Energy Use and Efficiency Measures For the New Zealand Arable and Outdoor Vegetable Industry

Prepared for:
Climate Change Office
and
Energy Efficiency and Conservation Authority

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AgriLINK NEW ZEALAND

CONTENTS

LIST OF ABBREVIATIONS

Energy & Power

J	joule	basic unit of energy
kJ	kilojoule	1,000 joules (E3)
MJ	megajoule	1,000,000 joules (E6)
GJ	gigajoule	1,000,000,000 joules (E9)
PJ	petajoule	1,000,000,000,000,000 joules (E15)
W	watt	basic unit of power = 1 joule per second
kW	kilowatt	1,000 watts
kWh	kilowatt-hour	3.6 MJ

Others

ha	hectare	10,000 square metres
kg	kilogram	
t	tonne	1,000 kg
ℓ	litre	
CO_2	carbon dioxide	
CCO	Climate Change Office	
EECA	Energy Efficiency and Conservation Authority	
MAF	Ministry of Agriculture and Forestry	
MED	Ministry of Economic Development	

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

AgriLINK New Zealand Ltd was contracted by the Climate Change Office (CCO) and the Energy Efficiency and Conservation Authority (EECA) to provide a stock take of the existing information on energy efficiency measures for the New Zealand Arable and Outdoor Vegetable Industry. The key areas investigated were soil cultivation, irrigation, and grain drying and storage. The intention was to also investigate vegetable postharvest grading and storage; however there was insufficient information to complete this aspect of the report. A MAF SFF project currently being conducted will include an energy audit of a vegetable packing shed, which will improve our understanding in this area.

This report brings together an extensive list of energy efficiency measures for the arable and outdoor vegetable industry and provides a foundation that can be added to in the future as well as identifying gaps and the actions required to improve energy efficiency.

The emphasis has been on collecting the breadth of information rather than specific details. As a lot of the information revolves around management techniques rather than technologies the stock take notes where this information is held rather than reproducing or critically analysing it.

A more detailed study is necessary to capture all aspects of concern to growers and to fully identify the limitations in uptake of different energy efficiency systems. There are also regional and crop type variations, as well as local service companies, that have not been shown in detail in this report.

2.0 ENERGY USE IN THE NEW ZEALAND AGRICULTURAL INDUSTRY

In this report all energy use has been calculated to the farm gate. Beyond the farm gate energy use various enormously depending upon the sector and how far away the customer is. Protected cropping for example only uses a small amount of energy for grading and short term storage; while kiwifruit uses considerably more energy due to storing a crop for up to 5 months; or the dairy sector that has a large transport component moving milk each day between the farm and factory. Section 2.5 provides an estimate of some sectors energy uses beyond the farm gate.

By national standards agriculture is a low energy consumer. In 2002 agriculture consumed approximately 13.4 petajoules (PJ) or 2.6% of national consumption [1] (13.6 PJ in 2004).

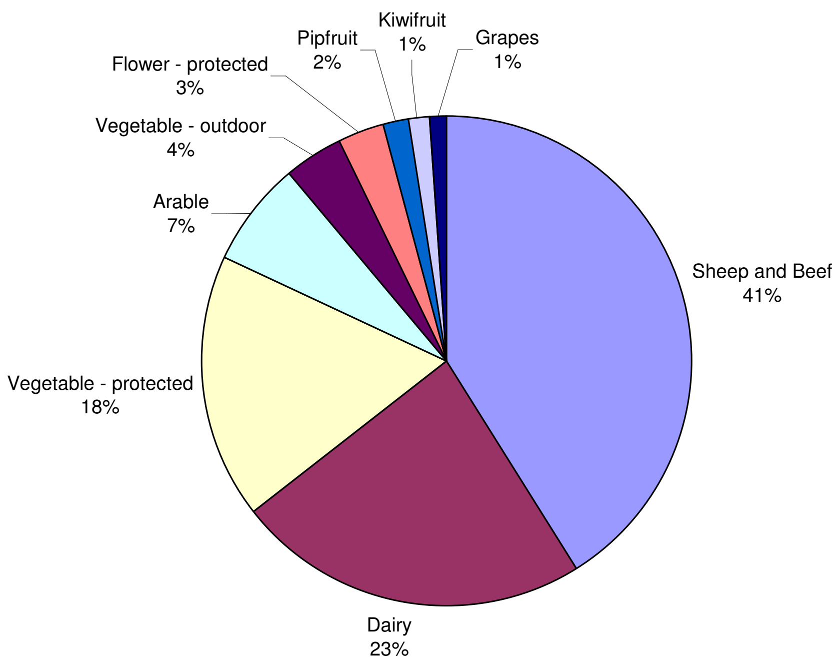
Obtaining national energy use figures for the different sectors within the agricultural industry is very difficult. The Ministry of Economic Development aggregates the agricultural figure and uses a method of “top-down” accounting, where they source data directly from fuel and electricity supply companies.

In order to construct a set of national agricultural energy use figures for each sector a method of “bottom-up” accounting was used to built a national energy use model. The results are presented in Table 1 and Figure 1. Energy use to the farm gate was calculated at 14.2 PJ. This is 0.8 PJ higher than that calculated by the Ministry of Economic Development; however their figure does not include an allowance for gas. Barber and Wharfe [2] found that gas contributed 50% of protected vegetable heating and 25% of protected flower heating, or approximately 1.4 PJ.

Table 1. National Agricultural Energy Use to the Farm Gate (PJ)

Sector	Energy Use (PJ)	Sectors Proportion
Sheep and Beef	5.86	41.2%
Dairy	3.30	23.2%
Vegetable - protected	2.50	17.6%
Arable	0.99	6.9%
Vegetable - outdoor	0.56	3.9%
Flower - protected	0.44	3.1%
Pipfruit	0.24	1.7%
Kiwifruit	0.18	1.2%
Grapes	0.17	1.2%
Total	**14.23**	

Figure 1. National Agricultural Energy Use to the Farm Gate



2.1 Sheep and Beef

The sheep and beef sector was calculated by splitting the sector into predominantly sheep farms and the more intensive beef and mixed sheep and beef farms.

In 2002 there were 3.7 million hectares of sheep farms carrying 40.2 million stock units, made up of 30.6 million sheep and 1.6 million cattle [3]. Energy use on these farms is estimated at 3.0 PJ, based on diesel use of 2 ℓ/SU and electricity at 1.3 kWh/SU [4].

In 2002 there were 2.1 million hectares of beef farms and mixed sheep and beef farms, carrying 20.7 million stock units [3]. The energy use on these more intensive operations was based on the energy intensity of nine conventional farms that contribute to the unpublished ARGOS (www.argos.org.nz) database. Total energy use was 2.8 PJ, based on 3.7 ℓ/SU and 2.0 kWh/SU.

2.2 Dairy Industry

Energy use in the dairy shed was 2.2 PJ [5], based on 3.9 million cows consuming 160 kWh per cow. Irrigation contributed 1.1 PJ [5] based on 161,500 irrigated hectares consuming approximately 2,000 kWh/ha.

2.3 Protected Crops

The protected vegetable industry covers approximately 225 ha, of which 181 ha is heated, and uses 2.5 PJ. The size of the flower industry is approximately 100 ha, 54 ha of which is heated and consumes 0.4 PJ [2].

2.4 Fruit

The three main fruit crops are grapes (17,300 ha), pipfruit (12,788 ha) and kiwifruit (11,964 ha). These three crops account for 72% of the area planted in fruit trees and vines [3].

Energy use in each of these sectors is described in Table 2 [6].

Table 2. Energy Use in the Fruit Sector

	Diesel – on orchard (ℓ/ha)	Irrigation (kWh/ha)	Area irrigated
Grapes	365	1,453	33%
Pipfruit	436	1,180	73%
Kiwifruit	222	895	58%

2.5 Postharvest

All the energy figures presented in this report are to the farm gate. However postharvest transport, grading and coolstorage can be significant energy users, particularly in the dairy industry. Some indicative figures are shown in Table 3.

Table 3. Postharvest Energy Use (PJ)

	Transport to Shed or Factory	Grading and Coolstorage
Dairy	0.305	a
Grapes	0.006	a
Pipfruit	0.023	a
Kiwifruit	0.013	0.176
Total	**0.347**	**0.176**

“ a ” energy values have not been calculated in this study

All transport was based on a cartage rate of 0.069 ℓ/t-km [7]. Milk tankers travel 70 million km’s per year [8] and transport 13.5 million tonnes of milk (13.9 million tonnes were produced but 0.4 million tonnes were used on farm) [9]. Based on the main season being 280 days the tankers travel 250,000 km per day to 13,500 farms or a round trip of 18 km per farm. Assuming a utilisation of 50%, fuel use is 8.6 million litres or 0.305 PJ.

The three fruit sectors were based on transporting their harvest an average of 15 km to the packhouse.

The kiwifruit grading and coolstorage, for up to 5 months, is based on 70 million trays at 0.697 kWh/tray [10]. There was insufficient information to estimate postharvest grading, manufacture, packaging and storage for the dairy, grape, and pipfruit sectors.

3.0 ENERGY USE IN THE NEW ZEALAND ARABLE AND OUTDOOR VEGETABLE INDUSTRY

Like the other sectors described in Section 2.0, there are no national energy use figures for the arable and outdoor vegetable sectors. The figures were constructed using the "bottom-up" method and were based on MAF and Department of Statistics figures for crop area and yields [3], and a series of assumptions that are described below.

The total arable area is 231,900 ha, made up of 187,900 ha in grain and seed crops [3] and a further 44,000 ha in silage or balage [12]. Approximately 72% of the arable crop is in the South Island. Total outdoor vegetable area is 52,100 ha, 34,300 ha in the North Island (66%) and 17,800 ha in the South Island [3].

