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SAFE UTILISATION OF FEEDLOT MANURE AND EFFLUENT

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Final Report prepared for MLA by:

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ABSTRACT

This project monitored crop production, and nutrient and water dynamics, when feedlot manure was applied to soil. A one-off application of 60 t/ha manure supplemented with nitrogen fertiliser produced 57.5 t dry matter/ha of hay over a 3 year period compared to 55.2 t/ha when annual applications of 20-25 t/ha of manure (the normally recommended rate), plus nitrogen fertiliser were made. These yields compare to 14.0 t/ha without manure and fertiliser. Surface and sub-surface water runoff was lower with the higher manure application rate and nutrient loss in runoff was similar, and environmentally safe, between the two manure treatments.

The results indicate that a single large application of manure, together with applications of inorganic fertilisers to balance the nutrition of the crop, is the most productive and environmentally safe way to profit from manure reutilisation. Relay cropping with minimal cultivation maintains soil surface structure, which enhances water infiltration and so provides more water for the crop and reduces water and nutrient loss.

These findings have been incorporated into recommendations for Best Management Practices for feedlot manure reutilisation.

EXECUTIVE SUMMARY

Why the work was done

In Australia, estimated manure production by the intensive cattle, poultry and pig industries is of the order of 1-1.5, 1-1.2 and 1.2 million t/year, respectively. Cattle feedlot manure contains a high amount of organic matter, as well as macro and micronutrients essential for plant growth, although the release rate of nutrients is dependent upon the nature of the manure, the nutrient concentration and form and climatic conditions. This manure resource has, in the past, been considered a “waste product” that had to be disposed of. This project investigated ways to turn this “waste product” into a valuable nutrient and organic matter source and to produce guidelines to define Best Management Practices (BMP’s) for manure reutilisation..

This was achieved through field trials located on the Darling Downs of Queensland and on the Northern Tablelands of New South Wales.
What was achieved.

The broad objectives of the project were to establish limits of nutrient loads in plants and soils define the nutrient cycle in manure reutilisation areas and to draw together research date via simple models for the development of Best Management Practices (BMP’s) for the industry.

Because of the comparatively narrow range of plant and soil nutrient concentrations experienced at the project sites it was not possible to establish limits of nutrient loads in plants and soils. It is recommended that the comprehensive data contained in Reuter and Robinson (1997),"Plant Analysis-An interpretation Manual" be used to set plant limits.

Because of the diversity of soils used in reuse areas it is unrealistic to set limits on soil nutrient concentrations. For example in some soils bicarbonate extractable phosphorus concentrations may exceed 200 ppm in their native state whereas this concentration may result in significant leaching in other soils.

The MEDLI model proved to be the most 'useful' model with respect to the study of modelling effluent irrigation.

The results from the “Tullimba” field trial indicate that manure that is surface spread should be incorporated to a shallow depth and then sown with forage crops immediately after. This reduces loss of nutrient by sediment and in water flows. Australian climatic conditions often permit summer and winter crop production. To maximise nutrient recovery and export via crop harvests continuous cropping of forage crops should be employed. Relay cropping ensures maximum benefit by reducing nutrient build up in the soil and losses via volatilisation and water flows. It is important to export the crop material away from the manure and effluent reuse area. The material may be sold off-farm or used for silage in the rations. Manure applications to the reuse area must be postponed if annual soil tests indicate excessive levels of nutrient content in the soil. Continued cropping, supplemented with inorganic fertiliser, will reduce these levels over time.

The application rate of manure to land areas is site specific. Factors such as method of handling, storage of manure and effluent and the resulting chemical composition, land spreading operation, soil fertility and nutrient buffering capacity, and climatic conditions will determine the rate of nutrient availability to plants. Manure sub-samples taken at the time of application for chemical analysis allow calculation of nutrient additions. Generally, manure applications require subsequent inorganic N additions to balance the nutritive requirements of crops. Crop tissue analysis allows timely application of inorganic fertiliser assisting in avoiding potential deficiencies or induced toxicities that reduce dry matter yields. Forage crops producing high yields result in a large export of nutrients which can be in excess of nutrient additions. In particular, the export of K from forage crops can be greater than that from grain crops so that K may become deficient in manure amended soil and need supplementing with inorganic K. In addition to plant tissue analysis, monitoring inputs and exports of nutrient along with changes in soil fertility will be fundamental in maintaining plant nutrient requirements.

Real time soil moisture monitoring will improve irrigation efficiency and reduce the risk of nutrient losses in runoff and sub-surface flow.

When calculating permissible nutrient loadings, there is a need to take into account initial P status and P buffering capacity of the soil and changes in P sorption on adding manure.

