Apple Futures: New Zealand's low pesticide residue apple production programme

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Abstract Apple Futures was a 3-year initiative (2008–10) to implement a low pesticide residue production system for New Zealand apple growers targeting European Union (EU) supermarket food safety initiatives. Its objectives included reducing pesticide residues to $\leq 10\%$ of the EU maximum residue limit and a maximum of three residues detected in any sample. By 2010, $>65\%$ of export crops were grown following the Apple Futures programme that maximised early season disease management, re-positioned all pesticide use to minimise residues and increased use of non-insecticidal methods. No insecticide residues were detected in 72% of crops while the remainder had very low residues. New Zealand's maritime climate restricted disease management outcomes; low residues of captan were found in most crops, only 9% had no fungicide residues. An economic analysis of Apple Futures found no impact on production costs, while it preserved \$113M in market revenue from EU exports between 2008 and 2011.

Keywords New Zealand apples, Apple Futures, insecticides, fungicides, residue profile.

INTRODUCTION

The export-dominated New Zealand apple sector is challenged by frequent changes in marketing and regulatory sanitary and phytosanitary requirements to maintain access to over 65 international markets. In the mid 1990s, it was challenged by food safety scares in the UK that led to new restrictions on pesticide use and a demand for more environmentally responsible production systems. The sector responded in 1996 with the introduction of an Integrated Fruit Production (IFP) programme (Batchelor et al. 1997; Manktelow et al. 1997; Walker et al. 1997, 1998) that by the late 1990s had transformed the entire crop protection system for apples. New monitoring systems eliminated calendar

applications and this resulted in significantly reduced total pesticide use (Walker et al. 2009), while a change from broad-spectrum to selective pesticides greatly increased the contribution of biological control (Shaw & Wallis 2008). Now $>90\%$ of apple exports are grown in accordance with the IFP programme while the balance of export production is grown following internationally accredited organic standards.

From the early 2000s, European supermarkets continued to expand their environmental and food safety compliance programmes (e.g. GLOBAL G.A.P. (2015)) to ensure the integrity of their food safety programmes. The New Zealand pipfruit IFP programme had introduced major benefits

for growers, the environment and consumer food safety. However, in 2005, in response to the actions of food safety groups, a number of UK and EU supermarkets began to implement private pesticide residue reduction standards; up to 50–70% less than the allowable EU regulatory maximum residue levels (MRLs). While many European growers viewed this demand for produce with lower than the legally approved residues as a threat, New Zealand growers identified this as a potential marketing opportunity that might also simplify the complexity of managing residue compliance into different global markets.

In 2006, following a strategic review (Innomarc 2006) and pilot testing of low-residue crop protection regimes, the sector set out to implement a practical production system for apples that resulted in ultra low, or even zero, residues on fruit at harvest. Known as 'Apple Futures', this programme was funded by New Zealand Trade and Enterprise and the sector (Pipfruit NZ Inc.) for 3 years (2008–10), with a total cost of approximately \$3.2M. The specific objectives of the Apple Futures programme included: (1) reducing average residue levels to $\leq 10\%$ of the EU MRL for each pesticide and (2) reducing the number of residues detected in any export consignment to three or fewer.

By 2006, several of the sector's research projects had already evaluated specific low-residue pest and disease management options for apple black spot (*Venturia inaequalis*), the most important pathogen, and codling moth (*Cydia pomonella*), the major phytosanitary insect pest. In spring 2007 the new Apple Futures programme integrated these strategies into a low-residue approach that included: (1) ensuring highly effective early-season strategies for pathogen control, (2) restricting the use or extending the pre-harvest interval of the more residual pesticides, (3) greater use of non-residual methods for pest control (e.g. pheromone mating disruption), (4) limiting pesticide options in mid/late summer with priority given to less residual or biological pesticides and (5) developing residue decay profiles for all major pesticides to determine probable intervals to achieve nil detectable residues at harvest.

