Crop & Food Research Report No. 31

Land Management for Grain Maize

Recommended Best Management Practices for New Zealand

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June 2006

CATALOGUING IN PUBLICATION
REID, Jeff
Land management for grain maize : recommended best management practices for
New Zealand / Jeff Reid, Andrea Pearson, and Peter Stone. – Hastings, N.Z.
: New Zealand Institute for Crop & Food Research, 2006.

(Crop & Food Research Report, ISSN 1171-7564 ; no. 31)

1. Grain maize 2. Land management 3. New Zealand I. Reid, Jeff II. Pearson, Andrea
III. Stone, Peter IV. New Zealand Institute for Crop & Food Research Ltd.

DDC 635.67 REI

RECOMMENDED CITATION FORMAT

Reid J, Pearson A, Stone P 2006. Land management for grain maize: recommended best management practices for New Zealand. Crop & Food Research Report No. 31. Christchurch, New Zealand Institute for Crop & Food Research Limited. 38 p.

Contents

1 Introduction

1.1 Using this document

This is a set of Recommended Best Management Practices (RBMPs) for land management to help New Zealand's grain maize industry to achieve environmental and economic sustainability.

The document is in 4 parts.

1. INTRODUCTION – important background information including this page. It is important to read this page first.

2. RECOMMENDATIONS – these are organised around the annual cycle of crop production. They are deliberately simple and practical.

3. FACT SHEETS AND REFERENCES – these back up and explain the information we used to compile the recommendations.

4. ABOUT – details of the program that produced the RBMPs, and how to contact the funding agencies and staff involved.

The RBMPs are published both on Crop & Food Research's website (www.crop.cri.nz/psp/rbmp/maize/index.htm) and in printed form. The recommendations and fact sheets are cross-referenced or linked so that it is easy for you to find more information about any particular topic. The cross links are always underlined and are usually in brackets. We suggest that you read all of the introduction and the recommendations before looking at the fact sheets.

If you are reading this from a printed document, then you can use the underlined text to guide you to a heading in Sections 2, 3 or 4. If you are viewing this on your computer, simply click the mouse on an underlined link to bring up the relevant page. We recommend that you use the website because it makes it very simple to navigate through the document.

Disclaimer

The information and recommendations in this document are given in good faith. Following these recommendations should improve the profitability and environmental sustainability of grain maize growing under New Zealand conditions. The circumstances under which this information is used are not under the control of either Crop & Food Research or the funding agencies associated with the program (see The Sustainable Crop Production Program (Section 4.1) and Contact (Section 4.4). Accordingly, Crop & Food Research, the Ministry for the Environment, the Foundation for Arable Research, Heinz Watties Australasia Ltd, the NZ Fertiliser Manufacturers Research Association, and the NZ Vegetable and Potato Growers Association cannot be held responsible for any losses arising from the use of this document.

1.2 Maize production and land management

In New Zealand, maize is grown for grain mainly in the Waikato, Manawatu, Bay of Plenty, Gisborne and Hawke's Bay areas. It is grown in a wide variety of environments. Yields can vary sharply from year to year, but they are usually best on the drier East Coast areas (Gisborne, Hawke's Bay).

In some areas growers must lease a large fraction of the land that they use. This causes them a number of problems. For many years now the cost to lease good quality land has been very high – due to competition from other land uses such as dairying and intensive horticulture. This can force growers into using land of marginal quality, and it forces more intensive use of the available land with tighter crop rotations.

The physical and biological qualities of soils are usually best under long-term pasture. Soil physical conditions can deteriorate markedly where maize is grown repeatedly (see for instance Page & Willard 1946; Cotching et al. 1979; Coote & Ramsey 1983). There are many causes of this deterioration, including badly timed or excessive cultivation, compaction by machinery, and the activities of the maize roots themselves (Ross & Hughes 1985; Gibbs & Reid 1988).

Overseas experience of these land management issues is not necessarily applicable to New Zealand. Here, maize is often grown in soils that contain much pumice and allophanic minerals from volcanic eruptions. Cotching et al. (1979) found that those soils can be much more resistant to degradation under maize than soil derived from, say, river deposits.

The realities of the market place mean that 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 Recommended Best Management Practices for land management under grain maize in New Zealand. The program, "Sustainable Crop Production", was funded by industry and central government (see sustainable crop production program, Section 4.1).

References

Coote, D.R.; Ramsey, J.F. 1983. Quantification of the effects of over 35 years of intensive cultivation on four soils. Canadian Journal of Soil Science 63: 1-14.

Cotching, W.E.; Allbrook, R.F.; Gibbs, H.S. 1979. Influence of maize cropping on the soil structure of two soils in the Waikato district, New Zealand. New Zealand Journal of Agricultural Research 22: 431-438.

Gibbs, R.J.; Reid, J.B. 1988. A conceptual model of changes in soil structure under different cropping systems. Advances in Soil Science 8:123-149.

Page, J.B.; Willard, C.J. 1946. Cropping systems and soil properties. Soil Science Society of America Proceedings 11:81-88.

Ross, C.W.; Hughes, K.A. 1985. Maize/oats forage rotation under 3 cultivation systems, 1978-83. 2. Soil properties. New Zealand Journal of Agricultural Research 28:209-219.

1.3 Aims of the RBMPs

These RBMPs aim to help the New Zealand grain maize industry to achieve environmental and economic sustainability. They are based on the premise that maize 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 maize production;
- improve crop yields and profitability.

Implementing the RBMPs is a crucial step towards achieving maize 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 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 maize crops (see potential yield and real yields). 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.

Recommendations

1.5 Site selection

If you are looking to lease a paddock, or you are prioritising paddocks that are already available to you, we recommend you apply the following selection procedure. Of course make sure that any lease fee is fair and will leave you with a sufficient profit margin!

1.5.1 Site selection - check before visiting the site

- **Use soil maps as a preliminary guide to suitability.** There is no guarantee the soil type(s) in a given paddock will be exactly as mapped, but the maps available from Landcare Research or your Regional Council are an excellent start. 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 many areas, clay loams may have dense subsoils that can cause problems in wet conditions. Note also that the soil texture assignation will help you to understand where the site fits within the landscape. Compared to 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.
- **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. We suggest you use the Maize Calculator (available from FAR) to forecast the most profitable fertiliser rate (see fertiliser application rates, the Maize Calculator). If that is not possible, try to select paddocks with Quicktest K >5, and Olsen P >8.

1.5.2 Site selection - check when visiting the site

- Arrange paddock layout and access to minimise driving over or parking agricultural machinery on cultivated areas. In particular, aim to minimise the number of turns tractors and harvesting machinery will need to make.
- **Give priority to sites that are 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.
- **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 yield losses through waterlogging and machinery damage to the soil because it is too wet (see water tables).
- Examine the soil, checking the soil profile for soil texture, the presence of compact layers, evidence of a shallow water table, and soil structure score. Do those assessments at three or more locations per paddock. For texture and soil structure, carefully excavate the soil to 15 cm depth using a spade. Record its condition against the descriptions given for the structure scoring system (see soil structure scorecard). Assess the soil texture (see assessing soil texture). Then repeat the process for 15-30 cm depth. It is a good idea to check at greater depths also - in case there is a

subsoil pan. Compare the average structure score for the paddock (for the top two depths together) against the graphs given elsewhere (see soil structure and yield). Then estimate if poor soil structure will restrict yield. Assessing soil structure is important because it has a large influence on crop performance.

- **Check for water tables.** If the paddock is bordered by open drains, check for signs that the water level comes close to the soil surface – if you are not familiar with the paddock it is worth asking others. It's also a good idea to use an auger or posthole digger to check for a water table in the top 120 cm or so. A water table at about 100 cm depth during the season can be very beneficial (see water deficit and yield). On the other hand if there are signs that a water table comes within 50 cm or so of the soil surface you should be wary of using the paddock (see water tables). When you are digging or augering the soil look for gleying (where the soil has an unusually grey or even faint blue hue), or strong red mottles on a pale grey background – these are signs that the soil has been waterlogged.
- If the site meets your requirements (see above) then take soil samples to assess the chemical fertility of the soil 4-6 weeks before planting. Take soil samples to 15 cm depth using a standard sampling technique (see sampling soil for chemical analysis). 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 soil chemical analysis). We also recommend that organic C% is measured. Keep copies of all test results.

