CENTRE FOR CONSERVATION FARMING

CHARLES STURT UNIVERSITY

The Performance of Wheat Crops in the Harden-Murrumburrah District 1994.

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Summary.

A crop monitoring project was conducted in nineteen ninety four in the Harden-Murrumburrah district by the Harden-Murrumburrah Landcare Group. Wheat crops were monitored by district wheat growers to increase understanding of the dynamics of wheat growth and yield. All information gathered was recorded on a data base for analysis of results Additionally 13 paddocks were subject to intensive monitoring to assist in interpretation of data base information. Due to below average rainfall for the year, yield was found to be highly correlated to water use, and any factor that increased the amount of water available to crops resulted in a corresponding increase in yield. For this reason, stored moisture at sowing, soil type, and sowing date all had significant effects on yield.

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Introduction

Nineteen ninety four was the initial year of a wheat monitoring project undertaken in the Harden-Murrumburrah district in the South-west Slopes of New South Wales.

This project was initiated by the Harden-Murrumburrah Landcare Group. The vast majority of climate, crop, and soil monitoring was assumed by wheat growers. All data compiled was recorded, and submitted for entry into a data base allowing analysis of data. The results of which are reported below.

Project goals

The goal of this project is to allow identification of practices and management likely to maintain or improve yields in wheat in a sustainable manner. However, this project has other equally important aims. For instance the extension/education value of encouraging growers to monitor the growth and yield of their wheat and compare it to the performance of others in the district. This "hands on" extension is likely to fortify other extension activities in farming systems provided by government and private agencies. Many of the results obtained form the wheat database project could be predicted, and may already be part of the district recommendations. However, observation of these results by the grower on his/her own property is likely to increase the credibility of any recommendations.

A further goal of the wheat database monitoring project is to identify any need for future research. A monitoring project may act as a "forward scout", uncovering previously unknown information that may warrant further investigation.

Methods

The format of the wheat monitoring project attempted to account for the range of influences on wheat yields. Five main field inspections, at strategic times in the plants growth cycle, along with additional information from cultural history, rainfall records, soil and plant analysis, allowed examination of yield influences. The total number of paddocks monitored by wheat growers in this manner totalled 65.

Additionally, more intensive monitoring was conducted on thirteen paddocks, of which four had neutron probe moisture monitoring allowing detailed examination of water use and water use pattern. Soil moisture was calculated at the beginning and end of the growing season, along with detailed plant analysis (tissue tests, NIR nitrogen tests) in all of the thirteen "intensive" paddocks. Measurements were made over a smaller area to reduce variation normally found across a paddock. This method reduces error due to variation and allows the easy identification of yield influencing factors. These relationships can then be used to aid analysis of wheat database information.

> * 65 paddocks were monitored and recorded on the Harden-Murrumburrah Landcare Group database.
> * An additional 13 paddocks were intensively monitored for extra data to assist in analysis of information.

In summary the approach to data collection had three levels of detail. These were;

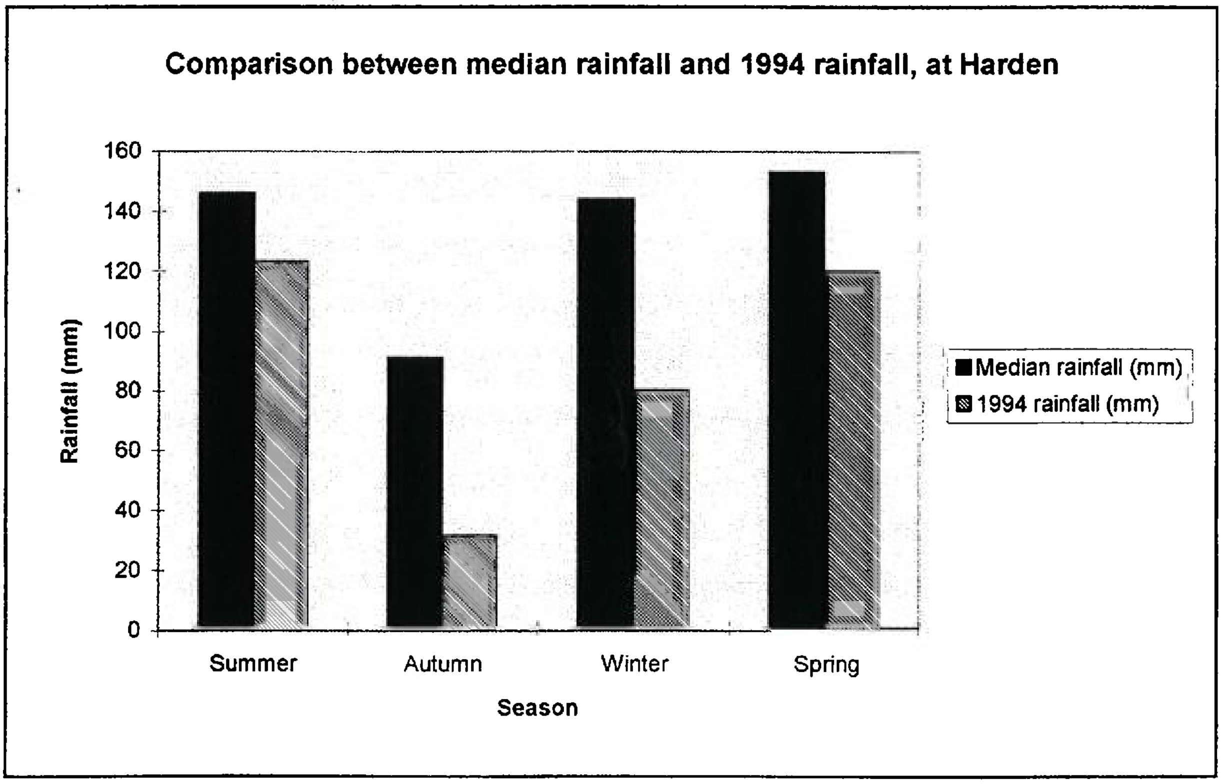
1) Collection of crop and rainfall data by wheat growers from 65 paddocks in the Harden district.
2) Intensive monitoring of 13 paddocks within the region. Soil moisture and plant nutrient levels were more intensively studied.
3) Of the 13 intensively studied paddocks, 4 paddocks had neutron probe access tubes installed for detailed study of water use.

Results from the Harden-Murrumburrah wheat crop monitoring project, 1994.

(i) Water use and yield relationship

Rainfall for the year 1994 was much lower than average. This is indicated in figure 1. Summer rainfall was high in some areas, however subsequent rainfall was very low leading to lower than average crop yields.

Figure 1. Median and 1994 rainfall at Harden.



Water use in the Harden District Wheat Database survey was simply described as the rainfall that fell in the growing period from sowing to physiological maturity. In the thirteen intensively monitored paddocks, the definition was rainfall, and the difference in soil moisture from sowing to maturity. This method allowed the contribution of fallow soil moisture to be accounted for. This is a more accurate method of assessing the effect of water availability on plant yield, since the contribution of soil moisture, or fallow moisture was large in many paddocks.

* Wheat yield was closely correlated to water use.
* Average transpiration efficiency was 16.6 kg/ha/mm.
* Average evaporation over the growing period was 81 mm.

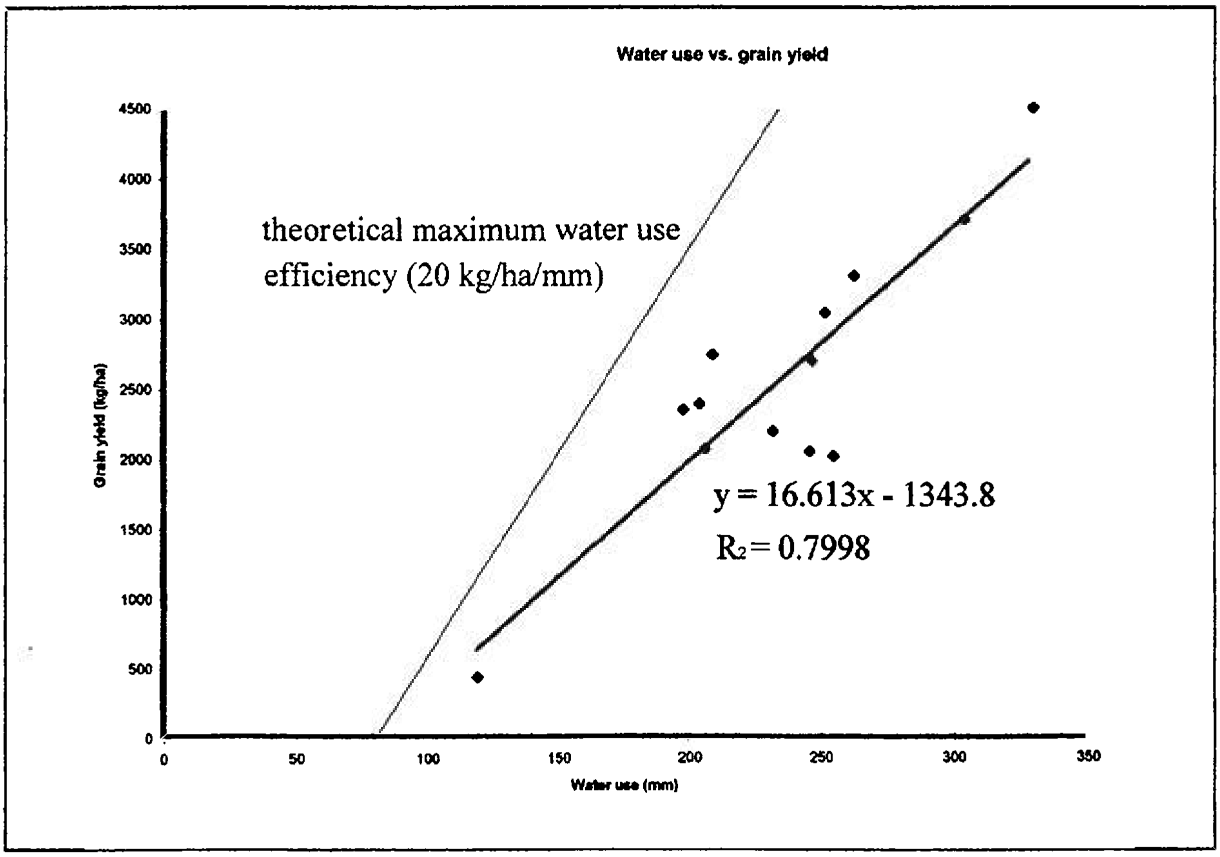
Examination of figure 2, which gives results from intensively monitored paddocks shows that grain yield is closely related to the water use of the crop (since r^2 value is 0.8 the yield is highly correlated to water use).

Other information can also be obtained from the water use vs. yield graph. Firstly the point at which the line meets the x axis (water use axis) is equivalent to the average amount of evaporation for the paddocks surveyed. This amount comes to **81 mm**. Therefore on average 81 mm was lost to evaporation over the growing period in 1994.

Transpiration efficiency can be calculated from the slope of the line in figure 1. This is the method used by French and Schultz (1984) to calculate the theoretical transpiration efficiency figure of 20 kg/ha/mm. At Harden, on the intensively monitored paddocks the average transpiration figure indicated by the slope of the line in figure 2 is **16.6 kg/ha/mm**. This compares well with the theoretical maximum of 20 kg/ha/mm proposed by French and Schultz (1984).

The high average transpiration efficiency , along with a strong correlation between water use and yield, indicate that other factors such as nutrition were of minor importance in 1994. In a wetter year when potential yields are higher, it is likely that other factors such as nutrition are likely to be a more significant influence on transpiration efficiency and yield than a dry year such as 1994, when potential yields are low.

Figure 2. The relationship between water use and grain yield for 13 intensively monitored wheat paddocks - Harden 1994.



