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# REMEDIATION AND RECOVERY TECHNIQUES FOR VOLCANIC ASH-AFFECTED PASTURE SOILS OF NEW ZEALAND

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## Executive Summary

The value of exports from NZ’s land-based primary production is around $34 billion per annum. Soils are the key resource that drives this primary productive sector. Soils are also the fragile skin of our Earth, and the host of many essential ecosystem services, including provision of substrate and nutrients to plants, nutrient cycling, carbon sequestration and decay of organic matter, water supply and water quality, and buffering and filtering of contaminants (Daily *et al*., 1997; Dominati *et al*., 2014). These ecosystem services operate on a delicate balance, which is easily disrupted by impacts from natural hazard events, particularly the widespread dispersal of volcanic ash. Once soils are disturbed in this way, their provision of vital soil functions is rapidly diminished. Volcanic activity represents a major natural hazard that could strike this production sector at any time. A recent example of this was in 1995/1996 when ash-falls over North Island (NI) covered >27,000 km$^2$ in primary production (Cronin *et al*., 1998).

Research to date on volcanic ash impacts on agriculture has been limited to direct impacts of ash killing plants, acidifying water and soil surfaces, and causing health issues for animals and plants, with some work focussed on mitigation techniques for short term fertility and production recovery. Very little information is available on remediating the ash-affected soil. In the long term (decades to centuries), addition of volcanic material can have positive effects on drainage, aeration, fertility and water retention (Nanzyo *et al*., 1993; Warkentin and Maeda, 1980). Short term impacts of ash fall however are, apart from the addition of some beneficial nutrients such as sulphur (Cronin *et al*., 1997), likely to be negative.

This research will help to identify and define the best possible remediation strategies for pastoral soils of North Island, New Zealand, following a large-scale tephra fall. This research will help in determining the best remediation technique suitable for effective recovery of pasture and pasture soil post heavy ash fall, in terms of economic feasibility and recovery time. This will be achieved by interviewing local farmers in two study regions and, based on their feedback, analysing selected remediation techniques through field and laboratory studies. The study will be undertaken in two different regions of New Zealand that are susceptible to serious ash fall in the future, namely *Waikato* and *Taranaki*.

## Background

The most widespread product of volcanic eruptions is tephra. As magma is propelled through a volcanic conduit prior to an explosive eruption, gas inside it expands to fragment the magma into pieces (called pyroclasts, or tephra). The coarsest particles fall near to the volcano, and the finer particles are propelled upwards in several-kilometre-high "eruption columns" produced by the uprush of heat, gas and finer "ash" particles (tephra that is <2 mm in diameter). The ash column is subsequently dispersed by wind so that ash falls on surrounding areas, often covering hundreds of square kilometres (Wilson et al., 2012). Depending on the height of the eruption column, temperature of the air, wind direction and wind speed, the volcanic ash can travel and stay in the atmosphere for two or three years after the eruption (Hamdan et al., 2008). Volcanic ash is dominantly composed of glassy fragments and a range of silicate crystals. The composition of the tephra can range markedly depending on the composition of the magma, from low-silica (~50 wt. % $SiO_2$), basaltic compositions, with dominantly olivine and pyroxene crystals, through intermediate/andesitic compositions (~60 wt. % $SiO_2$, associated with plagioclase, pyroxene and amphibole) to rhyolitic compositions (>70 wt. % $SiO_2$, with feldspar, quartz, amphibole and mica). Volcanic ash fall strongly affects agricultural areas downwind of volcanoes by smothering plants, changing drainage and soil infiltration, as well as chemically contaminating waterways and soils (Wilson et al., 2010). All forms of agricultural production are vulnerable to physical and chemical effects of volcanic ash fall, with impacts on vegetation, soils, animal health, human health and essential infrastructure (Blong 1984; Neild et al. 1998; Cronin et al. 1998; Ort et al. 2008, Wilson et al. 2011). The deleterious impacts on agricultural and aquatic environments are well known, as well as its impacts on living organisms, including humans and animals in ash fall areas. The impacts of ash fall result from a combination of (1) physical presence, leading to respiration problems from fines suspended in the atmosphere, turbidity in surface waters and the smothering, loading/burial or coating of plants; and (2) chemical impacts due to the low pH of ash and its cargo of adhering soluble salts, including $H_2SO_4$, and HCl.

Volcanic soils are well suited for crop growth, which makes agriculture a common land use near volcanic regions (Cronin et al. 1998; Annen and Wagner 2003; and Wilson el at. 2011). Much research has shown that ash fall has strong major immediate impacts on agricultural systems, with some important examples being the Mt St Helens, USA eruption in 1980 where over 1.5 $km^3$ of pyroclastic material was erupted dispersing ash of >1 mm across 391,000$km^2$ and burying pastures and crops, resulting in an estimated $US 100 million at the time (Cook et al. 1981; Johansen et al. 1981; Folsom 1986; Lyons 1986; and Wilson et al. 2011) and the eruption in Mt Pinatubo, Philippines in 1991, when over 5 $km^3$ of pyroclastic material was erupted, dispersing tephra >10 mm thick across 7,500 $km^2$, of which over 962 $km^2$ of agricultural land was seriously affected by ash fall, damaging crops, livestock and fisheries worth the equivalent of $US 86 million in 2009 (Mercado et al. 1996; Wilson et al. 2011).

