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Between-vine Variation in 'Hayward' Kiwifruit Vine Income: The use of Lorenz curves and Gini Coefficients to Describe Variation and Assess the Potential for Zonal Management

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Summary

Variability in kiwifruit income generation was studied per individual vine within an orchard block of 'Hayward' kiwifruit over three consecutive growing seasons (2003–2005). The objective of this study was to assess the applicability of Lorenz curves and Gini coefficients (G) to characterise the magnitude of the between-vine variation in income, and determine whether spatial variability of vine income in a small orchard block (0.17 ha) was stable over time and whether site-specific management could be applied to the orchard area. Lorenz curves illustrated that vine income in the 2003 season was skewed towards lower incomes with 50 % of the orchard area's income coming from ≈35 % of the vines when frost differentially affected vines, a result reflected in the high G of 0.208. In subsequent seasons vine income was more homogeneous, indicated by lower G values (0.067 and 0.068). Income was highest in homogeneous vine populations. A strong spatial pattern to between-vine income variation was identified in season 2003; in the subsequent seasons of 2004 and 2005 vine income was increasingly randomly distributed within the test site. We conclude that there was little stability in the spatial structure of between-vine variation in income. Within the orchard area, vine populations were identified that consistently generated higher or lower incomes across seasons. However, the lack of aggregation and the low temporal stability of these vine populations made the adoption of zonal management strategies unfeasible for this site, and has implications about the practicality of zonal management in larger kiwifruit production blocks.

Key words. kiwifruit – spatial variability – income – Lorenz curves – Gini coefficient

Introduction

Fruit quality attributes are not uniformly distributed within an orchard area, and despite uniform management practices fruit production systems are particularly heterogeneous. Heterogeneity arises as a result of the interaction of a hierarchical series of variables (both biotic, such as competition between vines for soil nutrients, and abiotic, such as temperature) that fluctuate at many different spatial and temporal scales. Crop management practices are now recognising this inherent variation in productivity and quality through the application of precision horticulture (Bramley and Hamilton 2004).

The key driver for the implementation of precision horticulture will be whether targeted orchard management practices can deliver an economic benefit over conventional uniform orchard management tools. Significant variation in fruit quality has been shown within individual kiwifruit vines (Smith et al. 1994), and across small production areas (c. 0.5 ha) of apples and grapes (Bollen et al. 2001), and this variation has been linked to orchard profitability (Praat et al. 2003b).

The null hypothesis of precision agriculture is that given the large temporal and spatial variation in crop attributes then the optimal risk aversion strategy is uniform management, subsequent investigation has refuted this proposition (Bramley and Proffitt 1999). The authors proposed that the adoption of precision agriculture was potentially highly profitable, and subsequently demonstrated selective harvesting of grapes to increase the value of production by over $ 30,000 ha^{-1} (Bramley and Proffitt 1999; Bramley et al. 2003). Before accepting a precision horticulture approach it needs to be determined whether patterns of within orchard variation are consistent from year to year (Bramley and Hamilton 2004) and whether the crop displays enough variation – both in terms of magnitude and spatial distribution – to warrant a change from uniform management (Pringle et al. 2003).

Weiner and Solbrig (1984) expressed dissatisfaction with the traditional statistical measures of variation used in describing the highly dynamic patterns in the structure of populations and proposed the use of methods developed in economics to evaluate inequality in wealth, including the Lorenz curve and Gini coefficient (G). The

Lorenz curve is widely used in economics to describe the inequality of wealth distribution, where G summarises the total amount of inequality (Lorenz 1905; Weiner and Solbrig 1984). Lorenz curves and G have become common tools in population biology but have received scant attention in addressing agronomic issues (Vega and Sadras 2003). Relationships between G and crop yield have been reported in wheat (Pan et al. 2003) and maize (Sadras and Bongiovanni 2004). Variation in maize grain yields has been described using G, with G highlighting the relative contribution of low- and high-yielding sections of the production area to total yield (Sadras and Bongiovanni 2004).

Adoption of zonal management strategies, such as selective harvesting to maximise grower returns, requires an understanding of crop variability in time and space (Cuppitt and Whelan 2001). The present study investigates between-vine variation in income generation within an orchard area across consecutive growing seasons to quantify both the magnitude and spatial component of variation to assess the potential for zonal management of commercial kiwifruit plantings.

