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# Land Management for Process Tomatoes

***Recommended Best Management Practices for New Zealand***

**Jeff Reid, Andrea Pearson, and Jacinda English**

**Crop & Food Research Hawke's Bay, RD 2, Hastings**

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# Contents

# 1 Introduction

This is a set of Recommended Best Management Practices (RBMPs) for land management to help New Zealand's process tomato industry achieve environmental and economic sustainability. The original version of this document was an internet web site, launched in March 2000. That web-site is no longer maintained, and we replaced it with this revised document that can be downloaded. In 2005, a much more detailed and broader document on process tomato crop management was released for Heinz-Watties growers only. However, we have kept this land management document available for the general public.

The recommendations are organised around the annual cycle of tomato crop production. They are deliberately simple and practical. They are cross referenced to fact sheets with more detailed information.

We recommend that you first read the background information below and the aims of the RBMPs, then read the recommendations through before the more detailed fact sheets.

## *1.1 Disclaimer*

The information and recommendations in this document are given in good faith. Under New Zealand conditions, following these recommendations should improve the profitability and environmental sustainability of process tomato growing. The circumstances under which this information is acted on are not under the control of either Crop & Food Research or the funding agencies associated with this project (see Sections 4.1 and 4.4). Accordingly, Crop & Food Research, Ministry for the Environment, Heinz Wattie's Australasia Ltd, the Foundation for Arable Research, NZ Fertiliser Manufacturers Research Association, and NZ Vegetable and Potato Growers' Association cannot be held responsible for any losses arising from the use of this document.

## *1.2 Process tomato production in New Zealand*

In the 1990s, process tomato production utilised about 1830 ha of land in the North Island of New Zealand. Although this area is relatively small, the economic value of the industry is large and the land used was generally the prime horticultural land of Hawke's Bay and Gisborne.

Over the last 20 years of the 20$^{th}$ century, pressure on the already limited resource of suitable soils increased due to competition from other land uses. Increasingly, this pressure forced production onto more marginal soils, where productivity can be low and the environment more fragile. It also forced growers into more intensive management systems, and particularly into tighter crop rotations. Those rotations rest the soil much less between crops and increase the risk of environmental damage (e.g. groundwater pollution).

Another key trend has been for fewer and fewer tomato growers, each managing more and more land area. Now, much of the production area is leased, and the competition for land is such that the growers have little influence over the nature and duration of crop rotations. Increasingly, land owners lease their land to the highest bidder on a year by year basis.

There is no sign that these trends will ease in the 21$^{st}$ century. To compete in the world arena, New Zealand faces the challenge of growing crops in an economically competitive and environmentally sustainable manner. To meet that challenge, in 1997 we commenced a program to develop a set of Recommended Best Management Practices (RBMPs) for land management under process tomatoes in New Zealand. The program, 'Sustainable Crop

Production' was funded by industry and central government (see Section 4.1 ).

## 1.3 Aims of the RBMPs

These RBMPs aim to help the NZ process tomato industry to achieve environmental and economic sustainability. They are based on the premise that tomato crops perform best when grown in soils that are in excellent physical, chemical and biological condition.

The RBMPs aim to:

- maintain or improve soil quality;
- minimise nitrate leaching to groundwater;
- provide a protocol for growers and regulatory agencies to monitor soil quality in a way that is appropriate for tomato production;
- improve crop yields and profitability.

Implementing the RBMPs is a crucial step towards achieving tomato production that is demonstrably sustainable in environmental terms, and yet achieves better yields and profitability than ever before. One consequence of these changes is that growers will have a strong economic incentive to manage smaller areas better, so environmental sustainability becomes a financially profitable strategy.

## 1.4 Key concepts – the Yield Gap

- The RBMPs are based on methods to minimise what we call the Yield Gap.
- The Yield Gap is defined as the difference between attainable and actual yields.
- The yield gap can be expressed in t/ha or as a % of the attainable yield.
- Attainable yield is the yield that the crop could have achieved if it was grown in soil in
- excellent physical and biological condition. To calculate this we use a computer model of the growth of tomato crops (see Section 3.2). The model takes account of factors such as planting date, soil chemical fertility, fertiliser and irrigation applications, crop variety, and the weather (air temperature, rainfall, solar radiation). The model has been calibrated on sites where the soil was in excellent condition.

# 2 Recommendations

### 2.1.1 Site selection - check before visiting the site

**Use soil maps as a preliminary guide to paddock suitability**. There is no guarantee the soil type(s) in a given paddock will be exactly as mapped, but the maps are an excellent start (see Section 3.11). Note that the texture classes attached to the soil names mainly reflect topsoil properties, and subsoil textures may be quite different from the topsoil. In general give top priority to silt loams, followed by silty clay loams and sandy loams. In Hawke's Bay, some clay loams have dense subsoils that can cause problems in wet conditions (e.g. Kaipo clay loam, class19 on 1938 and 1997 soil maps). Note also that the soil texture assignation will help you to understand where the site is in the landscape. Compared with sandy loams, clay loams and silty clay loams tend to be lower in the landscape and further from existing or previous water courses, often with the silt loams between.

**Identify possible problems from the recent history of the paddock.** The paddocks with least problems will be those that have spent most of the previous 5 years under grass. Generally, paddocks that have been continuously cropped with little or no cover of grass over autumn and winter will present the most problems. Sites that were recently orchards vary greatly in their suitability, and there is no general rule for comparing orchard soils with those used for crops or grass.

**Irrigation water should be available** and the user must have the appropriate resource consent from the regional council.

**Obtain whatever copies of recent soil test results are available**. Use these to check that you will not need to apply large amounts of fertilisers (see Sections 3.7 and 3.4) As a general rule, try to select paddocks with exchangeable K >1.0 meq/100g, and Olsen P >25. In particular, try to avoid paddocks where soil pH <5. Those paddocks often need lime, but lime applied close to planting may also suppress yield (see Section 3.4.4).

### 2.1.2 Site selection - check when visiting the site

**Check layout and access** – these should enable you to minimise driving over or parking agricultural machinery on cultivated areas. In particular, aim to minimise the number of turns tractors and harvesting machines will need to make.

**Sites should be level or nearly level**. Under heavy rainfall or irrigation low points within paddocks can become ponded, which can reduce crop yields and the ability of the soil to withstand movement of machinery (see Sections 3.12.1, 3.2.2, and 3.3.1).

**Avoid paddocks that are low points in the landscape** - to minimise the risk that the site will receive run-off and drainage from adjacent areas.

**Give priority to paddocks that are tile drained** -this will reduce the chances of water ponding on the soil surface.

**Examine the soil**, checking the soil profile for soil texture, the presence of compact layers, and soil structure score. Follow the procedure given in Section 3.9.1.

Record soil texture and soil structure score (see Sections 3.1 and 3.9.1) for the 0-15 cm depth. Then repeat the process for 15-30 cm depth. In addition to the soil structure measurements at 0-20 cm depth it is a good idea to check at greater depths also - in case there is a subsoil pan. For this you do not need to record the soil structure score, but we suggest you dig or use an augur to excavate soil to about 50 cm depth, noting if there are any especially dense or hard zones that mean subsoil ripping is advised.

Then estimate if poor soil structure will restrict yield (see Section 3.9.2). Assessing soil structure is important because it has a large influence on crop performance.

### 2.1.3 Site preparation

Assess the chemical fertility of the soil at least one month before planting. Take soil samples to 15 cm depth using a standard sampling technique (see Section 3.6). Send these samples immediately to an accredited soil testing laboratory for the measurement of pH, extractable P, exchangeable Ca, Na, K and Mg, cation exchange capacity, and readily mineralisable N (see Section 3.7). We also recommend that organic C% is measured.

Identify the most cost-efficient combination of fertiliser products, with the following limitations:

- Avoid products containing chloride (chloride can damage tomato plants);
- Use readily available phosphate sources rather than very slow release products such as rock phosphate;
- Keep nitrogen applications to a minimum (in most circumstances the crops will need <100 kg N/ha);
- Choose applications to achieve a good rate of return on your investment - it is usually poor policy to simply aim for maximum yield;
- Remember that fertilising for high yields will only be effective if the rest of the crop management is also optimal. It is false economy to apply ample fertiliser if the yield will be limited by poor soil structure or inappropriate irrigation, pest and disease management - it also increases the risks of pollution.
- Do not apply fertilisers simply to replace the anticipated removal by the crop - make sure that there will be an economic response to a fertiliser application (see Sections 3.4.2 and 3.4.3).

Plan the fertiliser application times and methods carefully. Your choices here must be consistent with the NZFMRA Code of Practice for Fertiliser Use (Section 3.4.1). In particular, do not apply N fertilisers prior to planting. If large quantities of K or P fertiliser are recommended (>100 kg K/ha or >100 kg P/ha) then apply these prior to planting, and preferably prior to ridging. Under dry conditions, large applications of K need to be left at least two weeks before planting to minimise the chance of stressing the plants.