Volcanic eruptions can also affect pastoral grazing agriculture in New Zealand. A recent example of this was in 1995/1996 when the ash falls over the North Island following an eruption from Mt Ruapehu covered >27,000 $km^2$ in primary production (Cronin et al., 1998). Burial and coating of pastures, ash in atmosphere and chemical impacts of ash have all been implicated in animal deaths following ash falls in New Zealand and overseas. In recent recorded history, New Zealand agricultural systems have been affected only by miniscule ash thicknesses, usually only a few millimetres of fine-grained ash. However even this has led to chemical changes in soils and plants that have lasted from a few days up to 9-10 months after the events. Soil pH, extractable sulphate and total sulphur are a few of the soil parameters which are immediately affected following 3mm of ash fall; for example the soil samples taken seven weeks after the October 1995 Mt Ruapehu ash fall were higher in Sulphur than the samples collected four weeks prior to the eruption (Cronin et al., 1997).

Far exceeding the historical events, however, the geological record of many NZ volcanoes shows that large areas of farmland in the Taranaki, Kaimanawa/Hawkes Bay and Bay of

Plenty regions could reasonably expect tephra falls of tens of centimetres to up to a metre in thickness from future large magnitude eruptions of Mt. Taranaki, Mt. Ruapehu or Mt. Tongariro stratovolcanoes, along with Taupo and Okataina caldera volcanoes. The recurrence intervals for such events lie in the order of 1 in 300 years for each of Mt. Taranaki, Ruapehu and Tongariro, and ~1 in 1000 years for Taupo and Okataina Calderas. Recent overseas experience has shown how dramatic such large-scale tephra eruptions are for agricultural systems, with the Puyehue-Cordon-Caulle eruption in Chile depositing up to 5cm of fine ash on agricultural land between Jacobacci and Bariloche (Wilson et al., 2012).

Until now little preparation has been made for the potential large-scale impacts of such an eruption on New Zealand's agricultural production systems, despite the fact that agriculture is one of the main economic activities in the volcanic areas of the north island, with pastoral (livestock) farming for meat and wool production dominating the region (Wilson et al., 2010) and rural service towns heavily dependent on the productivity of surrounding farms.

In the event of substantial tephra fall, farmers will be faced with the mammoth task of recovering pastoral farming, cropping or any other horticultural activities. Unfortunately, fresh tephra has very few plant-growth nutrients and no organic material. Apart from the addition of some beneficial nutrients such as sulphur (Cronin et al., 1997), short-term impacts of ash fall are likely to be negative. Furthermore, many tephras are associated with acid aerosols adhering to the particles, which may hinder the germination of seeds.

The long-term damage to agricultural systems by volcanic ash is in many ways determined by its thickness. A thin coating of ash can be washed away by rain. Ash falls of up to 10 cm or so could be quickly remediated by ploughing. With thicker ash falls, the remediation actions are more complex. The options for remediation open to the farmer are similar in some respects to areas affected by thick inundations of flood deposits. In the flood silt case, however, the sediments contrast with ash fall because they normally contain organic material and a high natural degree of fertility. The low organic content of volcanic ash and its low natural fertility means that re-establishing a buried pasture will be a long, time-consuming process. Remediation options include, but are not limited to, the following:

1. Re-establishing a soil by adding organic material (mulch) and soil amendments/treatments before re-sowing a pasture.
2. Ploughing the ash to mix it with the underlying topsoil and organic material (if the fall layer is thin enough, i.e., >20 cm). With thicker falls (>20 cm), implements such as deep sub-soil plough or ripper could be employed.
3. Removing ash from the pasture surface, for example with machinery such as bulldozers or motor scrapers.
4. Abandoning farming operations and/or waiting for natural remediation/recovery

For all of these recovery strategies, along with others that agricultural advisors or farmers may attempt, it is unknown (a) how successful they would be; (b) how rapidly a pasture could be re-established; (c) how long before productivity returns to pre-eruption levels (if at all); (d) how much each strategy would cost (weighing rehabilitation investment against length of time out of production).

The research proposed here aims to define the ideal remediation strategies for pastoral systems in the North Island of New Zealand (and by comparison agricultural systems elsewhere) following large-scale ash deposition. This project will employ a mixture of social-science research, agricultural experiments and economic modelling.