1.6 Site preparation

1.6.1 Organic matter management

- Increase soil organic C content if it is <2.5% (see soil organic matter).
    - If it is close to 2.5% and previous yields have been good, then compost applications will probably suffice (see organic composts or manures). Cultivate bulky composts into the soil at least two weeks before final seedbed preparation and planting.
    - If it is <2.0%, then compost will still be useful, but leave the site under grass for at leastthe following season, or preferably two seasons, or until the organic C returns to around 2.5%. Try to avoid leasing paddocks with soil organic C content values of <2.0%.
- Give high priority to repairing soil if the preceding 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.

1.6.2 Fertilisers

- **Consider applying lime if the soil pH is <5.0.** Wherever possible apply fine lime at least one month before planting, and always before beginning cultivation.

- **Identify the most suitable fertilisers to optimise yield.** We recommend use of the Maize Calculator, available from FAR (see fertiliser application rates). This requires that chemical soil testing is carried out. Identify the most cost-efficient combination of products, with the following limitations:
    - keep N applications to a minimum if the soil has been under pasture in the previous two years;
    - 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, drought, pests or diseases - it also increases the risks of pollution (see nitrate leaching).
- 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 economic vs maintenance fertiliser applications). This particularly applies to P, K and Mg.
- Plan the fertiliser application times and methods carefully. Your choices here must be consistent with the NZFMRA Code of Practice for Fertiliser Use (see Code of Practice for Fertiliser Use). In particular, avoid applying N fertilisers prior to planting. It is widely believed by growers that broadcasting a light dressing of N may help the soil microorganisms to breakdown trash from the previous crop before planting. However, there is no scientific evidence for this under New Zealand conditions. Only apply N for the purpose if you are sure you will have problems drilling the crop through the trash – modern machinery can often cope well under those circumstances.
- Band or broadcast N fertiliser. However, unless it is about to rain, broadcast N fertiliser should be immediately cultivated into the soil. Considerable amounts of ammonia may rapidly volatilise (evaporate) from urea and ammonium-based fertilisers left on the soil surface. Apart from the fact you've already paid for the fertiliser lost, ammonia is a greenhouse gas that can contribute to global warming.
- Reduce the chances of nitrate leaching. If large amounts of early season rainfall are likely or if the soil is very free draining then apply half or less of the required N fertiliser at planting, and side-dress the rest before stem elongation.

1.6.3 Soil structure and cultivation

- **Encourage good soil structure** (see soil structure and yield). This requires particular attention to soil organic matter, machinery traffic over the soil, and cultivations. 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 to that level in the next 2 years (see organic composts or manures, and soil organic matter).
- **Wherever possible, cultivate only areas that will be planted, and minimise the number of cultivation passes that are used.** This is important because cultivation weakens the soil and encourages loss of organic matter. Align crop rows to minimise the amount of turning by tractors and trucks (to reduce the risks of compaction).

- Where possible, arrange the rows 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.
- **Where possible, plant headlands in grass to improve soil resistance to structural damage by machinery.** Headland areas that will not be planted with crops should be cultivated as little as possible - especially areas used for machinery traffic.
- **Don't cultivate the soil into a fine seedbed.** Cultivation for a fine seedbed increases the risk of substantially weakening the soil structure and is rarely necessary for maize.
- **Keep all cultivations to a minimum by careful timing;** do not plough, rotary hoe, or grub when the soil is very wet or very dry (see cultivations and soil water content).
- **Fracture any pans using a subsoiler or deep tines when the soil is dry** (see cultivations and soil water content). A compact layer or pan at 15-30 cm depth is usually 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 crop because they limit root growth and increase the risks of waterlogging and drought damage to the crops (see water tables).

1.7 Planting operations

- Schedule cultivations and sowing to minimise the length of time that finely cultivated soil is exposed to wind and rain. This will reduce the chances of erosion.
- **Apply all or most of the P fertiliser at planting**. 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. Do not broadcast P fertiliser.

1.7.1 Land management during crop growth

- Control weeds with a careful combination of herbicides and cultivation.
- Cultivate only when the soil is friable (see cultivations and soil water content). Wherever possible avoid cultivating if rain is forecast in the next three days (see last paragraph of cultivation and soil water content).
- Wherever possible minimise the amount of compacted soil by reusing the same furrows or tracks for tractor wheels.
- Apply any side 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).
- Apply only enough irrigation to return the soil to within 15 mm of field capacity. 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.

- 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 >30 mm of water is applied). Make sure that "gun" irrigation rigs are 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.

1.8 Harvest and post-harvest operations

- **Avoid compaction of soil by trucks and harvesting machinery.** If the soil is reasonably dry then that compaction can be repaired by careful cultivation later, but both the original compaction and the subsequent cultivation weaken the soil structure so it is more easily damaged by later stresses due to say heavy rain, machinery or animal treading.
- Harvesting should be avoided if there has been significant rainfall (>25 mm, say) in the previous 48 hours.
- Minimise the amount of time that the soil surface is left unprotected by plant cover.
- We recommend that following harvest, crop residues are left to protect the soil surface.
- **Chop trash and sow a grass or a break crop, such as oats or lupins, in the residues if the weather is mild.** The grass or break crop can be cultivated in later to help build up soil organic matter content (a 'green manure').

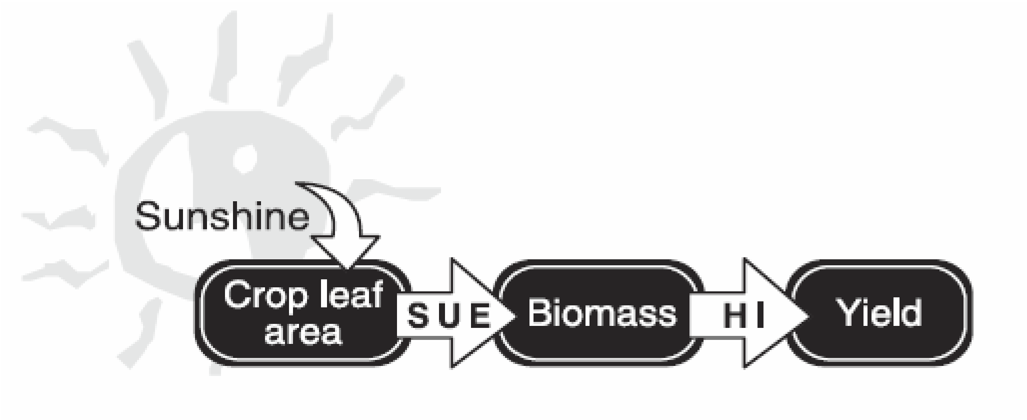
Establishing grass or a break crop quickly will also help reduce nitrate leaching into ground-water (see nitrate leaching in the following winter). It also helps reduce organic C loss by microbial respiration.

2 Fact sheets

2.1 Potential yield

Potential yield is the maximum yield that a given hybrid can achieve when sown at a certain time, place and population. It occurs when there are no limitations to growth caused by inadequate water, nutrients or soil physical characteristics.

The process by which potential yield is formed is simple and well understood.



- First, sunshine is absorbed by the crop according to the amount of leaf area that it has. This sunshine is converted to crop biomass via photosynthesis, according to the sunshine use efficiency (SUE, biomass made per unit sunshine absorbed). For maize, crop biomass increases by about 1.6 t/ha for every 100 MJ of sunshine absorbed. This takes about 10 days for a rapidly growing crop.
- Crop biomass is converted to yield according to the harvest index (HI, yield as a fraction of crop biomass). In maize, harvest index at maturity is around 0.5, which means that about 50% of the total biomass of the crop is in the grain. These 'rules' of potential crop growth and yield apply to virtually all healthy maize crops.
- Sunshine is the driving force behind potential yield, but the ability to use sunshine most effectively is altered by temperature, hybrid, sowing time and plant population.
- So what is the role of other factors such as temperature, hybrid choice, sowing time and plant population? These affect potential yield mainly because they affect the amount of sunshine absorption. Let's look at the effect of each of them.

