Cost effective Manuka plantation establishment

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FOREWORD

Site selection for the plant species being planted is an important aspect for cost-effective plantation establishment. If the wrong site is planted, not only is the cost of the seedling lost, but also a whole year in growth as re-planting on a large scale would need to occur the following year to coincide with the rainy season. When land rehabilitation is not generally considered commercial, this set-back would be a major impediment to further planting.

The selection of the site has numerous factors for success. The most important is soil moisture which is related to the texture of the soil and the minerals captured within its structure. Surprising is how quickly the soils can change across the south-west of Western Australia landscape, and so there are many technologies being developed to accelerate this process of soil mapping and the understanding of this soil map to plant survival and growth.

This project explored two technologies, the use of electromagnetic induction to correlate to soil moisture and texture, and drone capture of the crop for assessment of plant growth and survival. Whereas the latter technology has been successful for forestry plantation establishment, the structure of the *Leptospermum nitens* offered a new challenge.

The easier the establishment, and with a highly successful result, will encourage more land being rehabilitated to Leptospermum species for the high-value production of Manuka honey.

Dr Liz Barbour
CEO
CRC for Honey Bee Products Limited

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ABOUT THE AUTHORS

A/Prof Matthias Leopold

Matthias Leopold is a soil geomorphologist focussing on soils and their properties for a better understanding of landscape evolution and soil functions. Frequently used methods of his studies include soil and geomorphic mapping, shallow geophysics, various sedimentological and geochemical laboratory methods including XRD for minerology. He is based at the School of Agriculture and Environment at the University of Western Australia where he currently acts as Department Head for Environmental Science.

Matthias integrates knowledge from pedology and geoscience to study and to understand near surface processes at various scales and environments. Thus, he develops 2D and 3D subsurface models using geophysical methods, to characterise vertical and horizontal differences in the upper meters including soils. Portraying the complexity of the subsurface, recently known in science as the "critical zone", allows statements about possible rooting depths, hydrological flowpaths, material composition, thickness variations of soil horizons and geomorphic layers – information highly wanted by agriculture, forestry, geography and engineering as well as archaeology.

Hira Shaukat

Hira Shaukat is currently completing her PhD working with Associate Professor Dr Ken Flower and Associate Professor Dr Matthias Leopold at The University of Western Australia, School of Agriculture and Environment. Her research is focused on soil mapping in broad acre farming using non-invasive and mobile electromagnetic induction sensors, particularly in relation to the soil moisture availability in rainfed agriculture. Hira has recently published work in *Agriculture Water Management* and *Frontiers in Environmental Science* Her work with the Cooperative Research Centre for Honey Bee Products (CRCHBP) and the Department of Industry, Science, Energy and Resources (Grant # 20160042) is focused on the potential for integrating high value native medicinal shrubs in cropping system. Hira is an international candidate from Pakistan and was awarded an Australian Government Research Training Program (International) and University Postgraduate Scholarship for her PhD in Australia. Prior to joining UWA, she worked for a multinational agribusiness company with the goal of working closely with farmers to introduce new hybrid varieties and implement global sustainability projects.

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Importantly, we also thank Shane McLinden from the Honey for Life group for access to the field sites.

ABBREVIATIONS

ASC	Australian Soil Classification
CRCHBP	Cooperative Research Centre for Honey Bee Products
DGPS	differential global positioning system
DHA	dihydroxyacetone
DOE	depths of exploration
ECa	apparent electrical conductivity
ECMI	electromagnetic conductivity imaging
EMI	electromagnetic induction
ERT	electrical resistance tomography
GCP	ground control point
GPS	global positioning system
L. nitens	*Leptospermum nitens*
MGO	methyl glyoxal
PCA	principal component analysis
QGIS	Quantum geographic information system
RMSE	root mean squared error
RTK	real time kinematic
Rx	receiver coil
Tx	transmitter coil
UAV	unmanned aerial vehicle
WRB	World Reference Base

EXECUTIVE SUMMARY

Background

Leptospermum species produce nectar containing dihydroxyacetone (DHA), allowing production of high value, medicinal honey. *L. nitens* is native to Western Australia and has been shown to produce higher levels of DHA than the commercially successful *L. scoparium*. Cultivating *L. nitens* to produce medicinal honey on marginal agricultural land may contribute to reversing land degradation through reforestation. Reforestation can decrease wind and water erosion and dryland salinity and has the potential to sequester carbon and the income from medicinal honey production may offset the costs of reforestation.