## Impacts of Volcanic Ash Fall on Agriculture

Volcanic ash is the most widespread product of volcanic eruptions and can be damaging to humans, animals, the environment, infrastructure as well as agriculture. Some of the agricultural impacts are listed as below:

- Contamination of pasture making it unpalatable; heavy ash fall may reduce the availability of feed affecting the growth of livestock;
- Contamination of water supplies (for drinking and irrigation);
- Impacts to health of livestock feeding on ash-affected pasture (eye and respiratory irritation, grinding of teeth, fluorosis);
- Corrosion and wear-and-tear of the machinery including irrigation pumps
- Degradation in the quality of animal product (wool, leather, dairy product)
- Disruption of electricity supplies, transportation and modes of communication

Some historical volcanic eruptions have generated heavy ash fall leading to severe impacts on the surrounding region's agriculture. Some are detailed below:

***Mt St Helens 1980 eruption – USA:*** The 1980 eruption of Mt St Helens had some notable impacts on agriculture in Washington State (Warrick et al., 1981; Cook et al., 1981). Not much work was done at the time to mitigate damages caused by volcanic ash fall. Kittitas County, an area which is 150 km away from Mt St Helens received 5-20 mm of volcanic ash (Wilson et al., 2009). Ash affected its environment, infrastructure and agriculture in various ways. The irrigation system in the area was affected, as it distributed surface water by ditch network. Accelerated sedimentation of ash was observed in the water ditches; the large ditches washed out easily but the smaller ditches needed manual removal (Warrick et al., 1981; Wilson et al., 2009). Ash also affected equipment such as electrical panels, sprinkler heads and pumps (Warrick et al., 1981; Wilson et al., 2009). The deteriorated heads of water sprinklers put excess pressure on motors of the water pumps; sprinkler heads clogged due to ash preventing them from turning (FEMA, 1984; Wilson et al., 2009). The area of Ritzville County, despite being located approximately 300 km from Mt St Helen received higher ash fall than Kittitas County, around 20-40 mm but the irrigation system of the area was not impacted because the system was mainly groundwater fed (Wilson et al., 2009). Other impacts included ash-induced shorting of electrical panels and switch boards, especially following heavy rain on 25-26 May 1980 which increased the ash conductivity (Warrick et al., 1981; Wilson et al., 2009). The 1980 eruption of Mt St Helens highlighted limited knowledge of volcanic ash impacts, and triggered significant effort in this field over subsequent decades (Wilson, 2009).

***Mt Hudson 1991 eruption – Chile:*** The eruption of Mt Hudson in August 1991 in southern Chile was one of the biggest of the 20$^{th}$ century. It was so enormous that around 8,000,000 ha of agricultural land in Santa Cruz province, Patagonia, Argentina was covered by volcanic ash (Inbar et al., 1995; Wilson et al., 2009). The thickness of the ash varied from 2m in the Andean area to <1mm at the Atlantic coast zone (Inbar et al., 1995, Wilson et al., 2009). Deaths of livestock occurred and were reported to be more due to starvation than fluorosis, as pastures and horticulture crops were covered by thick ash fall (Inbar et al., 1995; Rubin et al., 1994; Wilson et al., 2009). Irrigation ditches were blocked by the 50 to 100 mm thick ash fall, which required manual removal of the ash at several places (Wilson et al., 2009). Irrigation ditches were contaminated and blocked repeatedly for a period almost of two years after the eruption, due to re-sedimentation of ash through wind and fluvial erosion (Inbar et al., 1995; Wilson et al., 2009). After windstorms, irrigation water became turbid, making it unfit for livestock to drink (Inbar et al., 1995; Wilson et al., 2009). Coupled with these impacts, livestock water consumption increased dramatically following the eruption due to reliance on the alternative dry supplementary feed needed and the drying effect of ash on vegetation (Inbar et al., 1995; Wilson et al., 2009). A large number of livestock died through getting trapped in the muddy ash deposits when attempting to drink water (Wilson et al., 2009). The moving parts in pumps, motors and windmills were clogged and heavily abraded by the fine remobilized ash, still requiring continual maintenance in 2008 (Wilson et al., 2009). Farmers from the heavy ash fall area such as Ibanez valley had some success in pasture recovery by spreading different types of grasses (indigenous and foreign ryegrass and red and white clovers) on the ash (Wilson et al., 2011). Spreading of hay over the ash gave good results, but proved to be very expensive (Wilson et al., 2011). Some farmers unsuccessfully tried to flood their farms in order to break the hard formed ash, but this did not prove to be very effective (Wilson et al., 2011).

***Mt Pinatubo 1991 eruption – Philippines:*** Another large explosion of the twentieth century occurred from 12$^{th}$ – 15$^{th}$ June, 1991 from Mt Pinatubo in Philippines (Newhall et al., 2002; Wilson et al., 2009). Heavy ash fall hugely impacted the Central Luzon, and the area close to the volcano was demolished by the large pyroclastic flows (Wilson et al. 2009). As reported by Mercado et al. (1996), 96,200 ha of agricultural land suffered serious impacts due to the ash fall, 70% of which was used for rice cultivation and thus reliant on regular irrigation. Seasonal conditions made the impact of the eruption worse, with ash fall and volcanic lahars during the monsoon months causing major damage to farm irrigation systems; the river-fed and ditch-flood irrigation system in the area of Papanga and Zambales provinces experienced particularly severe impacts (Bautista, 1996, Wilson et al., 2009). The river channels, irrigation systems and the major river feeders were so terribly impacted by the volcanic floods (lahars) that it took three years to dig and restore the irrigation systems (Wilson et al., 2009). Farmers formerly reliant on gravity-fed irrigation systems were forced to pump water from the active river channel, adding cost to their produce (Wilson et al., 2009). Mercado et al. (1996) reported that the total cost of damage to infrastructure up to August 23, 1991 (just two months after the eruption) was 3.8 million pesos. Damage to water-resource infrastructure was reported to be up to 1.6 million pesos over this period, while destruction of crops, livestock, and fisheries was estimated at 1.4 billion pesos (1991; Mercado et al., 1996; Wilson et al., 2009).