**Lime may be necessary if the soil pH is <5.0**, but lime applications can restrict yield (see Section 3.4.4). Wherever possible apply fine lime at least one month before planting, and always before beginning cultivation.

**Soil structure** has an important impact on the productive capacity of the soil, and it has a strong influence on the yield of tomatoes (see Section 3.9.2). Growers should encourage good soil structure. This requires particular attention to soil organic matter, machinery traffic over the soil, and cultivations.

**Encouraging good soil structure**

- Apply organic composts before cultivating if the soil organic C is less than about 2.5%, or if a comparison with previous tests indicates that it is likely to fall that level in the next 2 years (see Section 3.8).
- Cultivation weakens the soil and encourages loss of organic matter. Wherever possible, cultivate only areas that will be planted, and minimise the number of cultivation passes that are used. Align crop rows to minimise the amount of turning by tractors and trucks (to reduce the risks of compaction). Where possible, arrange the rows so that furrows are parallel to any natural contours in the land - this will help to prevent run off which could damage plants in low points of the paddock or pollute nearby waterways.
- Headland areas that will not be used to plant crop should be cultivated as little as possible - especially areas used for machinery traffic. We recommend that headlands are planted in grass. This will not encourage aphids and thrips. It will improve soil resistance to structural damage by machinery.

**Reduce the risks of waterlogging damage**. To do this, tomatoes should be planted into raised beds. This requires that the soil is cultivated quite finely before ridging. That cultivation increases the risk of substantially weakening the soil structure. Keep cultivations for bed preparation to a minimum by careful timing; do not plough, rotary hoe, or grub when the soil is very wet or very dry (see Section 3.3.1).Where you expect bed formation will be difficult, we recommend that the centre line of each bed is ripped to a depth of about 30 cm with a single tine. This will assist establishment of the plants.

**Check for soil compaction problems.** Preliminary examination of the soil with a spade may indicate a compact layer or pan at 15-30 cm depth. On the Heretaunga and Gisborne Plains these pans are the result of excessive cultivation under wet or dry conditions. Deeper pans are occasionally seen, and these are usually a natural feature of the soil itself. Both types of pans pose a significant risk to the success of the tomato crop because they limit root growth and increase the risks of waterlogging and drought damage to the crops. The pans should be fractured using a subsoiler or deep tines. This is a special case of cultivation and should be carried out when the soil is dry (see Section 3.3.1).

### 2.1.4 Planting operations

**Schedule cultivations and planting to minimise the length of time that finely cultivated soil is exposed to wind and rain**. This will reduce the chances of erosion. In Hawke's Bay and Gisborne, tomato crops are now transplanted rather than sown. This is to be encouraged as it shortens the time taken for the crop canopy to protect the soil surface.

**Wherever possible, at planting apply most of the P fertiliser that has been recommended.** Small quantities of fertiliser (say <25 kg/ha of N, P or K) may be applied "down the spout" with the plants, but larger quantities should be side-dressed, about 5 cm deep and at least 5 cm from young plants. Once flowering has begun, applications of P and K are unlikely to be effective and should be avoided. Do not broadcast N fertiliser.

**When transplanting conserve water** by applying it only "down the spout", and irrigate in the first week only if soil conditions become very dry.

### 2.1.5 Land management during crop growth

**Control weeds with a careful combination of herbicides and cultivation**. Minimise cultivations when the soil is very dry (see Section 3.3.1). Wherever possible avoid irrigating within 3 days of cultivating (see Section 3.3.2).

**Wherever possible minimise the amount of compacted soil** by reusing the same furrows or tracks for tractor wheels.

**Apply any dressings of N fertiliser into moist soil** - do not spread the fertiliser onto the soil surface (this can cause large gaseous losses of the applied N). Avoid applying N fertiliser before heavy rain or irrigation (to reduce the risks of leaching losses).

**If irrigation is needed, apply only enough irrigation to return the soil to within 15 mm of field capacity**. In most seasons, irrigation will be advised. Like heavy rain, irrigation makes the soil more susceptible to compaction. Furthermore, if the application rate is large the irrigation water itself may damage the soil, either scouring it or breaking down the soil aggregates so that they form a crust that seals the soil surface. Excessive soil water content can dramatically decrease yields (see Section 3.12.1), adding another incentive to ensure that only the required amount of irrigation is applied.

**Try to keep machinery off the paddock within a day of irrigation or heavy rain** (two or more days if the soil is already in poor structural condition or if >30mm of water is applied).

**"Gun" irrigation rigs should be set up correctly**, so that you know accurately how much water is applied and so that the irrigator keeps moving. Irrigators that remain in one position for any length of time can cause severe damage to the soil. Growers should check that jets of water are not scouring the soil surface or causing run off over distances of more than say 30 cm; irrigator speed and output rate should be adjusted to avoid these problems.

**Do not irrigate for at least two weeks before harvest**; it is important that the soil surface is as dry as possible at harvest time. Again economics reinforces environmental needs: irrigation in the two weeks before harvest will not increase yields and may decrease them by encouraging ripe fruit to rot.

### 2.1.6 Harvest and post-harvest operations

**Minimise risk to the soil**

The main risk to the soil during harvest is from compaction by trucks and harvesting machinery. Trucks may run over 60-70% of the soil surface. This causes immediate compaction. That compaction can be repaired by careful cultivation after harvest, but both the original compaction and the subsequent cultivation weaken the soil structure so it is more easily damaged by subsequent stresses due to, say, heavy rain, machinery or animal treading.

**Try to avoid harvesting if there has been significant rainfall (>25 mm, say) in the previous 48 hours.** New technology may reduce this requirement, but with present (2005) harvesting technology harvesting can do a great deal of damage to wet soils.

**As soon as the water content is suitable after harvest lightly cultivate the soil** to incorporate crop residues and break up compact zones (see Section 3.3.1). This is not essential if you are using a permanent bed system.

**Minimise the amount of time that the soil surface is left unprotected by plant cover.** As soon as possible establish grass or a break crop such as lupins that can be cultivated in to build up soil organic matter content (a 'green manure'). If the paddock is to be used again for tomatoes, we strongly recommend that the grass is not grazed during wet weather (see Section 3.10). Establishing grass or a break crop quickly will also help reduce nitrate leaching into groundwater (see Section 3.5.5). It also helps reduce organic C loss by microbial respiration. Note that white clover can act as a host for *sclerotinia*, so we suggest it is best not to include white clover with the resown grass.

**Take action to increase soil organic C content if it is <2.5%** (see Section 3.8). If it is close to 2.5% and the yield has been good, then compost applications will probably suffice, either before the grass or break crop is sown or before planting the next crop.

**If soil organic C is <2.0%**, then compost will still be useful, but we also strongly recommend that the site is left under grass for at least the following season or until the organic C returns to around 2.5%.

**Give high priority to soil repairs** especially if the harvest had to be carried out immediately after a significant rainfall. If there is severe compaction damage, then we strongly recommend applying composts prior to cultivation, and establishment of grass. In late winter the structural condition of the soil should be reassessed (see Section 3.8). If the soil structure score is 2 or more points less than the previous year, we strongly recommend resting the soil under grass for the following season.

New technology is needed to minimise the compaction damage caused by trucks and harvesting machinery. If traffic over beds can be eliminated, then growers will have the opportunity to further reduce cultivations, and install permanent or semi-permanent irrigation (such as drippers).

# 3 Fact sheets

## 3.1 Assessing soil texture

"Soil texture" describes the proportions of sand, silt and clay sized particles in the soil. The effective diameters of these particles are: coarse sand 0.2-2 mm, fine sand 0.02 to 0.2 mm, silt 0.002 to 0.02 mm, clay <0.002mm.

Laboratory analyses of soil texture require the soil to be thoroughly dispersed so all the primary particles are separate before the amount in each size range is measured. While this yields important information for soil scientists, field soil behaviour is often strongly influenced by small, tightly joined particles of clay and silt ("microaggregates"). Growers need to be more concerned with what we call the field texture of the soil. This is more closely related to how the soil behaves under field conditions, where those microaggregates can be important.

To assess field texture, take a small sample of the soil (removing particles >2 mm if possible), and moisten it while working it thoroughly between thumb and fingers. Stop adding water and working it when there is a thin surface film of moisture that reflects light. Then classify the soil texture according to its feel, using the table below as a guide.

***Table 1: Assessing soil texture.***

| **Feel and sound** | **Cohesion and plasticity** | **Field texture class** |
|---|---|---|
| Gritty and rasping | Cannot be moulded into a ball<br>Can almost be moulded into a ball - but falls apart when flattened | Sand<br>Loamy sand |
| Slight grittiness/rasping sound | Moulds into a ball that cracks when pressed flat | Sandy loam |
| Smooth soapy feel | Moulds into a ball that cracks when pressed flat | Silt loam |
| Very smooth, slightly sticky to sticky | Plastic, moulds into a ball that deforms without cracking | Clay loam |
| Very smooth, sticky to very sticky | Very plastic, moulds into a ball that deforms without cracking | Clay |

Clay textures are rare for topsoils in Hawke's Bay and Gisborne, but intermediate textures are common. You will often find silty clay loams (between silt loam and clay loam) and fine sandy loams (usually these are silt loams but with a recognisable feel and sound of fine sand).