Materials and Methods

Measurements of vine production and fruit quality were made on a commercial kiwifruit orchard in Te Puke, Bay of Plenty, New Zealand (37 °49 'S, 176 °19 'E), over three consecutive growing seasons (2002/03, 2003/04 and 2004/05). The orchard area was selected because historical records indicated that the block produced a highly variable crop. The vines were mature (>10-year-old) *Actinidia deliciosa* (A. Chev.) C. F. Liang et A. R. Ferguson var. *deliciosa* 'Hayward' kiwifruit plants trained on a pergola trellis. The rootstock was unknown but assumed to be seedlings of open-pollinated *A. deliciosa* var. *deliciosa* 'Bruno', the most common rootstock used in the New Zealand kiwifruit industry. The orchard area studied was a 0.17 ha block (30 x 65 m) with rows 4.6 m apart and vines spaced at 4.5 m within rows (84 vines in total). Vines were uniformly managed under standard commercial practices (Sale and Lyford 1990).

Each season when the block attained commercial harvest maturity (6.2 °Brix), vines were harvested individually. Fruit numbers and quality characteristics were determined on a commercial kiwifruit grader (Compac™ grading equipment, Auckland, New Zealand) fitted with a near infra-red grading (NIR) system (Taste Technologies Ltd, Auckland, New Zealand). For each fruit the grader measured fruit weight, and the NIR system provided a non-destructive estimation of fruit dry matter (DM) content. A calibration fruit set was used to determine a correction factor between NIR estimates of fruit DM and a standard destructive measure of DM (McGlone and Kawano 1998).

Income per individual vine was determined across seasons using the New Zealand industry payment schedules of 2004 (Zespri International Ltd 2004) and reported as income/ha. The payment schedules were based upon a base fruit payment with a differential fruit payment for fruit size and a premium payment for high DM fruit.

To quantify the extent of between-vine variation in income the measure of 'spread' was calculated. Spread is defined as the range divided by the median, expressed as a percentage and has been suggested to better indicate the magnitude of between-vine variation, despite sensitivity to outliers, than other measures of dispersion, such as the more commonly used coefficient of variation (Bramley and Hamilton 2004).

To determine the contribution of individual quality parameters (vine crop load, fruit weight and fruit dry matter content) to vine income, discriminant analysis was performed in SPSS software.

To investigate the persistence of the spatial patterns of between-vine variation in income two approaches were used to group vines into populations of distinct incomes: quartile scoring and k-means clustering.

Quartile scoring is a modification of the procedure developed by Diker et al. (2003) and subsequently modified by Bramley and Hamilton (2004) (Diker et al. 2003). For this study annual vine income was assigned to one of four groups based on which quartile of the overall distribution for any given year the vine performed in. The resulting summation of quartile scores (QS) across the three-year study period yielded scores ranging from 3 to 12, a greater range of detail than the methods used by earlier authors. Vines were deemed to be consistently high income earners with a QS≥9, and consistently low income earners with a QS≤6. Vines with intermediate scores (7–8) were discarded from the analysis as such vines could not be distinguished between being consistently average across the study period to those vines whose performance (QS) varied between seasons.

The second method used to delineate vine populations of distinct income profiles was k-means clustering. This technique has been successfully used for the delineation of management zones using such information as yield, elevation and soil electrical conductivity (Cuppitt and Whelan 2001; Bramley and Hamilton 2004; Bramley 2005). In the present study, the goal was to identify vine populations with similar incomes across seasons. Vine income for each season was normalised against the average income for that season to facilitate between season comparisons of individual vine performance on a uniform scale. Each season's normalised measurements were used as a

Table 1. Summary statistics of 'Hayward' kiwifruit vine (n=84) gross income across consecutive seasons (2003–2005).

