Physiological aging in taewa Māori

(Māori potatoes, *Solanum tuberosum*)

and the suitability of different cultivars for short season cropping.

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Abstract

Altering the storage regime of potato (*Solanum tuberosum*) seed tubers alters the performance of crops grown from those tubers. The size and nature of these effects are cultivar specific. Potato seed tubers progress through a number of stages during storage, a process known as physiological aging. The rate of aging is affected by many factors the most significant of which is the amount of warming (thermal time) the seed is exposed to during storage. Having seed tubers of an appropriate age can increase early crop growth and improve early yields. With the recent establishment of the Tomato-Potato Psyllid (*Bactericera cockerelli*, TPP) in New Zealand, shorter growing seasons have become desirable, as ongoing costs of controlling TPP on potatoes and other crops are significant. Taewa Māori (Māori potato; *Solanum tuberosum* ssp. *tuberosum & andigena*) have been grown in New Zealand for over 220 years and have developed into a range of potato cultivars unique to New Zealand. Taewa hold significant cultural value and are part of the story of early colonial New Zealand.

Seed tubers from three cultivars of taewa, Moemoe, Kowiniwini and Waiporoporo, were exposed to different periods of warming (thermal time, degree-days) prior to planting. All three cultivars displayed some level of resistance to the effects of physiological aging over the range of thermal time studied. However some effects were observed. There was an increase in tuber number with an increased thermal time in the cultivar Moemoe, but no change in tuber fresh weight in any treatment. The tuber dry matter in Waiporoporo was highest in tubers exposed to 728 degree-days indicating there may be an optimal amount of degree-days in terms of this parameter. The resistance of these taewa to physiological aging means growers might save on cool-storage costs by reducing storage time.

The early harvests and physiology of the three cultivars were assessed for their suitability to a short (90 day) season. The cultivar Waiporoporo showed the best yield characteristics for a table potato crop over a 90-day season. Waiporoporo set fewer tubers than the other two cultivars but the tubers it produced were larger and more suited to the table market. Waiporoporo had a higher tuber fresh weight than Kowiniwini and greater leaf area than Moemoe at 90 days after planting (DAP). Moemoe showed the best potential in terms of the salad potato, new potato and gourmet markets that require smaller tubers than the table market. Taewa growers looking to shorten their cropping season should consider using the cultivar Waiporoporo for the table market, and Moemoe for markets that require smaller potatoes.

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Candidatus Liberibacter solanacearum

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Chapter 1. Introduction

1.1 Taewa Māori.

Taewa Māori (Māori potatoes, *Solanum tuberosum,* ssp. *tuberosum & andigena*) is the collective name for a range of cultivars of potato, grown primarily by Māori, that have developed into a number of cultivars unique to New Zealand. Officially their introduction to New Zealand is credited to the early explorers, whalers, sealers and settlers, although some oral traditions maintain there was at least one cultivar native to New Zealand (Roskruge, 1999). There is also some evidence that the first cultivars were introduced prior to Captain Cook's arrival by Captain Stivers, from whom the name taewa may derive (Richards, 1993). The narrative and provenance of taewa can vary depending on the source of that narrative, however this difference is of little concern and reflects only the different experiences and history of various iwi and hapū around the country (McFarlane, 2007). Taewa hold the stories of early post-contact and colonial New Zealand.

1.2 Māori world-view.

Throughout their history in Aotearoa a close relationship has developed between Māori who grew taewa and the crop itself. The Māori world view is one where all things in the universe, both physical and spiritual, have a shared origin and as such can be viewed as being related or whanau (family) (Roberts *et al.*, 2004).

Circumstance and narrative are used to connect the people with the world around them in order to bring about understanding and respect of the world, its workings and the resources relied on for survival. This extends to horticulture, which historically provided food, tools and clothing as well as a deep connection to, and understanding of, the land.

Looking at the world through this lens Māori developed a philosophy that connects their identity with the land through ties of whakapapa (genealogy). The elements of the world around them, including crops and other food resources are considered family. Through their use, taewa were brought into the folds of whakapapa and as a result became connected to Māori identity and their sense of place (turangawaewae) (McFarlane, 2007).

1.3 Māori horticulture.

1.3.1 Colonisation.

The introduction of new crops such as taewa, as well as new horticultural tools, technology and practices initially led to growth in economic prosperity for many Māori as they became the market gardeners for the new settlers (Hargreaves, 1963; Petrie, 2002). They did so well in fact, that complaints were often heard on the part of the new settlers that Māori out-competed them in the produce markets (Petrie, 2002). Māori were the first exporters of produce from New Zealand, trading with Australia and having trading contacts as far away as the Americas. This resulted in a so-called golden age of Māori horticulture. There have since been attempts to resurrect this golden age, most notably by Sir Apirana Ngata in the 1930's (Morrell,

1955) however they have not been successful in returning Māori to the land and to horticulture. The more recent return to primary production from Māori resources by Māori is perhaps a signal of positive change (Te Puni Kōkiri, 2011b; Wood, 2013)

1.3.2 Modern Māori horticulture.

There has been a resurgent interest in Māori horticulture with the recent Māori renaissance that has seen an increased interest in Māori culture. Some of these efforts have been focused on creating opportunities for Māori in the primary sectors especially in a post treaty settlement period (Wood, 2013). It is seen as not only an economic opportunity, but also an opportunity to reconnect Māori with the land through returning to land-based activities (Roskruge, 2004). It is thought that this reconnection with the land will help in the process of reconnection with Māori identity, through the use of Māori crops and practices allowing Māori to fully participate in the opportunities of a modern world on their own terms (McFarlane, 2007).

Māori horticulture is dynamic and will continue to evolve. Neither Māori culture nor horticulture have ever been static, rather they have adapted as they faced contemporary pressures. Modern understandings around the physiology of plants and soil science as well as new technologies such as GPS in precision agriculture are needed if Māori are to compete on a level playing field with other producers.

Whilst there is much oral tradition around taewa, there is little modern scientific understanding of the physiology of taewa, how they compare to modern potatoes and how physiological differences between cultivars align to various cropping situations. One of the aims of this thesis is to quantify the differences between three commercially available taewa cultivars, Moemoe, Kowiniwini and Waiporoporo, and access their suitability to short season cropping.

1.4 Short-season cropping and the Tomato-Potato Psyllid (*Bactericera cockerelli*).

An important aspect of the relationship of Māori with the land is kaitiakitanga, or guardianship (Marsden and Henare, 1992). This is a philosophy of caring for the land and with respect to horticulture, involves the sustainable use of land. Having a shorter cropping season can promote sustainable and economic cropping, for example by reducing agrichemical use for pest and disease control. This has become particularly relevant with the recent establishment of the Tomato-Potato Psyllid (TPP) in New Zealand that has resulted in an increase in the use of insecticides.

1.4.1 Control of the Tomato-Potato Psyllid.

Since its arrival TPP has cost New Zealand potato growers over $100 million dollars in crop losses and extra control measures (Ogden, 2011). The most effective control programmes involve the weekly spraying of a number of insecticides, including organo-phosphates, which are being phased out of use due to their detrimental health and environmental effects (Scott, 2008). There has been a recent reassessment of organo-phosphates in New Zealand that has led to tighter restrictions on their use (EPA, 2013). Not only are such spray programmes costly, but they are in opposition with Māori ideals of kaitiakitanga that include sustainability.

A shorter cropping season can help avoid these issues by harvesting before TPP becomes an issue in mid-summer.

1.5 Physiological aging.

As well as the suitability of individual cultivars to a shorter season, the usefulness of physiological aging as an agronomic tool in taewa was also studied. Physiological aging is generally measured in terms of thermal time (degree-days; dd) however the phenomenon is complex (Reust *et al.*, 2001; Caldiz, 2009). Although many factors affect the rate of aging in seed tubers it is clear the variation in the amount and timing of thermal time is a major influence (Struik, 2006; Caldiz, 2009). It is also the most useful method for manipulating age, as it requires little extra input.

Aging can alter various crop yield and quality factors. These changes are often cultivar specific (Reust *et al.*, 2001; Struik, 2006). Adding further complexity to this, seed tubers from the same cultivar, raised in different conditions, can have varying responses to aging treatments (Caldiz, 2001). There is interplay between agronomic, environmental and genetic factors that come together to influence the effect of aging on the final crop yield. There has yet to be a single measure of age in potato tubers that can be adequately used to predict crop outcomes across different cultivars and environments (Jenkins *et al.*, 1993; Caldiz, 2009). To understand the effects of aging within a particular cultivar, it must be studied in that cultivar.

It is clear that exposure to thermal time alters the performance of seed tubers in many potato cultivars (Struik, 2007; Caldiz, 2009). Altering the storage regime of seed tubers through the timing, rate and length of warming changes the performance of the seed tubers. It offers a potentially simple, low input strategy that optimises seed tubers for specific uses and potentially saves on cool-storing costs. Optimising seed tuber quality for different production systems and environments can be achieved relatively easily.

One of the effects of aging seed tubers is to alter the growth rate and final yields of the potato plants grown from those tubers. Younger seed generally has a slower growth rate, but over time will have a higher yield than older seed (Wiersema, 1985; Struik, 2007). Older seed can have a faster initial growth rate, as well as set more tubers (*ibid*.). Older seed therefore can have increased yields over younger tubers over a shorter (90 day) season. The hypothesis applied in this thesis is that aging can be used in the cropping of taewa to improve the yield of a short season crop.

1.6 Aims.

- To study the suitability of three taewa cultivars to a short season cropping system in order that the impact of TPP may be managed.
- To see if seed tuber quality can be manipulated using physiological age in order to improve crop yield over a shorter season.
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1.7 Objectives.

- Assess the physiology of three cultivars of taewa: Moemoe, Kowiniwini and Waiporoporo.
- Determine which cultivar holds the best potential for short season cropping.
- Determine whether physiological aging can help improve the yield of a short season cropping window.
- Produce information that can be used for the avoidance of the peak TPP season and the optimisation of seed tuber storage regimes in taewa.
- Produce baseline information for the further study of taewa.
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1.8 Research Questions.

- Which taewa cultivar yields best over a 90 day cropping window?
- Can the performance of these three cultivars be manipulated through physiological aging?

1.9 Thesis structure.

The thesis begins by outlining Māori horticulture and its importance, making the case that taewa are valuable as both an economic and cultural resource. It then looks at the latest potato crop pest to enter New Zealand, the Tomato-Potato Psyllid (TPP), the phenomenon of physiological aging and how it can be used to manipulate seed tuber quality for different cropping situations. The methods and results are then outlined and the findings discussed. From this discussion, several conclusions are reached and recommendations given.

Chapter 2. Māori horticulture, development and the relevance of taewa

2.1 Introduction.

Māori horticulture has a long history of providing daily needs such as food, tools and clothing for Māori (Yen, 1990; Petrie, 2002).It is also inextricably linked to Māori identity, through connections of whakapapa (genealogy) and kaitiakitanga (guardianship) (Marsden and Henare, 1992; Roberts *et al.*, 1995). As will be outlined in this chapter, the Māori worldview is a holistic one, with all things in life, physical and spiritual being linked to each other. The question 'No hea koe?' or 'Where are you from?' carries with it deep connotations of a person's place in the world - where they are from (their 'stomping ground' or turangawaewae), their family, home, knowledge and skills (McFarlane, 2007). These aspects tie together to inform the individual of who they are and where they fit in the world (*ibid.*).

Horticulture is linked to one's identity though the intimate contact it provides with the earth, weather, climate, plants and their associated pests and diseases. Unfortunately various historical events have led to a disconnection with the land, primarily the shifting of land rights to colonists, and this has contributed to a subsequent disconnection from identity. This separation is seen to have had an influence on the current socio-economic issues that affect many Māori (Gilling, 1994).

This being the case, one way to reconnect Māori to their identity is to open up opportunities in horticulture that are distinctly Māori in origin and practice. While the commercial opportunities are obvious, it is important to note that Māori hold both social and cultural development as being as important as, if not more so than purely economic goals (McFarlane, 2007). This is one of the differences in worldview between Māori and Western culture that has led to much misunderstanding and mistrust that has historically marred Māori/Pakeha relations. Some of this will be outlined in this chapter.

The development of traditional Māori crops and Māori horticulture is a potential mechanism for the melding of western economic and Māori ideals. It can help provide tools and a pathway for the promotion and spread of Māori culture and identity to those who wish to embrace it. It can also provide significant economic benefits so those Māori can fully participate, on their own terms, in the modern world and the opportunities it presents. Māori culture and horticulture have never been static. They have evolved as Māori have encountered new environments, crops and cultures, and that evolution continues today. The use of traditional crops, combined with modern day horticultural techniques and knowledge can synergise to facilitate the further evolution of sustainable Māori horticulture. It can provide a path and tools to help the restoration of, and reconnection with identity though working with the land.

Taewa Māori (Māori potatoes) are a crop that has been grown by Māori for generations and have developed into a number of cultivars unique to New Zealand.

They have the potential to be marketed as a gourmet, niche product due to their unique provenance, physical characteristics and nutritional benefits such as high levels of antioxidants (Lewis *et al.*, 1998). There is also a tendency for taewa to set many, small tubers making them suitable for the salad potato market (Hayward, 2002).

While there is much oral tradition surrounding taewa Māori, there has been very little published in the scientific literature. As of July 2013 a search of the scientific database web of knowledge using the term taewa yields just nine journal articles, mostly focused on the processing qualities of taewa. This is in part due to the relatively recent wider interest in taewa, but is also due to Māori having specific views on how knowledge is handled and disseminated, (McFarlane, 2007). As such a balance must be struck where the sources of knowledge are recognized and respected as they wish to be (Benjamin, 1987; Marsden and Henare, 1992). This chapter will look at the knowledge around Māori horticulture and taewa Māori and makes the case that both are valuable and useful in modern economic and cultural development of Māori.

2.2 Māori world-view.

2.2.1 Whakapapa.

The Māori view of the land and its flora and fauna is seen best through the oral traditions that houses the knowledge of the people, their genealogy (whakapapa), historic traditions and customs. The Māori trace their whakapapa not just to historic human ancestors (tupuna) but through lineages of gods and demigods, who were in turn created from a single origin, Io (Marsden, 1975; Roberts *et al.*, 2004). As the gods were ultimately the ancestors of humankind, they were also the ancestors of all the things surrounding Māori, from birds and mammals to the rocks and stars (*ibid.*). Everything has its own whakapapa; there is no break between the whakapapa of the natural and the supernatural (Marsden, 1975). Everything is part of the unified whole. Hence many Māori view themselves as kin (whanau) to all things, including the land and resources, and are expected to treat them as such. From this a tradition of kaitiakitanga (guardianship, see section 2.2.2) developed where Māori respected and cared for the land as they would for their own human family members.

Whakapapa is more than just genealogy. It places a person, plant, animal or object within the world, not just its physical presence, but purpose, its mātauranga (associated knowledge) and its mauri (spirit) (Roberts *et al.*, 1995). Whakapapa also serves to display the origin of an individual's knowledge and their right to use it, as well as their right to their standing in a community (Roberts *et al.*, 2004). It traces not only the descent of their blood, but also the descent of their skills and mana (prestige/power). It provides identity and for Māori, identity is closely linked to the earth and by extension, to horticulture (*ibid.*). It also provides a means by which to transfer knowledge and as new knowledge is gained, whakapapa evolves and the associated narratives adapt (Binney, 1987).

Due to various historical events, the majority of Māori have been disconnected from the land and its associated horticulture, leading to a disconnect with identity

(Sorrenson, 1956; Gilling, 1994). This loss of identity combines with a loss of connection to Te Reo (Māori Language) and Māori culture as a whole (*ibid.*) and is seen as a contributing factor to the economic and social issues that affect many Māori today (Marsden and Henare, 1992; Gilling, 1994). It therefore provides extra impetus for the preservation and promotion of taewa and other Māori crops as they are imbued with much cultural and historical importance. As such they have the potential to provide a path and tools for the restoration of identity.

2.2.2 Kaitiakitanga.

Kaitiakitanga has its root in the word tiaki, roughly translated as 'to guard', with kaitiakitanga translated at 'guardianship'. However, it is sometimes incorrectly translated in legal documents as 'stewardship', an English word meaning 'to guard someone else's property' (Marsden and Henare, 1992). Furthermore kaitiakitanga does not accurately describe the practices of some iwi (Ngapo, 2004). Different iwi have different approaches, and one should not assume all Māori are the same (Cunningham *et al.*, 2005). Kaitiaki is the term used to describe the people who are recognised as having the mana and knowledge to guide the process of kaitiakitanga (Ngapo, 2004). The role of kaitiaki can be wide and is based on the lore particular to their iwi or hapū. The roles, responsibilities and interpretation of kaitiaki are unique to each group, determined by their history, narrative and circumstances (*ibid.*).

Before contact with Europeans, Māori had no concept of individual ownership of the land. Māori belonged to the land and its resources were held in communal right (Marsden and Henare, 1992). These tribal and communal rights were exercised though Rangatiratanga (Roberts *et al.*, 1995). Rangatiratanga is the exercise of the authority of the rangatira, for example a chief or a tohunga, for the benefit of the hapū or iwi and the land (*ibid.*). In contrast the predominant western view is one of individual ownership and rights, where land and its resources are viewed primarily for their potential resources and their market value (Waitangi Tribunal, 2011). If using that land and resources for a wider benefit is considered, it is done so in terms of providing jobs, saleable goods and the economy. Providing and caring for the land is rarely considered and where this does occur it is usually after much damage has been done.

Māori exercise kaitiakitanga in order to care for the land and the life it nurtures in an effort to make sure there will be enough for all. Traditionally this has been largely done through the practice of rahui. This involves placing a temporary ban on the harvest of a particular resource or area of land (Marsden, 1992). This practice has emerged from kaupapa, the first principles. Māori look to kaupapa when coming to a decision about what to do (*ibid*.). These first principles are deeply rooted in Māori oral tradition, history and whakapapa (Roberts *et al.*, 1995).

From these first principles, Māoritanga (the ways of Māori) and tikanga (customs, the 'correct ways') were developed. Rangatira enforce rahui though the exercise of rangatiratanga (Marsden, 1992) usually at the behest of the tohunga (expert) who has the expertise in that particular resource. Rahui allows the Mauri Ora (life force) of the resource to be replenished, traditionally being assisted by ritual and prayer (*ibid.*). Mauri is perceived as a universal energy that penetrates all things and if a resource is weakened, its mauri has to be restored (*ibid.*).

2.2.3 Tikanga.

Tikanga has its roots in the word 'tika' meaning correct, true or just, and in this manner tikanga is seen as the correct or just way of doing something (Mead, 2003). Within Māori horticultural practice tikanga dictates everything, deciding where and when to plant crops, prepare the land, propagate and plant, as well as in-season management, and the timing and processes of harvesting and storage (Hargreaves, 1963). The knowledge of tikanga Māori is passed down through deep narratives that direct the people in the correct course of action (Hargreaves, 1963; Mead, 2003). Tikanga is closely linked to kaitiakitanga, the obligation to care for the land (Roberts, 2004). Tikanga arise from kaupapa Māori that are deeply rooted in oral tradition, shared history and experience (Roberts, 1995).

The institution of rahui and tapu are key regulatory concepts with respect to kaitiakitanga and tikanga in order to facilitate sustainable practices (Clarke, 2007). All worldly and otherworldly realms and concepts are connected, influencing the operations of each other in the Māori world (Marsden, 1992). Whakapapa, history and tikanga all flow from and into one another, reflecting the holistic view Māori have of the universe and its processes (*ibid.*). This worldview acknowledges a sacred relationship with nature and the relationship to the land (whenua) is one that cannot be overstated (Marsden and Henare, 1992; Cheung, 2008). Preserving their way of life, and indeed, life itself, historically depended on their understanding of and relationship to nature (Iwikau, 2005).The formation and application of tikanga with respect to horticulture revolves around these ideas, aiming to not only feed the hapu and provide enough to give to visitors and travellers, but to care for the land so that it in turn can care for them. Tikanga were vitally important for maintaining this relationship.

It may seem that tikanga is based on the practical necessities of a subsistence lifestyle and therefore, has no real place in modern production horticulture. For many Māori tikanga are still very important, being a link to their history, narratives, whakapapa and kaitiakitanga. Tikanga evolved over many generations and developed in to the practice of kaitiakitanga, with the aim of maintaining the mauri of the various parts of the natural world (Ngapo, 2004). Tikanga is linked to Māori identity and provides a connection to cultural knowledge. This knowledge has been dismissed and marginalized through the process of colonization and as such many Māori have been disconnected from their traditions, their identity.

At the beginning of New Zealand as a British colony, Māori provided the bulk of the produce, not only in terms of local supply but also for exports markets, increasing not only their own prosperity but that of the developing colony (Hargreaves, 1963; Petrie, 2002). Through political and legal processes, both the land and traditions of Māori were marginalised and Europeanised, which led to a disenfranchisement of land, tradition and identity (Sorrenson, 1956; Gilling, 1994). Reviving tikanga in horticultural practice offers an opportunity for Māori to reconnect with the land, their identity, knowledge, skills, history and whakapapa.

The application of tikanga could help bring Māori back in contact with their traditions and knowledge. Horticultural production involving tikanga would also promote sustainable practices, through rahui and kaitiakitanga. Horticultural practice that embraces kaitiakitanga would have the health of the land as its primary concern. This would lead to horticultural practice that includes the use of rahui for fallowing the land. This could combine with modern knowledge around the use of green manures for adding organic matter and biofumigation to create a sustainable production system that relies less on the use of agrichemicals for nutrition as well as pest and disease control. Such practices also provide a branding opportunity, distinguishing Māori produce from other options in the same markets, providing a point of difference that can be used to promote Māori products.

2.3 Māori horticulture.

Horticulture has traditionally played a major role in Māori culture, supplying food, medicine, clothing and building materials. More than this however, it has also provided a connection to the land and reinforced the place of Māori within it. New Zealand has few endemic sources of carbohydrate and those that are present are labour intensive, requiring significant processing to become edible or de-toxify (Clarke, 2007). Both bracken fern (*Pteridium esculentum)* and karaka (*Corynocarpus laevigatus*) provided significant sources of food, however both needed much processing (cooking, washing, grinding) before being edible (*ibid.*). However for many Māori horticulture still provided an essential carbohydrate resource. The first Māori settlers would have undertaken explorations and experimented with wild food resources, establishing successful horticulture and searching for a place for themselves within the new landscape (Yen, 1990). As such, Māori horticulture and society evolved in response to the challenges in a new land and later to the influences of colonization.

2.3.1 Pre-contact Māori horticulture.

The original migrants, sometimes referred to as archaic Māori, brought with them traditional crops such as kūmara (*Ipomoea batatas*), taro (*Colocasia esculenta*), hue (bottle gourds, *Langenaria siceraria*), tī (cabbage tree, *Cordyline* sp.) and uwhi (yams, *Dioscorea* sp.) (Roskruge, 1999). They would have worked hard to establish known foods with what they would have considered the proper techniques (tikanga). These horticultural techniques were passed down over generations through an oral tradition, with the use of narrative to explain why certain things were done, and why certain events happened (Binney, 1987).

In their new homeland they found conditions to be quite different to those of the tropical regions they had migrated from. Even though there is evidence that New Zealand was on average warmer than it is today they would have found it cooler than their ancestral homelands (Clarke, 2007). The new immigrants would have found the difference between seasons more pronounced, especially as they ventured further south. This lead to a period of adaptation and experimentation that is evident in archaeological sites and materials (Bishop, 1903; Anon., 2003)

The traditional crops they brought with them struggled to thrive and some failed to survive at all (Roskruge, 1999). They found they had to adapt their techniques if they were to provide for themselves over the winters they now found themselves facing (Yen, 1990). These winters meant cropping seasons were shorter and forage foods were mostly seasonal. Occasionally the weather would have prevented them accessing other important wild food sources such as seafood (kai moana). This forced a change in cropping and food storage techniques including the development of storage pits and the extensive modification of soils and growing sites to improve localised growing conditions (Jones, 1989; Yen, 1990). Horticultural knowledge and narrative had to adapt. The whakapapa and tikanga associated with horticulture had to evolve if they were to find a permanent place in their new home. The knowledge (mātauranga) and cropping techniques used by Māori evolved and adapted to New Zealand conditions, maturing into cropping systems and horticultural techniques that are distinctly Māori.

Māori horticulture provided a valuable resource for many Māori and it evolved with local conditions and a changing world. While some groups, such as Tuhoe in Te Urewera, relied heavily on their knowledge of wild foods (Hargreaves, 1963) for many Māori horticulture provided significant, social, cultural and food resources. Archaeological records show that much attention and effort was put into modifying areas of land. This included the clearing of extensive areas by slash and burn techniques, erection of stone walls (Anon, 2003), the extensive modification of soils (Bishop, 1903; Hargreaves, 1963; Anon, 2003) and innovations surrounding the storage of harvested food and seed (Walsh, 1974; Yen, 1990). The first Māori settlers had to adjust their traditional techniques to successfully grow the imported tropical food crops they brought with them (Yen, 1990).

2.3.2 Post-contact Māori Horticulture.

Contact with Pakeha sparked significant changes in the Māori world. New crops were introduced and began to displace the crops that the Māori grew. Cropping of tī halted in favour of white sugar (Rudman, 1992). Sugar could easily be traded for, and involved a lot less work than digging up the root of tī and preparing *kauru*, the major source of sugars in the Māori diet (*ibid.*). Whakapapa and tikanga began to evolve with the changing world.

Māori eagerly took on the cultivation of the newly introduced potato that was higher yielding in New Zealand conditions than the traditional root crops of kūmara, taro and uwhi. Different iwi have different narratives on how the taewa came into their hands and fit into their world (McFarlane, 2007). The stories of taewa and how it fits into the whakapapa of Rongomaraeroa (the god of cultivated foods) vary from place to place in accordance with the needs and knowledge of the people concerned (*ibid.*)

As well as the introduction of new crops there were new horticultural ideas, tools and techniques that changed tikanga and ideas around tapu. Māori were at first aghast when the saw missionaries manuring the soil in preparation for new crops (Orbel, 1987). However, this idea eventually caught on when Māori observed the benefits to soil fertility and it is now a common practice in some Māori gardens (Moon, 2005). Thus tikanga around issues of tapu and manure shifted.

Armed with new crops and techniques Māori became the main market gardeners to the fledgling colony, trading their crops for new food sources, clothing and equipment (Hargreaves, 1963; Yen, 1990; Petrie, 2002). Māori horticulture and trade initially flourished but eventually started to decline as the best land was appropriated by the new colonists (Gilling, 1994). Like many native cultures they suffered from introduced diseases and under new laws of the incoming settlers. The Māori population declined and over the years much land was handed over to, or taken by, the new colonists, who eventually took over the bulk of production horticulture in New Zealand (*ibid*.). Those with knowledge of traditional horticulture and its whakapapa became fewer. They were often in isolated areas where Te Reo was still spoken as a first language and the influence of the outside world was limited (Roskruge, 2011).

Māori horticulture not only has the potential to provide a business opportunity with what are now seen as niche products and benefits such as employment. It's long history and whakapapa provides a resource for Māori far beyond any economic value. It provides a proud and unique tradition of knowledge (mātauranga) that contains information about the local environment, the people, their place and how they can exist sustainably within it. The whakapapa of horticulture can help with restoring lost identity and culture to Māori, connecting them to the land, the land to them, providing a place, a purpose and opportunities to flourish.