2.1.1 Temperature and potential yield

- Temperature affects potential yield mainly because it affects the rate of crop development.
- As temperature rises, leaves are produced more quickly and the times taken to reach silking and maturity decline. All are signs of increased development rate.
- Increased temperatures generally reduce potential yield because they shorten the duration of crop growth. This gives crops a smaller number of days to absorb sunshine, which lessens the total amount absorbed which, in turn, reduces growth and yield. This largely explains why average maize yields in the relatively cool NZ environment

(11.5 t/ha) are higher than those in the much warmer Australian (7.0 t/ha) or USA environments (9.3 t/ha) (FAOSTAT 2000).

- There is a widely held misconception that crop growth increases with temperature. In most cases it does not. Total growth seems to be greater as temperature rises because plant parts are produced more quickly. This is actually evidence of enhanced development, not increased growth.
- **Growth and development are not the same**. While they usually occur together they respond quite differently to temperature - development rate increases with temperature, growth usually does not.
  - *Development*— is the accumulation of growth stages and is measured in leaf numbers or times of silking or maturity.
  - *Growth*— is the accumulation of mass and is measured in kg or tonnes.
- We can see that crop growth and development are different because crops that develop at the same rate do not necessarily have the same biomass or yield. The analogy in humans is that a light and heavy person (different growth) may share dates of birth, puberty and death (same development).
- Many growers are aware of the idea of degree days or thermal time. Generally the warmer a day is the more thermal time passes in that day. Crop development depends on the accumulation of thermal time, so in warm weather the crop develops quickly. On the other hand, growth depends on the amount of sunshine the crop intercepts and that depends on the leaf area index, the amount of sunshine each day and the total number of real or clock days available for the crop to grow. If the crop develops quickly (under warm conditions) it has fewer real days to grow, which limits the total amount of sunshine available to it. So, generally, yields are best when the crop gets a lot of cool sunny conditions.

"There's not been any frost, but weather's been very cool and my crop is so short…"

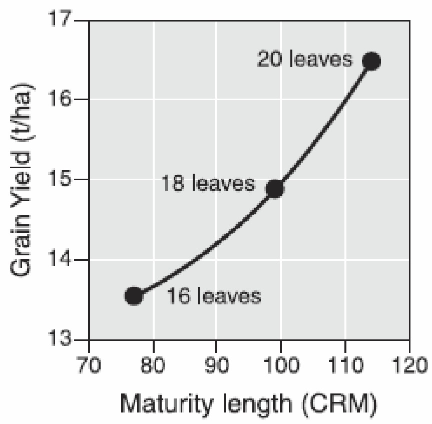
Don't worry about it Maize goes through a period of rapid height increase. This stem elongation is a developmental event – it occurs earlier under warm conditions. Remember that growth is a change in dry mass, and final yield depends on a crop's mass not its height. Under cool conditions stem elongation is delayed, but that gives the crop more days to intercept sunshine and put on mass. Provided the sun shines well, longer periods of cool weather may delay stem elongation but they give the crop more days to grow.

Let's now look at how the choice of hybrid affects potential yield.

2.1.2 Hybrid and potential yield

- Hybrid affects potential yield mainly because it affects sunshine absorption.
- Hybrids differ very little in either their sunshine use efficiency or harvest index.
- In general, short season hybrids yield less than long season hybrids because:
  - they have a shorter lifespan, and consequently fewer days in which to absorb sunshine, and
  - they have fewer and smaller leaves, and consequently less ability to absorb sunshine.

***Figure 1**: The effect of hybrid maturity length on yield of maize.*



- That advantage of the long season hybrids depends on you sowing them early enough, and on the weather being warm enough for them to reach maturity before there can be any frost damage.

We've looked at the direct effects of light, temperature and hybrid on potential yield. Now let's use this information to make sense of how sowing time influences potential yield.

2.1.3 Sowing time and potential yield

- Sowing time affects potential yield mainly because it affects sunshine absorption. This occurs via two main routes.
  - First, the amount of sunshine varies dramatically during the growing season, and sowing time has a major influence on whether growth occurs when there is more or less sunshine.
  - Second, sowing time affects the temperature during crop growth which, as outlined above, influences crop development, duration and yield.
- Maximum potential yields occur when crops are sown so that they reach maximum leaf area close to the longest day of the year. For many hybrids this would equate to silking between Christmas and the New Year.

Figure 2: Change in sunshine energy throughout the year. Data from Gisborne, 1990.

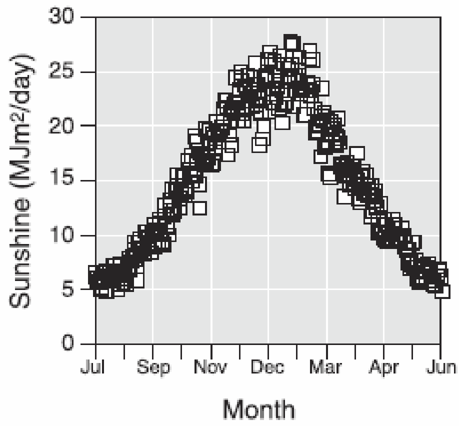
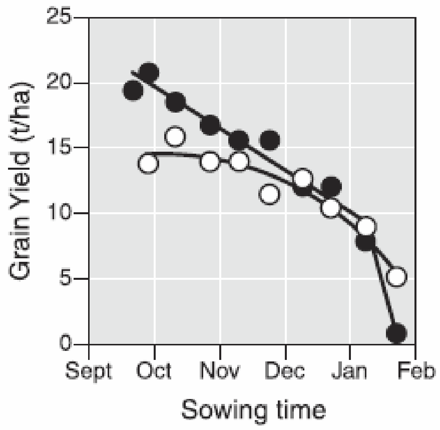


Figure 3: The effect of sowing time on yield of short season (hollow symbols) and long season (filled symbols) maize.

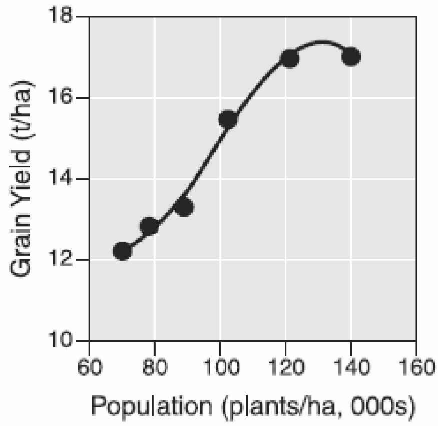


Now, let's look at one final factor that influences potential yield – plant population.

2.1.4 Plant population and potential yield

- Plant population affects potential yield mainly because it affects the amount of - you guessed it - sunshine absorption.
- As plant population increases so does total crop leaf area. This has a two-fold effect on sunshine absorption:
  - First, more leaf area gives more rapid row closure, which minimises wasteful loss of sunshine to the soil surface and maximises use by the crop.
  - Second, more leaf area increases the amount of sunshine absorption after canopy closure.
- The net effect is that maize growth and yield increase with plant population, to a maximum at around 120 000 plants/ha in New Zealand.
- Of course, the response to population will be limited in crops where nutrient or water deficiencies constrain growth. Furthermore, the beneficial effects of high plant population on yield need to balanced against the possible negative effects on quality and crop accessibility.