Period	Average vine income ($)	Standard deviation ($)	Coefficient of variation (%)	Spread (%)	Gini coefficient
Season 2003	38.95	29.12	75	272	0.208
Season 2004	126.49	31.19	25	131	0.067
Season 2005	149.67	36.16	24	117	0.068

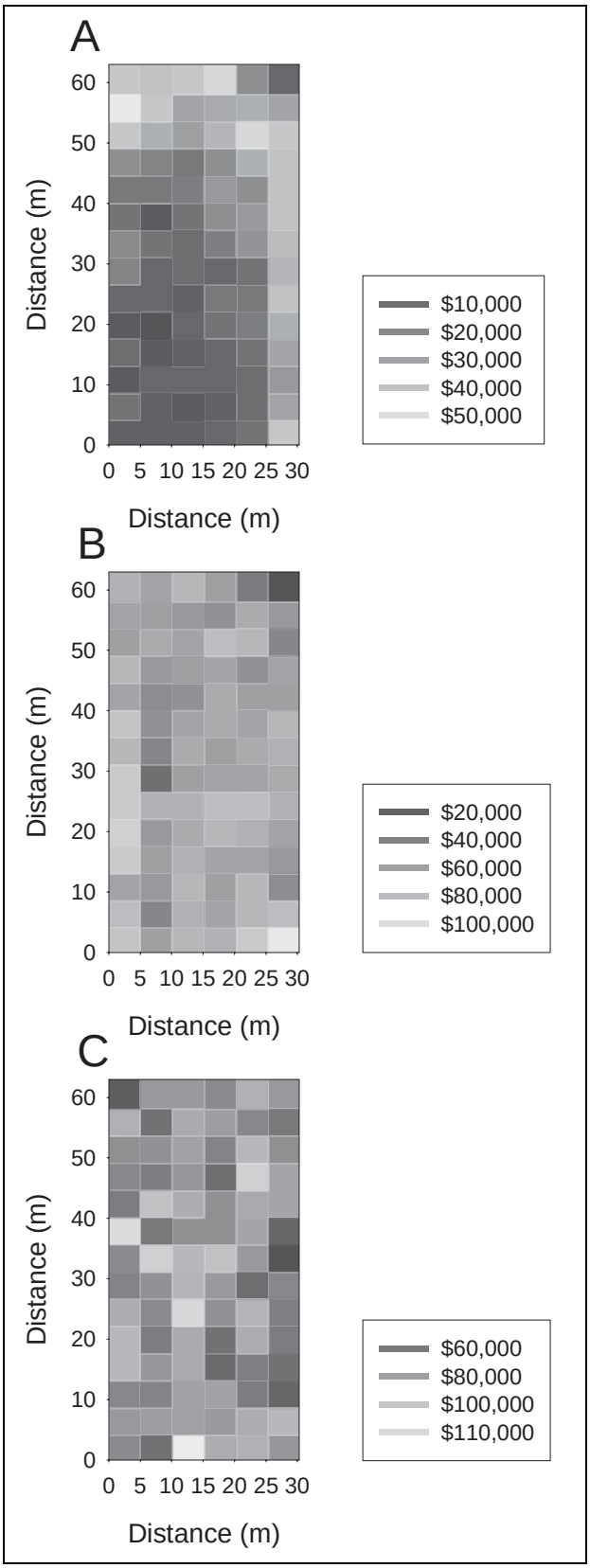


Fig. 1. Raw variation in 'Hayward' kiwifruit vine incomes ($ ha^{-1}) per individual vine in a 0.17 ha Te Puke orchards block: A: Season 2003; B: Season 2004; C: Season 2005. Each season is mapped on its own scale to highlight between vine variation within any one season, and differences of scale between seasons.

variate in the clustering. Vine membership of high and low income clusters was determined using PROC FASTCLUS in the SAS system.

The spatial structure of the between-vine variation in income and vine groupings were quantified using Moran's I statistic (Jaynes et al. 2005). Moran's I statistic is similar in concept to correlation and ranges from −1 to 1. A Moran's I near −1 indicates that members of different clusters are evenly interspersed across the field like the coloured squares of a checkerboard. A Moran's I = 0 indicates a completely random distribution of the clusters and a value near 1 indicates that members of a cluster are grouped closely together in space.

To define the range of spatial dependence of between-vine income variation, variograms were calculated for each season using the PROC VARIOGRAM procedure of SAS.