2.4 Taewa Māori.

Taewa, Peruperu, Riwai, Parareka and Mahetau are some of the terms used to describe the more than 40 cultivars of potato that have historically been grown by

Māori in New Zealand (McFarlane, 2007). These names vary depending on tribal dialect (*ibid.*) but for the purposes of this thesis they will be referred to as taewa. A collection of taewa cultivars can be seen in Figure 2.1. There has been some debate over the exact timing of the introduction of taewa into New Zealand. There is some evidence and oral history that states that the first introduction of taewa was by Captain Stivers, a year or two prior to Captain Cook's arrival in New Zealand (Richards, 1993).

Figure 2-1 Various taewa cultivars. (Source: N. Roskruge)

It should also be recognised that the Ngā Rauru iwi of South Taranaki have an oral history that maintains there was a native cultivar present before the arrival of Europeans (McFarlane, 2007). This cultivar, called Tatairongo, is said to have been obtained from the Te Ao Pō (the under world) by their ancestor te Reke Tatairongo (*ibid.*). This highlights the strong connections between Māori, their crops, narrative and whakapapa.

Officially the introduction of taewa to New Zealand has been credited to the earliest adventurers such as Cook and de Surville in 1769, and later through trading with whalers, sealers and the first settlers (Harris and Niha, 1999). By the beginning of the 19th century taewa crops were widely grown in the North Island (Richards, 1993). They offered a higher yielding carbohydrate source than traditional root crops, particularly for Tuhoe in Te Urewera and South Island iwi where traditional crops had always struggled to grow (Hargreaves, 1963).

The introduction of new crops and tools began to transform the Māori horticultural economy. Until this time Māori horticulture had been largely subsistence based (Jones, 1989; Petrie, 2002). Such was the increase in productivity that as early as 1803, Māori were exporting potatoes to Australia and had begun to establish international trade links in China and the Americas (Hargreaves, 1963).

Over time much of the taewa seed stock has become heavily infested with viruses, bacteria and other pathogens, all of which affect the health and vigour of developing plants (Roskruge, 1999). This has resulted in a shift from traditional cultivars to healthier, more productive seed stock that came to New Zealand later. These cultivars had fewer pathogens, were more vigorous and therefore had greater productive potential than the old taewa lines. Taewa fell out of favour and survived only in the backyard gardens of those who still remembered their cultural significance and in many cases had a culinary preference for them (Roskruge, 2011).

Recent years have seen a Māori cultural renaissance that has included a re-kindling of interest in traditional Māori horticulture and crops. Massey University in conjunction with Tahuri Whenua (see section 2.6) has spent a number of years building and maintaining a tuber seed bank. This project seeks to preserve taewa lines and conduct research to improve both the seed stock and the commercial potential of taewa (Roskruge, 2004). There has also been work done creating and maintaining pathogen free lines of taewa using cell cultures taken from the meristems of taewa sprouts to eliminate the virus and raise disease free clones (*ibid.*).

Research has shown that taewa have good processing potential, as well as high levels of antioxidants and other beneficial nutrients (Jaspreet *et al.*, 2006; Philpott *et al.*, 2009). The lack of published work is in part due to the relatively recent resurgence in interest, but is also in part to the caution Māori exercise in disseminating their knowledge. Māori have distinct views on how knowledge should be shared as well as who has the right to share and receive such knowledge (Binney, 1987; Marsden and Henare, 1992; Bevan-Brown, 1998). Such caution appears justified. The recent WAI 262 report on Māori intellectual property rights states that Māori have no inherent legal protections over their knowledge as much of it is already out in the public domain (Waitangi Tribunal, 2011). The only legal protection Māori have over their knowledge is to keep it out of the public domain (*ibid.*).

2.5 Māori horticulture today.

Māori horticulture has traditionally been an organic production system that resembles bio-dynamic practice in its use of natural signs such as the waxing and waning of the moon to provide guidance on the correct time to plant and harvest (Roberts *et al.*, 2006).There is an opportunity to access niche markets that pay a premium for produce raised in such a manner (Reganold, 1995). At present the Māori horticulture sector is using traditional crops and cropping techniques to provide unique and gourmet produce estimated to be worth $520 million annually (Smith, 2005).

The application of tikanga practice to traditional Māori foods presents a branding opportunity. It provides a point of difference and a potential way to access high-end markets that are willing to pay a premium for interesting, unique and niche foods (Lambert, 2004). Tikanga is still important to Māori horticulture in the modern world. It evolves to provide guidance for good horticultural practice. Tikanga can be applied in modern production horticulture by promoting sustainability, reconnecting Māori to identity through contact with the land and its history and providing a unique branding opportunity for marketing of Māori produce.

Māori society and horticulture has successfully adapted in the past to meet the demands of a changing world. The embracing of new technologies and techniques would be one way to encourage the further evolution of Māori horticulture. In the case of the Māori growing group Gourmet Mokai there is a focus on the use of state of the art climate controlled greenhouses for the production of tomatoes and capsicums (Te Puni Kōkiri 2011a). This group also has access to renewable geothermal resources that are used for energy generation and heating, promoting both economic and environmental sustainability (*ibid.*)

Precision agriculture is an example of new technologies that could be taken up by larger Māori grower groups. Precision agriculture is a combination of micro electronic and computer technologies such as GPS mapping that is seen as a way of not only increasing profitability, but doing so in a manner that matches the capability of the land and therefore is more sustainable (Yule *et al.*, 2004).While the outlay for such systems is expensive, there is funding available for groups who wish to convert to more sustainable systems through the MAF Sustainable Farming Fund (Duncan and Wallace, 2004). It is also clear, that the adoption of precision agriculture ultimately leads to reduced inputs and therefore increases sustainability and profitability (Yule *et al*. 2004).

Less expensive options include laboratory assessment of soils and the use of decision support tools that provide information to help with various management decisions (Hewitt *et al.*, 2004). Such information can help prevent incorrect or economically unwise decisions that can result in increased environmental and economic costs (*ibid*.).

2.6 Modern Māori development.

There is a desire by Māori to manage their land and resources within the mainstream by using Māori procedures and devices (Kawharu, 1978; McFarlane, 2007). This has not always been easy and several issues have hindered the development of Māori land into viable and economic entities, mostly relating to management and obtaining finance for development of the land.

The structure of Māori incorporations, their uncertain legal capacity and accountability has made banks and other financial institutions reluctant to deal with them (Kingi and Maughan, 1998).The fragmented and incomplete state of information around Māori lands and the complex web of legislation make informed decisions around land difficult (Anon., 1998). There are also concerns about a lack of management and business skill within the incorporations, something that is being addressed through both education and the employment of people with the necessary skills (*ibid.*) Issues also arise around the awareness of the resources that could be accessed to help develop land (*ibid.*).

Compounding these issues there is a lack of desire on the part of banks to accept Māori land as security due to the legislative restrictions on the transfer of Māori land (Kingi and Maughan, 1998).There is also an equal, if not stronger desire by Māori not to risk their lands in such a manner (*ibid.*) This has so far restricted development of Māori land, however some groups have worked successfully within the limitations they face (Anon., 1998).

Some banks are willing to lend on alternative forms of security (Kingi and Maughan, 1998). Māori incorporations have set up companies that separate responsibilities around social, cultural and land issues from business activities, providing protection, transparency and accountability (*ibid.*). Combined with increased education and skill development around business and farming practices, several groups have been successful at developing their lands (*ibid*.) In 2008, over half of the $NZ 16.5 billion worth of Māori owned commercial assets were tied up in primary industry, which includes agriculture, horticulture, forestry and fishing (Figure 2.2) (Te Puni Kōkiri, 2008).

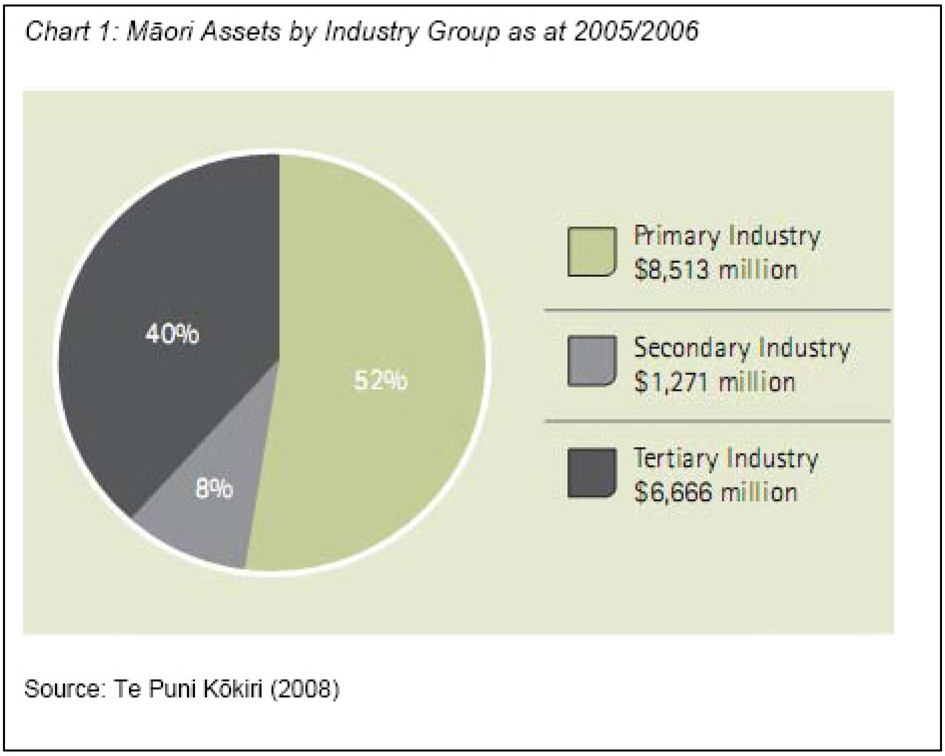

Figure 2.3 Breakdown of Māori assets by sector. Source: Te Puni Kōkiri, 2008.

There are organizations have been successful in moving in this direction. The Ngāi Tahu iwi is actively involved in developing the land it has in order to help young Māori get further involved the agricultural opportunities available (Wood, 2013). Te Whanau-ā-Apanui iwi of the Bay of Plenty region has begun an initiative to develop long-term sustainable employment within the fruit-growing sector (Te Puni Kōkiri, 2011b). They have provided training for over 3000 people, the majority of whom have found employment in the horticultural sector (*ibid.*). Such programmes aim to reverse the trend of a 13% reduction in Māori employment in the horticultural sector that was seen between 2003 and 2008 (*ibid.*).

Tahuri Whenua Inc. is a collective of Māori growers and horticulturists that seeks to establish opportunities for Māori to develop on their own terms (Roskruge, 2004). Tahuri Whenua in simple terms means returning to the land and aims to represent Māori interests in the horticultural sector (*ibid*.). It was set up with the purpose of providing a unified national identity for Māori growers. This helps facilitate the promotion of Māori horticulture and crops by providing a structure that encourages participation, rather than competition with, existing sector bodies such HorticultureNZ and MPI (*ibid*). Tahuri Whenua aims to promote sustained growth in Māori economic development through mechanisms based on tikanga. As such, Tahuri Whenua is overseen by a group of kaumatua who ensure that tikanga is not compromised (*ibid.*).

The opportunities for Māori do not just include production horticulture or agriculture. There are opportunities to be involved in agriscience and research, providing information needed to improve knowledge around production practices (Dyck, 2004). There is an increasing interest in the use of precision agriculture, decision support tools and other science to help improve productive capacity and sustainability (Yule *et al*., 2004). There is a need for continued research and development in this area in order to optimise knowledge so that it is applicable to different production systems and environments (Dyck, 2004).

The modern progression of Māori horticulture and the production of scientific information offer new opportunities for Māori. There are opportunities to create knowledge through research, science and technology (*ibid.*) Understanding how production impacts the land aligns with kaitiakitanga. It is also important from the point of view of quality standards; as such information is needed to gain certification in order to access particular markets (*ibid.*).

2.7 Chapter summary.

Colonization had a significant effect on the Māori people. With regard to Māori horticulture the introduction of new crops, tools and techniques was initially a boon for the Māori, securing food supplies and bringing economic prosperity. However settler desire for land and the imposing of European ideals and laws, led to the alienation of many Māori from their land. It separated many Māori from a significant part of their cultural and spiritual heritage, divesting them of turangawaewae. The fragmented lands left were mostly of low horticultural quality.

There have been issues around the complex laws surrounding Māori incorporations and land, the differing worldviews and structures of Pakeha and Māori institutions, a lack of information and education has inhibited the development of these lands to the benefit of Māori. There is however hope, as more treaty settlements are finalised with lands transferred back to Māori and groups such as Tahuri Whenua and Ngāi Tahu continue to develop opportunities.

There are opportunities for Māori in agriculture and horticulture, not just in production but also in research and development. In order for the full potential of Māori-based agriculture to be realised, there must be a continued evolution of horticultural practices. The use of precision agriculture technologies, decision support tools and laboratory based assessments of land and its produce can all help advance Māori horticulture, adding to the sustainable practices and theories that already exist. There is compatibility between the Māori views of kaitiakitanga and tikanga with modern ideas and technology that promote the sustainable use of land.

This thesis uses a modern scientific analysis in order to further promote an agronomic understanding of taewa that can be used to sustainably and profitably produce a crop. Such production holds potential for the economic, cultural and individual development of Māori. Horticulture can provide business and employment opportunities that have the potential to reconnect Māori with the land. In order to achieve this, research should be carried out on taewa to further quantify and understand the parameters around their production and potential markets.

This thesis looks at two aspects with respect to these goals; the suitability of different taewa cultivars to short season cropping in order to avoid the recently established pest TPP and whether the phenomenon of physiological aging can be used to improve the yield of a short season taewa crop. This would improve sustainability (synergising with kaitiakitanga) through the reduction of agrichemicals needed to produce a quality crop.

Chapter 3. The Tomato-Potato Psyllid (*Bactericera cockerelli,* TPP)

3.1 Introduction.

The Tomato-Potato Psyllid (*Bactericera cockerelli,* TPP) is a phloem feeding insect of the Psylloidae family that is a significant horticultural pest in New Zealand, North and Central America (O'Connell *et al.*, 2012). It is a polyphagous insect being reported as having a wide host range of over 20 different plant families (Yang and Liu, 2009), and can complete its lifecycle on more than 40 known host species (Butler and Trumble, 2012a). It survives best however on the families Solanaceae, Convolvulaceae and Menthaceae (Martin, 2008). TPP is a major pest of the solanaceous crops potatoes, tomatoes and capsicums. The feeding of both adult and nymph stages of TPP can cause significant yield reductions through an unidentified mechanism, but this effect can be controlled through insecticide treatments (Sengoda *et al.*, 2010). It is the development of TPP as a vector of the bacteria *Candidatus* Liberibacter solanacearum (liberibacter) that plays the largest role in reducing tuber yield and quality (Cameron *et al.*, 2009; Thomas *et al.*, 2011).

3.2 Taxonomy and Distribution.

Originally described as *Trioza cockerelli* by Karen Sulc from insects found on capsicum plants, TPP has been through several taxonomic re-classifications before settling in the family Triozidae with the name *Bactericera cockerelli* (Butler and Trumble, 2012a). TPP is endemic to North America and was thought to be limited to 18 states in the USA on the western side of the Mississippi river, ranging as far north as Colorado right down to Texas and California (Teulon *et al.*, 2009; Butler and Trumble, 2012a). There have been recent reports of TPP spreading out of its known range into Idaho, Oregon and Washington where 50% of all potato production in the USA takes place (Goolsby *et al.*, 2012; Munyaneza *et al.*, 2012). TPP has also be found in the southern provinces of Canada as well as Mexico, Guatemala, Honduras and Nicaragua (Munyaneza *et al.*, 2012). In all cases TPP has had significant economic impacts for potato growers in those regions (*ibid.*). TPP was thought to be an issue only for North and Central America until 2006 when it was identified in New Zealand.

3.2.1 Establishment in New Zealand.

In 2006 TPP was detected on greenhouse tomato and capsicum crops as well a volunteer field grown potatoes in the North Island of New Zealand (Gill, 2006). It is thought to have arrived in New Zealand as early as 2005 (Thomas *et al.*, 2011). TPP quickly established due to the temperate climate in New Zealand and has now spread throughout the major potato growing regions by both wind borne dispersal and the transport of infested plant material (Figure 3.1) (Teulon *et al.*, 2009). Liberibacter infection was first confirmed in New Zealand grown potato crops in May 2008 (Thomas *et al.*, 2011).

The incursion of TPP into New Zealand was unexpected and somewhat perplexing as there is a large geographical distance between New Zealand and the Americas. There also seems to be a mismatch between the known importation of risk goods and the locations where it was first discovered (*ibid.*). Investigations have been unable to establish a definitive pathway for its introduction into New Zealand. On the balance on probabilities it seems most likely that the TPP was introduced into New Zealand through the smuggling of primary host material (*ibid.*).

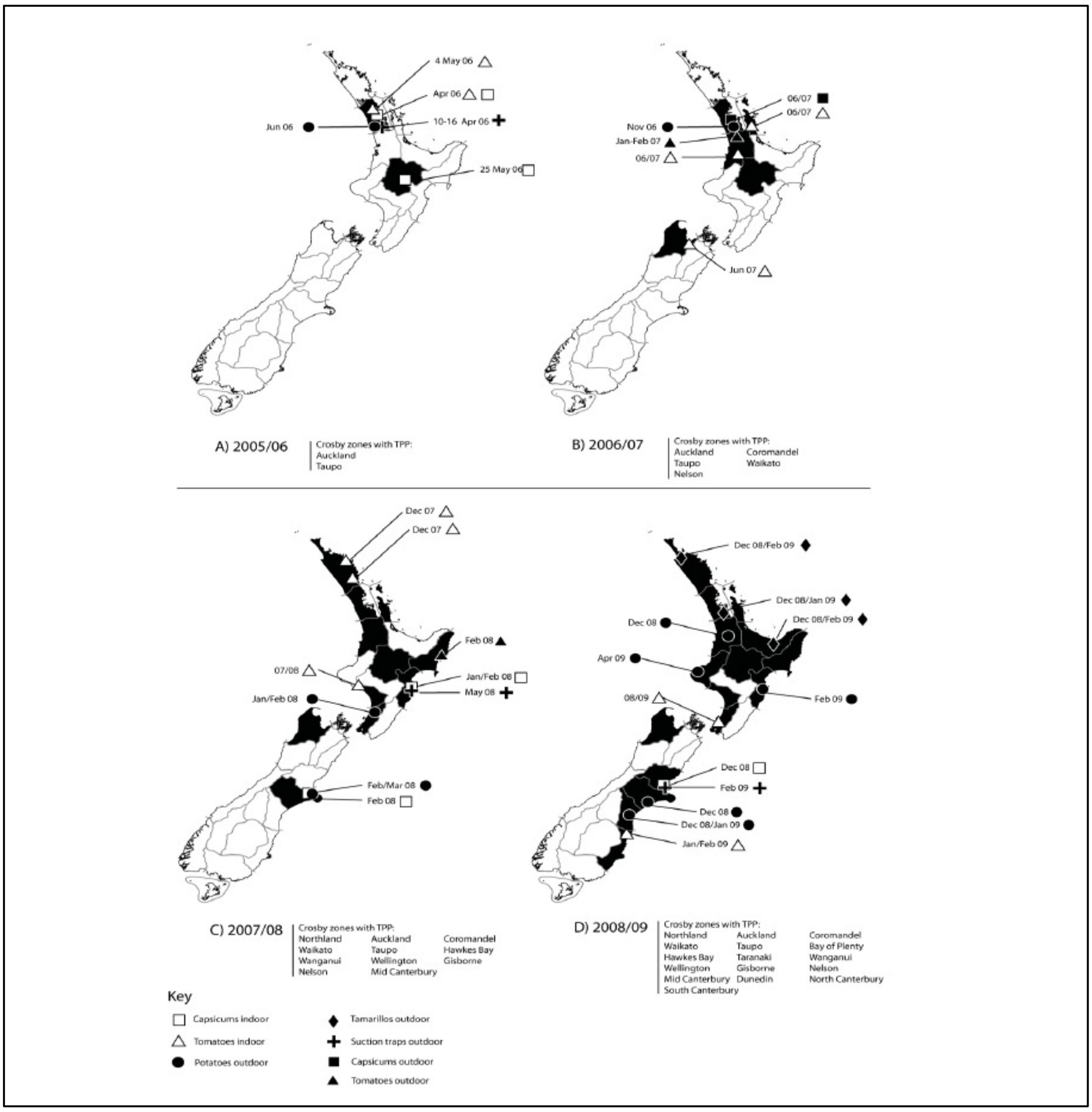

Figure 3-1 Incursion and spread of TPP. Source: Teulon et al. 2009: 138

3.3 Life Cycle.

TPP is known as a hemimetabolous insect, undergoing incomplete metamorphosis by bypassing a pupal stage (Puketapu, 2011). Both adults and larvae exploit the same range of host plants but have a preference and a higher rate of survival on potato crops than other host plants studied in New Zealand (*ibid.*). The life cycle begins with females laying small, oblong eggs which can hatch after 3-9 days, depending on environmental conditions and the species of host plant (Teulon *et al.*, 2009; Puketapu and Roskruge, 2011). The eggs extend out from the plant on a small stalk from which the developing nymph derives water (Puketapu, 2011).The reported number of eggs laid varies from 40 (Abdullah, 2008) up to 1000 eggs per female (Hodkinson, 2009). After hatching the larvae progresses through five nymph stages with moulting occurring between each stage before final emergence as light yellow or pale green adults (Teulon *et al.*, 2009). The exoskeleton hardens over the next 24-48 hours with the adults changing colour to black (Puketapu, 2011). These life cycle stages can be seen in Figure 3.2.

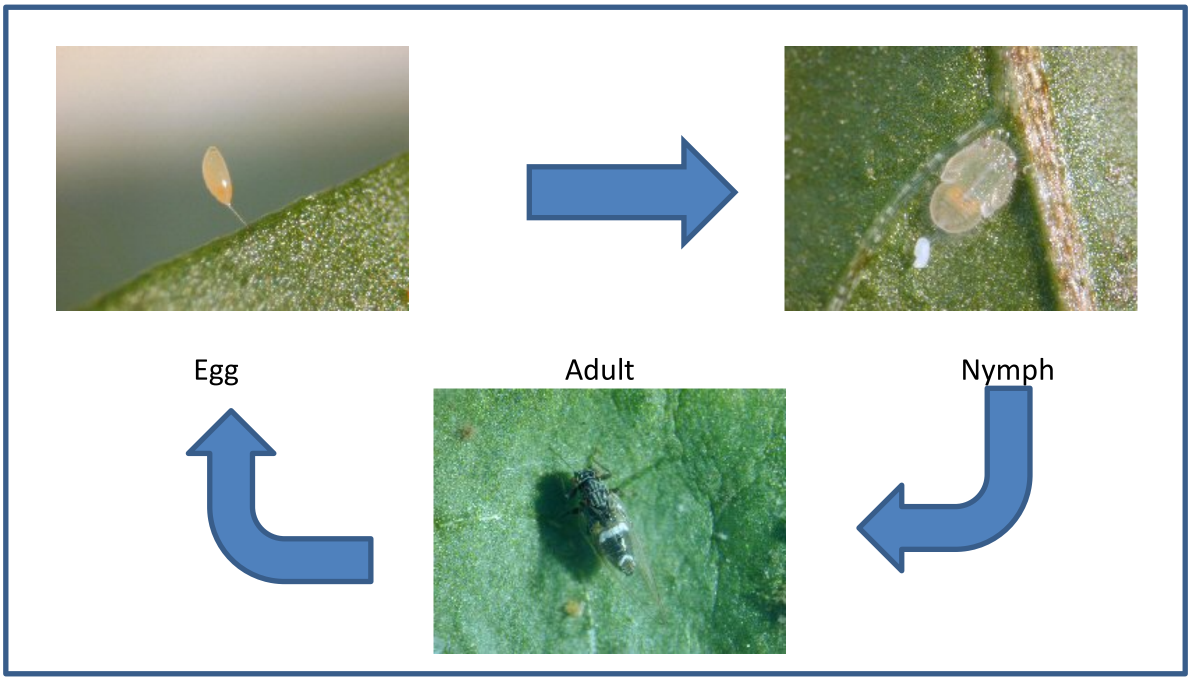

Figure 3-2 The lifecycle of the Tomato-Potato psyllid, Bactericera cockerelli. Source images MAF Biosecurity New Zealand, 2009.

3.3.1 Migration and overwintering.

In the USA, TPP is thought to move south during the winter months and overwinter in the southern states, particularly California, Arizona, southern New Mexico and the lower Rio Grande Valley in Texas (Munyaneza *et al.*, 2009; Goolsby *et al.*, 2012). It is known to migrate up to 12 km to locate suitable host plants when assisted by wind borne dispersal (Puketapu, 2011). In its native range these hosts includes various species of nightshades (*Solanum* spp.) and species wild wolfberry (*Lycium* spp.) (Goolsby *et al.*, 2012). There is little information on the alternative hosts, migratory and overwintering behaviours of TPP in New Zealand (Puketapu, 2011). Research has shown that while the native nightshade poroporo (*Solanum aviculare*) can act as a host in absence of preferred host plants, it does not appear to be an important overwintering host in the central North Island of New Zealand (*ibid.*) This raises the possibility that TPP migrates to warmer climates in the northern North Island during the winter months, migrating down the country during summer in search of preferred host species. Such a migratory pattern has yet to be identified in New Zealand (*ibid.*). There may also be other plant species yet to be identified as overwintering hosts.

3.3.2 Host plants.

The source plants from which TPP infect crops in New Zealand are largely unknown (Cameron *et al.*, 2009). In the Auckland and Pukekohe growing regions it has been reported that the weeds *Datura stramonium* L. and *Nicandra physalodes* (L) Gaertn can act as host plants in the absence of suitable crops (*ibid.*). It is probable that volunteer potato plants act as an important source of TPP, as adults are detected in these plants earlier in the season than in weedy habitats (Cameron *et al.*, 2009). It is also known that TPP will exploit some non-solanaceous crops, particularly kūmara (*Ipomoea batatus*) (Martin, 2008) although it does not thrive on this crop as well as it does on potatoes or poroporo (Puketapu and Roskruge, 2011).

It seems reasonable to assume that TPP will exploit nightshade plants as it does in North America. Research shows however that in New Zealand the common weed black nightshade (*Solanum nigrum* L.) does not support the full development of TPP (Martin, 2008) but could still act as a feeding and overwintering host. It also been noted that Boxthorn (*Lycium ferocissimum*) could also act as a host as the psyllid is known to exploit other members of the *Lycium* genus in the USA (*ibid*.)

3.3.3 Population dynamics.

In New Zealand monitored adult TPP populations are generally low from July to October (Martin, 2008; Puketapu, 2011). TPP begins to move into crops in November, although their numbers are not thought to be economically significant until late December, as crops harvested before then have satisfactory yield and quality (Martin, 2008; Cameron *et al.*, 2009). There have been similar findings overseas, indicating that early crops subjected to low populations of TPP suffer damage below the economic threshold of control (see section 3.5.3) (Goolsby *et al.*, 2007). From January through to February, the populations of both adults and nymphs, as well as the resulting damage to unprotected crops increases rapidly, reaching a peak in late February before dropping off though to July to undetectable levels in the winter and early spring months (Martin, 2008; Puketapu, 2011). This pattern can be seen in Figure 3.3.

