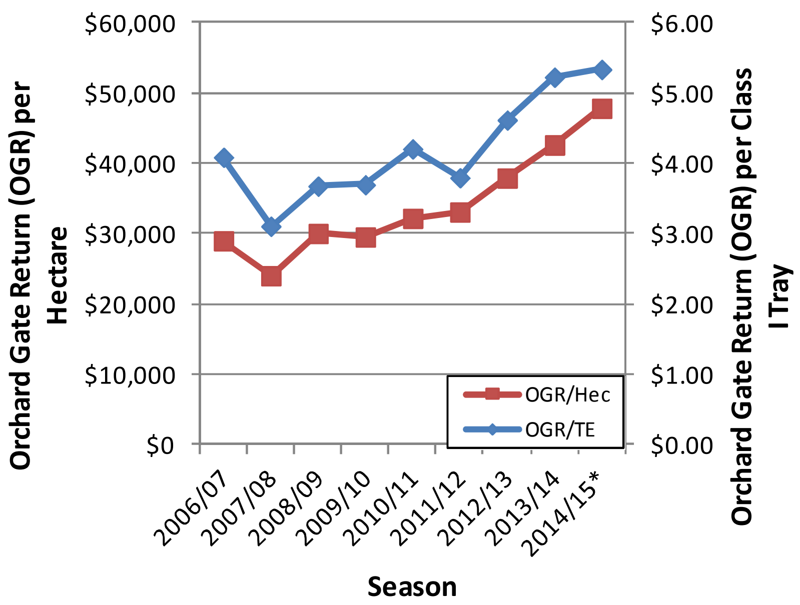

Figure 1. Historical national industry average returns for conventionally produced Hayward (HWCK) kiwifruit orchards 2006/07 – 2014/15 presented as Orchard Gate Returns (OGR) at a tray and hectare levels. The 2006/07–2013/14 figures are actuals; the 2014/15 figure is based on the ZESPRI August 2014 forecast.

In regards to what impact these returns have had on kiwifruit orchard values, QV New Zealand reports that horticultural land sales values in the Bay of Plenty region (New Zealand's main kiwifruit producing region) for the six months ended 31/12/2013 to be $155,816 per hectare (www.qv.co.nz). In comparison, kiwifruit orchard specific data shows actual HWCK purchase prices to have increased from an estimated average of $165,622 per hectare in August–October 2013 to an estimated average of $277,258 per hectare in April–July 2014; an increase in HWCK orchard market values of 67.4% (Figure 2).

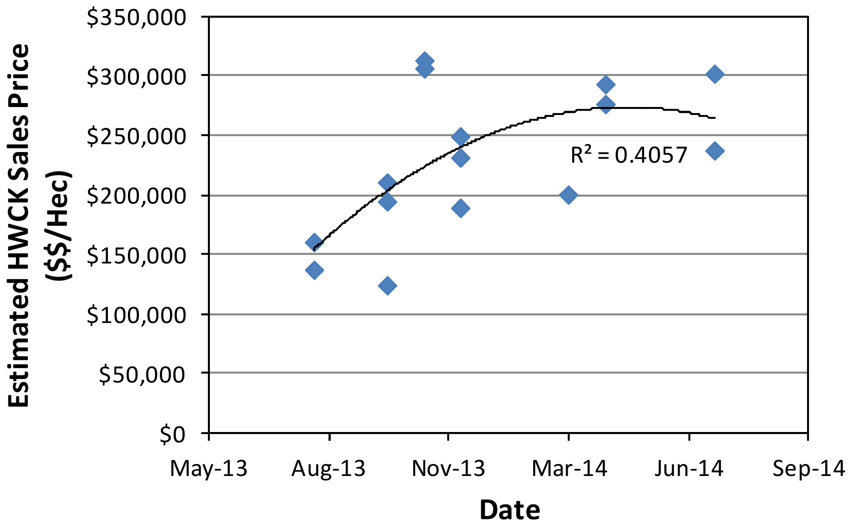

Figure 2. Estimated sales price for HWCK orchards in Te Puke from August 2013 – July 2014. Estimated sales price is for producing hectares, excluding value of shedding, housing etc, and based on 15 orchard sales. (Source: Bayleys Real Estate Limited).

The industry average returns presented in Figure 1 provide no information on how returns may vary between individual orchards. Accordingly, the individual returns of orchards supplying their fruit through the Aerocool Ltd packhouse are summarised in Table 1 (individual orchard returns (OGR/Hec) by season are presented in Appendix 1). There is significant variation in OGR returns between orchards both within and between seasons. What I wish to examine in this study is:

- Is there any consistency in individual orchard returns – is it the same orchards generating higher and lower returns across seasons?
- Where are the higher and lower returning orchards located?
- Is orchard location predictive of orchard returns?
- What implications do orchard returns have on orchard values?

Table 1. Summary statistics of Conventional Hayward (HWCK) orchard returns (OGR/Hec) across consecutive seasons for orchards supplying their fruit through Aerocool Ltd (2009-2013). Individual orchard returns (OGR/Hec) by season are presented in Appendix 1.

Period	Number of HWCK Orchards	Average OGR/Hec	Standard Deviation	Interquartile Range	Coefficient of Variation
Season 2009	86	$27,711	$11,492	$18,588	41.5%
Season 2010	84	$33,406	$11,789	$15,089	35.3%
Season 2011	88	$30,527	$9,972	$13,857	32.7%
Season 2012	83	$34,934	$11,735	$14,588	33.6%
Season 2013	64	$42,779	$15,277	$21,494	35.7%

1. HWCK refers to conventionally grown Hayward Kiwifruit marketed as ZESPRI GREEN Kiwifruit.
2. OGR refers to orchard gate return which is the net fruit revenues less postharvest processing and cool-storage costs.