(ii) Soil Type Influence

Examination of yields on the two broad soil types; granite soils, and basalt soils show large and significant yield differences (see figure 3). The types of soils coming under the banner of granite soils are; red and yellow podzolics, solodised solonetz and lithosols. All of these soils are spread throughout the granite areas of the Harden - Murrumburrah area. The basalt type soils are those formed on basalt rock, and occur in the Wallendbeen area. The main soil type formed on Basalt in this

* Wheat crops grown on basalt soils out-yielded those grown on granite soils by an average of approximately 1.1 tonnes/ha
* At a wheat price of $130/tonne, this yield difference equates to a difference in gross income of $150/ha.
* For every millimetre extra of stored water at sowing, gross income would have increased by $2.16/ha.

area is the Euchrozem soil.

Examination of data shows that available water storage on Basalt soils was much higher than that on granite soils. Average moisture in the 120 cm soil profile at sowing was 305 mm in the basalt soils, but for granite soils was only 230 mm. Also, the contribution of stored soil to plant water use was much higher in basalt soils. The fallow moisture contribution of basalt soils averaged 117 mm, while on granite soils the average fallow moisture contribution was only 47 mm on average. This extra available moisture on basalt soils would result in an extra 1.16 tonnes/ha of wheat (using water use efficiency equation in figure 2). At a harvest price of $130/tonne on farm, this extra moisture storage is equivalent to an additional $150/ha gross income.

Increasing water storage is a likely way of improving yield on and within granite soils also. For every extra millimetre of water stored in the soil at sowing, yield can be expected to increase by 0.017 tonnes/ha, provided that other factors such as weeds, disease and nutrition are not limiting. This correlates to an extra $2.16/ha for each millimetre of moisture that is stored in the soil. **However, this assumption may not be accurately applied in years other than 1994, due to the complexity of factors influencing transpiration efficiency, and the dry nature of the year 1994.**

Examination of neutron probe data shows that water extraction at depth (below 45-60 cm) was low on granite soils compared to basalt soils. In basalt soils water extraction occurred below 120 cm. At the same depth in the granite soils, change in water content was so small that it may only have been due to capillary action.

On granite soils, high bulk density of the subsoil and/or high moisture content at wilting point may be restricting root growth beyond this zone. This warrants further investigation as these factors may be restricting productivity on granite soils.

Yield therefore was strongly influenced by pre-sowing moisture storage (see figure 4). Those practices that improve soil moisture at sowing are likely to improve yield in a dry season. **Not only can increased soil moisture improve yields directly, but more timely (earlier) sowing that may result from better soil water status in autumn can improve yields also.**

Figure 3. Influence of Soil type/rock base on yield on wheat crops

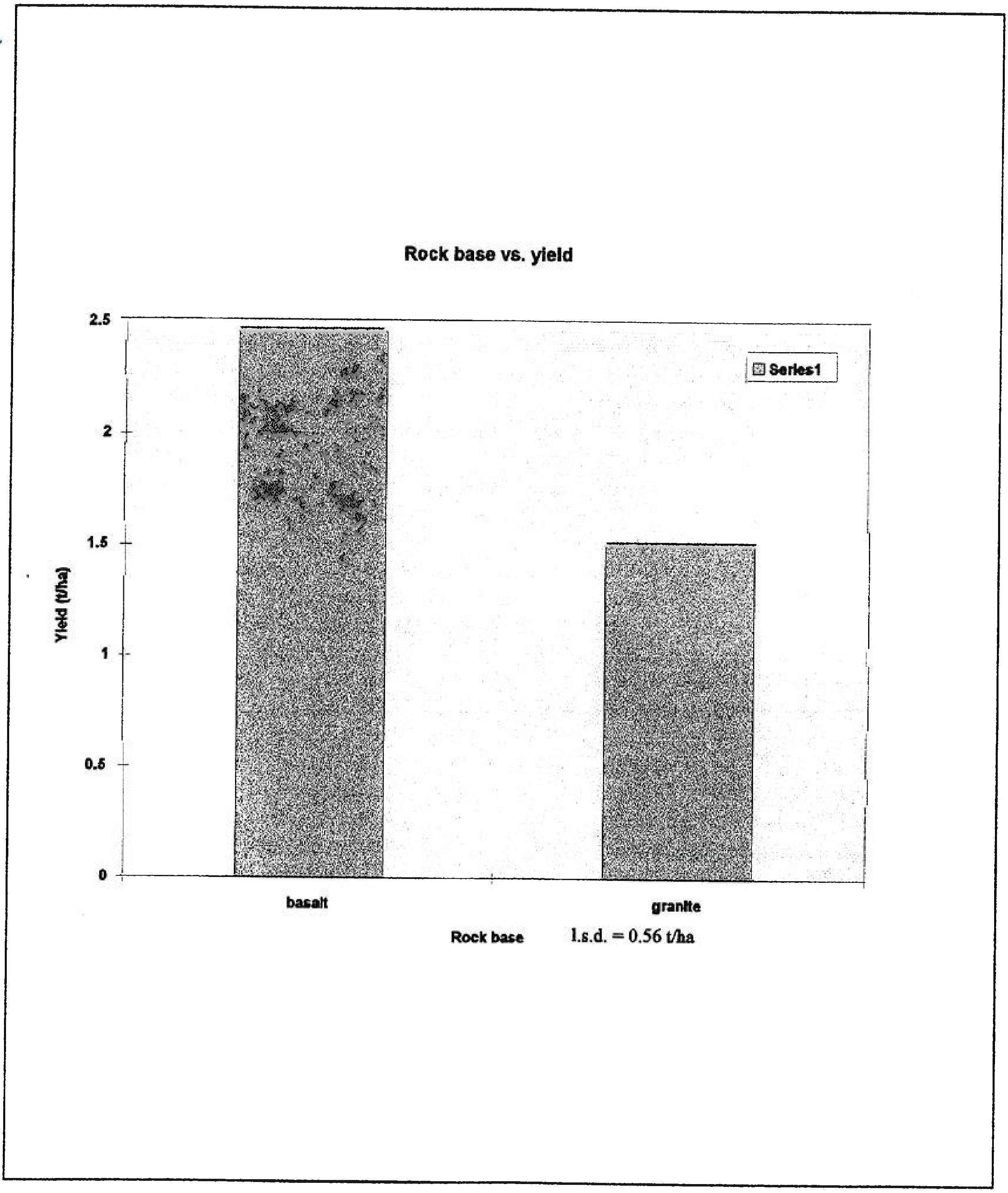
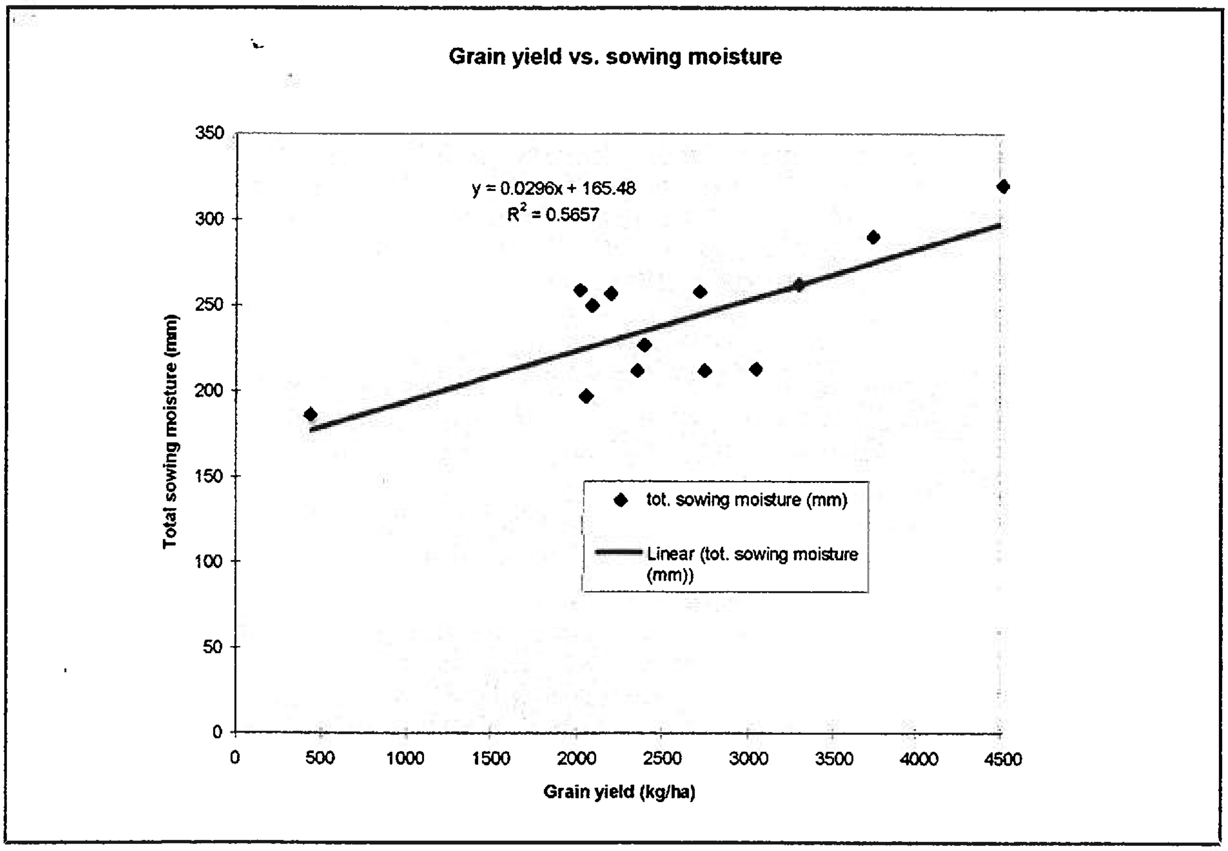


Figure 4. Relationship between grain yield of wheat crops and total sowing moisture



(iii) Sowing date effects

> * Sowing date had a significant effect on yields.
> * Yield penalty of 34 kg/ha/day for each day after 15 May that sowing commenced.

Examination of wheat database figures show a definite and significant trend toward decreasing yield with later sowing. For the purpose of analysis, sowing dates were grouped into two week periods. Figure 4 shows the trend in sowing date. It must be noted that although there were crops sown outside the dates indicated in figure 4, there were not enough individual paddocks sown to provide significant results, and thus no conclusion could be drawn from the results from these paddocks. However the trend is obvious, with a later sowing date incurring a yield penalty. The period 1/5/94 to 15/5/94 had an average yield of 1.9 tonnes/ha (this is not significantly different from the period from 16/5/94 to 31/5/94).

The basis for the yield penalty may lie in the fact that a shorter growing season will decrease water use and therefore decrease the total amount of water transpired, as well as decreasing the total amount of solar energy intercepted, thus decreasing yield potential.

Additionally, the later sowing will mean an increased chance of flowering and reproductive development occuring in conditions of water stress due to higher daily temperatures. These conditions are likely to result in grain number (grains produced per unit area) being decreased.

It must be noted that in some early sown crops (particularly those not using zero till or direct drilling sowing methods) where early vegetative growth was high, water use was higher than optimal in the vegetative stage. Too much water use in the vegetative stage may result in exhaustion of soil water reserves, leading to water stress in the critical reproductive stage of the wheat life cycle. This is due to the fact that transpiration is proportional to leaf area. This problem became evident on some crops grown on granite soil. However in a more average year these crops would have been likely to be high yielding.