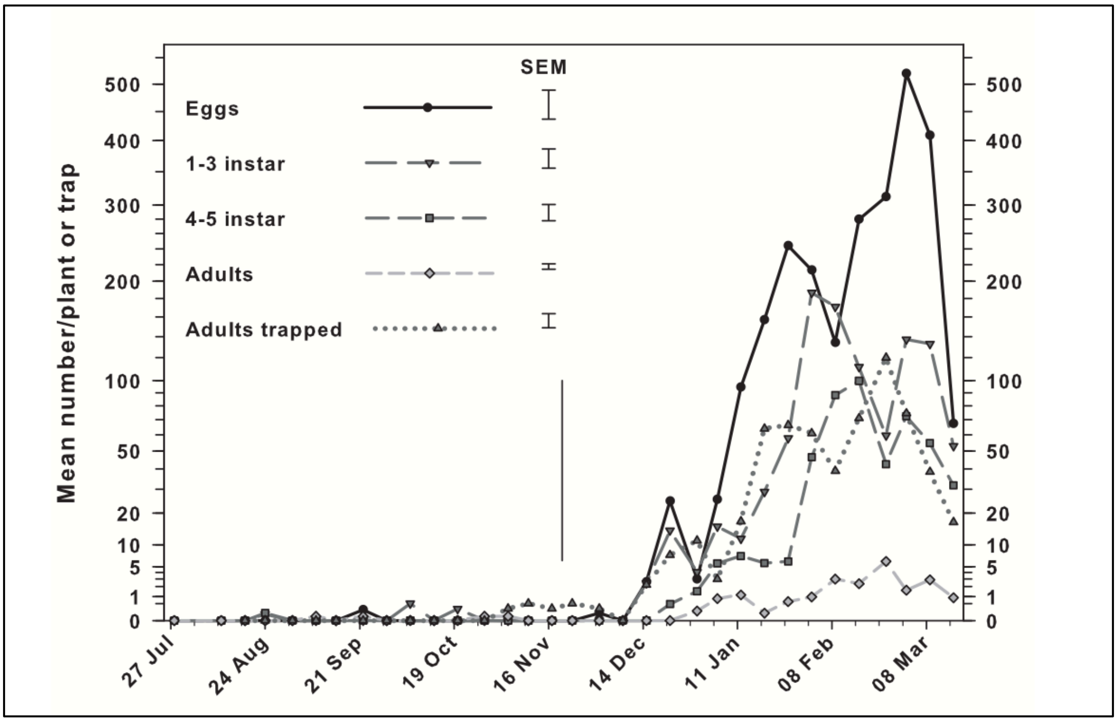

Figure 3-3. Seasonal rise in the TPP population in Pukekohe in an unsprayed potato crop. Source: Walker *et al.* 2011: 272

3.4 Effect on potato crops.

3.4.1 Psyllid Yellows.

Infestations of TPP have historically been associated with the disease known as psyllid yellows (Figure 3.4), a physiological disorder that is thought to be a result of the plant reacting to a toxic feeding secretion of TPP (Teulon *et al.*, 2009). The exact mechanism by which this happens is not clearly understood and a toxin is yet to be identified (Sengoda *et al.*, 2010). It is manifested by the yellowing or purpling of leaves and shoots, stunted growth, shortened internodes, reduced tuber yields and can result in total crop loss (Sengoda *et al.*, 2010; Butler and Trumble, 2012a). Psyllid yellows were first noted in potato crops in Utah, USA in 1927 and became widely documented in potato crops grown in the surrounding Rocky Mountain states in the 1930s (Butler and Trumble, 2012a). Since then, the control of psyllid yellows has been done almost exclusively by insecticides (Butler and Trumble, 2012a). Early detection and control of TPP with suitable insecticides can result in recovery of the crop with minimal effect on final yield (Sengoda *et al.*, 2010). Many years after the original issues with TPP were thought to be under control, a new problem emerged in the form of zebra chip disease.

Figure 3-4 Symptoms of TPP feeding. Purpling of leaves (right) and chlorosis (left). Source: Munyaneza et al., 2012: 332

3.4.2 Zebra chip disease.

First seen in Mexico in 1994, then Texas in 2000, Zebra Chip disease (ZC) is an economically important disease that has been documented in all countries where TPP is found (Buchman *et al.*, 2011; Munyaneza *et al.*, 2012). It is a disease which reduces both the tuber yield and quality (Miles *et al.*, 2010). The above ground symptoms of ZC are similar to psyllid yellows even in the absence of TPP feeding (Sengoda *et al.*, 2010). In addition however the disease causes a significant pathology in the tubers (Munyaneza *et al.*, 2007). ZC-infected tubers display a characteristic striped pattern, the appearance of which is more pronounced when fried (Buchman et al., 2011; Sengoda et al., 2010) as seen in Figure 3.5. Such tubers are commercially unacceptable and ZC infection has led to entire crops being abandoned (Munyaneza *et al.*, 2012).

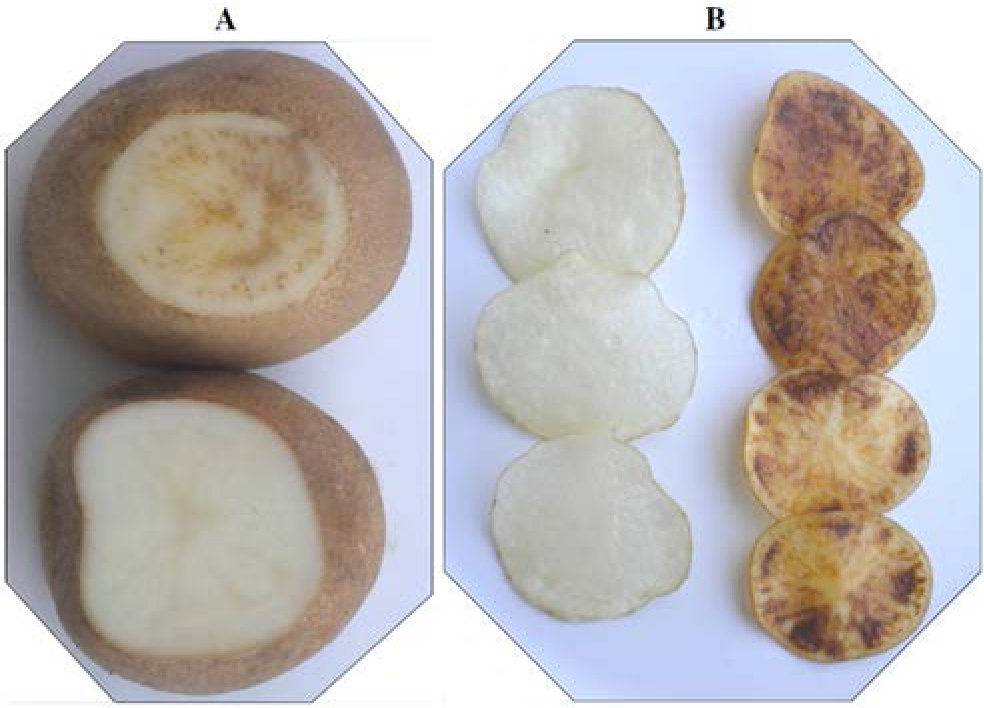

Figure 3-5 Zebra Chip symptoms in potato tubers. A: Top, Infected tuber; Bottom, healthy tuber. B: Left, Fried potato chips from a healthy tuber; Right, Fried potato chips from an infected tuber. Source: Miles et al. 2010: 341

This disease is caused by the pathogen *Candidatus* Liberibacter solanacearum (liberibacter), which is transmitted to the plant by the feeding action of TPP (Munyaneza *et al.*, 2007). Infection of tubers causes cell death in the parenchymatic medullary region, vascular ring and cortex in the tubers (Miles *et al.*, 2010). This results in the leakage of the cell contents and the degradation of starch stored in those cells into sugars. It is the reaction of these sugars to high temperatures that primarily gives ZC the browning effect seen in Fig. 3.5 B (*ibid*.). It is both the increase in sugars and the loss of starch that decreases the processing quality of ZC infected tubers (Buchman *et al.*, 2012). Liberibacter infection of crops has the potential to significantly affect the production of table, process and seed potatoes, but in particular it has the largest impacts on crops destined for the processing market.

Liberibacter can also be transmitted from infected mother tubers into the developing progeny tubers, resulting in both symptomatic and asymptomatic daughter tubers (Pitman *et al.*, 2011). It is suggested that such transmission plays a role in the lifecycle of liberibacter, acting as an inoculum and allowing TPP to acquire the pathogen (Henne *et al.*, 2010; Pitman *et al.*, 2011). It appears however that the presence of liberibacter-infected plants within a crop does not significantly increase the incidence or spread of liberibacter in regions where the disease is already established (Henne *et al.*, 2010). This is thought to be because ZC infected plants have often already died or been obscured by the canopy of neighbouring healthy plants by the time adult TPP comes into the area (*ibid.*)

The realization that many tubers from an infected crop can be asymptomatic and not display any of the typical symptoms of ZC has potentially serious consequences for seed tuber producers. Seed tubers that are raised from liberibacter infected tubers or plants infected during production may pass visual inspections for the disease and even more advanced detection techniques such as the Polymerase Chain reaction (PCR) which can detect small amounts of liberibacter RNA can fail to diagnose liberibacter in potato crops (Henne *et al.*, 2010; Buchman *et al.*, 2012). Some certified seed crops that display no overt symptoms of disease in tubers have tested positive for the presence of liberibacter (Henne *et al.*, 2010). This lack of display of tuber symptoms is a due to the fact that the amount (titre) of liberibacter in a plant does not necessarily correlate to the severity of the symptoms displayed (Rashed *et al.*, 2013; Wallis *et al.*, 2013).

There has been some recent progress in improving laboratory based testing for liberibacter (Beard and Scott, 2013) but it still remains a costly procedure. Infection of seed tubers with liberibacter results in 60-80% of tubers failing to sprout depending on cultivar and severity of the infection (Munyaneza *et al.*, 2007; Secor *et al.*, 2009; Henne *et al.*, 2010). The tubers that do sprout typically produce plants with shallow root systems that display the symptoms (purple tops, brown flecking in tubers) of ZC (Henne *et al.*, 2010). It has been noted however, that tubers grown from liberibacter infected tubers can be the same in terms of starch and sugar levels (both seen as markers of processing quality) as those from disease free plants, although this may vary with the pathogen load (*ibid.*). The relationship between the severity of infection and the display of symptoms is complex and research continues to understand it (Rashed *et al.*, 2013; Wallis *et al.*, 2013).

3.5 Economic impacts of the Tomato-Potato Psyllid and Zebra Chip disease.

3.5.1 United States of America.

Both TPP and ZC have had significant economic impacts in areas where they are present. In Texas, USA crop losses are estimated at over $US 25 million per year (CNAS, 2006). The impact on the entire industry across the United States in terms of extra control measures and related job losses is thought to be over $US 125 million annually (*ibid.*) In Texas, the cost of control in the 2010-2011 season ranged between $US 420-1460 /hectare, averaging $US 740 /hectare (Guenthner *et al.*, 2012). Even with these inputs, some growers still lose 75% of their crop (Munyaneza *et al.*, 2012). The costs in other states is similar, averaging around $US 700 /hectare but can vary significantly between locations, and even within fields at the same location (Guenthner *et al.*, 2012) Although pest control strategies have been shown to be effective at reducing the incidence of ZC in crops (Goolsby *et al.*, 2012), crop losses can still vary widely from 0.5-75% (Guenthner *et al.*, 2012). Even with judicious control and best practice, crops in areas where ZC is prevalent have crop rejection rates averaging 20% (Munyaneza *et al.*, 2012). The Centre for North American Studies (CNAS) suggests that if the spread of ZC is not checked that potato farming in Texas may have to be abandoned (*ibid.*).

3.5.2 New Zealand.

Since its establishment in New Zealand it is estimated that TPP and ZC have cost the potato industry over $NZ 100 million dollars in terms of crop losses and extra control measures (Ogden, 2011). The costs increase yearly and in the 2010-2011 season alone, the estimated cost was $NZ 28 million (Kale, 2011). A breakdown of these costs can be seen in Table 3.1, while the cost per hectare for the different areas and potato sectors can be seen in Table 3.2. As can be seen in these tables, the financial impact of TPP and ZC in New Zealand is significant.

Table 3.1. Cost of Psyllid in New Zealand during the 2010-2011 season. Source: Kale 2011: 5

Current Cost Snapshot

Total Current Industry Psyllid Induced Extra Costs

Growers Costs	$21,661,810
Processors and Seed Industry Costs	$5,330,000
Research and Associated Costs	$1,012,456
Total	$28,004,266

Table 3.2. Break down of cost by region and market in New Zealand. Source: Kale 2011: 5

Psyllid Induced Extra Cost per Hectare- By Sector

Breakdown by cost Type

Region	Description	Seed	Fresh	Process
Auckland	Crop Impacts		$763.8	$4,088.0
	Control Costs		$680.0	$798.4
	Other costs		$1,554.2	$217.5
	Total Cost per Hectare		**$2,998.0**	**$5,103.9**
	Hectares Surveyed		**1,728**	**1,338**
Hawkes Bay	Crop Impacts		$615.4	$3,594.6
	Control Costs		$1,120.7	$1,314.4
	Other costs		$4,104.8	$747.2
	Total Cost per Hectare		**$5,840.9**	**$5,656.2**
	Hectares Surveyed		**39**	**361**
Manawatu	Crop Impacts	$1,614.5	$1,451.2	$2,381.1
	Control Costs	$1,065.8	$1,206.9	$1,077.7
	Other costs	$136.2	$842.0	$292.1
	Total Cost per Hectare	**$2,816.5**	**$3,500.1**	**$3,750.9**
	Hectares Surveyed	**62**	**206**	**141**
Canterbury	Crop Impacts	$0.0	$0.0	$184.7
	Control Costs	$446.8	$172.8	$299.2
	Other costs	$125.8	$24.8	$56.4
	Total Cost per Hectare	**$572.5**	**$197.5**	**$540.2**
	Hectares Surveyed	**283**	**228**	**1,272**

3.5.3 Economic threshold of control.

The concept of economic thresholds of control was developed in 1959 as a decision support tool for producers (Wilkerson *et al.*, 2002). This concept states that the cost of a control measure should not exceed the returns that the application of the control measure will bring about through controlling the pest population (*ibid*). The result is a defined level of pest population that has the potential to cause economic losses that exceed the cost of control (Walker *et al.*, 2012).

Some work has been done to construct decision support tools to help optimize the timing and the efficacy of spraying for TPP in potato crops, with the aim of promoting informed and economic control decisions (Nansen *et al.*, 2011) There are many factors that can be considered in such a model. In terms of insect pest control, adequate sampling procedures are crucial as they need to reflect the population across an entire field to accurately determine whether a control measure is needed (Cameron *et al.*, 2009). There is currently a need for the development of such a model in for TPP in potatoes (Butler and Trumble, 2012b) which is hampered by the lack of a reliable sampling protocol for TPP nymphs (Walker *et al.*, 2012).

3.6 Control of the Tomato-Potato Psyllid and Zebra Chip Disease.

3.6.1 Sampling, detection and monitoring.

It is recognized that sampling for TPP can be a difficult task (Wright *et al.*, 2006). There have been many methods tried for the sampling of TPP including suction traps, vacuum sampling, sweep nets, examination of the plants and the use of yellow sticky traps (Butler and Trumble, 2012a). It is difficult to observe young nymphs in the field and the population of adults detected by standard sampling procedures do not always correlate with the population of nymphs on the crop (Cameron *et al.*, 2009). There can also be plant factors such as leaf drop and plant death that can make detection and monitoring difficult, particularly later in the season (Puketapu, 2011). Both suction traps and vacuum samplers have been found to be ineffective at detecting TPP populations in the field (Butler and Trumble, 2012a) while sweep nets can be difficult to use effectively (Cameron *et al.*, 2009).

The standard yellow sticky traps can be quite sensitive in terms of detecting adult TPP populations early in the season and can act as a good indication of the presence and increase in the population of adult TPP (Cameron *et al.,* 2009). They are not adequate however to develop a reliable model for the determination of an economic threshold for control (Goolsby *et al.*, 2007; Cameron *et al.*, 2009). Leaf sampling gives an accurate and detailed view of all life stages of the TPP, however it is time consuming to undertake and is not seen as a practical tool for producers (Goolsby *et al.*, 2007).

There has been the recent development of a statistically valid sampling plan for horticultural crops (Butler and Trumble, 2012b) but this has not yet had time to be assessed on a large commercial basis. There is a feeling among producers that any population level of a pest that vectors pathogens need to be controlled. This 'better safe than sorry' approach is preferred by many growers when it comes to insect pest control (Nansen *et al.*, 2011) and will probably continue to be with respect to TPP and ZC in the near future.

3.6.2 Control with Agrichemicals.

The experience of potato growers in New Zealand is that control of TPP requires the careful and timely application of agrichemical sprays (Walker and Berry, 2009; Walker *et al.*, 2012). Before TPP came into the country, insecticides were used mostly to control various aphid and moth pests for both the prevention of crop damage and transmission of viruses (Stufkens and Teulon, 2001; Walker *et al.*, 2012). Insecticide application is seen as an important responsive pest control tactic in potato crops, but needs to be done in an informed manner to be most effective (Nansen *et al.*, 2011).

There have been several studies looking at the efficacy of different agrichemicals in the control of TPP (Berry *et al.*, 2009; Gharalari *et al.*, 2009; Page-Weir *et al.*, 2011). Abamectin is consistently effective across these studies at field label rates and as such forms a large part of the currently recommended spray programmes in New Zealand (see Table 3.3). Rotation of insecticides as part of a resistance management programme is important as TPP has been known to rapidly develop resistance to agrichemicals in some growing areas (Schreiber *et al.*, 2012). It would appear that the most effective agrichemicals are those which are directly toxic to TPP such as pyrethroids and organo-phosphates (Gharalari *et al.*, 2009). Sprays that work as antifeedants such as pymetrozine, or hormone mimics such as pyriproxyfen, seem to have little or no effect on psyllid populations (*ibid*.)

Table 3.3. Three month spray program for tomato-potato psyllid. Source: Clarke, pers. comms., October 5, 2012

Product name and active ingredient	Rate	Number of applications*	Mode of action **
Avid (Abamectin)	10.8g ai/ha	2	Contact
Movento (Spirotetramat) and Deis Forte (Deltamethrin)	48g ai/ha 11g ai/ha	2	Contact Systemic
Avid (Abamectin)	10.8g ai/ha	2	Contact
Karatae (Lambda-Cyhalothrin)	10.2g ai/ha	4	Systemic
Metafort (methamidophos)	480g ai/ha	4	Contact

*Applications spaced 7-10 days apart.
** Contact sprays applied in the evening, systemic sprays applied in the morning

For full and effective control of TPP populations, the application and action of the agrichemical should reflect the predominate stage in the life cycle which the population is at.(Page-Weir *et al.*, 2011). When TPP first colonizes a crop, adults form the vast majority of the population and sprays that are most effective against the adult life stage should be used. As the season progresses, nymphs begin to increase in number, therefore, the agrichemicals used should be rotated to include sprays that are effective against nymphs. There should also be rotation of sprays that have differing modes of action to help prevent the build-up of resistance in TPP populations (Zalom *et al.*, 2005).

3.6.3 Integrated pest management.

Integrated pest management (IPM) is seen as an effective way of achieving economic and environmentally sensitive pest management (EPA, 2012). IPM relies on integrating knowledge of the interactions between the crop and pest, detection of the pest, control thresholds, non-chemical control methods and the informed use of insecticides (*ibid.*). The issues with sampling and the setting of economic thresholds mentioned earlier cause significant problems for the development of such a programme for TPP.

Such information and the use of IPM is seen as being more sustainable and easier on the land and the natural populations of non-pest insects, a concept which fits with Māori horticultural ideals that include sustainability. IPM can also integrate organic, biological and cultural controls outlined below. There is currently no established IPM programme for TPP in New Zealand (Page-Weir *et al.*, 2011). It has been noted in the New Zealand tomato sector that the arrival of TPP has hampered and in some cases halted the use of IPM programmes (EPA, 2012).

3.6.4 Organic control.

There are few proven organic control techniques available for TPP. Early work showed that sulphur and lime-sulphur mixes to be effective at reducing populations though reducing the viability of eggs, and therefore the number of juveniles hatched (Tate and Hill, 1944; Riedl and Harrison, 1945). Although such an approach may be useful in conjunction with other control strategies its use is limited as such treatments are phytotoxic to the plants and they provide no knockdown of adult TPP

(Cranshaw, N.D.). There are some reports of organically approved neem oil and the purified form of its active ingredient azadirachtin, giving effective knockdown of TPP adults and nymphs in a laboratory situation (Berry *et al.*, 2009; Scott *et al.*, 2009). However work conducted in greenhouses fails to reproduce these results (Page-Weir *et al.*, 2011).

There has been some success using fine netting to provide a physical barrier to the psyllid (Cranshaw, N.D.) but this method can be costly and is impractical in larger production systems. Crop rotation is a standard practice for many organic and conventional producers, however given the ability of TPP to disperse widely and travel relatively long distances it may only be of use on isolated or very large farms. Organic growers are limited in their control options and for the moment are better off manipulating planting and harvesting dates in order to avoid peak TPP populations.

3.6.5 Biological control.

The 'enemy release' and 'enemy free space' hypotheses form the basis of biological control theory. They predict that organisms that are introduced into areas where there are no pests or disease that are usually present in their native habitat will thrive unchecked by these natural balancing mechanisms (Letourineau and Alteri, 1999). These hypotheses also mean that the introduction and spread of both exotic pest species and control agents share similar processes in that they will find abundant resources, little if no completion for these resources, few predators, parasites and pathogens (*ibid.*)

Following these hypotheses there has been much work looking at the natural predators and pathogens of TPP and assessing whether they hold any potential as biological control agents (Workman and Whiteman, 2009; Casique-Valdes *et al.*, 2011; Lacey *et al.*, 2011; Butler and Trumble, 2012a; Hail *et al.*, 2012; Liu *et al.*, 2012; O'Connell *et al.*, 2012). Many potential predators and parasites have been identified from both its native range (Butler and Trumble, 2012a) and from insects that are generalist predators here in New Zealand (O'Connell *et al.*, 2012).

The parasitoid *Tamarixia triozae* has shown some promise in the USA as a biological control agent and was imported into New Zealand in 2008 (Workman and Whiteman, 2009). Its potential as a control agent would appear limited, as it is sensitive to the currently used insecticides (Liu *et al.*, 2012) and only results in low levels (13-27%) of parasitism of TPP nymphs (Butler and Trumble, 2012a). It may however be useful in the control overwintering populations or as part of an IPM programme (*ibid.*). It is difficult in most situations to establish effective and economic biological control programmes and work still continues to see if effective agents can be found.

3.6.6 Cultural control.

Cultural control can be defined as the manipulation of a cropping environment to reduce the rates of pest increase and damage (Pedigo and Rice, 2006). With respect to TPP, the timing of planting, the use of trap crops, destruction of breeding sites and the use of coloured mulches have all been investigated and found to be effective (Butler and Trumble, 2012a). It has been a longstanding recommended practice to control weedy host plants that act as breeding and overwintering sites for insect pests, including TPP (Knowlton and Thomas, 1934; Cranshaw, 1994). The use of sacrificial trap crops of capsicums has been successful in attracting TPP away from the developing potato crop (Cranshaw, 1994). Reflective aluminium and white plastic mulches are known to be effective in reducing the density of TPP on tomatoes (Demirel and Cranshaw, 2006) but is limited to garden plots and not readily applicable to medium and large scale production.

Early observations noted that late-planted potatoes had a significantly reduced incidence and severity of psyllid yellows (Hartman, 1937; Eyer and Enzie, 1939; Wallis, 1948). In New Zealand it has been noted that early crops can be grown to 20th December without significant effects on crop yield or quality (Cameron *et al.*, 2009). It has also been noted that the population of TPP at some sites drops significantly at the end of February, giving a potential window for late and winter grown potato crops (*ibid.*).

Early crops run the risk of early blight (*Alternaria solani*) and late crops run the risk of late blight (*Phytophthora infestans*). Both of these diseases can be managed and there are many cultivars available that have resistance to these diseases (Alexandrov, 2008; Tiwari *et al.*, 2013). As will be discussed in section 3.6.7, there are no available potato cultivars yet that display resistance to TPP or ZC. It may therefore be easier and cheaper to manage early blight and late blight than TPP.

Given the lack of data concerning the over wintering and migratory habits of TPP in New Zealand late-planted crops may only be viable in certain locations. Improving the performance of early and short season crops through agronomic tools such as the manipulation of physiological age is a potential means of dealing with TPP while maintaining economically rewarding crop yields. The avoidance of TPP through the manipulation of planting and harvesting times holds potential for reducing costs through the elimination or reduction of the need for chemical controls.

3.6.7. Resistant cultivars.

The cost and difficulty in controlling TPP has led to research examining the resistance of different potato cultivars to both TPP feeding and ZC-infection (Diaz-Valasis *et al.*, 2008; Munyaneza *et al.*, 2011; Anderson *et al.*, 2013). There has been some positive results with the cultivars Alpha, Gigant and Lady Rosetta displaying some resistance to the effects of TPP feeding (Diaz-Valasis *et al.*, 2008). There as yet appears to be little resistance to ZC infection in cultivars that have been studied (Munyaneza *et al.*, 2011; Anderson *et al.*, 2013). Some work in New Zealand has shown that the cultivar Nadine performs well under a reduced spraying scheme (4-5 vs. 13-15 applications) (Anderson *et al.*, 2013). However there are still significant losses if no insecticide is present, therefore Nadine cannot be considered a true resistant cultivar.

Breeding efforts are focusing on the crossing of modern commercial varieties with wild potato species and have shown some promise, with resistance to TPP and ZC found in some breeding clones (Novy *et al.*, 2012). There is currently no commercially available variety that displays significant resistance or tolerance to either TPP or ZC. The development of tolerant and resistant varieties is seen as an important part of developing an effective IPM programme against TPP (Page-Weir *et al.*, 2011).

3.7 Chapter Summary.

TPP is a recently established insect pest that brings with it two new plant diseases, psyllid yellows and zebra chip disease. Both diseases come about through the feeding of nymph and adult TPP in the phloem of potato plants. Psyllid yellows is suspected to be caused by a yet to be described toxin, and ZC is caused by the vectoring of the pathogen *Candidatus* Liberibacter solanacearum. Both cause decreases in plant health and subsequent reduction in yields. While psyllid yellows can be remedied through the control of TPP in the field, once ZC is established in the plant it cannot be treated. It is of particular concern to the producers of process potato crops as whole crops can be rejected due to ZC's distinctive browning effect when the potatoes are cooked.