The lower the fertility of the soil, the greater the value of manure. In the "Tullimba" soil applying 60 kg/ha or less on a 3 year cycle compared to current industry practice of annual applications of 20 - 25 t/ha has some advantages. It limits the amount of cultivations thus reducing deep and shallow soil compaction resulting from manure spreading operations and minimises disturbance of the soil structure. In addition, the combination of residual nutrient from further decomposition of manure with inorganic fertiliser in order to balance crop nutritive requirements allows depletion of nutrients derived from manure and thus reduction of pollution potential.

When and how can the industry benefit from the research

The industry and the broader environment can benefit immediately from the research by adopting the following. Many of the recommendations should be included in guidelines for manure reuse.

(a) It is essential to measure the nutrient composition of each batch of manure before application.

(b) Soil analysis of the disposal area must be undertaken prior to application. P sorption capacity needs to be measured to avoid P loading and samples should be analysed down the profile.

(c) The rate of application should consider

- (i) potential plant production,
- (ii) risk of surface nutrient loss (rainfall, slope, infiltration rate
- (iii) The soils capacity to retain nutrients,

(d) Manure should be applied as close as possible to planting of the crop to minimise risks of loss to environment. Manure should be well composted to reduce the risk of pathogen contamination of soil.

(e) If analysis of the manure indicates a low concentration of a particular nutrient then a starter application of that nutrient should be made to maximise the utilisation of the other nutrients in manure. If the analysis shows a gross deficiency then top-dress applications may need to be made

(f) Crops should be sown at very high seeding rates to establish ground cover and a nutrient sink as quickly as possible.

(g) The N status of the crop should be monitored by coloured charts, or a SPAD meter and supplemental additions of N made as required to maximise the utilisation of the other nutrients in the manure.

(h) Relay cropping should be practiced to provide a nutrient sink. Cultivation should be avoided between crops to maintain soil surface characteristics favourable for infiltration.

(i) Large infrequent manure applications are preferable than smaller annual additions as the need for regular incorporation, which destroys soil structure, is reduced.

(j) Real time monitoring of soil moisture with an Enviroscan should be encouraged to optimise moisture conditions for plant growth and reduce the risk of nutrient loss in surface runoff subsurface flow.

(k) The yield and nutrient content of harvested forage must be monitored to avoid nutrient overload or depletion. This method of measurement is more sensitive than total soil analysis.

CONTENTS

1. BACKGROUND

Consumer preference, encouraging the production of grain-fed livestock in both domestic and export markets has resulted in the expansion of new and existing intensive livestock facilities. Such animal industries include broiler production, piggeries and beef feedlots. In Australia, the gross capacity of these industries is about 900 000 cattle (1.5 million head/yr), 307 000 sows (3.1 million pigs/yr) and an estimated 17 million hens producing more than 330 million birds for slaughter and 170 million dozen eggs (ALFA 2001; Lott *et al*., 1999).

Cattle lot feeding enables rapid and consistent production of a high quality product under controlled conditions. In addition, feedlots allow a reduction in land degradation during periods of drought (Zoebl 1996). Worldwide the number of animals fed in beef feedlots has increased over the past few decades. The Australian feedlot industry is comparatively small with a total feeding capacity of 900 000 head which supplies both the domestic and export markets namely, the Pacific Rim. In the course of beef production a substantial amount of by-product is produced, namely manure and effluent, that is commonly applied to land areas designated for crop and pasture production.

Feedlot production of grain-fed beef exists in both the north and south of Australia, close to grain growing areas. The Darling Downs region of Southern Queensland has about 60% of the national capacity with the northern slopes and Riverina districts of NSW accounting for most of the remainder (Binden 1996). Watts (1992b) reported that feedlots with capacity greater than 5 000 head constitute only about 3% of the feedlots in Australia but contain almost 50% of the total pen capacity.

The history of feedlots in Australia began in the mid 1960's with steady development until the closure of the lucrative Japanese market in 1975 which forced an industry collapse. Recovery was slow but gradual and by the late 1980's, the expansion of new and existing feedlots generated concern regarding animal welfare and the impact of cattle feedlots as nutrient point and non-point sources of pollution. At the time, Australia adopted USA technology and feedlot design, which proved environmentally unsuitable for the Australian climate. Tucker *et al*. (1991) showed that the majority of Australian feedlots are in climatic zones characterised by summer dominant rainfall and high evaporation, and that 59% of feedlots receive more than 625 mm of rainfall annually. This compares to the majority of US feedlots that receive less than 500 mm of precipitation per year, some of which is snow. Comparatively, Australian feedlots are closer to the equator and operate in a hotter and more humid climate than their counterparts in the US (Lott 1997).