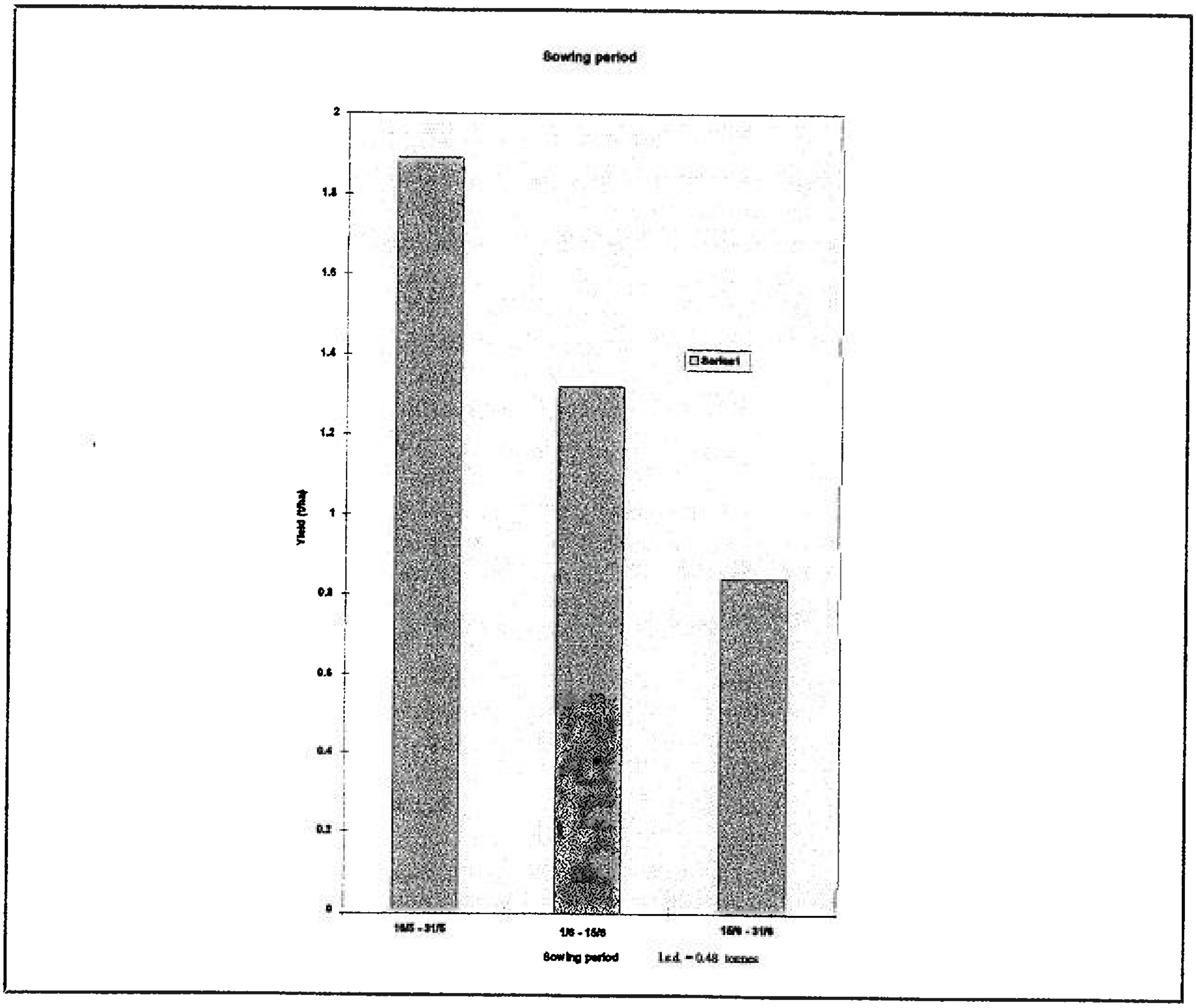
It is therefore likely that any management practice likely to result in earlier sowing will improve yields and gross income. For every day after 15 May 1994 an average yield reduction of 34 kg/ha/day was evident. This equates to a gross income reduction of approximately $31.00/ha per week for every week sowing is delayed after 15 May (at a price of $130/tonne).

(iv) Nutrition effects

As already indicated wheat yields in 1994 were highly correlated to water use. By virtue of this fact there is little scope for other influences such as nutrition to have a significant bearing upon yields. This is to be expected in a dry year when yields are low (for with low yields nutrient demand decreases). While nutrient availability was more than adequate for all crops, the more water stressed plants had higher nutrient concentrations since growth was limited by water availability. These water stressed plants were likely to yield less and have lower water use efficiencies. Data concerning effect of nutrients on yield and water use efficiencies is contained in the appendix 2 and 3.

Correlations between applied nutrients and yield were not significant. In the detailed paddock monitoring both yield and water use efficiency were largely unrelated to plant nutrient levels. Interestingly, a negative correlation between nutrient levels and water use efficiency of some nutrients was obtained (as the more efficient plants were able to use more of the nutrients for growth processes).

Figure 4. The effect of sowing date on wheat yields



(v) Soil pH effects

Soil pH was shown to have little effect on water use , water use efficiency or yield. This effect is illustrated in appendix 2 and 3. The fact that water use was so highly correlated to yield, again leaves little scope for pH to have a significant effect on yield, water use or water use efficiency. In a more average or wetter year pH effects may have a larger effect through the pH influence on micro-nutrient availability and root growth.

(vi) Effect of previous crop

Examination of results indicates a trend towards higher yields following canola, lower yields following lupins, and lowest yields following oats. These results were not statistically significant, ie, the variation of yields within each set of data (previous crop) was much greater than the differences between averages for each set, therefore no conclusions can be drawn from these results. However, since the trend was as expected then this same result may prove to be significant in a more average year.

(vii) Grain protein

In the detailed paddock monitoring grain protein was shown to be well correlated to yield. This was a negative correlation however, ie; as yield increases then grain protein decreased. This effect is best explained by the fact that the most water stressed plants yield less but have higher protein levels due to restricted grain filling. When water status is favourable protein may be diluted by extra deposition of carbohydrate in the grain. Grain yield and grain protein did not show such strong correlations from total database results (see appendix 3).

Figure 5. Effect of previous crop on yield of wheat crops

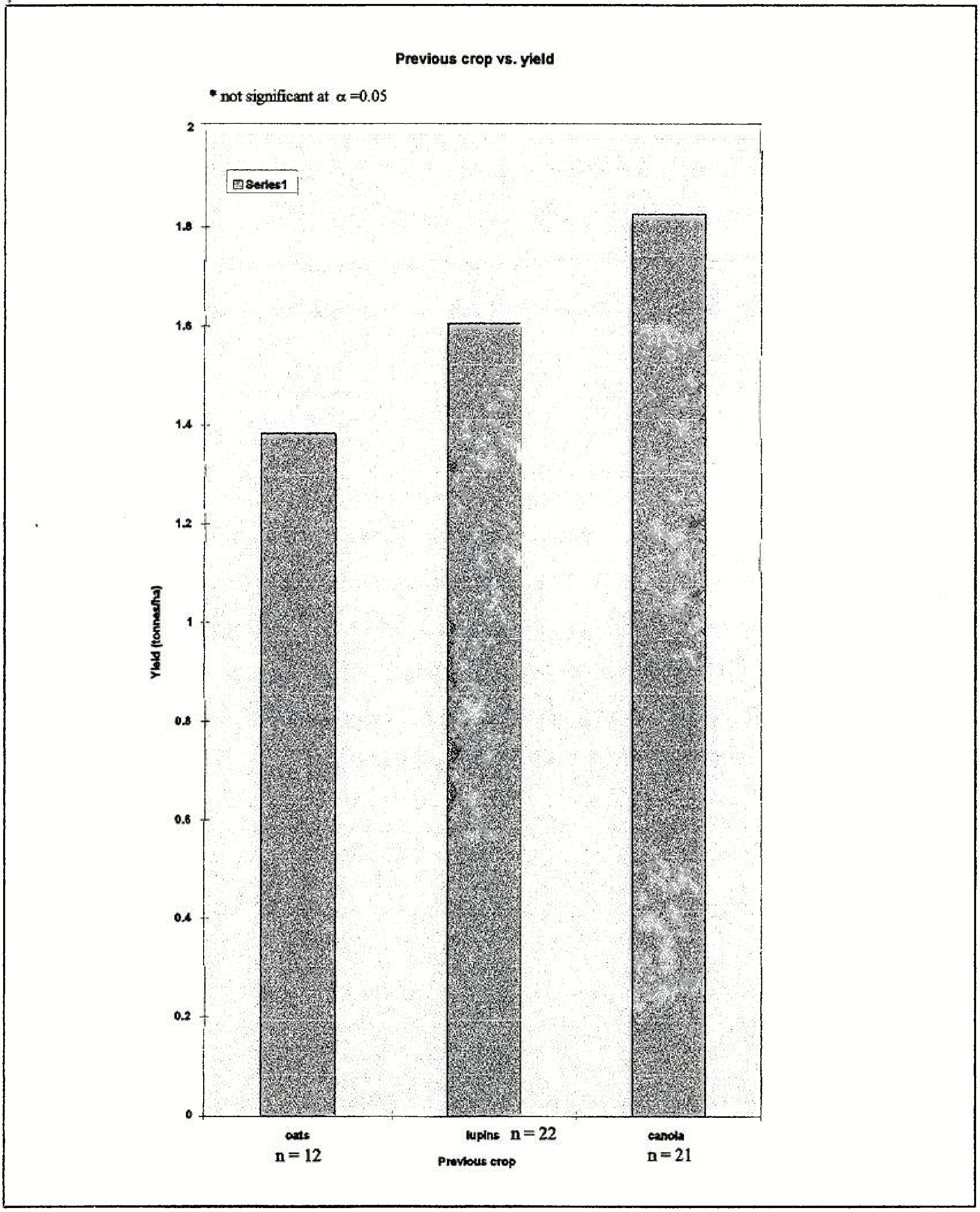
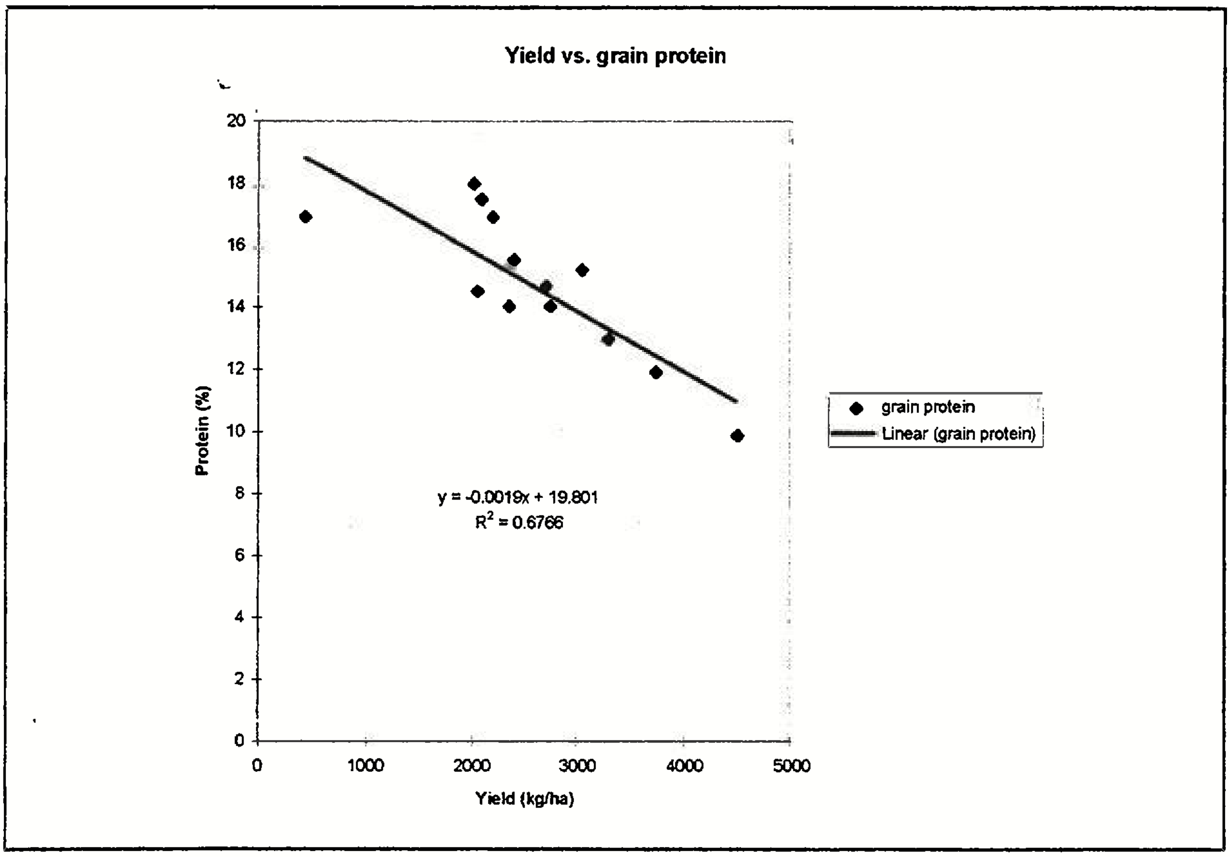


Figure 6. Grain protein and yield of wheat from 13 sites in the Harden Shire in 1994



(viii) Comparison between high and low water use efficiency paddocks

> * top 20% performing paddocks had a higher proportion of basalt soils and an average sowing date 28 days earlier than the lower 20%

A comparison was made between the top 20% and the lower 20% of paddocks in the database (with a complete set of data) , ranked on the estimated water use efficiency (in this case transpiration efficiency). The estimated transpiration figure was arrived at by using data from intensively monitored paddocks and applying it to the database figures. This data includes contribution of fallow moisture to total water use and an evaporation estimate. While the estimated water use efficiency is only "rough" it is accurate enough to be a guide to paddock performance (table is contained in appendix 3).