***Mt Ruapehu 1995-1996 eruption – New Zealand:*** Over the period of one year from October 1995 to 1996 numerous small eruptions occurred from Mt Ruapehu which were followed by a large explosion in October 1996. Multiple eruptions caused repeated ash dispersal across pasture land at a thickness between 1-3 mm, which led to the death of around 2,000 sheep and lambs due to fluorosis (Cronin et al., 1998; Wilson et al., 2009). At first the reason for the death of livestock was considered to be ingestion of ash covered pasture, but later on it was discovered that surface water was also contaminated by ash and could have also been a reason for poisoning (Cronin et al., 2003; Wilson et al., 2009). Cronin et al., (1998) reported high levels of soluble selenium in Ruapehu ash, which had the potential to be a serious threat within water. This eruption caused impacts to pasture land and livestock feeding on the ash-covered grass and water, and sedimentation of ash in house gutters led to the ash becoming firm and forming a hard material which was not easily washed out (Wilson et al., 2009). In heavy ash fall areas and at weakly pH buffered soils, remedial liming was suggested to the farmers (Cronin et al., 1997).

## Soil Rehabilitation

Although these past eruptions were high profile and much is known about their impacts, very little is known about time, cost and methods of rehabilitation of pasture following such events. Soil remediation has always been an area of concern to the environment. Continuous agricultural practices and other human activities make soil infertile after a certain period of time. Furthermore, activities such as excessive use of chemical fertiliser leave heavy metal and waste behind. Abandoning the land is often the only option left for humans especially at the sites where significant floods or activities such as long-term mining and industrial waste dumping have occurred, as the site soil is completely contaminated and/or eroded and would take a long time to recover (e.g. Fellet et al., 2011). Volcanic ash fall may also lead to forced abandonments of agricultural farms temporarily or permanently (Wilson et al., 2010). Examples of volcanic events where the farmlands were abandoned are:

1) Hekla, Iceland; 1104: Approximately 2.0 $km^3$ of rhyodacite tephra fall covered >50,000 $km^2$. Farms impacted by tephra deposits >250 mm (compacted) and marginal farms impacted by tephra deposits ~100 mm (compacted) were never resettled and were permanently abandoned (Thorarinsson, 1979).
2) Hekla, Iceland; 1693: Approximately 0.18 $km^3$ of andesitic tephra fall covered ~22,000 $km^2$. Farms impacted by tephra deposits >250 mm were never resettled. Farms impacted by 150 mm were abandoned for 1-4 years (Thorarinsson, 1979).
3) Mt Hudson; 1991: Over 4 $km^3$ of trachy-andesitic pyroclastic material was erupted over tens of thousands of hectares of pasture, resulting in farms being abandoned with no pasture recovery on the thick, coarse-grained ash deposits (Scasso et al., 1994; Bitschene et al., 1995).

Abandonment of pasture is thus the worst case remediation technique for volcanic ash affected soil. Insight into other possible techniques can be gleaned by evaluating soil affected by mining, industrial pollution, flooding and continuous agriculture practice. Landscape rehabilitation becomes inherently more difficult as the level of disturbance increases, this often results in onerous and costly procedures that attempt to reconstruct landscapes according to pre-disturbance physical environments and associated ecological functions (Bell, 2001; Koch and Hobbs, 2007; Mulligan, 1996; Doley et al., 2012). Examples of some other remediation techniques are as follows:

- ***Phytoremediation:*** Growing plants to recover affected land is called as Phytoremediation (EPA, 1998), it is a biological way to treat the affected soil. This is comparatively cheaper than other techniques like excavation and in-situ fixation (Lambert et al., 1997), and has proven useful to stabilize mine tailings and to prevent wind/water erosion and leaching of the pollutants (Fellet et al., 2011). In this technique the land area is planted with grass to prevent mobility of heavy metals.
- ***Biochar:*** Lehmann and Rondon (2006) proposed biochar application as a sustainable biological way to improve highly degraded lands. Biochar is a soil conditioner that enhances plant growth by supplying and retaining nutrients and by providing other services such as improving the physical, chemical and biological properties of the soil (Glaser et al., 2002; Lehmann et al., 2003; Fellet et al., 2011). Furthermore, Biochar influences the porosity and consistency through changing the bulk surface area, the pore size distribution, the particle size distribution and the density and packing (Downie et al., 2009; Fellet et al., 2011).

