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A Review of Scientific Information Relating to the Sustainability of Current Land Use Practices on Cultivated Land in the Franklin District of Auckland

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EXECUTIVE SUMMARY

The ARC contracted Dr Doug Hicks, soil scientist, to review existing information relating to the sustainability of current land use practices on cultivated land in the Franklin District. The report was finalised in June 2006.

There are around 8000 hectares of cultivated land in the Franklin district, shared between Environment Waikato and the Auckland Regional Council. Since the completion of the Franklin Sustainability Project in 2004 the ARC has put considerable effort into requiring growers to implement sediment control measures including dams and raised access ways to reduce the off site movement of soil. Concerns are regularly raised about the potential adverse impact of repeated cultivation on soil carbon levels and soil physical properties.

The report found that:

- Off site soil loss does not threaten the viability of cultivation
- Most soil leaving cultivated areas resettles either within the property or on adjacent land
- Sediment control devices have value in preventing soil getting onto roads and into watercourses but no good data exists on their efficacy
- Cultivation has reduced soil organic matter and therefore reduced the soil's ability to retain nutrients, nitrogen in particular
- Soil fertility is being maintained by heavy applications of fertiliser
- There is some scope to reduce nutrient losses by ensuring fertiliser is applied at appropriate rates and times, when it can be taken up by crops rather than leached into groundwater
- Nitrogen contamination of groundwater is likely the single largest environmental impact of vegetable growing
- Little work has been done on soil contamination, but it is expected that cadmium levels are elevated due to heavy use of super phosphate
- Biological contamination of soils by disease organisms is present in many fields
- Economic conditions are more likely to threaten the sustainability of vegetable growing in this area than the physical or chemical condition of horticultural soils. Between 1992 and 2002 the area growing onions reduced by 36% and potatoes by 70%. Growers are moving out of the region to utilize cheaper land elsewhere.

As a result of issues raised in Dr Hicks' report the ARC should review where attention is focused, including:

- Measure the effectiveness of sediment control devices and using that information to review current recommendations
- Develop a programme to address the increasing nitrate levels in the Pukekohe aquifer. Possible measures include nutrient budgeting for fertilizer application, and increasing carbon levels in topsoil to help retain nutrients
- Improve the monitoring of contaminant levels in cultivated soils to ensure that they don't increase to a level where food quality or public health standards are exceeded
- Take into account the economics of growing when considering impacts of urban growth and policies to protect versatile soils

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1 INTRODUCTION

This review has been commissioned by Auckland Regional Council (ARC) as part of its ongoing role in monitoring sustainability of land use. South of the urban area, Franklin District contains land that is amongst the most intensively used in New Zealand. About 8000 hectares of cultivated land supply fresh vegetables to Auckland's markets, to supermarket chains nationwide, and in the case of onions to export markets as far afield as the United Kingdom and Japan.

From time to time, questions are raised about whether cultivation, fertilisers and pesticides have adverse impacts on the soils; and if so whether they threaten sustainability of vegetable production. These concerns are voiced from diverse quarters - vegetable growers themselves, local residents, local body councillors, planners and scientists. They are not new, having been expressed every few years since the 1960s. Public agencies, notably the Auckland Regional Council and its predecessor the Auckland Regional Authority, have commissioned scientific investigations in response, and there are now a large number of these. In recent years the Pukekohe Vegetable Growers' Association has also obtained public funding to run the Franklin Sustainability Project between 1997 and 2003. This trialed and publicised a number of practices that are thought to reduce the impacts of vegetable growing on Franklin District's soils.

The scientific investigations' findings are in unpublished contract reports or papers published in scientific journals, so it is rather hard to form an overview of what they tell. The Franklin Sustainability Project has publicised trial results in its newsletters, and has also produced a set of leaflets which recommend certain practices to growers. The extent to which these are under-pinned by scientific investigations, conducted parallel with field trials, is not always clear.

The purpose of this review is to pull together scientific information, provide a readable summary between one set of covers, and supply some comments about what it shows. The review has been prepared by Dr. Douglas L. Hicks, a soil scientist who supplies advice to ARC (and other Councils) about soils and their conservation. Dr. Hicks has not previously been involved in the scientific investigations and field trials conducted at Pukekohe, but has knowledge of local soils, so is in a position to make independent comments on the investigations and the issues they raise. ARC's specific brief to the consultant is to :

* Review scientific literature relating to the sustainability of current land use practices on cultivated land in the Franklin District,

* Assess available data relating to soil loss from cultivated land, and movement within cultivated sites, and how cultivation is affecting soil quality,

* Identify measures that that hold soil in place and preserve soil quality,

* Comment on fertiliser use and soil fertility trends,

* Comment on the future sustainability of current practices in terms of the ongoing viability of cultivation.

2 HISTORICAL BACKGROUND

Commercial vegetable growing commenced about 1870 on the volcanic soils of Pukekohe Hill, to supply the markets of an as-yet small city. Construction of a railway line through Pukekohe, which eventually formed part of the main trunk line completed in 1908, enabled local growers to supply onions and potatoes nationwide; two crops for which Pukekohe became well-known on account of quality and quantity of yields, as well as rarity of frosts and warm growing temperatures which enabled year-round harvest. Throughout the 20th century, the area and diversity of vegetable crops expanded to meet the demands of a growing city that expanded to 1.1 million residents by the year 2000. From the 1970s, local growers developed an export trade in onions and also high-value produce. Currently 80% of the onion crop is exported, as is most of the glasshouse-grown capsicum crop.

Vegetable growing has spread away from the original market gardens on Pukekohe and Bombay Hills. Much of the rolling land around Tuakau and Patumahoe has been converted from dairy pasture into vegetable crops. Now commercial growing is increasingly evident on flatter land in the vicinity of Karaka, Kingseat and Waiuku. Table 1 gives some idea of how cultivation has expanded.

Table 1 *Area of Franklin District in horticulture at various dates*
(pre-1989 data are for Franklin County)

	Hectares (all land in horticulture)
1900	no data
1922	334
1946	425
1971	2185
1982	5688
1992	8407
2002	8620

3 PHYSICAL BACKGROUND

Before discussing any impacts of cultivation on local soils, it will be helpful to outline what the soils are. Vegetable growers' concentration on some soils in Franklin District - but not others - is not just a consequence of proximity to an urban market, or a favourable climate. It has a great deal to do with the soils, which have been mapped and described by staff of the former DSIR (Taylor et al 1954, Fieldes et al 1968, Orbell et al 1973).

Market gardening started on Pukekohe clay loam. It is a soil weathered from basaltic ash overlying basalt rock on the flanks of Pukekohe Hill, a gently sloping extinct volcano on the town's southern outskirt. It has a uniform red-brown profile, a well-aggregated granular structure, friable consistence, and moderate natural fertility. Whatitiri clay loam is a related soil, weathered from basalt flows where there is little ash cover. Maori, European settlers, and other migrants with a tradition of intensive vegetable growing - notably Chinese and Indians - quickly recognised these soils as easy to cultivate, well-draining, and productive.

Vegetable growing expanded onto similar soils in the wider area, notably Patumahoe clay loam. This soil is not just at Patumahoe, but in a triangle of land between Bombay, Tuakau and Waiuku. Here the landscape was showered with rhyolitic ash from eruptions in the central North Island, at intervals between 250,000 and 50,000 years ago. On flatter slopes some distance from the local volcanic vents, the rhyolitic ash was interspersed with basaltic ash, on top of basalt flows from fissures around their base. Admixture of rhyolitic ash has given Patumahoe clay loam a somewhat different mineral composition from Pukekohe clay loam, though in other respects (profile, structure, consistence, fertility) it is similar, and equally good for cropping.

Vegetable growing is also carried out on Hamilton clay loam. Its distribution is patchy, interspersed with the Pukekohe and Patumahoe soils. Typically it occurs where rhyolitic ash remains as a thick soil-forming layer on the landscape's surface i.e. the ash has not mixed with underlying basaltic ash or weathered basalt. Hamilton clay loam's mineral composition differs to the extent that its structure and fertility are not quite so good as Pukekohe or Patumahoe clay loam. Nonetheless it is a good soil for growing vegetables, as well as grain crops such as maize.

Several variants of these soils occur in small pockets around the district. Helvetia clay loam is a variant of Patumahoe soil that has impeded drainage. It typically occurs in hollows. Mauku silt loam is a variant on elevated ground, where fine particles of Patumahoe soil were blown about by strong winds, forming patches of hummocky terrain which stabilised beneath scrub and forest. The hummocky relief has been destroyed by cultivation, but the textural difference remains. Ararimu clay loam is a variant of Hamilton soil, occurring as a thin layer over sandstone in eastern parts of Franklin, where Hunua clay loam is a similar variant over greywacke. Matakawau clay loam is another variant of Hamilton soil, occurring as a thin layer over old weathered sand on the Awhitu peninsula.

In recent years vegetable growing has expanded onto Karaka complex soils. These occur on undulating terraces, towards Drury, Karaka, Kingseat and Glenbrook. The surface layer of soil is volcanic ash - a mixture of rhyolitic and basaltic - which has been water-sorted and settled on a sub-surface layer of alluvium varying in texture from sand through silt to clay. Some of the Karaka soil formed where rhyolitic ash fell on mudflats, now slightly up-lifted above sea level around southern shores of the Manukau harbour. In other places, rhyolitic or basaltic ash was washed down tidal creeks by streams draining higher ground; here the surface volcanic layer is somewhat thicker. Farther up the stream valleys, terraces of freshwater alluvium are an admixture of ash with silt or clay; these too are mapped as part of the Karaka complex.

The most widespread soil in the complex is Karaka silt loam on deep waterlaid ash. It has a yellow-brown topsoil with good structure and friable consistence, underlain by a brown clay loam with blocky structure and crumbly consistence. Karaka mottled silt loam is a variant in depressions on terraces where drainage is slow. Its subsoil is seasonally wet with red and grey mottles. Whatapaka silt loam is a variant in depressions where drainage is impeded. Its topsoil has red and grey mottles, while its subsoil is seasonally waterlogged and grey with a few yellow-brown mottles. Orere silt loam is a soil related to Karaka silt loam, on waterlaid ash terraces in valley bottoms in the eastern part of Franklin.

Table 2 *Area of arable soils in Franklin district*

Pukekohe clay loam	380
Whatitiri clay loam	520
Patumahoe clay loam	17200
Helvetia clay loam	40
Mauku silt loam	25
Hamilton clay loam	4765
Ararimu clay loam	1370
Hunua clay loam	2462
Matakawau clay loam	4641
Karaka silt loam	12080
Karaka mottled silt loam	150
Whatapaka silt loam	3060
Orere silt loam	5837

Some older weathered volcanic soils e.g. Bombay clay loam, also young gritty or stony soils e.g. Kapu sandy loam, are excluded from the table on the grounds that they are unsuitable for cultivation and generally not used for vegetable growing. Ardmore peat loam (1854 ha in Franklin) is excluded on the grounds that little is currently cultivated.

4 SOIL LOSS FROM CULTIVATED LAND

Available data

The first scientific investigation known to have been carried out was by R. Cathcart for the ARA and MWD, between 1971 and 1973. Cathcart set up runoff plots with sediment traps at Bombay, measured soil leaving the plots for three years, and converted measurements to tons of soil loss per acre. Results were never published as a report specifically on the project. Data were kept on file for several years, and occasionally cited in other publications or unpublished reports on the subjects of market gardening or soil erosion. Table 3 summarises what has been located (Cathcart 1980), expressed as tonnes per acre.

Table 3 *Soil loss from runoff plots on cultivated land*

Vegetable crops, annual average	16.0 - 21.5 tons/acre/year
Vegetable crops, four largest storms	0.01 - 5.61 tons/acre/event
Pasture, four largest storms	<0.01 - 0.01 tons/acre/event

Between 1988 and 1994 the ARA (later ARC) measured suspended sediment in several streams around Franklin District. One of these was the Whangapouri headwaters, a 180 hectare catchment predominantly used for vegetable growing. In 1994 ARC commissioned D.M. Hicks of NIWA to analyse Whangapouri flow and sediment records, and compare sediment yields with those of other catchments under different uses. His analysis appeared as an unpublished report to ARC (Hicks 1994a), was compared with data from other catchments in a further report (Hicks 1994b and was discussed in a co-authored scientific paper (Basher et al 1997). Table 4 is a summary of the sediment yields.