Generally, clay feels sticky, silt feels soapy, and sand makes a rasping sound when worked between finger and thumb. Organic matter often feels like silt. If there is a lot of organic matter (usually this makes the soil very dark) then sandy and clay soils feel more loamy, and you may need to correct your assessment. Clay in soils formed from Papa mudstone (especially around Gisborne) feels particularly sticky, and you may overestimate the clay content of those soils.

## *3.2 Crop yield*

Crop yield depends on a lot of things, and often it varies a great deal from year to year. Since the mid-1990s there has been a lot of research in Hawke's Bay to develop a model to explain what regulates yield and how growers can influence it. Here we will look at what's in this model and use it to look at some case studies of crops grown in 1997-98 and 1998-99.

For now we will concentrate on the total yield of fruit that a crop produces. It is important that we distinguish three different components of this yield:

- The potential yield – the yield the crop would have attained if it was unstressed
- The attainable yield – the yield that the crop could have reached given the amounts of water and nutrients actually supplied
- The actual yield.

Finally we have to consider what we call the yield gap – this is the difference between the attainable and actual yields. Below we'll look at these in more detail.

### 3.2.1 Potential yield

Potential yield is the unstressed yield. It is mainly determined by the choice of crop variety and the weather. Sunlight (radiation) levels and air temperature are the weather factors that have the most influence. Basically, the model:

- Calculates the expansion of the leaf area on a daily basis.
- Uses the leaf area information to calculate the daily changes in the amount of radiation (sunlight) intercepted by the crop.
- Multiplies the intercepted radiation by the radiation utilisation efficiency (g dry matter per
- MJ of light intercepted) to calculate total crop dry matter (t/ha).
- Calculates through the season how much of the total dry matter is allocated to fruit.
- Calculates the final fresh fruit yield at a standard dry matter percentage (6.5%).

### The sun's work

After transplanting, the crop canopy grows and intercepts radiation. An important measure of this is *f*, the fraction of available radiation that is intercepted. *f* is closely related to the amount of ground cover. The maximum value of *f* is about 0.9 for present planting arrangements.

Potential yield is directly related to the amount of radiation intercepted. Aside from day-to-day variations in cloudiness, the amount of radiation available each day generally increases through spring and early summer. It reaches a peak in late December (around the midsummer solstice), and then decreases. The graph on the right shows the cumulative amounts of radiation that our study crops had available from planting to harvest. Generally those planted earlier had more radiation available to them.

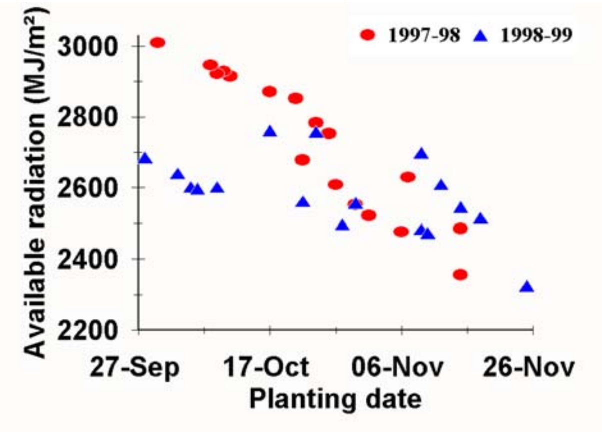


**Figure 1: Radiation (sunlight) available for Hawke's Bay tomato crops in two successive years.**

### And air temperature?

This is a little more complicated. Cool temperatures slow down the rate that the crop reaches maturity - and this gives the crop more days to intercept radiation. So on the one hand cool temperatures can help to increase yields. On the other hand, cool temperatures early in the season slow down the rate that the leaf area grows and f increases. This decreases the amount of radiation the crop can intercept. Of course, if the air is cool enough for a frost then the crop can be severely damaged and yield less.

### How do growers influence potential yield?

An important way we influence potential yield is by choice of plant varieties. Some varieties yield better in New Zealand simply because they are better adapted to our relatively cool temperature but high radiation environment. Of course, resistance to pests and diseases is another reason for choosing varieties. Another way to influence potential yield is by choice of planting dates. Planting date affects both the intensity of radiation and the air temperatures that the crops experience.

The two graphs below show how planting date affected the cumulative amounts of radiation intercepted by our study crops, and how this translated into potential yield.

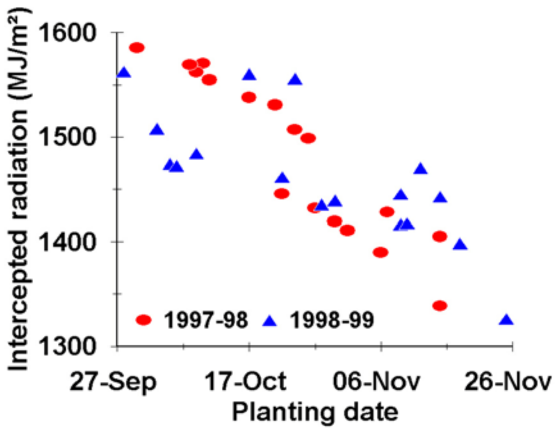


**Figure 2: Influence of sowing date on the total amount of radiation intercepted by the crops represented in Figure 1.**

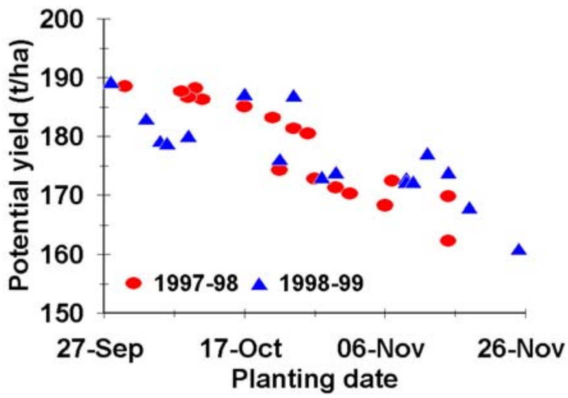


**Figure 3: Influence of sowing date on the potential yield calculated for the same crops shown in Figure 1.**

### 3.2.2 Attainable yield

This is the potential yield adjusted for drought, water excess and inadequate nutrient supply. That adjustment assumes the soil is in good physical and biological condition.

Attainable yield is what the growers should have achieved if the soil was in good condition. Basically it is the yield that the grower has already paid for in terms of inputs like water and fertiliser.

We calculate attainable yield using the potential yield value, and with information on how the amounts of water and nutrients supplied. Those calculations can be complicated, and for this we use the PARJIB model (Reid 2002; Reid et al. 2002) that sits at the heart of the Tomato Calculator (Reid et al. 2004). The nutrients considered to affect the yield are N, P, K and Mg; other nutrients are assumed to be in adequate supply. The model accounts for interactions between nutrients. A correction is made for the reduced yield of plants that are infected with *Sclerotinia* or late blight (that fraction is measured in the field at harvest). A correction is also made for loss of yield due to inadequate or excessive water supply or poor soil aeration (see Sections 3.12.1 and 3.12.2).

In our case studies the attainable yields were 50-100% of the potential yield (see Figure 4 and Figure 5).

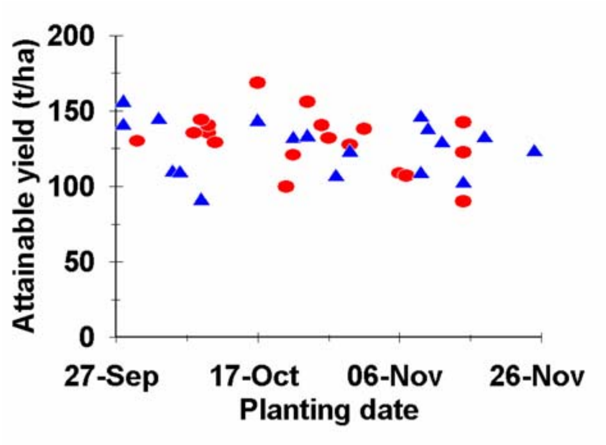


**Figure 4: Attainable yield for the case study sites in 1997-98 and 1998-99.** Compare these results with those in Figure 3.