In order to improve public perception and the sustainability of the feedlot industry in Australia, regulatory authorities implemented national feedlot guidelines, codes of practice for animal welfare and environmental management strategies in the late 1980's (Watts & Tucker 1994). Today, a state of the art feedyard design suited to Australian conditions is managed so that manure and effluent on the feedyard surface does not cause pollution of waterways, land degradation and odour nuisance. In addition, current research pertaining to the collection, storage and land application of manure and effluent aims to prevent off-site pollution via nutrient leaching, and surface sediment transport.

In the early days, with the advent of synthetic fertilisers after World War II, most researchers focused on manure and effluent as a waste disposal problem (Gilmour *et al*., 1977; Linderman & Ellis 1978; Watts & McKay 1986), which biased the efficacy of utilising the product to its full capacity. However, a conceptual shift by some authors has lead to manure and effluent being seen as a valuable fertiliser resource in crop production (Chang *et al*., 1991; Lander *et al*., 1998).

The addition of organic matter to degraded soils increases the soil's physical and chemical fertility. Cattle feedlot manure contains a high amount of organic matter, as well as macro and micronutrients essential for plant growth, although the release of nutrients is dependent upon rate of mineralisation, the nature of the nutrients and climatic conditions.

Australia is a large country of 768.3 million hectares, with about 60% used for commercial agriculture (van Sliedregt *et al*., 1997, after NFF 1993). Cropping and fodder production occupies approximately 6% of this area. Recent surveys indicate much of this land is degraded with substantial losses of soil organic matter and nutrients (Dalal & Mayer 1986), soil structural degradation and decreases in crop quality and yields (Whitbread 1996). The application of manure may improve the production and sustainability of these systems.

Many international studies have demonstrated the effects of livestock excreta on increasing crop yields, improving soil physical properties and the long-term advantages associated with an organic source of fertiliser. Literature pertaining to the use of nutrients and salts contained in manure and effluent is limited for the climatic and soil regimes found in Australia.

Worldwide the social dilemma still occurs over the use of manure because of odour problems, cost of application, storage and handling of manure compared to commercial inorganic fertilisers and potential health risks. Moreover, from an ecological viewpoint the presence of salts and the imbalance of nutrients relative to plant requirements contained in manure and effluent has the potential to lead to adverse nutrient accumulation in the soil profile, reduced soil physical attributes and water pollution.

To avoid deleterious effects upon the soil-plant system and decrease pollution potential it is imperative waste is 'characterised' within the system so as to determine a safe application rate to land re-use areas. In characterising the effects of waste on the soil-plant system, such factors as soil chemical interactions, plant export of nutrient, and improvement in soil physical conditions require examination. Research into better utilisation of nutrients derived from manure by plant uptake will reduce the potential risk of environmental hazards such as surface runoff, and leaching of nutrient associated with land spreading of manure.

The primary concern of the work undertaken in this project was to examine within the soil-plant-water system the effects of beef feedlot manure and effluent applied to a land area in Australia.

2. PROJECT OBJECTIVES

The primary objective of this project is to provide the Australian feedlot industry, through research and transfer of technology, with best management practices to obtain the maximum benefit from land utilisation of feedlot manure and effluent with the least detrimental consequences to the environment.

The specific objectives of the project were:

(a) To broadly define the upper and lower limits of nutrient and salt concentration in crops commonly grown in feedlots and receiving manure and effluent and provide these data for use in guidelines and design methods.

(b) To describe criteria that express limits of high/excess levels of nutrient and salt in soils receiving feedlot wastes and provide data for use in guidelines and design methods.

(c) To fully define the nutrient and salt cycles in waste utilisation areas by obtaining closure of the mass balance of the key components of the cycles.

(d) To balance the inputs and outputs of the soil-plant system receiving feedlot manure and effluent to define safe levels of waste application and acceptable levels of nutrient and salt loss from the system.

(e) To draw together, research data and data from other sources, via simple models, for the development of BMP's and design methods for sizing land areas for feedlot manure and effluent application.

3. METHODOLOGY

3.1 Work Area 1 - Database of Crop and Soils Data from Land Receiving Feedlot Wastes

The compilation of data for a database focused on sourcing data from researchers in Australia and overseas. Contacts with researchers were made in Years 1 and 2 of the project.

A study tour to review overseas research work was undertaken in October/November 1998. Over 40 contacts were made with professionals working in agricultural waste management. An exchange of data occurred with researchers at the West Texas A & M University.