- ***Organic Fertilizer and Liming:*** Other techniques such as addition of organic fertiliser to increase soil fertility or application of lime onto the soil in order to increase soil pH also help in soil remediation. These techniques would be example of biological and chemical methods of treatment. Continuous agriculture practice make soil infertile and loose its nutrients as all the nutrition is taken up by the crops, for which bioremediation techniques such as organic farming, using vermi-compost as fertiliser are used. Adding crop residues to the soils superficially increases carbon content and controls soil erosion (Lal R., et al., 2004).
- **Excavation:** This is an example of physical remediation of soil involving the removal of soil. It is also the oldest known remediation technique for contaminated soil (Lambert et al., 1997). The advantage of this method is in the complete removal of the contaminants, and rapid clean-up of the contaminated sites (Wood, 1997; Lambert et al., 1997). This technique has been used at many locations, including residential areas contaminated by lead in southwest Missouri (Lambert et al., 1997). It involves the risk of spreading the pollution during transport of the soil form one place to another. It can prove to be the most expensive remediation technique when a large amount of soil has to be removed and disposed of (Lambert et al., 1997).
- ***In-situ fixation:*** In-situ fixation or stabilization is a chemical method of remediation in which the heavy metals present in the soil are stabilized by external addition of chemicals (Lambert et al., 1997); this is generally practised to recover mining land. The heavy metals react with chemicals forming minerals which are not easily soluble in water and remain as less toxic compounds that are not easily taken up by the plants, animals or humans (Lambert et al., 1997).

These techniques have proved to be useful to remediate soil that has been polluted by heavy metals and other hazardous chemicals, but very little work has been done on soil remediation following large volcanic ash falls. Available data is from Heimaey and Hudson volcanic eruptions. This study aims to determine whether physical, biological and/or chemical rehabilitation or a combination are best suited to recover pasture soil following heavy volcanic ash fall.

## Research objectives

This practical research programme will reveal several features of relevance to the New Zealand agricultural sector, specifically providing data to underpin volcanic-hazard management strategies.

The hypothesis of this research is that, given the lack of organic material, the low contents of plant growth nutrients and the weak water-holding capacity of volcanic ash, great thicknesses (>10 cm) of ash from large NZ eruptions will require highly capital-intensive approaches for pasture renewal. The objectives of the research will thus be to:

1. Evaluate which high-cost approach provides the most cost-effective and efficient means of pasture recovery (taking into account long-term sustainability where possible) for both andesitic and rhyolitic eruptions.
2. Evaluate the point at which the costs of recovery approaches outweigh a natural recovery process, and the tipping point at which land should be abandoned for years or decades.

3. Evaluate the current beliefs of the NZ farming, farm advice and agricultural science community in relation to recovery from large-scale volcanic eruption (tephra fall) impacts.

## Methods

### *1) General Plan*

This research will focus on farm recovery in two study regions that could expect large-thicknesses of tephra fall, namely the southern Waikato region (rhyolite tephra from Taupo and Okataina), and the eastern Taranaki area (andesitic tephra from Mt. Taranaki). Figure 1 is a schematic diagram explaining the general plan for this research.