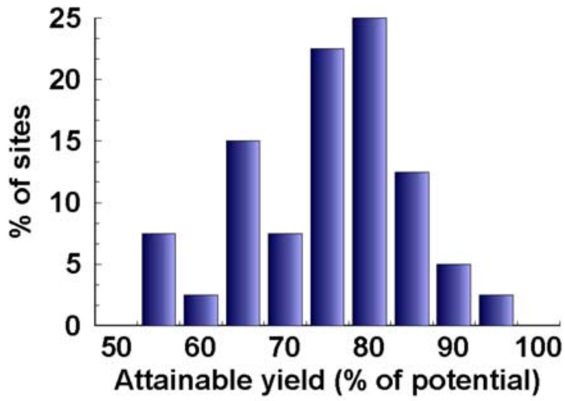


**Figure 5: The attainable yield as a percentage of the potential yield for crops in 1997-98 and 1998-99.**

Why were the attainable yields so much smaller than the potential? Also, why was there only a weak influence of sowing date on the attainable yields? We have used the model to take apart the performance of the crops in the 1997-98 and 1998-99 seasons.

Drought caused only small reductions in yield (Figure 6). At most of the sites 10-15% of the yield was lost due to excessive water (see Section3.12.1). Often that was unavoidable - due to heavy rain - but better irrigation management could have increased many yields. A lot of yield was lost through inadequate nutrition. We can do better there, but achieving maximum yields with heavy fertiliser rates rarely makes economic or environmental sense. *Sclerotinia* and late blight diseases caused relatively little yield loss (not shown on the graph).

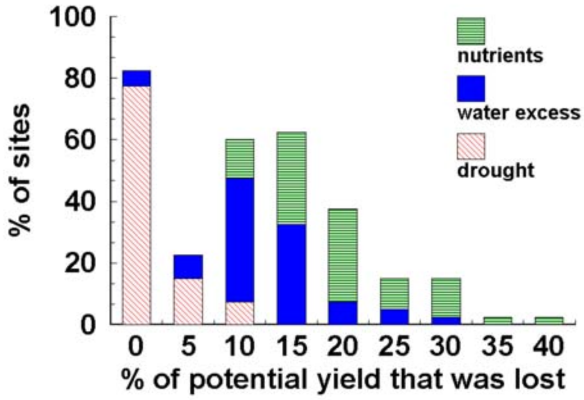


**Figure 6: Yield losses due to nutrient supply, water excess and drought in the 1997-98 and 1998-99 seasons.**

### 3.2.3 Actual yields and the yield gap

Look again at the potential yields in Figure 3- they were huge. Even the attainable yields (Figure 4) were very large.

The actual yields achieved were much smaller (Figure 7). As with attainable yield, there is little apparent effect of planting date. Clearly other factors are reducing yields.

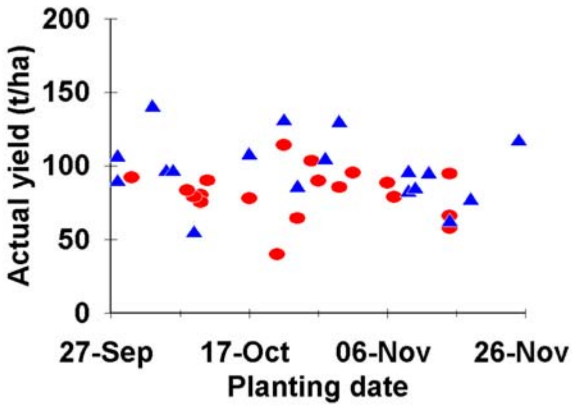


**Figure 7: Influence of sowing date on the actual yields of the crops studied.**

Actual yield was often even less than the attainable yield. The yield gap is the difference between attainable and actual yields. Our results showed that the yield gap was often as much as 40% of the attainable yield (see Figure 8).

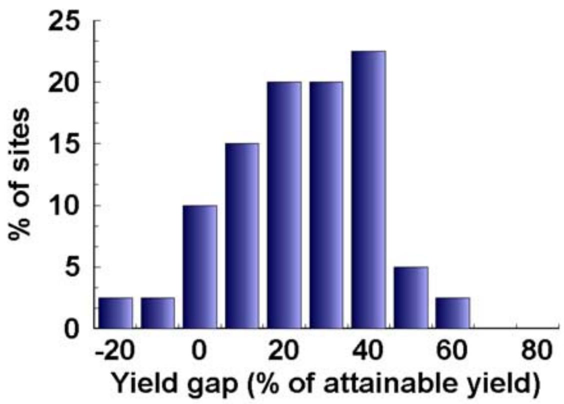


**Figure 8: The yield gap, as calculated for the tomato crops in 1997-98 and 1998-99.** A few sites recorded negative yield gaps, meaning that the actual yield was better than our model calculated. At most sites though the actual yields were noticeably smaller and there was a positive yield gap.

A few sites recorded negative yield gaps, meaning that the actual yield was better than our model calculated. At most sites though the actual yields were noticeably smaller and there was a positive yield gap.

What causes the yield gap? Basically, it is caused by factors which are not included in the model for attainable yield - namely inadequate soil structure and biological conditions. Reducing the yield gap will improve $ returns from the crops. It will also improve the soil. The most obvious way to reduce the yield gap is to improve soil structure (see Section 3.9.2).

## 3.3 *Cultivations*

### 3.3.1 Cultivation and soil water content

Cultivation when the soil is wet increases compaction, draught requirements on the tractor, and the need for further cultivation. It is energy inefficient and is not recommended.

Cultivation of topsoils when the soil is too dry produces a large proportion of hard clods and very fine aggregates. The clods make bed formation difficult and resist root penetration. The very fine aggregates are susceptible to wind erosion which is highly undesirable (it causes air pollution, transfer of nutrients and agricultural chemicals to adjacent land, damage to the plants in the same paddock, and can adversely affect growth and marketability of nearby crops). The very fine aggregates will also readily form crusts on the soil surface under rain or irrigation which is also undesirable (reducing water and air penetration into the soil, and increasing local runoff).

Cultivation to break up pans in the soil is a special case. This is the only time we would recommend cultivation under dry conditions. Often it is impractical to completely shatter the compact layer, but careful cultivation with a subsoiler or deep tines can fracture it sufficiently to reduce the risks posed. Subsoiling when the soil is dry increases the draft requirement, but it encourages fracture of the pans so roots and water can more freely penetrate them.

Subsoiling when the soil is moist is at best poorly effective, and under many circumstances may make the problem worse. So, if you wish to break up a pan you may need to plan the operation well in advance, so that you are prepared to do the cultivation when the soil is dry but before planting. Take advantage of any extended dry weather in winter or spring; if you are reusing a previous paddock then it may pay to cultivate deeply very soon after harvest if the soil is dry.

### 3.3.2 Irrigation after cultivation

For some time after cultivation the soil is in a weakened state, and sprinkler irrigation or heavy rainfall can cause substantial damage to the soil surface. Overseas research suggests that a 3-day interval between cultivation and irrigation can reduce the chances of such damage.

## 3.4 *Fertiliser application rates*

### 3.4.1 Code of Practice for Fertiliser Use

This was produced by the New Zealand Fertiliser Manufacturers Research Association. *All use of fertilisers should be consistent with this code.*

The code gives valuable information for the transport, storage, application and disposal of fertilisers, and relates these processes to growers' responsibilities under the Resource Management Act. It also contains an excellent glossary of technical terms.

The code does not contain a user guide specifically for vegetable production; however, the user guide for arable farming is appropriate. Copies of the code can be obtained from NZFMRA (see Section 4.4) or downloaded from the internet:

http://www.fertresearch.org.nz/index2.html

### 3.4.2 Deciding application rates

One approach is to set a target yield, and calculate the amount of nutrient that will be lost from the field if that yield is achieved. Although it sounds environmentally sustainable, this "maintenance" approach has significant drawbacks, and we do not recommend it (see Section 3.4.3). Another approach is to compare the soil test results for each paddock with previously established optimum values, and then estimate the best product and rate needed to bring the soil test values up to the optimum. Historically, those ‘optimum’ values were the values at which maximum yield appeared to be achieved. Wood et al. (1986) report that those values are:

- P: 35-45 ug/ml or ppm for soils with phosphate retention in the range 0-40% (most
- Hawke’s Bay and Gisborne soils have P retention in this range).
- K: 0.84, 1.05 and 1.4 meq/100g for sands, loams and clays respectively.
- Unfortunately no definitive guidelines were given for N, although it was noted that the
- crop required about 120 kg N/ha from the soil and fertilisers combined (and that figure is far too low).

We recommend instead that growers use the Tomato Calculator software model that Crop & Food Research developed for Heinz Watties (Reid et al. 2004). The Tomato Calculator calculates how yield and crop value vary with soil test results and fertiliser applications, calculating the economic optimum products and rates for each paddock.

**What information do you need?**

In order to use the Tomato Calculator, you will need to have the results from a recent set of soil tests (see Soil chemical analysis). You will also need to know the likely planting date for the crop, the variety, the value of harvested fruit in $/t, and how much it costs you to apply fertiliser ($/ha). The Tomato Calculator will expect you to choose a likely weather scenario, and to be clear as to your financial aims for the fertiliser program. We recommend that you establish a consistent set of financial aims, expressed in terms of either the $/ha or $ returned per $ spent on fertiliser.