<u>What determines orchard returns?</u>

In the New Zealand kiwifruit industry, orchard returns are determined by the yield of export grade fruit, fruit weight and fruit dry matter content (DM: the ratio of dry weight to fresh weight) (Woodward et al., 2007), with additional premium payments being made for timing of harvest, and fruit storage incentive payments. Analysis of the 2009 - 2013 fruit payments for conventional Hayward orchards supplying their fruit through Aerocool Ltd demonstrated that on average approximately 60% of the orchard return was determined by fruit yield and fruit size, 20% of the orchard return came from the taste payment (calculated from the fruit DM), while the remaining 20% of fruit revenues came from payments related to the timing of harvest, and fruit storage incentive payments (Data not shown).

There is a direct link between Hayward kiwifruit DM at harvest and consumer preference for fruit when ripe, with consumers preferring higher DM fruit (Lancaster, 2002; Burdon et al. 2004). Supplying markets with fruit of consistently high DM is a major industry goal. Consequently, fruit DM at harvest is used as a measure of commercial acceptability within the New Zealand industry with orchardists paid more for the production of high DM kiwifruit.

The industry's payment schedules are weighted such that yield is the primary determinant of Hayward orchard return followed by fruit size and then fruit quality premiums. The discriminant analysis of Woodward et al (2007) revealed that between-vine variation in income generation was primarily determined by variation in individual vine crop-load.
Increasing croploads of Hayward kiwifruit have consistently resulted in smaller average fruit size (Snelgar & Thorp, 1988). No such negative correlation has been found between crop loading and

fruit DM in Hayward kiwifruit, while a weak positive correlation between Hayward fruit size and fruit DM has been reported (Woodward & Clearwater, 2008). This finding implies that production of high yields of high DM fruit is not mutually exclusive; similarly, Bramley and Hamilton (2004) could find no evidence of a trade off between grape yield and grape quality. As such kiwifruit orchard returns are optimised by production systems focussed on the attainment of high fruit numbers per unit of land area, adequate fruit size to achieve export grade standards and high fruit DM to meet consumer expectations (Patterson & Currie, 2011).

In terms of gross variation in individual production characteristics between kiwifruit orchards, the magnitude of variation in average yields has been reported to be higher than that of variation in average fruit size; the magnitude of variation between orchards in average fruit DM being the least, both within and across seasons (Woodward & Clearwater, 2011; Woodward & Clearwater, 2012). The magnitude of variation in fruit quality has previously been reported to be less than variation in fruit yield in other horticultural crops (Bramley & Hamilton, 2004; Bramley, 2005). Orchard yield is more independent of season than fruit size; fruit DM appears to be the production characteristic under the greatest seasonal influence. Conversely, orchard yield is more responsive to orchard management practices than fruit size, while fruit DM is the least responsive (Woodward & Clearwater, 2011; Woodward & Clearwater, 2012). The hierarchy of production characteristics which drive orchard return (crop-load > fruit size > fruit DM) also appears to follow the same pattern in terms of responsiveness to orchard management practices.

High-productivity Hayward kiwifruit orchards in New Zealand have been reported to consistently produce c. 43,200 kg of export grade fruit per canopy hectare across seasons with a mean fruit weight of 110-115g (Patterson & Currie, 2011) and a typical mean fruit DM in the range of 14-17% (Burdon et al. 2004). However, not all orchards achieve such productivity. An improved understanding of how production characteristics vary within and between orchards is required to enable the management of such variation, and assist in understanding the key drivers of orchard profitability.

This study builds on two previous companion studies in which the spatial component of between-orchard variation in fruit DM (Woodward & Clearwater, 2011), and fruit size and orchard yield (Woodward & Clearwater, 2012) were investigated across the same production region and orchards to assess the potential for the implementation of zonal management strategies at a regional level. In both prior studies consistent spatial variation was identified, however the scale and pattern of between-orchard variation across the region varied with the production characteristic considered. The general conclusion was that despite there being statistically significant and consistent spatial variation between orchards, the magnitude of variation was not sufficient to justify zonal management or segregation of fruit based on orchard location (Woodward & Clearwater, 2011; Woodward & Clearwater, 2012).
The present study builds on the previous two studies by investigating the amalgamation of the various production characteristics into the ultimate production measure – financial return.

The objective of the present study was to investigate between orchard variation in approximated gross revenue at commercial harvest within the Te Puke growing region across consecutive seasons to quantify the magnitude and spatial component of such variation. Two hypothesises were tested:

- Firstly, orchards that consistently produce high or low gross revenue outcomes can be identified and that such orchards are spatially aggregated within the Te Puke growing region.
- Secondly, the proposition was tested that the spatial aggregation of such orchards was temporally consistent with orchard location being predictive of orchard gross revenue outcomes at commercial harvest which would enable implementation of zonal management strategies.

Knowledge of the spatial distribution of between-orchard variation in income is valuable for a variety of private and public decision-making purposes at an individual orchardist level and at a regional scale. It could, for example assist orchardists understand the key drivers of profitability in their businesses and help inform investment decisions about orchard development and purchase. At an industry/governmental level such information has implications for rural support programmes, land values and taxation. For example, orcharding regions generating larger economic surpluses would be better positioned to weather downward pressures on per unit fruit returns (e.g. the ongoing high value of the NZ dollar) or increases in production costs (e.g. affording a Psa protective spray programme).
Alternatively, if orchard location is found to have only a small effect on orchard revenue, then this could suggest that orchard management practices are the primary determinant of orchard outcomes, returns, profitability and land values.

Materials and Methods:

Study Area:

The study utilised harvest information collected from March 2003 through to June 2008 with Actinidia deliciosa (A. Chev.) C. F. Liang et A. R. Ferguson var. deliciosa 'Hayward' kiwifruit harvested from 341 conventionally managed commercial orchards in the Te Puke region (37˚49'S, 176˚19'E), New Zealand (Figure 3).