3.2 Work Area 2 - Nutrient and Salt Cycles from Manure and Effluent Application, Tullimba feedlot

3.2.1 Experimental Site

Location

The property “Tullimba” (30^{o} 20’ S, 151^{o} 12’ E) is located about 50 km west of Armidale on the western side of the Great Divide watershed (Figure 2) at an elevation ranging between 700 and 780 m ASL. It is 743.1 ha in extent and the topography is low undulating to moderately hilly, cleared to semi-cleared land. Prior to the establishment of a beef cattle feedlot facility (capacity 1000 head) in 1994, the property was primarily used for cattle and sheep grazing with timber clearing and pasture improvement evident to varying degrees over the property (R. Geddes pers. comm.). Today the property has distinct management areas such as the feedlot, grazing, cropping and land for manure and effluent reuse. It has a large water storage reservoir (dam) constructed in 1981, with a capacity approximating 1 200 ML.

Soils

The soils of “Tullimba” are predominantly yellow solodics developed on Palaeozoic greywacke, a sedimentary rock known locally as “trap” (Lawrie 1993). According to the Australian Soil Classification Key (Isbell 1996), the soils belong to the order Sodosols, suborder Brown AB; in the USDA classification the soils are Alfisols, typic natrustalf. The topsoils are typically light grey loams, 10 - 15 cm thick, containing various amounts of angular gravel. The A_2 horizon is a very pale, sandy loam to loamy sand, up to 30 cm thick, usually more gravelly than the surface horizon. The B horizon is a yellowish grey clay, but often well structured and shrinks readily on drying (Table 3.1). Soils are shallowest on the upper slopes but on mid and lower slopes, which represent about half the property, soil depth exceeds 0.5 m.

Surface soils are acidic (pH_{CaCl2} 4.7 - 5.3) but pH increases with depth (Table 3.1). Nitrogen and phosphorus levels are low, as are organic C concentrations with values in the surface soil ranging from 1 to 1.5%. Soil bulk density and the proportion of exchangeable sodium, especially in the lower slope positions increases at depth, favouring clay dispersion and soil structural breakdown.

In the lower slope regions of the property, where the sediment basins and effluent holding ponds are located, subsoil sodicity increases to an ESP of over 20%, as does the bulk density with values typically greater than 1.8 Mg/m^3. The marked reduction in permeability promotes waterlogging in the lower A_2 horizon overlying the clay subsoil and localised perched water tables. The subsoil of the middle slopes where the manure and effluent reuse area, the trial site and pens are located, are slightly less sodic compared to the lower slopes but bulk density is similar.

Table 3.1: Physical and chemical properties of "Tullimba" soil closest to the experimental site (Lawrie 1993).

Depth (cm)	Colour [a]	Texture [b]	Bulk density (Mg/m^3)	pH ($_{CaCl2}$)	EC (dS/m)	Bray P (mg/kg)	Total C (%)	Total N (%)	Exchangeable cations (cmolc/kg)			
									Ca	Mg	K	Na
0-10	lg	SL	1.58	4.7	0.03	4	1.19	0.08	2.4	0.9	0.53	0.08
25-35	vlg	LfS	1.75	5.5	0.01	<3	0.37	0.03	2.0	1.6	0.06	0.12
40-50	dyg	LC	1.81	6.0	0.05	<3	0.48	0.07	7.1	8.7	0.19	0.95
70-80	yb	LC	1.90	7.0	0.07	<3	0.29	0.04	6.2	8.0	0.11	1.47

a d – dark, l – light, v –very, y – yellow, b – brown, g – grey, b f – fine, C – clay, L – loam, S – sand

Climate

As a seasonal indication of rainfall and temperature patterns in the area**Error! Reference source not found.**, the mean monthly rainfall (1888 - 1992) and temperature (1965 - 1970) data for Bundarra Post Office (610 m ASL) situated 35 km NNE of "Tullimba, " and mean evaporation data sourced from Inverell Research Station (1946 - 1995) are presented in **Figure 1**.