In New Zealand TPP has cost the potato industry $NZ 100 million so far, with costs of $NZ 28 million in the 2010/2011 season alone. It poses a significant problem for the industry as a whole. Control costs to the producer can exceed $NZ 5000 per hectare and as such new avenues to reduce these costs must be explored. While efforts continue to breed varieties of potato resistant to TPP and ZC, promising cultivars have yet to be developed to the point of commercial release. Cultural controls, particularly manipulation of planting and harvesting dates, has been shown to result in economically minimal damage to the crop. Early crops harvested before early summer, and late crops planted after the peak of the TPP population have the potential to provide significant cost savings to the producer through reduced agrichemical use. As will be discussed in the next chapter, the performance of short season crops can be improved through the manipulation of the physiological age of seed tubers. The combination of physiological aging and the manipulation of crop planting and harvesting times holds the potential to improve producer margins by managing the exposure of the crop to TPP.

Chapter 4. Physiological age.

4.1. Introduction.

In potato crops, climate, soil, agronomic practices and the initial quality of the seed tubers used at planting all influence crop yield and tuber quality (Struik, 2006). The final product is a result of the interaction of these factors with the genetics of the cultivar (Reust *et al.*, 2001; Caldiz, 2009). Within these factors, seed tuber quality is vitally important and can be characterized by size, shape, the presence of wounds, disease status and physiological age (Struik, 2006). Physiological age can be defined as 'the physiological state of the seed tuber which influences its production capacity' (Struik, 2007).

The major influence on physiological age is the timing and duration of warming (thermal time) seed tubers are exposed to from the time the haulm on the mother plant dies through to the planting of the seed tuber. After 60 years of research there is still no unified concept or measure which can rapidly asses physiological age in a manner that leads to accurate predictions of how aging will affect the final yield of the crop (Caldiz, 2009). It is however known that the physiological status of seed tubers can be matched to a production system to optimize yields. (Struik *et al.*, 2006).

The effects of aging vary widely. Genetics, growing environment, agronomic factors and other influences contribute to the effect of aging on a batch of seed (Struik, 2007; Caldiz, 2009). As such, the usefulness of physiological aging as an agronomic tool varies between cultivars and environments and at the present time, the only way to understand the effects of physiological age in particular cultivars and environments is to study them within those cultivars and environments.

There has been no work conducted looking at physiological age as a quality factor in taewa Māori seed tubers. It is unknown if it can be used to manipulate the crop and optimize crop yield to different production systems and environments. There is some indication that older lines of potato are resistant to the effects of physiological aging (Asiedu *et al.*, 2003) and it therefore may not be a useful tool in taewa Māori production. Rather the resilience of taewa tubers to aging could be used to save on cool-storage cost by decreasing the length of the cool-storing period. This chapter will look at the complexities of physiological age, the development of the knowledge around it, and its potential as an agronomic tool in potatoes.

4.2 Definition and stages of physiological age.

4.2.1. What is physiological age?

Aging progresses chronologically and while it is affected by many factors, the most important influence is the thermal time (degree-days, dd) that a seed tuber has been exposed to and how this interacts with the genotype of the cultivar (Struik, 2007). The physiological age of the seed can have a strong influence on the emergence, number of stems per plant, number of tubers per stem, canopy structure, tuber size distribution and the final yield and quality of the crops (Struik and Wiersema, 1999) . It has therefore been proposed as a potential agronomic tool to manipulate various crop factors in order to optimize seed tubers to the production system and conditions in which they will be grown (Struik, 2007).

4.2.2 Thermal time and its effect.

The effect of thermal time can vary depending on when in the seed tubers lifetime it has been warmed and in some cases, the timing of warming is as important as the amount (Caldiz *et al.*, 2001; Struik *et al.*, 2006; Oliveira *et al.*, 2012). Physiological age is often expressed in accumulated temperature sums such as degree-days (dd) and it is the build-up of temperature sums that are seen as a major influence on physiological status of seed tubers (Struik & Wiersema, 1999). Aging of seed can change the growth pattern of a crop in terms of dry matter accumulation, shifting the growth curve that describes dry matter accumulation in leaves and tuber (Figure 4.1). It has therefore been proposed as a potential agronomic tool to manipulate various crop factors in order to optimize seed tubers to the production system and conditions in which they will be grown (Struik, 2007). As can be seen in Figure 4.1, tuber dry matter accumulates faster in potato crops grown from older seed. Younger seed however will yield higher over time. It is therefore important to understand how aging affects seed tubers destined for short or long season cropping. However, the concepts and understanding of how accumulated thermal time influences seed tuber aging and crop yields still needs some refining (Struik *et al.*, 2006).

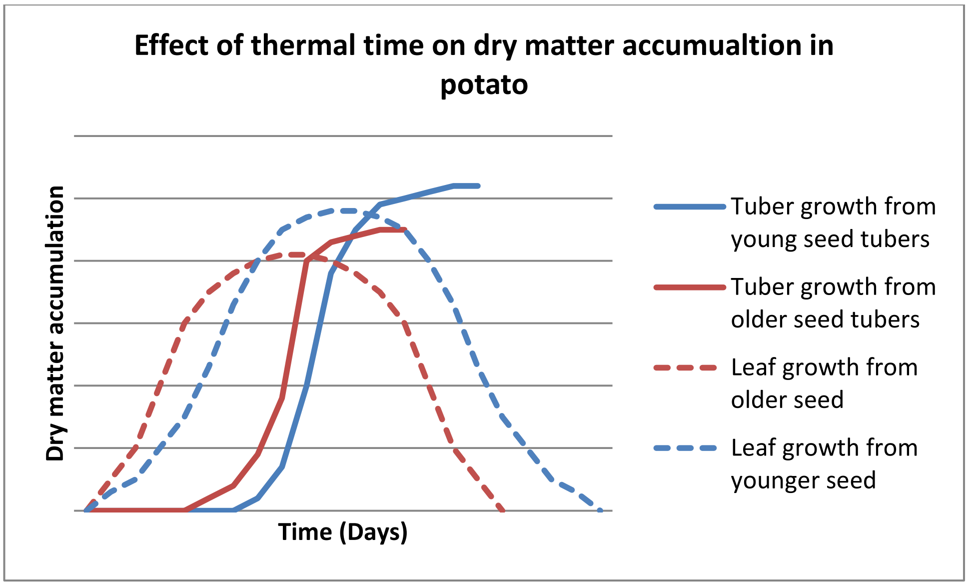

Figure 4-1 The effects of aging seed tubers on plant growth in potatoes.. Redrawn from Wiersema, 1985: 14

4.2.3 Stages of Physiological aging.

4.2.3.1 Dormancy of seed potatoes.

Dormancy is the period from haulm killing until the appearance of new shoots on the tuber (Struik, 2007) and may be defined in different ways. Struik and Wiersema (1999) define dormancy as 'the physiological state of the tuber in which autonomous sprout growth will not occur within a reasonable period of time (usually 2 weeks), even when the tuber is kept in ideal conditions for sprout growth'. Immediately after it is initiated, the tuber will develop a certain degree of dormancy (Struik, 2006; Eshel and Teper-Bamnolker, 2012). Once the haulm is killed, the new tubers become physiologically independent from the mother plant, dormancy deepens and the new tubers begin their own physiological development (Struik & Wiersema, 1999). The length of dormancy varies with cultivar and is influenced by genetics, harvest date and the time until they enter cool storage, but is thought to be at least 2 weeks regardless of these influences (Struik, 2006). During this period, the tuber is inactive in terms of morphological changes (*ibid.*). It cannot be induced to sprout without significant stresses or chemical treatments to break dormancy (Delaplace *et al.*, 2008a; Eshel and Teper-Bamnolker, 2012).

During dormancy tubers have active biochemical processes that can influence sprout number and their vigour (Suttle, 2004; Struik *et al.*, 2006). Environmental conditions both pre and post-harvest can influence the length of dormancy, the rate of aging and can have an effect on the performance of the crop grown from those seed tubers (*ibid*). This innate dormancy can be followed by a period of enforced dormancy, which is primarily induced by low temperatures typical of cool storing (Struik & Wiersema, 1999). This environmentally induced dormancy is referred to as ecodormancy (Vreugdenhil, 2007). Dormancy may also be induced through factors in the structure of the meristem that restrict growth and in this case is referred to as endodormancy (*ibid.*)

It is important to distinguish between innate and enforced dormancy as different environmental factors, particularly light, have different effects on the dormant state (Struik & Wiersema, 1999). The effect of light on innate dormancy is small (Wiltshire and Cobb, 1996). It can however promote or induce dormancy in an enforced dormancy situation depending on the environment, the intensity, photoperiod and quality of light the seed tuber is exposed to (Wiltshire and Cobb, 1996; Struik and Wiersema, 1999). After dormancy has broken, diffuse light may also slow physiological aging, highlighting the importance of diffuse light storage when tubers are stored at warm temperatures (*ibid*.). In the experimental literature there is some variation in the parameters used to assess when dormancy is broken, but all measures use the appearance of sprouts and their length as a sign of dormancy break. The most common measure of dormancy break is when 80% of tubers within a sample have sprouts that are > 3mm in length (O'Brien *et al.*, 1983; Struik, 2006).

4.2.3.2 Phases of sprouting.

When dormancy breaks the seed tuber progresses through three definable sprouting phases (Struik & Wiersema, 1999). The amount of time spent in each phase varies between cultivars and storage conditions (Es and Hartmans, 1987; Hartmans and Loon, 1987; Struik *et al.*, 2006). The main driver of the rate of ageing however is storage temperature (Struik & Wiersema, 1999). Different storage regimes have different effects on both the sprouting capacity (number of sprouts), the growth vigour of sprouts and consequently the number and vigour of emergent stems (*ibid*). Sprouting capacity has been defined as ' sprout growth (or re-growth after de-sprouting: removal of the present sprouts), usually expressed in terms of the sprout weight of uniform tubers (in g per tuber) after a standard sprouting procedure" (Struik and Wiersema, 1999). As such, the ratio of sprout weight to tuber weight has been suggested as a way of quantifying the physiological age of tuber.

Seed tuber size, the number of eyes and genetics also dictates sprout capacity (*ibid*). However for a tuber of a given size, prolonged cool storage before exposure to thermal time will increase the number of sprouts per tuber though allowing the tubers to bypass apical dominance and progress through to the multiple sprout phase (section 4.2.3.4) (*ibid.).* Growth vigour is defined as 'the potential to develop a well-developed, vigorous plant within a reasonably short period of time and is expressed in grams of dry weight per plant' (*ibid.*) The effect of physiological age on sprout and crop behaviour can be seen in figure 4.2

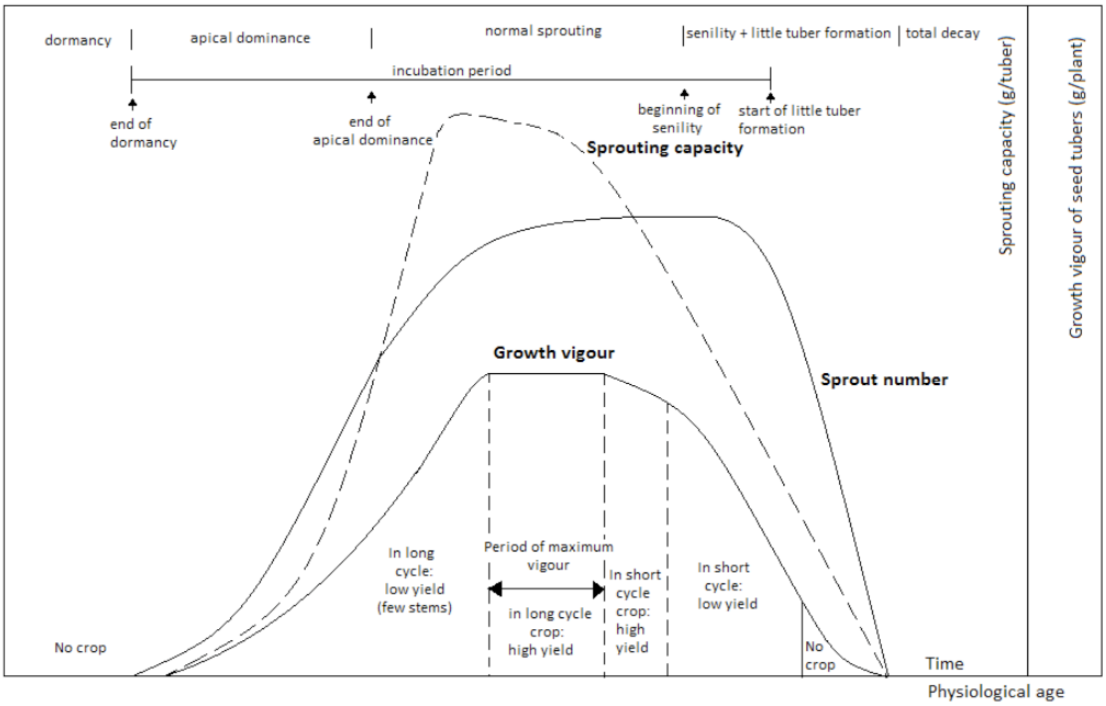

Figure 4-2 The hypothetical effects of physiological aging on seed tuber and crop parameters. Source: Struik and Wiersema 1999: 81

4.2.3.3 Apical dominance.

This is the period just after the breaking of dormancy and is referred to as paradormancy (Vreugdenhil, 2007). It is characterized by sprout growth at one end of the tuber (Struik and Wiersema, 1999; Vreugdenhil, 2007). Such young seed is generally considered to be unsuitable for cropping (Struik and Wiersema, 1999; Muller *et al.*, 2010; Eshel and Teper-Bamnolker, 2012). This is of particular concern in areas that double crop within a single season as young tubers from the first crop are often used as seed for the second, resulting in poor crop performance (Struik and Wiersema, 1999; Quattrini *et al.*, 2001). Dominant sprouts inhibit the growth of other sprouts on the tuber, decreasing the number of stems and consequently reducing leaf area and final yield (*ibid.*). Again, the duration of this stage varies with cultivar, and in some cases it would appear that some cultivars either skip or move rapidly through this stage (Struik and Wiersema, 1999). Tubers may also be induced to pass through this stage directly into the multi-sprout phase outlined below through prolonged cool storing (ibid).

4.2.3.4 Multiple sprout phase.

This is generally considered to be the optimal age for tubers to be planted and can be split into an early and late stage (Struik and Wiersema, 1999). These stages can be seen in figure 4.3. The early stage exhibits multiple sprouts from different locations on the tuber and is thought to be the best age for planting long season crops. In the later stage, the sprouts exhibit branching and there is some wrinkling of the tubers skin. This later stage is considered to be best for short season and seed crops (*ibid.*).

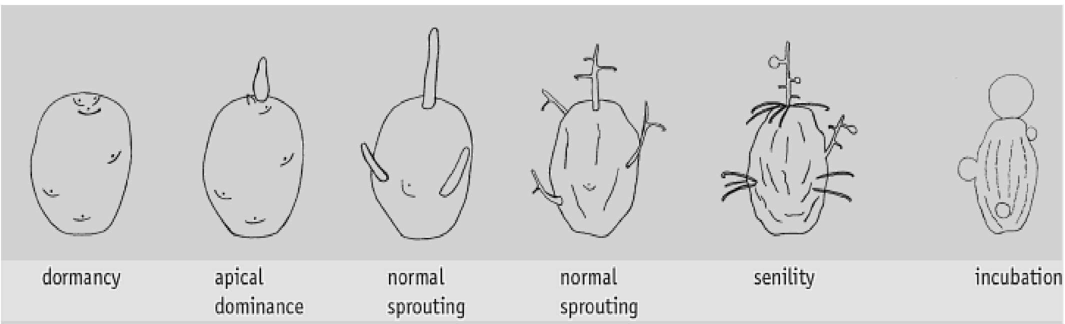

Figure 4-3 Stages of sprouting and physiological age in potato. The normal sprouting stage is split into an early and a late stage. Source: Struik and Wiersema 1999: 78

4.2.3.5 Senility

At this stage, the tubers are shrivelled and exhibit long, thin sprouts that may have begun to form small tubers (Struik and Wiersema, 1999). The formation of small tubers is used as a marker for the length of the incubation period of the cultivar (Caldiz *et al.*, 2001). The length of time from haulm killing to this stage can be used as a measure of the rate at which a cultivar ages (*ibid.*). This stage is considered unsuitable for any cropping due to decreased or no yield (Struik and Wiersema, 1999).

4.3 Physiological age as an agronomic tool.

4.3.1 Why optimize seed tuber physiological age?

The physiological age of seed tubers can be optimized for a chosen production system (Asiedu *et al.*, 2003; Struik, 2007; Caldiz, 2009). Generally, early crops receive a price premium over main crop potatoes which, combined with reduce agrichemical inputs due to a shorter season, can lead to increased profitability (Asiedu *et al.*, 2003). Inappropriate aging however can reduce yields with seed that is too young and seed that is too old both having yield reductions over seed tubers that are aged appropriately (Asiedu *et al.*, 2003; Struik, 2007). It can result in high input crops not being able to take full advantage of the resources provided, while in low input crops only low yields can be expected from inappropriately aged seed (Caldiz, 2009). While there has been much work conducted on physiological aging, its application in current production systems needs refining as its effects depends on the cultivar, growing environment and agronomic practices associated with the crop (Zaag and Loon, 1987; Caldiz *et al.*, 1998; Asiedu *et al.*, 2003).

4.3.2 Disease avoidance.

The production area may be known to have late season pest and disease issues. In organic potato production there is no effective treatment for late blight (*Phytophthora infestans*) (Hospers-Brands *et al.*, 2008; Hagman, 2012). Current practices rely on protective measures such as copper spraying, good field hygiene, the use of resistant cultivars and agronomic tools that advance the crop so it matures before late blight can strike (Karalus and Rauber, 1996; Moller and Reents, 2007; Hagman, 2012). In such situations where the producer is striving to speed the maturity of the crop, physiological aging can be an important tool in the successful production of a profitable potato crop (Asiedu *et al.*, 2003; Hagman, 2012).

4.3.3 Pest avoidance.

TPP is a recently established pest species in New Zealand and is discussed in detail in Chapter 3. It has become a significant pest of summer potato crops, requiring increasing inputs to control (Kale, 2011; Ogden, 2011). As yet, there is currently no low-input, organic or IPM program that is effective in combating TPP in medium and large-scale production environments. The best option in these situations is the manipulation of planting and harvesting dates in order to manage infestation of the crop. As mentioned, physiological aging can be used to increase the yield of a short season crop and shorten the growing season.

This would not only be helpful to organic and low input growers. It has the potential to increase returns in commercial main crop potatoes by reducing the length of the growing season, thereby reducing the amount of spray needed to bring a crop to maturity. This is a balancing act as although a 90-day crop will yield less in terms of t/ha than a 120-day crop, the savings on inputs may outweigh any decreased yields. The usefulness of physiological age in this context it cultivar dependent and can be affected by other factors. Therefore its use as a cost saving tool has to be investigated in each cultivar and production system. In the case of taewa the effects of physiological aging and benefits it might have are not known.

4.3.4 Enhancing yield in early crops.

It has been shown that in some cultivars, aging can significantly increase early yields (O'Brien *et al.*, 1983; Vakis, 1986; Roy and Jaiswal, 1997; Rykaczewska, 2000; Asiedu *et al.*, 2003).Tuber fresh yield varies greatly depending on harvest date, earliness of cultivar and physiological age of seed tubers (Asiedu *et al.*, 2003; Struik, 2006). Aging can have both a positive and negative effect in final yield depending on the situation in which it is used (Asiedu *et al.*, 2003). Care should be exercised when removing seed from cool storing too early in order to save on costs (Vakis, 1986). Some varieties age slower and show traits for resistance to aging (Reust *et al.*, 2001). It is therefore important to understand the dynamics and rates of aging in different cultivars in order to improve early yields and to optimize storage regimes (Asiedu *et al.*, 2003).

4.3.4.1 Physiological vigour.

Physiological vigour refers to the ability of a cultivar to perform after extended aging and is related to the rate at which a cultivar ages(Reust *et al.*, 2001). Older or heritage cultivars seem to be able to be exposed to more thermal time than modern varieties without significant effects on yield (*ibid*.). While no exact reason is given in the literature for this, it seems reasonable to assume that older cultivars have a history of selection that pre-dates the availability of cool storing. In this context, seed that maintain their vigour when stored at ambient temperatures will produce more tubers and therefore contribute more seed tubers to the following season.

Cultivars that were grown before widespread access to cool-storing facilities would have undergone a selection process for traits that confer resistance to the effects of thermal time. It is important for the potato industry to understand both the dormancy and aging of different cultivars of potatoes in order to optimize storage regimes and aging protocols. In general, cultivars with a short period of dormancy should be keep in cooler conditions longer than those that have a longer dormancy in the absence of chemical sprout inhibition (*ibid.*)

4.3.5 Optimizing physiological age for specific production systems.

For both seed tuber and short season (very-early) crops, seed tubers in the later multiple sprout stage show a more suitable tuber size distribution (for seed tuber crops) a greater yielding potential (for early table and process crops) over younger seed (Struik and Wiersema 1999). Longer season crops however benefit from seed in the earlier stages of multiple sprouting, which yield higher over time than older seed (Figure 4.1). There can also be an effect on the amount of sugars, dry matter, starch and polyphenols which all have an impact on the processing quality of tubers (Caldiz *et al.*, 1996; Freitas *et al.*, 2012).

Appropriately aged seed can increase the processing quality of a crop, both through the manipulation of the composition of the tubers and through the avoidance of disease such as Zebra Chip (section 3.4.2). The best storage regime for a given cultivar and a given market depends on genotype and how it interacts with the environment and physiological age of the tubers (Freitas *et al.*, 2012). In terms of taewa Māori with a good processing potential, understanding and optimizing storage regimes and consequently manipulating physiological age could help further improve the processing quality of a crop.

4.4 Measuring and assessing physiological aging.

4.4.1 Morphological markers.

Despite the extensive research into physiological age, an easy, non-destructive and universal measure of aging that accurately predicts crop yield has yet to be developed (Caldiz, 2009). Early efforts focused on visual assessments of the morphological changes seen in the sprouts (Krijthe, 1955), sprouting capacity (Krijthe, 1962) and the length of the longest sprout (O'Brien *et al.*, 1983). The weight of sprouts and their ratio to the weight of the tuber have also been shown to be an appropriate measure of the age of physiological age in some cases (Hartmans and Loon, 1987; Ezekiel, 1994; Ezekiel, 2004). More recent work has looked to use non-destructive measurements such as ultrasound to assess the morphological characteristics of the seed tuber (Mizrach and Eshel, 2008). While such assessments can correlate with aging, they can be time consuming and take trained and skilled personnel to measure and interpret (Caldiz *et al.*, 2001).

4.4.2 Biochemical markers.

As laboratory techniques advanced, biochemical markers were assessed to see how they correlate with aging and final tuber yields. It was seen that as a tuber ages it's sugar contents increases and enzyme activities change (Es and Hartmans, 1987) as do a number of metabolites (Caldiz, 2009). The assessment of these markers however requires the destruction of the tuber samples and their relationship to the final tuber yield is not always clear-cut (Caldiz *et al.*, 2001; Delaplace *et al.*, 2008b; Caldiz, 2009). Recent work has employed proteomic techniques, looking at changes across a wide range of proteins and metabolites (Delaplace *et al.*, 2009). This has found some novel and potentially useful markers associated with aging, but how they relate to final crop yields is yet to be determined.

4.4.3 Biophysical markers.

The use of biophysical markers, particularly the thermal time that seed tubers are exposed to, became a widely accepted measure of physiological aging to seed tubers (Allen and O'Brien, 1986; Struik *et al.*, 2006; Caldiz, 2009). There have been several approaches developed to calculating thermal time including the accumulated degree-days from dormancy break (O'Brien *et al.*, 1983) and the storage temperature sum (Scholte, 1987). It is clear the thermal time has varying effects on different cultivars, and the timing of warming had different impacts on the performance of the crops depending on whether it was before or after storage (Struik *et al.*, 2006; Oliveira *et al.*, 2012).

If the entire accumulated temperature from haulm killing onwards is taken into account then the accumulated temperature sum is still an effective tool for measuring differences in the physiological age of seed tubers exposed to the same environmental and agronomic conditions (Caldiz, 2009). The understanding of thermal time and its application in manipulating seed tuber quality still needs some refining, however it is still seen as one of the best and easiest measures of differences in physiological aging in seed potato tubers (Struik *et al.*, 2006; Caldiz, 2009).

4.4.4 Physiological age index.

In order to deal with the issues arising from the varying effects of dissimilar environments on different cultivars, the physiological age index (PAI) was developed (Caldiz *et al.*, 2001). This index relied purely on the chronological age of the seed tuber and looked at the ratio between the difference in time from haulm killing date to planting and the time it takes for a batch of seed from a particular cultivar to complete its incubation period (Equation 1).

Equation 1: $PAI = T_1/T_2$

T_1 is the time between haulm killing (T_0) and planting date and T_2 is the length of the incubation period.

The incubation period is the time from haulm killing until the plants reach the 'little tuber' stage seen in figure 4.2. The incubation period is a measure of the rate at which a cultivar ages, and therefore it's physiological vigour (Caldiz, 2009). As will be discussed in section 4.6, the incubation period of seed tubers in a cultivar can vary depending on the storage regime and the environment in which it is raised. Despite these differences, the index was found to be predictive of ground cover duration and yield while also being cheap, non-invasive and simple to measure (Caldiz, 2009). However it can take a long time to obtain final results which limits its predictive value (Caldiz *et al.*, 2001). Also in some situations, particularly those where haulm killing dates vary widely, PAI does not adequately describe the effects of physiological age on crop growth and yield (Caldiz, 2009).

4.5 Influence of environment and crop management on physiological age.

4.5.1 Environmental factors.

Environmental factors such as climate and soil temperature can affect the expression of physiological age in a potato crop (Asiedu *et al.*, 2003). This becomes most apparent in temperate regions such as New Zealand, where the effects with physiological age are more prominent in early potato plantings than with later planted crops (Reust *et al.*, 2001). Physiological age and its expression are determined by the combined effects of chronological age, environment and genetics (Caldiz, 2009). These effects begin at tuber initiation, and with respect to a seed tuber crop, environmental factors and crop management play a role in determining the progression and effects of physiological age in seed tubers from that crop (*ibid.*). Important environmental factors that influence physiological age of seed tubers include day length, solar radiation and water supply during tuber development (Struik and Wiersema, 1999). However largest and most consistent factor is the temperature during tuber growth and development (Struik *et al.*, 2006; Caldiz, 2009).

4.5.2 Altitude and cool climates.

It has been known for centuries in the Andean region that seed potato tubers raised at higher altitudes produce a more vigorous and robust crop than those grown at lower altitudes. (Caldiz, 2009). Initially this was put down to low pathogen loads in the seed crop due to the lack of insects responsible for vectoring those pathogens at such altitudes (*ibid*). Other factors involved are greater light intensity and spectral composition, which combines with better photosynthetic utilization of this light due to the cooler conditions and delayed maturity, which all favour the production of vigorous seed (Postic *et al.*, 2012). This effect of cooler growing conditions on the potential vigour of seed lead to the American trademark 'northern vigour' (Caldiz, 2009). This brand represented seed tuber raised in northern latitudes and recognised the superior productive potential over seed tubers grown in the warmer southern climates (*ibid*.) Until the development of widely available virus testing it was unclear whether these effects were down to pathogen load or physiological vigour (*ibid.*).

4.5.3. Degeneration and declination.

The term 'degeneration' was initially used to describe any decrease in vigour of a potato line (Caldiz, 2000; Postic *et al.*, 2012) and is seen as a factor in the decreased use of taewa in favour of modern cultivars (Roskruge, 1999). Much of the taewa seed stock is now infected with viruses. This has resulted in the degeneration of the seed lines as they accumulated pathogens.