For the New Zealand kiwifruit industry, the majority of kiwifruit is grown in the Bay of Plenty province with the bulk of production centered within the Te Puke region.

Data Analysis:

Industry databases pertaining to the 2003-2008 harvest seasons were supplied by ZESPRI International Ltd (Mount Maunganui, New Zealand) and collated to obtain orchard geographic location, altitude, average Class I (export) fruit size, fruit dry matter content (DM: the ratio of dry weight to fresh weight) and average orchard yield at commercial harvest per season for conventionally managed Hayward orchards located within the Te Puke growing region. Commercial harvest operations typically run annually from late March until early June for kiwifruit orchards within the Te Puke growing region, therefore the production data was collected across a ~10 week period each year.

Gross income per individual orchard was estimated across seasons using the New Zealand industry payment schedules of 2008/09 (Zespri International Ltd, 2010) and reported as gross revenue per hectare. The payment schedules were based upon a base fruit payment per export tray with differential fruit payments for fruit size and fruit DM.

Note that this approach to estimating gross orchard revenue excludes such payments as early supply, loyalty and net time payments but accounts for approximately 80% of the total fruit payments (Data not shown).

The subsequent orchard data set was separated into two orchard groupings within the Te Puke growing region: model orchards and test orchards (Figure 3). The model orchard dataset comprised of 288 individual orchards with 6 consecutive years of gross revenue information (2003-2008) that were used to model the spatial distribution of between-orchard variation. The test orchard dataset consisted of 53 orchards lacking consecutive seasonal information which were used to assess the predictive power of the spatial models developed using the model orchards.

Geostatistics assumes normality in the variables modelled; Kolmogorov-Smirnov tests were used to confirm that orchard gross revenue per hectare was normally distributed between-orchards both within seasons and across seasons (data not shown).

For the spatial analysis, the use of a single season's payment schedule (2008/09) applied across all six seasons studied (2003-2008) facilitated between-season comparisons of gross revenue independent of any seasonal effect. The spatial component of between-orchard variation was modelled by calculating variograms from normalised average orchard values for each season and then interpolated using block kriging with a global variogram, onto a 1km grid with VESPER software (Bramley & Hamilton, 2004; Bramley, 2005; Minasny et al., 2005).

The temporal persistence of the spatial patterns of between-orchard variation in gross revenue across the Te Puke growing region was investigated using *k*-means clustering (Bramley, 2005; Woodward & Clearwater, 2011; Woodward & Clearwater, 2012). Interpolated predictions for each geographic point in the interpolation grid were grouped into zones consistently producing distinct gross fruit revenue outcomes at commercial harvest by *k*-means clustering, using SPSS v13 software (SPSS Inc, Chicago, Illinois, USA), in which each season was used as a variate in the clustering.

The number of clusters used in this approach is principally a matter of user choice (Bramley & Hamilton, 2004). The cluster analysis was repeated using differing numbers of clusters and the resulting cluster groupings compared for consistency of partitioning within and across seasons. Of the cluster numbers investigated only the three cluster solution produced cluster groupings whose centres were in consistent directions both within and across seasons (2003-08).

Gross fruit revenue was compared between orchards located within each geographic cluster both within seasons and between seasons using one-way ANOVA with revenue having three levels (one for each cluster group) in SPSS v13 software.

The validity of spatial models was assessed by a nearest neighbour analysis where interpolated predictions (derived from the model orchard dataset) were correlated with test orchard actual gross revenues. As gross fruit revenue at commercial harvest was normally distributed between orchards and across seasons Pearson product moment correlation coefficients were calculated.