To construct Lorenz curves, gross incomes per vine were ranked from lowest to highest, and the cumulative fraction of total income (y) was plotted against the cumulative fraction of the population (x). The upper limit of this curve is the y = x line indicating perfect equality. G quantifies the area between the Lorenz curve and the line of perfect equality (y = x) expressed as a fraction of the area under the y = x line. It ranges from 0, when all units are equal, to a theoretical maximum of 1 in an infinite population in which all units but one yield 0 (Weiner and Solbrig 1984). Polynomials were fitted to describe Lorenz curves in SigmaPlot (Version 8.0), and G was calculated from the fitted curves (Weiner and Solbrig 1984; Harch et al. 1997).

Results

Variation in vine income was marked, both between-vines within seasons and between seasons (Table 1). Inter-vine variation was greatest in the 2003 season, and this can be attributed to a spring frost disrupting flowering, an event that reduced crop loads throughout most of the block, with only vines located next to shelter belts escaping damage and carrying what can be considered normal commercial crop loads into the 2003 harvest. In the two subsequent 'normal' seasons of 2004 and 2005; average vine incomes were higher, variability between vines was less (measured by coefficient of variation (CV) and spread) and inequality between vines was less (Gini coefficient).

Maps of vine income provide a visual representation of the spatial distribution of income generation across the orchard block in each season and how these distributions varied between-seasons (Fig. 1). To quantify the spatial component of between-vine income variation variograms were calculated for each season's data (Fig. 2). Variograms show spatial relationships between vines varying with season. The frost event of 2003 was the key event of the entire study period that created extreme spatial relationships. The strong spatial pattern observed in 2003 is best described as a linear relationship whereby vines were increasingly dissimilar with increasing separation distances. The season 2005 variogram was relatively flat and dominated by a large nugget effect (variation at zero separation distances which in this study is indicative of within vine variation) suggesting a non-spatial distribution of vine income across the orchard block in season

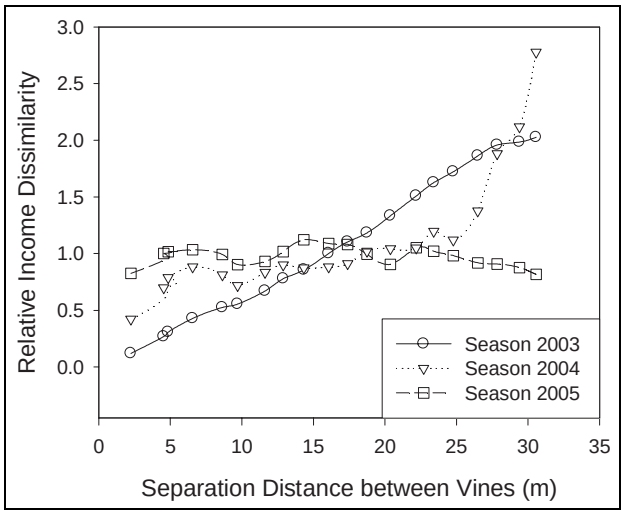


Fig. 2. Spatial dependence of 'Hayward' kiwifruit vine income distribution: variograms used to model the overall spatial correlation within each season. Experimental variograms were calculated for each season and points connected with lines to illustrate trends only.

2005. The season 2004 variogram appears to be an intermediary result with a large nugget effect but then a linear relationship emerging at larger separation distances (possibly a lag effect of the previous season's frost event). Moran's I statistic confirmed the variogram analysis with values of 0.73, 0.24 and 0.05 for the spatial structure of between-vine variation in the 2003, 2004, and 2005 seasons respectively. Moran's I indicated a strong spatial structure to the distribution of vine income within the orchard block in 2003 and an increasingly random distribution of vine income in the subsequent two seasons of 2004 and 2005.