3.1 Irrigation

The irrigated arable area was estimated by MAF Policy as being 57,300 ha [11] or 30% of the total area. The industry believes that this is a little too low and a figure of 72,000 ha has been used instead [12]. Given this it was assumed that 7,500 ha of the North Island (23%) was irrigated; leaving 64,500 ha in the South Island irrigated (42%). The energy use per pass was 400 kWh/ha, applying on average 35mm. This was based on a survey conducted for Vegfed [13]. The North Island arable crops each received on average 2 passes or 70mm, while the South Island crops received 140 mm in 4 passes. This meant that the irrigation energy use was 800 kWh/ha in the North Island and 1,600 kWh/ha in the South Island. In the report by Wells [14] he found that on dairy pasture big gun irrigators used 2,070 kWh/ha. Barber [7] found that the 3 irrigated arable properties surveyed used on average 1,958 kWh/ha. Both these figures suggest that the assumptions in this reports model are reasonable.

The irrigated vegetable area is 37,200 ha [11] or 71% of the total area. Given this it was assumed that the irrigated area was 65% and 84% of the North and South Islands respectively. The energy use per pass was again 400 kWh/ha, applying on average 35mm. The North Island crops each received on average 3 passes or 105mm, while the South Islands crops received 245mm in 5 passes. This meant that the irrigation energy use was 1,200 kWh/ha in the North Island and 2,000 kWh/ha in the South Island. Total irrigation energy is shown in Table 4.

Table 4. Irrigation Energy Use

	Irrigated area (ha)	MWh	PJ
Arable NI	7,500	6,000	0.022
Arable SI	64,500	103,200	0.372
Sub total	**72,000**	**109,200**	**0.393**
Vegetable NI	22,295	26,754	0.096
Vegetable SI	14,905	29,810	0.107
Sub total	**37,200**	**56,564**	**0.204**
TOTAL	**109,200**	**165,764**	**0.597**

3.2 Cultivation

Energy use for cultivation was split between full cultivation, minimum tillage and no-tillage. Barber [7] found that arable full cultivation used 80 ℓ/ha and vegetables 300 ℓ/ha. Minimum tillage was assumed to reduce fuel use by 40%, and no-tillage saves 75% of fuel. Minimum tillage uses 48 ℓ/ha for arable crops and 180 ℓ/ha for vegetables. No-tillage was only used for arable crops, reducing fuel use to 20 ℓ/ha [16].

The area under some form of reduced cultivation was assumed to be 30% for arable and 10% for vegetables. All the reduced tillage for vegetables was minimum tillage, while 10% of the reduced tillage in arable was no-tillage.

Some vegetable crops have cultivation practices closer to that of arable crops. Peas, pumpkin, squash, sweet corn, and beans, which account for 21,900 ha, were allocated the fuel use of 80 ℓ/ha and the same proportions of reduced tillage as arable cropping. Asparagus (2,000 ha) which is a perennial crop was allocated a fuel use of 20 ℓ/ha.

The land area under cultivation was sourced from MAF and SNZ [3] and the arable silage and balage areas from Pyke [12]. Table 5 describes the cultivation energy use.

Table 5. Cultivation Energy Use

	Cultivation area (ha)	Fuel Use (litres)	PJ
Arable NI	64,200	4,465,752	0.158
Arable SI	167,700	11,665,212	0.413
Sub total	**231,900**	**16,130,964**	**0.572**
Vegetable NI	34,300	6,534,436	0.232
Vegetable SI	17,800	3,150,528	0.112
Sub total	**52,100**	**9,684,964**	**0.343**
TOTAL	**284,000**	**25,815,928**	**0.915**

3.3 Grain Drying

The energy used for grain drying is very dependant on the prevailing weather conditions around harvest, the time of harvest and the type of dryer.

Each crop has a target moisture content ranging between 13.6% for wheat to 15.0% for peas. It was assumed that after harvest 4% moisture needed to be removed from each crop except maize grain that required 10% to be removed, in order to reach the target moisture content.

Hellevang and Reff [15] estimated the energy required for different dryers to remove a pound of water. Table 6 shows the average figure for each dryer, in BTU's/lb and converted into kWh/kg water removed.

Table 6. Energy Use by Different Grain Dryers

Dryer Type	BTU's/lb of water removed	kWh/kg of water removed
Natural air	1,100	0.711
Low temp	1,350	0.872
Batch-in-bin	1,750	1.131
High temp (air circulation)	2,000	1.292
High temp (no air circ.)	2,500	1.615

While the whole range of dryers is used, given that there is no information on the proportions of each, it was assumed that all grain was dried using the batch-in-bin method. This is an approximate average of the different dryer types.

Table 7 shows the energy used in grain drying. The Department of Statistics records show the quantity harvested for each crop except the "other" category. Most of the crops in this category were assumed to be seed crops and the estimated weight is 40,000 tonnes [12].

Table 7. Energy Used For Grain Drying

Crop	Grain Harvested (Tonnes)	Percentage of Grain Dried	Grain Dried (Tonnes)	Energy Use (MWh)	Energy Use (PJ)
Wheat	301,499	30%	90,450	4,091	0.015
Barley	440,883	30%	132,265	5,982	0.022
Oats	34,987	70%	24,491	1,108	0.004
Other cereal grains	13,162	30%	3,948	179	0.001
Maize grain	148,847	100%	148,847	16,831	0.061
Field / seed peas	29,457	10%	2,946	133	0.000
Other pulses	3,302	15%	495	22	0.000
Other crops	40,000	90%	36,000	1,628	0.006
TOTAL	**1,128,055**		**439,442**	**29,974**	**0.108**

The energy use per tonne of water removed is 4,000 MJ, and can vary between 2,500 for natural air drying to 5,800 MJ for high temperature systems with no air circulation [15]. These figures are much higher than those presented in CAE [4] of between 1,000 to 2,500 MJ/tonne. It is not clear in the CAE publication if this is per tonne of water removed or per tonne of crop. However, because there can be an enormous variation in energy use depending on the moisture content of the crop at harvest, energy use in drying is usually expressed per tonne of water removed.

3.4 Transport Between Paddock and Shed

Barber [7] found that transport between the paddock and a central shed was a major component of energy use in vegetable growing in the Auckland and Waikato regions. This is due to growers having paddocks scattered over the whole region as they implement the best management practice of crop rotation. Transport to the shed was found to account for just over 25% of fuel use. The same issue was not discovered in the South Island where there tends to be single large properties, with crop rotation occurring within the farm.

Barber [7] found that cartage used 0.069 ℓ/t-km, this compares to Wells [14] who found it was 0.079 ℓ/t-km. The North Island crops were assumed to be moved 20 km, while the South Island crops were moved 5 km.

There is no crop weight data for vegetables, so it was assumed that the average weight per hectare carted was 35 tonnes or 1.8 million tonnes from 52,100 ha. The weight of arable crops was 1.1 million tonnes [3].

Table 8 shows the energy used in transporting the crop between paddock and a central store.

Table 8. Transportation Energy Use Between Paddock and Store

	Crop Weight (tonnes)	Fuel Use (litres)	Fuel Use (PJ)
Arable - NI	238,016	328,462	0.012
Arable - SI	890,039	307,064	0.011
Sub Total	**1,128,055**	**635,525**	**0.023**
Vegetable - NI	1,197,287	1,656,690	0.059
Vegetable - SI	626,675	214,935	0.008
Sub Total	**1,823,962**	**1,871,625**	**0.066**
TOTAL	**2,952,017**	**2,507,150**	**0.089**

3.5 Overall Energy Use

Table 9 and Figures 2, 3 and 4 shows the overall energy use for arable and vegetable crops.

Table 9. Energy Use for NZ Arable and Vegetable Production (PJ)

	Arable	Vegetable	**Total**
Irrigation	0.393	0.204	**0.597**
Cultivation	0.463	0.288	**0.751**
Transport (padd. to shed)	0.023	0.066	**0.089**
Grain drying	0.108	0	**0.108**
Total	**0.987**	**0.558**	**1.545**

Figure 2. Energy Use in NZ Arable and Vegetable Production to the Farm Gate

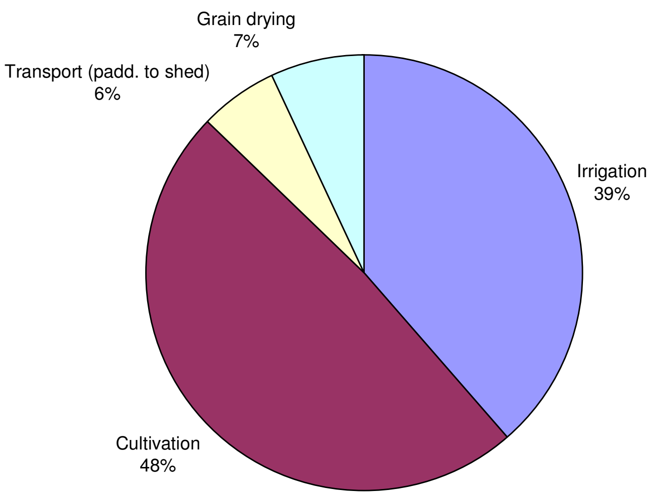


Figure 3. Energy Use in NZ Arable Production to the Farm Gate

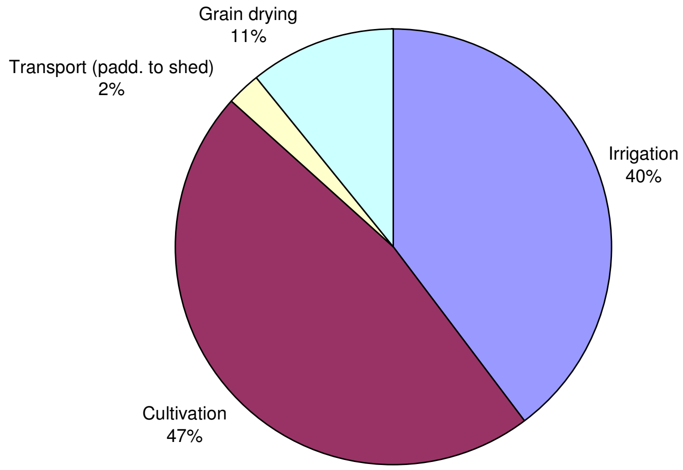
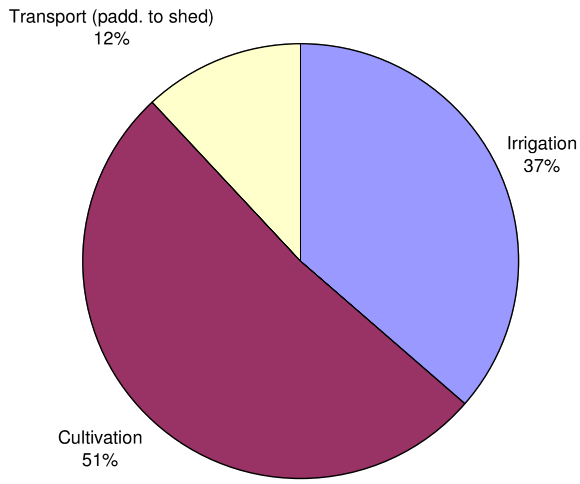


Figure 4. Energy Use in NZ Vegetable Production to the Farm Gate



4.0 ENERGY SAVING MEASURES

Results from this study have been collated into sections that broadly fit the three main energy uses of cultivation, irrigation, and grain drying and storage. Each section includes a description of the energy measure, comments including advantages and disadvantages, factors to be aware of, companies, and costs. The list of companies has been developed from personal contacts and internet searches. Inclusion in this list is not to be taken as any form of recommendation or endorsement by AgriLINK NZ of the stated skills or experience, or of any product offered by those companies or organisations. Growers must make their own assessment of companies and organisations, products and capabilities.