In the first season (2007–08), 85 growers based mostly in Hawke's Bay and Otago, participated in the Apple Futures programme. It included: (1) adherence to new crop protection regimes, (2) supply of spray diary information and (3) supply of fruit to a comprehensive residue-testing programme. Grower confidence for low-residue crop protection regimes was assisted by specialist-led crop protection training programmes. Growers also had access to new crop disease risk prediction models and new residue management information and tools via the sector's website. Three regional coordinators (the Nelson region joined the programme in year two) also identified and responded to local crop protection issues and assisted with the collection of fruit samples for the residue testing programme. Annual reviews of Apple Futures residue performance were presented to growers and, together with their feedback on fruit quality and residue test outcomes, new or improved recommendations were supplied to participating growers in late winter each year. By 2010, 144 growers were involved and $>65\%$ of apples exported were grown following the Apple Futures programme.

This paper evaluates the consequences of recent changes in the pipfruit sector's crop protection system on the pesticide residue profile of New Zealand apples, comparing outcomes from the 2000, 2010 and 2014 seasons.

METHODS

Residue testing

Traceability of fruit production with full reporting of spray diary information is a mandatory component of the sector's compliance programme to meet regulatory export certification requirements. Prior to 2001 residue testing of export apple crops was undertaken by ENZA. Residue data from their 2000 random residue programme were used for comparison because the IFP programme was nearing full implementation and the sector was not yet responding to any early market demand for fruit with even lower pesticide residues.

Data from 2010 were used as this was the final year of Apple Futures implementation

and represented three seasons of programme refinement. Recent residue data (2014) are also presented to confirm the durability of the Apple Futures programme and the ongoing adaptation of it by the sector to meet the requirements of increasingly important Asian export markets. Identical sample collection procedures and analytical test methods were used in both ENZA and Apple Futures residue sampling programmes.

Growers participating in the Apple Futures programme allowed team members access to their test results in return for discounted residue test charges; the number of residue tests completed each season varied from 399 in 2008 to 1125 in 2010, with increasing grower participation in the Apple Futures programme. Residue sampling was completed on both early and late apple cultivars on each orchard in accordance with CODEX procedures. Each sample comprised of ~1.5 kg fruit placed in double polythene bags that were sent to an accredited analytical laboratory for processing within 24–48 h. Samples were fully traceable from each orchard and were collected from each cultivar block 10 days prior to harvest, again at harvest and later from packed cartons. Residue data for the 2000, 2010 and 2014 seasons reported in this paper were taken from fruit sampled from packed cartons only.

Up to five analytical methods were used for residue analysis that were reported in mg/kg: gas chromatography mass spectrophotometry (GCMS), liquid chromatography mass spectrometry (LCMS), dithiocarbamate fungicides (e.g. metiram, mancozeb, thiram, ziram) as CS₂, dithianon and captan (including its metabolite tetrahydrophthalimide or THPI). The testing procedures used allowed detection of some 400 analytes including residues of all of the active ingredients that were registered for use on apples in New Zealand, and many more. Increasing sensitivity of analysis lowered the level of detection (LOD) for some active ingredients and this is appropriately identified where this may have influenced the outcomes.

Data collation and analysis

All pesticides applied to apple crops are fully traceable through their unique property

identification number and ultimately to designated blocks within an orchard. This information is captured each year and stored within a comprehensive database of pesticide use. While growers have always had access to their individual residue test results, the authors were able to access the residue data linked to pesticide use in each participating orchard-specific cultivar block. This allowed analysis of the major factors contributing to residues present on fruit at harvest, e.g. the pre-harvest interval (PHI), the cumulative number of applications or spray application volumes. All residue data in this paper are referenced against EU MRLs as a benchmark of programme performance. Some EU MRLs changed between 2000 and 2014. Unless stated otherwise, all references in this paper are benchmarked against the 2014 EU MRL.

RESULTS

Trends in pesticide use

Pesticide use in the sector declined substantially between 1996 and 2005 with its transition to IFP (Figure 1). The frequency of insecticide application decreased by almost 60% to ~4 applications per season with growers applying several different insecticides as part of a resistance management strategy. Organophosphate insecticides were increasingly replaced by selective insecticides (e.g. tebufenozide, indoxacarb). IFP also resulted in a similar reduction in use of protectant fungicides (e.g. captan and dithiocarbamates), use of which declined from ~14 applications to ~6 applications by 2000 (Figure 2).