Table 4 *Sediment yield in a stream draining cultivated land cf. other uses*

	yrs record $t/km^2/yr$	measured* $t/km^2/yr$	long-term**
Whangapouri (vegetable growing)	3	49	52
Manukau (drystock pasture)	17	49	46
Pakuranga (urban)	4	24	24
Wairau (urban)	6	107	100
Alexandra (urbanising)	1	970	2370

* continuous flow sampling, 3 year record
* calculated from storm event frequencies, 20 year record

Most of the Whangapouri's yield is fine suspended sediment. Yields during individual storms vary greatly, from 10 kg/km^2 up to 13 t/km^2. Yields are higher during winter and spring, when ground cover is poor. 50% of long-term yield is supplied by small rainfalls (return period less than one third of a year). Hicks 1994a commented that yield from the Whangapouri basin is much lower than expected erosion rates on market garden fields, and indicates a low sediment delivery ratio from the fields to the drainage network.

ARC has continued to monitor suspended sediment in several Franklin District streams from 1994 through 2005. Summary data are given in published technical reports summarising baseline water quality every 5 years (Grogan et al 1993, 1998, 2003); but all are catchments with mixed land use (Papakura, Puhinui, Wairoa).

Subsequent analyses of off-site soil loss have not been undertaken, because D. M. Hicks' reports indicated that future investigations should focus on sites where soil is being deposited i.e. lower slopes and drains (see Section 5, Soil movement within cultivated sites).

Comments

Despite much sediment moving off fields after rain, net sediment loss down the Whangapouri stream is quite low compared with many other New Zealand catchments, including catchments in pasture, scrub and bush. D. M. Hicks et al (1997) give a range of yields for lowland catchments under natural vegetation cover:

Sedimentary rocks	27 to 1026	tonnes /km^2/yr
Volcanic rocks	27 to 143	
Greywacke	12 to 1961	
Schist	29 to 1019	

The Whangapouri's measured yield is within the range for catchments on volcanic terrain. It is also in line with estimated sediment yields of 23 to 88 tonnes per square kilometre a year for several catchments with a high proportion of cultivated land, that drain to the Waikato from the Tuakau side of the divide (Zuur 1989).

Where Franklin District's catchments are on volcanic terrain, low off-site soil loss is attributable to two factors identified by Basher et al 1997 :

* Local soil properties: volcanic soils are erodible, but have clay minerals which aggregate quickly and settle out of suspension when water velocity drops. Much eroded soil may settle on lower slopes or in drains, before it reaches streams. They contrast with sedimentary soils around Auckland, which have a high percentage of silts (dispersive in water) and fine clays (which do not aggregate), so eroded soil remains in suspension at low water velocities, and is transported down streams into estuaries.

* Local climate : while prone to intense rainstorms (50 - 100 mm an hour has been measured at Pukekohe) their frequency is quite low (return periods of 10 + years) compared with many other parts of the country. So over a long period of time, the volume of soil transported down streams by infrequent floods at Pukekohe is much less than the volume transported by frequent floods at a site with similar soils but higher rainfall e.g. Ohakune or Taranaki.

Some anecdotal observations by local growers, confirmed by ARC staff and contractors (P. Begley and S. Bryant pers. comms.), are that a lot of the sediment entering streams has settled out along low-gradient reaches which gradually turn into riparian wetlands, on a time scale of decades. These observations, while as yet unconfirmed by measurements of the deposited sediment, may help explain why so little suspended sediment passes gauging sites farther down the Whangapouri and similar streams such as the Ngakoroa.

My conclusion from available evidence, scientific and anecdotal, is that vegetable growing contributes measurable quantities of sediment to Franklin District's streams, but the sediment quickly settles out along the streams' upper reaches, and is not a significant source of sediment entering the Manukau harbour or reaching the Waikato river.

Measures that reduce off-site soil loss

In 1997 the Franklin Sustainability Project commenced trials of several measures thought to reduce off-site soil loss. The trials were undertaken co-operatively by local growers, researchers (Crop and Food, Landcare Research), and regional council staff (ARC and EW). Some of the field trials were single-season, while others lasted for several. Documented results vary from anecdotal accounts in FSP newsletters, through data summaries with comments (progress reports to FSP often reproduced in newsletters) to unpublished contract reports. Descriptions of preferred practices were published as leaflets in FSP's "Doing It Right" series to inform local growers.

Contour drains

One pre-existing drain, which approximated a contour drain in its position, was selected for monitoring by FSP staff. The drain was visited and photographed on several occasions, but there do not appear to be any published measurements of its efficacy in diverting runoff from the cultivated field downslope.

Basher and Thompson (1999) observed five contour drains in 350 fields they surveyed after the January 1999 storm. Four out of five had failed, actually causing erosion in the fields from which they were supposed to divert runoff. Basher and Thompson noted that the remaining drain, which had diverted storm runoff without silting or breaching, was the only one constructed in accord with ARC recommendations.

Grassed waterways

Grassed waterways were installed on a demonstration site, as benched headlands in top-slope and mid-slope positions, by a local grower in conjunction with FSP staff. These were visited and photographed on occasion, and some photographs after storms show fresh sediment deposited in the grass. However there do not appear to be any measurements of the grassed waterways' efficacy, either as diverters of runoff from downslope, or as traps for sediment in runoff from upslope.

Hedges

Vetiver grass and lemon grass hedges were established at two trial sites by ARC staff, in support of FSP. The sites were visited and photographed as the hedges established, but there does not appear to have been any measurement of subsequent soil accumulation. FSP newsletters, and one of the FSP guidelines, refer to the value of existing barberry hedges and similar for trapping soil before it leaves fields. The supporting evidence is anecdotal e.g. photographs of soil built up against old hedges.

Silt fences

A silt fence was installed on the downslope side of a cultivated field next to a drain, on one demonstration site by a local grower in conjunction with FSP staff. The site was visited and photographed, and photographs were published in at least one FSP newsletter. The observer and grower both commented that the fence trapped silt, and water in the drain appeared clearer than before. However there do not appear to be any measurements either of trapped sediment, or of water clarity before and after fence installation.

Silt fences were used by Basher (2000) to trap soil moving down ripped and un-ripped wheel tracks over a period of 6 months, during a separate trial of wheel track ripping.

Table 5 *Soil trapped by silt fences downslope of a cultivated field*

Un-ripped wheel tracks	28.5 mm depth
Ripped wheel tracks	0.5 mm depth

Basher considered that the silt fences performed satisfactorily, though commented that repair was needed during the trial to maintain their function.

Bunds and silt traps

Bunds and silt traps were installed on two demonstration sites by local growers in conjunction with FSP staff. These were visited and photographed. The traps were cleaned annually, but quantities of sediment trapped do not appear to have been recorded (though some information is now available from silt traps installed subsequently by other growers - see below). Visual observations of silt trap efficiency were discussed in FSP newsletters, to the effect that while some fine sediment was lost in discharge down snorkels (outlet pipes) or over spillways, much was being trapped each year for re-distribution back on fields. Growers' observations in FSP newsletters were mixed. On the one hand they recognised the efficacy of bunds and silt traps. On the other, they liked neither the area of field taken out when constructing them, nor the cost of earthworks. Some growers also had reservations about quality of the trapped sediment for re-spreading on fields. It had a high percentage of fine silt and clay particles, which they perceived as deleterious to structure if incorporated into well-aggregated soil.

One exception to the dearth of information on silt trap efficiency is some unpublished suspended sediment measurements and estimates of soil loss collected towards end of the Franklin Sustainability Project (G. Pellow and A, Barber pers. comm.). They collected suspended sediment samples from runoff leaving fields without silt traps, also fields with various standards of silt trap, during rainfalls of differing intensity. Results are given in Table 6 (excluding their estimates of annual soil loss, which cannot be validly calculated from measurements during a few events).

Table 6 - Sediment leaving fields without and with silt traps

Field	Rainfall intensity mm/hr	Suspended Sed. Conc. mg/l	Event soil loss Kg/ha/hr
Flat, no silt trap	3		2
	20		55
Sloping, no silt trap	-		-
	8		68
Sloping, sub-standard silt trap	2		6
	11		79
Sloping, standard silt trap	3		12
	11		25

Pellow's and Barber's measurements suggest that silt traps make little difference to soil loss from fields during low-intensity rainfalls, but start to have an effect during medium to high-intensity events. They also suggest that silt traps installed to ARC design specifications are more efficient during medium to high-intensity events.

Some recent information from a grower (J. Sutherland pers. comm.) is that a sediment trap at Bombay, regularly cleared each year, collects about 60 cubic metres of soil from a catchment area of 6 hectares. Bulk density is unknown but would be in the range 0.8 to 1.6 tonnes per cubic metre (uncompacted cf. compacted sediment). This equates to a trapping rate of between 8 and 16 tonnes a hectare.

General comments on FSP trials

These particular FSP trials produced little scientific data about efficacy of the techniques that were supposed to reduce off-site soil loss. In contrast the measurements undertaken by Basher, Pellow and Barber, and Sutherland are simple and informative. It seems unfortunate that similar measurements were not made at an early stage of the trials, as an alternative to anecdotal observations or photographs during site visits.

Fortunately some other trials, funded by FRST, ARC or FSP, produced rather more data about soil movement within cultivated sites, enabling some inferences about what is lost and where it ends up. These trials are discussed in the next section.

Refer to Section 9 for information about growers' uptake of the measures trialed, and what effect they have on sustainability of cultivation.

5 SOIL MOVEMENT WITHIN CULTIVATED SITES

Available data

In 1996 Landcare Research obtained FRST funds for an investigation of soil erosion on cropland at several sites around New Zealand, including two in Franklin. ARC also contributed funds towards the Franklin component. Results appeared as an unpublished contract report (Basher and Ross 1997) and a scientific paper (Basher and Ross 2002) At the first site in Bombay, Basher and colleagues re-analysed Cathcart's unpublished data for soil moving through runoff plots over 2.5 years, 1971 to 1973. At the second in Pukekohe, they tracked movement of soil around a field by analysing samples for caesium 137, a radioactive isotope normally present in the soil at a low concentration. Where its concentration is below average, soil has been lost; conversely where above average, soil has been deposited. Results are given in Table 7.

Table 7 - Short and long-term soil movement in cultivated fields at Bombay and Pukekohe

Runoff plot data (1971-73)		
Minimum trapped in an event		t/km^2
Maximum trapped in an event	1000	t/km^2
Annual average trapped	5680	$t/km^2/yr$
Caesium 137 data (1954-1999)		
Removed from upper slope since 1954		310 mm
Annual average removed		7.4 mm
Deposited on lower slope since 1954		430 mm
Annual average deposited		10.2 mm
Net loss from field since 1954		98 mm
Annual average lost		2.4 mm = 2100 $t/km^2/yr$

Soil movement through runoff plots occurred during intense rainfalls, more during winter and spring than at other times of year. Annual quantity of soil moving through the Bombay fields was enormous (though may reflect that 1996 and 1998 were wet years with above-average rainfall and storm incidence). The Caesium 137 study confirmed that soil movement has been occurring long-term and is substantial; but also indicated that much soil is moving around the fields rather than out of them. Basher et al attributed the deposition to several factors:

* a small proportion of fields deliver to drains,
* soil is strongly aggregated, so resists dispersion in water,
* aggregated particles quickly settle on lower slopes or in drains when flow velocity drops.

Nonetheless, Basher et al's data indicate about 2100 $t/km^2/yr$ net soil loss from the fields (see comments below).

Basher and Thompson (1999) undertook an additional study of soil movement for ARC after the intense rainstorm on 21 January 1999. 157 mm fell in 3 hours, an event of 140 years' return period, on soil already saturated by 100 mm rain over the preceding days. Basher and Thompson measured surface areas eroded in 350 fields, from aerial photographs taken 5 days after the storm. They also measured depth of soil removed from areas eroded in 18 fields, by ground surveys within 10 days. Results are given in Table 8.

Table 8 - Soil erosion during the 21 January 1999 storm

350 fields	No. of fields	% of surface eroded				
	n	<1	1-2	3-5	6-10	11-50
Weeds (fallow)	11	9	1			1
Bare, cultivated	131	45	3	39	23	21
Bare, stubble incorporated	1				1	
Cover crop	11	11				
Greens (vegetable? Fodder?)	39	34		2	3	
Celery	2	1		1		
Squash	12	2		2	4	4
Potatoes	2	2				
Onions	60	45		8	5	2
Onions, dug	62	33	4	8	8	9
Onions, harvested	7			4	2	1

18 fields	% of surface eroded					
	<1	1-2	3.5	6-10	11-50	
Number	0	0	3	4	11	
Average depth eroded	0	4*	9	18	90	mm
Soil loss	0	43	108	216	1080	Tones/ hectare

* The authors do not explain how they obtained an average depth eroded for this category.