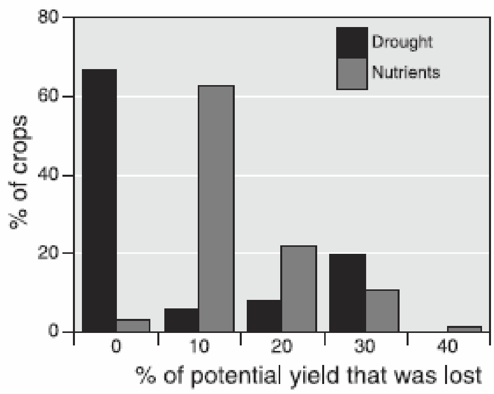
Figure 4: *The effect of plant population on yield of maize grown in Hawke's Bay.*



2.2 Real yields

So why don't commercially grown crops usually reach the dizzy heights of potential yield? Apart from the fact that good growers of commercial crops aim for maximum money rather than maximum yield, there are two basic factors that we have identified: (1) water and nutrient deficiencies and (2) soil physical and biological health. Let's look first at water and nutrient deficiencies at our study sites in the Waikato, Bay of Plenty, Manawatu, Hawke's Bay and Gisborne.

Figure 5: *Yield losses due to drought and inadequate nutrient supply at our study sites, 1997-2000.*



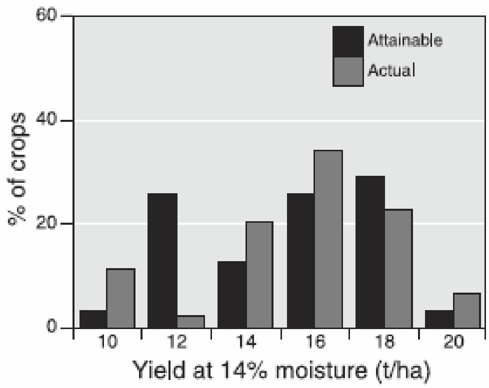
Most of the crops suffered relatively little from drought, although under some conditions big yield losses are possible (see water deficit and yield). Most of those that did lose yield from drought were grown on sandy soils without a water table. By contrast, very few crops received all of the nutrients that they needed to achieve their potential yield. The nutrient most often lacking was nitrogen (N) (see nutrients and yield).

2.2.1 Attainable yield and the yield gap

- Attainable yield is the potential yield adjusted downward for stresses due to drought and inadequate nutrient supply. In effect, it is the yield that the grower paid for in terms of seed, fertilisers, cultivation and irrigation.
- For each crop in our survey we used our computer models to calculate the attainable yield, and then compared this with the actual yield. The results were very interesting (see Figure 6).

- Attainable yields ranged from 9.5 to 18.1 t/ha – with the highest values from Gisborne and Hawke's Bay. Actual yields varied from 8.6 to 19.4 t/ha.
- A few crops exceeded the attainable yield. For those crops the model underestimated the potential and hence attainable yields because the hybrids grown were so new that we did not have adequate information on their leaf areas. For several sites though the attainable yield was greater than the actual yield.

Figure 6: *Attainable and actual yields of the surveyed crops.*



The yield gap

- The yield gap is the difference between the attainable and actual yields. In practice, there is always some uncertainty associated with the calculation of attainable yield. For our calculations a yield gap is only significant if it is greater than 12%.
- Most of the surveyed crops had yield gaps that were not different from zero, which is good news for many maize growers. On the other hand, about one-third of the crops had yield gaps in the range 12-40%.
- A yield gap greater than zero occurs where yield is being limited by factors notincluded in the calculation of potential and attainable yield – namely soil physical and biological quality. So, our results suggest that improving soil quality will benefit yield at about one-third of the sites we surveyed.

See soil structure and yield for more information about the yield gap.

2.2.2 Water deficit and yield

- Water deficit, or drought, reduces yield of maize in a predictable manner. To understand how we need to know some basic rules about crop water balances, which are similar to bank balances.
  1. The opening balance is the amount of water stored in the soil at the time of planting,
  2. withdrawals are caused by evapotranspiration, or 'ET' for short, and
  3. deposits are caused by rainfall or irrigation.
- For maize, yield becomes reduced when the crop water balance drops below half the available water holding capacity of the soil. In many cases this gives a threshold value (below which water deficit starts to reduce yield) of 90 mm, although in deeper soils the value may be as high as 120 mm. Furthermore, we know that yield of maize drops by about 500 kg/ha for every 10 mm below the drought threshold. Together, this makes it

easy to calculate how much yield is lost through water deficit. An example is shown in Fig. 7.

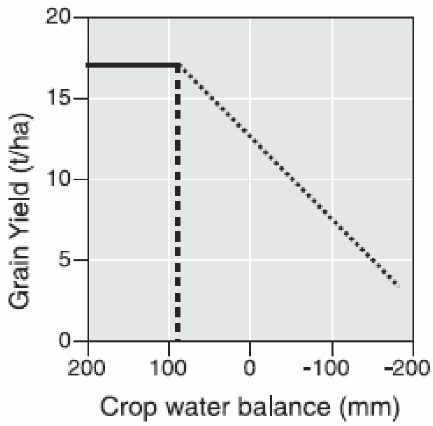


***Figure 7**: Effect of water deficit on yield of maize. Dotted line shows water balance threshold below which yield reduction occurs.*

In the period from sowing to silking, it is the amount rather than the timing of deficit that determines the response of yield to drought under New Zealand conditions. Maize is equally sensitive to water deficit throughout this period - the only thing that changes is the rate at which deficits accumulate. Interestingly, maize appears to become less sensitive to water deficit after silking. While this may seem strange it probably occurs because, by this time, the roots have in many cases reached deep into the moist layers of the soil profile.

See also water tables.

2.2.3 Nutrients and yield

- The main nutrients affecting crop growth and yield are nitrogen (N), phosphorus (P) and potassium (K).

Nitrogen

- The picture shows how dramatically maize crops can respond to N fertiliser when the soil N levels are low to moderate. The crop in the foreground received no N fertiliser, the one in the background received 92 kg N/ha at planting. In the top 15 cm soil, the readily available N was about 60 kg N/ha (see soil chemical analysis).
- The contribution of N to growth and yield is large and readily quantifiable. As mentioned above, N influences yield largely because of its role in determining (1) the amount of sunshine absorbed by crops and (2) the efficiency of conversion of sunshine to biomass. Nitrogen deficiency reduces leaf size, which reduces total crop leaf area and consequently the ability to absorb radiation. Furthermore, N deficiency reduces the concentration of N in leaves, which reduces their sunshine use efficiency (SUE), or ability to photosynthesise.
- Nitrogen deficiency also causes premature leaf death because crops are able to sense when leaf N concentration is getting too low to sustain adequate levels of SUE. To combat this problem crops sacrifice leaves so that N can be shifted to a smaller number of more efficient leaves. Together, these responses underline the importance of adequate N for crop growth and yield. A typical maize crop contains about 1.5% N, which for a 15 t/ha yield requires an absorption of about 450 kg N/ha, with

approximately 275 kg N/ha residing in the grain. Nitrogen contributes most effectively to yield if provided for the duration of crop growth.

Phosphorus

- The effects of P on yield are substantial, but less clearly quantifiable than those of N. P is essential for the storage and transport of the energy used to drive plant processes and is an important part of biochemicals such as DNA that control plant growth and development.
- Phosphorus deficiency symptoms may include smaller leaves, thin stems, and a limited root system (due to reduced sunshine interception by the leaves rather than any direct effect on the roots). A red/purple colour is also common in older leaves, which is evidence of the fact that, when deficient, P is moved to younger expanding leaves.
- Phosphorus concentration is generally stable over time and consequently P supply is most urgent during periods of rapid growth. It is maintained at around 0.2% of crop DM. A typical 15 t/ha maize crop therefore absorbs only about 65 kg/ha P, with approximately 45 kg/ha residing in the grain at harvest.
- Yield responses to P fertiliser are rare unless the Olsen P level in the soil is <10 mg/ml.
- The requirement for P fertiliser appears to be much lower for maize than for sweet corn, despite the fact that maize crops absorb more P than sweet corn crops. Future work is aimed at determining whether this is related to a greater efficiency of P absorption or utilisation in maize than sweet corn.