In the Tomato Calculator, fertiliser performance is assessed against the financial aims you set, and against the potential yield as dictated by the variety, planting date and likely weather. Remember, conditions that restrict the potential yield also reduce the requirement for fertiliser. Also, remember that it is wasteful to fertilise for high yields unless the rest of your crop management (irrigation, disease control etc) is also designed for high yields.

### 3.4.3 Economic vs maintenance fertiliser applications

We do not recommend applying inorganic fertilisers just to replace anticipated nutrient removal by the crop. Instead we recommend that inorganic fertilisers are applied only when you know they will increase the profit from the crop. There are various reasons for this, and it is a good example of the needs of economic and environmental sustainability reinforcing each other.

**The $ argument**

Generally, don't put extra fertiliser on a crop just in case it may be needed by a later crop. Spend the money when you know it will increase profit - unspent money can still earn interest! By contrast, in pastoral agriculture application costs can be large, and response times slow, so often it is economic to apply fertiliser for more than one season. If you are sure to manage the same site for several years and wish to use slow release fertilisers like rock phosphate then several seasons' applications at once can be good practice - but check the sums carefully!

**The environmental argument**

Fertiliser increases the nutrient loading in the soil. This increases the chances for runoff, erosion or leaching to transfer nutrients into the wider ecosystem where they can be undesirable. (This is not to say that fertilisers directly increase, say, nitrate leaching - merely that more nutrients can be lost from high fertility soils.)

**Economic and environmental needs coincide**

Amounts of P, K and Mg (but not N) are often greater in horticultural soils than in virgin soils, and sometimes they are so large that there will be no economic return on fertiliser use. Then there is little to gain and something to lose from maintaining such elevated concentrations with 'maintenance' applications. Why increase the environmental and financial risks unless you have a good economic reason to apply the fertiliser?

**Organic growing?**

Nutrient concentrations are usually small in soil amendments such as composts and rock products. Restoring fertility with these and with legume crops can be slow. So, for organic production it is important to replace quickly nutrients removed by the crop. Having said that, sometimes organic growers inherit situations where previous fertiliser applications have raised nutrient levels beyond the range required by their crops. Then we advise a carefully observed run down in nutrient concentrations.

**What would maintenance applications be?**

New Zealand data are scarce; the best we are aware of is from an experiment carried out in Gisborne in 1994-95 (D.J Sher, personal communication). There, fruit from a 78 t/ha crop removed 138, 18, and 198 kg/ha of N, P and K respectively. That suggests a maintenance N application of about 177 kg N/ha, for a target yield of 100 t/ha. We strongly recommend against such a large rate of N fertiliser - it could cause substantial problems with too many green fruit, and greatly increase the risk of nitrate leaching (see Section 3.5). It is worth noting though that the Tomato Calculator usually indicates that the most profitable P and K applications are close to the maintenance rates (except in unusually depleted or fertile soils). Nutrient removals by crops are rarely so large that you cannot restore safely 5 years of losses in a few applications of concentrated fertiliser on crops that will economically respond.

### 3.4.4 Lime applications and yields

Our experience has been that recent applications of fine lime can substantially reduce tomato yields. We believe this happens because of competition between Ca from the lime and K from the soil and applied fertiliser.

An example...

Let's look at results for two nearby sets of four plots on a Waipukurau silt loam in 1998-99:

**Table 2: Comparison of limed and non-limed plots in 1998-99.**

| | Treatment 1 (limed) | Treatment 2 (unlimed) |
|---|---|---|
| Lime applied 30 days before planting (t/ha) | 1.5 | 0 |
| ***Soil chemical analysis at planting:*** | | |
| pH | 5.7 | 5.2 |
| Readily available N (kg/ha) | 62 | 45 |
| Olsen P (ppm) | 44 | 41 |
| Exchangeable K (meq/100g) | 1.0 | 0.9 |

## *3.5 Nitrate leaching after tomatoes are harvested*

### 3.5.1 Assets and liabilities - organic matter, ammonium ($NH_4^+$) and nitrate - ($NO_3^-$)

When soil microbes dine on organic matter containing N, ammonium ions are produced. Soon after, in most agricultural soils, other microbes oxidise the ammonium to form nitrate ions. Many fertilisers supply N directly as ammonium or nitrate - even urea is rapidly converted to ammonium and then to nitrate in the soil. Achieving high yields frequently requires use of N fertiliser, and most crops prefer to take up N as nitrate. So a good supply of nitrate in the soil is an asset - but too much is a liability. Nitrate is **very** mobile and readily leached out in drainage water. At this point it ceases being an asset and can become a pollutant in groundwater. Significant concentrations of nitrate in drinking water can be a health risk, especially to the very young. Nitrate leaching is natural and occurs under most land uses, but we must be careful to minimise it.

Generally, less N fertiliser is applied to tomato crops than to most other annual crops. Furthermore, in Hawke's Bay, there is little risk of nitrate leaching from fertilisers during crop growth . This is because most N fertiliser is applied when the crops are already established. Also, the amount of drainage during crop growth is usually small: irrigation is usually confined to a relatively short period when the plants are already quite large and the soil is dry. But what happens following the harvest in autumn? Generally, drainage is greatest in autumn and winter. So, any nitrate left after the tomato crop is susceptible to leaching then.

We measured nitrate leaching below 60 cm depth in paddocks that had just grown tomatoes. We did this in a total of 23 paddocks in Hawke's Bay during autumn and winter of 1998 and 1999.

### 3.5.2 First the good news

Compared to measurements made for other crops overseas, the amounts of nitrate leached (Figure 9) were small. There are few NZ data to compare with. We do have some comparable measurements for maize paddocks around the North Island (1998 and 1999) and sweet corn paddocks in Hawke's Bay and Gisborne (1999). For the maize paddocks, nitrate leaching ranged from 1-250 kg N/ha (the highest values were observed in the Bay of Plenty). For sweet corn, the range was 5-29 kg N/ha. On this basis, there is no evidence that growing tomatoes has caused substantial nitrate leaching.

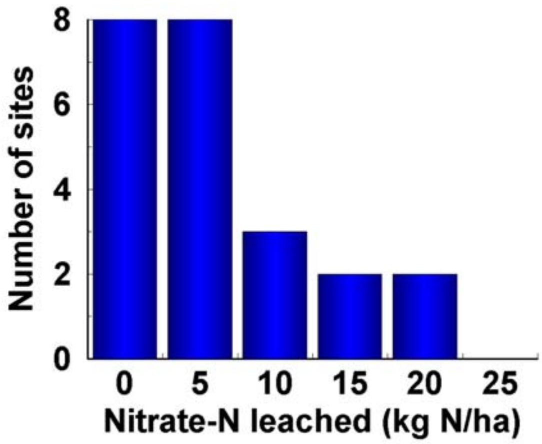


**Figure 9: Nitrate leached after tomato crops, autumn-winter 1998,1999.**

These results are very encouraging. However, a closer look shows no room for complacency…

### 3.5.3 Why was there so little leaching?

Nitrate leaching requires two main things: significant concentrations of nitrate in the soil water, and enough rainfall or irrigation for drainage to occur. In the two seasons when we studied leaching after tomato crops, the soils were quite dry at harvest and there was little winter rainfall. From harvest through to late August, the average amount of drainage was only 32 mm. This is one explanation for the small amounts of leaching found in our study.

If there had been more rainfall would there have been enough leaching to cause environmental concerns? This is difficult to answer, but some pointers indicate there is no room for complacency.

To start, let's look at the amounts of mineral N (ammonium and nitrate) that were left in the soil after harvest. We call this the residual mineral N, and it's a prime source of nitrate that can be leached.

### 3.5.4 How much mineral N remained after harvest?

Too much, too often! Take a look at our results in the graph on the right. This shows the amounts of residual mineral N down to 60 cm depth.

To reduce the risk of nitrate leaching, it is important that the residual N is not too large. Admittedly, it is difficult to say what the right amount should be. It should not be zero - if there is any organic matter in the soil, microbial action will always be producing some ammonium and nitrate. Also, some residual N is needed for growth of the following crop. On the other hand, we can be pretty sure that 100 kg N/ha or more is excessive and increases the risk of nitrate leaching.

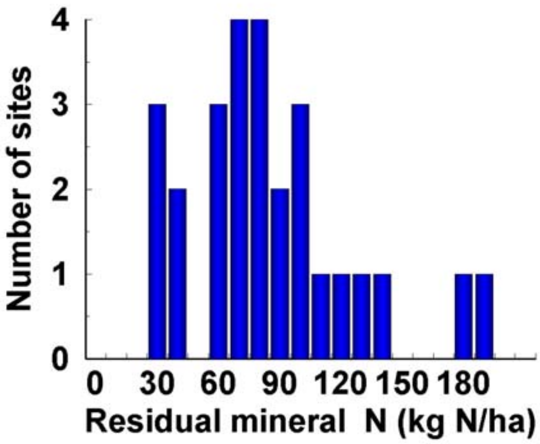


**Figure 10: Residual mineral N after tomatoes, 1997-98, 1998-99.**

The residual mineral N comes from two main sources - natural mineralisation of soil organic matter by microbes, and fertilisers. Growers can influence the impact of both sources by;

- Planting another crop or grass as soon as possible - those plants will take up nitrate and reduce the amount available for leaching; and
- Never applying more N fertiliser than the crop needs. Environmentally, this is good practice, and it makes good financial sense too. One way or another, the grower has paid for that residual mineral N, so why waste money?