The temporal stability of the spatial patterns identified were investigated by grouping vines into consistently high and consistently low performing categories using the two different approaches of quartile scoring and k-means clustering; this was done to assess the feasibility of zonal management strategies. Both approaches identified similar vines within the orchard block that had consistent income characteristics across seasons (Fig. 3 and Table 2) suggesting there was a temporally stable effect on vine productivity and quality patterns. Mean vine in-

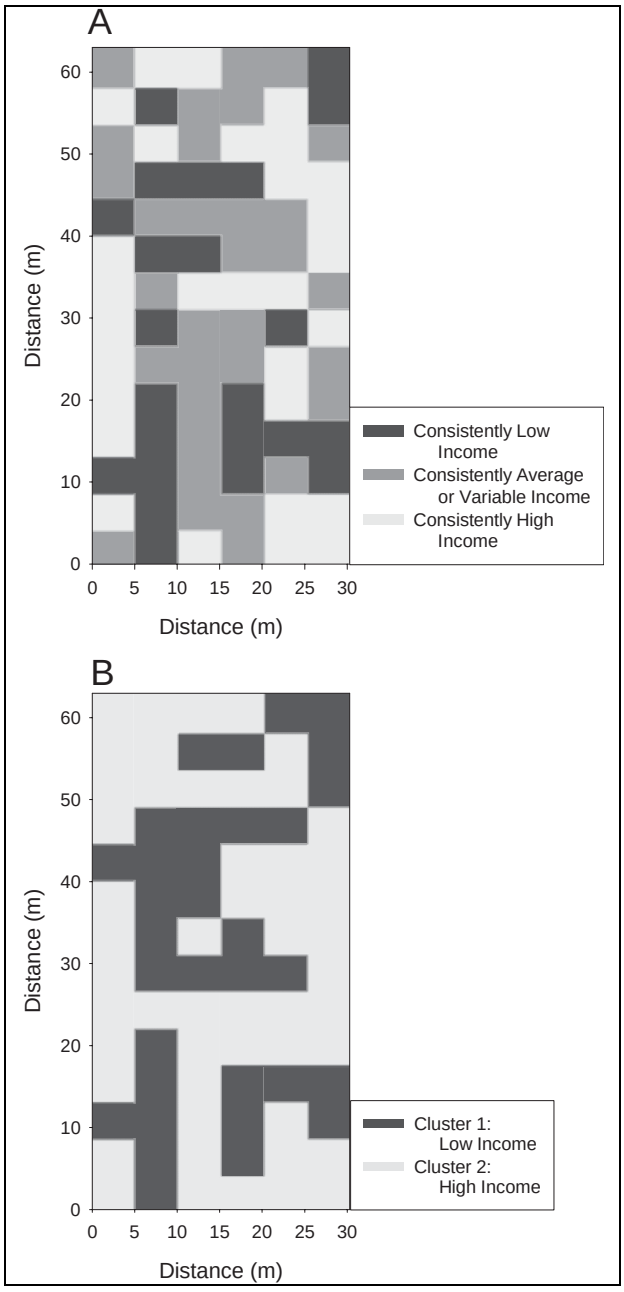


Fig. 3. Analysis of persistence in the patterns of income variability between 'Hayward' kiwifruit vines across three consecutive seasons (2003–2005). Vine location of high and low income vine groups derived from quartile scoring (A) and k-means clustering (B).

Table 2. Average income per 'Hayward' kiwifruit vine population identified through k-means clustering and quartile scoring. Income values (all in $) presented are means ± 1 SEM.

Period	k-means clustering		Quartile scoring	
	Cluster 1	Cluster 2	Low quartile score (≤6)	High quartile score (≥9)
Season 2003	28.49 ± 3.82	45.72 ± 4.39	24.99 ± 4.52	48.55 ± 5.68
Season 2004	104.75 ± 4.49	140.55 ± 3.64	107.88 ± 6.08	142.99 ± 5.23
Season 2005	147.05 ± 6.25	151.36 ± 5.12	126.47 ± 5.16	163.36 ± 6.89
All Seasons	93.43 ± 5.71	112.55 ± 4.61	86.45 ± 6.14	118.29 ± 6.38

come increased with increasing quartile score and with cluster group although the rate of response varied with season (Table 2). For example, season 2005 exhibited a less marked difference between clusters than observed in 2003 and 2004.

To further test the validity of the high/low income vine groupings and quantify the contribution of individual fruit quality parameters to vine income, a discriminant analysis was conducted. This classified 83.7 % of vines to their correct income type (high/low income, quartile scoring/clustering) based on season, vine crop load, average fruit weight and DM content. Of the predictors, crop load was given the greatest weighting in the discriminant function, and further analysis demonstrated that crop load differed significantly ($P<0.05$) between the high and low income vine types identified with quartile scoring and k-means clustering. Vine income was primarily determined by vine crop load.