Each arable and vegetable operation is unique and each business has its own set of criteria that needs to be met. Any energy saving measures that are instigated must not compromise crop quality, nor lead to food safety issues or create adverse environmental effects, and to be widely adopted must improve the grower's profitability.

4.1 Irrigation

4.1.1 Irrigation Management

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Knowledge	Irrigation Manual Essential information for anyone irrigating		i ii	$125
Monitor Water meters	An essential component of managing an irrigation system is accurately knowing and tracking how much water has been applied.	Most meters will have an accuracy of ± 2%. Meters need to be installed in a straight length of pipe, 10 times the pipe diameter before and 5 times the pipe diameter after the meter.	iii iv v xiii	$200 to $2,500 (8")

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Monitor Rain gauges	Install rain gauges under the irrigator and one outside the irrigation area to monitor irrigation and rainfall	Ensure the rain gauges under the irrigator are representative of what is being applied. The gauges should have a cone shaped lid to prevent evaporative losses.	hardware stores	$40 - $200
Monitor Soil moisture Own equipment	Maintain soil moisture between stress point and field capacity to ensure growth is not limited. The most efficient and practical system is to irrigate when soil is 2 – 3% above the stress point and stop when soil is 2 – 3% below field capacity. This allows maximum utilisation of rainfall. This can not be achieved without monitoring. Measuring soil moisture provides information to determine when to irrigate and how much water to apply	Continuous readings (datalogging system) give the greatest level of accuracy. This should be combined with observing the effect of various irrigation / rainfall events on plant performance. Datalogger systems can be linked to telemetry or automatic control systems.		$260 - $6,000 + Depending on accuracy and technology used.
Monitor Soil moisture Weekly service	Monitoring soil moisture levels and utilising the information to schedule the irrigator can provide significant savings.	Companies providing soil moisture monitoring services	i vi xiv	$30/wk/site
The feel method	A simple, inexpensive method to determine when to irrigate.	It is subjective and should involve a number of samples in a paddock to have confidence in findings. This system requires experience to understand findings. The results give no measure of the amount of water in the soil or the volume of irrigation required. Often soil moisture in the crop root zone is not measured.	Farmer	Free

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Tensiometers General information	An inexpensive soil moisture monitoring system. They are not affected by osmotic potential of the soil solution (ie salt concentration) however plant roots can be affected [17]. The tube requires refilling after a dry period. Can take 24 hours for an irrigation to soak soil to the deep of the ceramic tip . As a general rule a 1mm application will decrease the tensiometer reading by 1 centibar [18]. Avoid repeatedly standing close to the tensiometer to prevent soil compaction. Avoid damaging nearby plants as readings will not be representative of crop water use. If plants become diseased it may be necessary to reinstall the tensiometer. Measures soil water tension through vacuum pressure on the tip. As the soil around the tip dries, water moves out of the tip until the equilibrium is re-established between the tip and the soil. Thus a vacuum is created equivalent to the soil water potential. The soil water potential relates directly to the amount of energy the root uses to remove water from the soil, hence is a measure of plant stress rather than soil water content [20]	If the tip is in an area of limited root activity or looses contact with the soil you can get unrepresentative readings of crop soil moisture status [17]. Can only measure soil moisture in the immediate area of the tensiometer tip. Tend to be installed in permanent positions. Install midway between the irrigator and the limit of its throw, avoiding wet or dry spots. A shallow and deep tensiometer should be installed. The shallow tensiometer indicates when to start irrigating and the deep when to stop to avoid deep percolation losses [21]. Advisable to install a number of tensiometers across the farm to account for topography, soil type and climatic differences. If irrigation cycle takes more than 3 days it is recommended that there are tensiometers installed at both early and late cycle periods as application rate may need adjustment [18]. Mark clearly tensiometer sites so can find them in the mature crop.		
Irrometer Tensiometer	There are different tip types according to soil type. Can be equipped with a pressure transducer for data logging	Available in probe lengths of 150 – 1200mm	x xi xii	\$260 - \$900

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Soil spec tensiometer	Tubes with a rubber cap are installed at desired monitoring sites. A portable electronic monitor is used to take tensiometer readings. Convenient for properties with a large number of monitoring sites. Must allow time for re-equilibration after installing needle at each site [18].	To maintain same size air bubble for each reading usually will need to read tube and top up with water daily [18].	xi xii xiii	$1,350
Capacitance Sensor	These sensors use electrical capacitance to measure soil moisture. Originally they were connected to a data logger for continuous monitoring but now is also available in a portable version. EnviroSCAN and Diviner are two products.	It is imperative that any soil moisture monitoring equipment is placed in a representative part of the paddock and that the installation does not disturb the surrounding soil as that will change the water holding characteristics of the soil being monitored.	vi xiv	$4,500 +

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Time Domain Transmission	The Aquaflex product uses this principle. Measures the dielectric constant of soil to find its volumetric water content. The sensors measure the signal oscillation frequency, which is related to the soil dielectric constant. The signal gives a good indication of the soil moisture status [20]. Temperature is also measured. It can be linked to a datalogger, (with or without telemetry options) or spot read using a lap or palmtop. Sensors measure soil moisture over a 3m length and cylindrical 6 litre volume of soil. As soil moisture is not uniform this method gives spatial averaging to readings increasing the accuracy.	Sensor cable can be expected to last approx 10 years. Sensor tape is laid in the paddock and a long data cable connected between the tape and battery box. This allows the tape to be laid in the paddock (giving representative readings of the crop) and the battery box attached to a fence post for protection. To minimise pugging damage over the top sensor it can be laid at 100mm depth. Like all monitoring systems installation is critical and soil is re-laid over cable as close to the original configuration as possible. In arable / vegetable crops remove the cable pre cultivation and relaying at planting.	ix x xi xii	$1,350 +

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Avoid irrigating in windy conditions	Although this is not always possible if the system does not have extra capacity. Not irrigating in windy conditions may lead to reduced crop growth. Also windy periods can last for days. Windy conditions require greater application rates. Irrigation losses can be minimised by increasing the surface roughness of paddocks e.g. by leaving organic residue on the soil surface or not cultivating soil finely.	Operating at lower pressure can increase droplet size and reduce losses, but need to monitor application rates to avoid run-off. Using drop tubes on centre-pivots and travelling irrigators' places the water closer to plants and reduces distortion and losses. Growing shelterbelts can reduce wind influence but they must be designed to filter the wind not block it or get turbulence and damage. Shelterbelts have to be sighted so as not to interfere with the irrigators' path of application. They can harbour insects and reduce the productive pasture area. They provide shelter and shade to cows. In windy conditions lane spacing is reduced and application rates can be decreased to improve distribution. Evaporation rates will be higher. Systems discharging water close to the ground are less affected by wind e.g. centre-pivots or booms with drop tubes, long laterals, k-lines or micro-sprinklers	Farmer	Zero
Irrigation when required on a little and often basis	This may mean running the irrigator at higher speeds and two shifts per day (consideration of time component, labour availability is necessary) or running two irrigators covering half the area each, so applying half the water volume each [23], or changing nozzle sizes.	Light soil types require low application depths, some sprinkler irrigators can not achieve this. Short cycle systems need to be incorporated into the system design.	Farmer	Zero

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Irrigating at night if possible	Advantage of reduced evaporation losses and possibly night-rate electricity tariffs.	Most systems can not supply sufficient water to operate only at night. Maybe possible in wet seasons and during shoulder seasons to utilise night application for maximum advantage.	Farmer	Zero
Reduce peak load	Turning the irrigator off during milking to reduce peak load tariff charges can reduce line charges. To do this a time of use meter is needed.	Additional labour may be required. Will waste some water as the pressure in the line falls and builds up again. Starting the pump and motors puts load on them even with soft starts and VSD's adding extra wear and tear. The majority of irrigation systems are designed to operate for 20 - 22 hours per day, stopping for milking will upset the irrigation application pattern and may reduce grass growth.	Farmer	Zero

Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:

1. Consider substituting lower water demand crops in the cropping mix; spring wheat uses more water than winter wheat; spring barley uses more water than maize.
2. Stagger planting dates so peak demand for water is spread. Peak water usage will occur when leaf area is at its' maximum.
3. Reduce the irrigation area to allow the irrigation applied to match the full irrigation requirement. In this system the highest net return crops are irrigated and low value crops revert to dryland cropping with the associated adjustment in other inputs e.g. fertiliser and herbicides. Crops would usually be irrigated before pasture.

4. Retain crop residues on the soil surface where possible to act as mulch. This reduces evaporation and improves infiltration and rainfall utilisation. Reduced cultivation has been shown to save 30mm of irrigation [12].
5. Monitor soil moisture levels, starting irrigation early in the season, maintaining high soil moisture levels but avoiding percolation drainage and utilising rainfall where possible. Monitoring soil moisture levels is essential to provide direct quantitative information on how much water to apply and when to apply it. For crops, the last irrigation should be applied so that the readily available soil moisture is used when each crop achieves maturity [21].