171 out of 350 fields were eroded; 94 by runoff from drains, 50 by runoff down wheel tracks where recently cultivated, and 27 by runoff down wheel tracks where onions had been recently dug.

Table 8 shows there was negligible erosion amongst growing crops (vegetable or cover). Erosion was concentrated in bare or harvested fields. Here there was little sheet erosion of seed-beds, indicating that soil infiltration rates were not exceeded even by 100 mm/hr (the peak) rainfall intensity. Most of the erosion was by rills, in two situations:

* where drains adjacent to fields had overflowed,

* where soil was compacted by wheel-tracks, under depressions in cultivated areas, or in headlands where machinery had repeatedly turned.

Measured erosion in 18 individual fields ranged from 29 tonnes a hectare, with 100% of soil delivered to drains, up to 597 tonnes a hectare, with 12% of soil delivered to drains. A great deal of soil was deposited downslope within the same field it had been eroded from. The balance appeared to have been delivered onto adjacent fields, over roads, or into drains. These proportions were not measured.

Basher and Thompson also made some observations about the efficacy of various measures introduced to control soil movement through fields :

* there was negligible erosion in cover crops,

* all but one of five contour drains observed had worsened erosion, by overflowing or breaching. Just one diverted runoff and prevented erosion. It was the only one constructed to ARC's specifications.

ARC subsequently commissioned NIWA to computer-model soil movement, based on Basher's soil erodibility data, records of rainfall duration and intensity for Pukekohe, and the physics of runoff on various lengths and angles of slope. Results are in an unpublished contract report to ARC (Stroud and Cooper 1998), though some figures have appeared in FSP newsletters. Table 9 summarises NIWA's predictions for slopes longer than 100 metres.

Table 9 - Predicted soil movement on slopes longer than 100 metres

Slope Degrees		Patumahoe 000t/km^2/yr	Hamilton 000t/km^2/yr	Karaka 000t/km^2/yr
2	uniform	<3	<3	<3
	concave	<3	<3	<3
	convex	<3	3-10	3-10
	concave-convex	<3	<3	3-10
	convex-concave	<3	<3	3-10
4	uniform	<3	3-10	3-10
	concave	<3	<3	<3
	convex	3-10	10-20	>20
	concave-convex	<3	3-10	10-20
	convex-concave	<3	<3	10-20
6	uniform	3-10	3-10	10-20
	concave	<3	<3	<3
	convex	3-10	10-20	>20
	concave-convex	3-10	3-10	>20
	convex-concave	<3	3-10	>20
8	uniform	3-10	3-10	>20
	concave	<3	<3	3-10
	convex	10-20	>20	>20
	concave-convex	3-10	10-20	>20
	convex-concave	3-10	3-10	>20
10	uniform	3-10	10-20	>20
	concave	<3	<3	3-10
	convex	>20	>20	>20
	concave-convex	10-20	>20	>20
	convex-concave	3-10	3-10	>20

Stroud et al's modeling suggested that soil movement increases with :

* slope angle moving from 0 to 10+ degrees,
* slope form moving from concave through uniform to convex shape,
* slope length moving from 0 to 100+ metres,
* soil type moving from Patumahoe through Hamilton to Karaka soil.

The model's predictions appear considerably higher than field-measured data (Basher et al various dates). The authors comment that specifically for the field-measured slopes, their model predicts 1600 t/km^2/yr moving out of fields cf. Basher et al's 2100 t/km^2/yr.

Comments

Stroud and Cooper's model suggests that soil movement is quite variable in Franklin's landscape, which is undoubtedly correct; but the modeled yields have un-stated error margins. They have to be regarded as less reliable than field data. The main value of the model is its indication, utilising soil physical properties (available from DSIR Soil Bureau analyses), that given the same rainfall on the same slope, Hamilton soil may be more erodible than Patumahoe soil; and Karaka soil may be more erodible than Hamilton soil. As yet there have been no field studies of soil movement on the Karaka soils, where there has been much conversion of dairy pasture to vegetable growing in recent years.

Basher et al's field data confirm visual observations that large quantities of soil are moving around cultivated fields at Pukekohe and Bombay. They also confirm that the bulk of soil is deposited downslope in the same fields. This is not news to local growers, most of whom have long been in the habit of carting it back upslope for re-spreading. What is perhaps new, is Basher et al's evidence that about 2100 tonnes/km^2/yr is lost from fields. It is a much greater figure than the 49 tonnes/km^2/yr lost down streams (Hicks 1994a). Basher et al cite Franklin District Council records of annual clearance from public road drains, converting to a figure of 505 t/km^2/yr. That leaves another 1546 tonnes/km^2/yr unaccounted for.

My conclusion is that the scientific evidence definitely demonstrates accelerated erosion - and deposition - of soil within fields that are under long-term cultivation for vegetable-growing.

It also demonstrates that, out of the 2100 tonnes/km^2/year that leaves the fields, diminishing portions settle out downstream - about 500 tonnes in public drains, and about 50 tonnes in streams. A large part of the unaccounted 1550 tonnes is likely to be deposited somewhere on growers' properties, or on adjacent properties downslope. Situations where this can occur include :

* hedges,
* rank grass and weeds on headlands,
* natural depressions in the landscape,
* bunds,
* silt traps,
* drains,
* ponds.

In some, soil accumulates from year to year e.g. behind hedges. In others e.g. private drains, it is cleared annually by growers and either re-spread or dumped. As yet almost nobody has measured the quantities of soil that are being trapped and cleared from these situations. One exception is an approximate measurement of sediment removed from a silt trap annually by J. Sutherland (pers. comm.). Depending on bulk density (un-known), it equates to between 800 and 1600 tonnes per square kilometre a year. This figure is within range of the 1550 tonnes as yet unaccounted for by scientific investigations.

Measures that reduce on-site soil movement

The Franklin Sustainability Project also trialed several measures thought to reduce on-site soil movement.

Cover crops

Oats, sorghum, mustard, phacelia, and annual ryegrass were trialed on 3 properties between 1997 and 1999. They were installed by growers and monitored by Crop and Food. Changes in soil carbon, nitrogen, phosphorus and other soil minerals were measured before sowing, during growth, and after cover crop incorporation i.e. when fields were cultivated prior to planting the next vegetable crop. These results were supplied to FSP in three progress reports and a final report, and were discussed in FSP newsletters. They are discussed in this review under the heading "Measures that improve soil structure".

None of the scientific reports contain any measurements of cover crops' effect upon on-site soil movement. FSP newsletters contain anecdotal observations that less soil movement could be seen amongst cover crops during rainfall, than on adjacent fallow ground. Nobody knows whether this was because less soil movement actually occurred, or because the cover crops obscured visibility. The only reliable measurements appear to be those of Basher and Thompson (1999) on a number of fields (which include the cover crop trials). These are given in Table 10.

Table 10 - Soil erosion in cover crops cf. fallow or bare ground

	Fields	% of field eroded				
		<1	1-2	3-5	6-10	11-50
Cover crop	11	11				
Fallow	11	29	1			1
Bare, stubble incorp.	1				1	
Bare, cultivated	131	45	3	39	23	21

The data demonstrate that cover crops reduce soil erosion during high-intensity rainfall. Their effect on soil movement during low and medium-intensity rainfalls remains un-measured.

Subsoiling

Two fields on properties at Pukekohe (sloping) and Patumahoe (flat) were selected for sub-soiling trials. Sub-soiling was carried out by the growers. Fields were measured before and after sub-soiling by Landcare Research for changes in soil structure and Crop and Food for changes in soil nutrients. They also observed water movement through sub-soiled profiles with tracer dyes. Results were supplied as unpublished contract reports to FSP (Ross and Dando 1999, Williams et al 2000a).

The scientists reported that in summer, water moved to a depth of 0.4 - 0.5 metres on rip lines, compared with 0.1 metres on controls that hadn't been ripped. On deep-ripped sites, water flowed laterally between rip lines somewhat more than on shallow-ripped sites. By winter, water moved to a depth of 0.4 metres or more on rip lines and un-ripped controls alike. The observations suggest greater rain infiltration into dry soil during summer and autumn, which would reduce the likelihood of surface runoff and soil movement. Unfortunately no measurements of surface runoff or soil movement were made to confirm this. The measurements that were made (soil structure and nutrients) are reviewed under relevant sub-headings in Sections 6 and 7.

Wheel track ripping

A field on a property at Pukekohe was selected for a wheel track ripping trial. Ripping was carried out by growers, using specially-designed long tines attached to their tractor chassis behind the wheels. Wheel tracks were measured before and after ripping by Landcare Research over two seasons, 1998 and 1999. Results were supplied as unpublished contract reports to FSP (Basher 1999, 2000).

Measurements from the first trial indicated some improvement in soil porosity and hydraulic conductivity, where wheel tracks were shallow-ripped (to 10 - 15 cm). Great improvements in infiltration were measured, up to 360 - 454 mm/hr on ripped wheel tracks cf. 0.7 - 3.5 on un-ripped. Because measurements were only made in one month (October), the trial was repeated with deeper ripping (to 30 - 40 cm), and measurements over an entire onion growing season from June to January. Very great apparent infiltration rates were measured on the deep-ripped wheel tracks - initially 60,312 mm/hr in June, falling to 12,456 in October and 8,582 in January. What was measured appears to be unsaturated flow down rips rather than infiltration, with a gradual decline as the rips re-sealed. Infiltration rates measured in onion beds - not compacted by wheels and not ripped - seem more consistent with the properties of local soils. These were 411 mm/hr in June, rising to 485 mm/hr in October, and 907 mm/hr in January. Measurements on the un-ripped wheel tracks were consistent with the previous season's - initially 0.5 mm/hr, rising to 12.7 mm in October and 77.2 mm in January. Both sets of measurements indicate improving infiltration, as compacted soil (wheel tracks) and cultivated soil (beds) loosen with the passage of time.

Table 11 - Water infiltration and soil movement along ripped wheel tracks

	Not ripped mm/hour	Ripped mm/hour	Onion beds mm/hour		
Infiltration					
June (before planting)	<1	60,312		411	
October (crop growth)	13	12,456		485	
January (after harvest)	77	8,582		907	
Soil movement (planting to harvest)	21.3		1.1	-	t/ha
Change in elevation downslope	+28.5		+0.5	-	mm

What has been measured on the ripped wheel tracks is unsaturated flow down soil macropores (rips), not infiltration in the strict sense. Nonetheless, data convincingly demonstrate a great improvement in soil water movement after wheel track ripping, with a corresponding reduction in soil movement downslope.

General comment on the FSP trials

Except for wheel-track ripping, none of these particular trials have actually measured reductions in soil movement through fields, or reductions in runoff through fields. What the trials have measured, is changes in soil properties, which are thought by soil scientists or agronomists to reduce the likelihood of soil movement in runoff. What they think is probably correct, in the sense that similar measures have demonstrably reduced surface runoff and soil movement, in many scientific investigations by overseas soil conservation agencies. However it seems somewhat of an oversight not to have verified the FSP trials by hydrological measurements.

Clearly there is a case for cover crops, subsoiling and wheel track ripping, as all three can reduce the quantity of soil moving in runoff within fields. There is also a case for bunds and silt traps, to reduce the quantity that leaves fields and goes either onto land outside, or into public drains and watercourses. Some growers who have installed them are now convinced they work, based on their own observations of what happens during storms. Other growers are sceptical, and will remain so, given that public agencies have produced so little data about reductions in soil movement where the measures are installed.

Refer to Section 9 for information about growers' uptake of these measures and what effect they have on sustainability of cultivation.

6 HOW CULTIVATION IS AFFECTING SOIL QUALITY STRUCTURE

Available data

Some data from the 1960s are given in scientific papers published by Barratt 1971, Gradwell and Arlidge 1971, and Gradwell 1973. A follow-up paper was published by Gradwell in 1987. The measurements were undertaken by Soil Bureau DSIR in response to some early concerns about deterioration of soil structure expressed by local growers/Ministry of Agriculture?

Barratt reported visual changes in soil structure for profiles described under forest and pasture (granular to nutty), 15 years of vegetable growing (platy to blocky) and 50 years (massive). Gradwell and Arlidge measured changes in soil organic matter at the same and other sites, from 6% under bush and pasture, to 3% after 5 to 10 years vegetable growing, to 1 - 2% after 60 to 80. Gradwell measured reductions in the proportion and size of water-stable aggregates with increasing length of cultivation i.e. the soil was becoming easier for runoff to detach and transport. In 1987 he reported significant reductions in soil porosity (water storage capacity) at the sites, associated with tillage pans forming in the sub-soil. Nonetheless all these early investigators concluded that the changes were too slight to impede continued use of Patumahoe clay loam for vegetable growing.