Since water use is so highly correlated with yield then few other factors are likely to show up as having a significant contribution to yield. However certain trends are obvious. With increasing water use efficiency, yield increases also. Additionally, the top 20% of performers contained a higher proportion of basalt soils. As, yields increased, then protein content of grain decreased.

The most significant trend from this comparative analysis was sowing date. In the top 20% of paddocks on average, sowing commenced on 14 May, while in the lower 20%, sowing commenced on average at 11 June.

Comparison of previous crop shows that in the top 20% of paddocks, there was a slight increase in the number of paddocks following canola, with a decrease in the number of paddocks following wheat and oats.

Sowing rate, pH, altitude and wheat variety had no effect.

Using data from the NSW Agriculture Farm Budget Handbook, 1995, and assuming that production costs are equal for all crops; the following gross margins can be calculated.

Table 1. Water use efficiency, and its effect on gross margins for wheat

	Lower 20%	**Average**	**Top 20%**
variable costs	$230.16	$230.16	$230.16
av. yield (t/ha)	0.75	1.59	2.58
gross income (@$130/t)	$97.50	$206.70	$335.40
gross margin ($/ha)	-$132.66	-$23.46	$105.24

Conclusion

Wheat yields in the Harden Murrumburrah district in 1994 were highly correlated to water use. Paddocks with high water use also yielded higher. It is therefore desirable to maximise water use of a crop, to maximise yields and gross income from it. Since 1994 was a dry year yields were low. Therefore nutrients were in good supply compared to the yields. Hence, the effect of nutrients on water use efficiency was not detectable.

Maximising water use can be achieved in a number of ways. The first and most obvious way is to sow crops early. Crops sown later were shown to yield less and it is likely that this is because later sown crops will use less water than early sown crops. For every day after the fifteenth of May an average yield reduction of 34 kg/ha was observable. This relates to a reduction of $31/ha per week for every week after the fifteenth of May that sowing is delayed (wheat price of $130/tonne).

Increasing water storage from summer rain may enable more timely sowing as well as increasing total water use by the plant. Such practices as stubble retention, direct drilling, and chemical weed control may assist in reducing losses of water through transpiration, and run off. A well structured soil is likely to benefit more from rainfall since run off is likely to be reduced (Hamilton and Packer, 1985).

Crop growth on basalt soils was much higher than granite soils, again due to higher water use. Wheat grown on basalt soils extracted more moisture (since basalt soil stored more available water) and from a greater depth, than from wheat grown on granite soils. Average yields of crops on basalt soils were around 1.16 tonnes/ha higher when compared to crops grown on granite soils. This was equivalent to a gross income difference of $150/ha (@$130/tonne). It is likely that basalt soils will out perform granite soils in a year such as 1994 where substantial rains were recorded in the summer period before sowing and subsequent rainfall was very low. In a wetter year the difference may not be as substantial. This requires further investigation.

Other factors such as nutrition, pH and previous crop had no, or little observable effect on yields or water use efficiency. In a more average year (wetter), these factors may be of more importance. Hence it is crucial to monitor wheat crops over a number of seasons to be fully informed as to the dynamics of wheat yields in the Harden-Murumburrah district.

Glossary of terms

bulk density This is the mass of dry soil per unit bulk volume. The unit of measurement is usually grams per cubic centimetre. This measurement is a measure of soil porosity, and may also be an indicator of soil structure. Low values may indicate better structure.

coleoptile This is the sheath that surrounds and protects the first leaves of the wheat plant as they emerge from the soil.

endosperm This is the carbohydrate (starch) storage area of the grain.

evaporation This refers to the water that leaves the surface of the soil and moves into the atmosphere as water vapour.

floret Each individual flower contained within the ear of a wheat plant.

meristem The area of most rapid cell division in the plant. Each wheat plant may have a number of meristematic areas, producing new leaves, tillers and roots.

neutron probe A device that measures the water content of soils at different depths, using a neutron source to detect the presence of water.

NIR This stands for Near Infra-Red, and is a method used to determine nitrogen content of a plant sample.

nutrients A broad term referring to the chemical compounds and elements that a plant requires for growth eg; phosphorus and nitrogen compounds.

pH A measure of alkalinity or acidity of a soil. A value of 7.0 denotes neutrality, higher values indicate alkalinity, while lower values indicate acidity. pH can be measured in water or 0.01M $CaCl_2$. Values measured in 0.01M $CaCl_2$ are usually 0.5-0.8 units lower than those measured in water. Most plants grow best in a pH range of 5.5-8.0 (water).

physiological Refers to the growth, development of, and biology of living things.

pollination When the pollen (male gamete in the wheat flower) contacts the female part of the flower immeadiatly prior to fusion of male and female gametes in the ovary of the flower.

transpiration The movement of water through the plant and into the atmosphthrough its leaves.

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Technical background and important concepts and principles

Water use and water use efficiency

To meaningful compare performance of wheat crops scattered over a wide area can be difficult, since it is a well known fact that rainfall will vary, and therefore yields will vary from place to place. It is therefore important to take this variation in rainfall, or more precisely available water into account when comparing performance between crops. This is the concept at the heart of the water use efficiency method of analysing crop performance.

> * Transpiration is the water that moves from the soil up through the plant and out through its leaves.
> * Evaporation is the movement of water from the soil directly into the atmosphere.
> * Water use may refer to evaporation and transpiration together or only transpiration.
> * Water use efficiency is the amount of plant material produced per millimetre of water used.
> * If water use is defined as transpiration, water use efficiency may be termed *transpiration efficiency*.

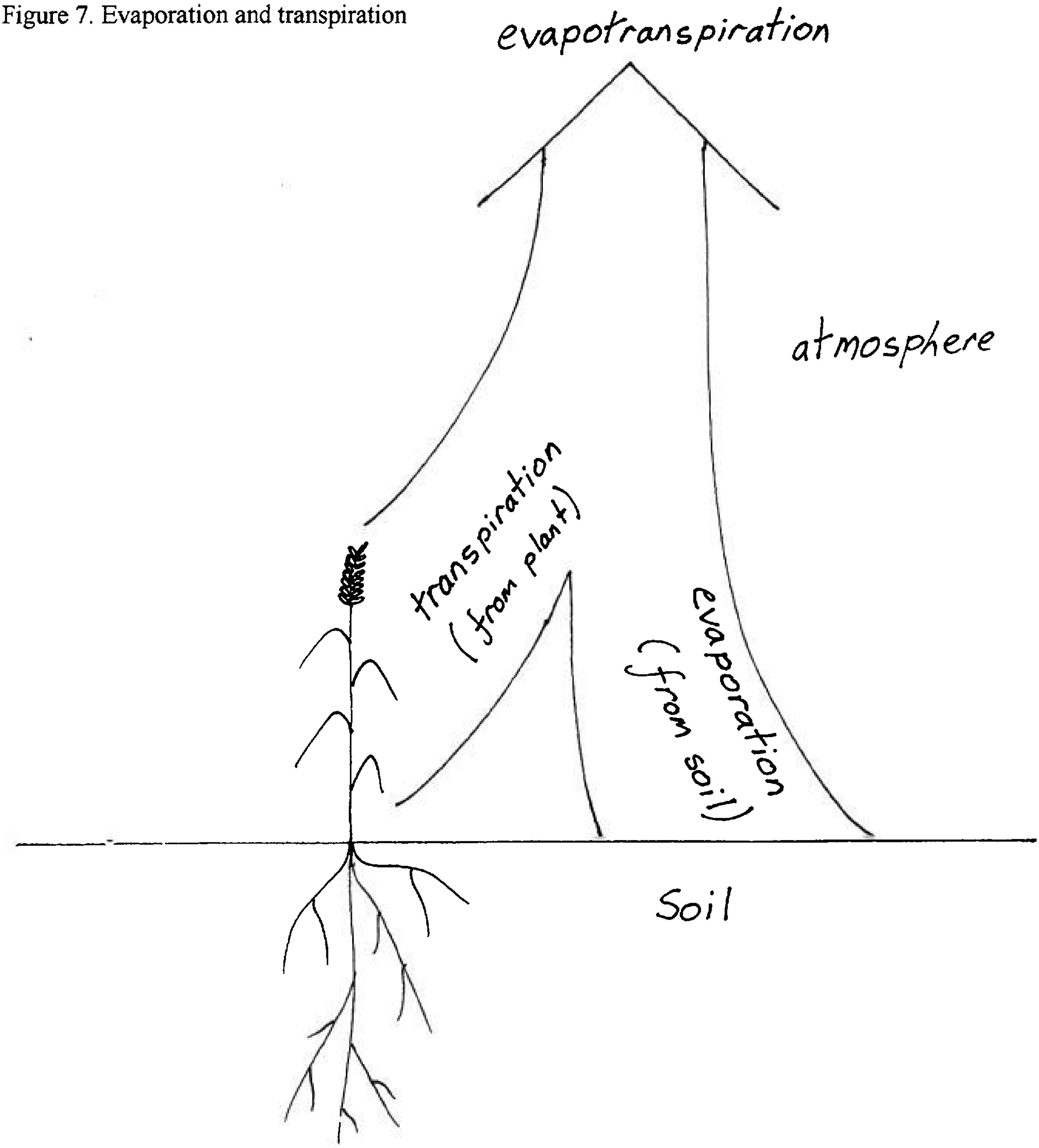
Water use is a concept often used with a degree of flexibility. An individual plant will "use" soil water by taking it up from the soil via the root system. This water is used to drive many of the plants physiological processes. Much of the water taken up by the plant is released to the atmosphere as water vapour via the plant leaves. This process is known as *transpiration*. In some cases water use is defined as transpiration.

In a crop or community of plants, water use may be defined as transpiration, plus the water that evaporates from the soil and plant surfaces. Evaporation and transpiration collectively, are referred to as *evapotranspiration*. This is the most common definition of water use, since it is difficult to calculate evaporation and transpiration values separately.

Water use efficiency refers to the productivity of the plant in producing biomass (total plant dry matter or grain yield). In grain crop studies water use efficiency is usually expressed in kilograms of grain produced per millimetre of water used (kg/ha/mm). Water use in this case is defined as evapotranspiration.