Sources of information and manufacturers:

Company Reference	Manufacturer / Service Company	Phone Number	Website	Location
i	Hydro-Services Ltd	03 341 0970	hydro@caverock.net.nz	National
ii	Environment Canterbury	0800 324 636	www.ecan.govt.nz	Canterbury
iii	Netafim NZ (water meters)	09 256 2551	www.netafim.com	National
iv	Deeco Services Ltd	0800 433 326	www.deeco.co.nz	National
v	Prosol (water meters)	09 414 1028	www.prosol.co.nz	National
vi	AgriLINK New Zealand Ltd	09 237 1273	www.agrilink.co.nz	Franklin/ Auckland
vii	T-L Pivot and Linear N.Z. Ltd	0800 8569 587		Canterbury
viii	Rainer Irrigation Ltd	03 308 1593		Canterbury
ix	Scott Technical Instruments	03 374 2101	www.scottech.net	National

Company Reference	Manufacturer / Service Company	Phone Number	Website	Location
x	Water Control Solutions	03 349 2605	www.wcsolutions.co.nz	National
xi	Pyne Gould Guinness Irrigation & Pumping Ltd	0800 TO IRRIGATE	www.pgg.co.nz	National
xii	Water Dynamics Ltd	0508 477 422	www.waterdynamics.co.nz	National
xiii	Fruitfed Supplies Ltd	09 571 5913	www.fruitfed.co.nz	National
xiv	Fruition Horticulture - Greg Dryden (Nelson) - Todd Whiffen (HB)	03 539 4961 06 870 4850	www.fruition.net.nz	National

4.1.2 Irrigation System

For optimum irrigation efficiency the system needs to be designed to match the maximum evaporative demand of the crop and allows variation in the depth of water applied.

Measures for energy savings	**Comments, advantages and disadvantages**	**Factors to be aware of**	**Companies**	**Investment**
Improve irrigation uniformity	Improving irrigation uniformity reduces the mean application depth applied to ensure an area is fully irrigated. For example improving distribution uniformity from 70% to 90% will reduce water and energy use by 30%, or alternatively allow 30% more area to be irrigated [24].	Choose the most appropriate system at the design phase, as changing systems once installed is not usually economic. Soils vary across paddocks so a compromise is usually required. It may be possible to irrigate different soil types separately but often this is impractical. Auditing systems can show inefficiencies in the design and/or operation of the system. Irrigators can audit their own system or contract the services of company specialists.	iii iv vii vii ix	audit $1,000 +
System maintenance	Pre-season maintenance including replacing worn sprinklers and nozzles, and removing blockages in pipes and emitters allows system to run more efficiently during the season. Check well performance by measuring static water level and specific capacity (pumping rate / drawdown) and compare the results with previous measurements such as at drilling [21]. During the season monitoring pumps, cleaning blocked emitters and detecting leaks improves efficiency.	Maintenance pre-season reduces risk of having non-operational periods during critical irrigation application times which could lead to low soil moisture levels and reduced grass growth.		Low - medium

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Variable speed drives	Reduces wear and tear on pump and motors by evening out the load. Particularly useful where changes in elevation affects hydrant pressure. Avoids the need to use energy dissipating devices like pressure reducing valves.	May be able to reduce motor size and lower capital investment.	viii	Medium - High 15kW unit $8,000 – $10,000. Soft start controller $2,000 - $3,000.
Use energy efficient pumps and motors	Highest pump efficiency occurs when operating at the highest efficiency flow and selecting the pump brand and model matching irrigation requirements.	Differences in efficiencies between brands can be small.		
Use appropriately sized pumps, pipes and irrigators	Match irrigator number and size to pump capacity	May require additional labour and capital inputs to maximise system capacity if extra irrigators are required		
System design	Minimise head loss in rising columns, and mainlines by appropriate sizing Tight bends and sharp corners restrict flow resulting in higher pressure losses [25]. Over-sized pumps results in excessive pressure within the irrigation system pipes which can require the gate valves to be partially closed. This means high electricity usage for the volume of water pumped.	Correct pipe diameter sizing of rising column and headwork's reduces friction loss and pressure loss so smaller motors can be used and less electricity. Replacing rising columns will only occur if it is damaged, corroded or pressure loss is excessive – a high investment option. Headwork and mainline replacement is generally uneconomic until redesigning the system.		

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Use efficient irrigators	Centre-pivot, linear move types and fixed-boom linear type irrigators are the most efficient, followed by rotorainers and solid set irrigators, then travelling guns, followed by side-rolls and K-lines.			
Centre-pivot	High initial cost, but short return interval (1 – 3 days) Energy requirement can be high Uniformity of application better than most other systems. Can operate at 90% efficiency if less than 500m long [27]	Fitting low pressure spray nozzles can save energy but may require higher application rates to be used leading to lower application efficiency and longer operating times, so may not save significant amounts of energy [21] Used with accurate soil moisture measuring systems they can achieve very efficient irrigation applications. Accurate soil moisture measuring can give confidence to turn irrigators off without sacrificing crop growth rates.	i ii iii iv v vi	
Rotorainer, linear and rotary booms	Lower capital cost than centre-pivot. Return interval can be 7 – 15 days. Application rates can be low thereby avoiding ponding. Can operate at 75% efficiency [27]	Strong wind causes rotation and travel speed to slow therefore application rates increase. In calm conditions uniformity is generally good if the boom is operated at the correct pressure and correct sized nozzles are used. Linear booms suit rectangular shaped paddocks.	i ii iii iv v vi	

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of	Companies	Investment
Self-propelled gun sprinkler hard and soft hose	Subject to interference by wind. Operating at closer lane spacings, using low angle guns and operating at the correct gun pressure can reduce the impact of wind interference. Circular application pattern. Larger diameter hose, shorter hose, larger hydrants and fittings reduce pressure losses.	Irrigator may not have power to pull larger diameter hoses. Changing pipe diameters is a medium to high investment.	iii iv v vi	
Siderolls and Hand-shift-pipes	Are moved manually down the paddock Application rates are low. Providing the same nozzles are used and they are not worn, they can achieve uniform distribution.	Low capital investment Laterals need to be shifted at the recommended spacing.	ii iv v vi	
K-line	Lowest capital investment. Requires manual moving down the paddock Application rates are very low seldom leading to surface ponding. Systems are often designed to operate 24 hours a day and tend to have long rotation times. Efficiency often as low as 40% 27	Often spacings are set too far apart to achieve uniform application.	ii iv	

Sources of information and manufacturers:

Company Reference	Manufacturer / Service Company	Phone Number	Website	Location
i	T-L Pivot and Linear N.Z. Ltd	0800 8569 587		Canterbury
ii	Rainer Irrigation Ltd	03 308 1593	www.briggs.co.nz	Canterbury
iii	Pyne Gould Guinness Irrigation and Pumping Ltd	0800 TO IRRIGATE	www.pgg.co.nz	National
iv	Water Dynamics Ltd	021 879 957	www.waterdynamics.co.nz	National
v	Plains Irrigators Ltd	03 307 2027	www.plainsirrigators.co.nz	Canterbury
vi	Bosch Irrigation Ltd	0800 500 424		Canterbury
vii	AgriLINK New Zealand Ltd	09 237 1273	www.agrilink.co.nz	National
viii	Danfoss – (Varivac)	0800 326 3677, 09 259 2519	www.danfoss.co.nz	National
ix	Page Bloomer Associates Ltd	021 356 801	www.pagebloomer.co.nz	National

4.2 Cultivation

Cultivating soil not only requires large amounts of energy it also results in soil carbon loss from soil organic matter in the form of carbon dioxide. The amount of carbon dioxide loss varies with tillage type. A Minnesota study [22] showed that after 19 days CO_2 losses from different tillage practices were:

9,108 kg/ha mouldboard ploughing,
4,739 kg/ha mouldboard plus two disk harrow passes (secondary tillage reduces CO_2 loss compared to ploughing alone)
1,825 kg/ha tilling no-till plots

It is this loss of carbon, or organic matter, which has many follow on implications requiring greater energy use for cultivation and irrigation management.

4.2.1 Tractor Setup and Driving

There are numerous measures available to reduce fuel use in conventional full cultivation systems, as well as minimum tillage operations. These have been well documented by the Ministry of Energy's Tractor Facts Manual [47] in about the early 1980's, and revolve around driver education and awareness. The manual includes information on:

Tractor Selection
- Traction
  - Tyre size and type (radial and cross ply)
  - Dual tyres
  - Tread pattern
  - Crawler tractors.
  - Four and two wheel drive tractors
- Tractor Size

Tractor and Implement Operation
- Fuel Consumption Records
- Engine Speed and Gear Selection
- Traction Efficiency
- Hydraulics
- Tyre Inflation Pressure
- Power-Take-Off Operation
- Idling

Implement Selection
- Matching of Tractor and Implement
- Hydraulic 3-Point Linkage Equipment
- Power-Take-Off Equipment

Tractor and Machinery Maintenance

Field Efficiency
- Farm layout
- Travel patterns
- Large paddocks
- Implement type, for example reversible ploughs

There are still limited copies of the Tractor Facts Manual available from Graeme Martin at Lincoln University. The information has also been summarised in the report Seven Case Study Farms: Total Energy & Carbon Indicators for New Zealand Arable and Outdoor Vegetable Production [7]. At the time it was estimated that 30% fuel savings could be achieved by setting up and driving the tractor efficiently. With general improvements in the industry over the past 20 years that figure is now probably around 15% savings, although there is likely to be large variations in that across the industry.

Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:

1. Utilising weather forecasts and knowledge of current soil status plus crop requirements to determine which cultivation tools to use, how many passes to make etc. An easy to use and accurate decision support tool is required for each soil type cultivated. This would lead to less passes being made across a paddock and better utilisation of those passes.
2. Determining soil quality and soil health with accurate, easy to use and interpret, decision support tools.
3. Greater understanding by growers of the role of organic matter in the soil system and the benefits derived from having it at reasonable levels. Knowledge of how to improve organic matter levels economically especially when at a degraded level and understanding the impact of actions taken e.g. planting different cover crops, using different cultivation tools etc.
4. Greater understanding of the impacts of soil losses on the production system (degradation and erosion). Many consider the soil to be an infinite resource and struggle to understand the small losses occurring until it is a major problem; little changes are too difficult to pick up easily. A system that quickly and dramatically shows the changes occurring from one season to the next with technical back up that assists growers to confidently make changes necessary to halt and reduce the degradation would be very beneficial and ultimately save energy in many ways (decreased fuel usage, reduced irrigation, reduced fertiliser and agrichemical inputs etc)

5. Limited number of service industry personnel with technically sound skills and knowledge of sustainable cultivation management, including the interactions between different components of the system and effect on yield and profit.
6. A better definition of the required seedbed. Crop & Food have a study underway looking at tilth requirements [29].