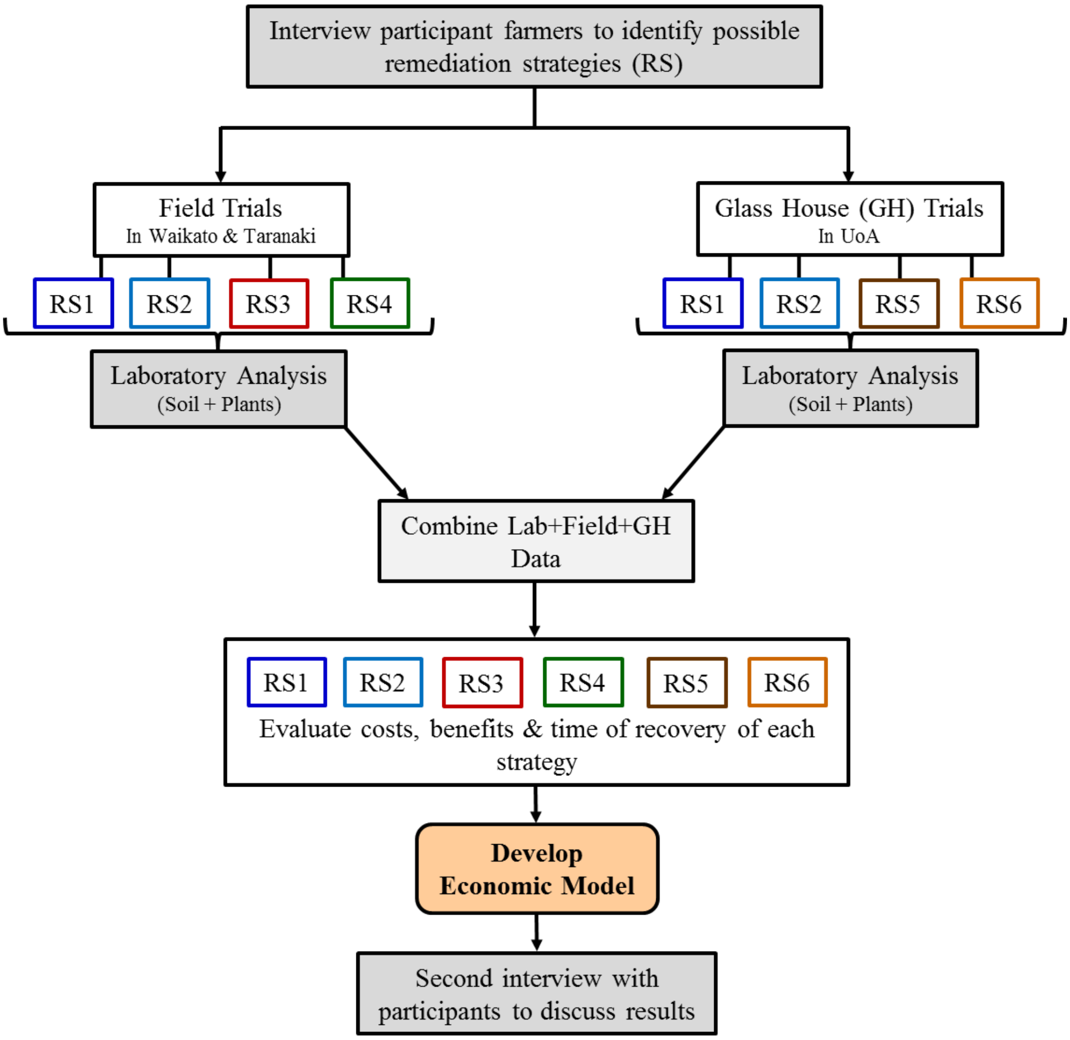


Figure 1: Schematic layout explaining the research plan

- **Farmer Interviews:** Pastoral agriculture farmers and farm advisors (from a range of organisations) in the two areas, along with agricultural productivity experts in academia, will be selected based on simple random sampling or snowball sampling and will be questioned in one-on-one interviews to understand the range of remediation techniques that they would expect to use to recover pasture from the impact of a major volcanic tephra fall. Based on these interviews a careful selection will be made of the most common strategies that are also suitable for further investigation either in the field, in the lab or both. The Regional Councils of *Waikato* and *Taranaki* and the Federated Farmers group will help put the researcher in touch with potential farmers willing to volunteer for the study. Ideally twelve farmers in each area will be interviewed in person to understand the various remediation techniques they use on the farm or would consider practising on their farm following a heavy ash fall or any other natural disaster. Interviewing the farmers will also help in comprehending the diversity in possible soil remediation techniques and help shortlist the most popular and the most effective techniques.
- ***Field Trials:*** A field trial to simulate these selected approaches will then be carried out. These approaches may include some of the treatments identified under ‘soil rehabilitation techniques’ above if not included in the strategies suggested by the farmers. Field trials will simulate a range of recovery options following large-scale tephra fall on a test-farm site in each area, using imported fresh ash. Care will be taken to develop statistically sound experiments. For example it may be too expensive to have multiple sites, but multiple replicates of three or four management options might be feasible. Features investigated will be: (a) time to pasture seed germination; (b) pasture growth recovery (yield based); (c) pasture chemistry; (d) cost effectiveness of the remediation strategy. Neighbouring pastures will be used to provide control on productivity and chemistry.
- ***Glass House Trials and Laboratory Analysis:*** Based on the interviews, laboratory trials will also be conducted to investigate further specific seed-germination strategies (these might include hydroseeding, mulch/fertiliser options, and raw-ash vs. mixed soil-ash substrates). The perennial ryegrass (*Lolium perenne*) seed will be used for the study (in both the field and glass house trials) as this is the most common grass grown on New Zealand farms and has an ability to keep on growing over many years. The selected remediation techniques tested in the glass houses may or may not be similar to those in field trials. Existing pasture/soil samples transported to the lab environment will provide control measurements of productivity. The pot experiments will be carried out at the greenhouse at East Tamaki Campus, University of Auckland, and the analytical experiments will be performed in the labs of School of Environmental Science, University of Auckland.
- ***Developing the Economic Models:*** Based on the treatments suggested by the interviewees, along with data from the experiments above, an economic model will be built that considers the cost of remediation measures against the pace of productivity recovery (with a control being no remediation). This will factor in all machinery, fertiliser, organic soil amendments and other costs, along with availability of labour, machinery and the feasibility of the recovery operations. The best recovery technique would be decided based on cost and time to recovery. The effectiveness of remediation on the affected soil will also be evaluated by

analysing the basic physical, chemical and biological soil parameters relevant to pasture growth. Dairy NZ representatives (farm consultants) would be approached for their advice regarding this part of the research given that they regularly carry out cost benefit analyses regarding farming practices with farmers (J. Haultain pers. Comm.).

- ***Final interview with the farmers:*** The results of the experimental and economic study will be communicated to the participants of the survey and a further interview process and a follow-up survey of their strategies and perceptions will be carried out. Recommendations will be prepared for the Ministry of Primary Industries and Federated Farmers NZ for the recovery of pastures following major volcanic ash falls.

***2) Experimental Plan***

Experiments will be carried out in the field and in the laboratory. The soil from the two study regions will be treated with different concentrations of volcanic ash to form various thicknesses of ash over the soil. Analysis will be carried out to investigate a number of parameters, which reflect the health of soil and plants with respect to time of recovery, cost involved and the quality of recovery, cost involved and the quality of recovery:

- ***Source of Volcanic Ash***

  ***Andesitic ash*** will be sourced from *Sakurajima* volcano, Japan. *Sakurajima* is one of the most active volcanoes of the world and has persistent small to large explosions happening every 4-24 hours. Fresh ash will be imported from Japan to be utilised for the field, pot and laboratory experiments. Collaborators of S Cronin in Japan will assist by collecting and sending ash to New Zealand in sufficient quantity for the experiments; some ash is already available and will be utilised for the pot experiments in the *Tamaki* campus glasshouse. Andesitic ash will be used on soils from *Taranaki* as these soils are at risk of andesitic ash fall from Mt Taranaki.