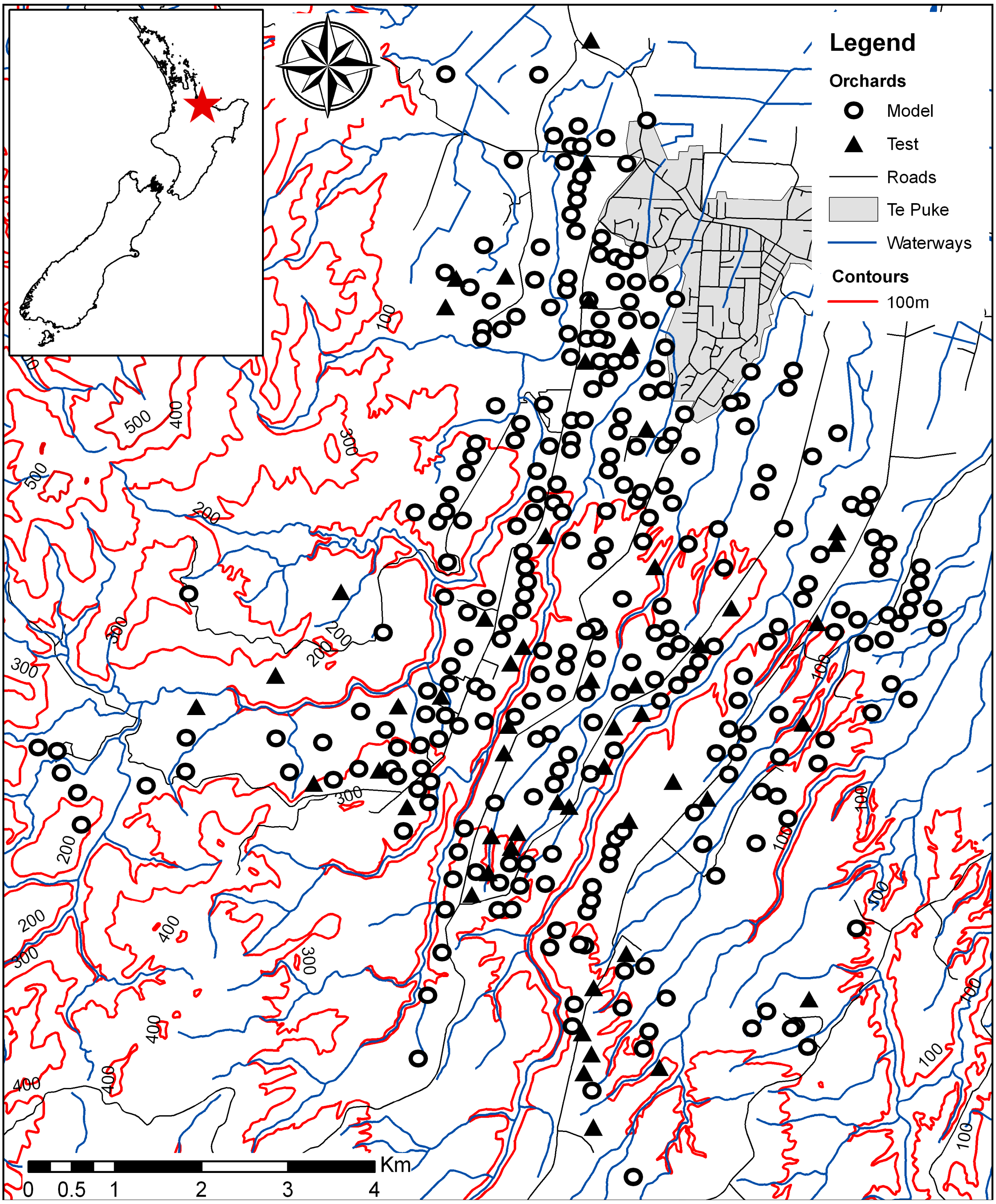

Figure 3. Geographic location of the Te Puke kiwifruit growing region within New Zealand (inset), and the location of model orchards (○) and test orchards (▲) within the Te Puke growing region. Numbers indicate 100 m contour intervals for altitude above mean sea level.

Results:

Summary statistics of between-orchard variation in gross revenue are presented in Table 2. Season 2008 produced the highest average orchard gross revenues and season 2003 produced the lowest average gross revenues, which was driven by the underlying seasonal differences in average orchard yields (export trays/hectare) - 9,794 TE/hec in season 2008 versus 7,582TE/hec in season 2003. The lower average orchard yields in 2003 can be attributed to a spring frost which disrupted flowering, and reduced subsequent crop loads on orchards across the Te Puke region.

Across seasons, a positive correlation between average orchard gross revenue and between-orchard variation in gross revenue was noted, that is in seasons of higher average gross revenues the variation in revenues between individual orchards was typically greater too (Table 2).

By comparing the measures of variation between seasons (~temporal variation) with the measures of variation between orchards within seasons (~spatial variation) the relative importance of both components of variation was estimated. Comparison of the measures of variation would suggest that variation between orchards within seasons (potential spatial variation) was greater than variation between seasons (potential temporal variation) (Table 2).

Table 2. Summary statistics of approximated Hayward kiwifruit orchard gross revenue per hectare within the Te Puke growing region across consecutive seasons (2003-2008). Measures of variation are between orchards for each individual season and between seasons for the 2003-08 figures.

Season	Count	Average	Standard Deviation	Interquartile Range	Coefficient of Variation
2003	316	$37,050	$10,106	$12,876	27.3%
2004	337	$42,779	$10,726	$12,602	25.1%
2005	311	$42,720	$9,308	$11,079	21.8%
2006	335	$40,656	$11,589	$13,847	28.5%
2007	336	$46,579	$11,925	$15,300	25.6%
2008	337	$51,657	$11,897	$15,725	23.0%
2003-2008	6	$43,574	$5,036	$4,457	11.6%

The summary statistics presented in Table 2 describing variation in gross revenue between orchards are simple measures of gross variation and provide no information about potential differences between orchards located within different parts of the Te Puke growing region. Therefore spatial techniques were used to provide a visual representation of the distribution of gross revenues between orchards across the Te Puke growing region within seasons and to identify geographic zones within the growing region containing orchards consistently earning distinctly different revenues across seasons.

Maps of interpolated predictions of gross orchard revenues within individual seasons are presented in Figure 4. Spatial structure in between-orchard variation in gross revenue was evident in the six seasons investigated, along with some temporal consistency to these spatial distributions across seasons (Figure 4). Within each individual season, lower orchard gross revenues were typically associated with orchards located in the south and west of the Te Puke growing region and higher orchard gross revenues with orchards located within the mid east of the Te Puke growing region (Figure 4).