It became clear that degeneration is a multi-factorial phenomenon, and soon the concept was split into seed degeneration, caused by the effects of the build-up of pathogen in the seed tubers, and seed declination, caused by the environmental conditions (particularly high temperatures) in which the seed were raised (Caldiz, 2009). While the effects of degeneration on Taewa Māori are clear the potential effects of declination have not been studied.

4.5.4 Influence of crop management.

In terms of crop management, irrigation during tuber development and the time between of haulm killing and harvest are the major factors which can affect the vigour of seed tuber crops (Struik and Wiersema, 1999; Caldiz, 2009). In seed tuber crops, early haulm killing is a common practice to both avoid viral infection by aphids and to ensure a tuber size distribution that is optimal for the seed tuber market (Caldiz, 2009). High temperature leading to harvest, as well as delayed harvest can increase the physiological age of seed tubers taken from the crop (*ibid.*) Like most aspects of physiological age the magnitude of this effect varies between cultivars (Panelo and Caldiz, 1989).

4.6 Seed tuber storage environment.

4.6.1 Storage options and their influence.

The potato producer has no influence on temperatures during crop growth and can only work around nature by manipulating the storage regime and the planting, haulm killing and harvest dates (Caldiz, 2009). The advent of widely available cool storing where temperature and humidity can be controlled allowed producers some control over the rate at which their seed tubers aged (Espen *et al.*, 1999; Struik and Wiersema, 1999; Caldiz, 2009). Temperatures of 2-4°C are recommended where tubers are to be stored for longer than 6 months and where they are to be used in longer growing seasons, as younger seed yields better in this situation (Caldiz, 2000). In areas where cool storing is not available, the use of traditional diffuse light storage systems can be used to slow aging (Acasio *et al.*, 1986; Struik *et al.*, 2006). The presence of light can however have different effects. It can shorten dormancy in seed tubers harvested immaturely, while lengthening it in tubers harvested at a mature stage (Struik and Wiersema, 1999).

4.6.2 Optimizing storage for specific production systems.

If the seed is to be used in a shorter growing season, such as in areas where climate restricts the length of the season, then higher storage temperatures can be used to help advance aging to the optimal level (Caldiz, 2009). It is important to understand these effects in individual cultivars in order to optimize the storage regime for different outputs. For instance, in areas where double cropping systems are used, seed should be stored no longer than 90 days at elevated temperatures in order to advance aging (Quattrini *et al.*, 2001).

As with all aspects of physiological aging, relative merits of different storage regimes vary depending on cultivar but they are also affected by the origin of the seed (Caldiz, 1991). This origin effect can be seen in figure 4.4, where tubers of the cultivar Spunta from different locations were subjected to different storage regimes (*ibid*.). As can be seen both the origin and storage regime in the same cultivar can affect the rate of aging (i.e. incubation period) and the performance of a cultivar. It is important to look at any results obtained from work done on physiological aging in light of these storage and location effects.

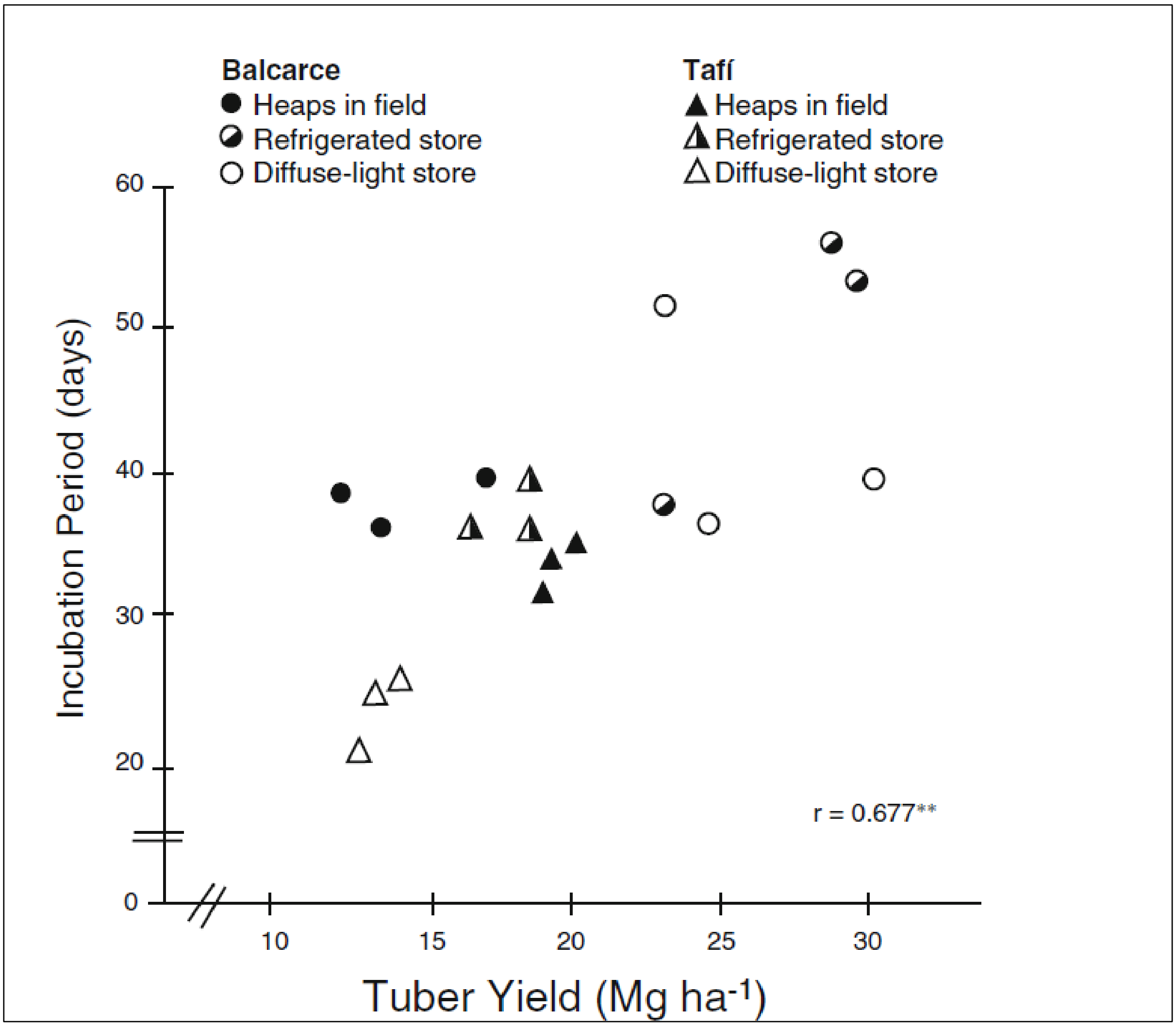

Figure 4-4 Effect of location and storage regime of potato seed tubers on tuber yield. Source: Caldiz 1991: 4

4.7 Chapter summary.

Physiological age holds the potential to be a powerful agronomic tool. It can allow the producer to manipulate the quality of seed tubers so they will give optimal results in varying environmental and agronomic conditions as well as in different production systems and markets. It can be used to manipulate both yield and quality factors in a prospective crop. The effect of physiological age varies with the cultivation and storage history of the seed tubers, the agronomic and environmental conditions in which the crop is grown and with cultivar. These interactions can be complex. This has made it difficult for researchers to create a universal, non-destructive measure of physiological age that is predictive of the final crop outcome. The effects of aging are cultivar and environment specific. They therefore need to be studied as individual cultivars as well as across several seasons and locations to understand the dynamics of aging within a cultivar and assess any potential benefits.

Accumulated thermal time, while not a perfect assessment of physiological age, is the best measure of differences in seed tuber age within a cultivar and environmental space. It can adequately describe differences in crop performance and is useful for assessing the effects of aging. Ultimately the results should be viewed in terms of the history of the crop that the seed came from, the storage regime used and the dynamics of aging for a particular cultivar. Understanding how physiological age affects a cultivar can lead to improved storage regimes for seed tubers destined to be used in different production systems.

Understanding the effects of physiological aging in taewa Māori could help with their commercialization. Improved yields and quality aspects, optimized storage regimes and shorter growing seasons (and therefore reduced agrichemical use) can all contribute to increased profitability and sustainability. Due to the cultivar specific nature of physiological aging, work must be conducted to assess the dynamics and effects of aging in taewa and if it holds potential to improve crop yields.

Chapter 5. Methods

5.1 Cultivars.

Three cultivars of taewa, Moemoe, Waiporoporo and Kowiniwini were chosen on the basis of availability from Alex MacDonald Merchants Ltd in Canterbury, New Zealand. Moemoe is described as a round potato with a yellow skin colour that has purple and red blotches (Figure 5.1) (Hayward, 2004). The flesh is a creamy colour and has a firm texture (*ibid*.). The word 'moe' means sleep, with the name Moemoe referring to the long storing qualities of the cultivar (Roskruge, pers. comms., 5 October, 2012). Waiporoporo is also round, with a purple skin and has a dense, white flesh (Figure 5.2). Waiporoporo literally means purple and refers to the colour of the skin (*ibid*.). Kowiniwini (also known as Karuparera in some areas) is a round potato with a purple skin, distinctive yellow involuted eyes and has a yellow, waxy flesh (Figure 5.3) (Hayward, 2004). The name Kowiniwini has its roots in the word 'wini', meaning window, and refers to the eyes of the tuber (Roskruge, pers. comms, 5 October, 2012). All three cultivars are currently grown as main crop potatoes.

Figure 5-1 Moemoe tubers

Figure 5-2 Waiporoporo tubers

Figure 5-3 Kowiniwini tubers

5.2 Thermal time.

The current industry planting protocol is to remove seed tubers from the cool-store and warm them at ambient temperature for 14-21 days before the planned planting date (Hughes, pers. comms., Sept. 17, 2012). It was decided that the seed tubers received would be aged for 14, 28 and 42 days in a controlled temperature room at 24°C. Using the thermal time calculation in Oliveira *et al.* (2012) creates three treatments; 448, 728 and 1008 degree-days (dd) respectively. The total accumulated thermal time experienced by the tubers before arrival at Palmerston North from

Christchurch was the same for all cultivars, therefore only the difference in treatments was considered. The full calculation can be seen in Appendix 1. The range of dd covers that which is often used in other studies of physiological aging (O'Brien *et al.*, 1983; Asiedu *et al.*, 2003; Struik *et al.*, 2006; Caldiz, 2009; Freitas *et al.*, 2012).

Tubers were removed from cool-storage in Canterbury at 2.8^{o} C and spent 3 days in transit before arrival and cool storing at 4^{o} C at the Massey University Plant Growth Unit (PGU). On December 10, 2013, 20 tubers of each cultivar weighing between 40-70g per tuber were removed from the cool-store and warmed at 24^{o} C. Another 20 of each cultivar of the same weight range were removed from the cool store on December 24, 2013 and also on January 7, 2013 to give the 3 treatment groups.

5.3 Experimental site.

The planting site was located on Poultry Road, Palmerston North (40^{o} 22' 55" S, 175^{o} 36' 22" E). The soil is a free draining recent Manawatu silt-loam type and was tested for nutrient levels and pH prior to plantings (Table 5.1). Soil samples were taken from a depth of 7.5cm by hand trowel from 16 locations on the site and were analysed by Hill laboratories using their standard methods. The pH was slightly lower than recommended for a taewa crop (Roskruge *et al.* 2010). Given a taewa crop had performed well in the same paddock at the same pH the previous season it was not thought to be a significant issue.

The site has had a recent planting history of taewa and kale (*Brassica oleracea,* Acephala Group). During the experimental period, kale, taewa and kōkihi (New Zealand Spinach, *Tetragonia tetragonioides*) were grown in different parts of the same paddock. The area of the paddock where kale and taewa were to be planted was given a base dressing on December 15, 2013 of 200kg/ha of 12:10:10 fertilizer. This level of nutrition is considered more than adequate for raising a taewa crop (Roskruge *et al.*, 2010). On January 9, 2013 the site where the taewa were to be planted was cultivated with power harrows. The site was irrigated weekly (2.5mm/week) after planting.

Table 5.1. Soil parameters at experimental site

Soil parameter	Soil test
pH	5.1
Nitrogen	106 kg/ha
Phosphorus	34 kg/ha
Potassium	83 kg/ha

5.4 Experimental design.

The field experiment used a standard random block design (Fromke and Bretz, 2004). The experimental plan is shown in Appendix 2 and consisted of three outer guard rows on the southern and northern ends of the plot, with guard plants at the end of each experimental row and between blocks. Four replicates were planted. The row order was randomized using a random permutation in the statistical package Minitab (Godfrey, pers. comms., December 12, 2012).

5.5 Physical measures of physiological aging.

When tubers were removed from the cool-store the number of sprouts was counted and recorded. The length of sprouts was measured using vernier callipers and recorded (O'Brien *et al.*, 1983). The average and longest sprout lengths, as well as the number of sprouts have been proposed a measures of physiological age (O'Brien *et al.*, 1983; Struik, 2006). Tubers left over from planting were desprouted. The sprouts and desprouted tubers were then weighed to obtain the ratio of sprout to tuber weight, which is seen as a measure of the degree of physiological aging in some cases (Hartmans and Loon, 1987; Ezekiel, 1994; Ezekiel, 2004).

5.6 Planting.

On January 21, 2013, trenches were made by hand at 1m apart and tubers were layered in the trench at 0.3m intervals before being covered in 10 cm of soil. (Figure 5.4). This spacing is as per established Massey University taewa crop trial guidelines.

Figure 5-4 Trenches with taewa laid out

5.7 Emergence and rogueing.

The crop site was then monitored every 2 days from 7 DAP onwards and time to emergence was noted. The aging of seed tubers can promote early emergence in some cultivars (Ezekiel, 2000; Struik *et al.*, 2006). Rows were considered emerged when 80% of the plants were visible above ground (Ezekiel, 2000). The crop rows were mounded by hand on at 27 DAP. An image of the mounded plot can be seen in Figure 5.5. At this time it was noted that several plants displayed severe symptoms of viral infection, most notably severely stunted growth and leaf curling (Figure 5.6). These plants were removed (rogued) from the field. A record of rogueing can be seen in Appendix 3. Due to this rouging, an analysis (ANOVA, Tukey's post-hoc) of the tuber fresh weight and leaf area was carried out on the plants immediately adjacent to those removed to determine whether the reduced competition had any influence on plant growth, development or yield.

Figure 5-5 Mounded rows of taewa at experimental plot

At 30 DAP stem number was counted and recorded. Stem number is affected by aging with increased thermal time increasing the number of stems (Ezekiel, 2000; Caldiz *et al.*, 2001; Struik *et al.*, 2006). This is related to the potential number and size of tubers through competition amongst the stems for space and resources.

Figure 5-6 Comparison of virus infected (left) and healthy (right) taewa plants

5.8 Time to inflorescence.

The BCHH scale is used to provide a system that identifies different developmental stages in plants, particularly crop species (Hack et al, 1992). A row of plants was considered to have flowered when at least 80% of the plants had at least one open flower (BCHH Phenological stage 59) (*ibid.*).

5.9 Crop maintenance, monitoring and scouting.

The critical period of weed control is defined as 'part of crop growing season in which weeds should be removed in order to prevent crop loss due to weed competition' (Ahmadvand *et al.*, 2009).The length of this period can vary depending on environment, cultivar, relative time to emergence and many other factors but is generally from emergence up to 60 DAP (Ahmadvand *et al.*, 2009; Monteiro *et al.*, 2011).The experimental plot was hand weeded by hoeing at 20, 40, and 58 DAP.

The crop was inspected 3 times weekly for signs of pest and disease. TPP was first noted on the plants at 30 DAP and a spray programme was implemented (Table 3.3). At 42 and 65 DAP a preventative late blight treatment of copper hydroxide (1.5 kg/ha) was also applied. Approximately a dozen aphids (possibly *Myzus persicae*) were noted at 40 DAP and a treatment of Confidor 200 SC® (Imidacloprid, 60g ai/ha) was applied with the 42 DAP copper hydroxide treatment.

5.10 Late blight (*Phytophthora infestans*) control.

Signs and symptoms of late blight were noted on the plants on 75 DAP. At 76, 86 and 96 DAP control treatments of Taratek (250g/l chlorothalonil and 250g/l thiophanate-methyl) at 500g ai/ha were applied.

5.11 Harvest protocol and measurements.

The original trial design was to have 4 harvest dates at 30, 60, 90 and 120 DAP. Due to the loss of plants through virus and TPP damage, the design was reworked to harvests at 60 and 90 DAP.

Plants were selected randomly (random permutation, Minitab, see Appendix 4) and harvested as to collect all the tubers. The leaves, stems and tubers were separated and their fresh weights recorded. Leaf area was measured with a LiCor 3100C leaf area meter. Physiological aging can change leaf area and the development of the canopy. (Lohmus and Joudu, 2000). The size of the leaf canopy has an effect on the total dry matter accumulated into tubers in potato crops (Tekalign and Hammes, 2005). Leaf area and dry matter distributions can help explain differences seen in crop performance (Hunt, 1982; Gardner *et al.*, 1985).

Aging of seed tubers can decrease the dry matter accumulated into newly formed tubers (Bhargava and Banerjee, 1994). The accumulation of dry matter is often studied as it is the most economically important measure of crop performance (Tekalign and Hammes, 2005). The study of the how a plant partitions dry matter into different tissues (leaf, stems, tubers) helps evaluate the productivity and yield in potatoes (Nganga, 1982) and understand the factors that influence that yield (Gardner *et al.*, 1985). Leaves, stems and tubers were put in separate, labelled paper bags and placed in a 70^{o}C oven until the weight of the material stopped decreasing (one week). The dry weight of the separate plant materials was recorded. The proportion of dry matter (%DM) accumulated into stems, leaves or tubers was calculated to determine the dry matter distribution of the three cultivars.

5.12 Zebra Chip (ZC) symptoms.

At 120 DAP, ten sample tubers from each block were taken and cut in half to be examined for symptoms of ZC (Figure 5.7). The tubers were scored for disease severity and the score for each block totalled (Wallis *et al.*, 2012).

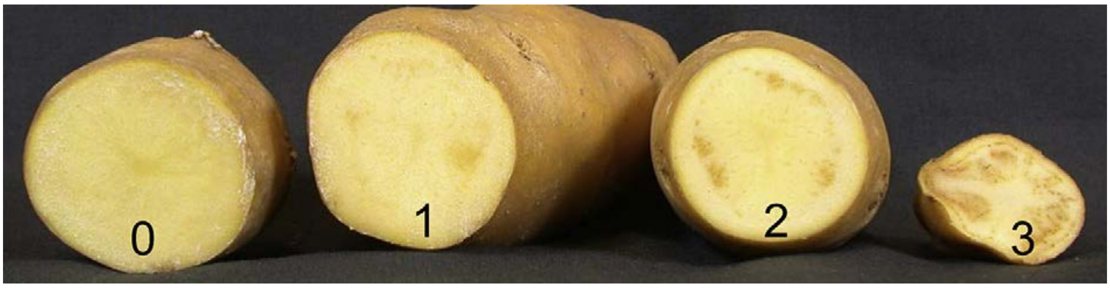

Figure 5-7 Symptoms of Zebra Chip in raw tubers from no symptoms (0) to severe symptoms (3). Source: Wallis et al. 2012: 67.

5.13 Data analysis.

Results were entered into a Microsoft Excel spread sheet and analysed in the statistical programme Minitab. A general linear model was used to detect any significant trends and an ANOVA with Tukey's post-hoc analysis was used to analyse groupings as recommended (Godfrey, pers. comms., December 12, 2012).

Chapter 6. Results

6.1 Cropping issues.

6.1.1 Virus.

Due to limitations both the 30 and 120 DAP harvests could not be done. The discovery of a number of plants with severe viral symptoms (see Figure 5.5) led to the removal (rogueing) of these plants. The number of viral plants in each cultivar and treatment group was analysed to see if there was and pattern in the rates of infection. No significant patterns were found. With the reduction in available plant numbers, it was recommended to focus on the 60 and 90 DAP harvests.

6.1.2 Tomato-Potato Psyllid (TPP).

The plot was inspected twice weekly for signs and symptoms of pest and disease. At 30 DAP, TPP adults were observed on guard row plants and TPP nymphs were observed at 43 DAP. A spraying programme (Table 3.3) was initiated. Signs and symptoms of TPP feeding (yellowing and purpling of leaves, Figure 3.4) were first noted on guard row plants at 45 DAP. At 58 DAP TPP adults were observed on plants in experimental blocks C and D, with some plants in these blocks displaying symptoms at 72 DAP. Plants displaying severe symptoms were excluded from sampling, and the next plant in the harvest randomization list was taken.

6.1.3 Late Blight (Phytophthora infestans).

At the 75 DAP, brown lesions (Figure 6.1) were noted on some plants. It was suspected that this was late blight as the environmental conditions at the time were favourable for this disease. The crop diary documenting all agronomic decisions and actions taken is provided in Appendix 5.

Figure 6-1 Signs of late blight on potato leaves. Source: Ministry of Agriculture, 2004

6.2 Weather data.

Temperature and rainfall data are shown in figure 6.2. Sunlight hours were above average during the growing period (Hyde, 2013) and are shown in figure 6.3.

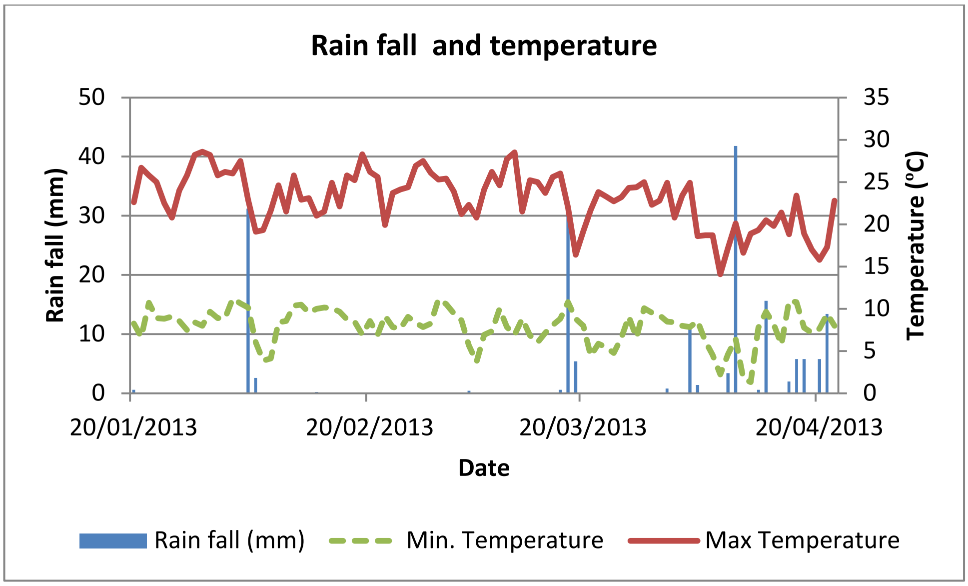

Figure 6-2 Rainfall and temperature over experimental period.
Data from Agresearch weather station, Orchard Road, Palmerston North

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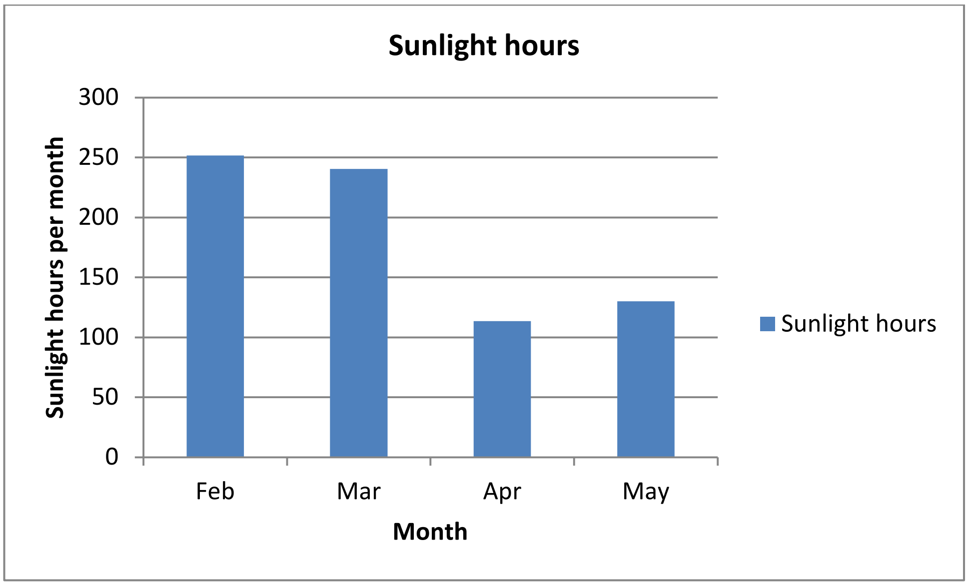

Figure 6-3 Sunlight hours per month for mid-late summer 2013.
Data from Agresearch weather station, Orchard Road, Palmerston North

6.3 Tuber sprout data.

6.3.1 Ratio of sprout to tuber weight.

Differences in several aspects of sprout physiology were observed. The sprout:tuber weight ratio has been proposed as a measure of the degree of aging in a tuber (Ezekiel, 2004). There was a significant (ANOVA, P<0.05) decrease in this ratio with increased thermal time in all cultivars (Figure 6.4). Moemoe had a larger proportion of weight in the sprouts than either Kowiniwini or Waiporoporo that resulted in a lower sprout:tuber weight ratio.

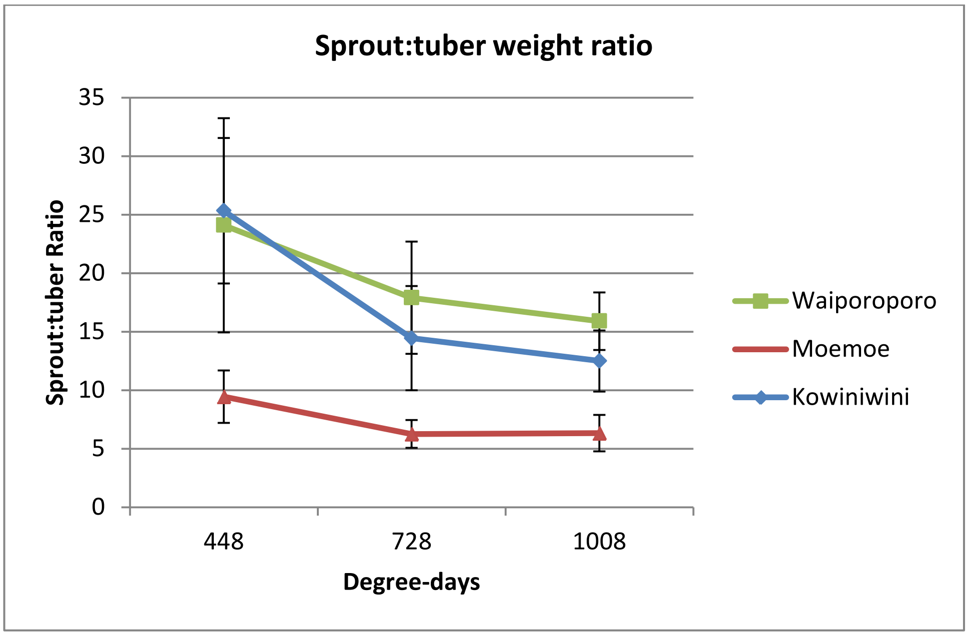

Figure 6-4 The effect of thermal time on the ratio of sprout weight and tuber weight in three taewa cultivars. Error bars are standard deviation.