The question that naturally arises is whether some growers applied too much N fertiliser. Let’s look at that possibility and draw some recommendations.

### 3.5.5 Did some growers apply too much N fertiliser?

We used the model in the Tomato Calculator to calculate how much N fertiliser was needed to achieve the measured yields. We then compared these figures to the amounts actually applied, and calculated the "surplus" N fertiliser applied for each of the 40 crops we studied.

The surplus fertiliser N varied from 0 to 109 kg N/ha (see graph on right). At 14 sites all of the applied N fertiliser was surplus. These results suggest that the large values of residual N we found - and the risk of nitrate leaching - could have been reduced by applying less N fertiliser.

Growers' fertiliser plans are designed for high target yields. If those yields are not achieved due to other factors then it will appear that the growers applied surplus N fertiliser. With this in mind, let's put the calculated surpluses into context.

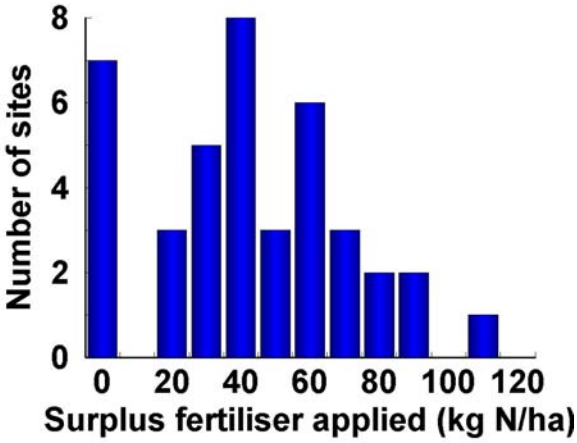


**Figure 11: Surplus N fertiliser applied to tomatoes, 1997-98, 1998-99.**

***What yield was possible with the fertiliser applied?***

Yields of up to 150 t/ha are achievable in good seasons if all management practices are right. However, at some sites there was enough N fertiliser to support yields beyond 160 t/ha (Figure 12). So, many crops received much more N than their actual yields required - and some received much more than required for realistic target yields. This increases the risk of nitrate leaching - and it represents wasted money and effort in the first place

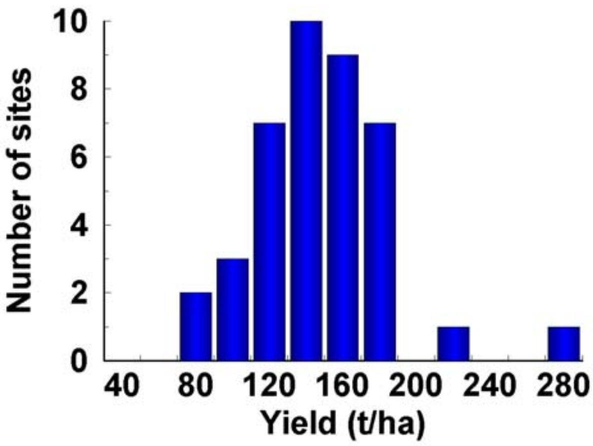


**Figure 12: Yield that could have been supported by the amount of fertiliser N applied. Tomato sites 1997-98, 1998-99.**

**How many $ were wasted?**

At 1999 prices, applying 100 kg N/ha would cost about $93/ha using urea and about $200/ha using calcined ammonium nitrate (CAN). But there's more... excessive N fertiliser can depress yield and delay fruit ripening. Surplus N fertiliser is not a good form of insurance!

**How do we avoid nitrate leaching?**

Part of the answer is to apply no more fertiliser than the Tomato Calculator indicates. Also, it's important to minimise yield gaps caused by poor soil structure. In most cases, improving soil structure will encourage higher yielding tomato crops that take up more N - giving a better return on your investment in fertiliser, and leaving behind less mineral N to be leached. Finally, establish grass or another crop as soon as possible after harvest to take up surplus N and improve soil structure (See Sections 1.4, 3.9.2, 3.8.3, and 3.3.1). Here again environmental sustainability makes good business sense.

## *3.6 Soil sampling for chemical analysis*

Sample before fertiliser or lime is applied. You are recommended not to sample within 3 months of fertiliser application (see Section 3.4.1), although sometimes this is unavoidable.

Divide each paddock into areas of similar soil types, slope, and previous management. From each of these areas you will need to take a separate sample for analysis.

Set up at least two sampling lines within each area, avoiding unusual features such as gateways, and headlands. Walk along each line taking soil core samples from 0-15 cm depth. Space your samples so that you take at least 15 cores from each area.

It is a good idea to place the samples in a clean bucket or bag as you go. At the end, mix the samples thoroughly by hand and then place at least 0.5 kg into a clean plastic bag to go to the laboratory. Make sure that the bag is clearly labelled with the origin of the samples and your own name.

Take the samples to the laboratory as soon as possible. If you cannot get them there on the same day, then you can store them overnight in a refrigerator - but they must not freeze.

See Section 3.7 for the list of measurements you should request from the laboratory.

## *3.7 Soil chemical analysis*

Nutrient analysis should be carried out for each paddock. Keep the results in a safe place for future reference. Where the same paddock is used several times, it is important to check for any unnecessary or undesirable rise or fall in soil test results.

To forecast fertiliser requirements using the Tomato Calculator (see Section 3.4), the following analyses are required:

- soil pH (1:2.5 w/v in water) (Cornforth, 1980);
- Olsen P (bicarbonate extractable P) in units of ug/ml or ppm (Cornforth, 1980);
- Exchangeable K, Na, Ca and Mg in units of meq/100g (Cornforth, 1980);
- Cation exchange capacity at pH 7.0 (Cornforth, 1980);
- Soil dry bulk density in the laboratory (the laboratory will provide this information to

- enable PARJIB to convert measurements made per unit volume of soil to values per unit
- mass).
- Readily available or readily mineralisable N, measured by anaerobic incubation at 40°C
- (Keeney and Bremner, 1967).

We also recommend assessment of soil organic matter content. For this we recommend that the laboratory measures soil organic C (% w/w) using either an automated CHN analyser (a furnace method) or the dichromate oxidation method of Walkley and Black (1934).

You must use a representative and standardised sampling procedure in the field (see Sampling soil for nutrient analysis). Identify fertiliser rates using the PARJIB model if possible (see Fertiliser application rates).

## *3.8 Soil organic matter, composts and manures*

Organic matter in soils is mostly the remains of dead plants, animals and microbes. It is easier to measure organic C rather than organic matter - soil organic matter is normally about 60% C. Soil organic carbon concentration is usually given as a percentage by weight of dry soil.

### 3.8.1 Why worry about soil organic matter?

In any given soil, there is usually a strong relationship between soil organic matter content and soil quality. Microbes use soil organic matter as an energy source. In doing this they release some nutrients (especially N) in a form that crops can use. Organic matter also acts as a glue that stabilises soil structure.

However, it is difficult to identify a critical soil organic C concentration for tomato production in New Zealand. In our studies at 40 sites we found no simple relationship between soil organic C and the yield gap. Nevertheless, we did find that soil structural score decreased rapidly if the soil organic C content fell below about 2.5% (see Section 20). We also found that as the soil structural score decreases so does the chance of significant yield losses (see Section 3.9.2).

### 3.8.2 How does land management affect soil organic matter?

Organic compost applications can increase soil organic matter content. Cultivation increases the rate that microbes eat soil organic matter. Soil organic matter content decreases most quickly under warm, moist conditions when no crop is present and the soil is cultivated often. Growing crops add organic matter to the soil (some more than others). They also slow the rate at which soil microbes respire soil organic C, so when you need to restore organic matter levels it is important to keep some form of crop cover.

Overseas, and in many parts of New Zealand, soil organic matter content may decrease rapidly under cropping management.

This general trend was seen also in our measurements on Hawke's Bay and Gisborne soils. In Figure 13 we have plotted the organic C% of the topsoil against the number of years in the past five that the soil had been used for vegetable or arable crop production. Only silt loam and silty clay loam soils are included, and most had been cropped for considerable time prior to the previous 5 years.