The spatial structure to the location of high and low income vine populations was quantified with Moran's I statistic. The values of 0.18 and 0.19 for the vine types identified by quartile scoring and clustering, respectively, indicate that the spatial distribution of these vine populations within the orchard block was essentially random and not conducive to the adoption of zonal management strategies.

Variation in vine income was investigated using Lorenz curves and frequency distributions of vine incomes across 3 seasons (Fig. 4). The season with the highest inter-vine variation was 2003 (Table 1), this is also apparent with the highest deviation of the 2003 Lorenz curve from the line of perfect equality. This shows the 2003 season crop to have been skewed towards lower incomes, with 50 % of the total income coming from ≈35 % of the vines, and is reflected in the high Gini coefficient of 0.208. In seasons 2004 and 2005 vine income was more homogeneous with Gini coefficients of 0.067 and 0.068, respectively, and, lacking the extreme disparities seen in 2003. This suggests that there was a positive relationship between orchard area income and vine homogeneity (a negative relationship with the value of G). The Gini coefficients for the populations of high and low income vines identified by quartile scoring and clustering were determined and correlated with the average income of each income group (Fig. 5). As predicted the high income groups had lower Gini coefficients than those of the low income groups,

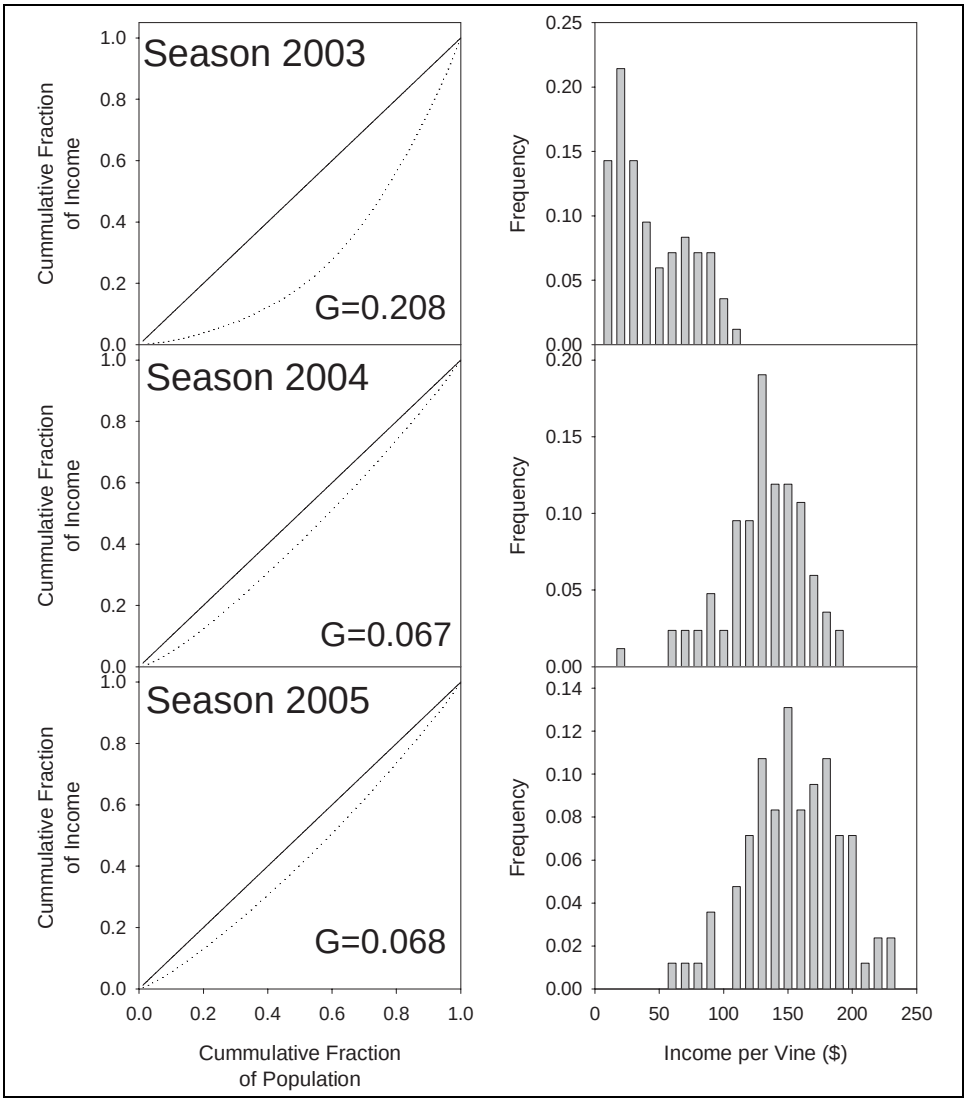


Fig. 4. Lorenz curves and frequency distributions of gross income per 'Hayward' kiwifruit vine across 3 seasons. Within each season the solid line represents the line of perfect equality, the dotted line represents the modelled Lorenz curve for the vine population within the season. The Gini-coefficient (G) is defined as the area between the line of perfect equality and the Lorenz curve, and is higher in inequitable populations (season 2003) than in equitable populations (seasons 2004 and 2005).

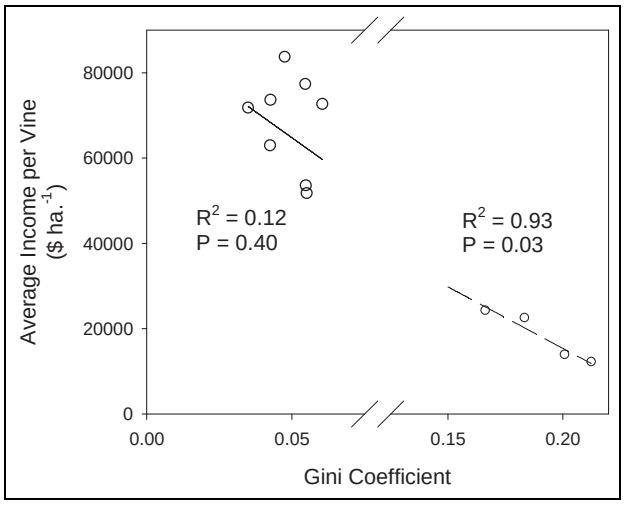