To realise these possible benefits, the honey bee industry needs rapid, low cost methods to determine if land is suitable for *L. nitens* cultivation. Electromagnetic induction (EMI) may be a promising tool for soil surveying prior to establishing new native plantations, with the potential to measure soil parameters like salt content, soil moisture, soil texture, stratigraphic layers or depth to bedrock. These soil parameters can be correlated with data on plant survival and growth gathered using drones/unmanned aerial vehicles. Such tools have the potential to help the honey bee industry identify the soil conditions most suitable for *Leptospermum* growth in WA and growers to identify the most suitable areas for *Leptospermum* plantations for honey bee products.

Objectives and aims

The project objective was to investigate the performance of WA native *Leptospermum* plant material in different soil types and environments to optimise survival and growth which leads to flowering and nectar production for high-value honey production.

The project aimed to:

Develop a robust, rapid and non-invasive soil mapping system to identify soil parameters influencing the survival and growth of *L. nitens*, for potential commercial cultivation across different soil types.

Give a prognosis for the most suitable soil conditions for commercialisation of *L. nitens* in Western Australia.

Key findings & implications for the honey bee industry

Soil texture affected *L. nitens* growth and survival (Table 1). There was a significantly larger shrub survival and growth rate in sandy loam and loamy textured soils (medium and heavier texture classes) compared with deep sandy areas. However, further increase in the clay content did not improve the shrub survival or size.

L. nitens cultivations can thrive on marginal agricultural lands with low fertility, providing an alternative to cropping for these lands. The survival rate of *L. nitens* at Mooribin was 75% ha^{-1}, despite the site having a uniformly deep sandy soil with low agronomic value due to water repellence and lower water retention rate (Roper et al., 2015). In addition, areas with higher clay content, with high cost of production for growing crops had similar survival rates of *L. nitens* medium-textured soils.

Table 1. Leptospermum nitens performance in different soil textures after 2-3 years of growth at Mooribin or Kukerin, Western Australia.

Parameter		Deep sandy soil (light texture)	Sandy top & loamy subsoil (medium texture)	Loamy top & loamy subsoil (medium texture)	Loamy top & clayey subsoil (heavy texture)
Shrub survival (% ha^{-1})		75	88	89	83
Shrub growth (diameter cm)	Median	27	28	37	28
	Average	26	25	38	33

EMI spatial soil mapping is a quick and robust tool to identify areas with potential for *L. nitens* plantation establishment. EMI spatial soil mapping has potential to be a useful tool for planning new plantations of *L. nitens* to improve growers' capacity to identify areas where plantations are most likely to succeed.

Recommendations

Growers considering establishing *Leptospermum* plantations should take into account that sandy loam and loamy textured soils (medium and heavier textures) supported greater survival and growth of *Leptospermum* than sandy soils (Table 1). Growers should perform a soil survey to identify which soils have the most suitable texture and EMI spatial soil mapping is a cost-effective and effective tool to perform such a survey. EMI spatial soil maps obtained during the dry season can identify variations in soil texture and those obtained during the wet season may be useful for identifying zones requiring different soil management.