4.2.2 Subsoiling

Subsoiling, which is a high energy demanding operation, is a short term solution to soil compaction problems. If management practices that caused the compaction continue even more severe compaction can easily redevelop.

The best way to minimise compaction, and a double effect on energy use, is to limit the number of field operations. When field operations do occur, limit wheel traffic to the same rows as much as possible. Other beneficial options include staying off wet soils, rotating crops, adding organic matter in the form of animal waste or cover crops, till soil deeper in dry years when tillage is needed and adopt conservation practices which reduce tillage (see NebGuide NF 96-258 Subsoiling and G89-896 Management Strategies to Minimize and Reduce Soil Compaction).

Comments, advantages and disadvantages	**Factors to be aware of**
Timing is critical for effective subsoiling. Achieving good shattering is necessary. Minimise compaction to reduce need for subsoiling. Breaking up pans increases available soil area for roots to explore and for nutrient uptake and moisture availability.	Avoid recompacting soil after subsoiling. Cultivating soil in wet conditions increases compaction. Driving trucks on paddocks during harvesting compacts soil – road tyres are not designed for low soil compaction

Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:

1. Determining when the soil in a paddock is ready for subsoiling – not too wet or too dry. An easy to use and accurate tool is required for each soil type cultivated
2. Determining when soils are compacting or compacted and suitable methods for breaking compaction – an easy to use and accurate tool is required for each soil type cultivated
3. Limited number of service industry personnel with technically sound skills and knowledge in subsoiling.

Sources of information and manufacturers:

Manufacturer / Service Company / Information Source	**Website**	**Location**
Foundation for Arable Research Arable Extra No. 33 August 2000. Soil Compaction	www.far.org.nz	New Zealand
Nebraska Guides on soil compaction – University of Nebraska, Lincoln	http://ianrpubs.unl.edu/soil/nf258.htm	USA
Caterpillar – information on causes of compaction and use of tracks to reduce compaction	www.cat.com/industry_solutions/agriculture	
Grains Research and Development Corporation,	www.grdc.com.au	Australia

Useful books and reports:

Soil Management Guidelines for Sustainable Cropping, T.G. Shepherd, C.W. Ross, L.R. Basher, S. Saggar. Manaaki Whenua Press, Landcare Research, 2000. http://www.mwpress.co.nz/store/viewItem.asp?idProduct=326

4.2.3 Reduced tillage systems

Comments, advantages and disadvantages	Factors to be aware of and knowledge gaps
Can reduce inputs especially fuel and labour and improve timeliness of operations. Reduced tillage is not suitable for all soils or all cropping systems. It is not suitable for root crops e.g. carrots - requiring harvesting of even, straight roots. It is not suitable for potatoes, as they require soil to be brought up around the tubers as they grow.	Planning is critical for success. There are fewer opportunities for fixing mistakes. If something goes wrong then it may be necessary to revert to full cultivation to fix it. A grower may need access to full cultivation equipment as well as reduced tillage equipment. The paddock needs to be in "reduced-tillage-ready" state, that is it needs to be level, not require remedial drainage or high levels of nutrients to be incorporated. If any of these factors are identified they need to be addressed prior to starting a reduced tillage programme.
Reduced tillage systems only allow for minimal contouring of paddocks during cultivation process.	"Why is contouring necessary?" Management should seek to avoid contouring. In some cases, cultivation and contouring is needed to suit the drill or the planter being used; planter design overcomes this.
Method of handling stubble residue is important. Having the machinery and skills to incorporate it in one pass achieves the greatest benefit. Adding organic matter to soil improves soil structure, decreases soil bulk density, and binds particles as aggregates so there is less damage by wheel traffic. There is an increase in soil nutrient availability for crop growth. Glyn Francis (CFR, Lincoln) studied residue management under a range of management practices. He found that leaving residues on the surface was the best way to increase soil OM levels [28].	Higher residue levels can increase pest and disease levels especially slug populations and diseases associated with residue breakdown or carryover of spores from one season to the next. Conventional tillage would bury residue and any associated spores. Some crops e.g. cucurbits require surface residue to be cleared using row-cleaner attachments in-front of the planter. Others such as maize can be drilled into some residue. Some suggestion that residues may reduce herbicide efficacy [30] so requirements may increase. LandWISE trials suggest the mulch effect can reduce need for herbicides, particularly in heavier maize residue situations [28].

Comments, advantages and disadvantages	Factors to be aware of and knowledge gaps
Less passes across the paddock thereby reducing compaction, fuel and time inputs [19] Planting times can be optimised.	
Conserves soil structure and aeration and may improve infiltration and drainage. Earthworm populations and biological activity is greater than under conventional tillage systems due to higher residue levels. Soil organic matter levels improve compared to conventional tillage systems.	
Surface residue can reduce topsoil erosion from wind blow and raindrop redistribution or raindrop impact.	
Cover crop residues in some situations can be used as weed suppressing mulches and to conserve moisture.	Cover crops can have possible allopathic effects on subsequent cash crop [22]. This has been observed in LandWISE trials in Gisborne. It is necessary to allow time for the system to 'resettle' after incorporating fresh residues, 2 week minimum.
Incorporating fertilisers and pesticides can be more difficult. Lime needs to be applied early. Fertiliser programmes may need to be altered to account for reduced ability to incorporate fertiliser and the reduced number of passes.	Increased nitrogen applications may be required as residues breakdown, although a fallow period of 4-6 weeks may overcome this [28]. LandWISE has begun a trial, banding fertiliser in exactly the same place crop on crop. Trial is investigating nitrogen and phosphate, and monitoring those plus pH and EC in order to identify problems [28].

Comments, advantages and disadvantages	Factors to be aware of and knowledge gaps
Increased reliance on agrichemicals for weed and pest control. Often cultural, physical and alternative methods of control are impractical. Soil active agrichemicals can be more difficult to use, as they often require incorporation for activation. LandWISE recommends a 4 – 6 week fallow period following the previous crop to ensure good residue breakdown. This can create timing issues for planting.	Cultivation reduces insect pests, brings them to the surface for birds and disturbs their habitat. Cultivation also buries weed seeds and residues from the previous crop, which could harbour diseases. Likewise cultivation can also bring weed seeds to the surface. Knowledge of crop thresholds and critical weed free periods to avoid yield penalties are essential. Knowledge of insect and disease lifecycles, the ability to identify lifecycle stages and the time and skills to regularly scout paddocks for symptoms of pest presence and management plans to action findings are essential. Knowledge of appropriate successful control strategies for each insect, disease and weed pest are critical for successful management of reduced tillage crops.
These systems require new skills, management systems and machinery to operate at their optimum. Suitable equipment is available from Europe and USA. Used equipment not excessively priced, and high dollar makes importing easier.	Can get poor and uneven crop growth reducing crop yield. Possible causes are poor residue removal, uneven seed depth placement, planter unsuitable for conditions, wet / cold soils, and management skills. Undulating paddocks can result in uneven seed depth placement and therefore uneven germination.

<u>Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:</u>

1. Management knowledge and skills for these systems
2. Availability of suitable machinery to be purchased off the shelf, especially planters, transplanters and side-dressing units
3. May require the purchase of new machinery. There is a limited market for second-hand tillage equipment
4. A small number of contractors available in each district with appropriate machinery and skills
5. Grower confidence that crop profitability will not be reduced compared to current level of achievement

6. Fear of change
7. The memory of negative past experiences with reduced tillage systems and poor crop yields during development of these systems [26]
8. Confidence to identify reduced-tillage ready paddocks and for those not suitable. The ability (time, resources, skills) to address the issues for the unsuitable paddock to make the transition
9. Surface compaction of topsoil by stock can affect achievement of uniform planting depth and planter performance
10. Can change crop rotation patterns and crop mix grown
11. Root and tuber crops not suitable for reduced tillage systems. Growing these crops would require a return to conventional tillage for that crop
12. Limited number of service industry personnel with technically sound skills and knowledge in reduced tillage management
13. Knowledge of soil component interactions and the soil web has limitations, especially in relation to crop production.

Sources of information and manufacturers:

Manufacturer / Service Company / Information Source	**Website**	**Location**
Yetter	www.yetterco.com	USA
LandWISE Incorporated	www.landwise.org.nz	Hawkes Bay Gisborne Manawatu
Appropriate Technology Transfer for Rural Areas (ATTRA) Sustainable Soil Management, Sustainable Soil Mgmt - Soil Systems Guide	http://attra.ncat.org/attra-pub/PDF/soilmgmt.pdf	USA
Purdue University information on crops and tillage	www.agry.purdue.edu/ext/corn/dbase	USA

Manufacturer / Service Company / Information Source	Website	Location
Alberta Reduced Tillage Linkages Program	www.reducedtillage.ca	Canada
The Conservation Technology Information Centre	www.ctic.purdue.edu	USA
CB Norwood Distributors	http://www.norwood.co.nz/	NZ
Simba International	http://www.simba.co.uk/	UK
Core4	http://www.ctic.purdue.edu/Core4/Core4Main.html	USA
AEA: Agricultural Engineers Association	http://www.aea.uk.com/index.htm	UK
Scottish SAC	http://www1.sac.ac.uk/info/External/About/publicns/TN/Tn553.pdf	Scotland
HDRA the Organic Organisation	http://www.hdra.org.uk/organicweeds/downloads/mintill.pdf	UK

Useful books and reports:

Management of Erosion Risk on Arable Soils: A Review. Report U00/49. Prepared for Environment Canterbury. C.W. Ross, L.R. Basher, C.J. Baker

Patterson, D.E. (1982) The performance of alternative cultivation systems In The Agricultural Engineer Vol 37: No.1. Spring 1982. Journal and proceedings of the Institution of Agricultural Engineers. Pp8-12.