"There are purple and red colours in my crop — should I have added P fertiliser? "

Growers are occasionally alarmed to see red colours in young maize plants and worry that this is a sign of P deficiency. Under New Zealand conditions that red colour is most often a characteristic of the hybrid, or due to cold stress and not P deficiency. The plants almost always grow through this stage satisfactorily.

Potassium

- Potassium is the third major nutrient required by maize. Its function within the crop is less clear than that of N and P, but it is nevertheless obvious that significant quantities of K are required for crop growth. A mature maize crop contains about 2% K, so a crop yielding 15 t/ha contains approximately 300 kg K/ha, of which about 60 kg K/ha will be held in the grain. Despite this high requirement of maize for K, responses of yield to K fertiliser are rare. Responses are likely to occur only on sites where Quicktest K values are <4. Generally, there is little need to apply K fertiliser to maize crops, mainly because there are usually abundant supplies of accessible K in New Zealand soils.

(see also fertiliser application rates)

2.2.4 The Maize Calculator

- As part of this program we developed a computer model for the attainable yield of maize crops. We call this model “The Maize Calculator”. A version of the Maize Calculator is available to levy-paying maize growers through the Foundation for Arable Research (see contacts).
- The Maize Calculator starts by calculating potential yield at a standardised plant population. The maths for these calculations were initially developed by Muchow et al. (1990) and modified for cool climate maize production by Wilson et al.(1995).
- Basically, the Maize Calculator calculates how green leaf area index changes with time and temperature. It uses these values to calculate the amount of sunshine intercepted and the daily growth of the crop. Finally, it calculates grain yield assuming that harvest index increases with thermal time after silking, up to a maximum of 0.5 (see potential yield).
- To do these calculations the Maize Calculator uses standard weather observations. You can also use it to forecast potential yield, if you make some assumptions of what the weather will be like.
- Next it adjusts the potential yield for plant population, and the supply of water and nutrients. To do this it uses PARJIB™, another model developed by the team at Crop & Food Research. The version of the Maize Calculator that is distributed concentrates on N responses, because maize yields rarely respond to P, K, and magnesium (Mg) fertilisers in New Zealand, and it does not allow for drought. The version we used to analyse our survey results enabled us to look at the effects of all these nutrients and drought.
- We calibrated the model using measurements of a wide range of crops that were very unlikely to have been affected by poor soil structural conditions.
- How good was that calibration? Well, we calibrated it twice. The first time, we used a set of measurements of crops from the Waikato, Bay of Plenty, Manawatu, Hawke’s Bay and Gisborne. The root mean square error of calibration was 0.66 t/ha. Then we compared the model’s predictions of yield at another set of independent crops from the same districts, and it performed very well. Finally, we pooled both sets of data for a combined calibration. The results are shown in Figure 8. Clearly the model was very accurate. The root mean square error was 0.92 t/ha and the model explained 83% of the observed variation in yield.

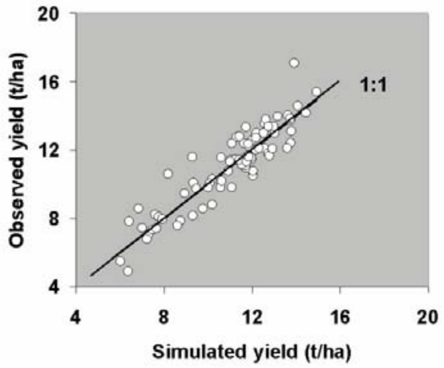


***Figure 8**: Model calibration using measurements of a wide range of crops unlikely to have been affected by poor soil structural conditions.*

References

Muchow, R.C.; Sinclair, T.R.; Bennett, J.M. 1990. Temperature and solar radiation effects on potential maize yield across locations. Agronomy Journal 82: 338-343.

Reid, J.B. 1999. Forecasting nutrient responses in annual crops. Proceedings Agronomy Society of New Zealand 29:in press.

Reid, J.B.; Stone, P.J.; Pearson, A.J.; Cloughley, C.; Wilson, D.R. 1999. 'The Maize Calculator' - a simple system for predicting fertiliser nitrogen requirements of maize. Proceedings Agronomy Society of New Zealand 29: in press.

Wilson, D.R.; Muchow, R.C.; Murgatroyd, C.J. 1995. Model analysis of temperature and solar radiation limitations to maize potential productivity in a cool climate. Field Crops Research43:1-18.

2.2.5 Soil structure and yield

- Soil structure is the physical arrangement of the solid, liquid and gas components of the soil. It affects crop growth in a great many ways. For instance, a soil with a dense compact structure may:
  - be difficult for roots to penetrate, making the crops prone to deficiencies of water and nutrients,
  - retain water well,
  - contain only small amounts of air,
  - be prone to waterlogging, which can damage plants through poor air supply to the roots and microbes in the soil around the roots,
  - have excellent capacity to support machinery when dry.
- On the other hand, very open or porous soil structure can drain too easily, leaving crops susceptible to drought and encouraging leaching of nutrients such as nitrate.

"But I know a paddock where..."

Growers often know of paddocks that have been cropped for many years with obvious signs of soil structural damage and yet yields have risen. Some sites with relatively poor soil structure do produce high yields. So why does this practical experience sometimes run contrary to scientific theory?

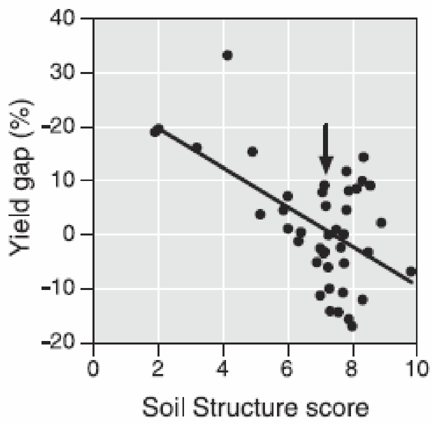
There are four main reasons:

1. Modern varieties have a higher yield potential than their predecessors. Over the years, changes in varieties will tend to counter the losses due to increasingly poor physical or biological conditions.
2. Better management of irrigation, pests and diseases may also help to hide those losses.
3. Changes in fertiliser practice - growers today are using an increasingly comprehensive range of fertilisers and organic manures to raise yields.
4. The effects of poor soil structure will depend on the weather conditions. For instance a plough pan may often restrict root growth and cause waterlogging damage to the crop following heavy rainfall. If the same amount of rainfall is spread across several smaller events, the chances of noticeable waterlogging damage are much less.

Soil structure, the yield gap and risk

- When developing these RBMPs, we used the yield gap approach to avoid complications due to the first three reasons above (see key concepts). We used our models to calculate the yield gap for the crops in our survey (see the sustainable crop production program).
- The yield gap became larger as the soil structure became poorer. The confidence limit for an individual yield gap figure is about 12%, so values between –12% and +12% are effectively not different from zero. With that in mind, our results suggest that if the soil structure score is better than about 7, there is relatively little chance of a significant yield gap. On the other hand, if the structure score falls below 7 there is a good chance of losing yield – the yield gap increases by about 3.5% yield per unit drop in the soil structure score.
- These results show that the chances of losing significant amounts of yield are increased by poor soil structure. If the soil structure score falls by say 2 units, due perhaps to pugging damage by stock in the winter before, then you could lose about 7% maize yield. For a crop with an attainable yield of 15 t/ha that loss equates to about $210/ha. Careful management of the soil structure makes good sense, both financially and environmentally.

Figure 9: Influence of soil structure on the yield gap for maize crops in the Waikato, Bay of Plenty, Manawatu, Gisborne and Hawke's Bay. The soil structure score was measured using the soil structure scorecard.