Further concerns were expressed about soil structural deterioration from time to time in the 1970s and 1980s, mainly by ARA's rural soil conservators, as local growers steadily converted former dairy pasture into an increasing hectarage of cultivated land throughout the western part of Franklin district. However apart from the 1987 paper by Gradwell, no scientific investigations appear to have been undertaken for some 20 years between the mid-70s and mid-90s.

In 1998 Crop and Food Research Institute obtained funds from MfE to develop a soil quality monitoring system for cropland. Over the next few years trials were set up at several sites around the country, including Franklin District with assistance and funding from FSP. 21 paddocks on 4 growers' properties were measured in 1998 - 1999. Trials were undertaken on Patumahoe clay loam, Hamilton clay loam, and a soil misidentified as Aruhoa clay loam (not a recognised soil type); but data were averaged across paddocks, not soil types. The Franklin results were supplied in a contract report to FSP (Beare et al 1999). Table 12 gives a summary for four indicators that relate to soil structure.

Table 12 - Changes in soil physical structure under vegetable crops

Structural condition score	Grower 1	Grower 2	Grower 3	Grower 4
Long-term pasture				
> 20 years	-	-	8.5	9.5
After long-term pasture :				
Cropped < 5 years	6.5	6.0	6.0	-
Cropped 5 - 20 years	-	-	3.5	-
Cropped > 20 years	2.0	2.0	-	-
After long-term cropping				
Pasture < 5 years	-	5.0	-	-
Pasture 5 - 20 years	5.0		-	-

Aggregate stability	Grower 1	Grower 2	Grower 3	Grower 4
Long-term pasture				
> 20 years	-	-	-	95
After long-term pasture :				
Cropped < 5 years	65	80	-	-
Cropped 5 - 20 years	-	-	-	-
Cropped > 20 years	40	45	-	-
After long-term cropping				
Pasture < 5 years	-	70	-	-
Pasture 5 - 20 years	70	-	-	-

Water storage	Data aggregated for all growers
Long-term pasture	60 - 80% of soil dry weight
Short-term cropping	35 - 60%
Long-term cropping	35 - 40%
Short-term pasture	40 - 45%

Structural condition score, aggregate stability and water storage all show the same trend - decline from pasture to cropland, further decline under cropping, and partial recovery when cropland is sown to pasture. Penetration resistance was also measured but not presented in the report, other than comments that there were no discernible differences in between-field measurements; high variation within fields; and the variation seemed to be related to wheel track compaction (cropland) or stock treading (pasture).

Ross and Dando 1999a also undertook measurements of aggregate stability under different vegetable crops and cultivation techniques on Patumahoe clay loam, in a separate trial conducted for FSP.

Table 13 - Cultivation techniques' effect on aggregate stability

	Average aggregate size in mm	Average aggregate size in mm
Onion - (subsoiled, ploughed, rotary hoed and tine harrowed)	9.7	31
Potato - (cover crop hoed in, subsoiled, ploughed, and rotary hoed)	8.1	35
Lettuce 1 - (subsoiled and power harrowed)	17.8	12
Lettuce 2 - (sprayed, jumbo-bustered and rotary hoed)	14.3	17

Compared with Beare et al's results, their data add a little extra information, specifically as regards type and timing of cultivation. Different cultivation techniques did not appear to affect aggregate size, given the difference in lettuce treatments, also the difference between onion and potato treatments. Time of year appeared more important - onions and potato sites had been cultivated in summer and autumn when dry; lettuce sites in spring when moist.

Beare et al (2005) subsequently reported another three years' measurements as part of a nationwide "Land Management Index" project funded by MAF, regional councils and NZPVGA. Summary data for Auckland and Waikato sites are given in Table 14. Most of the vegetable crop sites (60) are within Franklin District.

Table 14 - Average values for LMI indicators under different land uses, topsoil (0-15cm)

	Aggregate stability m.w.d. mm	Pot.erod aggregates %	Large aggregates %	Penet. resistance MPa	Bulk density g/cm^3
Allophanic soils:					
Sheep pasture	2.26	10.9	35.8	1.84	0.83
Dairy pasture	2.36	16.7	24.4	2.02	0.79
Intensive crop	1.63	40.7	16.4	1.11	0.71
Vegetable crop	1.74	27.5	24.3	1.05	0.67
Gley soils:					
Sheep pasture	2.15	3.5	76.7	1.76	1.04
Dairy pasture	2.31	10.5	39.6	1.44	0.86
Intensive crop	1.58	12.6	37.5	0.99	0.87
Granular soils:					
Sheep pasture	2.43	9.1	33.4	2.14	0.87
Dairy pasture	2.47	8.1	36.2	2.34	0.91
Vegetable crop	1.45	16.4	30.2	1.56	0.80
Intergrade soils:					
Sheep pasture	2.28	-	-	1.46	1.02
Dairy pasture	2.25	-	-	1.39	0.77
Intensive crop	1.68	18.2	30.6	0.76	0.79

Table 14 shows, for cropping and vegetable growing when compared with sheep and dairy pasture:

* declines in aggregate stability,
* increases in potentially erodible aggregates, particularly on allophanic soils,
* declines in large dense aggregates under cropping (but not vegetable growing),
* reduced penetration resistance, particularly on allophanic soils under vegetable growing,
* reduced bulk density.

Beare et al noted that changes were:

* for aggregate stability, not significantly different across soil orders,
* for potentially erodible aggregates, significantly greater for allophanic, and significantly smaller for granular soils,
* for large stable aggregates, significantly greater for gley soils, and not significant on granular soils,
* for penetration resistance and bulk density, not significantly different across soil orders.

From 1995-96 onwards, several sites on Patumahoe clay loam, Karaka silt loam and related soils were selected by ARC for its contribution to "500 Soils", a nationwide study of soil quality undertaken by Landcare Research with joint funding from regional councils and Ministry for Environment. Data and comments appeared in annual progress reports(Sparling and Rijkse 1996-2001) and a final summary report (Sparling et al 2001). Out the soil structural data analysed, Table 15 presents the ones that they viewed as useful measures

Table 15 - Soil structure under different land uses on arable soils, Franklin District

	Bulk density t/m^3	Total porosity %	Readily available water %	Aggregate stability m.w.d. mm
Patumahoe clay loam				
Bush	0.87	63.9	6.7	-
Drystock pasture	0.82	66.8	5.9	-
Drystock pasture	0.92	62.9	6.6	-
Drystock pasture (organic)	0.84	65.5	6.9	2.73
Dairy pasture	0.96	60.5	5.3	-
Vegetable crop (< 5 years)	0.83	66.2	5.8	2.48
Vegetable crop (> 30 years)	0.96	63.2	2.3	-
Kiwifruit orchard	0.97	60.9	5.0	-
Karaka silt loam				
Bush	0.52	76.8	6.2	-
Drystock pasture	0.77	68.0	10.2	2.62
Dairy pasture	0.95	60.2	7.1	-
Dairy pasture (organic)	0.86	65.1	9.3	2.69
Vegetable crop (< 5 years)	0.86	65.0	7.6	-
Kiwifruit orchard	0.96	61.8	5.0	2.63
Feijoa orchard (organic)	0.91	60.7	7.3	-
Matakawau clay loam				
Bush	0.92	61.6	11.0	2.17
Drystock pasture (organic)	0.86	64.7	11.3	2.71
Dairy pasture	0.92	61.6	11.0	2.17
Vegetable crop (< 5 years)	1.16	55.9	7.9	1.75
Orchard	1.16	54.6	6.1	2.62
Ararimu clay loam				
Bush	0.88	63.1	9.3	2.53
Drystock pasture	0.95	59.4	6.6	2.60
Dairy pasture	0.92	60.9	8.1	2.73

The cropped Patumahoe soils show a decrease in bulk density (=less compact) initially followed by an increase (=more compact) long-term. Porosity increases initially, and long-term is not significantly different. Readily available water declines both short- and long-term. The cropped Karaka and Matakawau soils show measurable increases in bulk density (= more compact), and decreases in porosity (= less water-holding capacity) short-term. Aggregate stability was not measured at enough sites to make comparisons. The nationwide summary document (Sparling and Schipper 2003) shows that while Franklin soil types change structure under cultivation, they remain towards the top end of a range in these values measured for cultivated soils nationwide. So while their structure has deteriorated somewhat, it is still excellent compared with other soils that are cropped for vegetables elsewhere.

Sparling et al (2005) summarise similar "500 Soils" data for 26 horticultural and cropping sites on Waikato soils, some of which are in Franklin. However the reported data merely indicate what percentage of sites exceed threshold values. 12% have low macroporosity, 4% have high bulk density, and other indicators are not a cause for concern. Comparisons for the same soils, as presented for ARC sites in Table 15, are not extractable from the report supplied by EW.

Comments

Early scientific investigators detected signs of structural deterioration under vegetable cropping at a limited number of sites (though at those sites sample replication is adequate and the differences are clear). Recent studies have sampled a much greater number, giving a picture of whether the deterioration is widespread. The results of Beare et al show consistent deterioration in soil structure with increasing length of cultivation, when averaged across sites by soil order. Those of Sparling and Rijkse for individual sites show deterioration at some but improvement at others, highlighting how individual growers' soil management can outweigh general trends.

My conclusion is that the scientific evidence shows soil structural deterioration does occur under long-term cropping. On the fields measured, it ranges from slight to severe; but sites are still not numerous enough to say which level is typical on different Franklin soils. Severity appears more related to length of cultivation (Beare et al) and soil type (Beare et al, Sparling and Rijkse), than to timing of cultivation or cultivation technique (Ross and Dando).

In the scientific literature, there are no reports of structural deterioration advancing to a stage where crop yields are reduced on the granular soils or allophanic soils of Franklin District. This reinforces an often-made assertion that local soil structure is resilient i.e. it recovers well from repeated cultivation. At most, the scientific investigations indicate that cultivation can be made easier, by implementing practices that reduce structural deterioration.

Measures that improve soil structure

The Franklin Sustainability Project's trials of measures thought to reduce on-site soil movement, actually have proven of rather more value as means of improving soil structure.

Cover crops

Oats, sorghum, mustard, phacelia, and annual ryegrass were trialed on 3 properties between 1997 and 1999. They were installed by growers and monitored by Crop and Food. Changes in several soil physical properties were monitored on 1 property during the first year of trials. Aggregate stability results were supplied to FSP in the first progress report (Francis and Williams 1997), and discussed in FSP newsletters.

Table 16 - Change in aggregate stability under cover crops

	mean weighted diameter (mm)
Pre-trial	0.87
Ryegrass	1.34
Mustard	1.32
Oats	1.32
Fallow	1.2

Williams et al noted that aggregate stability improved under cover crops, to a greater extent than in fallow fields. No data were reported for trends in bulk density, penetration resistance, porosity or readily available water. It is unclear whether this was because measurements were incomplete or inconclusive.

Subsoiling

Two fields on properties at Pukekohe (sloping) and Patumahoe (flat) were selected for sub-soiling trials. Sub-soiling was carried out by the growers. Fields were measured before and after sub-soiling by Landcare Research for changes in soil structure. They also observed water movement through sub-soiled profiles with tracer dyes. Results were supplied as an unpublished contract report to FSP (Ross and Dando 1999).

Table 17 - Depth of <2MPa penetration resistance due to subsoiling

Summer (February)	Flat site	Sloping site
No subsoiling	0.1	0.2
Shallow subsoiling	0.3 (patchy)	0.4
Deep subsoiling	0.4 (patchy)	0.5

Winter (June)	Flat site	Sloping site
No subsoiling	0.3	0.3
Shallow subsoiling	0.5 (patchy)	0.5
Deep subsoiling	0.5 (patchy)	0.5

Ross and Dando attributed patchy nature of the flat site to its being ripped in one direction cf. the sloping site which had been ripped cross-slope as well as down-slope. They concluded that ripping had reduced penetration resistance in the rip-lines; that double ripping was more effective than single ripping; that deep ripping was more effective than shallow ripping over the summer months; but that the difference disappeared in winter when soil moisture reduced penetration resistance in all the profiles.

Penetration resistance was also measured beneath one of the Crop and Food cover crop/nitrate leaching trials in its second year. Results are contained in an unpublished contract report (Williams et al 2000a). They are similar to what was found in the trial by Ross and Dando, with the additional conclusion that ripping did not produce any significant change in crop yield.

Wheel track ripping

A field on a property at Pukekohe was selected for a wheel track ripping trial. Ripping was carried out by growers, using specially-designed long tines attached to their tractor chassis behind the wheels. Wheel tracks were measured before and after ripping by Landcare Research over two seasons, 1998 and 1999. Results were supplied as unpublished contract reports to FSP (Basher 1999, 2000).