Residue test results are presented in the context of these changes to the frequency of insecticide and fungicide applications on apple crops nationally. In 2010, the final season of Apple Futures implementation, 25 active ingredients were recorded across sector spray diaries but only 18 were detected in residue tests and 8 of these were rare detections. Therefore, only data (Figure 3) for active ingredients that were found in ≥3% of the fruit samples tested in any one of the three seasons (2000, 2010 and 2014) are presented. The mean values of the residues detected in these positive tests are presented for each of the active ingredients in Figure 4.

Figure 1 Mean insecticide use on apples ('Braeburn') nationally. Organophosphate use declined as use of selective and biological products increased following implementation of Integrated Fruit Production (1996-2001) and Apple Futures (2008-10). Selective insecticides included insect growth regulators, neonicotinyl and ryanidone compounds, biological insecticides included codling moth granulosis virus, spinosad and emamectin benzoate.

Figure 2 Mean protectant fungicide (captan and dithiocarbamate) and dodine use on apples ('Braeburn') nationally following implementation of Integrated Fruit Production (1996-2001) and Apple Futures (2008-10).

Pesticide residues in 2000

Despite near sector-wide implementation of IFP in 2000, azinphosmethyl residues were still detected in 20% of residue tests with a mean residue of 0.10 mg/kg or 20% of the EU MRL in 2000 (Figure 3). Azinphosmethyl has not been used on New Zealand pipfruit since 2001. Chlorpyrifos was also detected in 42% of tests with a mean value of 0.05 mg/kg or 10% of the EU MRL (Figure 4). The 2001 cancellation of chlorpyrifos use on apples in the USA eliminated all subsequent post-flowering use on New Zealand apple crops. Carbaryl (applied for crop thinning) was present in 5% of residue tests in 2000 but this declined to 0.2% of tests by 2014. The reduction in carbaryl use was brought about by the effective withdrawal of the EU MRL, which was reduced to the limit of detection (LOD) of 0.05 mg/kg. The absence of an EU MRL for tebufenozide in 2000 meant that it was

not reported as a residue in that year, but by 2003 the frequency of tebufenozide residues detected had increased to 97% of tests with a mean residue was 0.07 mg/kg (J.T.S. Walker, unpublished data). The insecticides methoxyfenozide, chlorantranilprole, thiacloprid and spirotetramat were neither registered nor available for use on apples in 2000.

The dithiocarbamate fungicide group (e.g. mancozeb, metiram) and dodine were the dominant fungicide residues in 2000, detected in 76% and 68% of residues tests respectively (Figure 3). The mean residues in positive dithiocarbamate and dodine tests was 0.22 mg/kg and 0.18 mg/kg respectively (Figure 4) or just 7% and 18% of the 2014 EU MRL respectively (Figure 5). The low frequency of captan residues (16% of tests) was associated with low use in 2000 due to a lack of captan residue tolerances in Taiwan in 2000.

Figure 3 The frequency of pesticide active ingredients detected in residue tests conducted on New Zealand apples in 2000 (n=297) and following the introduction of the Apple Futures ultra-low residue production programme in 2010 (n=392) compared to 2014 (n=407).

Figure 4 The mean residue (mg/kg) in positive residue tests for the most commonly detected pesticides on apples in 2000 (n=297) and following the introduction of the Apple Futures ultra-low residue production programme in 2010 (n=392) compared to 2014 (n=407).

Residue profiles following Apple Futures

Since the introduction of IFP, codling moth has become the primary target of insecticides applied to New Zealand apple crops. To reduce the frequency of residue detection and residue values, Apple Futures restricted use of residual insecticides, including tebufenozide and methoxyfenozide, to early summer so consequently these were only detected in 5% and <1% of samples respectively at the completion of the programme in 2010 (Figure 3). By 2014 their frequency of detection had increased to 19% and 5% of samples respectively, driven by an increasing proportion of export crops being targeted for markets with a nil tolerance for codling moth (e.g. Asia). The mean value of these residues was 0.03 and 0.04 mg/kg respectively (Figure 4) or