Fig. 5. Relationship between income and Gini coefficient (G) of 'Hayward' kiwifruit vines: Comparison between high and low income vine populations as identified by quartile scoring and clustering for each season studied (2003–2005). The relationship between G and income is modelled separately for equitable populations (G<0.1) and inequitable populations (G>0.1) with linear models.

meaning high income groups were characterised by a greater level of homogeneity between vines. A significant (P<0.05) inverse relationship between vine income and Gini coefficient was observed in inequitable vine populations (G>0.15). In homogeneous vine populations (G<0.10) the relationship was not significant (Fig. 5).

Discussion

If we are to pursue zonal management strategies we must first examine the magnitude of variation. If the magnitude of variation is too small to economically justify the additional cost of zonal management then uniform management is the preferred management strategy (Cuppitt and Whelan 2001). A comparison of the levels of variability observed between-seasons illustrates that 2003 was the most variable and least equitable season with the greatest potential for zonal management. Selective harvesting strategies could have been pursued to isolate frost affected vines. The subsequent seasons of 2004 and 2005 displayed reduced but still significant levels of between-vine variation. The standard deviation is the most common measure of statistical dispersion and measures the average distance of the data from its mean, independent of that mean. The CV and spread are additional measures of dispersion in which variation is calculated relative to the mean value. This is why we noted standard deviation to increase with increasing average vine incomes over the course of the study period while CV, spread and Gini coefficient declined. He et al. (2005) noted that, conceptually, G is a different statistical parameter from traditional measures of population variance. While variance measures the extent to which individual observations of a data set are dispersed around their mean, and can be any value, G is an indicator of inequality, i.e. the degree of variation from a situation where all individuals are equal, and ranges between 0 and 1 in value (He et al. 2005).