Future research areas for the honey bee product industry to consider include additional EMI surveys on heavy clay soils planted with *Leptospermum* species to expand the soil-type recommendations. Future research should also determine if the land identified by EMI surveys as being able to support greater *Leptospermum* survival and growth also supports higher quality and quantity of nectar production. This information would allow the honey bee products industry to advise prospective growers on the suitability of a wider range of soil textures for growing *Leptospermum* and on the income they could potentially expect from reforestation with *Leptospermum.*

Academic outputs

Shaukat H, Flower KC and Leopold M. Soil mapping using electromagnetic induction to assess the suitability of 1 land for growing *Leptospermum nitens* in Western Australia. *Frontiers in Environmental Science Journal (2022)* 10:883533. doi: 10.3389/fenvs.2022.883533

Soil mapping using electromagnetic induction for *Leptospermum nitens* survival and growth in Western Australia. School of Agriculture and Environment Seminar Series, September 28, 2021.

Shaukat, H., Flower, KC, and Leopold, M (2022). Soil mapping using electromagnetic induction to assess the suitability of land for growing *Leptospermum nitens* in Western Australia, 22nd World Congress of Soil Science, 31 July – 5th August, Glasgow, UK.

Industry outputs

This project has a number of significant outputs for the honey bee products industry (see Recommendations). Primarily this project has identified that sandy loam and loamy textured soils (medium and heavier textures) supported greater survival and growth of *Leptospermum* than sandy soils (light texture). The industry can use this information to advise prospective growers on soils with potential as *Leptospermum* plantations for the production of honey bee products.

This project demonstrated that EMI is a cost-effective and effective tool that can be used by growers to identify which soils have the texture and moisture content that will support greater *Leptospermum* survival and growth. The industry can use this information to recommend that prospective growers have an EMI soil survey performed prior to establishing a *Leptospermum* plantation.

Figure 1: A native, *Leptospermum nitens* growing in plantation in the south-west of Western Australia.

INTRODUCTION

Leptospermum species are renowned for their essential oils, nectar production for honey, and are also used as ornamental shrubs. There are 85 *Leptospermum* species native to Australia and 15 native to Western Australia, including *L. nitens* (Bean, 1992, 2004). *Leptospermum* are closely related to the widely studied and commercially successful *L. scoparium*, found in Tasmania, the north-west mainland of Australia and in New Zealand (Adams et al., 2009; Porter and Wilkins, 1999; Stephens et al., 2005; Thrimawithana et al., 2019; Wicaksono et al., 2016).

Leptospermum honey is popular for its synergistic impact with common antifungal and antibacterial agents (Cokcetin et al., 2016; Lu et al., 2013). The high/medicinal value of *Leptospermum* honey is due to the presence of the chemical component methyl glyoxal (MGO) which is formed from its precursor dihydroxyacetone (DHA) (Adams et al., 2008; Mavric et al., 2008). Not all *Leptospermum* species produce DHA in their nectar. The WA species, *L. nitens* has been shown to produce higher DHA and MGO levels than *L. scoparium* (Williams et al., 2018).

Leptospermum are expected to succeed in managed plantings in the WA. They are dominant in low fertility, poorly drained environments (Thompson, 1989), grasslands, woodlands and heathlands (Bennett, 1994; Burrell, 1981). In agriculture, they are often known as a woody weed of pastures (Burrell, 1965) and are useful for erosion control (Marden and Phillips, 2015), carbon sequestration (Beets et al., 2014; Scott et al., 2000) and vegetation restoration (Marden and Phillips, 2015). Since *Leptospermum* can adapt to various soil and climatic conditions (Dodson and Kershaw, 1995; Hageer et al., 2017) it is expected that they will be responsive to managed cultivations (Cokcetin et al., 2019). *L. nitens* is one of the species identified with potential to make unproductive, low fertility areas in the "wheatbelt" region of WA a 'hot spot' for generating bioactive honey (Cokcetin et al., 2019).