3% and 2% of the 2014 EU MRL respectively (Figure 5). Residues of chlorantraniliprole, used by growers until mid summer, have remained relatively rare, being detected in just 4% of tests in 2014. Thiacloprid residues were detected in 18% of tests in 2010 with a mean residue of 0.03 mg/kg or 10% of the EU MRL. The long residual life of thiacloprid residues, together with growers trying to reduce the count of detectable residues in their crops, resulted in them being detected in just 0.5% of tests in 2014. While spirotetramat was not registered for use on apples in 2010, use of this selective insecticide for apple leafcurling midge (*Dasyneura mali*) control has increased since 2011, and residues were detected in 20% of 2014 samples with a mean residue of 0.02 mg/kg, or 2% of the EU MRL.

Figure 5 The mean residue expressed as a percentage of the 2014 European maximum residue level for the most commonly detected pesticides on apples for 2000, 2010 and 2014.

Apple Futures disease management emphasised the need for highly effective spring and early summer control to prevent primary *V. inaequalis* ascospore infections becoming the source of secondary conidial infection, and thereby reducing the need for fungicide applications in late summer. Minimising the count of residues in fruit samples also required growers to try and limit the number of fungicide active ingredients they applied in mid and late summer. To achieve this, captan became growers' fungicide of choice for late summer disease management, consequently detections rose to 86% of samples by 2010 and 93% by 2014. Some of this small increase in captan can be attributed to the inclusion of its metabolite THPI in the 2014 residue testing and reporting procedures. The mean value of these residues was 0.27 and 0.43 mg/kg or 9% and 14% of the 2014 EU MRL respectively. By restricting dithiocarbamate fungicide use to spring and early summer, the frequency of these residues in tests declined sharply to 21% in 2010 and just 12% in 2014; the mean residues detected in 2014 were 0.03 mg/kg or 3% of the EU MRL. New dodine fungicide resistance management guidelines (Beresford et al. 2013) combined with more effective early summer black spot control by growers resulted in its detection in just 6% of tests in 2014 with a mean residue of 0.04 mg/kg or 4% of the EU MRL. Myclobutanil residues were not detected in either 2000 or 2014 but occurred in 9% of tests in 2010 at just 0.02 mg/kg or 4% of the EU MRL. Similarly boscalid residues (a component of

Pristine®) were detected in 2010 at just 0.02 mg/kg, or 1% of the EU MRL.

A high proportion of samples tested (93%) met the UK/EU supermarket requirements of ≤ 3 residues in 2010 (Figure 6), the final year of the Apple Futures implementation programme. Insecticide residues were not detected on 72% of samples tested while a further 24% of samples had just one residue detected. These were mostly extremely low residues of spirotetramat or tebufenozide, just above their LOD. In contrast, very few samples (9%) were without fungicide residues, but a further 52% of samples had just one fungicide residue detected, mostly very low residues of captan (9% of the EU MRL).

DISCUSSION

While the MRL represents the highest acceptable level of a residue in food or produce that can be consumed by a person on a daily basis over an entire lifetime, without harm, Apple Futures was the apple sector's response to increasing consumer demand for produce with either no, or ultra-low residues. By minimising all pesticide residues, it simultaneously addressed two important issues for New Zealand apple growers; it turned a threat posed by EU demand for low-residue fruit into a marketing opportunity while also eliminating most of the global market residue and compliance difficulties that had confronted this export-focused sector. The programme goals, residues $\leq 10\%$ of the EU MRL and ≤ 3 residues on 93% of fruit

Figure 6 The percentage of insecticide, fungicide and total residues found in packed carton fruit samples tested ($n=341$) during the final year of the Apple Futures implementation programme (2010). The distribution of insecticide and fungicide residues is independent, so are not necessarily additive when compounded into the total residues across all of the samples tested.

samples, were achieved, while grower support and adoption of Apple Futures increased throughout the 3-year programme. The strategic re-positioning of insecticide use, combined with greater use of biological pesticides and mating disruption (Lo et al. 2013), enabled most growers to achieve either no (72% of crops) or ultra-low insecticide residues (~3% of the regulatory EU MRL) in 2010. The risk of wet weather diseases is relatively high in New Zealand's maritime climate so fungicide residues were more widespread. Only 9% of crops were free of fungicide residues in 2010. Nevertheless these residues, usually captan, were consistently low, ~9% of the regulatory EU MRL.