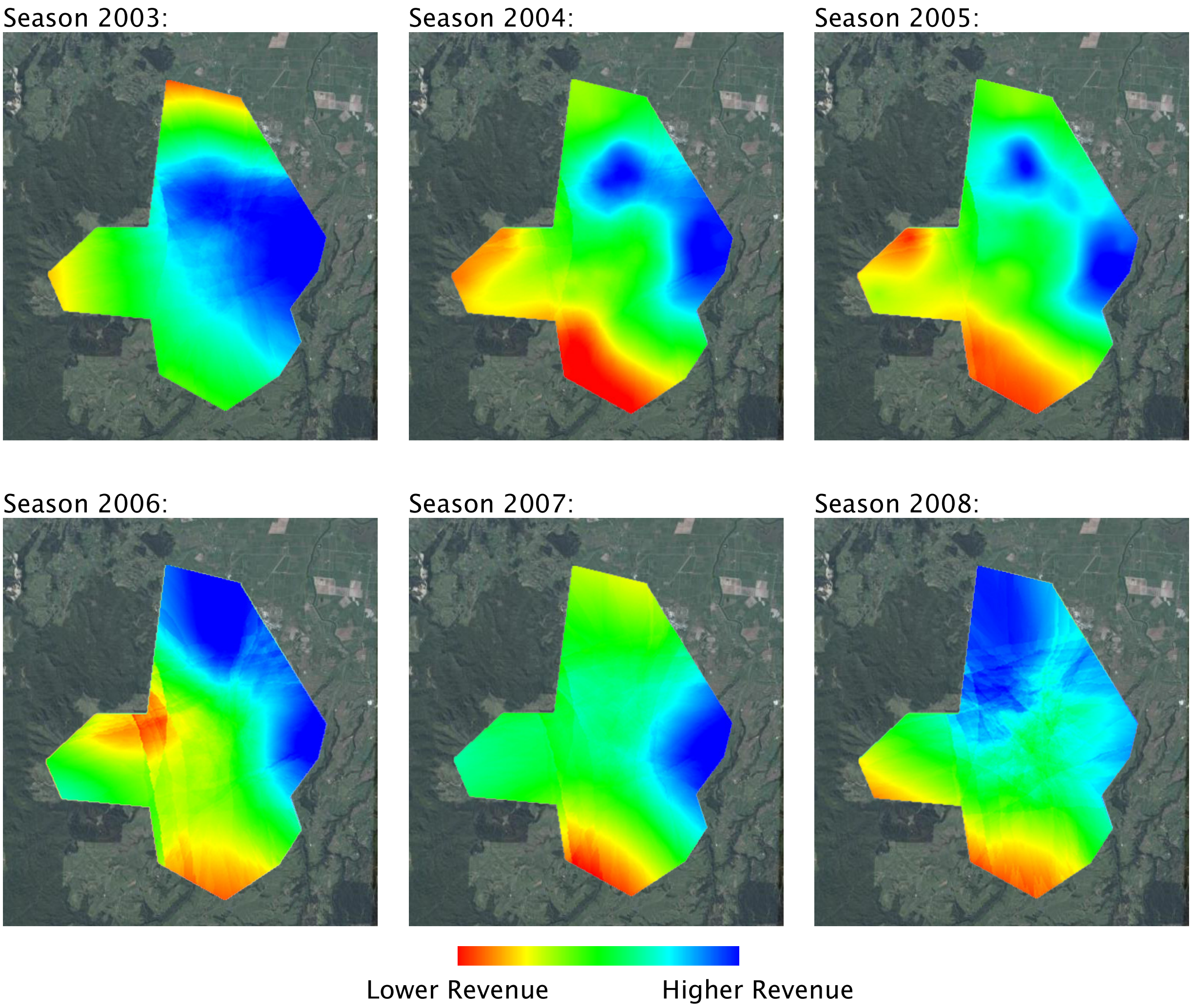

Figure 4. Modelled spatial variation between Hayward kiwifruit orchard gross revenue ($$/ha) at commercial harvest within the Te Puke growing region over consecutive growing seasons (2003-2008).

The interpolated spatial predictions were clustered to identify geographic zones that contained orchards producing consistently different revenue outcomes across years. When clustering the orchard revenue data, only the three cluster solution produced consistent groupings across seasons i.e. cluster one always had the lower revenue, cluster two always had intermediate revenue, and cluster three always had the higher revenue across seasons (Figure 5). The results of the cluster analysis support the view that the pattern of variation in gross revenue per hectare between orchards within the Te Puke growing region is temporally stable.

Model orchards located within the cluster 1 geographic area (located in the south and west of the Te Puke growing region) consistently generated lower gross revenues per hectare than orchards located within the cluster 3 geographic area (located in the centre and east of the Te Puke growing region). Model orchards located within the cluster 2 geographic area (located in the centre and north of the Te Puke growing region) generated intermediate revenues (Figure 5 and Table 3).

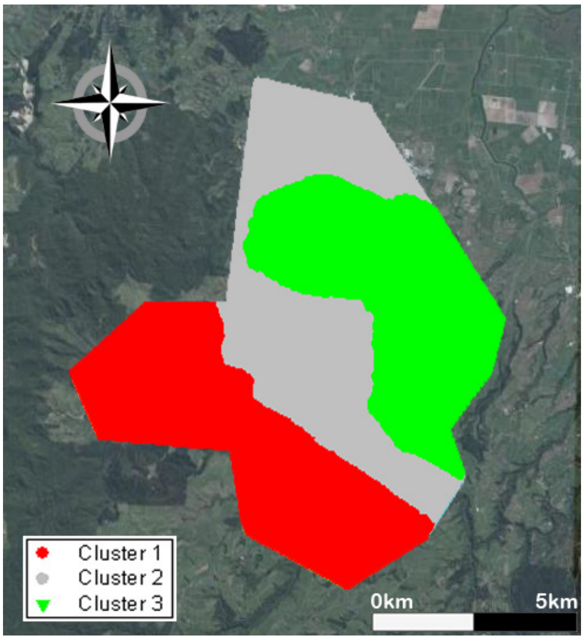

Figure 5. Geographic location of Hayward kiwifruit gross revenue ($$/ha) groupings across the Te Puke growing region as identified by *k*-means clustering. The gross revenues, individual production characteristics and altitudes of the orchards located within each geographic cluster are summarised in Tables 3, 5 and 6 respectively.

The differences in gross orchard revenues between orchards located in clusters 1 and 3 were statistically significant in each of the 6 seasons studied; the differences in gross revenues between orchards located in cluster 2 and orchards located in clusters 1 and 3 were statistically significant in 3 of the 6 seasons studied (Table 3). Across seasons, orchards located within

cluster 3 generated gross revenues that were on average $4,762/hec and $8,586/hec higher than those generated by orchards located within clusters 2 and 1 respectively (Table 3). The relative inequality of gross revenue generation of orchards between geographic clusters is summarised in Table 4.
The individual production characteristics of the orchards located within each geographic cluster are summarised in Table 5. Orchards located within cluster 3 typically produced higher yields of larger sized fruit with a higher fruit DM, and hence the higher fruit revenues than that produced by orchards located within clusters 1 and 2 (Table 5).