6.3.2 Sprout length and number.

When seed tubers were removed from the cool-store prior to warming the length of the longest sprout length and sprout number was recorded. These parameters have been previously proposed a measures of physiological age (O'Brien *et al.*, 1983;

Struik, 2007). In Kowiniwini and Waiporoporo the 448 dd tubers had significantly (ANOVA P<0.05) more sprouts than 728 dd and 1008 dd tubers. In Moemoe all three treatments groups had significantly different sprout number compared to each other (Figure 6.5). The length of the longest sprout in Moemoe and Waiporoporo was significantly longer (ANOVA P<0.05) in the 448 dd than the 1008 dd treatments when they were removed from cool-store to begin their treatments (Figure 6.6). There was no significant difference in Kowiniwini, although it did seem to follow the same trend.

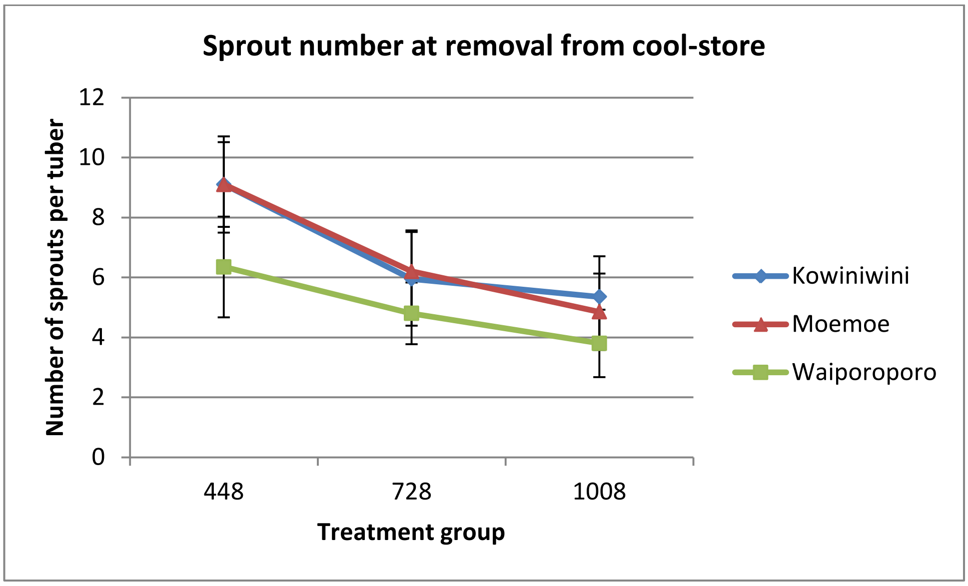

Figure 6-5 The difference in sprout number when tubers were removed from cool store to begin their treatments. Error bars are standard deviation

Sprout length and number have been proposed as markers of physiological age (O'Brien *et al.*, 1983; Struik, 2007) and indicates that some physiological aging, or at least sprout development happens at 4°C in taewa. Waiporoporo showed significantly less sprouts than Moemoe or Kowiniwini, which is possibly a reflection of a difference in the number of eyes in these cultivars.

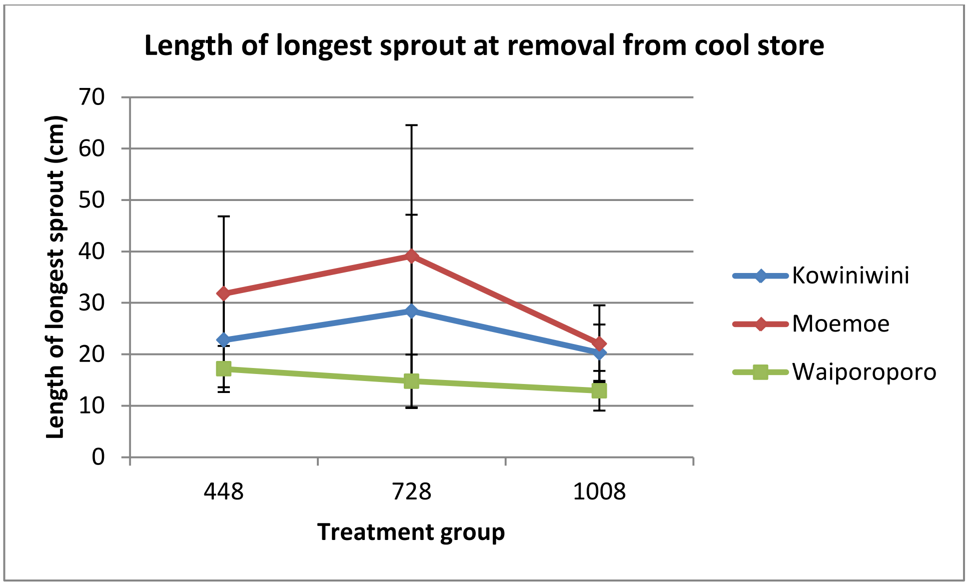

Figure 6-6 The difference in the length of the longest sprout when tubers were removed from cool store to begin their treatment. Error bars are standard deviation

6.4 Inflorescence.

There were no differences in time to inflorescence with respect to thermal time. There were differences however between the cultivars. Kowiniwini was not observed to flower during the trial. Moemoe flowered first, 9 days before Waiporoporo (Table 6.1).

Table 6.1. Time to Inflorescence in three taewa cultivars

Cultivar	Time to inflorescence
Kowiniwini	Did not flower
Moemoe	41 DAP
Waiporoporo	50 DAP

6.5 Emergence.

Although there was a trend for increased thermal time to speed emergence in the cultivar Moemoe, this effect was not significant. Moemoe emerged 2 days earlier than Kowiniwini and Waiporoporo across all treatments (ANOVA, P<0.05) (Figure 6.7).

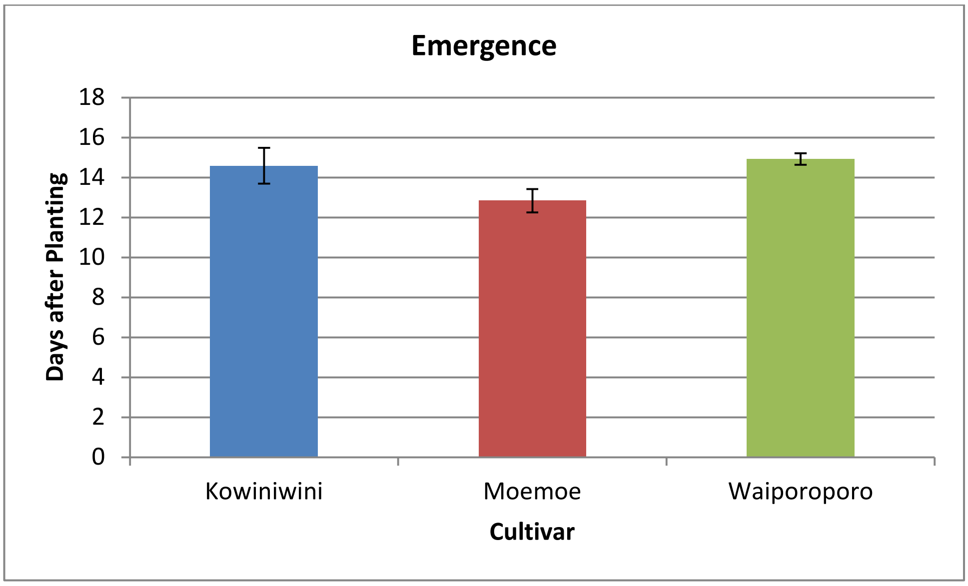

Figure 6-7 Time to emergence in three taewa cultivars. Error bars are standard deviation.

6.6 Number of emerged stems.

Waiporoporo had significantly less stems at 30 DAP than Moemoe or Kowiniwini (Figure 6.8). An increase in thermal time from 448 dd to 1008 dd increased the number of stems in Moemoe while slightly but significantly decreasing the amount of stems in Waiporoporo (ANOVA, P<0.05).

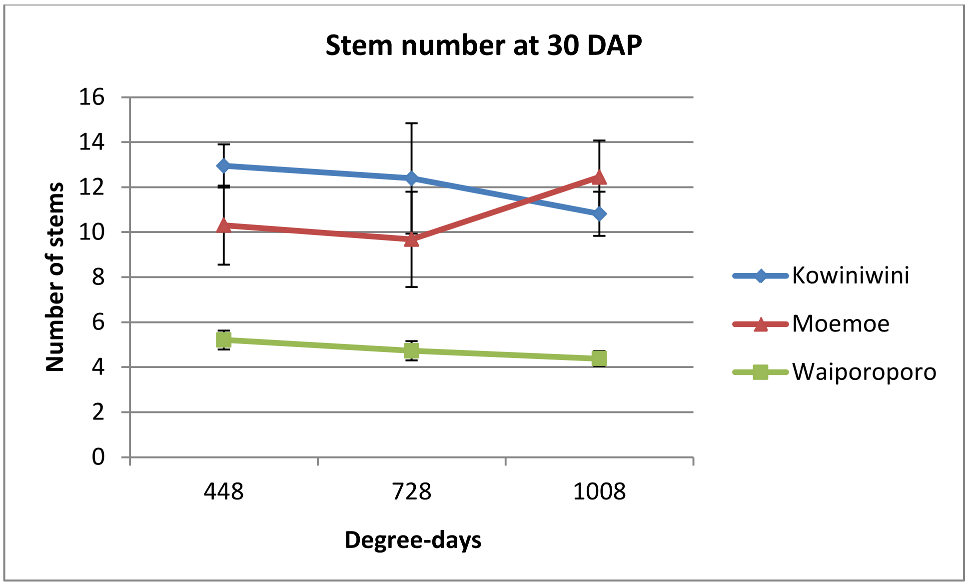

Figure 6-8 Influence of thermal time on main stem number at 30 DAP. Error bars are standard deviation.

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6.7 Sixty DAP harvest data.

6.7.1 Effect of thermal time on fresh tuber harvest

No significant differences were found with respect to thermal time at 60 DAP (Figure 6.9). Kowiniwini had significantly less fresh tuber weight (total per plant) at 60 DAP than the other cultivars across all treatments (ANOVA, P<0.05)

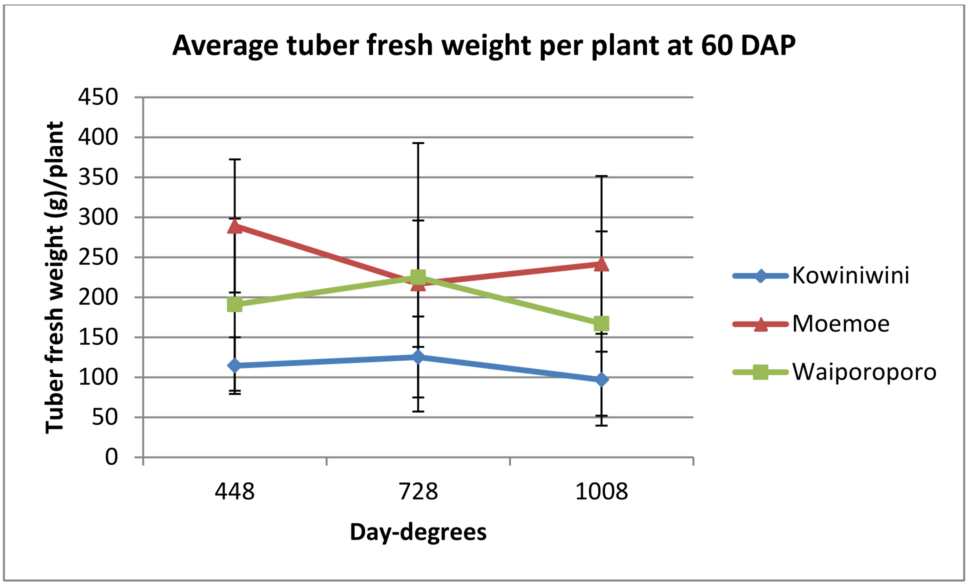

Figure 6-9 Effect of thermal time on tuber fresh weights/plant of three cultivars of taewa harvested at 60 DAP. Error bars are standard deviation.

6.7.2 Crop parameters at 60 DAP.

Leaf and stem dry weight in Waiporoporo was significantly heavier than either Kowiniwini or Moemoe (ANOVA P<0.05). In terms of dry matter distribution, Kowiniwini had the highest proportion of dry matter in the leaves, followed by Waiporoporo, then by Moemoe. Kowiniwini and Waiporoporo both had a greater proportion of dry matter in the stems than Moemoe. Moemoe had more dry matter (Figure 6.10) and proportion of dry matter (Figure 6.11) in tubers than the other cultivars (ANOVA P<0.05).

Waiporoporo had a lower tuber number that the other cultivars (Figure 6.12) and a larger average tuber fresh weight than Kowiniwini (Figure 6.13). Both Waiporoporo and Moemoe accumulated significantly more total dry matter than Kowiniwini (Figure 6.14). There was no significant difference in plant performance between blocks. Plants that were adjacent in the row to virus-infected plants that had been rogued were analysed via ANOVA to see if there was any effect of reduced competition. There were no detectable differences.

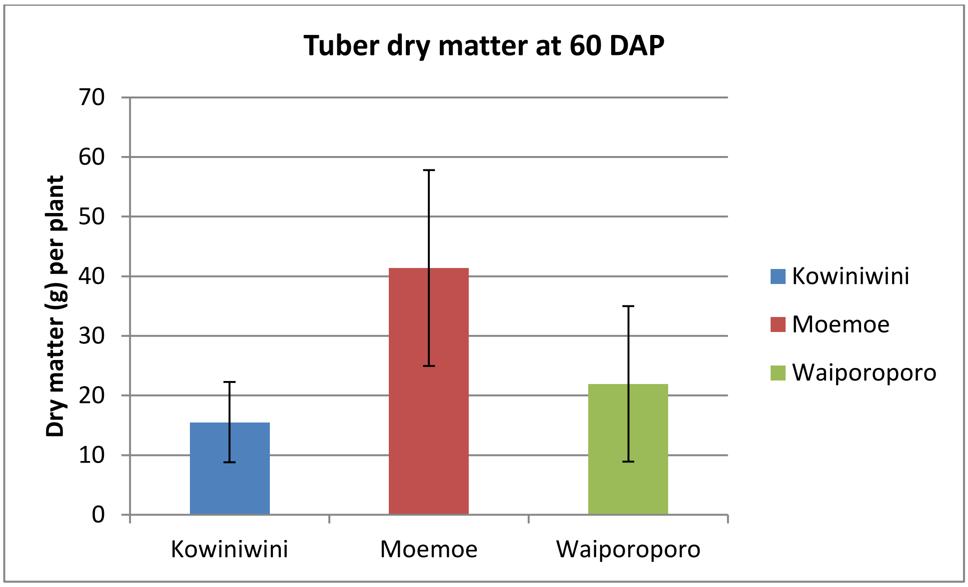

Figure 6-10 Tuber dry matter in three taewa cultivars at 60 DAP. Error bars are standard deviation.

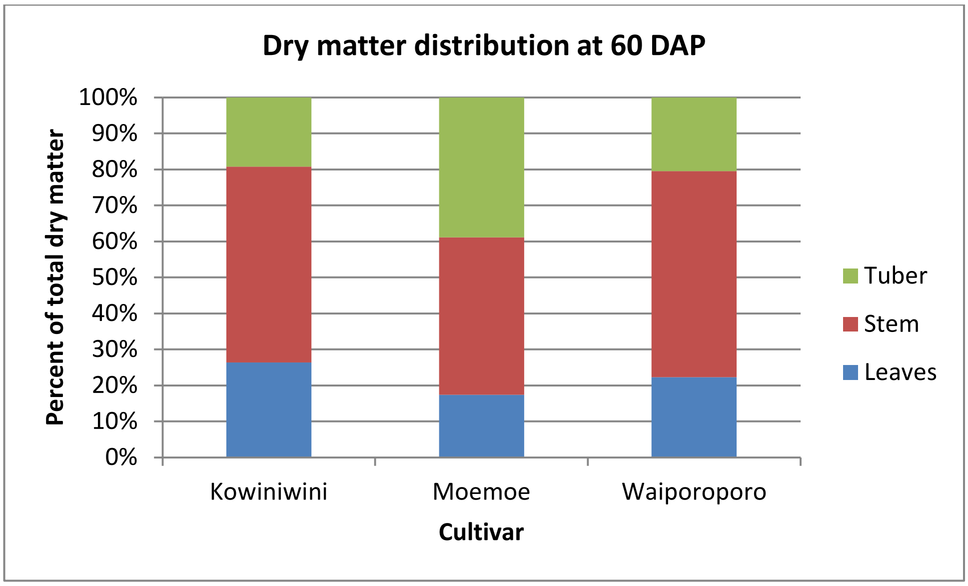

Figure 6-11 Dry matter distribution in three taewa cultivars at 60 DAP.

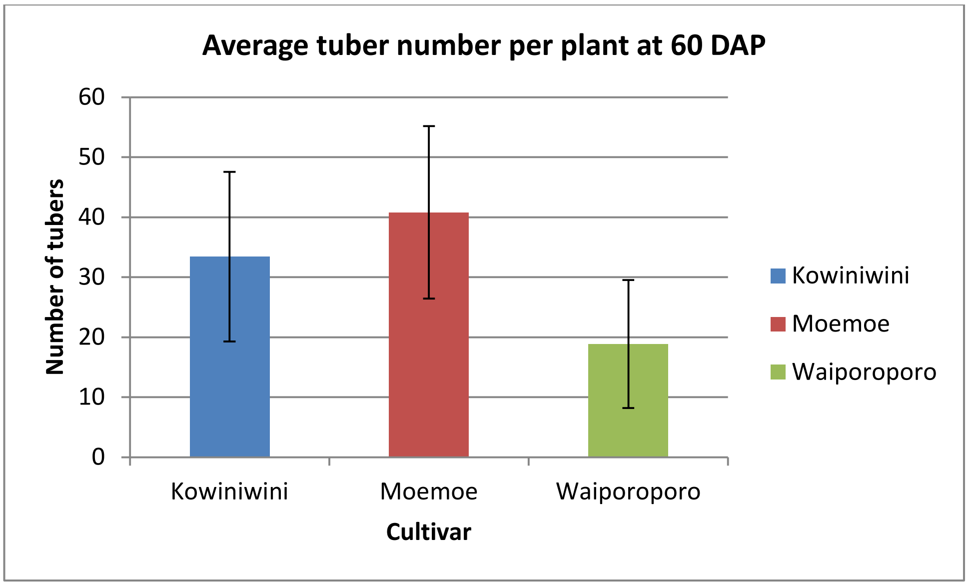

Figure 6-12 Tuber number in three taewa cultivars at 60 DAP. Error bars are standard deviation.

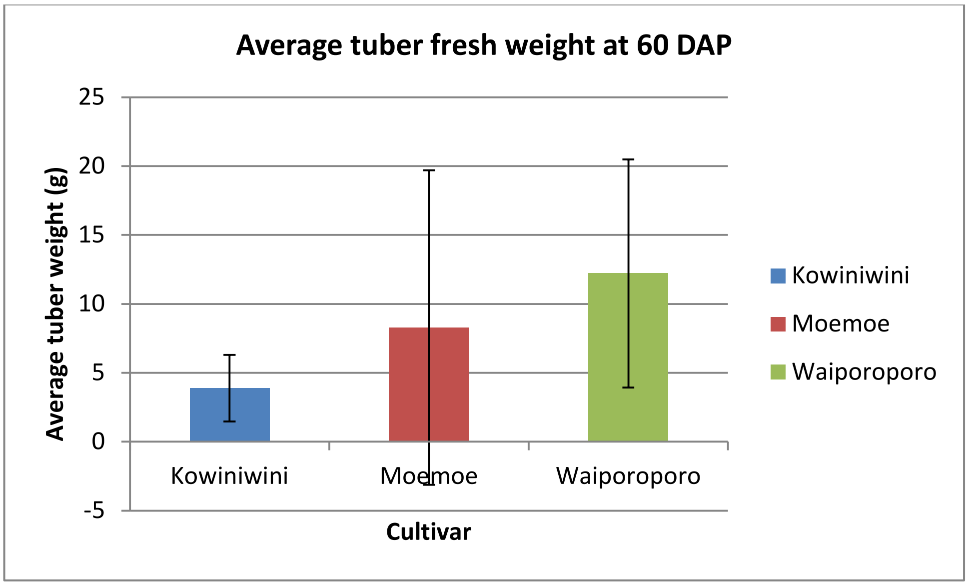

Figure 6-13 Average tuber fresh weight in three taewa cultivars at 60 DAP. Error bars are standard deviation.

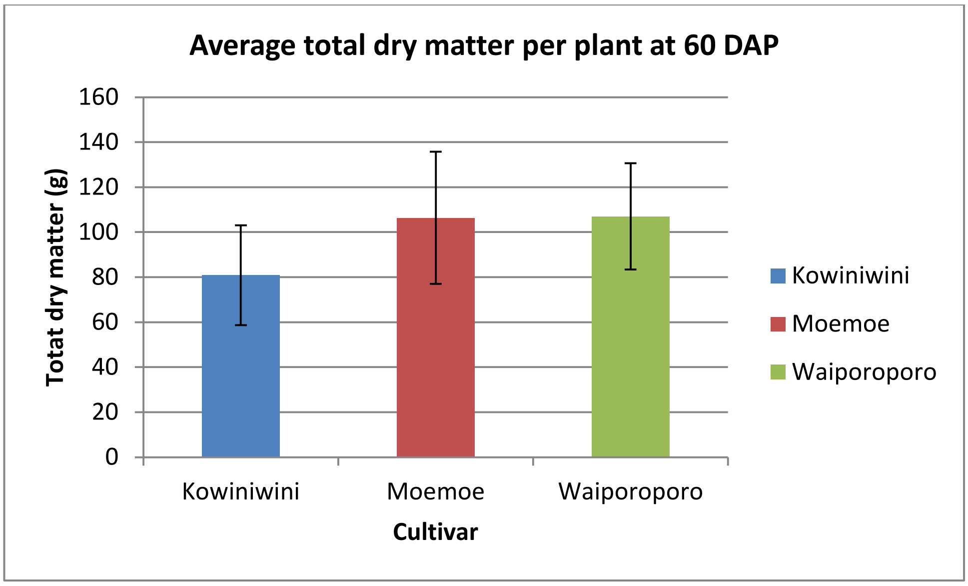

Figure 6-14 Total accumulated dry matter in three taewa cultivars at 60 DAP. Error bars are standard deviation.

6.8 Ninety DAP harvest data.

6.8.1 Effect of thermal time on crop performance.

In the cultivar Waiporoporo, there was a significant difference in the tuber dry matter accumulated between treatments. The 728 dd treatment group accumulated more tuber dry matter that the other treatments (ANOVA $P<0.05$) (Figure 6.15). There was a significant trend for increased thermal time to increase tuber numbers in Moemoe (ANOVA $P<0.05$) but not in Kowiniwini or Waiporoporo (Figure 6.15).

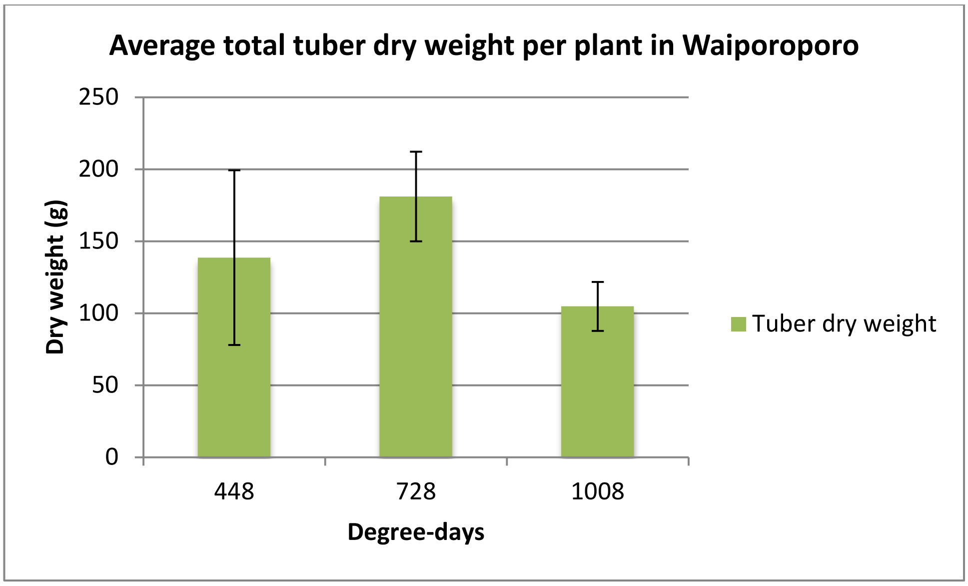

Figure 6-15 Tuber dry weight in Waiporoporo at 90 DAP. Error bars are standard deviation.

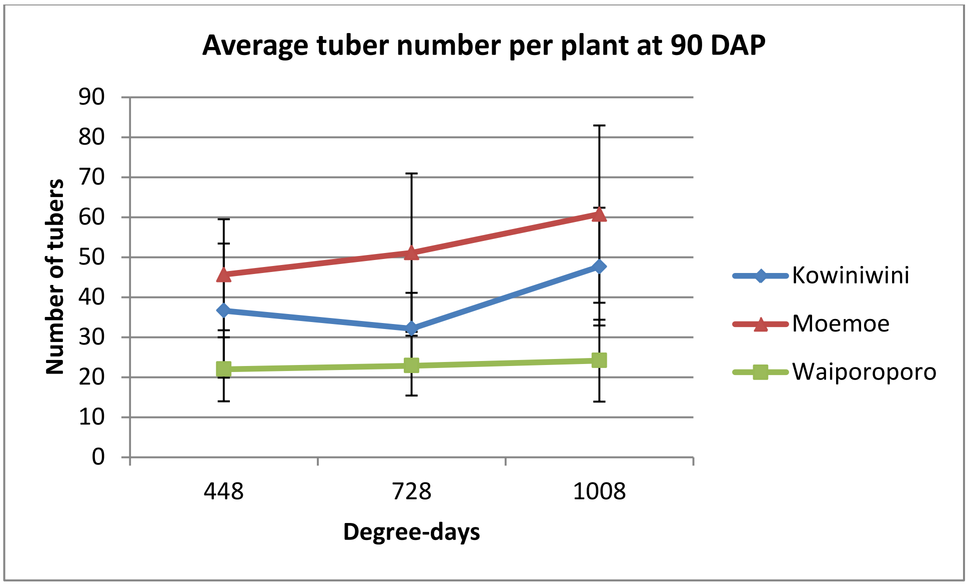

Figure 6-16 The effect of thermal time on tuber number in three taewa cultivars. Errors bars are standard deviation.

While there was an apparent trend in Moemoe for increased tuber fresh weight with increased thermal time, there were no significant differences in tuber fresh weight between the treatment groups in any cultivar. (Figure 6.17).