Table 18 - Water infiltration and soil movement along ripped wheel tracks

	Not ripped mm/hour	Ripped mm/hour	Onion beds mm/hour
Infiltration			
June (before planting)	<1	60,312	411
October (crop growth)	13	12,456	485
January (after harvest)	77	8,582	907

Basher et al reported great improvements in infiltration after ripping wheel tracks. Reduction in soil bulk density i.e. reduced compaction was slight, so they attributed infiltration increases to water flow down macropores (created between the ripped soil blocks). The effect was greatest in winter (when 80%-94% of rainfalls exceeded infiltration rate on un-ripped wheel tracks), declining through spring (0-34%).

General comment on the FSP trials

The trials provide some data on soil physical changes after cover crops, sub-soiling and wheel track ripping; but either not enough soil structural parameters were measured, or if they were (which passing mention suggests), they were not reported.

My conclusion is that the scientific evidence indicates improved aggregate stability under cover crops, lowered penetration resistance after subsoiling, and greater soil drainage after deep ripping. However there are insufficient data presented, to make any conclusions about these practices' effect on bulk density, porosity, or water storage.

Refer to Section 9 for information about growers' uptake of these measures and what effect they have on sustainability of cultivation.

7 HOW CULTIVATION IS AFFECTING SOIL QUALITY: FERTILITY

Available data

The DSIR published soil fertility data for reference sites where type descriptions were prepared for Patumahoe, Karaka and related arable soils (Taylor et al 1954, Fieldes et al 1968, Orbell 1973). These were for sites under semi-natural vegetation (bush and scrub) or pasture (dairy and drystock). Gradwell and Arlidge 1971, while focusing on soil structure, also analysed soil organic matter in their samples. The market gardens had lower soil carbon (1-2%) than dairy pasture (6%) or bush (6%).

Clarke et al 1984 produced fertiliser recommendations for a range of vegetable crops for distribution by MAF to growers. These were based in part on MAF data from years of field trials at Pukekohe. Recommended rates for crop growth, assuming soil test results are close to optimum levels, are given in Table 19 (data up-dated by Wallace 2000 in the light of more recent data from fertiliser companies).

Table 19 - MAF recommendations for fertiliser application to vegetable crops

		N kg/ha	P kg/ha	K kg/ha
Main crop onions	base	85	35	80
	side	30		
Winter onions	base	110	35	80
	side	30		
Main crop potatoes	base	75	40	45
	side	40		
Early potatoes	base	55	45	45
	side	55		
Main crop cabbages	base	40	40	80
	side	100		
Winter cabbages	base	40	40	40
	side	100		
Broccoli	base	115	45	150
	side	100		
Lettuces	base	25	80	100
	side	55		
Silverbeet	base	25	20	40
	side	0		

Sher 1996 analysed application rates on various crops at Pukekohe for the fertiliser manufacturer BASF. Application rates, removal rates in produce, and residue in the soil were compared with previous MAF data. He concluded that fertiliser application by local growers had increased, though considered that it was balanced to crop requirements and that there was no evidence for excess application.

Haynes and Tregurtha (1999) in a nationwide analysis of fertiliser use for vegetable crops, reported typical application rates at Pukekohe as being in the following ranges :

N	100 - 400 kg/ha/yr
K	100 - 400 kg/ha/yr
P	50 - 100 kg/ha/yr

commenting that fertiliser is typically applied as a basal dressing before sowing, followed by one to two side dressings during crop growth. Some additional information about local growers' practices is given by Wood (1997).

Crush et al 1997 analysed nitrogen fertiliser application rates for 15 market gardens, 5 orchards and 5 dairy farms in the vicinity of Pukekohe for ARC They did not measure crop uptake, leaching or soil residues, instead calculating nitrogen balance using "typical values" from published scientific literature. They estimated the following N surpluses i.e. plant-available mineral N left in the soil after crop harvest :

Table 20 - Estimates of nitrogen surplus under vegetable crops at Pukekohe

Drystock pasture	30 kg/ha	9% potentially leachable
Dairy pasture	157 kg/ha	10%
Kiwifruit	166 kg/ha	4%
Onions	118 kg/ha	17%
Potatoes	92 - 429 kg/ha	5 - 35%
Brassicas	168 - 286 kg/ha	1 - 3%

Crush et al postulated that that all land uses were likely to be substantial sources of nitrogen leaching to groundwater; vegetable crops more so than the rest because of:

* high fertilisation,
* reduced soil organic matter, so reduced ability to immobilise N,
* no retention of N by ground cover in winter.

In 1995-96 Crop and Food carried out field measurements under contract to ARC, on a limited number of fields under different crops at Pukekohe. Results are in an unpublished contract report (Francis and Williams 1997), and are summarised in a FSP newsletter as indicating substantial N leaching :

Table 21 - Field measurements of nitrogen balance under vegetable crops at Pukekohe

	Applied as fertiliser kg/ha	Removed in produce kg/ha	Surplus kg/ha	Leached in soil water kg/ha
Fallow	0	0	0	186
Spinach	418 & 356	85 & 80	333 & 276	294 & 107
Onions	-& 174	-& 85	-& 89	-& 219
Potatoes	580 & 539	90 & 90	490 & 449	276 & 321

They comment that :

* a low percentage of nitrogen was captured by crops (16-49%) suggesting N fertilisation in excess of plant needs,
* high nitrate leaching was associated with wet weather conditions in these years.

Crop and Food also carried out baseline sampling on three commercial growers properties at Pukekohe, Patumahoe and Tuakau, prior to cover crop trials for FSP. Results are documented in the same contract report (Francis and Williams 1997) :

Table 22 - Nutrient status of typical growers' fields after crop harvest
(ranges for ? fields on 3 properties)

Available P	before	155 - 180	ug/g
Available S	before	12 - 14	ug/g
Available N	before	6.0 - 9.1	ug/g
K	before	636 - 652	ug/g
Mg	before	136 - 151	ug/g
Ca	before	1379 - 1463	ug/g
Na	before	41 - 47	ug/g
Organic N	before	0.20 - 0.21	%
Organic C	before	2..11 - 2.21	%
Acidity	before	6.4 - 6.4	%

All sites had high residual values of plant-available nutrients left from the previous season's crops, confirming that fertiliser application rates generally exceeded crop requirements.

Beare et al 1999 measured changes in several soil nutrients in 21 fields on the properties of 4 growers, to collect data as part of their development of a soil quality monitoring system. Measurements are nutrient surpluses after crop harvest. They reported a wide range, but also measurable changes in range, with the transitions from long-term pasture to long-term cropping.

Table 23 - Changes in key soil nutrients under long-term vegetable cropping

Available nitrogen	Data aggregated for all growers
Long-term pasture	80 - 190 kg N/ha
Short-term cropping (1 - 5 yrs)	60 - 170
Long-term cropping (> 5 yrs)	40 - 120
Available phosphorus	Data aggregated for all growers
Long-term pasture	10 - 70 ug P/g
Short-term cropping (1 - 5 yrs)	20 - 70
Long-term cropping (> 5 yrs)	20 - 140 (most > 80)
Available potassium	Data aggregated for all growers
Long-term pasture	8 - 16 qt units
Short-term cropping (1 - 5 yrs)	10 - ?
Long-term cropping (> 5 yrs)	? - 36
Acidity	Data aggregated for all growers
Long-term pasture	5.5 - 6.6 pH units
Short-term cropping (1 - 5 yrs)	5.5 - 6.6 pH units
Long-term cropping (> 5 yrs)	5.5 - 6.6 pH units

Beare et al commented that all levels of soil nutrients appeared to match or exceed the optimum levels for growth of vegetable crops.

Beare et al (2005) subsequently reported another three years' measurements as part of a nationwide "Land Management Index" project funded by MAF, regional councils and NZPVGA. Summary data for Auckland and Waikato sites are given in Table 24. Most of the vegetable crop sites (60) are within Franklin District.

Table 24 - Average values for LMI indicators under different land uses, topsoil (0-15cm)

	Total C %	Total N %	Available C ug/g	Available P ug/g	pH units
Allophanic soils :					
Sheep pasture	6.82	0.67	1330	25.46	5.9
Dairy pasture	7.58	0.71	1654	26.79	5.9
Intensive crop	6.48	0.63	744	24.58	6.2
Vegetable crop	5.72	0.53	1170	41.99	6.1
Gley soils :					
Sheep pasture	3.84	0.36	1473	28.48	5.7
Dairy pasture	4.97	0.46	1291	39.11	5.8
Intensive crop	4.11	0.38	957	35.07	6.0
Granular soils :					
Sheep pasture	6.69	0.60	1505	15.65	5.8
Dairy pasture	6.02	0.55	1670	29.57	5.9
Vegetable crop	3.12	0.29	533	114.99	6.2
Intergrade soils :					
Sheep pasture	3.54	0.36	980	19.73	5.7
Dairy pasture	7.40	0.61	1709	30.77	6.0
Intensive crop	4.66	0.47	937	28.10	6.0

Table 24 shows, for cropping and vegetable growing when compared with sheep and dairy pasture:

* total carbon is slightly lower in allophanic soils, more so in granular and intergrade, and not significantly different in gley soils,

* total nitrogen is slightly lower in allophanic soils, more so in granular soils, and not significantly different in intergrade and gley soils,

* available carbon is somewhat lower in gley and intergrade soils, more so in allophanic, and substantially lower in granular soils,

* available phosphorus is slightly higher in gley and intergrade soils, very much higher in allophanic and granular soils,

* ph is slightly higher in all soil types.

Beare et al noted that changes were :

* for total carbon and total nitrogen, not significantly different for soil orders,
* for available carbon, significantly greater in allophanic and granular soils,
* for available phosphorus, significantly greater in granular soils.

The "500 Soils" study (Sparling and Rijkse 1997-2001, Sparling et al 2001) investigated soil nutrient status in somewhat more detail (though at a limited number of vegetable-growing sites) and compared them with other long-term land uses on the same soils. Table 25 gives soil nutrient data for the sites on Patumahoe, Karaka and related soils.

Table 25 - Soil fertility under different land uses on arable soils, Franklin

	Avail. P ug/ cm^3	Avail. N ug/ cm^3	Cation ex.cap. cmol/ cm^3	Base sat. % cm^3	Total C mg/	Acidity pH units
Patumahoe clay loam						
Bush	3.0	111	27.2	47	62.1	5.3
Drystock pasture	13.8	98	22.4	62	52.6	6.3
Drystock pasture	10.8	113	23.7	59	60.6	5.9
Drystock pasture (organic)	10.2	227	29.5	73	67.9	6.1
Dairy pasture	51.2	257	33.0	81	66.4	6.9
Vegetable crop (< 5 years)	15.1	120	22.2	90	46.5	6.4
Vegetable crop (> 30 years)	199.5	9?	22.1	103?	20.2	7.2
Kiwifruit orchard	39.2	104	27.4	72	56.2	6.3

? = typographic errors in authors' report? 93 and 100?

Karaka silt loam						
Bush	2.0	98.1	31.2	27	72.2	5.4
Drystock pasture	22.8	158	29.5	80	57.8	6.6
Dairy pasture	51.1	155	29.0	64	67.8	6.2
Dairy pasture (organic)	73.6	211	37.7	96	67.8	6.9
Vegetable crop (< 5 years)	19.6	73	28.1	78	56.2	6.6
Kiwifruit orchard	60.4	133	29.1	97	58.3	6.6
Feijoa orchard (organic)	48.1	99	24.3	73	59.6	6.2
Matakawau clay loam						
Bush	2.3	94	23.1	49	56.7	5.9
Drystock pasture (organic)	6.4	174	24.4	57	69.4	6.0
Dairy pasture	29.4	124	35.6	49	67.7	6.3
Vegetable crop (< 5 years)	83.3	91	22.9	45	66.9	5.8
Orchard	16.8	188	15.7	88	55.7	6.2
Ararimu clay loam						
Bush	35.4	85	38.9	15	114.5	4.1
Drystock pasture	50.3	159	27.2	52	71.3	5.7
Dairy pasture	14.7	152	23.9	77	64.2	6.1

Soil carbon declines short-term and long-term at horticultural sites, with one exception (Matakawau vegetable crop). Nitrogen is lower than at most pasture sites; a surprising result given the high nitrate fertiliser levels applied to horticultural land. For short-term horticultural sites, phosphorus is no higher than at pasture sites (again with the exception of Matakawau). For long-term sites it is very much higher; probably a consequence of heavy phosphate fertilisation several times a year. Cation exchange capacity and total exchangeable bases are variable and not significantly different, when compared with sites on the same soils under bush or drystock pasture. Ph is somewhat higher i.e. soil acidity is lower at horticultural sites, as a consequence of regular liming. Compared with the range of values for soils under vegetable crops elsewhere in the country (Sparling and Schipper 2003), Patumahoe and Karaka soils are at the low end of the range for soil carbon, but distributed through the range for other soil nutrients.