Table 3. Comparison of mean gross fruit revenue per hectare between orchards located within geographic clusters. Clusters 1, 2 and 3 contained 46, 120 and 122 of the 288 model orchards respectively. Mean values in the same row with different letters are significantly different (Tukey's LSD, $P<0.05$).

Season	Cluster 1	Cluster 2	Cluster 3
2003	$31,518 [a]	$34,242 [a]	$42,087 [b]
2004	$37,560 [a]	$41,402 [b]	$47,530 [c]
2005	$37,651 [a]	$42,154 [b]	$46,562 [c]
2006	$37,353 [a]	$39,381 [a]	$44,000 [b]
2007	$41,780 [a]	$45,835 [b]	$49,983 [c]
2008	$46,352 [a]	$52,143 [b]	$53,567 [b]
2003-2008	$38,702 [a]	$42,526 [b]	$47,288 [c]

Table 4. Summary of total land area and estimated total revenue generation of the geographic clusters identified within the Te Puke growing region 2003-2008. Total revenue was estimated as total land area per geographic cluster multiplied by mean gross fruit revenue per hectare (Table 2).

Geographic Cluster	Total Land Area	Total Revenue
Cluster 1	34.4%	31.1%
Cluster 2	32.9%	32.7%
Cluster 3	32.7%	36.2%

Table 5: Comparison of average individual production characteristics of orchards located within each geographic cluster across seasons (2003-2008). Clusters 1, 2 and 3 contained 46, 120 and 122 of the 288 model orchards respectively.

Orchard Average per Hectare (2003-2008)	Geographic Cluster 1	2	3
Yield (export trays/hec)	7,528	8,172	9,002
Average Fruit Size*	34.6	33.9	33.4
Average Fruit DM	16.4%	16.6%	16.7%
Average Gross Revenue ($/hec)	$38,702	$42,526	$47,288

*Larger count sizes indicate fruit of lower weight

The average altitude of orchards located within geographic cluster 1 was 199masl (metres above seas level) compared to the 121masl and 76masl of orchards located within geographic clusters 2 and 3 respectively (Table 6).

Table 6. Average altitude of model orchards located within geographic clusters. Altitude values are means ± 1 SEM expressed as meters above sea level (masl).

Geographic Cluster	Altitude
Cluster 1	199.36 ± 3.48
Cluster 2	120.56 ± 5.34
Cluster 3	76.46 ± 2.33

How predictive is orchard location of gross orchard revenue? The predicted orchard gross revenues derived from the spatial models from the model orchard dataset were correlated with the actual gross revenues of the test orchards (Table 7). The predictive power of the spatial models varied with season and despite correlations being significant in three of the six seasons investigated, and across seasons - the correlations were weak.

There was significant overlap in returns between orchards located within each individual geographic cluster (Figure 6) - all clusters contained orchards bucking the geographic trend. This observation supports the conclusion that though orchard location contributes to orchard revenues, the spatial component of between orchard variation is exceeded by that of non-spatial site-to-site variation.

Table 7. Correlations between modelled spatial predictions and actual test orchard gross revenue per hectare within and between seasons (2003-2008).

Season	Pearson Correlation	R^2
2003	0.417(*)	0.17
2004	0.127	0.02
2005	0.340	0.12
2006	0.124	0.02
2007	0.293(*)	0.09
2008	0.419(**)	0.17
2003-2008	0.266(**)	0.02

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

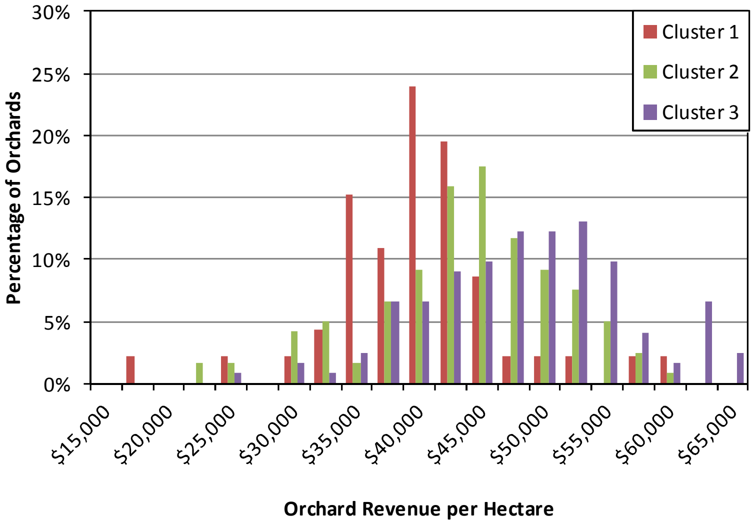

Figure 6. Frequency distribution of orchard revenues between geographic clusters (2003-2008).

Discussion:

Scope and limitations of the present study:

This study utilised a unique industrial dataset based on fruit measurements from 341 individual orchards across 6 consecutive years; such a dataset enabled robust investigation of regional scale spatial variation in a perennial fruit crop rather than the with-in production unit (e.g. paddock) scale variation of arable cropping systems typically the subject of investigations into spatial variation and the potential applications of precision agriculture (Bramley & Hamilton, 2004; Bramley, 2005).

In this study spatial variation in Hayward kiwifruit orchard gross revenue was investigated within the main production region of New Zealand, Te Puke. Knowledge about the spatial component of between-orchard variation is needed for the implementation of zonal management strategies (Bramley, 2005) and will assist in understanding the factors underlying variation in kiwifruit orchard revenue generation.