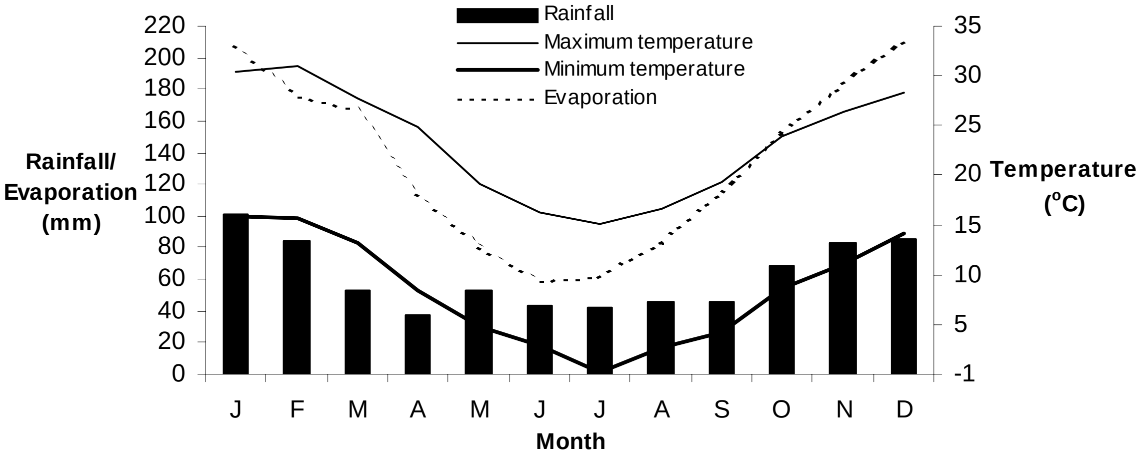

Figure 1: Mean monthly rainfall and maximum and minimum temperatures for Bundarra Post Office, NSW, and evaporation for Inverell Research Station (source: Bureau of Meteorology, Australia).

Figure 1 shows that the “Tullimba” area experiences summer dominant rainfall with annual precipitation about 805 mm, cold winter and warm summers. Maximum temperatures generally occur in February, whilst minimum temperatures are below 0^{o}C in July. Throughout the winter months humidity is as high as 80 - 85% whilst in November/December it drops to 65%. An average monthly maximum of 15 frosts per month during July and August is also experienced.

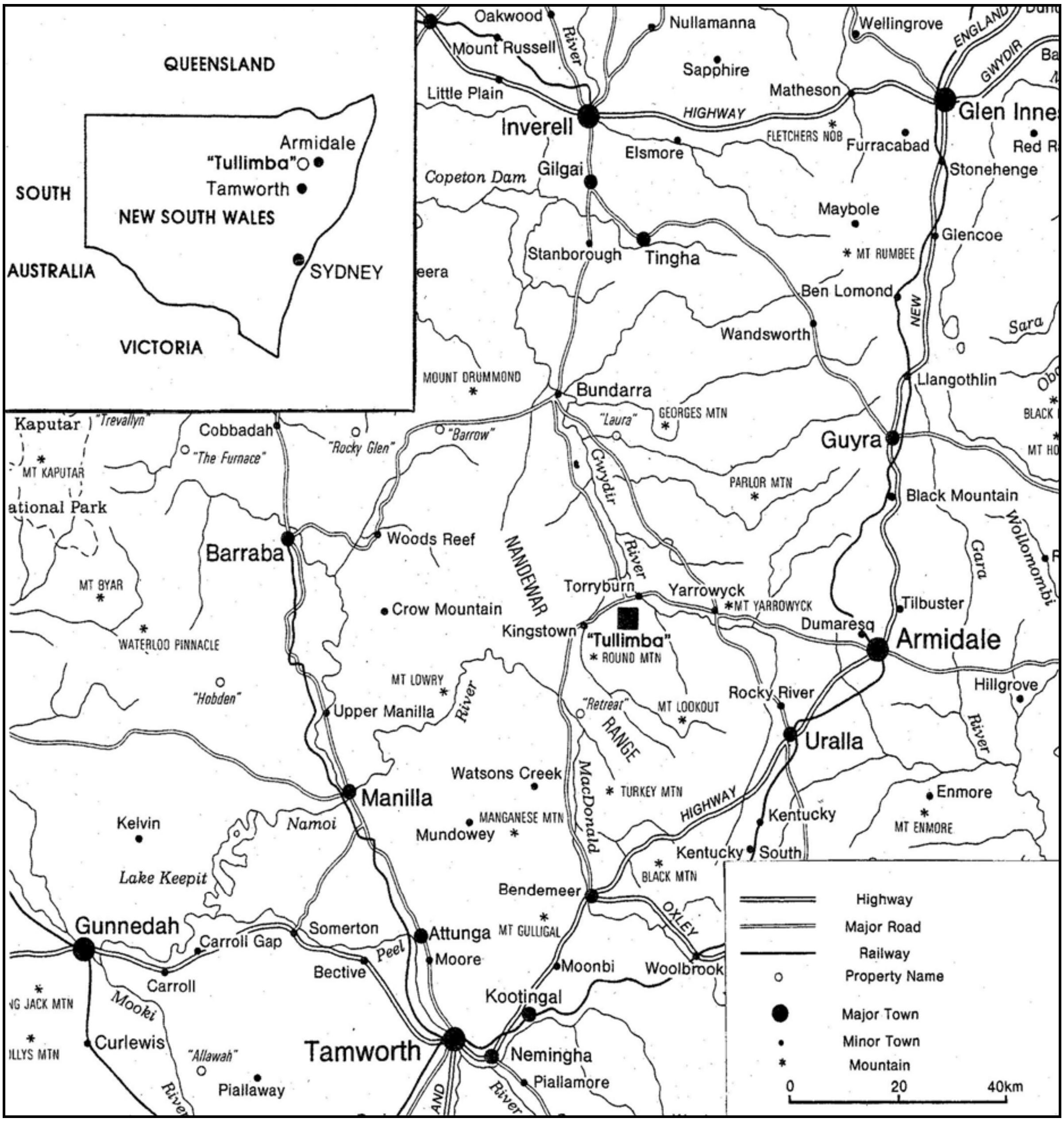

Figure 2: Topographic map (1:1 000 000) of the area around "Tullimba".