A published analysis by USDA of residues found on domestic and imported apples in the USA market in 2010 identified New Zealand apples as having the lowest average number of residues per sample (3.22) when compared to domestic (5.37) and Chilean fruit (4.78) (Warner 2012). New Zealand apples were also reported as having a 14- to 28-fold lower dietary risk index stating that they: 'had very few residues and posed only a slightly higher risk than organic apples' (Warner 2012).

An economic analysis of the Apple Futures in 2010 provided another illustration of the success of the programme. This found that Apple Futures had no impact on production costs, but at a cost of \$NZ3.2M, it preserved \$113M in market revenue between 2008 and 2011 (Kaye-Blake &

Zuccollo 2012). Kaye-Blake & Zuccollo's analysis concluded that, in each year of the programme, industry returns would have been between \$25M and \$35M lower without Apple Futures, or 7–10% of the industry's total revenue at that time. The benefit-cost ratio for the programme, assuming the otherwise significant loss of the Northern European markets, was greater than 30.

After three seasons of evaluating Apple Futures crop protection outcomes combined with comprehensive residue testing, it was apparent that an ultra-low residue production system was a more realistic outcome for New Zealand apple growers than a 'zero residue' programme. Furthermore, any inconsistencies in either grower performance or variable seasonal disease risks, and new advances in residue detection technology, could potentially threaten future claims of 'zero-residue' produce. Small increases in the frequency of both selective insecticide and fungicide use and residues occurred in 2014, driven by a shift in emphasis towards the increasing focus on Asian markets (tebufenozide for codling moth and spirotetramat for apple leafcurling midge) rather than any reduction in grower support for their ultra-low residue programme.

The earlier introduction of the IFP programme underpinned the success of the Apple Futures programme as it had all but eliminated organophosphate and broad-spectrum insecticide use by 2001. While this

change to more benign or selective insecticides was welcomed by growers, these insecticides were generally more persistent so that by 2003, some (e.g. tebufenozide) could be detected on most of the crops sampled, albeit at very low levels. Nevertheless, IFP had increased growers' willingness to embrace change and encouraged increasing adoption of tactics that were important to achieve the very significant Apple Futures pest management outcomes. This included greater use of residue-free control methods (e.g. mating disruption, biological pesticides and biological control) and limiting the use of any residual, selective insecticides to early summer.

Within the context of New Zealand's maritime climate, IFP disease management options were more constrained. Most of the 40% reduction in fungicide loading in IFP (Walker 2009) was achieved by reducing the number of protectant fungicide applications; from ~14 in 1996 to ~6 in 2000 and targeting applications to the major primary infection periods in spring and early summer. Less effective black spot control with this strategy on many orchards, together with resistance to some key fungicide groups (Beresford et al. 2013; Viljanen-Rollinson et al. 2013) and more stringent phytosanitary requirements in some markets, resulted in a resurgence of protectant fungicide use throughout the primary infection period under Apple Futures. Consequently, to minimise the count of residues on fruit, captan has become the primary protectant fungicide applied from early summer and therefore the most commonly detected residue at harvest, albeit at very low quantities.

The New Zealand apple sector has always produced apple crops with relatively low pesticide residues and has met the high standards of phytosanitary performance needed for export certification and access into all international markets. The success of the Apple Futures programmes, together with strong demand for ultra-low residue fruit by European supermarkets, has meant that this has now become the de facto crop protection standard used by New Zealand growers. A combination of high phytosanitary performance together with low pesticide residues has been invaluable to apple growers, as it has

provided them with greater financial returns through the increased flexibility to respond to commercial opportunities in all the international target markets. An important factor in the success of this ultra-low residue programme has been the absence from New Zealand of some of the major global pests of fruit crops. The future challenge for both the sector and New Zealand's border security programme will be to protect the economic, environmental and food safety gains achieved with this crop protection system from the increasing biosecurity risks arising from the globalisation of trade.

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