2.2.6 Crop residues

- Maize crops leave a lot of residues on the soil surface. On a dry weight basis, the mass of these residues is about equal to the grain yield. In other words the harvest index of the crop is usually about 50% (see potential yield). A crop that yields say 12 t/ha of dry grain (14 t/ha at 14% moisture) will leave about 12 t/ha of residues.
- The residues are usually made up of stalks (41%), leaves (23%), husks (15%) and rakis (21%).
- Some parts of those residues such as leaves are readily decomposed by microbes. Other parts such as the stalks are much more resistant.
- Often, decomposition of the older leaves is well advanced by the time of harvest.
- After harvest, these residues can be grazed, left in place (with or without mulching), or incorporated into the soil. Let's look at these options in turn.

Grazing

- The nutritive value of maize residues is slight, and grazing has some important disadvantages.
- If it rains then stock can do substantial damage to the soil structure by pugging. This increases the amount of cultivation needed to form a seedbed, and increases the risk of a substantial yield gap in the next crop (see soil structure and yield).
- Cattle also increase the risk of nitrate leaching - their urine contains a large concentration of urea that rapidly forms nitrate. There is no living crop there to take up this nitrate, and it is readily leached by rainfall.

Leaving residues on the soil surface

- Crop residues left on the soil surface will protect the surface from the physical impact of heavy rain - which can cause breakdown of the soil aggregates, capping, water runoff and erosion on hill slopes.
- Mulching residues can provide a better coverage of the soil surface, and the residues will be easily incorporated when preparing a seed bed for the following crop.

Incorporation

- Incorporating crop residues soon after harvest can help:
  - speed up the breakdown of the residues, easing cultivations and planting operations the following spring, and increasing soil organic matter,
  - temporarily mop up any excess mineral N in the topsoil (as the soil microbes use that N for the residue decomposition process) - this can reduce the risk of nitrate leaching, helping the soil to retain N for the following crop,
  - control plant diseases such as Fusarium (the jury is still out on this possibility, more research is needed to check it out).
- Ploughing inverts the soil and buries the residues in a narrow band - so decomposition can be very slow and the benefits of the added organic matter localised. Many alternative practices, such as discing, distribute the residues better. However, keep the number of cultivation passes to a minimum, and only cultivate at all if the soil water content is suitable (see cultivations and soil water content).

2.3 Soils and fertilisers

2.3.1 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 <0.002 mm.
- 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.

Feel and sound	Cohesion and plasticity	Field texture class
Gritty and rasping	Cannot be moulded into ball	Sand
	Can almost be moulded into a ball – but falls apart when flattened	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.

2.3.2 Sampling soil for chemical analysis

- Sample before fertiliser or lime is applied. You are recommended not to sample within 3 months of fertiliser application (see Code of Practice for Fertiliser Use), 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 soil chemical analysis for the list of measurements you should request from the laboratory.

2.3.3 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. The following are the standard soil tests for New Zealand conditions, and we recommend these as the minimum that you should request from the analytical laboratory:
  - soil pH (1:2.5 w/v in water) (Cornforth, 1980);
  - Olsen P (bicarbonate extractable P) in units of μg/ml, ppm or MAF QuickTest units (Cornforth, 1980);
  - Exchangeable K, Na, Ca and Mg in MAF QuickTest units or in meq/100 g (Cornforth, 1980);
  - Cation exchange capacity at pH 7.0 (Cornforth, 1980);
- In addition, we strongly recommend two extra tests:
  - Readily available or readily mineralisable N, measured by anaerobic incubation at 40°C (Keeney and Bremner, 1967). This is essential if you wish to use the Maize Calculator.
  - Soil organic C (% w/w), measured 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 chemical analysis). Identify fertiliser rates using the Maize Calculator if possible (see fertiliser application applications).

References

Cornforth, I.S. 1980. Soils and fertilisers - soil analysis and interpretation. AgLink AST 8. Media Services, New Zealand Ministry of Agriculture and Fisheries, Wellington.

Keeney, R.R.; Bremner, J.M. 1967. Comparison and evaluation of laboratory methods of obtaining an index of soil nitrogen availability. Agronomy Journal 58:498-503.

Walkley, A.; Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38.

2.3.4 Fertiliser 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 economic vs maintenance fertiliser applications).
- 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. Let’s look at the optimum values reported by Steel (1984):
  - P: greater than 11 μg/ml or ppm,

- K: 0.84, 1.05 and 1.4 meq/100 g for sands, loams and clays respectively,
- N: no simple figures available, because there was no accepted standard soil test for available N.

- You can also calculate the crop's response to soil and fertiliser supply of nutrients, and use those figures to work out the most profitable fertiliser rates. We used that approach, and it is an important part of the Maize Calculator available from FAR (see contacts and the Maize Calculator). To do this we built a computer model of how yield responds to supply of N, P, K and Mg from both soil and fertiliser sources. The model had to be calibrated across a wide range of conditions.
- Remember that the higher the potential yield the bigger the demand for nutrients. Generally, short season hybrids and late plantings will require less fertiliser than long season hybrids and early sowings. If you increase the plant population remember that this will also increase the demand for fertiliser.

Recommendations

- You must get a soil chemical analysis done for each paddock each year. Use those results to work out the fertiliser rates.
- P: apply P fertiliser according to the soil test result. If the soil test P is greater than10 μg/ml then no P fertiliser should be necessary. If the soil test value is <10 μg/ml then we suggest that 20-35 kg P is applied as a starter fertiliser. Use a rapidly available form of P, such as superphosphate, and do not broadcast it.
  - Steele (1984) suggested applying a maintenance P fertiliser if the soil test P was 11-14 μg/ml, and 50 kg P/ha as pre-plant and 20-35 kg P/ha as a starter fertiliser if the soil test P was less than 11 μg/ml. However, in our experiments across the North Island, we found no response to P fertiliser at soil test values as low as 8 μg/ml - and that result was backed up by a re-examination of Steele's experimental results. Soil test results vary within a paddock of course, and so if the average P level is say 10 μg/ml, there will be some areas where P is less than 8 μg/ml. Our recommendations are, therefore, to minimise the chances of these areas affecting the overall paddock yield - while maximising the chances that the fertiliser is profitable.
- K: apply K fertiliser only if the soil test value is less than about 4 MAF Quicktest unitsor 0.2 meq/100 g. Under those conditions apply K to replace the anticipated removal in grain, that is about 63 kg K/ha for a crop yielding 15 t/ha at 14% moisture. Use the cheapest source of readily available K that you have available.
  - Steele (1984) indicated that yield responses to fertiliser K will be unlikely at soil test values >4 Quicktest units. His results were based on 7 trials in the North Island over a number of years. We found that yield did respond to K application at soil test values greater than 4, but the responses were so slight that Steele's experiments would not have been sensitive enough to detect them. Needless to say, with such slight yield responses, K fertiliser applications are not economic unless the soil is severely depleted in K.
- N: N fertiliser is rarely needed if the readily available N test is greater than about140 kg N/ha. Use the Maize Calculator to work out the most profitable rates. Use the cheapest form of N you have available (usually urea). If you are applying composts, do not forget to allow for the N supplied by the compost.

- N supply has a dominant influence on yield, but applying too much is uneconomic and greatly increases the risks of nitrate leaching. A 15 t/ha crop will remove about 200 kg N/ha in the grain, although total uptake will need to be more than that. Remember that the soil can often supply a significant fraction of the crop's N requirements - and there are good environmental reasons for allowing the soil N levels to decline (see economic vs maintenance fertiliser applications). Steele (1984) outlined two other approaches for calculating N fertiliser rates, based on soil and plant analyses. These approaches are rather more complicated than using the maize calculator, and do not seem to give any more accurate forecasts.

Reference

Steele, K.W. 1984. Maize: In: Cornforth, I.S.; Sinclair, A.G. (Eds) Fertilizer Recommendations for Pastures and Crops in New Zealand. Second Edition. New Zealand Ministry of Agriculture and Fisheries, Wellington. pp. 34-35.

See also Code of Practice for Fertiliser Use, economic vs maintenance fertiliser applications, sampling soil for chemical analysis, soil chemical analysis, nutrients and yield.