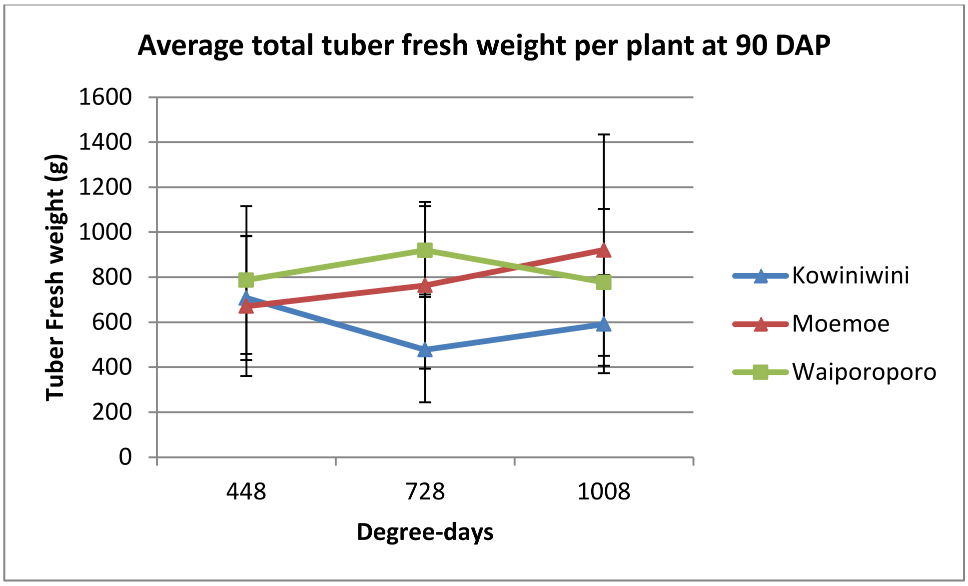

Figure 6-17 The effect of thermal time on tuber fresh weight in three cultivars of taewa. Error bars are standard deviation.

6.8.2 Influence of field position.

There was a significant difference (ANOVA, P<0.05) found between blocks in terms of tuber fresh weight and the distribution of dry matter in the plants. Both blocks A and B (southern blocks) had on average 37% more tuber fresh weight than blocks C and D (northern blocks) across all cultivars and treatments (Figure 6.18). This translated through to the tuber dry matter, with the southern blocks accumulating more dry matter into tubers than the northern blocks. As a result, blocks A and B have proportionally less dry matter in their leaves and stems, however there is no difference in the total dry matter accumulated into these tissues.

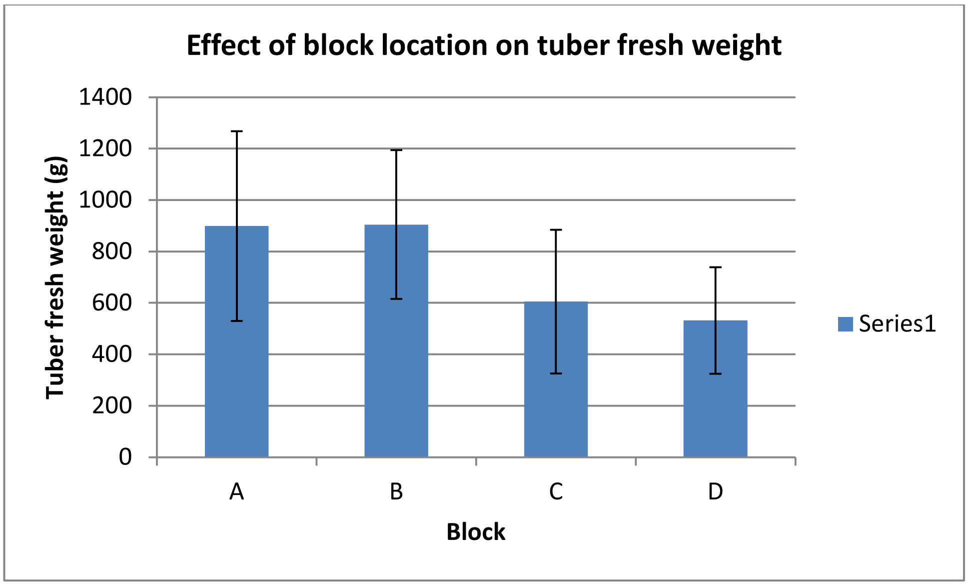

Figure 6-18 Effect of block location on tuber fresh weight. Error bars are standard deviation.

6.8.3 Cultivar physiology at 90 DAP.

The cultivars displayed different dry matter distributions as can be seen in Figures 6.19, 6.20 and 6.21. There was a trend for Kowiniwini to have proportionally less dry matter accumulated into tubers, but this was not significant (ANOVA P=0.076). Kowiniwini accumulated proportionally more dry matter into its stems than the other cultivars.

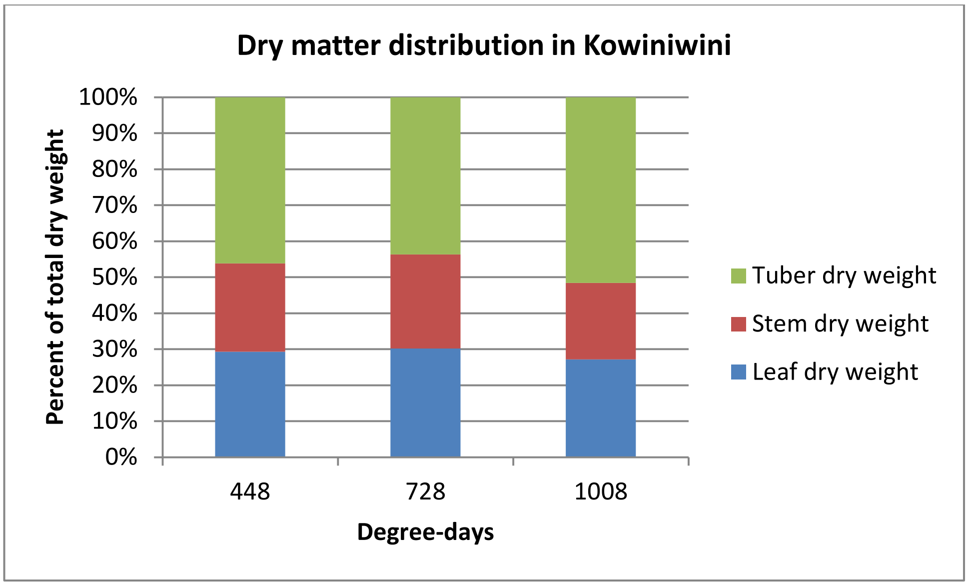

Figure 6-19 Dry matter distribution at 90 DAP in the cultivar Kowiniwini

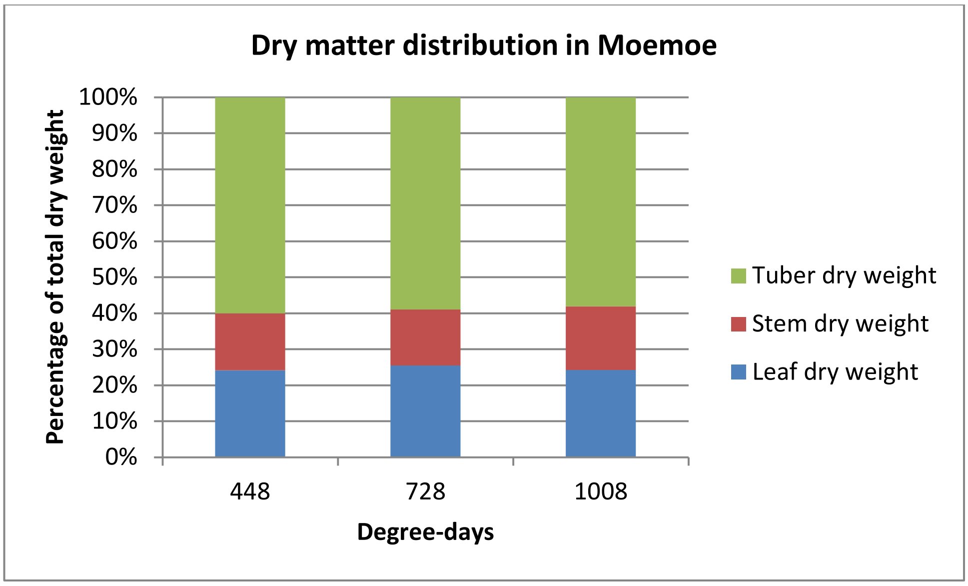

Figure 6-20 Dry matter distribution at 90 DAP in the cultivar Moemoe

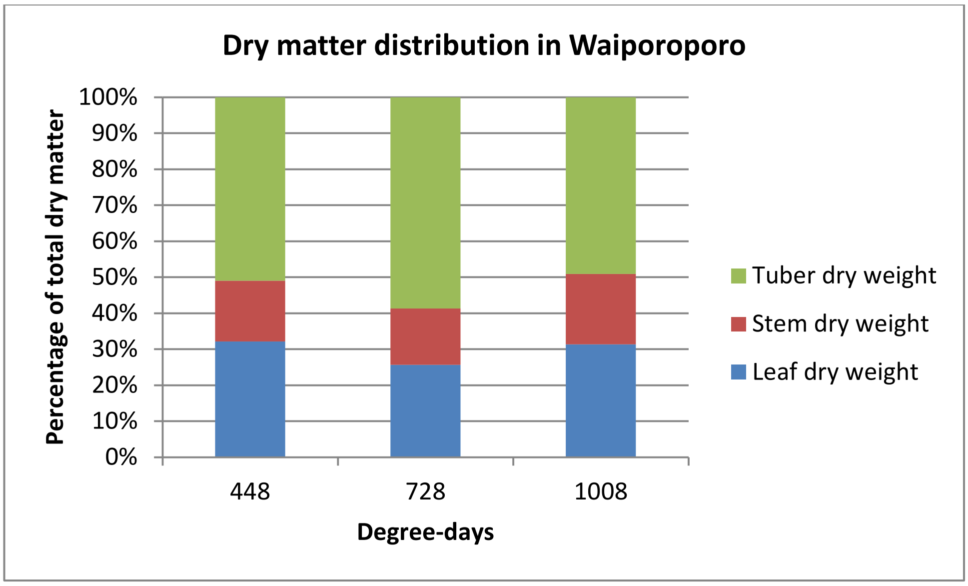

Figure 6-21 Dry matter distribution at 90 DAP in the cultivar Waiporoporo

Physiological differences were found between the cultivars. Waiporoporo showed the highest average tuber weight (Figure 6.22), had significantly more leaf area than Moemoe (Figure 6.23) and significantly more tuber fresh weight than Kowiniwini (Figure 6.24).

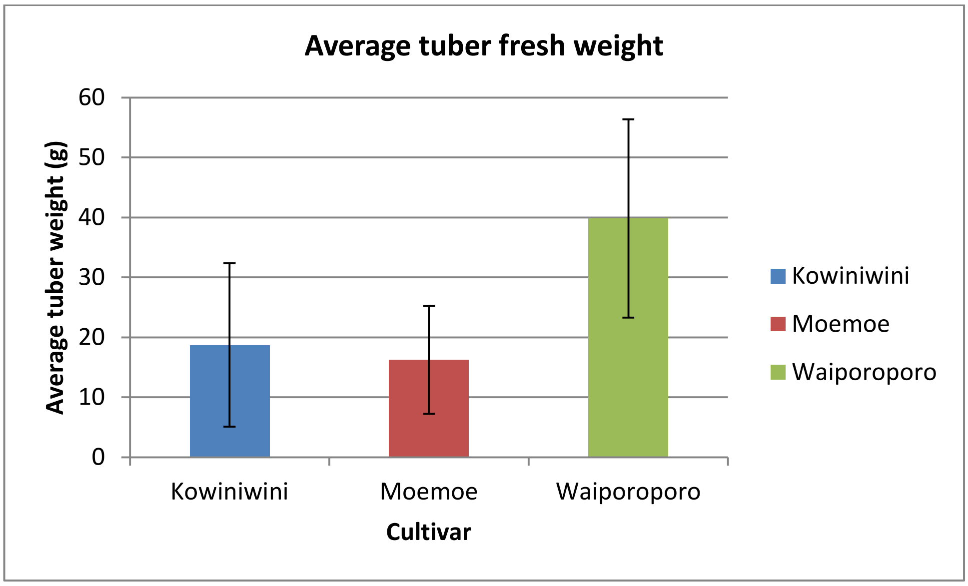

Figure 6-22 Average tuber weight in three taewa cultivars at 90 DAP Error bars are standard deviation.

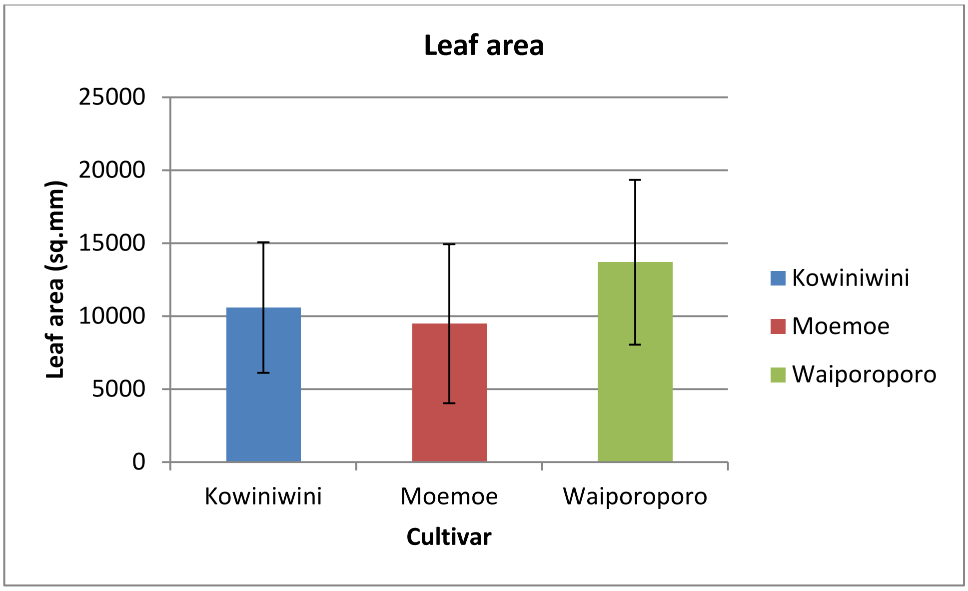

Figure 6-23 Leaf area at 90 DAP in three taewa cultivars. Error bars are standard deviation.

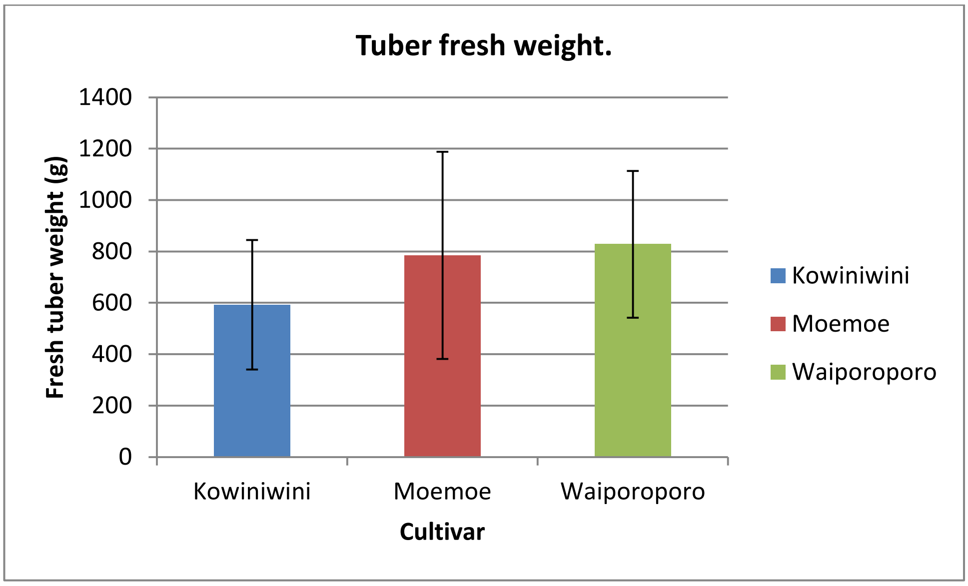

Figure 6-24 Fresh tuber weights in three taewa cultivars at 90 DAP. Error bars are standard deviation.

6.9 Zebra Chip (ZC) symptoms in raw tubers.

A sample of 10 tubers from each block was taken randomly to assess tubers for signs of ZC using the ZC severity rating scale presented in Wallis *et al*. (2012). Out of the 20 tubers from the southern blocks, only one displayed mild symptoms, while in the northern blocks, 6 displayed mild symptoms. These symptoms are shown in Figure 6.25. Significantly more tubers from the northern blocks displayed symptoms of Zebra Chip (Figure 6.26) (ANOVA P<0.05). No tubers displayed the moderate or severe symptoms in fresh tubers seen in Figure 5.3.

Figure 6-25 Zebra Chip symptoms in raw taewa. Top; clean tuber. Bottom; mild Zebra Chip symptoms of brown flecking.

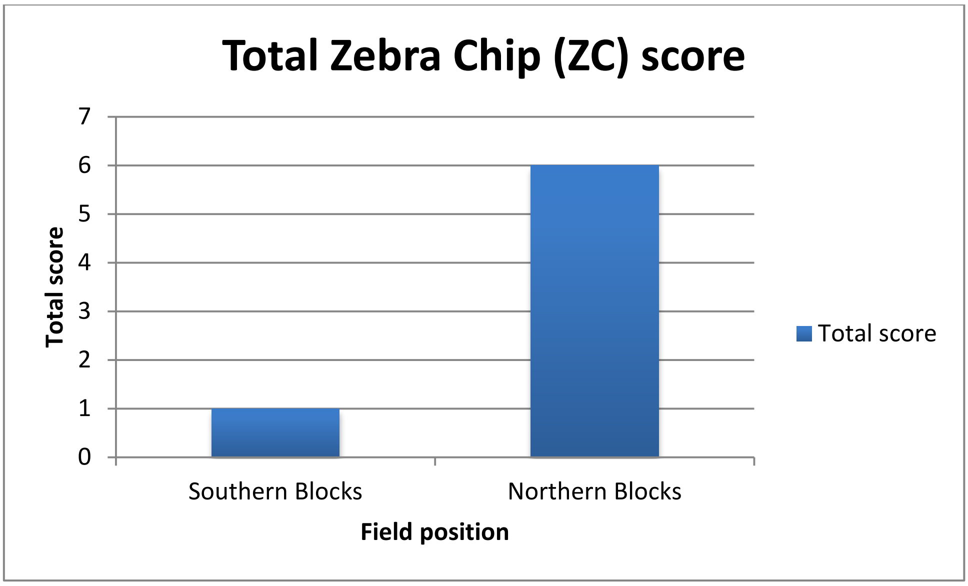

Figure 6-26 Total Zebra Chip score in raw tubers from northern and southern blocks.

6.10 Chapter Summary.

An increase in degree-days caused an increase in tuber number in the cultivar Moemoe. Waiporoporo seed tubers exposed to 728 dd accumulated more dry matter that both the 448 and 1008 dd treatments. Differences in physiology between cultivars were observed. Waiporoporo had less stems and larger leaves than the other two cultivars. Kowiniwini accumulated less total dry matter than the other two cultivars, and proportionally more of that dry matter was accumulated into the stems. There was a significant field position effect, with the northern blocks yielding less tuber fresh weight than the southern blocks. This was accompanied by an increase in the display of Zebra Chip symptoms in fresh tubers from the northern blocks.

Chapter 7. Discussion

7.1 Cropping issues.

The availability of both the original seed tubers for the study, the length of their treatment and the availability of the technical expertise needed to prepare the experimental plot led to the taewa crop being planted on the 21th January 2013. This date is in the TPP breeding season and would potentially take the crop through to a time where late blight could be an issue. Due to the fact that the tubers would not have to meet any spray residue guidelines and that the economics of spraying vs. potential returns did not have to be considered, a robust spray programme was designed to deal with these issues.

Both TPP and suspected late blight became apparent and proved difficult to control due to the issue of getting good spray coverage in a field of mature potato vines. This is a particular issue for taewa growers as taewa tend to produce large amounts of top growth (stems and leaves) compared to modern commercial cultivars (Roskruge, pers. comms., July 4, 2013). The original experimental design called for four harvest times at 30, 60, 90 and 120 DAP. Signs and symptoms of viral infection in 8.6% the plants led to the rogueing of those plants, and a reduction in the number of experimental plants available. To maintain a statistically sound trial design the 30 DAP harvest was abandoned. This rogueing had no apparent effect in terms of reduced competition with the plants that they were next too. There was no detectable difference in any crop parameter for plants that had more space to grow due to the early rogueing of plants next to them. This is in contrast to what is known about potato plant spacing, inter-plant competition and its effect on crop yields (Gulluoglu and Aroglu, 2009). It may be that the large variations in tuber size, numbers and fresh weight seen in this trail hid this effect.

TPP was noted at 30 DAP the spray program outlined in table 3.3 was begun. The guard rows on the windward (northern) side of the crop were affected first, which is consistent with behaviour of TPP reported in the literature (Puketapu, 2011). While initially the spray program was effective in limiting the spread of TPP, as the plants foliage grew it became increasingly difficult to control the TPP population and from 58 DAP onwards the TPP spread into the main body of the crop and began to affect the experimental plants. Several experimental plants displayed signs of TPP feeding seen in Figure 3.4 and were excluded from the trail. It should be noted at aerial tuber formation is seen as a symptom of liberibacter infection (Crosslin and Munyaneza, 2009) and was seen in this trial. It is however also a trait of taewa cultivars (Roskruge *et al.*, 2010) and is not a reliable marker of liberibacter infection in taewa.

At 80 DAP signs and symptoms of late blight (brown lesions, Figure 6.1) were noted on plants on the northern side of the block, despite the application of preventative copper treatments. Control treatments were undertaken (Taratek) which initially seemed to be effective. However, as can be seen in the climate data in section 6.2, a significant period of rain hit, making attempts at control difficult. A full cropping diary noting these issues, as well as the timing and nature of any interventions can be seen in Appendix 5.

7.2 Cultivar differences.

There is no published work on the physiology of the different Taewa cultivars and how this affects their suitability to different cropping scenarios. Early summer harvests have been shown to suffer economically acceptable levels of TPP damage in some areas (Walker *et al.*, 2012). One of the aims of this thesis was to examine the physiology of three different taewa cultivars and their suitability for a short season crop. The purpose is to provide base line information for the further study of taewa and to try and manage exposure to TPP by shortening the growing season.

7.2.1 Emergence and stem number.

Moemoe plants emerged two days earlier that both Kowiniwini and Waiporoporo. Waiporoporo showed significantly less stems at 30 DAP than Moemoe or Kowiniwini. This was reflected in the number of tubers per plant, with Waiporoporo having fewer tubers per plant than the other cultivars. The relationship between the number of stems and the number of tubers set is well established (Wiersema, 1987; Thornton *et al.*, 2007). This resulted in Waiporoporo producing larger tubers than the other cultivars, as fewer tubers allows potato plants to accumulate more dry matter into individual tubers (Wiersema, 1987). This resulted in greater individual tuber bulking over the course of the experiment.

7.2.2 Inflorescence.

Moemoe flowered first, followed by Waiporoporo 9 days later, while Kowiniwini was not observed to flower at all. This lack of flowering in Kowiniwini is possibly due to difference in the response to the environmental conditions at the time of growth that may have induced Kowiniwini to concentrate its resources on tuber formation, forgoing reproductive efforts by flowering. Kowiniwini seemed to set tubers at the same time as the other two cultivars in the absence of flowering, which is often associated with tuber set. Work has shown however that the initiation of flowering and tuber set are controlled by independent environmental cues (Navarro *et al.*, 2011), therefore flowering is not necessarily associated with tuber formation.

Flowering and tuber set are however closely linked with potatoes of the sub-species *tuberosum* initiating both under long day conditions (Rodriguez-Falcon *et al.*, 2006; Navarro *et al.*, 2011; Muthoni *et al.*, 2012). When the other two cultivars flowered day length was long and sunshine hours were high so it would be expected that Kowiniwini would flower. Genetics, day length and temperature all affect flowering in potatoes (Muthoni *et al.*, 2012). The interactions between environment and flowering can be complex. Further work would be required to understand this relationship in taewa.

7.2.3 Suitability for short season cropping.

Waiporoporo showed the best profile for use as a short season (90 day) crop, having significantly higher average tuber weight and as a consequence, more table grade tubers than either Moemoe or Kowiniwini. Table grade potatoes are those above 50mm in diameter (Turners and Growers, 2013). Although there was no recording of tuber size distribution, the observation was that Kowiniwini and Moemoe set many, small tubers and only a few large tubers. In contrast even though Waiporoporo had a lower number of tubers, it had more large tubers and fewer small tubers than the other two cultivars. Waiporoporo had less tuber sprouts and less stems than the other two cultivars, while having a similar or larger leaf area and mass that the other two cultivars. A lower number of stems and tubers combined with a relatively high leaf area, led to a greater accumulation of dry matter into individual tubers in Waiporoporo compared to the other cultivars.

The tendency for some taewa cultivars to set many small tubers lends them to use in the salad potato market (Hayward, 2004). The smaller sized tubers may also be more suitable for the new potato or gourmet potato markets that have size restrictions of 30mm and 50 mm maximum diameter respectively (Turners and Growers, 2013). Moemoe would be the best choice of these three cultivars for these markets as it had the same tuber fresh weight as Waiporoporo but had many more, smaller tubers. Kowiniwini did not yield as highly as Moemoe however may be able to demand a price premium given its unique appearance. These markets have yet to be fully developed for taewa and further work is required to investigate their potential as a profitable output for these cultivars.

7.3 Sprouts and sprouting behaviour.

The original experimental plan was to obtain seed tubers in a dormant state. However inspection of the seed tubers when they arrived at the PGU showed that dormancy had already been broken in all three cultivars, as there were sprouts visible on the tubers. There was an aim to look at some parameters around the breaking of dormancy however for such a measure to be made tubers would have to be obtained close to the haulm killing date.

The growth of sprouts has previously been put forward as a way of measuring and determining the physiological age of seed tubers (O'Brien *et al.*, 1983; Caldiz, 1991; Struik *et al.*, 2006). These measurements require trained personnel and are time consuming, as such they are not of practical use in a production situation (Caldiz *et al.*, 2001). They are however still useful in a research scenario. As such, the relatively simple measure of the ratio of sprout to tuber weight was investigated for the measurement of physiological age in taewa tubers.

7.3.1 Ratio of sprout to tuber weight.

All cultivars showed significant differences between the 448 dd and 1008 dd tubers at the time of planting in terms of the ratio of sprout to tuber weight. This difference in this ratio did not correlate with the final crop outcome in terms of tuber fresh weight (see section 7.4). It did correlate with the number of tubers the cultivar Moemoe set, however it did not predict any outcomes for the other cultivars. It would seem from these results that the ratio of sprout:tuber weight is not a good predictor of the effects of thermal time on crop yield in these taewa cultivars.

There were differences between cultivars, the most notable of which was sprout number. Both Kowiniwini and Moemoe had significantly more sprouts than Waiporoporo, which translated through to significantly more stems at 30 DAP in those two cultivars. The increased sprout and stem number in Moemoe and Kowiniwini resulted in increased tuber number and reduced average tuber size compared to Waiporoporo.