Also as Patterson, D.E., Chamen, W.C.T., Richardson, C.D. Long term experiments with tillage systems to improve the economy of cultivations for cereals. Jour Ag Eng Research. 1980, 25,1,1-35.

4.2.4 Precision Agriculture

Precision agriculture integrates a suite of technologies that retain the benefits of large-scale mechanisation, but recognises local variation. By using satellite data to determine soil conditions and plant development, these technologies can lower the production cost by fine-tuning seeding, fertiliser, chemical and water use. Not only can production costs be lowered, but there is much more management information available, improving the quality and quantity of production and reducing detrimental environmental impacts [31]. It is doing the right thing, at the right time, in the right place with the least impact on the environment.

Comments, advantages and disadvantages	Factors to be aware of and gaps in knowledge	Companies	Investment
There are 3 levels: 1. Site Specific Farming – identify spatial variability of the land and crop production processes 2. Smart Farming – utilise site specific farming for increased knowledge of crops and production system 3. Precision Agriculture – precise control of inputs in response to spatial variation of land and crop production process.	Timing of cultural practices is very important. Fertility is variable within paddocks – to maximise production there needs to be the ability to identify variations in a timely way and in response adjust inputs. This tends to be expensive to achieve. Tools for monitoring and application systems need to be less costly, less complex and more understandable to be of value.	i ii iii iv	Medium - High

Comments, advantages and disadvantages	Factors to be aware of and gaps in knowledge
To maximise the opportunity the system needs to create yield maps and be able to interpret the data collected. Yield map interpretation is a skill, and requires considerable knowledge of the paddock and growing conditions for accuracy. Need to have a number of years of yield mapping data of a given paddock (probably at least 5 years) to be confident of correlations identified.	Often involves monitoring throughout the season. Results are affected by calibration accuracy of sensors and timeliness of recordings. Greatest information will be obtained where a grower can overlay other maps such as topography, drainage, germination dates, pest and disease infestations etc. Considerable time in monitoring paddocks would be required to obtain this information and create appropriate maps. There can be problems with yield maps being used to make decisions about crop management. The yield map relates to a previous crop, season, climate and management. Current crop is entirely different. Peter Stone (CSIRO WA) investigated this and found there was little if any correlation between the yield information and the 'right decision' this time [28].
Meeting quality standards of the customer is an economic necessity. The ability to identify variable factors that influence yield and quality allows the manager to manipulate the production area to maximise returns and minimise inputs e.g. manipulating yield and protein content of a wheat crop using variable rates of nitrogen, selective application of inputs for greatest yield and profit benefit. Product traceability is an increasing issue. Activity mapping associated with application of agrichemicals allows instant recording.	Knowledge of interactions that affect crop response to an input is critical and then identifying those areas within a paddock or farm and managing them appropriately can be difficult to achieve in practice. For example soil type has an impact on nitrogen response. Improved understanding of the relationships and interactions between inputs and outputs to the production system is required for targeted management to be successful.

Sources of information and manufacturers:

Reference	Manufacturer / Service Company / Information Source	Website	Location
i	Trimble	www.trimble.com	National
ii	John Deere	www.deere.com/en_AU/equipment/ag/ams/	National

Reference	Manufacturer / Service Company / Information Source	Website	Location
iii	Grains Research and Development Corporation, (Includes lists of manufacturers and links to further information)	www.grdc.com.au	Australia
iv	Proceedings of the Workshop In Precision Tools for Improving Land Management, 2001	http://www.massey.ac.nz/~flrc/	Massey University

Popular article on GPS (1/11/04)
http://www.country-wide.co.nz/article/2733.html

Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:

1. Availability of hardware and costs
2. Low gross margins on broad acre crops
3. Limited access to specialist users of data management and analysis tools
4. Reliable yield monitoring systems
5. Presence of closed proprietary hardware systems and compatibility problems with different equipment
6. Cost of soil testing
7. Can be a loss of data capture and interpretation between sectors of the industry e.g. growers and packhouses / processors – seamless systems are required
8. Limited number of service industry personnel with technically sound skills and knowledge in precision agriculture.

4.3 Strip-tillage

Strip-tillage limits the planting and tillage operations to a strip that is less than one-third of the distance between rows; the area between is left untilled with a protective cover of crop residue on the surface for erosion control.

LandWISE strip-tillage trials in 2004/05 showed that ground preparation took just 40% of the time compared to conventional full tillage.

There is limited but increasing adoption of strip-tillage in NZ. Hawke's Bay is the most advanced, followed by Gisborne, with strong interest from the Waikato and Manawatu-Wanganui. In 2004/05 about 11% of sweet corn in the Hawkes Bay was produced using strip-tillage with a slight yield advantage. In 2002 Hawke's Bay had 2,795 ha in squash, 42% of the national crop, which is now mainly produced using strip tillage, particularly on wind erodible soils. Estimates suggest 30% of the national crop is produced under strip tillage in 2004/05 [28].

Comments, advantages and disadvantages	**Factors to be aware of**
Small strips of the bed are tilled only and seeds placed in these strips. Not suitable for small seeds.	A second pass with a roller can crush clods and create a suitable seedbed [32].
Allows for some incorporation of fertiliser during cultivation, therefore nutrients can be supplied near to the developing plant roots.	Presence of residue material can alter nitrogen requirements due to nitrogen mobilisation
Growing cover crops especially vetch, rye corn or phacelia have been found to be beneficial in Oregon for suppressing weeds and decreasing erosion, nitrate leaching and compaction. They also improve nutrient cycling, especially nitrogen fixation, enhancing phosphate availability (Vetches are leguminous), buffering pH levels, and providing an energy and nutrient source for soil biota [32, 22].	Cover crops can keep soil wet in spring delaying the start of tillage. This can be a problem for scheduling planting and harvesting. An extra pass is required to spray or till cover crops before strip tilling. Additional cost of cover crop seed, labour and equipment for seeding. Careful selection of the cover crop is required to avoid increasing pest levels and self-set issues in following crop.

Comments, advantages and disadvantages	Factors to be aware of
LandWISE trials showed strip tillage essentially eliminates wind erosion, even on extremely light (ash / pumice) soils [28].	Wind erosion prevention stops crop damage, a key reason for technology adoption in Hawke's Bay [28].

<u>Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:</u>

1. Suited to very few crops and even fewer crop to crop rotations
2. Management knowledge and skills for these systems
3. Availability of suitable machinery to be purchased off the shelf, especially planters, transplanters and side-dressing units. Growers often have to build their own machinery or import but may not have reliable backup for spare parts, setup service etc.
4. Only a small number of contractors, if any, are available in each district with equipment and skills
5. Grower confidence that crop profitability will not be reduced compared to current levels
6. Fear of change
7. Confidence to identify reduced-tillage ready paddocks and for those not suitable the ability (time, resources, skills) to address the issues for the paddock to make the transition
8. Surface compaction of topsoil by stock can affect achievement of uniform planting depth and planter performance
9. Can require change to crop rotation patterns and crop mix grown
10. Does not suit closely spaced row crops as these would require the cultivation of large portions of paddock anyway e.g. onions
11. Limited number of service industry personnel with technically sound skills and knowledge in strip tillage management
12. Knowledge of maximising the use of cover crops in the system
13. Management of weed control is critical and options available can be limited. Timing is critical.

Sources of information and manufacturers:

Manufacturer / Service Company / Information Source	Website	Location
LandWISE conference proceedings 2002 - 2005	www.landwise.org.nz	Hawkes Bay Gisborne Manawatu
Oregon State University –Strip-tillage and cover crop systems for vegetable production	http://ifs.orst.edu/pubs/StripTillVegPro.html	USA
Accurate Instruments (NZ) Ltd. (Auto steer, up to $18,000)	http://www.accurate.net.nz/mc11/vinealig.htm	National
Case-DMI	http://www.caseih.co.nz/ or www.caseih.com or http://www.dmifarm.com/	
Agronomy Journal	http://agron.scijournals.org/cgi/content/full/94/3/532	
Farm Industry News	http://farmindustrynews.com/mag/farming_set_strip_till/	

4.4 Controlled trafficking

Controlled Traffic Farming (CTF) depends on the ability to return operation after operation to the same path. Mechanisms that allow growers to achieve that goal range from the simple to the complex, the inexpensive to the more costly, mechanical to the electronic.

There is only minimal adoption of CTF in NZ – Opou is the only known farm to fully convert, a couple of others in the North Island are taking the first steps [28]. Adoption in Australia is reported at 1 – 2 million ha [33].

In Australia the controlled traffic system has shown a reduction of up to 40 – 50% in fuel use, by keeping all wheel traffic to the same tracks and reducing soil compaction in the cropping area. This means when undertaking cultivation there is a reduction in draft requirements and increased traction efficiency. In heavy clay soils the energy required to produce traction by the tractor is 25% of total tractor draft requirements [34]. Wheel traffic across the soil causes compaction and a single pass can reduce yield in the main wheel track by 30%, with multiply passes reducing yield by up to 80% [35]. This report went on to say that in conventional tillage systems 80-100% of a paddock suffers at least one wheel pass each season.

Another benefit of controlled traffic farming is the reduction of 5 – 8% in working overlap especially when spraying. Common practice is to overlap to avoid missed treatment areas [36]. Australian reports of 10% reduction in overlap are common. This may be high for some operations in vegetable cropping in NZ. The energy implications are considerable, as it involves spray and fertiliser over application as well as direct fuel use [28]; however it is limited to certain crop rotations and continuous cropping systems.