The approach we have taken of estimating gross revenue through the production characteristics of yield, fruit size and fruit DM ignores the significant premium payments made for early harvests and storage incentive payments, and excludes the postharvest processing and coolstorage costs, which were not included in the industry databases made available to us. Therefore, our measure of gross fruit revenue excludes some of the significant components of orchard revenue and postharvest costs which are accounted for in the industry standard measure of orchard return – orchard gate return (OGR). However, we believe our approach provides a reasonable estimate of orchard revenue as the orchard yield, fruit size and fruit DM data accounts for ~80% of the final fruit payment (data not shown).

Scale of variation in revenue between orchards

The first issue to consider is whether or not there is sufficient variation between orchards to even warrant consideration of location effects and potential applications of precision agriculture. Pringle et al. (2003) highlighted the importance of deciding whether a crop displays enough variation – both in terms of magnitude and spatial distribution – to justify the additional cost and warrant a change from uniform management to zonal management.

It must be acknowledged that the magnitude of between-season variation is understated in this study as a single seasons payment schedule (2008/09) was applied to all six seasons studied (2003-2008), when the payment schedules are known to vary from year-to-year (Figure 1). Despite only a single seasons payment schedule being modelled, the coefficients of variation between orchards within seasons ranged from 21.8-27.3% (Table 2), this being comparable to the level of variation typically reported in precision agriculture datasets (Bramley, 2005; Aggelopoulou et al., 2010). As long as the spatial component of the observed within-season variation between orchards is greater than the non-spatial component then this would suggest that the magnitude of between-orchard variation in orchard revenue is sufficient to enable the potential application of zonal management strategies.

Is orchard location predictive of orchard revenues?

Within seasons there were spatial patterns to the distribution of revenue between orchards (Figure 4). The temporal consistency of the spatial variation enabled geographic zones to be identified which contained orchards that consistently earned distinct revenues both within and across seasons (Figure 5 and Table 3).

It is important to note that the spatial structure of the geographic zones identified by *k*-means clustering (Figure 5) was not an artefact of the clustering procedure; clustering partitioned geographic points based on interpolated gross orchard revenue predictions without using any spatial information. Rather, the resulting spatial structure of the clusters reflected spatial correlation with some underlying phenomenon that affected gross orchard revenue.

Despite the modelling being able to describe the spatial variation occurring across the Te Puke growing region within any one growing season, the spatial models were only weakly predictive of orchard outcomes (Table 7). There was significant overlap in orchard returns between individual geographic clusters (Figure 6) – all clusters contained individual orchards bucking the geographic trend. Furthermore, Table 4 presents the relative contribution of low- and high returning orchard geographic zones to total orchard revenue generation across the entire Te Puke production region. The scale of 'inequality' is not large between geographic zones.

From this we could conclude that while orchard location has an effect on orchard earnings, the orchard location effect is less than the effect of non-spatial site-to-site variation – such as differences in management practices between orchards.

What is driving the differences between orchards?

The observed differences in gross revenue between orchards within the geographic clusters could be due to the influence of environment, management or a combination of both on orchard production characteristics. Salinger and Kenny (1995) identified three climatic factors as being important determinants of an area's suitability for cultivation of Hayward kiwifruit: winter chilling; growing season thermal time; and annual rainfall. The Te Puke growing region has a complex topography which results in significant local modification of climate. It is well known that these local-scale modifications of climate are important for crop production (Skaar, 1980; Salinger & Kenny, 1995).

Temperature is described as the major driver of all crop development (Salinger & Kenny, 1995; Snelgar et al., 2005). Warmer growth temperatures are known to favour the production of higher fruit yields and increase fruit weight in New Zealand grown Hayward kiwifruit (Manson & Snelgar, 1995; Snelgar et al., 2005). Warmer spring and cooler summer growth temperatures favour the production of higher DM kiwifruit at harvest (Snelgar et al., 2005).

Across the Te Puke growing region there is an altitude gradient increasing from the North East through to the South West; altitudes of the orchards included in this study varied by 280m. The literature reports an adiabatic lapse rate of 6°C Km $^{-1}$ (Hallett & Jones, 1993); as such we could expect average orchard temperatures to vary ~1.68°C between modelled orchards.

Temperature has been reported to have significant effects on kiwifruit growth and maturation (Snelgar et al., 2005). From the literature we could expect fruit produced at higher altitudes to have experienced lower growth temperatures compared to the warmer growth conditions experienced by lower altitude orchards leading to the production of lower yields of smaller sized fruit with lower DM content (Hopkirk et al., 1989; Snelgar et al., 2005) – and this is consistent with the differences in the average individual production characteristics between geographic clusters as reported in Table 5.

The hypothesis that a difference in orchard altitude, and therefore growth temperatures, is driving the observed differences in production characteristics and subsequent orchard revenues between clusters is consistent with cluster 1 (lower revenue) being located at higher altitudes in the south and west of the Te Puke growing region (199.36 masl), and with cluster 3 (higher revenue) located at lower altitudes in the centre and east of the Te Puke growing region (76.46 masl) (Figure 5 and Table 6). However, this is at odds with the orchards forming the northern portion of cluster 2 (intermediate revenue) being located in the northern extreme of the study area at the lowest altitudes (Figure 5). Therefore orchard altitude may contribute to, but is not responsible for the differences in orchard revenue between geographic clusters.

What about differences in soil types across the growing region? Bramley (2001) has previously reported that patterns of yield variation in a vineyard closely matched variation in soil properties. As such, could differences in soil type across the Te Puke growing region be influencing between orchard variation in production characteristics and subsequent orchard revenues? This does not seem likely as the Landcare Research Ltd soil maps of the Te Puke region demonstrate that soil type does not vary across the area studied (http://soils.landcareresearch.co.nz/maps/soilportal.html). However, the north-eastern portion of the study area borders coastal plains where soil drainage is known to be very different.