3.2.2 Experimental design and management

Plot design

Fifteen experimental plots (20 * 5 m) were constructed in July 1997 on a soil of 2 - 3% slope above the main effluent irrigation area at "Tullimba". An electric fence was constructed in June 1998 to prevent kangaroos from grazing the plots. Each plot was isolated using conveyor belting, 0.8 cm thick, which was installed around each plot to a depth of 0.7 m in order to prevent contamination via lateral water flow above the B horizon, and via surface water flows (Figure 3, Figure 4). Surface runoff from each plot was collected in galvanised guttering (0.3 m wide) located at the foot of the plots; subsurface water flow was intercepted by perforated conjugated plastic pipe in a cloth sleeve (retailed as 'Agpipe') located on top of the B horizon, below the surface guttering. A layer of bentonite underneath the Agpipe prevented drainage of water into the B horizon, whilst coarse sand packed between the conveyor belting and soil interface facilitated water flow into the pipe (Figure 4). Both surface and subsurface runoff were directed into perforated manifolds from which periodic sediment samples were collected, above tipping buckets (Figure 6). A data logger and battery operated counters recorded the number of tips for both surface and subsurface buckets, which had capacities of 6 and 4 L, respectively. A sample splitter positioned beneath each of the tipping buckets provided the means to collect a representative sub sample of water. Plots with low instrumentation had large drums from which water samples were collected. They did not allow volume measurements to be made. Two piezometers, two neutron probe access tubes, and one Enviroscan tube were installed in each plot (Figure 3). Two pluviometers connected to data loggers were installed at either end of the plot area to quantify the amount and intensity of precipitation. Data generated from piezometers, neutron probes, enviroscan tubes, and tipping buckets which recorded the volume of surface and subsurface flow formed part of the study of soil physical properties.