L. nitens cultivation in the south-west of Western Australia could also improve land degradation in the region. Land clearing and intensive cereal/annual pasture rotations have resulted in dryland salinity (Stirzaker et al., 2002) and have also exposed surface soils to excessive wind and water erosion (Lamb, 2014). According to the latest estimate more than 1 million ha of south-west Western Australia (WA) is affected by salinity resulting in the loss of at least $519 million per year (Australian Bureau of Statistics, 2002; Furby et al., 2010). Indeed, the current scale of this degradation problem now requires landscape level mitigation responses like reforestation (George et al., 2012). Species identified for mitigation are mainly selected based on their ecological role, however, estimated costs of such reforestation plans often exceeds the value of the land (Harper et al., 2017; Lamb, 2014). A major factor affecting large scale reforestation is to obtain an impactful hydrological response, without displacing farm production (Harper et al., 2014). Therefore, market driven reforestation has the potential to encourage the integration of trees into existing farming systems (Mendham et al., 2011). A recent report on high value honey derived from *Leptospermum* species in Australia has identified the opportunity of bioactive honey production at a commercial scale, either by diversifying traditional agricultural regions like the WA wheatbelt region or by using unproductive lands through revegetation focused projects (Cokcetin et al., 2019).

Electromagnetic induction (EMI) may be a promising tool for 3D-spatial soil surveying when establishing new plantations with native plants. Currently, there is limited information on a field scale to understand the impact of soil parameters, especially soil moisture, on the survival and growth rate of *L. nitens*. Such information could possibly identify factors correlated to yield and quality of nectar production for medicinal honey. EMI sensors, provide the simplest and least expensive method to assess soil variations on a broad scale because they can take readings at different depths simultaneously. These non-invasive sensors measure the contactless bulk soil electrical properties that contribute to the apparent electrical conductivity (ECa). The measured soil ECa is a response of conductive soil parameters like salt content, soil moisture, soil texture, stratigraphic layers or bedrock

(Corwin and Lesch, 2013; Dakak et al., 2017; Doolittle and Brevik, 2014a; James et al., 2003; Triantafilis et al., 2000; van Wesenbeeck and Kachanoski, 1988). Mostly, EMI assessments are used in agriculture (Arshad et al., 2020; Hanssens et al., 2019; Hedley and Yule, 2009; Shaukat et al., 2022). However, Bennett and George (1995) did an EMI survey to quantify salinity for the new plantations of *Eucalyptus globulus* and suggested that this method could be used for assessing soil variations, for risk assessments before establishing new plantations.

Moreover, remote sensing methods are becoming mainstream in planning for tree plantations and their management (Charron et al., 2020; Dainelli et al., 2021; Dixon et al., 2021). In particular drones or unmanned aerial vehicles (UAV) are providing efficient aerial mapping and estimation of deforestation rates, quantifying above ground biomass, monitoring climatic impacts on land use, woodlands and forest ecosystems and getting information from the sites that are difficult to reach (Muchiri and Kimathi, 2016; Pádua et al., 2017; Raparelli and Bajocco, 2019). Combination of new technologies for both soil and aerial surveys with quick turn-around times can provide data driven decisions for agroforestry (Pádua et al., 2017).

Objectives

The project objective was to investigate the performance of WA native *Leptospermum* plant material in different soil types and environments to optimise survival and growth which leads to flowering and nectar production for high-value honey production.

The project aimed to:

1. Develop a robust, rapid and non-invasive soil mapping system to identify soil parameters influencing the survival and growth of *L. nitens*, for potential commercial cultivation across different soil types.

2. Give a prognosis for the most suitable soil conditions for commercialisation of *L. nitens* in Western Australia.

Key activities

The key activities of the project were to map soil in two *L. nitens* plantings by electromagnetic induction (EMI) and correlate soil properties to plant growth.

Soil characterisation

Using the Dualem 1HS, which is a state of the art EM device allowing the measurement of depth slices in one pass, two sites were mapped that had been planted with *Leptospermum* seedlings in June 2018.

The overall size of the mapped area was dependent on local conditions and was subject to discussion with the partners to select a reasonable and representative subset of the overall area. The mapped area was 16 ha at Mooribin and 20 ha at Kukerin.

The first pass occurred before rain break in early June 2019. A second scan of area was undertaken during the winter in August 2019.

Maps were established of the data showing areas of soil differences. Plots within these different areas were pegged, soil samples were taken and moisture sensors established.