Previous studies of spatio-temporal variation in crop production have largely focussed on arable crops such as cotton, wheat, corn, maize and soybean (Aggelopoulou et al., 2010; Jaynes et al., 2003; Jaynes et al., 2005; Yamagishi et al., 2003). In such studies the investigators have looked to differences in topography, climatic growing conditions, soil properties, irrigation practices or nutrient inputs to explain the observed variation in production characteristics. In a perennial horticultural system, such as that of kiwifruit, there are many more cultural variables compared to those of broadacre cropping which could contribute to variation in production characteristics and many such cultural variables have carry over effects into subsequent seasons. Identifying the key drivers of the observed spatial variation between orchards is beyond the scope of the present study; our goal was to only determine whether orchard location had a consistent effect on orchard returns that would enable effective zonation of the Te Puke production region and implementation of targeted management practices.

Implications for Orchard Land Values

While there are a number of approaches to valuing rural property, one of the most common approaches is the income approach (Stillman, 2005). This basic theory states that rural land value is driven by the profitability of the land in its highest and best use. Therefore, land value is equal to the discounted sum of expected profits from production into the future (Stillman, 2005).
The average difference in annual gross revenues between orchards located in geographic Cluster 3 was $4,762/hec and $8,586/hec higher than those generated by orchards located within Clusters 2 and 1 respectively (Table 3), and as such we could expect the orchards located within the separate geographic zones, each having distinct revenues, to also have distinct land values.

However, is this the case? Does theory follow reality? Based on the ability to generate higher revenues (and presumably higher profits) we could expect orchards located within Cluster 3 in the centre and east of the Te Puke growing region to command a premium land value relative to that of orchards located in Cluster 1 in the south and west of the Te Puke growing region (Figure 5 and Tables 3 & 5). However, the market data we have available shows a general trend of increasing HWCK orchard sales prices across the Te Puke region in the twelve months ending July 2014 (Figure 2), and we lack the data to further differentiate sales values within the region.

Economics is based upon the principle of 'rational man' – the theory that people are rational and can identify their own self-interest, and always act on it (Stillman, 2005; Allan & Kerr, 2013). Anecdotal reports suggest that since July 2014 HWCK orchards within the Te Puke growing region have been selling for $310-320,000/hec. Based on an average production of 10,000TE/hec at $5.00 OGR/TE, a HWCK orchard would have a gross annual income of $50,000/hec; from which an average production cost of $25,000/hec is deducted to provide a net EBIT return of $25,000/hec which equates to 8% EBIT return on investment at current orchard pricing. Furthermore, if you consider that the average HWCK return over the last 9 years has been $4.20 OGR/TE (Figure 1), then at current orchard pricing this equates to a 5% EBIT return on investment. Is purchasing a HWCK orchard at these prices a rational investment decision?

I would argue that horticulture is a land use exposed to higher risk than either pastoral or arable farming, and in terms of developing an orchard the lag period between investment in development and positive returns is longer (e.g. 5 years before first crop). What return on investment is sufficient to compensate for the higher associated risk? This comes down to the risk appetite of the individual.

What other attributes does land have which we value? For example could general macro-economic factors which influence the price of all property types (e.g. interest rates and the availability of cheap credit), or the value of alternate land uses, or the amenity value of land (e.g. access to coasts and rivers, proximity to schools etc) justify the current market values of HWCK orchards (Allan & Kerr, 2013)?
If the current market value of orchards cannot be justified then perhaps the current market could be described as a 'bubble' where there are excessive expectations around future profitability and capital gains from land which temporarily elevate the value of rural land.

What next?

The spatial models presented here and the subsequent zonation of the Te Puke production region by orchard revenue generation is not a solution in itself but rather a decision support tool for providing new information, visualisation and insights to decision makers. Understanding the spatio-temporal stability in crop variability allows the use of historical records to predict site-specific responses for future crops, and conversely if spatio-temporal variability is high then historical data cannot be used with any confidence for predictive management strategies (Pringle et al., 2003).

Is kiwifruit orcharding an economically viable land use across all areas of the Te Puke growing region? Does the economic viability vary between kiwifruit varieties? While the answer may very well be yes across the region and kiwifruit variety investigated in the current study, the methodology developed here could equally be applied to other producing regions or across regions where the answer may very well be different. Alternatively this methodology could be used to assess the economic impact of natural events such as adverse weather events or plant diseases such as Psa-V on kiwifruit orchards at a regional level.

Conclusion:

Temporally consistent spatial relationships were identified between orchards for approximated orchard revenues enabling effective zonation of the Te Puke growing region. Though the differences in approximated orchard gross revenue between such zones were statistically significant, orchard location was not predictive of orchard revenue and therefore does not warrant a change from uniform to zonal management.

We can surmise that the weak correlations between spatial predictions and actual orchard revenues is a function of orchard management responding to vines and climate, layered on top natural climatic variation and location effects. As a result, despite the location of an orchard within the Te Puke region having a limited effect on the returns earned, the spatial component of between-orchard variation was exceeded by that of non-spatial site-to-site variation. This we attribute to differences in individual management practices between orchards.

As orchard revenue is determined (in order of decreasing influence) by fruit numbers, fruit size and fruit DM – the same hierarchy of responsiveness to orchard management practices – then it follows that orchard revenue is very open to manipulation by orchard management practices. Orchard revenue generation contributes to orchard land values, and we attribute differences in individual management practices between orchards to be a greater determinant of orchard revenue generation than any orchard location effect. Therefore geographic zonation between orchards should not be where the effort in managing variation in Hayward kiwifruit and/or land values is concentrated.

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Appendix 1:

Ranked actual Orchard Gate Returns (OGR/hec) by individual orchard and season for orchards that supplied fruit through the Aerocool Ltd Packhouse (2009-2013). The individual orchard results are summarised in Table 1.