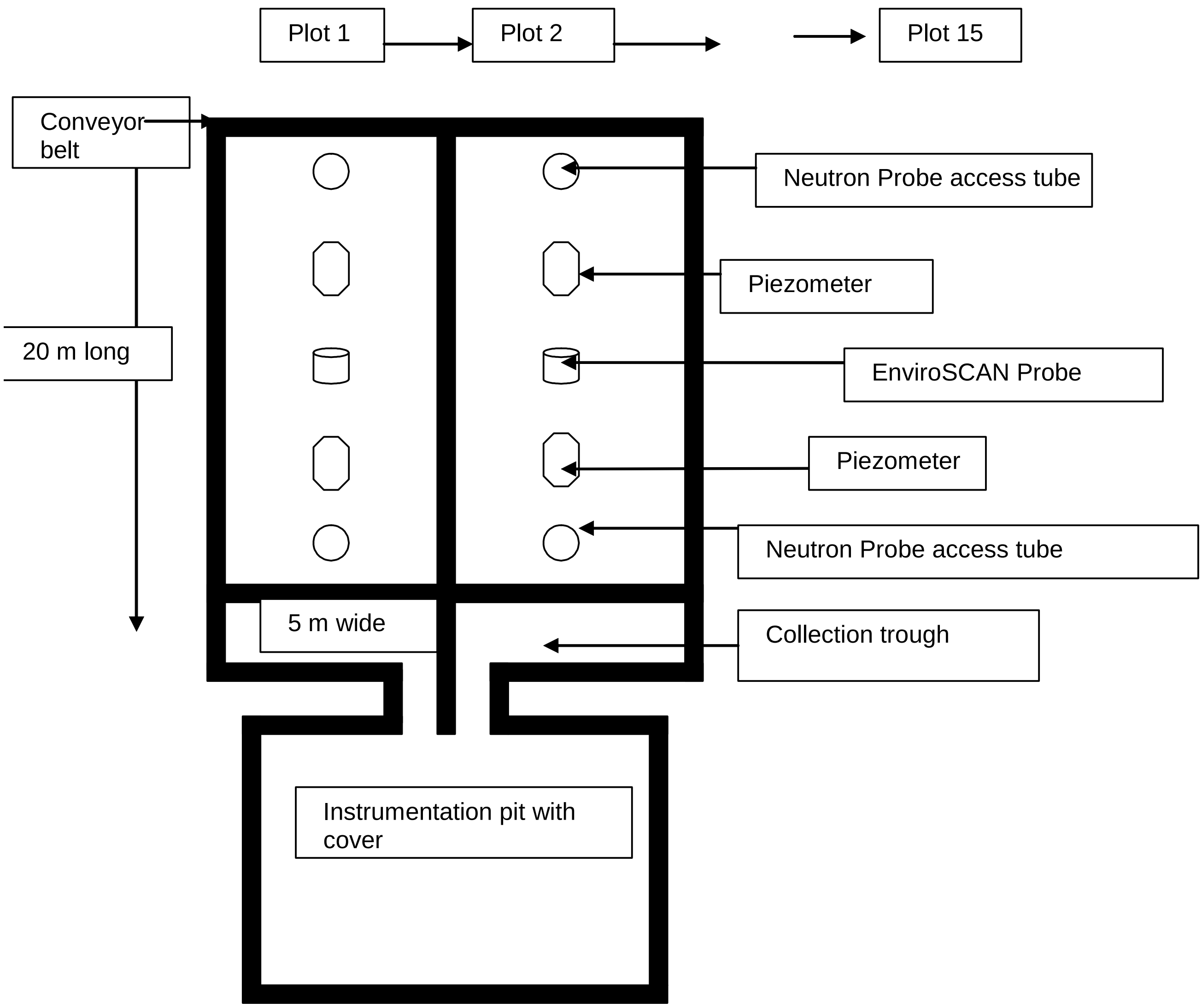

Figure 3: Schematic view of the instrumentation and layout of experimental plots

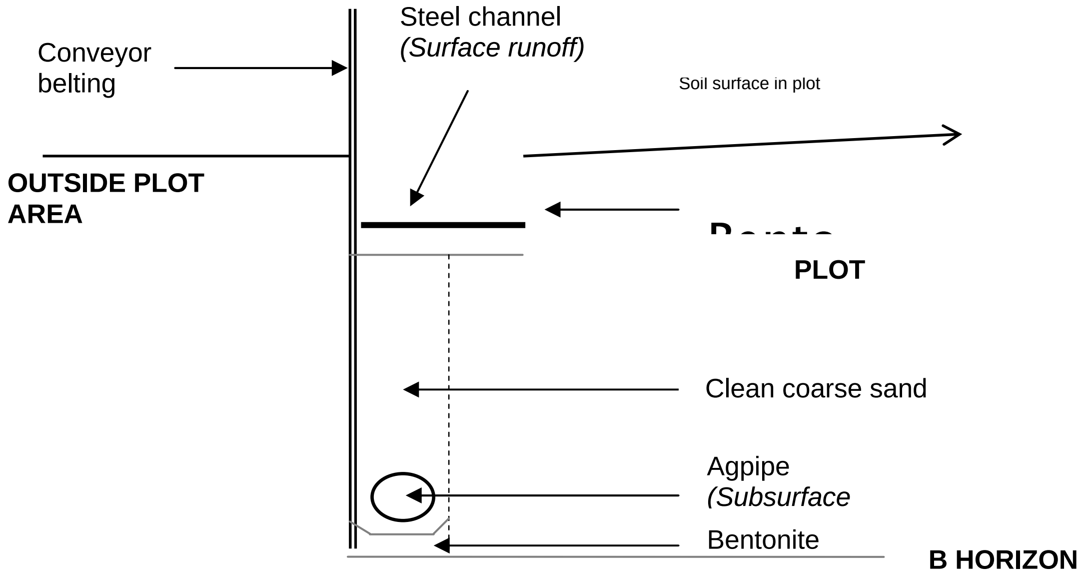

Figure 4: Cross section of runoff control design.