Sparling et al (2005) summarise similar "500 Soils" data for 26 horticultural and cropping sites on Waikato soils, some of which are in Franklin. However the reported data merely indicate what percentage of sites exceed threshold values. 31% have high available phosphorus, 4% have high total nitrogen, 8% have high available nitrogen, and 15% have low total carbon. Comparisons for the same soils, as presented for ARC sites in Table 14, are not extractable from the report supplied by EW.

Another scientific investigation, which approaches the nutrient status of Franklin soils from a different angle, is a report by Edmeades 2002 for Environment Waikato. This uses soil nutrient measurements from Haynes and Tregurtha 1999, to calculate total quantities of the main plant nutrients in a hectare of topsoil, and attaches dollar values to their replacement cost (Table 26).

Table 26 - Average nutrient content in topsoil of granular soils, Franklin District

	Amount of nutrient kg/ha/0-15cm	Value of nutrient $/ha/0-15cm
N	2600-5500	2340-4950
P	2890-9640	4624-15424
S	3050-12170	1220-4868
Ca	850-2550	51-153
Mg	68-170	54-136
K	140-420	126-378

The report proceeds to estimate value of topsoil lost through erosion each year, by applying these values to Basher et al's measurements of topsoil moving out of fields, and topsoil moving into watercourses. The economic value of nutrient losses in eroded topsoil is estimated as $35 to $570 a hectare each year for topsoil lost to growers (moving out of fields), and $1 to $21 a hectare each year for topsoil lost to the district (moving into watercourses). Edmeades comments that these are not large financial losses in the context of the budgets of most growers; and are unlikely to motivate growers to follow good management practices with respect to erosion control.

Additional points made by Edmeades are that :

* His estimates do not take the value of organic matter into account. It is known to benefit soil physical, chemical and biological properties, but it is not possible to attach dollar values to the improvements.

* Growers could reduce fertiliser applications and mine existing nutrient reserves in their soil (but scope for doing this is limited, given granular soils' slow release of nutrients cf. high plant nutrient uptake by continuous cropping).

* Presently commercial soil testing does not measure soil organic matter, or the splits between organic and inorganic N, P and S, which are useful things to know when planning fertiliser application.

* Estimates are crude because of the paucity of base data (though since his report was prepared, greater base data has become available through the Land Management Index and 500 Soils projects).

Comments

The scientific evidence indicates that, apart from soil carbon which is low, the Franklin soils' nutrient status is as good as soils used for vegetable cropping elsewhere in the country. Most soil nutrients are being maintained through heavy applications of fertiliser, that replace or exceed what is removed in produce. In this respect the Patumahoe and Karaka soils do not differ from any other regularly cropped soil.

There is evidence that nitrogen in particular is being leached from the soils; but also that fertiliser application is just one factor. Quantity leached can be high or low, depending on how much rain falls in the weeks following application. A substantial quantity can be leached, even from unfertilised sites, if N is available from other sources e.g. release from organic N in the soil or plant residue.

There are no reports in the scientific literature of vegetable crop yield declines in Franklin District, due to either nutrient deficiency, or to the plant nutrition problems that are sometimes associated with excessive fertiliser application, such as accumulation of heavy metals or other unwanted trace elements. Edmeade's estimates certainly indicate substantial nutrient losses to erosion each year, but the quantities are small relative to what growers apply to a field each year in the course of continuous cropping.

Measures that preserve soil fertility

FSP commissioned several trials by Crop and Food over the years between 1997 and 2002. Results are documented in a series of annual progress reports (Williams et al 1999a, 1999b, 2000a, 2000b, 2002) as well as a summary report which compares findings from these and other trials elsewhere in the country (Williams et al 2003). As with soil structure data, results from progress reports were communicated to growers through summaries in FSP newsletters, and also underpin some of the recommended practices in FSP's publication "Doing it Right". Each trial had multiple objectives, so findings can be separated out under three sub-headings.

Cover crops

Francis and Williams 1997 contains results from the first year of cover crop trials, giving soil nutrient status before cover crops were planted cf. immediately before they were ploughed in.

There were significant rises in available P, S and N. Ca and Na declined markedly. There were no significant changes in organic C, organic N, K or Mg. Under cover crops, levels of P and S were not significantly higher than in fallow fields. Mineral N was significantly lower under ryegrass, and significantly higher under mustard.

Table 27 - Cover crops' effect on soil nutrient status

		Ryegrass	Mustard	Oats	Fallow	
Available P	before	163	180	155	-	ug/g
	after	211	207	215	202	ug/g
Available S	before	14	12	14	-	ug/g
	after	32	31	32	30	ug/g
Available N	before	9.1	6.0	6.0	-	ug/g
	after	4.9	16.5	9.5	9.0	ug/g
K	before	636	652	646	-	ug/g
	after	640	675	680	670	ug/g
Mg	before	136	147	151		ug/g
	after	139	148	141	152	ug/g
Ca	before	1379	1481	1463	-	ug/g
	after	800	910	800	900	ug/g
Na	before	41	45	47	-	ug/g
	after	19	23	23	25	ug/g
Organic N	before	0.21	0.20	0.20	-	%
	after	0.21	0.21	0.21	0.20	%
Organic C	before	2.21	2.12	2.11	-	%
	after	2.19	2.15	2.14	2.08	%
Acidity	before	6.4	6.4	6.4	-	%
	after	6.3	6.3	6.2	6.4	%
N uptake		105	122	176	0	kg/ha
N leaching		5	6	3	9	kg/ha
Yield		5.2	3.9	6.6	0	t dm/ha

Francis and Williams concluded that :

* overall, cover crops did not significantly alter N leaching - N in soil water was very low under all cover crop and fallow sites - because no nitrogen fertiliser was applied over winter months,

* there is a risk of soil mineral N immobilising, if N% of the cover crop is below 2.5% (which is the case for ryegrass),

* cover crops that produce large amounts of dry matter can cause physical problems for establishment of a subsequent vegetable crop.

Timing of fertiliser application to reduce leaching loss

A subsequent trial in 1998 investigated effect of fertilisation after winter cover crops cf. after winter vegetable crops. Results are reported by Williams et al 1999 :

Table 28 - Effect of timing fertiliser application on soil nutrient status, crop uptake, and N leaching

Crop	Yield t/ha	Uptake kg N/ha	Leaching*	Fertiliser at planting	Leaching**
Fallow	-	0	100	-	40
Fallow	-	0	80	308	30
Oats+rye	7.4	145	not measured		
Sorghum	3.0	62	80	308	30
Phacelia	3.3	109	not measured		
Graze brassica	3.6	87			
Mulch brassica	4.0	135			
Winter veg + oats	-	-	70	308	15
Winter veg + fallow	-	0	70	308	10

* = under winter cover crop ** = under spring potatoes

Where fertiliser was applied in August after autumn-winter cover crops and at time of planting a spring vegetable crop (potatoes), there was significant increase in mineral N, also organic N and organic C, also most other soil nutrients; including on the fallow plots.

Where fertiliser was applied in October after an autumn vegetable crop and a winter-spring cover crop, and at time of planting a spring vegetable crop, there was slight increase in mineral N, no change in organic N, slight decrease in organic C, and slight increases in most other soil nutrients; including on the fallow plots.

Williams et al concluded that :

* Soil nutrient status was raised more effectively by late winter fertilisation than by spring fertilisation, because fewer soil nutrients were taken up in late winter-early spring when crops were growing slowly,

* Conversely uptake of nutrients by crops was more efficient when fertiliser was applied in spring when crop growth rate was faster,

* Nitrate leaching from winter cover crops was more substantial than in the 1997 winter, because the 1998 winter was much wetter,

* But there was just as much if not more nitrate leaching from fallow ground i.e. cover crops did not make any difference to nitrate leaching,

* There was less nitrate leaching from spring fertilisation than from late winter fertilisation, because more N was taken up by growing crops in spring.

Better matching of fertiliser application to crop needs

Williams et al 2000b reported results from the third year's trial, which investigated effect of varying rates of fertiliser application as well as times :

Table 29 - Effect of N fertiliser application rate on potato yield

Winter potatoes	Fertiliser treatment:				
	0	520	430	330	kg/ha
Mineral N before planting	8-115 (across all sites)				kg/ha
Leached before planting	62	42	40	45	kg/ha
Mineral N at planting	3-19 (across all sites)				kg/ha
Fertiliser at planting	0	370	180	180	kg/ha
Subsequent dressings	0	150(1)	250(3)	150(3)	kg/ha
Leached during crop	60	80	71	65	kg/ha
Plant uptake	90	243	264	248	kg/ha
Mineral N at harvest	14	301	301	143	kg/ha
Yield	28	59	63	61	t/ha

Spring potatoes	Fertiliser treatment :				
	0	420	350	250	kg/ha
Mineral N before planting	-				kg/ha
Leached before planting	87	-	84	86	kg/ha
Mineral N at planting	-				kg/ha
Fertiliser at planting	0	300	150	150	kg/ha
Subsequent dressings	0	120(2)	200(3)	100(2)	kg/ha
Leached during crop	18	-	40	38	kg/ha
Plant uptake	112	-	218	208	kg/ha
Mineral N at harvest	15	-	617	283	kg/ha
Yield	57	-	66	67	t/ha

Results from these trials were extremely variable, as regards initial mineral N in soil, N leaching, and mineral N at harvest. Also an additional 150 kg N/ha in each case was taken up by crops from mineralisation of organic N.

Williams et al concluded that :

* reducing N fertiliser application to 330 kg/ha had no detrimental effect on yield,
* had little effect on leaching during crop growth,
* reduced N remaining in the soil at harvest - but there was still a large quantity of mineral N available either for crop uptake or leaching the next season.

A similar trial was conducted for cabbages :

Table 30 - Effect of N fertiliser application rate on cabbage yield

Autumn cabbages	Fertiliser treatment:		
	0	150	kg/ha
Mineral N before planting	-	-	kg/ha
Leached before planting	-	-	kg/ha
Mineral N at planting	10-73	10-73	kg/ha
Fertiliser at planting (May)	0	150	kg/ha
Subsequent dressings	0	0	kg/ha
Leached during crop	68	178	kg/ha
Plant uptake	115	190	kg/ha
Mineral N at harvest	-50	0	kg/ha cf. mineral N at planting
Yield	12	37	t/ha

Williams et al concluded that :

* there had been substantial nitrogen leaching during the winter months when crop growth was minimal,
* nitrogen leaching could be reduced by applying fertiliser in August when plants were big enough to take up N.

Effect of sub-soiling on leaching

In 1999 Crop and Food investigated the effect of sub-soiling on nitrate leaching for FSP. Results are documented in a contract report by Williams et al (2000a) :

Table 31 - Sub-soiling's effect on nitrate leaching

	No subsoiling	Shallow subsoiling (to 35 cm)	Deep subsoiling (to 60 cm)	
N fertiliser at planting (June)				
1st side dressing (August)				
2nd side dressing (September)				
3rd side dressing (November)				
Mineral N before treatment	25	25	25	kg/ha
Mineral N after harvest	17	19	53	kg/ha
Crop uptake	86	87	98	kg/ha
N leaching	66	71	71	kg/ha
Unaccounted N	76	68	19	kg/ha
Onion yield (January)	158	153	154	t/ha

Soil drainage between planting and the first dressing was 150mm, was also 150mm between the first and third dressings, and declined to 100mm between the third dressing and harvest. Nitrogen uptake by the crop occurred from September onwards, peaking in late October and November. Nitrate leaching was high at the time of planting and initial fertilisation, declined until the first side dressing, increased from the first through the second and third side dressings, and was not measured after the third side dressing.

Williams et al concluded that :

* there was no significant difference in nitrate leaching as a result of sub-soiling,

* there was greater soil N storage in the deep-ripped plots,

* there may have been release of soil organic N in the deep-ripped plots,

* unaccounted N in the shallow-ripped and control plots may have been incorporated into soil organic N, or lost by denitrification,

* amount and timing of N fertiliser was about right, as it didn't increase leaching or result in an accumulation of excess N (except in the deep-ripped plots).