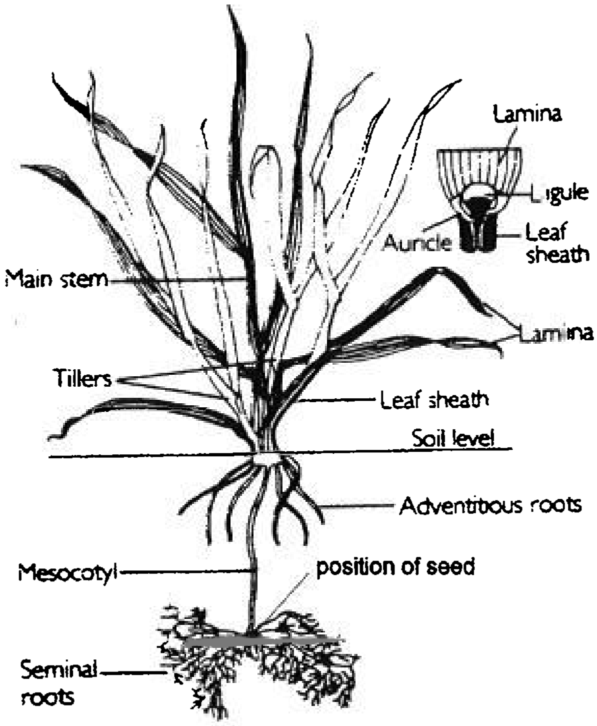
Water use efficiency using transpiration rather than evapotranspiration, in calculating water use is often called *transpiration efficiency*, and is also expressed in kg/ha/mm. A well known estimate of transpiration efficiency used commonly, is that obtained by French and Schultz (1984). By using water use and yield data, French and Schultz were able to calculate the transpiration efficiency for the South Australian wheat growing areas. The transpiration efficiency they established is 20 kg/ha/mm, and it is now often used to gain an idea of potential wheat yields in many wheat growing areas of Australia.

Figure 7. Evaporation and transpiration



The physiology of the wheat plant

Figure 8. The structure of the wheat plant (Langer, 1979)



The most commonly used identification of cereal growth stage is the Zadocks decimal code. For a full description of this code see appendix 1.

> * The three main cereal growth periods are;
> - the vegetative stage
> - the reproductive development stage
> - the grain development stage

The principal stages of wheat growth as described by Zadocks et al (1974) are;

00 - 09	germination
10 - 19	seedling growth
20 - 29	tillering
30 - 39	stem elongation
40 - 49	booting
50 - 59	inflorescence (ear) emergence
60 - 69	anthesis (flowering)

70 - 79 milk development

80 - 89 dough development

90 - 99 ripening

These stages can be further simplified into three main growth stages. These are, the vegetative stage (Zadocks code 0 - 29), the reproductive stage (Zadocks code 30 - 69) and the grain development stage (Zadocks code 70 - 99).

(a) *The Vegetative Stage*

This is the period of growth beginning at germination and ending at the onset of reproductive development at stem elongation.

* The vegetative stage starts at germination and ends at stem elongation.
* The meristems are areas of rapid cell multiplication.

Germination begins with the uptake of water by the seed. This triggers the growth of the seedling root system. The first roots to emerge are the seminal roots. These are very fine highly branched roots that are responsible for early uptake of moisture and nutrients. Following initiation of root growth, the coleoptile will begin its growth. The coleoptile is a sheath that protects the first leaves of the plant as it emerges from the soil.

Leaf growth is initiated by cell multiplication at the base of the stem. This area of cell multiplication produces new leaves and new tillers. Each tiller has its own zone of cell multiplication, known as the *meristematic* area to produce new leaves and tillers.

It is important to note that each tiller consists of rolled bundles of leaves that arise from the meristematic areas. The tillers are not actual stems. The stems become obvious at stem elongation, when the node become visible at the base of the plant.

From the meristematic area at the base of the plant, nodal or adventitious roots will arise. These are responsible for around 95% of the total root mass of the plant over its growth period.

Each tiller will in turn produce a number of daughter tillers, therefore tiller production will progress at an ever increasing rate , until reproductive development begins at stem elongation or stress is placed on the plant. Tillering will be decreased significantly by water stress.

Nutrition will also will also have an effect on the production of tillers. When nutrition is less than optimal addition of nitrogen, phosphorus, and potassium will increase the rate and number of tillers. This is especially true of nitrogen, that is needed in relatively large amounts in the leaf meristem areas.

(b) *The Reproductive Stage*

> * During the reproductive stage the reproductive structures of the plant are developing.
> * The plant is very sensitive to water and temperature stress during this period sometimes.

This is the period from stem elongation up until flowering. This is the period in which the reproductive organs are being produced, and pollination (fertilisation to produce seed embryo's) occurs. This period begins when the meristem at the base of the plant begin to be pushed upwards by the elongation of the stems, (now visible and can be identified by nodes on the stem). At the same time leaf production ceases and the leaf meristem begin to form the new ear or wheat head. At this point the new ear is only tiny , but after some growth may be visible as a slight swelling just above the highest node on each tiller. the growth of the new ear will continue and the ear will eventually be pushed up through the flag leaf to take its final position.

Flowering (sometimes called anthesis), which is the stage immediately preceding pollination, is observable by the opening of florets within the spikelets of the ear, this allows the anthers (pollen producing part of the flower) to elongate, and so pollination then takes place. The reproductive stage of wheat development is very sensitive to environmental stresses , especially water stress. Water stress may cause sterility of the anthers or other damage to the flowering organ, resulting in a decline in the number of seeds produced. Each floret in the ear is capable of producing seed, however the percentage of florets producing seed in field situations may vary from 25 to 90%. This is since floret death is commonly due to high temperature and water stress just prior to flowering. Since yield is highly correlated to number of seeds produced per unit area (this study and others), water status of the plant at this stage is critical to high yields.

(c) *The Grain Filling Stage*

This is the stage encompassing pollination to physiological maturity (when grain filling has ceased and the grain starts to dry out).

Formation of the new seed embryo takes place 30 - 40 hours after pollination. After rapid multiplication of endosperm cells (carbohydrate storage cells), the new seed begins preparation for storage of carbohydrates (starch). Cell multiplication will cease when the grain is approximately half its mature weight. It is at this point at which the protein component of the cell is formed around the outside of the endosperm cells. Increase in grain weight from this point onwards is due to increase in the size of endosperm cells already formed.

Water stress is likely to produce high protein wheat of low individual grain weight. This is due to the effects of water stress reducing the amount of starch being deposited into the endosperm area.

Some information on statistical analysis of data

> * Statistics allows us to determine if a result is due to some factor other than random error.
> * r^2 is a value that shows the relationship of one factor to another. A value of 0 means no relationship, whereas a value of 1 means a

Statistical analysis broadly refers to a mathematical method of determining the probability of wether a measurable factor (eg, yield) was affected by another factor(s) (eg, water use). It is necessary to conduct statistical analysis to be able to describe relationships (cause and effect) with any confidence. If an average from one group is higher than an average from another group, statistical analysis allows us to determine if the two groups have genuinely different averages, with variation within each group taken into account. The averages may differ between groups, but this may only be due to random error. Statistics allows us to say that one group differs from the other due to a reason other than random error.

For two measurable results to be significantly different from each other, they must differ by an amount calculated taking randomness or natural variation into account. This amount is termed the *least significant difference* and is often abbreviated as *L.S.D.* If the difference between two results is greater than the L.S.D. then the two results are said to be significantly different. In other words, they are different due to the treatment rather than natural variation. When variation in results is high, then the calculated L.S.D. is likely to be high also.

Another form of statistical analysis used regularly in analysis of wheat database information is *regression analysis.* This method calculates the relationship between two observable measures . If the two measures are related then measurement of one variable can be used to predict the other. This relationship can be expressed as an equation and can be represented by a line (see figure 3) . The degree to which one variable is rated to another variable is given by the r^2 value. The r^2 will vary between 0 and 1. A value of 0 will mean that there is no observed relationship between the factors. A value of 1 will mean that the two measures are perfectly related to each other. r^2 values of 1 are very rare in experimental agriculture. A researcher will consider most r^2 values of greater than 0.5 - 0.6 to indicate a good relationship between the two variables.

Appendix 1

Zadocks Decimal Code

0 Germination

00: Dry seed
01: Start of water absorption
03: Seed fully swollen
05: First root emerged from seed
07: Coleoptile (sheath around shoot) emerged from seed
09: First green leaf just at tip of coleoptile

1 Seedling growth

Count leaves on main stem only. Fully emerged = ligule visible. Subdivide the score by rating the emergence of the youngest leaf in tenths, for example, 12.4 = two emerged leaves plus youngest $^4/_{10}$ emerged.

10: First leaf through coleoptile
11: First leave emerged
12: 2 leaves emerged
13: 3 leaves emerged
14: 4 leaves emerged
15: 5 leaves emerged
16: 6 leaves emerged
17: 7 leaves emerged
18: 8 leaves emerged
19: 9 or more leaves emerged

2 Tillering

Count visible tillers on main stem; that is, side shoots with a leaf blade emerging between a leaf sheath and the main stem.

20: Main shoot only
21: Main shoot and 1 tiller
22: Main shoot and 2 tillers
23: Main shoot and 3 tillers
24: Main shoot and 4 tillers
25: Main shoot and 5 tillers
26: Main shoot and 6 tillers
27: Main shoot and 7 tillers
28: Main shoot and 8 tillers
29: Main shoot and 9 or more tillers

3 Stem elongation

Generally count swollen nodes or 'joints' that can be felt on the main stem.
Report as "detected by dissection" if stages 31 or 32 are determined by dissecting the stem.

30: Youngest leaf sheath erect
31: First node detectable
32: 2nd node detectable
33: 3rd node detectable
34: 4th node detectable
35: 5th node detectable
36: 6th node detectable
37: Flag leaf just visible
39: Flag leaf ligule just visible

4 Booting

Score the appearance of the sheath of the flag leaf.

41: Flag leaf sheath extending
43: Boots just visible swollen
45: Boots swollen
47: Flag leaf sheath opening
49: First awns visible

5 Ear or panicle emergence (from boot)

51: Tip of ear just visible
53: Ear $^1/_4$ emerged
55: Ear $^1/_2$ emerged
57: Ear $^3/_4$ emerged
59: Ear emergence completed

6 Anthesis (flowering)

Generally scored by noting the presence of emerged anthers (pollen sacs).

61: Beginning of anthesis (few anthers at middle of ear)
65: Anthesis half-way (anthers seen half-way to tip and base of ear)
69: Anthesis complete

7 Milk development

Score starch development in the watery kernel

71: Kernel water ripe (no starch)
73: Early milk
75: Medium milk
77: Late milk

8 Dough development

Kernel no longer watery, but still soft or dough-like.