Discriminant analysis revealed that income and between-vine variation in income was primarily determined by crop load. However, as payment schedules move towards a greater weighting on fruit quality attributes, then volume will no longer be the key driver of income. Indeed, within the New Zealand industry the taste payment (DM content) of the 2005 season was 20 % and 55 % of total fruit value for 'Hayward' and 'Hort16A' kiwifruit respectively (Zespri International Ltd 2005).

The agronomic implications of the inequality of plant income generation are substantial (Fig. 5), with the relevance of G being summarised with an inverse relationship with income. It could be considered that the inverse relationship observed here between vine income and G was largely driven by the difference between 2003 and the 2004–05 seasons. The spring frost event led to higher Gini coefficients in season 2003 as vines were differentially affected. Pan et al. (2003) used Lorenz curves and Gini coefficients to characterise variation in wheat crops along a gradient of water availability in China. They found an inverse relationship between harvest index and G, which is consistent with the inverse relationship between grain yield and G identified by Sadras and Bongiovanni (2004) and the inverse relationship between vine income and G reported here. Pan et al. (2003) reported the range of G between wheat crops to be from 0.067 to 0.190, while the study of Sadras and Bongiovanni (2004) observed a range of 0.027 to 0.191 in G. These reported values of G are comparable to those observed in the present study (0.035–0.212). Pringle et al. (2003) highlighted the importance of deciding whether a crop displays enough variation – both in terms of magnitude and spatial distribution – to warrant a change from uniform management to site-specific management. Lorenz curves and G provide this information; presenting crop heterogeneity in terms of inequality, and highlighting the relative contribution of low- and high yielding sections of the block to total orchard block income. However, the problem remains in that they provide no information on the spatial nature of the variation. The use of Lorenz curves enabled Sadras and Bongiovanni (2004) to illustrate that 50 % of a maize crop contributed approximately 20 % of paddock yield; they noted this information was valuable to growers yet was not self-evident from yield maps. In the present study Lorenz curves illustrated the inequalities between-vines in income generation within a single orchard area over time. Such vine-to-vine variation can have dramatic consequences for crop structure and functioning (Sadras 1996; Hide et al. 1997) and thus has agronomic implications.

The approaches used in the present study to construct potential management zones used crop production data directly to identify areas within a cropping system where plants respond similarly over years. Such methods assume that if crop production patterns are similar over time then the areas must respond similarly to weather variability and management inputs and may function as effective management zones (Lark and Stafford 1997; Lark 2001). Similar methods have been used previously to successfully delineate management zones for corn (Jaynes et al. 2003), wheat and maize (Yamagishi et al. 2003), and soybean (Jaynes et al. 2005). In the present study we used measures of kiwifruit vine income and

identified vines with consistently different income levels between years; and the location of these vines within the orchard area was consistent across seasons. The similarity in the location of high and low income vines delineated by quartile scoring and clustering approaches suggested the spatial patterns to the distribution of vine populations within the orchard block were temporally stable. 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 can not be used with confidence for predictive management strategies (PRINGLE et al. 2003). LAMB et al. (1996) reported that grain yields were not spatially consistent from year to year in a continuous maize-soybean cropping system (LAMB et al. 1996). Temporal stability in patterns of spatial variation has been demonstrated within an orchard block of 'Braeburn' apples classified into high and low value fruit classes (PRAAT et al. 2003a). However, the lack of aggregation in the location of the high and low income vine populations identified does not lend itself to commercial implementation of zonal management strategies and suggests uniform management practices may be more appropriate. Cropping systems exhibiting strong spatial structure, such as contiguous zones of similar crop productions are more conducive to site-specific management practices (PRINGLE et al. 2003). The lack of aggregation in the location of vines with similar income characteristics noted here could suggest that the patterns identified were the result of individual vine effects rather than environmental effects. These vine effects may be genetic, resulting from the use of seedling rootstocks, or the cumulative impact of the individual vine histories. Differences in early growth and development are compounded with time, leading to highly dynamic patterns in the structure of populations (HARPER 1977). Presumably such differences would be exacerbated in a perennial cropping system such as kiwifruit.

Conclusion

Despite substantial spatial and temporal variation in income generation between vines within this orchard block, uniform management practices are still the preferred option. We conclude that zonation of vines within an orchard area may not always be where the effort in managing variation should be directed.

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