  ***Rhyolite Ash*** will be sourced from the *Taupo Volcanic Zone*, likely from quarries. This ash will be used on soils from Waikato, to simulate thick rhyolite ash fall from the nearby silicic volcanoes of Okataina and Taupo.

- ***Soil and Plant Health Parameters***

  The following are some of the important factors to be considered during experimental analysis.

  Soil fertility is fundamental in determining the productivity of all farming systems. Soil fertility is most commonly defined in terms of the ability of soil to supply nutrients to crops and all the physical, chemical and biological parameters of the soil play an important role.

  In this study the soil texture, structure, density, porosity, temperature, colour, infiltration rate, water runoff and soil water holding capacity will be analysed in laboratory. Some of these parameters will also be tested in the field using a soil analysis kit.

  Soil chemistry is affected by mineral composition, organic matter and various environmental factors. The macro-nutrients NPK, nitrogen (N), phosphorus (P), and potassium (K), represent three of the most important nutrients in agriculture (Sinfield et al., 2010); some of the other micro-nutrients that are also important in determining soil fertility are iron (Fe), sulphur (S), manganese (Mn) and zinc (Zn). Nitrogen plays a fundamental role in the manufacture of chlorophyll in all plants and is an essential element of enzymatic proteins which catalyse and regulate the biological processes responsible for plant growth (Sinfield et al., 2010). Phosphorus in particular plays a significant role in root growth stimulation (Sinfield et al., 2010). Potassium, commonly referred to as potash, may be required for healthy plant growth in quantities equivalent to and sometimes greater than nitrogen. Potassium is highly mobile in plants and plays an important role in stomatal control in plants which effects water regulation and $CO_2$ exchange as well as enzymatic processes that enable photosynthesis (Sinfield et al., 2010). The most common laboratory method to determine NPK levels in the soil is by Atomic Absorption Spectroscopy. Soil pH will be calculated using glass electrode pH meter. Other micro nutrients of the soil such as manganese, total organic carbon, calcium, aluminium, iron, zinc, sulphur etc. will be analysed following methods of Blackemore et al. (1987).

Soil ecology will be studied in order to understand the effect of ash on biological parameters of soil. The effect of ash on Nitrogen cycling (e.g. Nitirification) and decomposition of plant litter, will be studied. The effect of ash on soil organisms will be checked, as these play an important role in plant growth. Earthworm count will be monitored and other microorganisms will be analysed using inoculation and staining methods.

These analyses will help in determining the health and fertility of the soil. The analysis will be carried out on the ash affected soils that are treated with various remediation techniques, to study which remediation technique was more effective with respect to improving soil health and time taken for recovery.

The biomass level will be measured to track plant growth, along with other growth parameters such as shoot length, Chlorophyll, Carotenoids, Polyphenols and Proteins. Chlorophyll content in the plants play an important role as it directly correlates with the healthiness of plants (Rodriguez and Miller, 2000; Zhang et al., 2005). Polyphenols provide plant pigments and also play a key role in plant stress. Carotenoids have a major function in the process of photosynthesis (Armstrong and Hearst, 1996) whereas proteins play a fundamental role in the growth and growth activities of plants. These parameters will be analysed using double beam spectrophotometer.

## Risks and Challenges Involved

Various risks and challenges will be involved in completion of this project. The most challenging part of the research would be to find potential farmers willing to participate in the study for which the Federated Farmers and the Regional Council will be supporting in getting in contact with the farmers. Another challenge will be finding farms to carry out field experiments. Overcoming the technical difficulties associated with various types of equipment in the field will also be a challenge. Getting sufficient funding to carry out the research will be a challenge

## Research outcomes

The outcomes of this research will include:

1. An economic and experiment-based model for planning agricultural recovery from large-scale tephra falls from NZ eruptions.
2. Development of a farmer-based dialogue, and demonstration of agricultural recovery strategies in relation to major volcanic ash falls.

The study will benefit the New Zealand agricultural sector as well as similar sectors from volcanic areas around the world. Based on the severity of ash fall the remediation model will help inform which remediation technique would be most effective, economically reasonable and will provide estimated times to recovery. This will help better farming and financial preparedness in case of such an event, informing both those directly impacted, as well as the financial sector, major cooperatives (e.g., Fonterra, Sheep and Beef NZ etc.) and Central Government relief, response and recovery agencies.