83: Early dough
85: Soft dough
87: Hard dough

9 Ripening

91: Grain hard, difficult to divide
92: Grain hard, not dented by thumbnail
93: Grain loosening in daytime
94: Over-ripe straw dead and collapsing
95: Seed dormant
96: Viable seed giving 50% germination
97: Seed not dormant
98: Secondary dormancy induced
99: Secondary dormancy lost

Appendix 2. Information from 13 intensively monitored paddocks

Figure 9. Grain protein vs. 100 grain weight of wheat

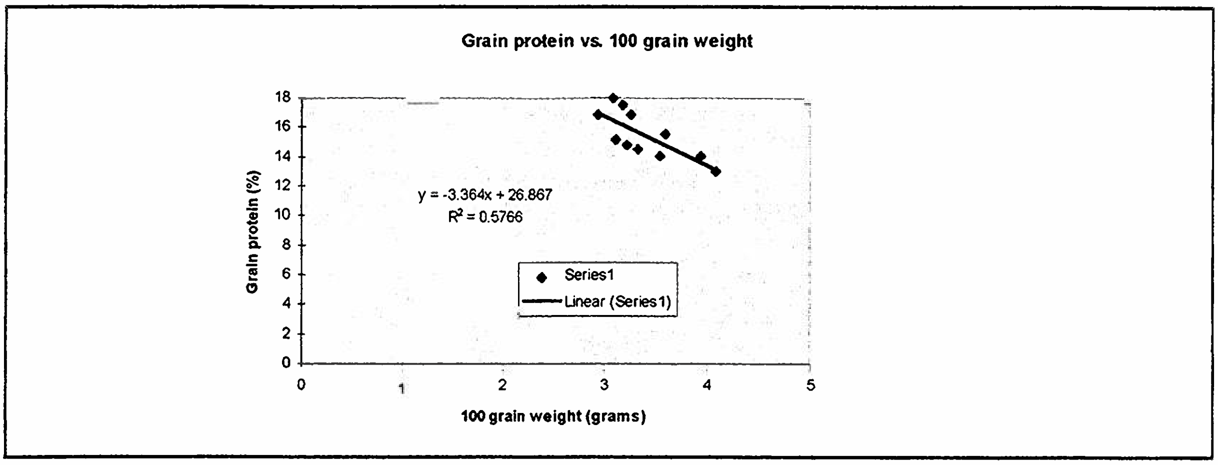


Figure 10. Water use of wheat crops vs. 0-30 cm pH

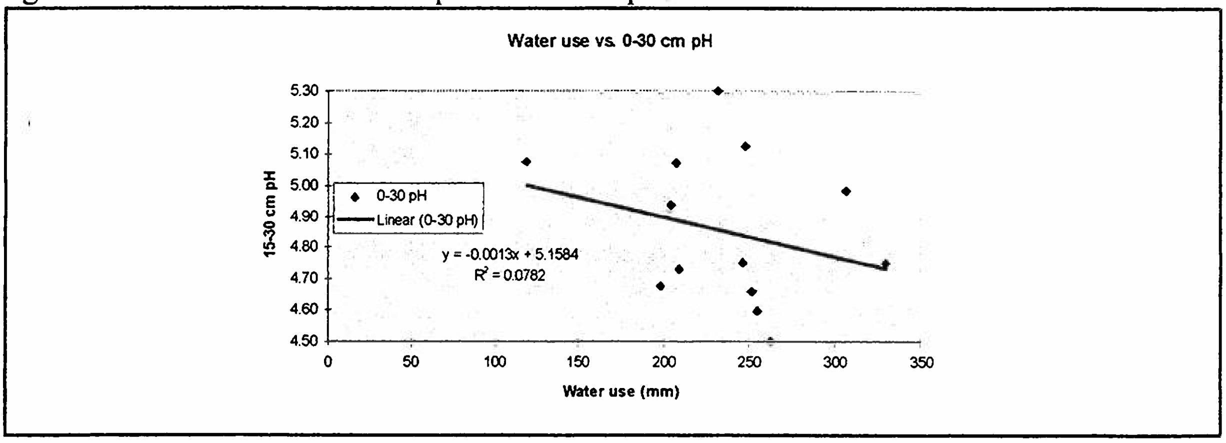


Figure 11. Water use efficiency of wheat crops vs. 0-30 cm pH

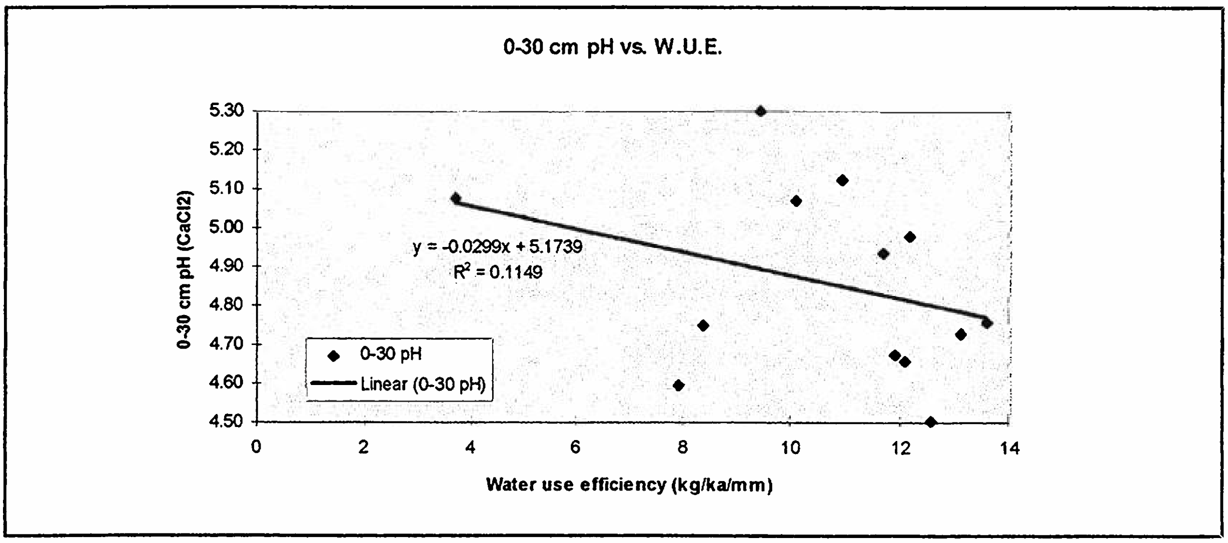


Figure 12. Water use effeciency of wheat crops vs. %P at flowering

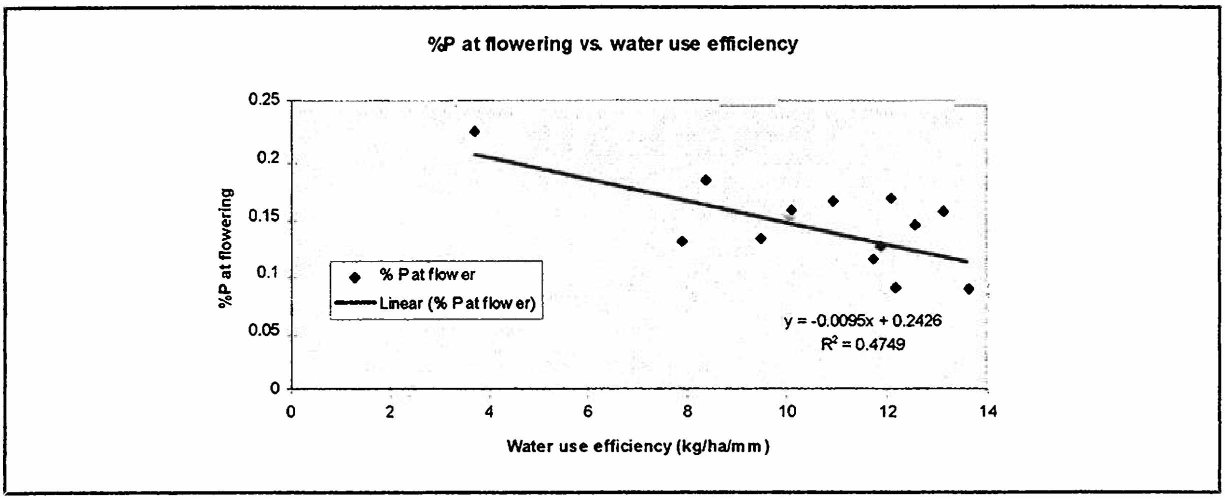


Figure 13. Grain number (wheat grains per square metre) vs. grain yield

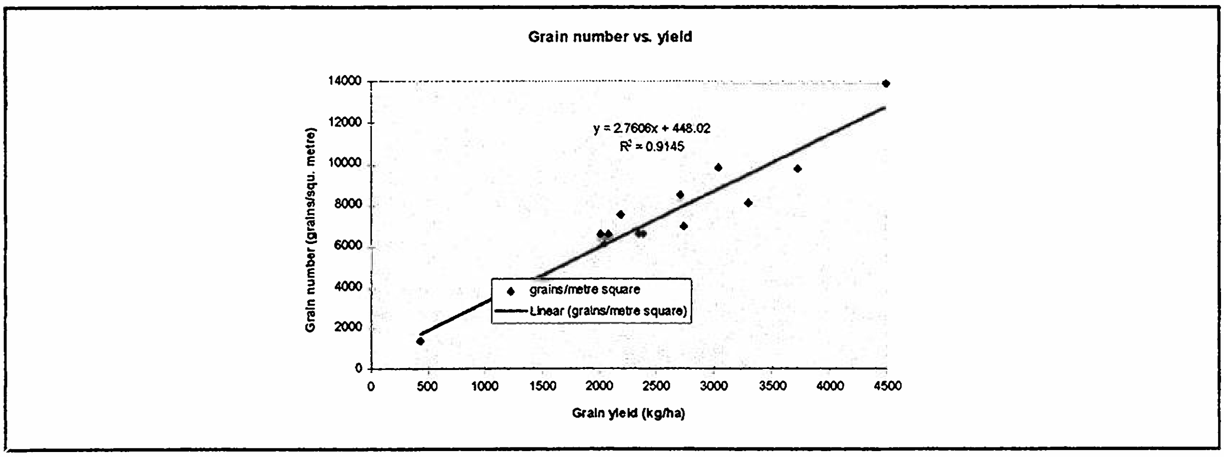
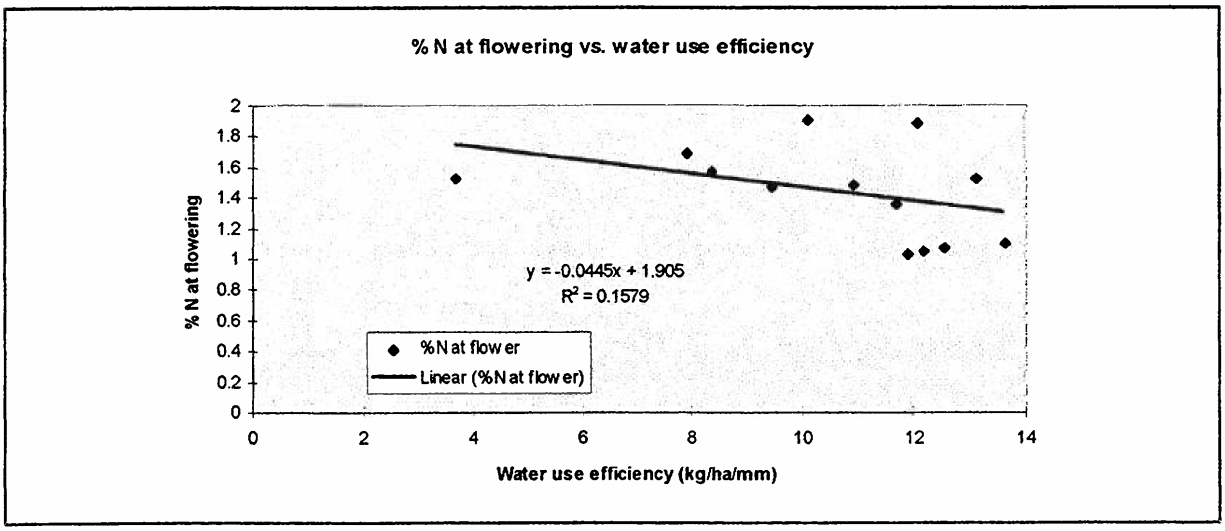