Effect of varying other fertiliser application rates

During the FSP extension (2000-2002) a final Crop and Food trial was conducted in 2002 for early-planted winter potatoes at Pukekohe (May) and Pukekawa (June). Results are documented by Williams (2002), and compared with results from other trial sites by Williams et al (2003)

Table 32 - Effect of reduced N, P and K on potato yield

	Pukekohe 1	Pukekohe 2	Pukekawa 1	Pukekawa 2	
P applied	?	?	200	100	kg/ha
K applied	?	?	200	100	kg/ha
N applied at planting	319	109	450	350	kg/ha
N applied during growth	150	150	0	0	kg/ha
N uptake by crop	108	103	180	147	kg/ha
N leached	171	111	145	147	kg/ha
N in soil at harvest	240	100	?	?	kg/ha
Yield	28	26	45	39	t/ha

Williams et al reported that :

* higher yields at Pukekawa cf. Pukekohe are attributable to higher initial soil nutrient status at Pukekawa (fertiliser residue from previous crops),

* reduced N application at planting, followed by same application during crop growth, maintains yield (from Pukekohe trial),

* reduced P and K application causes somewhat lower yield (from Pukekawa trial),

* N application rates need to be reduced below 300 kg/ha to have an effect on nitrogen leaching (from both trials).

General comments on FSP trials

The fertiliser trials conducted for FSP have had more thorough data collection and analysis than the trials of practices for runoff control and soil structural improvement.

My conclusions are that the scientific evidence convincingly demonstrates :

* that reduced fertiliser applications result in lower post-harvest soil nutrient status,

* though this does not limit crop growth or yield because residual fertiliser application is still sufficient for plant uptake requirements of the main vegetable crops (onions, potatoes, brassicas),

* varying the time and rate of nitrogen fertiliser application, to co-incide with the main periods of crop growth, reduces nitrogen leaching,

* however substantial nitrogen leaching can still occur because of N release from soil organic matter and plant residues, particularly during wet weather.

Refer to Section 9 for information about growers' uptake of these measures and what effect they have on sustainability of cultivation.

8 SOIL CONTAMINANTS

A summary of scientific information about soil contaminants was not part of the brief for this review. The following information has been supplied by Environment Waikato (N. Kim pers. comm.) following receipt of the draft.

Phosphate fertilisers contain a number of elements that naturally occur in rock phosphate deposits at well above background concentrations (McBride and Speirs, 2001). Some of these elements are steadily accumulating in New Zealand's agricultural (pastoral and horticultural) soils as a result of phosphate fertiliser use (mainly superphosphate, followed by diammonium phosphate), so could be expected in Franklin soils given the high rates of phosphate fertiliser application for continuous vegetable growing.

Cadmium is probably the most significant of these contaminants, because it has the potential to make soils unsuitable for production of certain crops, due to the problem of food standards being broken through cadmium uptake from soils with elevated cadmium and low pH. MAF has convened a Cadmium Working Group to carry out an updated risk-assessment on this issue. Waikato agricultural and horticultural surface soils (the latter include sites in Franklin District) have about 0.7 mg/kg cadmium on average (about four to five times the background concentration). Close to the soil surface, levels may be two to three times the average. Dairy soils sampled to date have more cadmium than other land uses (averaging about 0.82 mg/kg), due to higher superphosphate loadings. Ballance Agri-Nutrients report these levels as likely to approach 1 mg/kg in the longer term. This is the limit suggested for cadmium in New Zealand soils by the authors of the *Guidelines for the Safe Application of Biosolids to Land in New Zealand* (NZWWA, 2003).

Other contaminants that are accumulating in soils as a result of phosphate fertiliser use include fluorine and uranium (Cronin et al, 2000; Loganathan et al, 2001, Rothbaum et al, 1979; Taylor, 1997). Ballance Agri-Nutrients report that fluorine accumulates in soil at a rate of 5-10% per year. Over the longer term, this has the potential to lead to loss of production through onset of fluorosis in animals through ingestion of soil. This is currently an active area of research at Massey University (Cronin et al, 2000).

Contamination of agricultural land can come about through a number of pesticide sources, old and modern. Use of copper fungicides over horticultural soils causes accumulation of copper, with almost all applied copper being retained in the soil A horizon. In some cases this accumulation is sufficient to cause subsequent hindrances to subdivision (due to residential guideline values being exceeded), and in others it is sufficient to cause a dead zone in the soil surface where grass does not grow. Similarly, a number of the dithiocarbamate class of pesticides cause accumulation of zinc and manganese. On pastoral land, there is some indication that zinc used as an antidote for facial eczema in stock is likely to be accumulating in soils, and that some of this is also making its way to sediments of associated streams and lakes.

Potential issues with copper and zinc accumulation for soils are mainly that elevated levels can start to have a negative impact on both soil microbial function (e.g. the ability of organisms to mineralise nitrogen) and plant health. These contaminants do not pose significant risks to human health, but rather can pose problems for productive capacity.

Apart from the above paragraphs, no information has been supplied by Auckland Regional Council or Environment Waikato, about any data these agencies possess relevant to contamination of horticultural soils in Franklin District.

9 THE FUTURE SUSTAINABILITY OF CURRENT PRACTICES

What the scientific information indicates about sustainability of current cultivation practices

Off-site soil loss

Measured off-site soil loss averages about 500 tonnes a square kilometre each year into public drains, and about 50 tonnes a square kilometre each year into the lower reaches of watercourses. The figure for watercourses is within the bounds of sediment yield for similar catchments under natural vegetation and pasture, so any environmental impact on local watercourses from off-site soil loss is no greater than would be expected.

There are some anecdotal observations of sediment accumulation along riparian wetlands in the upper reaches of watercourses, but this deposition remains un-measured.

The accumulation in public drains is substantial, and has several impacts :

* loss of drains' flow capacity,
* flood overflows during heavy rain,
* traffic hazard when soil is deposited on roads by overflows,
* annual expenditure on drain cleaning (about $600,000 annually by the local drainage authorities).

On-site soil movement

On-site soil movement around fields averages 5700 tonnes a square kilometre each year, which is a very high figure. 3600 tonnes is deposited on lower slopes within the fields, and about 1500 tonnes leaves fields and is deposited elsewhere on growers' properties or their neighbours.

Sites of deposition remain un-measured. Anecdotal observations by locals and ARC staff, are that soil is deposited behind hedges, on headlands, in private drains, and in depressions within the landscape that function as overland flow paths during floods.

The impacts are :

* soil profile truncation on upper slopes,
* soil profile thickening on lower slopes,
* annual costs incurred by growers clearing private drains,
* soil loss if drain cleanings are dumped rather than re-spread.

Edmeades' recent assessment for Environment Waikato, is that the replacement value of nutrients in topsoil leaving fields is within the range $35 to $570 a hectare annually.

Soil structure

Structural changes are increased bulk density (compaction), decreased porosity (plant-available water storage), reduced aggregate stability (tilth), harder subsoil (pan), and reduced soil organic matter. Except for soil organic matter, all these changes are slight, even on soils that have been continuously cultivated for decades.

The impacts are on growers' cultivation practices:

* annual subsoiling to counteract pan formation,
* slightly greater irrigation frequency,
* somewhat increased cultivation passes to obtain good tilth,
* need to add plant residue or compost to topsoil to restore soil organic matter,

but there are no adverse impacts in terms of reduced crop yield. As the former DSIR's soil scientists used to say, granular volcanic soils have resilient structure. The recent Landcare Research comparative study "500 Soils" shows that their structure is still excellent compared with other soils under long-term cropping elsewhere in New Zealand.

Soil fertility

Fertility changes are reduced organic carbon and nitrogen; greatly increased mineral nitrogen, phosphorus and potassium; and somewhat increased calcium, magnesium, sodium and sulphur. What has occurred in the soils is a change from slow cycling of nutrients, mainly stored and released from soil organic matter under natural conditions, to rapid cycling mainly added to the soil as mineral fertiliser, incorporated into growing crops, and either removed at harvest or released from plant organic matter (crop residue) back into soil.

The impacts are :

* reduced storage and release of nutrients from soil organic matter,

* increased storage and release of nutrients from plant organic matter,

* need for growers to apply mineral fertilisers, to maintain faster cycling of nutrients through plant organic matter,

* greater leaching of nutrients by rainfall percolating through soil,

* nutrient accumulation, particularly nitrogen, in groundwater.

Soil contaminants

There is little or no published information specifically on Franklin soils, though general scientific reviews of New Zealand data in recent years indicate:

* With the exception of copper and zinc, modern pesticide residues in soils used for long-term vegetable cropping are measurable but low. Current levels in harvested produce are well below MAF/WHO thresholds for human consumption; and are more likely from direct application onto crops than by plant up-take from soil. Problems still arise with subdivision of long-term orchards and other horticultural sites, which are most frequently caused by soil

arsenic levels exceeding residential guideline values. Lead arsenate was in widespread use as an insecticide up until the late 1950s.

* Low levels of certain pesticides are accumulating in groundwater. It is unclear whether these are being leached from soil - pesticide residues in soil are generally well-bonded to clay minerals - or moving directly to groundwater through infiltrating rainwater after being washed off crops. Strong fixation should not be taken to imply that a pesticide will not leach in significant amounts (in relation to drinking water standards) or that non-equilibrium transport processes like colloidal transport are not dominating a given case. When pesticides are detected in groundwater, it is because they have leached to groundwater, where leaching is a blanket term to cover all these processes. As yet they are well below ANZECC/WHO thresholds for public water supply, though there would be concern if the levels increase.

* As far as being soil contaminants, most of the modern pesticides degrade within a reasonable timeframe, and there are comparatively few that might cause progressive accumulation. Some of those that do accumulate are so tightly locked up by the soil that they are unlikely to pose a long-term risk. The main exceptions are those with a metal component as noted above – copper fungicides and zinc and manganese containing dithiocarbamates.

* Biological contamination of soils by plant-disease-bearing organisms is present in many fields. This form of contamination impacts on growers either as reduced crop yields, or increased spraying costs. The Integrated Pest Management procedures promoted by FSP are essentially surveys for early detection of plant diseases and insect infestations, with a view to better targeting of spray, so as to reduce chemical residues as well as biological contaminants.

* Nitrogen in groundwater is of concern, because it already exceeds WHO thresholds. Mineral N is not really a soil contaminant; it is a naturally occurring substance in soil which may be elevated by manufactured fertiliser. Undoubtedly some of the nitrogen in groundwater under Franklin is due to excess fertiliser application. Under intensive cropping, large amounts are also released from soil organic N (nitrogen bonded to carbon in the soil), and from plant organic N (nitrogen bonded to carbon in crop residue).

What the trials indicate about practices that can help sustain vegetable growing

Off-site soil loss

FSP trialed grassed waterways, contour drains, vetiver and lemongrass hedges, silt fences, bunds and silt traps, for the control of off-site soil loss. Apart from anecdotal observations and photographs, there was very little measurement of how much soil actually entered or left these structures at the demonstration sites.

FSP promoted silt traps in particular, as a way to stop soil before it enters public drains or watercourses. There have been no thorough scientific investigations into the efficacy of silt traps on local soils. A limited amount of data, collected by FSP staff towards the end of the project, indicates that if constructed to specifications, they reduce sediment concentrations in runoff leaving fields. Records kept by one local grower suggest that silt traps are collecting between 8 and 16 tonnes of soil a hectare each year in runoff from continuously cultivated fields; but more records are needed from more sites, to verify the silt traps' performance.

The scientific investigations of soil loss (in the absence of silt traps, bunds or other protective measures) collectively indicate that about a quarter of the soil leaving growers' fields (500 - 600 out of 2100 t/km^2/yr) is actually lost, in the sense that it leaves land and enters watercourses. The balance is re-deposited somewhere else on growers' properties, or on their neighbours. Where it ends up is unaccounted for, but likely locations are on headlands, behind hedges, in depressions in the landscape which function as overland flow paths, or in private drains and ponds. These sites may also function as efficient de facto sediment traps, but how much soil is regularly cleaned from them, with the cleanings spread on fields or dumped, and how much simply accumulates from year to year, are unknowns.

On-site soil movement

FSP trialed cover crops, sub-soiling and wheel-track ripping for the reduction of on-site soil movement. Enough measurements were taken to demonstrate that wheel-track ripping greatly reduces movement of soil down wheel-tracks during rain. There were no measurements to ascertain how soil movement changed after sub-soiling or under cover crops.

FSP promoted all three measures as ways to reduce soil moving through cultivated fields. Some fortuitous measurements in the wider Pukekohe area, after the January 1999 storm demonstrated that the area of surface erosion under cover-cropped fields was similar to that under vegetable crops, and much less than in fields that were freshly harvested or fallow. This is good evidence for efficacy of cover cropping. Sub-soiling could be expected to alter downslope soil movement in a similar way to wheel-track ripping, but its effect has yet to be verified.