**Results so far**

***Stage 1: Interviewing the participant farmers***

To solicit farmer participants Dairy NZ, Federated Farmers, Waikato Regional Council and the Taranaki Regional Council were contacted. With support from these organizations a total of twenty-five farmers from Auckland, Bay of Plenty, Rotorua, Waikato and Taranaki district agreed to participate and twenty have been interviewed to date, with five interviews pending. Each farmer participant was interviewed for almost thirty to forty-five minutes. The farmers were interviewed in their homes and few were interviewed over the phone. Out of the twenty participants interviewed to date, four had experienced ash fall on their farms, during the 1995/96 Mt Ruapehu eruption. The farmers were interviewed to understand the various remediation or recovery practices/strategies/techniques they might consider using in order to recover the soils affected by volcanic ash fall. Figure 2 shows the most common responses received from the participants when asked what they would do if ash were deposited on their farm. Interestingly, the participants displayed a range of opinions on this, although most admitted they had not considered this possibility. The responses from farmers combined with lack of literature on the subject, confirmed the need for more study and research in this area.

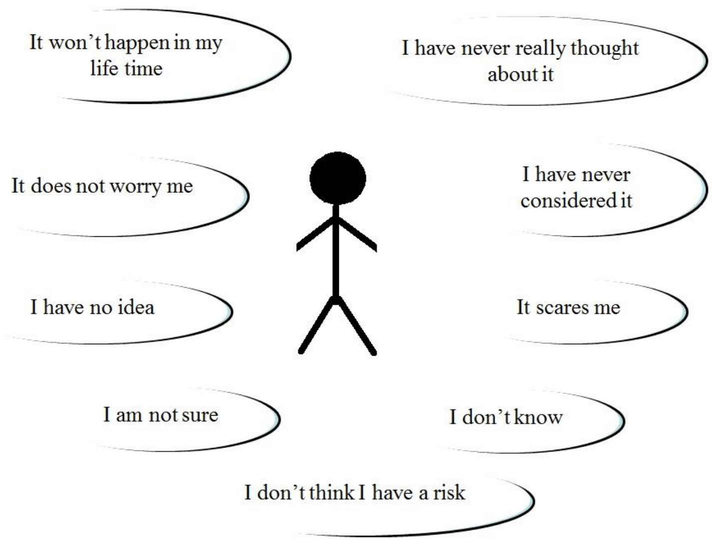


Figure 2: Common response from participants when asked what they would do if ash were deposited on their farm.

***Stage 2: Access to farms for research experiments***

Confirmation has been obtained by Dairy NZ to access a small plot on their Waikato research farms and on their Taranaki property. This research proposal will be submitted to Dairy NZ and Westpac Taranaki Agricultural Research Station (WTARS) for final approval once the School of Environment Doctoral Committee has approved it.

***Stage 3: Remediation / Recovery methods suggested***

Some useful remediation or recovery methods/techniques/strategies suggested by the participant farmers are as follows:

***Slight ash fall***

In case of slight volcanic ash fall the participants recommended the following recovery methods:

- ***Rainfall / Irrigation:*** In the case of slight ash fall the participants suggested that they would wait for rainfall so that the ash could be washed away. In this case the farmers anticipate that the grass and soil would return to their original conditions and could be continued to be used as before. Depending on the season, participants also considered irrigating the ash-affected soil as a recovery option. Irrigation would also have the effect of washing away the ash settled on soil.
- ***Liming:*** Considering the acidic nature of volcanic ash, most of the participants recommended liming as one of the recovery methods which would help neutralise the ash pH and help bring back the affected soil to its original pH to function better.
- ***Ploughing:*** Depending on the thickness of ash on the soils, farmers also recommended ploughing as a possible recovery technique. It was suggested that ploughing six to ten inches deep from the top soil and mixing the ash with soil may reduce the toxicity of ash and reduce its impacts.
- ***Grass Mix:*** Using different grass mix would also be useful in order to recover the ash-affected soil. It was suggested that a mix of ryegrass, clover and chicory gave good results with respect to pasture growth.
- ***Cow-shed Effluent:*** Some farmers sprayed the cow shed washings on to the paddock which helped in enhancing the pasture growth, increased organic nutrients in the soil and also help increase the number and growth of worms in soil. This method can be utilised to increase the level of organic nutrients in the soil which is likely to drop following volcanic ash fall.

***Heavy ash fall***

In case of heavy volcanic ash fall the farmer participants suggested the following remediation methods:

- ***Flipping:*** One of the farmer participant practised flipping on his farm in order to decrease the influence of the Taupo 186AD tephra layer, which apparently gave excellent results with respect to pasture growth and with regards to soil fertility. Flipping is defined as a method where a large excavator is used to bury the top soil and bring 1-1.5 meter deep soil on to the top. The pasture farmer who practised mentioned an increase of 40% dry matter over the dry matter grown in normal soil.

- ***Re-grassing / Cultivation:*** In case of heavy ash fall the farmers thought that re-grassing or cultivating the affected paddock would be useful. In this method the whole paddock would be spray killed followed by ploughing of soil and then re-sowing the grass seeds and cultivating the paddock all over again.
- ***Excavation / Burying:*** In case of catastrophic conditions where the ash forms a thick coat over the pasture soil, farmers thought that excavating the volcanic ash was the only option left to get rid of the ash on the soil.

**Next Steps**

The next step in this study is to evaluate farmer responses and remediation measures identified in the literature to finalise the experimental plan and then begin laboratory and field experiments. The remediation and recovery methods will be more or less similar to the ones that are mentioned above.

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