2.3.5 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 (see fertiliser application rates). There are various reasons for this. Deciding on when to apply fertiliser is a good example of economic and environmental objectives 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 putting on 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 that runoff, erosion or leaching will 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.) It is well known that losses of nitrates into groundwater can have severe environmental effects. However, there is increasing evidence that tiny amounts of P leached or lost through runoff or erosion can have very serious effects on water in creeks, rivers and lakes. The amounts of P that are needed to cause this damage are often very small - agronomically almost insignificant. So, environmentally it makes good sense to keep N and P concentrations in the soil fairly small, and apply those nutrients as fertilisers where and when they are needed.

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?

You can estimate this from the kg of each element taken up or removed per tonne of grain (Steel, 1984).

	N	P	K	Mg	S
Nutrient uptake by plants	24.2	6.0	17.9	2.1	1.9
Nutrient removal in grain	12.8	3.3	4.2	1.4	0.8

It is worth noting though:

- The values in this table do not show what you need to apply to achieve a given yield - crops often absorb more nutrients than they actually need ("luxury uptake"), and Steele's numbers undoubtedly reflected that for P in particular. If you apply a maintenance fertiliser in those cases you are just topping up an already oversupplied nutrient, which is a waste of money and increases environmental risks.
- The Maize Calculator usually indicates that the most profitable N 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' losses in a few applications of concentrated fertiliser on crops that will subsequently produce a profitable yield.

Reference

Steele, K.W. 1984. Maize: In: Cornforth, I.S.; SInclair, A.G. (Eds) Fertilizer Recommendations for Pastures and Crops in New Zealand. Second Edition. New Zealand Ministry of Agriculture and Fisheries, Wellington. pp. 34-35.

See also Code of Practice for Fertiliser Use, economic vs maintenance fertiliser applications, sampling soil for chemical analysis, soil chemical analysis, nutrients and yield.

2.3.6 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 on 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 maize production; however, the user guide for arable farming is appropriate. Copies of the code can be obtained from NZFMRA (see contacts) or downloaded from the internet: http://www.fertresearch.org.nz/index2.html.

2.3.7 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 most 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. This can cause micronutrient deficiencies. Unless soil pH is less than 5.0 or soil tests indicate a gross Ca deficiency do not apply mushroom compost.
- Composts should be cultivated into the ground immediately. Large single applications of composts can be difficult to incorporate, and smaller repeated applications prior to seedbed preparation are often best. A good maize crop can leave behind about 12 t/ha of organic C after harvest, so make best use of that (see crop residues). Often it is a good idea to use break crops as green manures - cultivating in pasture grass or a stand of say oats can add an appreciable amount of organic C.

See also soil organic matter, crop residues.

2.3.8 Soil organic matter

Soil organic matter and organic C

- 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.

Why worry about 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.

How does land management affect soil organic matter?

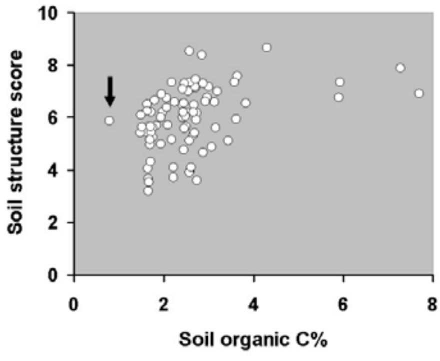
- Overseas, and in many parts of New Zealand, soil organic C decreases quite rapidly under cropping. Cultivation increases the rate that microbes eat soil organic matter. Soil organic matter content decreases most quickly under warm, moist conditions when no crop is present and the soil is cultivated often.
- Organic compost applications can increase soil organic matter content. 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.
- We recommend that management practices are directed towards keeping soil organic C content >2.5%. Growers can be reasonably confident organic C% will not be limiting soil quality and yields if it is in that range.

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 soil structure and yield).
- We found clear evidence that the soil organic C content influences the soil structural score (see Fig. 10). For mineral, non-volcanic soils 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.
- The soil structure score is influenced by more than just organic C%; no doubt recent cultivation practices will be important.

See also organic composts or manures, crop residues.

***Figure 10**: Relationship between average soil structure score (0-30 cm) and soil organic C content (0-15 cm) for non-volcanic silt loams and silty clay loams in the Bay of Plenty, Manawatu, Hawke's Bay and Gisborne. The outlier marked with an arrow is an unusual soil formed from Cyclone Bola silt in 1988.*



2.3.9 Soil structure scorecard

(for mineral soils that are not of volcanic origin)

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.

2.3.10 Cultivations and soil water content

- Cultivate when the soil has the right consistency. As the soil goes from very dry to very wet the consistency changes from hard to friable to plastic to liquid. Cultivate when the soil is friable.
- How can you check if the soil is friable? Take some soil from the depth at which the tillage implement will operate (say 15-20 cm for a plough) and roll it in your hand several times. Check if you can roll it into a worm about 4 mm thick:
  - if the soil is too dry and hard to form into a worm, then it is most likely too dry to cultivate,
  - if the soil cracks as the worm is being made then it is friable, and suitable for cultivation,
  - if it forms a worm readily then the soil is plastic and too wet for cultivation,
  - if it is too wet (liquid) to form a worm then it is definitely too wet for cultivation.
- Repeat those measurements at a number of locations in the paddock. Concentrate on the low points where you would expect the soil to be wettest.
- Cultivation when the soil is too 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).
- The actual water content at which a soil becomes too wet for cultivation differs between soils. If the soil is badly managed and its structure degrades then the critical water content becomes less, making it harder and harder for you to “catch” the soil in the right water content range to cultivate. Increasing the organic matter content of a soil will increase the range of water contents when the soil is friable and, therefore, suitable for cultivation.

Subsoiling

- Cultivation to break up pans in the soil is a special case. Here we do recommend that you cultivate when the soil is hard and dry. The dry conditions increase the power requirement, but it encourages cracking of pans so roots and water can more freely penetrate them. Often it is impractical to completely shatter a pan, but careful cultivation of a dry soil with a subsoiler or deep tines can crack it enough to greatly reduce the risks posed. Subsoiling when the soil is moist is at best poorly effective, and often it can may make the pan worse.
- 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.

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.

2.3.11 Nitrate leaching

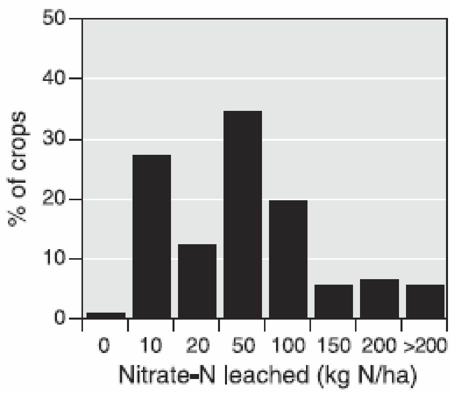
Assets and liabilities - organic matter, ammonium (NH_4^+) and nitrate (NO_3^-)

- 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 the 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.
- Substantial amounts of N fertiliser are applied to many maize crops. Generally, during crop growth there is relatively little risk of nitrate leaching from fertilisers applied at the appropriate rates. This is because the amount of drainage during crop growth is usually small and crop uptake of N is fast. But what happens following the harvest in autumn? Generally, drainage is greatest in autumn and winter. So, any nitrate left is susceptible to leaching then.
- We measured nitrate leaching below 60 cm depth in paddocks that had just grown maize. We did this in a total of 36 paddocks in Waikato, Bay of Plenty, Gisborne, Manawatu and Hawke's Bay from June to August in 1998, 1999 and 2000.

First the good news

- For two-thirds of the crops the nitrate leaching losses were less than 50 kg N/ha. Very little nitrate was leached in Hawke's Bay and Gisborne.

Figure 11: Amounts of nitrate leached at our study sites.