The scientific investigations show that rill erosion is the main process of soil movement through fields. The fortuitous storm damage survey associated some rill erosion with field tracks, but most of it with drain overflows upslope of fields. Anecdotal observations (in FSP newsletters and guidelines) suggest that adequate cut-off drains in the upper headlands of fields may be a necessary practice for the avoidance of rill erosion. This is another practice that needs closer investigation and measurement.

Soil structure

FSP trialed cover crops and sub-soiling as means of improving soil structure. Again, few measurements were made to ascertain whether these techniques had a beneficial effect on local soils. Sub-soiling was demonstrated to decrease soil penetration resistance and increase soil water movement. The soil physical measurements under cover crops are inconclusive as regards their effect on bulk density, penetration resistance, porosity and water storage, or soil organic matter.

A soil scientist would not expect significant changes in soil structural properties after a single season of cover cropping. Some changes might be expected after several seasons of cover crop incorporation, but the trials did not run for long enough to detect this.

Low soil carbon in long-term cropped fields suggests that not a great deal of plant residue is incorporated into soil after vegetable crop harvest. Crop trash incorporation is a practice known to improve soil structure in many overseas countries, but its feasibility on Franklin soils does not appear to have been investigated. There may be reluctance on growers' part to do this, because of disease problems or difficulty in cultivating soil that contains crop trash.

Soil fertility

FSP trialed practices that entail varying the quantity, timing and rate of fertiliser application. This is the one set of trials where adequate measurements were taken over several years. The measurements demonstrated that reduced fertiliser applications, timed to co-incide with growth periods, maintain yields of the main crops (onions, potatoes, brassicas) though result in lower soil nutrient status after harvest.

A plant agronomist might take the view that lower soil nutrient status at harvest is not actually a problem. Intensive vegetable growing, where two or more crops are grown each year, depends on mineral fertiliser application; not on a store of plant-available nutrients in the soil, which would be quickly exhausted by a few cycles of crop growth. Keeping post-harvest soil nutrient status low may actually benefit Franklin soils, because if it were high, many of the nutrients would be leached by rainfall before the next crop growth cycle.

One practice which has not been investigated, is raising the quantity of nutrients immobilised in soil organic matter and slowly released for plant growth. This practice is known to under-pin small-scale intensive vegetable production in some overseas countries, and is practised by at least some growers in other parts of New Zealand such as Otaki and Oamaru. It depends on incorporating very high quantities of compost or manure. Whether such quantities are economic - or available - to local Franklin growers, and whether they could be fitted into the growers' cultivation cycle, are as yet unanswered questions.

Soil contaminants

FSP trialed "integrated pest management" (IPM) procedures for early detection and control of several insects and plant diseases. They appear to have been amongst the more successful FSP trials in terms of success and grower uptake, though are beyond the scope of this review.

Several scientific reviews refer to measurements of heavy metals and pesticides in Franklin soils, indicating that residues are measurable but not problematical. The investigators do not appear to have promoted changes in pesticide application practice, apart from encouraging accordance with whatever ACB/ERMA regulations prevailed at the time.

The main groundwater contamination issue, nitrogen, is not a soil contaminant. Rather it is a naturally occurring substance in soil. The scientific investigations of Franklin groundwater have not established that the nitrogen comes from excess fertiliser application, as opposed to other sources. Reducing fertiliser application, or altering its timing, will not by itself reduce nitrogen levels in groundwater if much of the nitrogen is released from soil organic matter and plant organic matter. FSP trials indicate both sources are substantial, under continuous vegetable cropping on local soils.

Information available about growers' uptake of these practices since FSP

Information about grower up-take on specific properties has been available in the past from site inspections by ARC staff or consultants engaged by ARC. However as these were ad hoc responses to problems, they did not give a typical picture of grower up-take. An effort is now being made to undertake site-by-site surveys of measures present/absent on growers' properties each year, at least by viewing from the roadside (P. Begley and S. Bryant pers. comms.). When these survey results are available in summary form as tables or maps, they will provide a district-wide picture of what growers are doing by way of measures to reduce on-site soil movement, and reduce its loss off-site.

Erosion management property plans were developed for vegetable growers in the closing stages of FSP (A. Barber pers. comm.). As yet these have been produced for about half a dozen properties. As the number increases, they may prove to be a useful source of information about the measures that growers install on their properties.

Meanwhile, the only documents giving an overall picture of grower up-take are annual surveys conducted by A. Barber of Agrilink between 2002 and 2004 during the second phase of FSP. Each year between 27 and 20 growers were randomly selected (about a 10% sample of growers or a 5% sample of properties).

Off-site soil loss	2002	2003	2004
Grassed waterways	no data	no data	no data
Contour drains	74%	60%	60%
Silt fences	no data	no data	no data
Silt traps	78%	45%	75%
Hedges	74%	45%	40%
Raised accessways	55%	50%	40%
Headlands	67%	85%	90%
Grassed paddock edges	no data	80%	90%

Survey results show a majority of growers have adopted one or more techniques for reducing off-site soil loss. The mix of techniques is quite variable from one property to the next, in part due to different site requirements, and in part to individual preferences. A more detailed break-down by Barber of his 2003 and 2004 data indicates that in some instances the adopted technique is inadequate or inappropriate, and that another more suitable technique is needed.

On-site soil movement	2002	2003	2004
Cover crops	78%	50%	30%
Sub-soiling	15%	no data	no data
Wheel track ripping	37%	5%	0%
Changed cultivation	30%	no data	no data
Changed irrigation	55%	no data	no data

These results show a majority of growers were using cover crops (on part but not all their property) while FSP was in progress, but their use is now in decline. Likewise wheel track ripping. By 2002 a number of growers had reduced frequency of cultivation passes, and were applying less irrigation water more frequently; but later surveys do not indicate whether these trends continue.

Soil structure	2002	2003	2004
Cover crops	78%	50%	30%
Sub-soiling	15%	no data	no data
Crop rotation	11%	no data	no data

Cover crops to benefit soil structure are in decline. Sub-soiling was not used by many growers in the 2002 survey. A small number of growers had started to rotate crops or spell cropped fields in pasture.

Soil fertility	2002
Regular testing	74%
Adjusting timing	74%
Adjusting quantity	48%

A majority of growers commissioned regular soil tests, and all indicated that they adjusted timing of fertiliser application; though it is unclear whether this entailed application to co-incide with crop growth (as recommended by Crop & Food), or application after receipt of low test results. Half the growers indicated that they were now applying less fertiliser; again unclear whether this was due to Crop & Food recommendations about optimum rates for crop growth, or receipt of high test results).

Soil contaminants	2002
IPM crop walks/scouts	78%
IPM-linked spraying	67%

Most growers indicated that they had adopted the IPM inspection technique. Two-thirds indicated they had adjusted their spraying programme as a result of these inspections, though it is unclear whether the adjustments entailed less or more spray application.

10 CONCLUSIONS: THE ONGOING VIABILITY OF CULTIVATING FRANKLIN SOILS FOR COMMERCIAL VEGETABLE PRODUCTION

Key messages which emerge from the preceding sections of this review are given below, under the relevant sub-headings.

Off-site soil loss

Off-site soil loss does not threaten viability of cultivation. Although a large quantity of soil moves around fields (up to 5700 tonnes per square kilometre each year measured), about two thirds (3600 tonnes) is re-deposited within fields.

* About a quarter (1500 tonnes) is deposited elsewhere on growers' properties or adjacent land. Less than a tenth (500 to 600 tonnes) is actually lost, in the sense that it passes off land into drains and streams.

* Constructed bunds and silt traps are of value for trapping some of the soil that leaves growers' fields, before it gets elsewhere on their properties, their neighbours, or into watercourses.

* More records of sediment removed from silt traps are needed, to verify their performance on local soils.

* Several other locations on growers' properties may act as efficient de facto sediment traps. These are headlands, hedges, natural depressions that function as overland flow paths, drains, and ponds.

* There needs to be greater knowledge about how much soil is accumulating at these locations, and what happens to it afterwards.

On-site soil movement

On-site soil movement, although very great, does not threaten viability of cultivation, because about two thirds is re-deposited in the same field.

* Much re-deposited soil is re-distributed around fields by existing grower practices i.e. in the course of normal cultivation, and on occasion by bulk transportation and re-spreading upslope. However there is a long-term net transfer from upper slopes to lower slopes.

* FSP has identified five additional practices which can reduce on-site soil movement substantially : headland diversion drains, wheel track ripping, sub-soiling beneath seed beds, hedges, and cover crops.

* There is some grower resistance to cover crops for agronomic reasons. Wheel track ripping and sub-soiling fit in well with existing cultivation practices. Headland diversion drains and hedges are intermediate in terms of their impact on vegetable growing, so may be worth promoting somewhat more.

Soil structure

Structural deterioration does not threaten viability of cultivation. It occurs, but is minor in scale and effects, even in fields that have been cropped for many decades.

* FSP has confirmed that an existing grower practice - subsoiling - is beneficial in counteracting the minor deterioration that occurs i.e. slight compaction forming a weak tillage pan, with associated slight reduction in porosity and water movement.

* One issue of concern is low soil organic matter, not so much because of its structural effects on these particular soils which remain resilient even when soil organic matter is low, but because of its implications for nutrient cycling (see below).

Soil nutrients

Soil nutrient status does not threaten viability of cultivation. Intensive vegetable growing is sustained by rapid nutrient cycling between mineral fertiliser, crop up-take, and plant-available minerals in the soil.

* FSP has identified a need for growers to adjust quantity of fertiliser applied downwards, to match crop growth requirements.

* It has also identified a need to time fertiliser application better, to co-incide with crop growth periods.

* Surveys indicate some but not all growers are changing fertiliser application, so it may be worth promoting this advice somewhat more.

* Long-term fertiliser requirements could be off-set by raising soil organic matter, so that more nutrients are stored and released from it.

* Greater incorporation of cover crops and vegetable crop residue are techniques that can improve soil organic matter long-term, but there is grower resistance to these because they make cultivation more difficult and are perceived as increasing pest and disease infestations.

* Incorporation of compost or manure brought from off-site may be worth investigating as alternative techniques for raising soil organic matter. At this stage they cannot be recommended in the absence of information about availability, cost, and feasibility of incorporating into local growers' cultivation practices.

Soil contaminants

Heavy metals, pesticide residues and disease-bearing organisms are not part of the brief for this review. There do not appear to be any published documents that specifically deal with contamination of Franklin soils. General reviews of New Zealand information on these subjects (Cronin 1997, McBride and Spiers 2001) indicate that contaminants are measurable, but not yet at levels which exceed food quality or public health standards.

Excess nitrogen in the Franklin aquifer is likewise not part of the brief for the review, and the topic has already been summarised by another (Cathcart 1996). However because it is linked with vegetable growing on Franklin District's soils, the following comments are offered:

* Nitrogen is a naturally occurring substance in soil. It is not a soil contaminant, but it becomes a water contaminant when excess quantities move out of soil into waterways or groundwater.

* Excess nitrogen in groundwater is as likely to come from release of mineral nitrogen out of plant organic matter (crop residue), or out of soil organic matter, as from leaching of mineral nitrogen applied as fertiliser.

* So long as Franklin's arable soils are cultivated for vegetable production, rainwater will leach substantial nitrogen from all three sources out of the soils, and through porous volcanic rocks into the aquifer.

* This may be the single largest environmental impact of vegetable growing. It does not threaten viability of cultivation or sustainability of vegetable production, but it puts long-term usability of the Franklin aquifer in question.

Economic viability of vegetable growing

This also is beyond the scope of the review, though some brief comments are appropriate at its conclusion.

There is now some evidence that the area in traditional crops (onions and potatoes) is in decline at Pukekohe, as growers move elsewhere in Franklin, for instance onto the Karaka soils between Karaka, Drury and Kingseat, or out of the district altogether onto similarly productive granular and allophanic soils in the Waikato. A investigation currently under way (Goodwin 2006 in prep) reports that horticultural use of soils in the Auckland region has increased slightly between 1992 and 2002, but the area under onions has declined by 36%, and the area under potatoes by 70% between those dates. Goodwin considers that factors in decline are, firstly high land prices on Auckland's rural fringe, and secondly low returns to growers due to a shift from traditional auction marketing towards contract supply of supermarkets. These factors :

* encourage sale of horticultural land for alternative uses such as lifestyle blocks or urban subdivisions,

* decrease affordability of re-location onto other local soils suitable for horticulture,

* make vegetable supply to Auckland from cheaper land, in other parts of the country, an economic proposition.

Goodwin's comments are a timely reminder that economic conditions are more likely to reduce the sustainability of vegetable growing, than the physical condition of horticultural soils in Franklin.

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