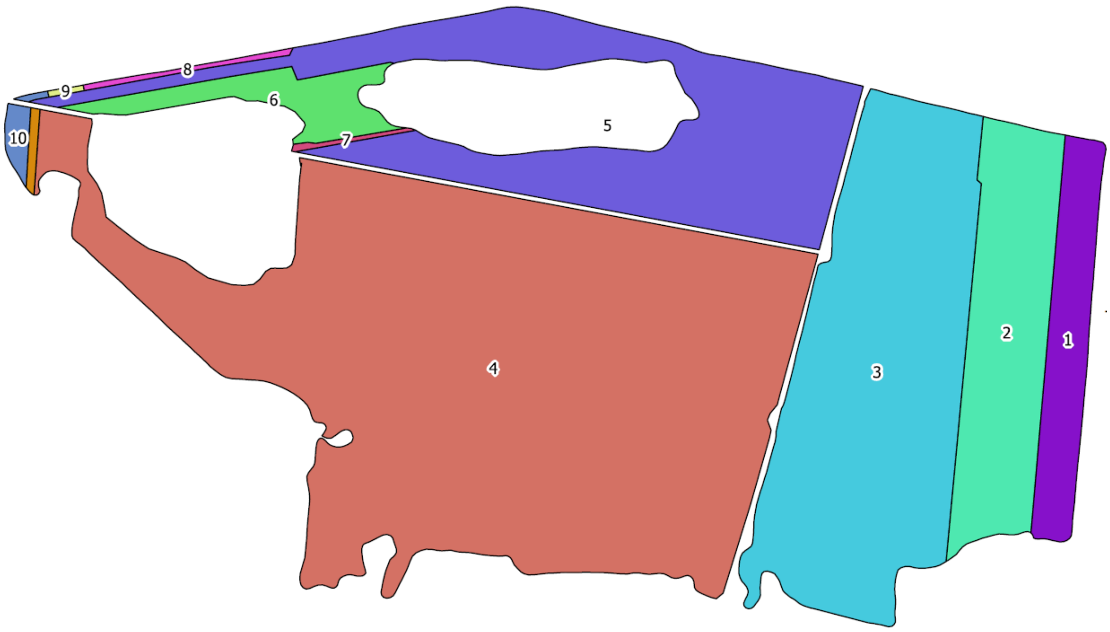

Figure 2: Mooribin site planted June 2018 with a mixture of *Leptospermum nitens* provenances and *L. scoparium.*

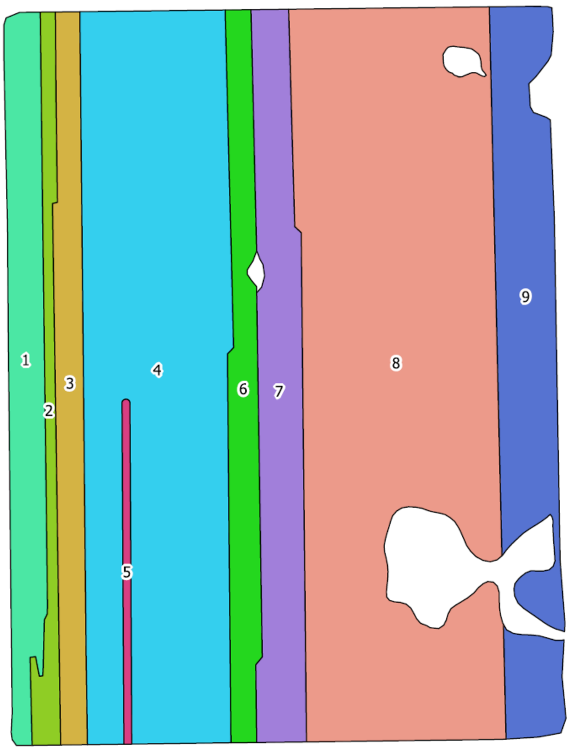

Figure 3: Kukerin site planted in June 2018 with a number of different provenances of *Leptospermum nitens*

Plant survival and growth

The *Leptospermum* plants within each plot assessed for survival and growth.