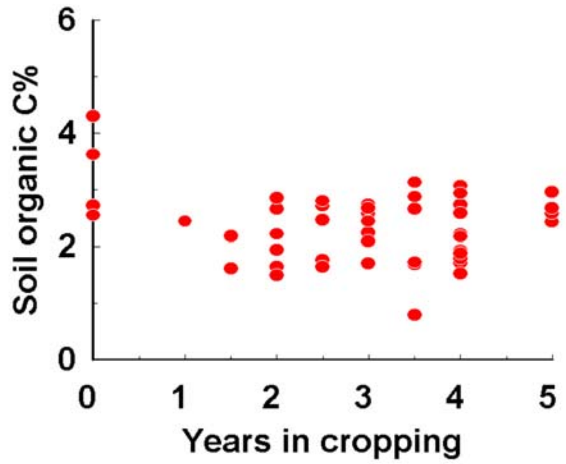


**Figure 13: Effect on soil organic matter of the number of years under vegetable cropping (out the previous 5).**

We recommend that management practices endeavour to keep soil organic C content >2.5%. Growers can be reasonably confident that organic C% will not be limiting soil quality and yields if it is in that range.

### 3.8.3 Organic matter and soil structure

Some parts of the organic matter in soil act as a sort of glue, stabilising the soil structure. Stabilising the soil aggregates in this way helps in the production of a fine tilth. It also protects the soil against mechanical stresses, such as those caused by inappropriate cultivation or the impact of heavy rain or irrigation. Furthermore, poor soil structure means an increased risk of poor yields (see Section 3.9.2).

We found clear evidence that the soil organic C content influences the soil structural score (see graph on the right).

For soils in Hawke's Bay and Gisborne it looks as though the soil structure score decreases rapidly once soil organic C% falls below 2.5%. However, increasing the organic C% much beyond 2.5% does not necessarily increase the soil structure score.

Clearly, the soil structure score is influenced by more than just organic C%; no doubt recent cultivation practices will be important.

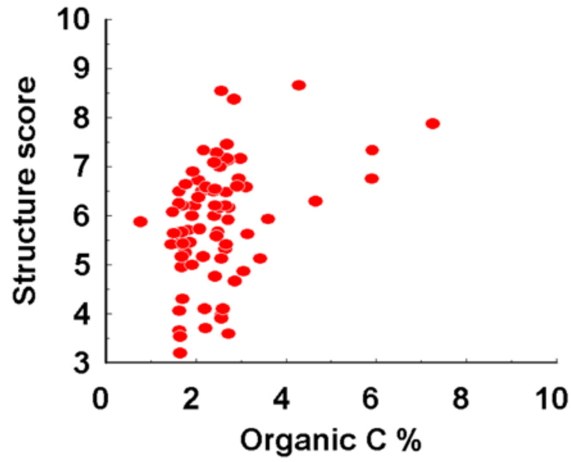


**Figure 14: Relationship between average soil structure score (0-30cm) and soil organic C content (0-15 cm) for silt loams in Hawke's Bay and Gisborne.** The Gisborne sites were used for sweet corn, the Hawke's Bay sites for tomatoes and sweet corn.

We recommend that growers aim to keep the organic C content of their soils above 2.5%.

### 3.8.4 Organic composts or manures

The composition of these varies widely, and the best rate to apply will vary with composition and consistency. Bear in mind that composts are usually sold wet and even when dried are usually <35% C.

In East Coast soils, increasing soil organic C by only 0.1% will require about 4.3 t/ha of dry compost (if the compost contains 35% C). Cereal straw may contain 80% C, but it has the disadvantage of immobilising soil N for protracted periods, and so it should not be applied until after harvest.

Mushroom compost usually contains large quantities of free lime or fowl manure, and will raise soil pH. Unless soil pH is less than 5.0 or soil tests indicate a gross Ca deficiency, do not apply mushroom compost in the same season that tomatoes will be grown (see Lime applications and yields).

Composts should be cultivated into the ground immediately. Large single applications of composts can be difficult to incorporate, and smaller repeated applications prior to cultivation are often best.

A good tomato crop can leave behind about 10 t/ha of organic C after harvest, so make sure that crop residues are incorporated quickly following harvest.

Often it is a good idea to use break crops as green manures - cultivating in pasture grass or a stand of say lupins can add an appreciable amount of organic C.

## 3.9 *Soil structure*

### 3.9.1 Soil structure scorecard (for silt and clay loam soils)

**Score 1-2**

Soil consists of large (> 5 cm) compact clods with few aggregates of smaller size. Soil breaks with effort into angular blocks with smooth flat sides. Some discolouration (dark blue to black) may be apparent.

**Score 3-4**

Soil consists of large (> 5 cm) firm clods that break into angular blocks with mostly flat or round smooth sides. Smaller unstable aggregates or loose fine powdery soil may be evident.

**Score 5-6**

Few large and medium (> 3 cm) firm soil aggregates but mostly smaller (< 3 cm) aggregates in friable mix of loose soil. Some smaller unstable aggregates or loose powdery soil may be evident.

**Score 7-8**

Friable soil consisting of many distinct soil aggregates (< 3 cm) of a rounded or nutty shape. Little loose powdery unaggregated soil.

**Score 9-10**

Porous loose soil of many distinct stable soil aggregates (< 3 cm) of a nutty or rounded shape. Aggregates are prominent with little or no loose powdery unaggregated soil. Roots may be growing in and around aggregates.

### 3.9.2 Soil structure and yield

For each of the 40 sites studied in 1997-98 and 1998-99 we calculated the yield gap (see Sections 1.4, 3.2.2 and 4.1). We then compared the yield gap to a range of different measures of soil quality.

The visual assessment of soil structure provides a score (1-10) which was well related to the yield gap (Figure 15).

It appears that the yield gap increases by about 6% for every unit change in the soil structural score. Clearly the soil structure score is not the only thing influencing the yield gap, but it is certainly important.

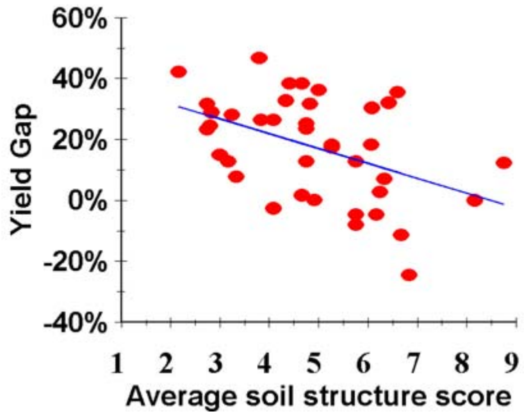


**Figure 15: Relationship between the yield gap and soil structure score for tomatoes in Hawke's Bay 1997-98 and 1998-99.** A negative yield gap estimate indicates that the attainable yield model had underestimated the yield. The 95% confidence interval around the yield gap estimates is about 16%.)

Consider an otherwise well managed crop growing in a soil that is damaged so that the structure score decreases by 2 units (this is not hard to achieve!). A 12% drop in yield could mean a loss to the grower of about $1140/ha if the attainable yield was a modest 100 t/ha.

Clearly it pays to minimise structural damage to the soil. This requires growers to minimise compaction, cultivate when the soil is at the best water content, and maintain soil organic matter.

## 3.10 Grazing grassed paddocks between crops

If the same site is to be used for tomatoes in the next year, then it is important to maximise the opportunities for the soil structure to recover after harvest. Part of this process is to overwinter the site under grass or another type of crop that will rest the soil and add organic matter to it. At present, most sites are regrassed, which is good practice. After the grass is established it is tempting to let the site be used for grazing.

Grazing the grass introduces a risk of compaction, especially in wet conditions. Compaction, and cultivations needed to repair the soil structure, weakens the soil, making it more difficult to prepare and maintain a good structure the following season. This in turn can reduce yields.

If grazing under wet conditions is suggested, then we strongly recommend that growers consider the economics.

For tomatoes, the yield gap increases by about 6% each time the soil structural score falls by one unit (see Section 3.9.2).

If grazing decreases the soil structure score by only 1 unit say, then the subsequent yield losses may be 6 t/ha for a crop with a (modest) attainable yield of 100 t/ha. So the penalty for grazing the site under wet conditions could be about $570/ha - and that does not include the extra costs of subsequent cultivations to prepare the soil for planting. Clearly, there are real economic reasons to keep stock out of grassed-down tomato paddocks in wet periods.

## 3.11 Soil maps

Wherever possible, growers should use the soil maps prepared for their districts. Although there is no guarantee the soil type(s) in a given paddock will be exactly as mapped, the maps are an excellent start for site selection. Note that the texture classes attached to the soil names mainly reflect topsoil properties, and subsoil textures may differ substantially from the topsoil.

Legends or interpretations of the information on these maps is also available and very useful. For Hawke's Bay and Gisborne the definitive sources of this information are:


- Department of Scientific and Industrial Research (1938). Soil Map of the Heretaunga Plains Hawke's Bay.
- Hughes, H.A.; Hodgson, L.; Harris, A.C. (1939). Soil survey of the Heretaunga Plains. Pp18-51 in Land Utilization report of the Heretaunga Plains, Department of Scientific and Industrial Research Bulletin 70. Government printer, Wellington, New Zealand.
- Pullar, W.A. (1962). Soils and agriculture of Gisborne Plains. New Zealand Soil Bureau
- Bulletin 20. Government printer, Wellington. 92pp.
- Griffiths, E. (1997). Soil Map of the Heretaunga Plains. Landcare Research New Zealand
- Ltd, Private Bag 11052, Palmerston North.
- Griffiths, E. (1999). Guide to soils of the Heretaunga Plains and their management.
- Report to Hawke's Bay Regional Council, August 1999, 48pp.