Comments, advantages and disadvantages	Factors to be aware of
Reduced cultivation reduces tractor work requirements. Plus in many cases there are more available work hours (no need to stop if it is dark), which means less tractors are needed [28]. Early indications from Gisborne are that power per tine/coulter etc is very significantly reduced. This allows higher work rates or smaller engines [28]. Report from Willamette Valley show cased property where a change to auto-steer and strip tillage allowed a 50% increase in cropped area, yet reduced tractor requirements by 1/3 i.e. 4 tractors do 50% more crop area than 6 did previously [28, 37]	Queensland research showed up to 50% reduction in fuel use when tramlines were not tilled compared to tilled soil in clay soils [38]
Tentative data from Gisborne [39] indicates a probable fuel saving of 30% resulting from a change to CTF. However difficult to assess because the soil condition, especially moisture level, has such a marked effect, and different cropping was carried out. CTF systems avoid or minimise the excess fuel consumption relating to operations conducted on wet soils; • The tramline will carry vehicles in even very wet conditions, provided it was established when the soil was in a good, medium (to dry) moisture state. • Rolling resistance in minimised • Cultivation for remediation is minimised or eliminated	
In NZ, marker arms are considered normal practice, and CTF is generally linked to GPS guidance. Auto-steer and RTK GPS offers best opportunity, although it is perceived to be expensive [28].	There is very limited room for error: >56cm tires in <76cm inter-rows. High accuracy also offers other opportunities, like mechanical weeders, band spraying etc [28].

Comments, advantages and disadvantages	Factors to be aware of
The key to a successful system is matching machinery widths. This is difficult in mixed cropping and when contractors are integral to the industry.	CTF in process sector requires an industry wide initiative to capture benefits as harvesters and transporters are not farmer owned. Setting 'industry standard widths' would enable a planned adjustment to an integrated industry. Suggestion is to focuses on 3m and 2m wheel spacings, based on 6 x 76cm row base. Allows larger equipment such as primary cultivation tractors (if required) and harvesters to fit to 3m, and smaller equipment to fit to 2 m wheel track [28].
Reduction in overlaps in operations can lead to significant cost savings, especially in pesticide use.	
Untilled permanent tracks improve tractor performance. In Queensland they recorded reductions of up to 50% in fuel use, even with cultivation, through reduced draft (less compacted soils) and improved traction efficiency [34]. In Western Australia a 10% fuel saving was found when unripped tramlines were used for seeding and spraying operations, compared to machinery running on deep ripped soil [40].	Need to have wheel tracks matching equipment widths for sprayer, cultivators, drills and if possible harvester. Wheel widths need to match as well. May need to couple multiple units to one drawbar for efficiencies e.g. 3 spring tyne cultivators pulled behind one tractor covering 3 beds in one pass. This can be difficult to achieve and the required tractor power has to be considered. Weed control in wheel runs may be an issue.
Raised bed system can improve drainage and therefore crop health	Machinery modifications to suit raised bed can limit use of system
This season (2005/06) land under controlled traffic farming was able to be planted much earlier in spring. Early planting increases solar energy capture by the crop, which offers higher crop yields for the same inputs, thus an increase in tonnes produced per unit energy input [28].	

<u>Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:</u>

1. Limited application to continuous cropping of certain crop types. However, 80 – 90% of the benefits can be achieved by tramlining, which are commonly practiced [12].
2. Management and staff knowledge and skills in a very new technology
3. Availability of suitable machinery to be purchased off the shelf, especially units for raised bed systems. Often have to build own machinery or import, but may not have reliable backup for spare parts, setup service etc.
4. Perception of very high cost against unknown benefits
5. Only a small number of contractors, if any, are available in each district with equipment and skills
6. Grower confidence that crop profitability will not be reduced compared to current levels
7. Fear of change generally and in particular fear of technology redundancy if they do change
8. Limited number of service industry personnel with technically sound skills and knowledge in controlled traffic management
9. Management of weed control is important. Timing is critical
10. Lack of an 'industry standard' product or dominant technology
11. Fear of poor compatibility between competing systems, potentially used by co-operating organisations (farmer and contractor)
12. Satellite signal reliability at certain times of day, and availability particularly in hilly topography
13. Need for base stations with line of site or repeaters
14. Lack of pre-set axles and difficulty adjusting to specific spacing
15. Cost of adjusting whole fleet to standard wheel track(s)
16. Associated problems with warranties for equipment if operated outside standard specification

Sources of information and manufacturers:

Manufacturer / Service Company / Information Source	Website	Location
LandWISE Incorporated CTF Discussion Group	www.landwise.org.nz	Hawkes Bay Gisborne Manawatu
Grains Research and Development Corporation,	www.grdc.com.au	Australia
Nebraska Guides - Management Strategies to Minimise and Reduce Soil Compaction	www.ianrpubs.unl.edu/soil	University of Nebraska
Controlled Traffic Framing Solutions	www.ctfsolutions.com.au	Australia
Queensland DPI	http://www.dpi.qld.gov.au/fieldcrops/3166.html	
Managing maize production with tomorrow's technology, a MAF SFF Project	http://www.maf.govt.nz/sff/about-projects/arable/01187maize.htm	
Manufacturers		
AgLeader	www.agleader.com	
Beeline	www.beeline.ag	
Case IH	www.caseih.com	
Cultiva	www.cultiva.com	
IntegriNautics	www.integrinautics.com/agriculture.htm	

Manufacturer / Service Company / Information Source	**Website**	**Location**
John Deere	www.deere.com	
Outback	www.outbackguidance.com	
Raven	www.accuspray.com	
Satloc	www.satloc.com	
Terradox	www.terradox.com	
Trimble	www.trimble.com/gps/	

4.5 No-tillage

No-tillage is a crop production system in which the soil is left undisturbed from harvest to planting. At the time of planting, a narrow strip up to 1/3 as wide as the space between planted rows (strips may involve only residue disturbance or may include soil disturbance) is engaged by a specially equipped planter. Planting or drilling is accomplished using disc openers, coulter(s), row cleaners, in-row chisels, or roto-tillers. Weed control is accomplished primarily with crop protection products. Other common terms used to describe No-till include direct seeding, slot planting, zero-till, row-till, and slot-till (www.epa.gov/agriculture/ag101/cropglossary.html).

Over the years Farmers and Growers have been strongly encouraged to adopt some form of conservation tillage, primarily for long-term environmental reasons. However, the experience of many farmers of no-tillage suggests greater short-term risk, in the form of reduced seedling emergence or crop yield. For no-tillage peas, areas rose from 19% in 2003/04 to 37% in 2004/05. However, problems with sheep droppings getting in product have flagged warnings. Unless it can be shown (to the satisfaction of processor quality assurance personnel) that this is a manageable issue, the use of no-till for peas could be banned [28]. In 2002 there were 10,925 ha in peas, 78% of which was in Canterbury [3]. In most Canterbury situations sheep droppings would not cause a problem [12].

No-tillage Association members report up to 75% savings in fuel use compared to conventional tillage systems. Ploughing based cultivations can use 50 - 80 ℓ/ha diesel (up to 90 ℓ/ha have been used on degraded English cropping soils with low organic matter levels and poor soil structure), minimum tillage can use 30-50 ℓ/ha and no-tillage 15 – 20 ℓ/ha with the Cross-Slot No-till drills using an average of 19 – 20 ℓ/ha. No-tillage growers also report a saving in irrigation usage, often not applying the usual first irrigation for the season due to higher soil moisture levels [16].

Trials in South Australia showed over four seasons a reduction in fuel of 15 – 40% between conventional cultivation and no-tillage [41]. The Conservation Technology Information Centre (CTIC) in America suggests fuel usage drops from 53 ℓ/ha to 33 ℓ/ha when comparing conventional tillage with no-tillage. The actual fuel use will depend on the soils clay and moisture content and type of tillage operations being eliminated. CTIC report fuel use rates for moldboard ploughing of 50 ℓ/ha (5.3 gal/acre), chisel ploughing 31 ℓ/ha (3.3 gal/acre), and no-till 13 ℓ/ha (1.4 gal/acre) [42].

Comments, advantages and disadvantages	**Factors to be aware of**
Less passes across a paddock so a reduction in compaction, fuel and time inputs [19] Planting times can be optimised.	Planter must be sturdy to handle conditions, which can mean a larger horsepower tractor to pull it. Current commercial planters in NZ don't suit planting in beds for vegetables.
Does not create tillage pans	
Conserves soil structure and aeration and may improve infiltration and drainage. Earthworm populations and biological activity is greater than under conventional tillage systems due to higher residue levels. Soil organic matter levels improve compared to conventional tillage systems. Surface residue can reduce topsoil erosion from wind and raindrop redistribution or raindrop impact. Can allow cropping (stock feed) and regrassing of pastoral land that would be at risk of erosion in traditional cultivated systems.	Earthworm populations may not be higher according to FAR trials in Canterbury. Under certain conditions, no-till openers sealed channels and appeared to drown worm population [12]. Higher residue levels can increase pest and disease levels especially slug populations and diseases associated with residue breakdown. Slug baits are available for control.
Soil moisture levels in the seed zone are conserved. This can mean that a grower does not need to apply the first irrigation when seedlings are small and plant use of the applied water is low due to a large portion of water falling on bare soil [19]	
Incorporating fertilisers and pesticides can be difficult compared to conventional tillage. Lime needs to be applied early and increased nitrogen applications may be required as residues breakdown.	Fertiliser programmes may need to be altered to account for reduced ability to incorporate fertiliser and the reduced number of passes.
Increased reliance on agrichemicals for weed and pest control, which could lead to the development of herbicide resistant weed and pest species. Cultivation reduces insect pests by bring them to the surface for birds and disturbing their habitat. Cultivation also buries weed seeds and residues from the previous crop, which could harbour diseases.	Some crops e.g. cucurbits require surface residue to be cleared using row-cleaner attachments in front of the planter. Others such as maize can be drilled into some residue.

Comments, advantages and disadvantages	Factors to be aware of
These systems require new skills, management systems and machinery to operate at their optimum.	Can get poor and uneven crop growth reducing crop yield. Possible causes are poor residue removal, uneven seed depth placement, planter unsuitable for conditions, wet or cold soils, and management skills. Undulating paddocks can result in uneven seed depth placement and therefore uneven germination.
LandWISE trials showed no-tillage essentially eliminates wind erosion, even on extremely light (ash / pumice) soils [28].	Wind erosion prevention stops crop damage, a key reason for technology adoption in Hawke's Bay [28].

Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:

1. Management knowledge and skills for these systems
2. High capital investment
3. Only a small number of contractors, if any, are available in each district with equipment and skills
4. Grower confidence that crop profitability will not be reduced compared to current levels
5. Fear of change
6. Confidence to identify no-tillage ready paddocks and for those not suitable the ability (time, resources, skills) to address the issues for the paddock to make the transition.
7. Surface compaction of topsoil by stock can affect achievement of uniform planting depth and planter performance
8. Can require change to crop rotation patterns and crop mix grown
9. Does not suit tuber and root crops requiring even produce, e.g. carrots without bends in roots, or potatoes as can not mould soil around developing tubers
10. Limited number of service industry personnel with technically sound skills and knowledge in no-tillage management

11. Management of weed control is critical and options available can be limited. Timing is critical

12. Currently no commercial planter for transplants.

Sources of information and manufacturers:

Manufacturer / Service Company / Information Source	Phone Number	Website	Location
New Zealand No-tillage Association. (MAF SFF Project)	06 329 2784	http://www.maf.govt.nz/sff/about-projects/arable/00-016-final-report.pdf	National
Cross-Slot drills – Baker No-Tillage Ltd. Includes publications and information on No-tillage	06 329 2784	www.cross-slot.com	National
Aitchinson Seed Drills	06 344 5053	www.aitchinson.co.nz	National
South Australia No-tillage Association		www.satfa.com.au	South Australia
No-Till Farmer magazine		www.no-tillfarmer.com	USA

Popular article on No-tillage (1/1/05)
http://www.country-wide.co.nz/article/2993.html

4.6 Drying and Storage of Seeds and Grains

4.6.1 Harvesting

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Determining harvest date	Seed or grain crops should be physiologically mature and have dried down to an acceptable level when harvesting begins. Moisture meters assist in determining moisture content and each crop has its own moisture content criteria. Moisture contents can vary between varieties. Natural drying to storage moisture contents are the most energy efficient but weather conditions often don't allow this to occur, also natural drying can lead to greater yield losses, difficulties in removing crop from the field and often greater field losses with shattering of heads. Artificial drying is required to maximise yield.	The optimum harvest time for some seed is only hours, for others it is a few days, therefore the ability to harvest a large volume of crop in a short period of time is critical or crop losses occur. Timelier utilisation of combine harvesters could improve yields e.g. co-operation of neighbours, shift combines from one region to another [12].
Combining crops – crop removal	Combining crops with high moisture contents can result in a higher percentage of damaged kernels which leads to storage issues, fines and disease problems.	Combine operator skill level influences how much kernel damage there is.

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Transporting crops to drying complex	Combining crops with high moisture contents means every transport movement is carrying water as a dead weight increasing the cost and reducing efficiency [12].	Grain can absorb 10 – 12°C radiant heat on hot sunny days, this temperature must be rapidly removed from bulk stored heat or "sweating" will occur, disease build-up and quality deterioration. Fungi also produce their own heat and consequential increases in grain temperatures. Aim to reduce seed temperature to within 5°C of ambient air temperature e.g. by blowing cool night air through bulk lot. Bagged seed often does not heat up [43].

4.6.2 Dryer

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Dryer system	Drier efficiency varies with system design. Cross-flow driers are the most efficient driers and result in better quality grain. For drying small lines or lines with varying moisture contents in-bin driers are the most efficient, simplest and cheapest driers. Stirring grain during drying can improve drying speed.	Often operational efficient systems require higher capital investment. Grains differ in their drying time and temperature sensitivity. These factors must be considered or seed quality will be affected. Continuous flow and high temperature driers require 24 hour operation and skilled staff to operate them.
	Dehumidification driers are easier to operate (less risky) and are flexible but unsuitable for high moisture content crops [43].	

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
	Low temperature driers require less energy to operate but rely on ambient temperature so relative humidity must be low and they are unsuitable for drying high moisture content grains.	
	Bulk medium temperature dryers obtain efficiencies due to the use of compression energy of the fan to generate heat and it uses expelled radiant motor heat. Tilting the flat bed will aid loading / unloading but there can still be a dead spot. There are tray, radial flow and sack driers also [43].	
	High temperature driers reduce drying time. Dryeration (tempering of grain 10 – 12 hours to even out moisture and temperature levels) using small fans increases fuel efficiency and throughput [43]. Continuous flow dryers maximise drying capacity and maintain grain quality. However, they require clean seed to operate efficiently [43]. Cumbria Dryers (and others) have alternating rows of inlet and exhaust ducts so require lower aeration rates and are more energy efficient [44].	The maximum air temperature must not cause seed cracking. Temperatures quoted are often for animal feed and must be lower for the food trade or seed growth [43]. Seed must be cooled before storage.
	Dry Air Generators require 20% less energy than heaters. These suit on farm drying using floor or bin drying. It uses dehumidification and reheating to dry the grain and is less affected by ambient relative humidity than other dryers. For bulk floor and bin drying systems drying time capacity is increased [43].	May allow drying to be undertaken at night [43] – perhaps utilising reduced electricity tariffs.
Insulation	Insulation of building and pipes where possible will reduce heat lost.	

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Heat recovery	Housing the fan and diesel or petrol driven motors can capture sufficient heat to increase air temperature delivered by 4 – 5 °C [43]	Diesel fumes must be kept separate from seed or grain otherwise quality will be affected.
Fan	Effective drying occurs where dry air is moved through the grain. Axial flow and centrifugal backward curved fans are the most efficient fans to operate. Both fans have non-overloading characteristics so can handle a range of grain crops with varying air resistance characteristics [43]. Resistance to air flow varies with different grains, low for large seeds and high for small seeds. Damp seed may tend to pack down during dryer filling and increase resistance to air flow. Resistance to air flow increases with increasing depth of seed, impurities in the line and surface consolidation. Stirrers will reduce airflow resistance [43, 45].	As resistance to airflow increases fuel consumption increases. As airflow volume increases so does resistance
Dryer capacity	Increasing fan size will reduce drying time but they are more expensive to purchase and operate.	High moisture content seeds must be dried slowly to avoid affecting seed viability.
Environmental conditions	Humidity and temperature influence drying and storage time. As temperature increases the moisture carrying capacity of the air increases [43, 44]. They also affect the energy required to dry grain to a storage-safe moisture content.	Drying of grain releases water which has to be removed quickly and efficiently.
Fuel system	Use of alternative fuel sources can be considered e.g. bio fuels. Water content of fuel is very important. CNG produces twice as much water compared to diesel. LPG is in the middle. This water has to be removed from the grain, which makes it an important consideration.	Solar energy with current technology is unlikely to provide all heating requirements, but could be a booster for high temperature systems or may run low-temperature systems. Petrol is only 20% efficient [43]

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Fines in product submitted	Fines (contamination) in seed or grain causes heat build-up and reduces the effectiveness of drying due to the difference in airflow rates.	Lines with a large portion of fines should be cleaned before drying.
End use	Knowledge of the end use and storage time required for a give tonne of grain or seed would allow management decisions to be made accordingly. Without such knowledge the crop is dried for the longest storage time, which may be unnecessary and wasteful of energy [12].	Storage time is influenced by moisture content. Communication within the industry about the end use could reduce unnecessary drying.
Monitoring of system	Monitoring improves the control of inputs and outputs, and improves efficiency.	

4.6.3 Storage

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Unit design	Must be rain and moisture proof. Wide eaves reduce store temperatures. White buildings will reduce heat absorption during the day and radiation heat loss at night [43]. Units that minimise heat flow into or out of them will be most efficient to operate and produce better quality seed.	Well-designed stores exclude moisture, lower temperature and have adequate ventilation [43].
Uniformity of grain / seed within storage bin critical	Dried grain must be cooled before storage in bulk lots. If using ambient temperature, it must be lower than the grain temperature and pass through the grain to achieve even cooling [44].	Sampling of grain or seed must identify areas of moist or hot grain. Moisture in any part of the storage bin affects the grain quality in that part of the bin. Poor temperature control can lead to moisture migration within the storage bin [46].
Aeration	Grain can be tempered for temperature and moisture control (warming or cooling).	Positive pressure systems allow grain at the top of silo to be monitored, whereas negative systems require monitoring of the grain at the base of the silo, which is hard to reach, and therefore determining completion of tempering cycle is difficult. Condensation at the top of the silo in positive pressure systems must be exhausted [46].
Monitoring of system	Monitoring improves control of inputs/outputs and improves efficiency. Installing temperature sensors will give more accurate information on storage conditions especially if automatically monitored with a data logger.	Stored grain should be level for even airflow through the grain.

Measures for energy savings	Comments, advantages and disadvantages	Factors to be aware of
Grain condition	Seed must be dry and cool when stored otherwise will get fungal infection, loss of germination percentage and quality deterioration.	Fungi generate heat.
Environmental conditions	In high temperature, high humidity environments it can be beneficial to dry seed to a safe moisture level to protect from fungal infection, and store in moisture proof containers [43].	Storing warm grain in cold temperatures (in autumn or winter) without cooling first, results in moisture migration. The reverse occurs in spring. If aeration of seed doesn't occur moisture problems occur [46].
Conveying systems	Screw conveyors require high power inputs to drive them compared to belt drives. Drag chain conveyors are high capacity and lower power use than augers, but higher than screw conveyors.	Screw augers are cheap to build but damage grain and are high power users.

Limitations to uptake, key factors that could improve energy efficiency, and areas requiring further study or development:

1. The end users of grain do not make it clear to growers how long the grain will need to be stored for. Long term storage requires grain with a lower moisture content. By default most grain is dried to levels suitable for long term storage. Improved communication within the industry regarding crop storage requirements and end use would reduce unnecessary drying.
2. Cooperation between growers and combine owners for timely harvesting of crops
3. Explore systems for on-farm drying facilities to reduce cartage of water as dead weight. This balance will be between the distance carted and larger central plants being able to afford more efficient dryers due to economies of scale
4. Encourage research in NZ on improved drying systems, especially utilising new technology
5. Encourage improved monitoring of harvesting, drying and storage to reduce crop wastage, input wastage and loss of quality.

Sources of information and manufacturers:

Manufacturer / Service Company / Information Source	Website	Location
Book: The drying and storage of grain and herbage seeds. Cost $20	www.far.org.nz	NZ
List of web resources developed by the Post Harvest Grain Quality & Stored Product Protection Program	http://pasture.ecn.purdue.edu/~grainlab/exten-pubs.htm#Grain%20Drying	USA
Canadian Grain Commission	http://www.grainscanada.gc.ca/main-e.htm	Canada

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