Firstly, in 2020 drone technology by Mapizy was used to map survival (number of bushes counted) and growth (biomass on each bush estimated).

Second, in 2021 ground-truthing was undertaken to correlate maps created from drone images with measures of survival (number of bushes counted) and growth (trunk diameter measured).

Figure 4: Growth after 12 months at the low rainfall site at Kukerin.

Figure 5: Growth after 12 months at the higher rainfall site at Mooribin

Data analysis

Data was analysed to show which soil types were superior for *Leptospermum* survival and growth.

Figure 6: Processing the drone footage from the two sites: Left: Section of Moribin. Right: Kukerin site

Impacts

This project impacts the honey bee products industry by mapping farmland for areas suitable for *Leptospermum* establishment to produce nectar for honey production. The remainder of the land can be established with other melliferous flora to support honey bee health.

This project also provides industry with information on the soil textures that support greater survival and growth of *Leptospermum* (Table 1). The results highlighted that a significantly larger shrub survival and growth rate in sandy loam and loamy textured soils (medium and heavier texture areas) compared with deep sandy areas.

Outputs

This project determined the suitability of *Leptospermum* (survival and growth) to the soils of south-west Western Australia using a Dualem 1HS EMI to identify the high-performing soil-types.

This project connects to the outputs of other projects funded by the CRCHBP:

1. This project contributed to testing new *Leptospermum* selections for land rehabilitation, flowering and bee-attraction performance (CRCHBP Output 4.4).

2. Design and develop a Spatiotemporal Geographic Information System database to house and link spatial information gathered across the CRCHBP projects and related sites; and developed an enhanced bee related floristic vegetation map for the SW of WA (Project 1 Objective).

3. Demonstrate and validate high value honey bee hive sites (*Leptospermum*) through honey bee product measurement and assessment (Output 3.3).

PROJECT ACTIVITIES & RESULTS

Detailed descriptions of the project activities and results are given in the following publication which is available for free online:

Shaukat H, Flower KC and Leopold M (2022) Soil Mapping Using

Electromagnetic Induction to Assess the Suitability of Land for Growing *Leptospermum nitens* in Western Australia.

Front. Environ. Sci. 10:883533. doi: 10.3389/fenvs.2022.883533

IMPLICATIONS

Texture and soil moisture affect *L. nitens* survival and growth

This project showed the impact of spatial soil variability on establishment and growth patterns of *L. nitens* plantation. In particular, two soil properties were identified as having an effect on *L. nitens* survival and growth: soil texture and soil moisture.

First, soil texture was related to *L. nitens* survival and growth (Table 1). The Mooribin site has uniformly deep sandy soils and *Leptospermum* plants performed well, with overall 75% survival rate ha^{-1}. At Kukerin, the variable textured soils had higher overall higher shrub survival of 82%. A detailed comparison of shrub survival and growth patterns showed there was a significantly larger shrub survival and growth rate in sandy loam and loamy textured soils (medium and heavier texture areas) compared with deep sandy areas. However, further increase in the clay content did not improve the shrub survival or size.

Soil moisture was also identified as being a limiting factor in *L. nitens* survival and growth. The areas with higher *L. nitens* survival (shrub count) and growth (shrub diameter) were correlated to areas that the EMI spatial soil mapping identified as having both medium textured soil *and* as a direct consequence higher soil moisture retention.

Table 1. *Leptospermum nitens* performance in different soil textures after 2-3 years of growth at Mooribin or Kukerin, Western Australia.