Figure14. Water use efficiency of wheat crops vs. tissue %N at flowering



Appendix 3. Wheat data base information

Figure 15. The relationship between applied nitrogen and grain protein

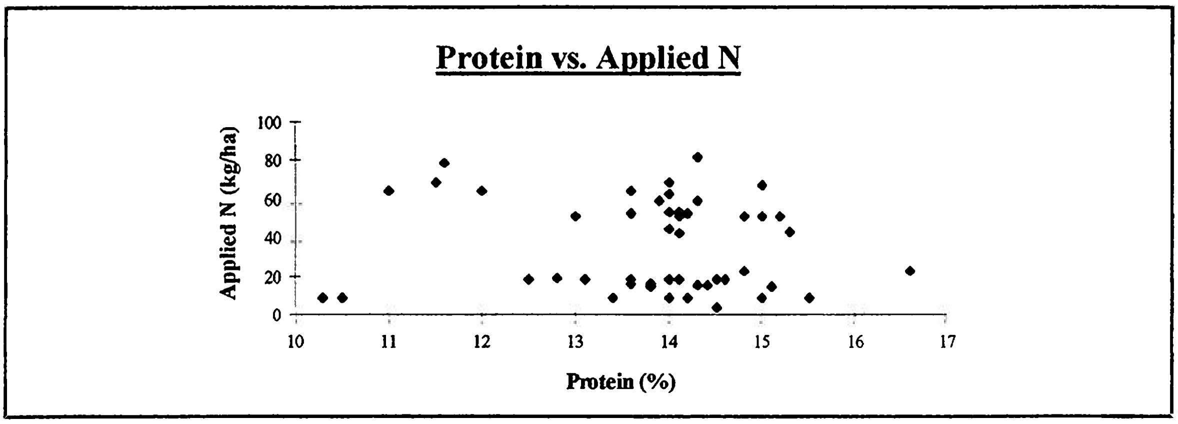


Figure 16. Grain yield vs soil pH

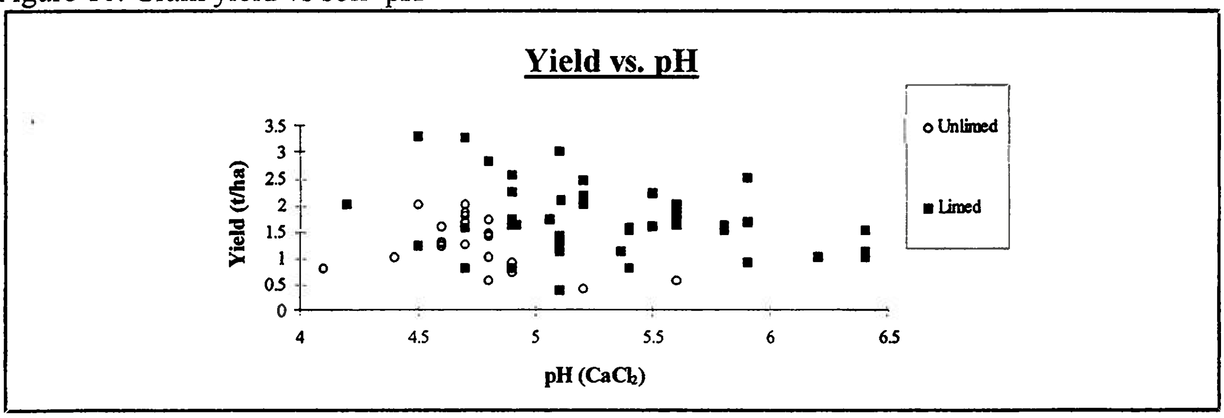


Figure 17. Grain protein vs. applied nitrogen

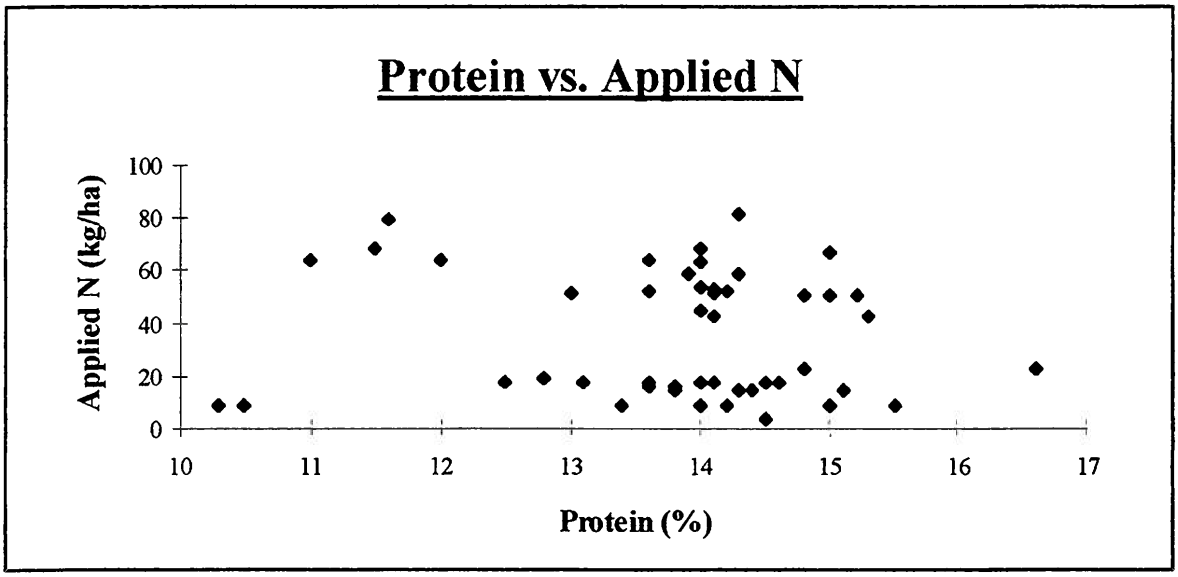


Figure 18. Grain protein vs. soil organic matter content

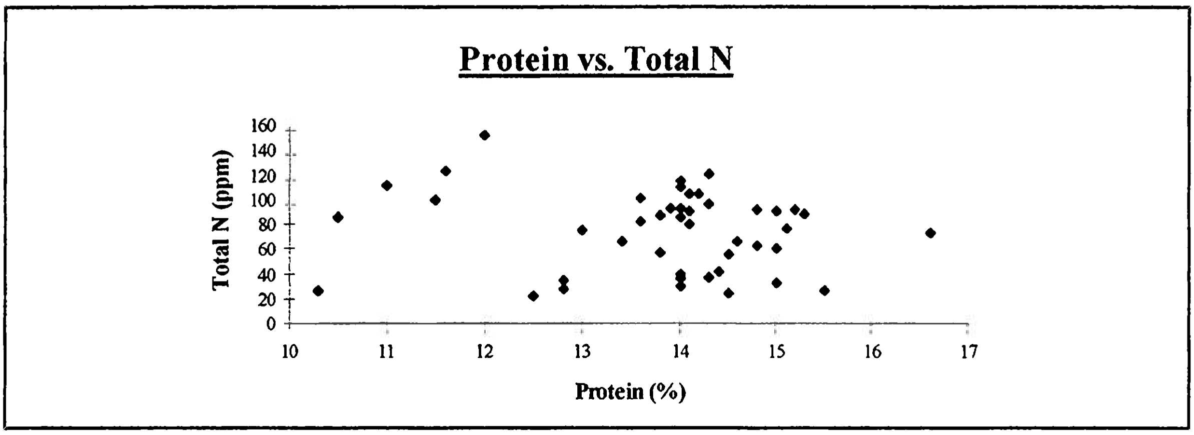


Figure 19. Grain yield vs. applied lime

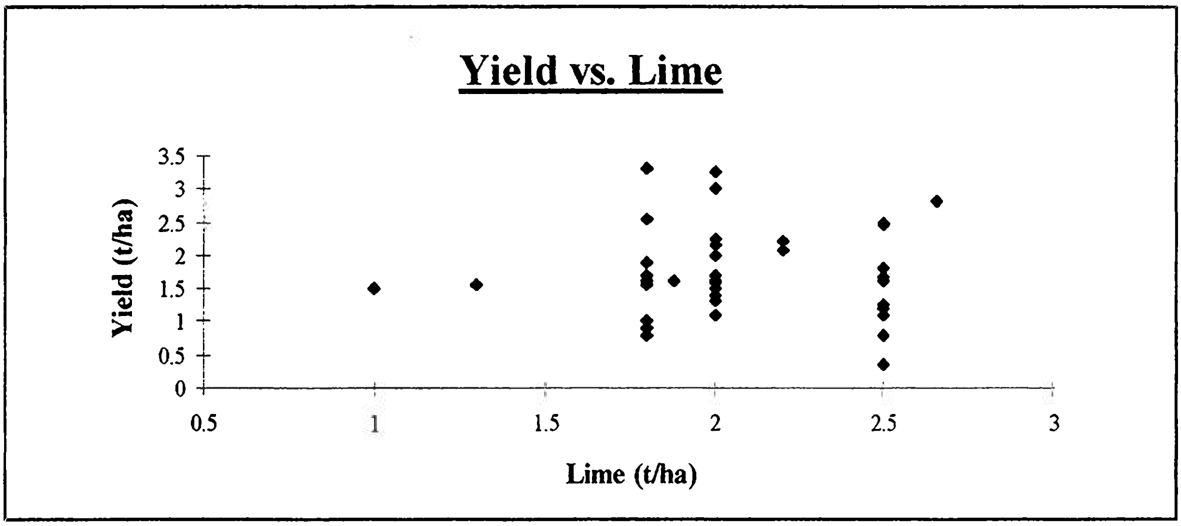


Figure 20. Grain yield vs. soil organic matter

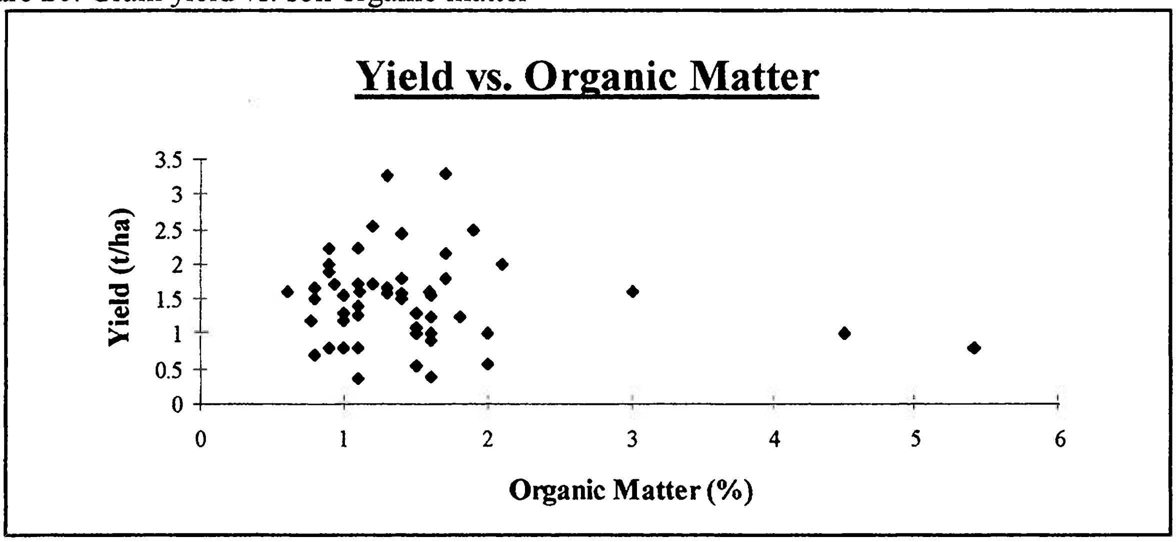


Figure 21. Grain yield vs. grain protein

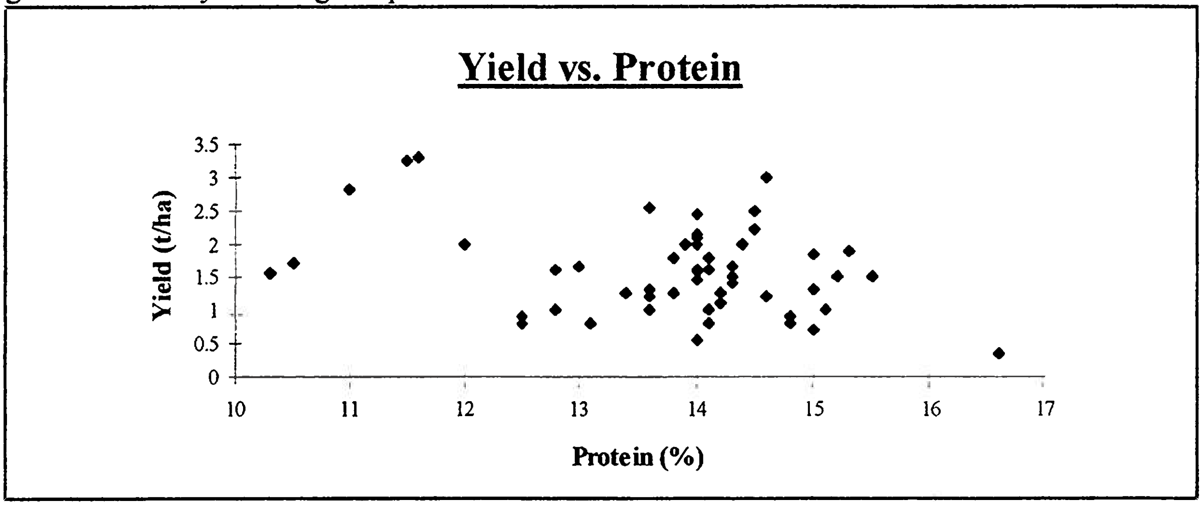


Figure 22. Grain yield vs. growing season rainfall

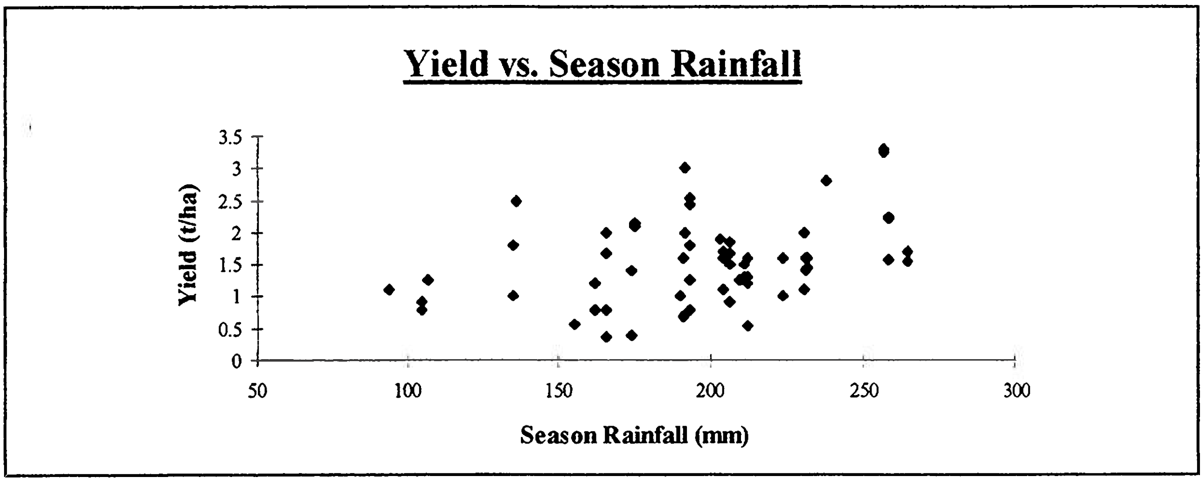


Figure 23. Grain yield vs. sowing rate

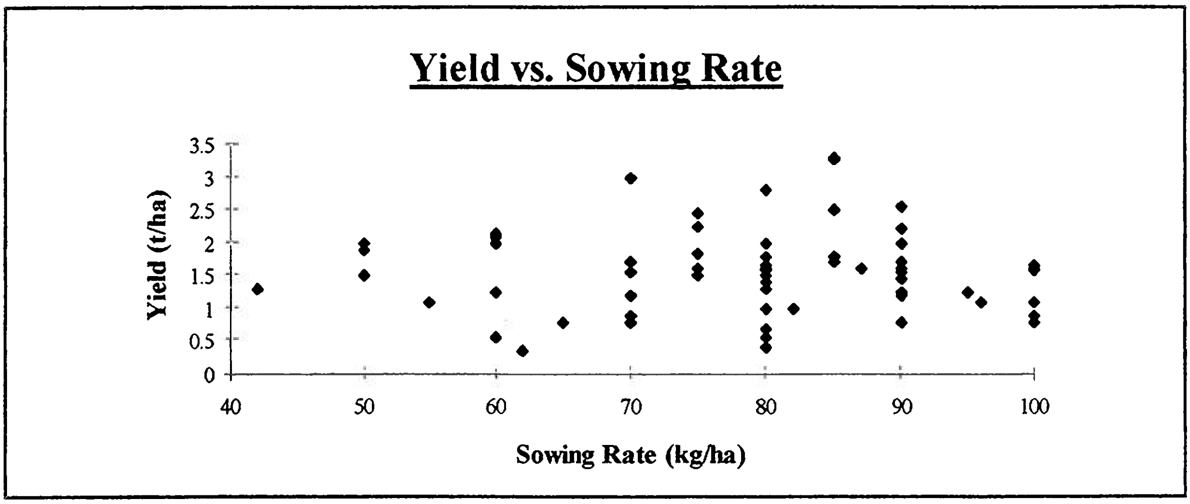


Table 2. Relationship between water use efficiency and some management factors

		lower 20%	average	top 20%
av. est. W.U.E.		6.42	13.46	21.65
av. yield		0.75	1.59	2.58
soil type	granite	100%		59%
	basalt			41%
av. protein		14.15	14.02	13.25
altitude		436	491	480
pH (CaCl)		5.07	5.125	4.97
prev. crop	oats	30%	22%	10%
	lupins	50%	40%	40
	canola	10%	33%	50
	wheat	10%	5%	0
variety	dollarbird	50%	17%	0%
	jantz	50%	52	60
	rosella		17	30
	darter		2	0
	sunbri		9	10
sowing rate		76	77	79
av. sow date		162	150	134

Table 3. Selected information from wheat data base

Yield	Protein	April-Nov. Rain(mm)	Rock Base	previous crop	pH (CaCl)	Soil P	Soil N	Sow Date
2.15	14	175.5	1. Granite	8. Canola	5.2	29	17	25-30 April
2.09	14	175.5	1. Granite	3. Oats	5.11	30	30	25-30 April
1.2	14.6	180	1. Granite	4. Lupins	4.6			1-10 June
0.8	13.1	180	1. Granite	4. Lupins	4.1			21-30 June
0.8	14.8	186	1. Granite	3. Oats	4.7	14	29	21-30 June
0.36	16.6	186	1. Granite	4. Lupins	5.1	29	36	21-30 June
0.4		161	1. Granite	3. Oats	5.2	29	16	21-30 June
1.4		153	1. Granite	3. Oats	5.1	25		11-20 June
3.26	11.5	226	1. Granite	4. Lupins	4.7	26	22	13-23 May
0.56		171.5	1. Granite	3. Oats	5.6	56	7	21-30 June
0.55	14	250	1. Granite	4. Lupins	4.8	16	19	11-20 June
1.26	13.4	245	1. Granite	3. Oats	4.6	14	41	11-20 June
2.22	14.5	237.5	1. Granite	4. Lupins	5.5	46	15	24-31 May
2.24		237.5	1. Granite	4. Lupins	4.9	30	19	1-12 May
1.58		237.5	1. Granite	4. Lupins	4.6	41	30	1-12 May
1.45	14	271	1. Granite	1. Wheat	4.8	26	9	24-31 May
1.6	14	271	1. Granite	8. Canola	5.6	13	15	11-20 June
2.45	14	220	1. Granite	8. Canola	5.2	29	23	13-23 May
0.8	14.1	220	1. Granite	4. Lupins	4.9	24	28	1-10 June