7.3.2 Sprout number and length of longest sprouts.

The number and length of sprout was measured at the time the seed tubers were removed for cool storage. Both of these parameters with the exception of sprout length in Kowiniwini were increased in the 448 dd group compared to the 1008 dd groups. The 1008 dd treatment groups were removed from cool-storage earlier than the 448 dd groups. Despite being held at 4°C there was significant growth in the length and number of sprouts in the 448 dd group. As these are seen as indicators of aging, it is possible that the tubers in the 448 dd groups are physiologically older than the number of dd indicates.

The calculation for degree days in the literature can vary with some authors using 0°C as the base temperature (Jefferies *et al.*, 1989) while others use 4°C (O'Brien *et al.*, 1983). The measurement of responses to thermal time can be affected by the choice of base temperature used, particularly in seed tubers that have been exposed to thermal time at the end of storage (Oliveira *et al.*, 2012). Physiological aging is also a complex phenomenon and although dd are a major influence, genetics and other environmental parameters can come into play.

7.4 Effects of thermal time on crop physiology and performance.

In terms of the most important commercial parameter, fresh tuber weight, the three cultivars of taewa studied show resistant traits over the range of thermal time studied. Reust *et.al* (2001) use the term "rusticity" to distinguish cultivars that display resistance to the effects of aging. These rustic potatoes tend to show resistant traits in terms of physiological aging and can accumulate more heat units without adversely affecting crop yields when compared to modern commercial potatoes (Reust *et al.,* 2001). Before the advent of widespread cool storage seed potatoes were kept at ambient temperatures above 4°C. This would have led to the selection of tubers that could be exposed to more thermal time while maintaining vigour. As a consequence they would have contributed more seed tuber to the next crop.

Struik *et al*. (2007) recommend that to get a full picture of the effect on physiological aging in a tuber that it should be de-sprouted before being planted. This is due to the sprouts themselves undergoing an aging process as they progress and as such, experiments where the sprouts are left on are technically a measure of the effects of aging on both the tuber and its sprouts (*ibid*). It is not common in large commercial practices to de-sprout tubers before planting. This experiment looked to mimic the current commercial cropping situation in New Zealand and did not de-sprout tubers before planting.

It is interesting to note that it is standard practice for some Māori gardeners to completely de-sprout seed tubers before planting (Roskruge, Pers. Comm., October

5, 2012). It is known that in some cultivars de-sprouting physiologically older seed can improve its performance (Struik and Wiersema, 1999). Traditionally taewa growers did not have access to modern cool storing facilities. It would seem this practice was adopted in Māori gardens in order to improve the performance of seed stored at ambient temperatures.

7.4.1 Effects on crop growth.

The hypothesis applied was that aging seed tubers could increase the yield of short season taewa crops by accelerating crop development, leading to an increased early harvest over that of younger seed tubers. Aging seed tubers can shift the growth curve used to describe the accumulation of dry matter in tubers to the left, while also decreasing the potential maximum yield (Figure 4.1). As such, emergence and time to inflorescence were measured in order to see if thermal had any effect on the rate of development of the crop. There was no effect on either emergence or the timing to inflorescence over the range of thermal time studied. It is difficult to say whether these parameters are useful measures of the age of the seed tubers as there seemed to be little overall effect of thermal time on the three cultivars studied. Future studies could assess the rate of canopy and tuber development over a wider range of aging to help qualify the effects of aging in taewa.

7.4.2 Stem number.

In Kowiniwini there was no significant difference in terms of the effect of dd on stem number. In Moemoe, increasing thermal time from 448 to 1008 dd significantly increased stem number. As mentioned earlier, an increased number of stems results in an increased number of tubers. The 1008 dd group in Moemoe did have more tubers (see section 7.4.4.). Waiporoporo in contrast had a decrease in the number of above ground stems with increased thermal time. This is possibly a result of variation in tuber size as the tubers for the 448 dd group were slightly but significantly larger than the other two treatment groups. This is explored in section 7.6.

It is interesting to note that even though the 448dd Moemoe seed tubers had more sprouts than the 1008dd seed tubers, the number of stems in the 1008dd plants was greater than the 448dd plants. There is a general trend for an increased number of sprouts on seed tubers to increase the number of stems in potato plants (Genet 1985; Gill *et al.*, 1989). The stem count was done at removal from cool-store, not before planting. It is possible that on the day of planting the 1008 dd Moemoe seed tubers had more sprouts than the 448 dd Moemoe seed tubers. Other factors such as stem dominance as well as soil and environmental factors affect the emergence of stems (Genet, 1985; Mahmood and Gill, 1984; Gill *et al.*, 1989). Further work would be needed to understand the influence of sprout number and other factors on the number of emerged stems.

7.4.3 Effect of Thermal Time on harvest parameters.

Whilst there was an apparent trend for decreased tuber fresh weight with increased thermal time in Moemoe at 60 DAP this was not statistically significant. There was no effect of dd on any parameter measured at the 60 DAP harvest. There was a significant trend at 90 DAP for an increase in tuber number with increased thermal time in the cultivar Moemoe. This effect is consistent with other findings in the literature (Struik and Wiersema, 1999; Struik *et al.*, 2006; Caldiz, 2009). This is in contrast with Waiporoporo where there was no effect, highlighting that the effect of aging on crop performance is cultivar specific. There was a trend for Moemoe to have increased tuber fresh weight at the 90 DAP harvest, but this was not significant due to the large variations in tuber size, which is a typical taewa trait (Roskruge, 1999; Hayward, 2002)

Waiporoporo showed a statistically significant increase in the dry matter accumulated into tubers in the 728 dd treatment group. It is known that younger seed tubers can accumulate more tuber dry matter than older seed tubers (Caldiz *et al.* 1996). The 448 dd and 1008 dd groups however accumulated the same amount of tuber dry matter. There may be an optimal degree of aging for Waiporoporo in terms of tuber dry matter, and this would have to be investigated further before any firm conclusions could be reached.

Increased in tuber number led to a trend in decreased average tuber weight, but this was not significant. The effect of thermal time on the number of tubers set has implications for producers. Those who wish to produce Moemoe seed tubers for example, may want to leave their seed tubers to age longer than those wishing to produce for the ware or process markets. The manipulation of storage regimes in this way can help optimize the producers output for their target market (Struik and Wiersema, 1999; Hagman, 2012).

Conversely, the lack of any significant effect on Waiporoporo tuber fresh weight suggests that producers wishing to grow this cultivar can possibly save on the cost of cool storing seed by bringing tubers out of cool storage earlier without fear of impacting crop yield. However, there does appear to be an effect on tuber dry matter that would need to be investigated further before any firm recommendations could be given. Whilst the same could be said for Moemoe and Kowiniwini, there are trends that suggest there could be an effect on tuber yields, and further work would be needed to confirm these trends.

The tubers experienced approximately 2089 dd before the treatments began (Appendix 1). Despite the many factors that can influence physiological age the total thermal time experienced by tubers from haulm killing to planting is a good measure of the degree of aging (Caldiz, 2009). The three cultivars studied were raised, harvested and stored at the same time and in the same manner. Therefore only the difference in thermal time after storage was considered.

The total thermal time ranged from approximately 2537 dd to 3097 dd. This exceeds the thermal time some studies with modern commercial cultivars have used where there have been detrimental effects on crop harvests (O'Brien et al., 1983; Allen and O’Brien, 1986; Asiedu et al., 2003; Struik et al., 2006.) This suggests that taewa have resistance to the effects of thermal time on physiological aging when compared to modern cultivars.

7.5 Block effect.

There were large standard deviations in this study which were particularly exacerbated by a large block effect at 90 DAP in terms of tuber fresh weight. While there is no difference in other aspects of physiology of the plants, there was on average a 37% decrease in tuber fresh weight in blocks C and D (the northern blocks) over the tuber fresh weight in blocks A and B (the southern blocks). It is possible that variation in soil factors may have contributed to this effect. It should also be noted that the northern side of the experimental block was the windward side. This may have afforded the plants on the southern side some extra protection from the wind.

It was also noted that TPP colonized the crop from the northern (windward) side. TPP may have caused the reduction in tuber fresh weight as longer exposure to liberibacter infective TPP is known to increase the severity of the effects on yield (Rashed *et al.*, 2013). Upon inspection of tubers it was found that more tubers in the northern blocks displayed symptoms of ZC, than tubers from the southern blocks.

Using the data collected, the southern blocks would have had a 30% crop rejection rate for processing, while the northern blocks would have had a 5% rejection rate. Such rejection levels are probably uneconomical given the expense of the control measures that were not fully effective at the time of year the crop was grown, highlighting the difficulty of producing an economic summer grown taewa crop in New Zealand.

7.6 Pre planting tuber weights.

There was a discrepancy between the tuber weights in the cultivar Waiporoporo when they were selected to undergo the aging process. Studying tubers of the same weight is important as the size of the tuber is related to the sprouting capacity (Struik and Wiersema, 1999; Struik, 2006). It is known that larger tubers produce more stems, resulting in smaller tubers and reduced yields per unit area that tubers of an appropriate size (Wiersema, 1987; Thornton *et al.*, 2007). Variation in seed tuber size could introduce error into the experiment through the different performance of seed tubers of varying size. The group of Waiporoporo seed tubers that were exposed to 448 dd was heavier than the other two treatment groups. This was due to a limited number of tubers the 50-70g weight range set for the experimental work. This was accompanied by a small but significant increase in stem number in the 448 dd group for the cultivar Waiporoporo. This difference did not have any significant effects on other parameters related to stem number such as tuber number or tuber size.

7.7 Implications for growers of taewa.

The lack of any significant effect on tuber fresh yield demonstrated that in terms of this parameter, the three cultivars studied display resistance to accumulated degree-days and there are potential cost savings in terms of a reduced need for cool-storage. It also indicated that physiological aging over the range studied is not a useful agronomic tool to improve the yield in a short season taewa crop and improve returns.

In combination with other practices such as varying plant spacing, aging may be useful in Moemoe to manipulate tuber number, tuber size distribution, and improve the potential numbers of seed, new or gourmet sized tubers produced. It also suggests that those wishing to grow Moemoe for table or processing markets may need to take care when removing seed from cool storage as to not let the seed age too long before planting.

The study also demonstrated the difficulties of growing a summer taewa crop in an environment now dominated by TPP. Taewa tend to produce a large amount of greenery (leaves and stems) and getting good spray coverage was difficult. As the season progressed there was a need for a larger volume of spray to cover the crop area as the canopy grew. The meant the readjustment of spray concentration to maintain the same rate per hectare. Despite a regular and varied spray programme, TPP still managed to colonize the crop and cause ZC symptoms in a significant number of plants.

7.8 Study limitations.

Before any broad conclusions or recommendations are made this work should be repeated in at least 2 more seasons, preferably with the 90 DAP harvest being circa 20th December. Such timing would also help avoid issues with late season issues such as late blight and would also mimic the commercial situation in terms of the timing of planting and harvesting.

The addition of data from 120 DAP would also provide a clearer picture by giving a measure by which to compare the 90 DAP harvest to, allowing an economic analysis to be done. Such an analysis would look at the costs of growing the crop for a further 30 days in an environment where TPP must be controlled, allowing a comparison between the cost of control and the reduced yield of a shorter season crop. Data from a 30 DAP group would help establish the effects of aging on early crop development. One of the distinguishing features of early cultivars is accelerated early canopy development (Asiedu *et al.* 2003). Such a measure would be useful when looking at other taewa cultivars and their suitability for an early harvest.

It would also be advantageous to have seed that is harvested as close to haulm killing as possible so the storage process can be more closely controlled. This would also allow the collection of data around dormancy break and incubation period in taewa. Information on dormancy break and incubation period is useful in optimizing the storage regime of tubers (Reust *et al*., 2001)

Cultivars with short dormancy periods generally require longer cool storing than those with longer dormancy (Reust *et al*., 2011; Asiedu *et al.,* 2003). It would be interesting to look at the incubation period of various taewa, to further quantify the apparent resistance to thermal time. It would also allow the calculation of PAI to see if this measure is applicable to physiological aging in taewa. The addition of de-sprouted groups could provide further insights into the effects of aging on the tubers from a purely scientific point of view, and improve the understanding of this phenomenon as it applies to taewa Māori.

Conclusions

The hypothesis for this study asked two questions; which taewa cultivar yields best over a 90 day cropping window and, can the performance of these three cultivars be manipulated by physiological aging? The variety Waiporoporo clearly produced a higher yield in this period; especially table sized tubers so can be considered the best yield in early trials. Secondly, the physiological aging did not impact on the crop or yield in a significant way thus indicating that physiological aging over the range studied is not a useful agronomic tool to improve the yield in a short season taewa crop and improve returns.

A number of other conclusions can be made however as a result of this study. Primarily these conclusions align to the opportunity that exists for taewa as a commercial crop for various markets.

- Taewa producers growing for the table and process markets and looking to manage TPP by shortening their growing season should consider using the cultivar Waiporoporo;
- Taewa producers aiming for the salad, new or gourmet potato markets should consider using the cultivar Moemoe;
- Physiological aging over the range studied is not a useful agronomic tool for increasing short season yields in these three cultivars of taewa;
- The cultivars Moemoe and Kowiniwini show potential for the salad, new and gourmet potato markets. These markets and the suitability of these two cultivars for those markets should be further investigated;

- Cool-storing costs could be reduced for these cultivars of taewa as they display resistance to the effects of thermal time in terms of tuber fresh weight;
- Taewa growers should avoid cropping from January through to March as the large amount of foliage taewa produce makes TPP control difficult;
- Further work should be conducted on physiological aging in taewa. Specifically aspects around dormancy break, the progression through stages of aging, the length of the incubation period and the effects of the timing of warming (i.e. before or after cool-storing) should be investigated;
- The addition of de-sprouted groups to future work will help further the understanding of physiological aging in taewa, and;
- A comparison of the effects of thermal time on physiological age with modern commercial cultivars would confirm the relative resistance of taewa to those effects.

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Roskruge, N., personal communication, July 4, 2013

Appendix 1. Thermal time calculation.

Thermal time calculated as the total accumulated degree days above 0°C (Oliveira *et al.*, 2012)

Thermal time (dd) = $(T-T_b) \times t$

Where T= Average temperature
T_b = Base Temperature
t = Days
dd = Degree-days
Base temperature = 0°C

Approximate Thermal time from haulm killing to cool storing
17°C* x 75days**=1326 dd
*Average temperature for Canterbury
**Plant tops sprayed off March 2 2012, cool-stored @ 2.8°C

Thermal time at 2.8°C cool-store
2.8 °C x 171 days = 478 dd

Approximate thermal time in transit = 17°C x 3 days = 51 dd

Thermal time at Massey PGU = 4°C x 46 days = 184 dd

Approximate thermal time before treatments = 1326 + 478 + 51 + 184= 2089 dd

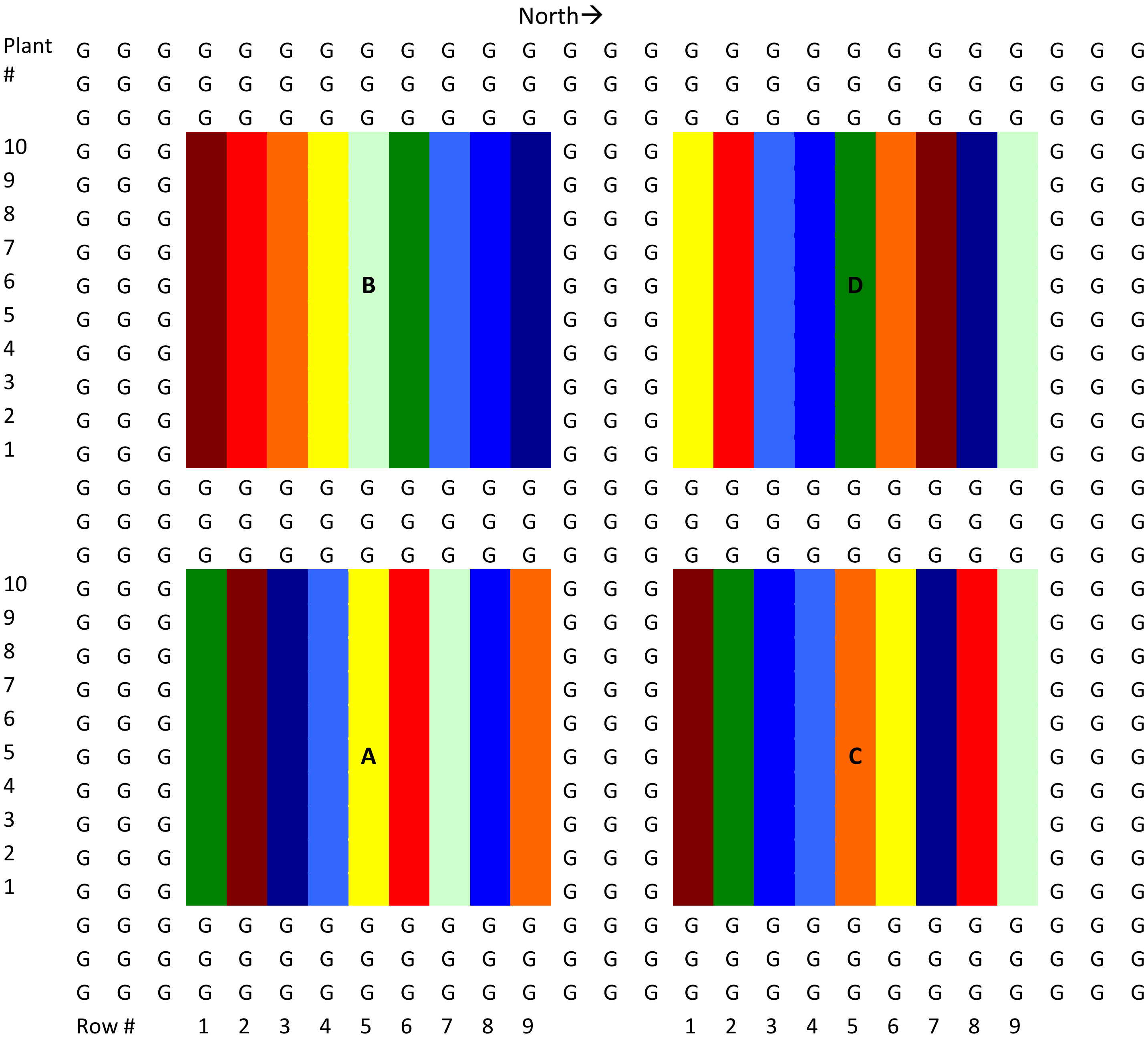
Thermal time of treatments
Tubers removed from cool store 6 weeks before planting
24°C x 42 Days = 1008 dd

Tubers removed from cool store 4 weeks before planting
4°C x 14 Days = 56 dd
24°C x 28 Days = 672 dd
Total thermal time = 728 dd

Tubers removed from cool store 2 weeks before planting
4°C x 28 Days= 112 dd
24°C x 14 Days = 336dd
Total thermal time = 448 d

Appendix 2. Planting plan.

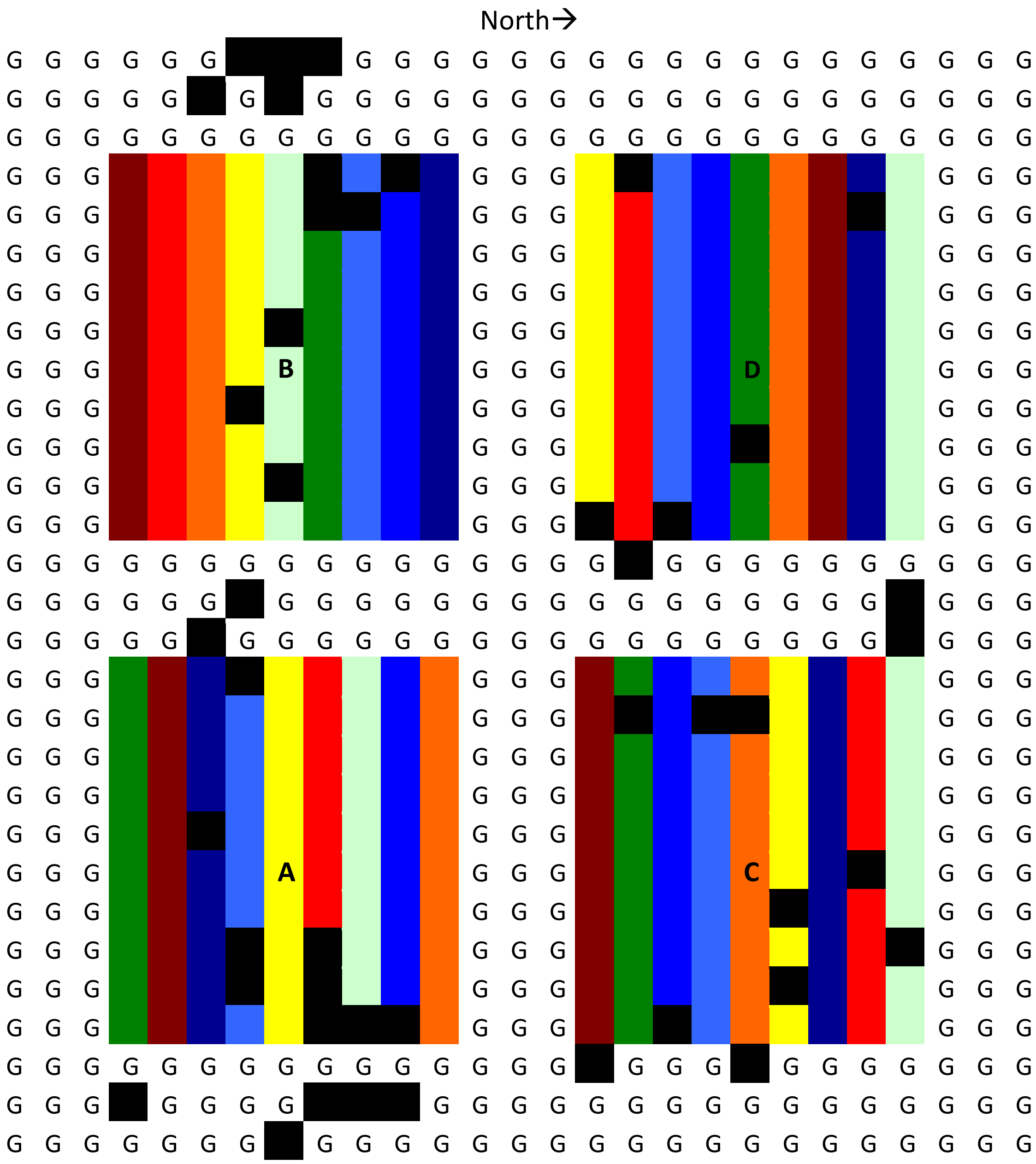
Guard plant	G
Kowiniwini 1008 dd	
Moemoe 1008 dd	
Waiporoporo 1008 dd	
Kowiniwini 728 dd	
Moemoe 728 dd	
Waiporoporo 728 dd	
Kowiniwini 448 dd	
Moemoe 448 dd	
Waiporoporo 448 dd	



Appendix 3. Rogueing record

Key

- Guard plant G
- Rogued plant
- Kowiniwini 1008 dd
- Moemoe 1008 dd
- Waiporoporo 1008 dd
- Kowiniwini 728 dd
- Moemoe 728 dd
- Waiporoporo 728 dd
- Kowiniwini 448 dd
- Moemoe 448 dd
- Waiporoporo 448 dd



Appendix 4. Harvest randomization.

Plant numbers randomized in Minitab using a random permutation. Plant displaying signs and symptoms of TPP feeding were excluded and plant next on the randomization list taken.

Block and row	A1	A2	A3	A4	A5	A6	A7	A8	A9
Plant	1	2	8	4	9	5	6	10	1
Plant	10	3	9	3	7	1	8	8	8
Plant	2	1	5	9	4	4	10	5	10
Plant	7	9	2	6	10	9	9	3	6
Plant	9	4	1	8	2	3	7	2	4
Plant	3	7	3	5	6	10	3	7	5
Plant	6	5	4	1	1	6	4	9	9
Plant	5	6	7	10	8	8	2	6	7
Plant	4	8	6	7	5	2	5	1	3
Plant	8	10	10	2	3	7	1	4	2
Block and row	B1	B2	B3	B4	B5	B6	B7	B8	B9
Plant	4	3	8	1	5	9	3	9	8
Plant	3	7	4	7	10	3	5	1	6
Plant	9	1	7	5	1	7	2	5	10
Plant	6	6	1	10	9	4	4	6	1
Plant	1	8	2	8	8	1	6	7	7
Plant	5	2	9	9	6	2	8	8	9
Plant	2	4	3	3	2	8	9	10	5
Plant	8	10	10	2	7	6	7	2	2
Plant	7	9	5	4	3	5	1	3	4
Plant	10	5	6	6	4	10	10	4	3
Block and row	C1	C2	C3	C4	C5	C6	C7	C8	C9
Plant	8	3	5	5	2	9	10	10	9
Plant	3	6	7	9	6	5	5	6	6
Plant	2	5	2	10	7	3	8	3	3
Plant	6	9	8	3	3	6	1	8	3
Plant	9	1	1	7	1	1	2	5	2
Plant	3	2	6	2	3	7	9	9	5
Plant	5	8	10	1	5	8	3	3	7
Plant	10	7	9	6	8	10	3	2	10
Plant	7	3	3	3	9	2	6	1	8
Plant	1	10	3	8	10	3	7	7	1

Appendix 4 cont.

Block and row	D1	D2	D3	D4	D5	D6	D7	D8	D9
Plant	3	9	5	2	1	7	5	8	9
Plant	7	2	2	1	2	8	3	6	1
Plant	6	7	6	7	7	2	10	9	3
Plant	1	3	9	9	8	1	9	3	5
Plant	8	6	3	8	6	5	6	5	2
Plant	2	8	10	10	10	9	3	10	8
Plant	10	5	3	3	5	3	8	3	7
Plant	9	10	1	6	3	3	7	2	3
Plant	3	1	7	3	3	6	1	7	10
Plant	5	3	8	5	9	10	2	1	6

Appendix 5. Crop Diary.

Date	Action	Note
December 2012 15th	 Site top dressed with 200 kg/ha 12:10:10 fertilizer	
January 2013 9th 21st	 Cultivated with power harrows Seed tubers planted	
February 2013 10th 17th 20th 21st 29th	 Weeded by hoeing Rows mounded by hand Rogueing Stems counted Spray with abamectin Spray with abamectin	 Virus affect plants noted TPP adults noted on northern guard plants
March 2013 2nd 4th 7th 17th 20th 22nd 27th	 Aphids (possibly green peach aphid *Myzus persicae*) noted. Plot hand weeded by hoeing Spray with copper hydroxide and Confidor Spray with Movento and Decis Forte. Spray with Movento and Decis Forte. Plot hand weeded by hoeing 60 DAP harvest Spray with abamectin and copper hydroxide.	 Northern guard plants showing effects of TPP feeding Plants in block D showing signs of TPP feeding

April 2013 6th 7th 17th 21st 27th	 Spray with abamectin and Taratek Spray with Karatae and taratek 90 DAP Harvest Spray with Karatae and Taratek	 Signs of late blight Most of the crop suffering blight/TPP damage
May 2013 21st	 Tubers harvested for ZC scoring	