Parameter		Deep sandy soil (light texture)	Sandy top & loamy subsoil (medium texture)	Loamy top & loamy subsoil (medium texture)	Loamy top & clayey subsoil (heavy texture)
Shrub survival (% ha^{-1})		75	88	89	83
Shrub growth (diameter cm)	Median	27	28	37	28
	Average	26	25	38	33

L. nitens suitable for marginal agricultural lands

This project showed that the *L. nitens* cultivations could thrive on marginal agricultural lands with low fertility, providing an alternative to cropping. Generally, medium textured areas showed the best shrub establishment rate, but this textural class is also most suitable for agricultural cropps due to their nutrient holding capacity, better aeration and drainage capacity as compared to more sandy or clayey soils (Salter and Williams, 1965). Mooribin had a uniformly deep sandy soil with low agronomic value due to water repellence and lower water retention rate (Roper et al., 2015). Despite this, the survival rate of *L. nitens* was 75%. The 2021 season was relatively wet and it was observed that the flowering of shrubs at Mooribin was good, regardless of shrub size. In addition, areas with higher clay content, with high cost of production for growing crops had similar survival rates of *L. nitens* medium-textured soils. These results demonstrate that *L. nitens* plantations can be a good option for utilising these low fertility/productivity soils. Furthermore, the cost to reforest marginal lands may be partly offset by the income from medicinal honey and, potentially in the future, income from carbon credits.

EMI a tool for preliminary surveys before establishing *L. nitens* plantations

This project showed that EMI spatial soil mapping can be used to identify areas with potential for *L. nitens* plantation establishment. EMI spatial soil mapping was robust and quick to determine the spatial soil variability at both a site with uniform texture and a site with variable textured and in different rainfall seasons. The technique measured apparent electrical conductivity (ECa) at three depths and strongly reflected variation in soil moisture and texture. At both sites, there was a significant difference in *L. nitens* survival (shrub count) in the mapped ECa areas and areas with higher soil ECa were found to have greater growth of *L. nitens* (larger shrub sizes). EMI spatial soil mapping has potential to be a useful tool for planning new plantations of *L. nitens* to improve growers' capacity to identify areas where plantations are most likely to succeed.

In addition, this project showed that EMI spatial soil maps obtained during the dry and wet season may give growers additional information. The EMI soil spatial maps that were obtained during the dry season, when there was little moisture in the soil, largely reflected differences in soil texture and can therefore be used to identify areas with soil textures where Leptospermum is likely to thrive. In contrast, the EMI spatial soil maps that were obtained during the wet season reflected differences in both soil texture and soil moisture. These maps may be used by growers to identify zones which require different soil management strategies. This could be especially useful for growers planning for intercropping with Leptospermum.

RECOMMENDATIONS

1. When choosing where to plant *Leptospermum* for honey production, growers should take into account that sandy loam and loamy textured soils (medium and heavier textures) supported greater survival and growth of *Leptospermum* than sandy soils (Table 1). However, *Leptospermum* may still perform well on sandy- and clay-textured soils.

2. Before planting *Leptospermum*, growers should perform a soil survey to identify which soils have the texture and moisture content that will support greater plant survival and growth and thus economic benefit.

3. Electromagnetic induction (EMI) spatial soil mapping is a low-cost and effective tool to perform such a survey. EMI spatial soil maps obtained during the dry season can identify variations in soil texture. EMI spatial soil maps obtained during the wet season may be useful for identifying zones requiring different soil management, which is particularly useful for intercropping with Leptospermum shrubs.

4. Additional EMI surveys should be performed on heavy clay soils planted with *Leptospermum* species to expand the soil-type recommendations, because the current study only considered deep sands and loamy textured soils. This information would allow the honey bee product industry to advise prospective growers on the suitability of a wider range of soil textures for growing *Leptospermum*.

5. Further research should be performed to determine if the land identified by EMI surveys as being able to support greater *Leptospermum* survival and growth also supports higher quality and quantity of nectar production. This information would allow the honey bee products industry to advise prospective growers more accurately on the income they could potentially expect from reforestation with *Leptospermum*.

6. The honey bee product industry could reduce the cost of future research to identify sites with high potential for *Leptospermum* plantings by using unmanned aerial vehicles (UAVs) to measure plant survival and growth at additional sites with different soil conditions. To improve the accuracy of UAV estimates of plant survival and growth, UAV imagery of *Leptospermum* should be collected when the plants are more than two years old and as close in time as possible to ground truthing.

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