2.55	13.6	220	1. Granite	4. Lupins	4.9	20	35	13-23 May
1.8	14.1	220	1. Granite	8. Canola	5.6	15	19	11-20 June
1.25	14.2	220	1. Granite	4. Lupins	5.1	19	37	24-31 May
1.6	14.1	210	1. Granite	4. Lupins	4.9	35	44	21-30 June
0.7	15	210	1. Granite		4.9	25	7	11-20 June
1.2	13.6	255.5	1. Granite	4. Lupins	4.5	50		24-31 May
1.6	14	255.5	1. Granite	3. Oats	5.8	22	21	13-23 May
1.3	13.6	255.5	1. Granite	4. Lupins	4.6	29		13-23 May
1	14.1	225.5	1. Granite	4. Lupins	6.2	44	44	1-10 June
1	13.6	225.5	1. Granite	8. Canola	6.4	37	46	1-10 June
1	12.8	251.8	1. Granite	1. Wheat	4.8	25	11	21-30 June
1.6	12.8	251.8	1. Granite	1. Wheat	5.6	25	6	1-10 June
1.67	13	231	1. Granite	8. Canola	5.9	19	17	1-25 April
1.8	13.8	135	1. Granite	3. Oats	4.7	23	52	13-23 May
1	15.1	135	1. Granite	4. Lupins	4.4	41	44	11-20 June
1.5	15.2	250.5	1. Granite	8. Canola	5.8	25	29	24-31 May
1.85	15	250.5	1. Granite	4. Lupins	4.7	63	17	1-10 June
1.3	15	217.5	1. Granite	4. Lupins	5.1	117	17	11-20 June
1.5	15.5	217.5	1. Granite	8. Canola	6.4	52	13	11-20 June
1.9	15.3	236	1. Granite	8. Canola	5.6	13	32	11-20 June
2	14.4	0	1. Granite	3. Oats	5.2	30	19	11-20 June
1.5	14.3	0	1. Granite	8. Canola	5.4	25	16	
1.25	13.8	127.5	1. Granite	3. Oats	4.7	49	29	11-20 June
1.1	14.2	110	1. Granite	4. Lupins	6.4	60		11-20 June
1.59	14	268.5	1. Granite	8. Canola	5.5	26	50	24-31 May
1.4	14.3	268.5	1. Granite	8. Canola	4.8	30	28	24-31 May
1.7		0	1. Granite	3. Oats	4.8	15	26	11-20 June
1.6		256	1. Granite	8. Canola	4.92	17	25	11-20 June
1.1		256	1. Granite	4. Lupins	5.36	32	30	1-10 June
1.7		256	1. Granite	8. Canola	5.06	33	30	13-23 May
1.7	10.5	286	1. Granite	3. Oats	4.9	19	55	21-30 June

1.55	10.3	286	1. Granite	3. Oats	4.7	21	13	11-20 June
1.1		271.25	1. Granite	8. Canola	5.1	26	26	11-20 June
2	12	271.25	1. Granite	3. Oats	4.5	18	63	13-23 May
0.9	14.8	250.5	1. Granite	4. Lupins	4.9	21	29	13-23 May
2.81	11	260.3	2. Basalt	8. Canola	4.8	34	34	13-23 May
1.67	14.3	194	2. Basalt	3. Oats	4.7	83	27	11-20 June
2	13.9	194	2. Basalt	8. Canola	4.7	41	24	13-23 May
2.5	14.5	146	2. Basalt	4. Lupins	5.9	28	27	1-10 June
3.3	11.6	246	3 Serpentine	. 4. Lupins	4.5	49	31	24-31 May
2	14	224.5		8. Canola	5.6	17	69	21-30 June
3	14.6	224.5		8. Canola	5.1	12	34	13-23 May
1.55		0		8. Canola	5.4	42	43	1-10 June
2		0		4. Lupins	4.2	35	34	1-10 June
0.8	12.5	132		1. Wheat	5.4	25	3	21-30 June
0.9	12.5	132		3. Oats	5.9	23	3	21-30 June

1.

CORRECTION

Page 23 A value of 0 means no relationship, whereas a value of 1 means a perfect correlation between the two factors.

Page 29 Figure 18 All total N(ppm) values should be x 10.