The soil maps for Hawke's Bay can be obtained from the Hawke's Bay Regional Council.

## 3.12 Tomato crops and water

- Tomato crops can be very sensitive to too much or too little water. It is important that irrigation is managed carefully to avoid the negative effects of both situations.

### 3.12.1 Excessive water

If too much water is supplied, then nutrients are leached out of the root zone, the oxygen content of the soil can decrease sharply, and crop growth may stop temporarily, reducing yield. If water sits on the soil surface for two days or more, then most of the root zone is probably waterlogged, and there is a risk that the soil oxygen concentration will decrease to the point where the roots die. Paradoxically, one of the first signs of waterlogging is wilting leaves – the lack of oxygen in the root zone decreases the ability of the roots to take up water to supply the leaves. If those conditions persist then plants may die, especially in low-lying areas. This can occur at any stage of crop growth.

**Tomatoes are very sensitive...**

Tomatoes are one of the most sensitive of all crops to poor soil oxygen supply (Gales, 1976; Poysa et al., 1987). Periods of excessive soil water content tend to result in smaller crop canopies, and greatly reduced yields.

Heavy rainfall can have other adverse effects on tomato crop production. Wet soils have very limited ability to support machinery, and yield losses will result if harvesting operations must be postponed or cancelled. The rainfall will also encourage diseases such as *Sclerotinia*, late blight and botrytis, all of which can substantially reduce yield.

On average, yield decreases by about 0.4% for every day that the soil is 10 mm wetter than field capacity. Irrigation followed by prolonged rain is a common cause of reduced yield in Hawke's Bay. Crops can lose 4-10% of their yield because of excessive soil water content. Those figures *exclude* situations where the soil was visibly waterlogged and the yield losses could have been even larger. In some seasons (e.g. 1992-93), whole crops have been lost because the damage due to excessive soil water made harvesting them uneconomic.

### 3.12.2 Insufficient water

If there is too little water available to the crop then fruit yield may decline, and some quality disorders may increase (e.g. blossom-end rot and internal blackening). However, mild water stress late in fruit growth can increase Brix levels in the pulp and decrease processing costs, without having any noticeable effect on overall yield.

Overseas, tomato yields are regarded as very sensitive to water deficit. By contrast, in the silt loams, silty clay loams and clay loams of Hawke's Bay it has often been hard to detect yield increases from irrigation. Recently we have reanalysed the experiments conducted in Hawke's Bay from 1973 to 1995 and Crop & Food Research's surveys of Hawke's Bay tomato crops from 1997 to 2000. It seems that in the Hawke's Bay environment many, but not all, crops have access to water from soil water tables at 100-150 cm depth. This greatly reduces the need for irrigation once the crop is established.

If a water table is not present, and the soil dries to the point of stressing the crop, then yield decreases for every day that irrigation is delayed or rain does not fall. In most seasons in Hawke's Bay, the final yield will decline by about 0.04% for every mm of potential evaporation (PET) that occurs when the crop is in this state. In summer, the PET is often about 5 mm/day, so delaying irrigation by a week can decrease final yields by 1.4%. This does not sound much, but many crops have a potential yield of more than 150 t/ha – at a contract price of $95/tonne delaying irrigation for a week could reduce your income by $200/ha.

Even if a water table is present at 100-150 cm depth, irrigation may still be needed:

- soon after planting, to ensure fast and even establishment of the crop. Yields and profitability will increase substantially if transplants are encouraged to get growing rapidly after planting, and if there are few gaps in the crop;
- during the main flowering period, to reduce the risk of blossom end rot and internal blackening of the fruit. Quite small water deficits at this time can greatly increase the incidence of these disorders. For instance, in 1992-93 we found that increasing the soil water deficit during flowering from about 50 to about 65 mm increased the incidence of internally blackened fruit from 0.6 to 5.6% but did not affect total fruit yield.

See also Section 3.3.1.

# 4 About

## 4.1 The Sustainable Crop Production program

The aim was to produce Recommended Best Management Practices (RBMPs) for the production of process tomatoes, maize and sweet corn in the North Island of New Zealand. Details of the funding agencies and staff are given elsewhere (see Sections 4.2, 4.3, and 4.4). The work was carried out from 1997-2000, but it built on research that began in 1992.

**Approach**

We surveyed commercial tomato crops in Hawke's Bay in 1997-98 and 1998-99. The sites were chosen to represent a wide range of soil conditions. The crops were managed by the growers as part of their normal practice. At each site we set up four monitoring plots. On each plot we measured:

- soil chemical properties at 0-15 and 15-30 cm depth before fertiliser application - readily available N, Olsen P, exchangeable K, Na, Mg and Ca, cation exchange capacity, pH, phosphate retention, organic C and N (see 3.7);
- soil physical properties at 0-15 and 15-30 cm depth - visual score of soil structure (see Section 3.9.1) particle density and soil porosity at harvest, aggregate stability (by wet sieving of air-dried soil) at planting, leaching of nitrate below 50 cm depth in the winter following harvest.
- soil biological properties at planting - microbial biomass C 0-15 cm depth (Vance et al. 1987), immature and mature earthworm populations (sampling by spade);
- nitrate leaching in the autumn and winter after harvest - for this we installed suction cup samplers at 60 cm depth, removing and measuring the nitrate in soil water samples after every significant rain event. Drainage was estimated using a soil water balance model (after Ritchie 1972). When installing the samplers we also took soil samples to measure the amount of mineral N in the soil to 60 cm depth (ammonium and nitrate ions, extracted using 2 M KCl solution). Not all sites were available for nitrate leaching measurements.

We also made a number of plant measurements on each plot at harvest - plant population; incidence of *Sclerotinia* and late blight diseases; weed cover; fresh and dry yield of good and reject fruit; fruit quality (% soluble solids, dry matter %, pulp pH); visual assessment of root diseases (root knot nematodes, corky root, *Pythium*, etc).

Weather data were obtained from a number of government and private weather stations around the district. The growers provided us with information on fertiliser and irrigation applications, paddock history, etc. With all these data we calculated the attainable yield for each plot (see The model for attainable yield in tomatoes). Then we calculated the yield gap - the difference between attainable and actual yields corrected to a standard fruit dry matter content of 6.5% (see Section 1.4). Finally, we looked for relationships between the yield gap, the various indicators of soil quality, and site management history.

## 4.2 The authors

**Jeff Reid**

BSc Agric. Chem. (Leeds, 1977)
PhD Soil Science (Reading, 1980)
MRSC C. Chem (1983)
*Program concepts and design, crop physiology and modelling*

**Andrea Pearson**

BSc Tech Earth Sciences (Waikato, 1992)
Post grad. diploma in Rural Studies, (Massey, 1997)
*Soil science*

**Jacinda English**

BApplSc Natural Resource Mgmt (Massey, 1996)
Certificate of Proficiency Macroeconomics (Massey, 1997).
Certificates of Proficiency Natural Resource & Environmental Economics (Massey, 1998)
*Experimental scheduling, crop measurements and analysis*

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- Ministry for the Environment, Sustainable Management Fund
- Heinz Watties Australasia Ltd Foundation for Arable Research
- NZ Vegetable and Potato Growers Federation (Now
- NZ Fertiliser Manufacturers Research Association

(see Section 4.4).

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## 4.4 Contacts

Authors:

Jeff Reid, Andrea Pearson, Jacinda English

Crop & Food Research Hawke's Bay

RD 2, Hastings, New Zealand

Ph (06) 8700 514 email: reidj@crop.cri.nz

Funders:

**Sustainable Management Fund**

Ministry for the Environment

PO Box 10362

Wellington, New Zealand

ph (04) 917 7400 email: smf@mfe.govt.nz

**Heinz Wattie's Australasia Ltd**

PO Box 439

Hastings, New Zealand (Attn Diana Mathers)
ph (06) 878 0660

email: Diana.Mathers@nz.hjheinz.com

**Foundation for Arable Research**

PO Box 80

Lincoln, New Zealand (Attn Nick Pyke)

ph (03) 325 6353 email: Pyken@crop.cri.nz

**NZ Fertiliser Manufacturers Research Association Inc.**
PO Box 9577

Newmarket
Auckland, New Zealand (Attn Hilton Furness)
ph (09) 309 9782 email:
enquiries@fertresearch.org.nz

**Horticulture New Zealand**

PO Box 10232

Wellington

New Zealand (Attn Ken Robertson)

ph (04) 472 3795 email ken.r@hortnz.co.nz

Other contacts:

Soil maps, details of Hawke's Bay

**Hawke's Bay Regional Council**

102 Vautier Street,

Private Bag 6006

Napier, New Zealand, ph (06) 835 9200

Napier, New Zealand, ph (06) 835 9200

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