Not such good news

- For 16% of the crops nitrate leaching losses were >100 kg N/ha. All these crops were in the Waikato and Bay of Plenty. Losses over 200 kg N/ha were recorded at some crops in the Waikato, Bay of Plenty and Manawatu.
- Clearly most growers are doing well, but we need to look at why such large amounts of N were leached after some crops. It's also a good idea to work out if Hawke's Bay and Gisborne were just plain lucky with the weather.
- Nitrate leaching requires two main things: significant concentrations of nitrate in the soil water, and enough rainfall or irrigation for drainage to occur. For the Hawke's Bay and Gisborne crops where we measured leaching, the soils were quite dry at harvest and there was little winter rainfall. This is one explanation for the small amounts of leaching found after those crops. 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.

How much residual mineral N?

- Too much! Figure 12 shows the amounts of residual mineral N down to 60 cm depth in all crops and districts. The very large amounts were found at the sites where we measured large amounts of nitrate leaching (see above), but even where leaching was slight there was still a substantial amount of residual N in the soil - so heavy rain could have resulted in large amounts of nitrate leaching even in Hawke's Bay and Gisborne.
- It is difficult to say what the right amount of residual mineral N 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. 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.
- 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: (1) planting another crop or grass as soon as possible - those plants will take up nitrate and reduce the amount available for leaching; and (2) 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. We look at that possibility and draw some recommendations below.

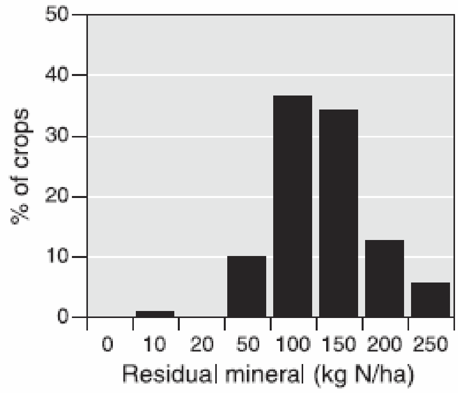


Figure 12: Amounts of residual mineral N down to 60 cm in all crops and districts.

Did some growers apply too much N fertiliser?

- We used our crop models 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 crops we studied.
- Just under 70% of the crops received within 50 kg N/ha of the required amount of fertiliser - which is pretty good management. But - the surplus fertiliser N varied from 0 to 250 kg N/ha (see Fig. 13). So some growers were letting the side down - and wasting money! The worst cases were where N fertiliser was applied to land that had just been ploughed up from old pasture. Soil test N levels were already high, and there was no need for N fertiliser.
- Overall, our results suggest that of about 30% of the crops we surveyed 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 appears that the growers applied surplus N fertiliser. With this in mind, let's put those surpluses into context.

How many $ were wasted?

- At 1999 prices, applying 100 kg N/ha would cost about $93/ha using urea. Surplus N fertiliser is not a good form of insurance! So here again economic and environmental aspects of sustainability are reinforcing each other.

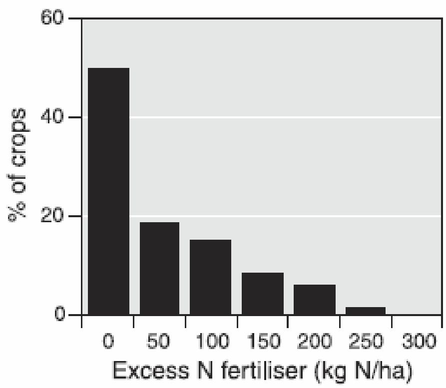


Figure 13: "Surplus" N fertiliser applied for each of the crops studied.

How do we avoid this?

- Part of the answer is to apply no more fertiliser than the Maize Calculator indicates.
- Even without the Maize Calculator you can work out whether N fertiliser is likely to be necessary on the basis of soil tests (see fertiliser application rates).
- Also, it's important to minimise yield gaps caused by poor soil structure. In most cases, improving soil structure will encourage higher yielding 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, for early harvested crops, establish grass or another crop as soon as possible after harvest to take up surplus N and improve soil structure. Here again environmental sustainability makes good business sense.

2.3.12 Water tables

- A moderately deep water table can be good for the crop. We have found that yields are often best where the soil has a water table at about 100 cm depth during the early part of the season. As the crop uses water the upper layers of soil dry out, and this helps suck water up from the water table, helping the water balance. Also, maize roots can grow downwards at a surprising rate – sometimes 20 mm per day. They won't usually grow below the water level itself, but the few roots just above it can often take up a large part of the water the crop needs. All this increases the threshold water balance below which yield loss occurs, making drought stress less likely (see water deficit and yield).
- On the other hand, a shallow water table can be bad for three reasons.
  - Under heavy rainfall the soil will drain slowly and the water table can move quite quickly towards the soil surface. Then the lack of air in the soil can kill roots, and slow crop growth because of nutrient deficiencies and poisons that soil microorganisms produce in very wet soil.
  - As the water table recedes it leaves behind a weakened and shallow root system that makes the crop very vulnerable to drought stress.
  - Wet soil is weak and can be severely damaged by machinery. Compaction and smearing damage to wet soil can take a long time to recover. This limits the productivity of the soil for the current crop and future ones.
- Tile drains at about 100 cm depth are an excellent way of reducing the chances of problems due to shallow water tables. However, even with tile drainage you must avoid compaction damage to the soil, and be wary of fine textured layers of clay, silty clay or sandy clay loam above the drain level. Compact or fine textured layers in the soil can greatly slow water flow to tile drains after rain, so that the soil has a water table "perched" above the tiles. Some strongly layered soils may have two or even three quite separate water tables within the top 200 cm.

3 About

3.1 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 the authors, acknowledgements, and contacts). The work was carried out from 1997 to 2000, but it built on research that began in 1992.

3.1.1 Approach

From 1997 to 2000 we surveyed commercial maize crops in the Waikato, Bay of Plenty, Manawatu, Gisborne and Hawke's Bay. 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 soil chemical analysis),
- soil physical properties at 0-15 and 15-30 cm depth - visual score of soil structure (see soil structure scorecard) 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 weeds, pests and diseases; fresh and dry grain yields,
- 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 attainable yield and the yield gap). Then we calculated the yield gap - the difference between attainable and actual yields corrected to a standard dry matter content of 14% (see key concepts). Finally, we looked for relationships between the yield gap, the various indicators of soil quality, and site management history.

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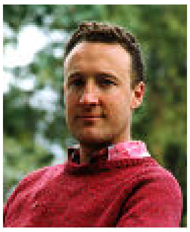

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3.3 Acknowledgements

Information used in these RBMPs comes from published research, and more especially from the results of our experiments carried out in Waikato, Bay of Plenty, Gisborne, Manawatu and Hawke's Bay from 1996 to 2000.

The principal experimental program was "Sustainable Crop Production" (SMF Contract 2120) (see the sustainable crop production program). We thank the following for funding that program:

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

- NZ Fertiliser Manufacturers Research Association.

(see contacts).

The program owes much to the early vision and drive of Alan Kale of Heinz Wattie's, Nick Pyke of the Foundation for Arable Research, Lloyd Glenny and Arthur Duncan of Ravensdown Fertiliser Cooperative Ltd.

We are also deeply grateful to the many maize growers who allowed us access to their crops and records, and shared their experience. Thanks are due to our many colleagues, notably Jacinda English, Brian Rogers, Isabelle Sorensen and Derek Wilson (of Crop & Food Research), Marg Willimot (of Ravensdown Fertiliser Cooperative Ltd), and David Densley (of Genetic Technologies Ltd), for their assistance and advice.

The Sustainable Crop Production program arose from earlier research into the effects on maize, sweet corn and tomato production of nutrient supply, and irrigation and weather (funded jointly by Heinz Wattie's, Foundation for Arable Research, NZ Fertiliser Manufacturers Research Association and the Public Good Science Fund of the Foundation for Research, Science and Technology).

We thank Justine Lee and Jo Smith of Crop & Food Research for advice on web page design, and Tracy Williams for editorial inspiration.

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