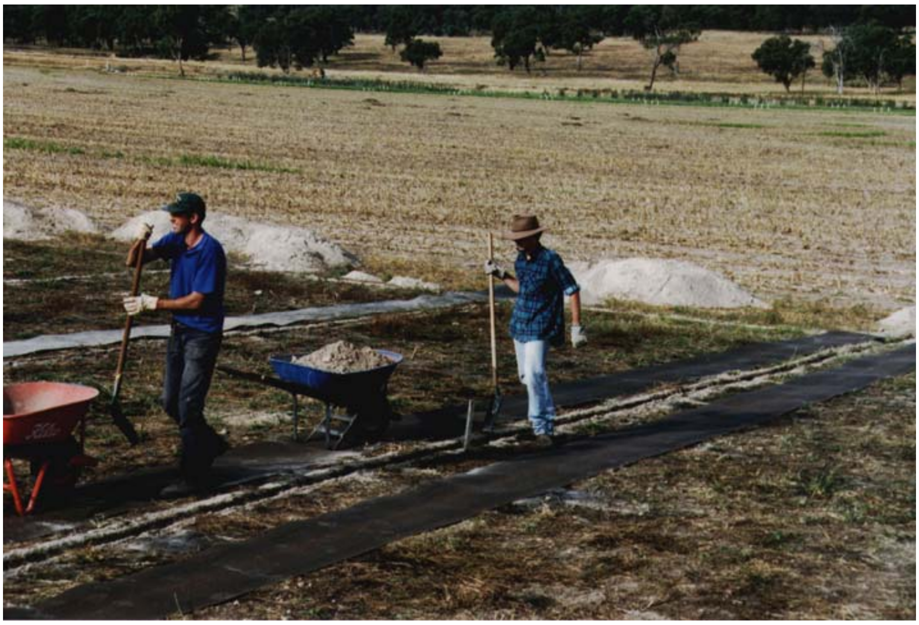

Figure 5: Installation of conveyor belting (July 1997) between plot boundaries.

Figure 6: Tipping bucket instrumentation in pit for surface and subsurface water flows.

Figure 7: Experimental site showing plots, and raised lids of the instrumentation pits where tipping buckets are located. White boxes located next to instrumentation pits contain data loggers and counters.

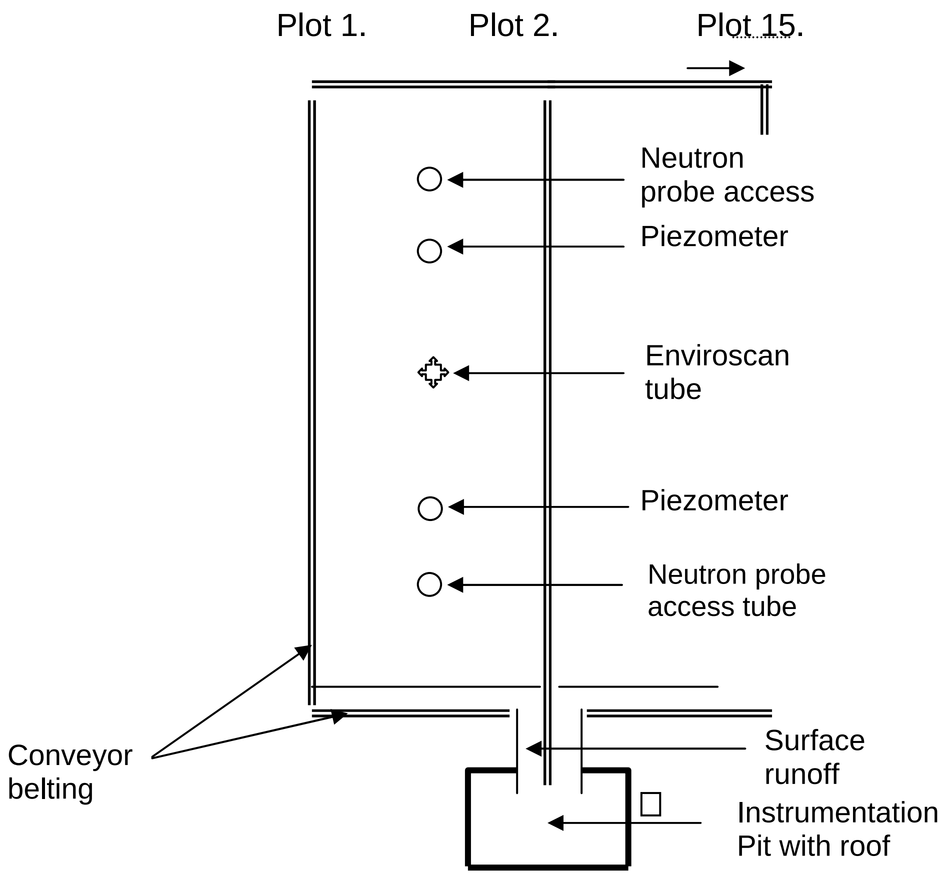

Figure 8: Overhead view of instrumentation in a plot.

Treatments

Treatments consisted of a control, with and without effluent; two manure application rates with and without effluent; and an inorganic fertiliser treatment which received single superphosphate, muriate of potash, urea, and irrigation water only (Table 3.2). Treatments were randomly allocated to plots and replicated twice, except the control plus effluent (0t/ha+E). One replicate was assigned to tipping buckets and the other to large drums that collected surface and subsurface water.

The manure application rates and inorganic fertiliser treatment were selected to compare crop response and efficiency of nutrient re-use within the soil-plant-water system. The manure application rate of 20 – 25 t/ha was that recommended by current industry practice for annual application in irrigated cropping areas. A large application of 60 t/ha of manure applied once at the start of the 3 year experiment was used to determine pollution potential and residual value compared to 3 applications annually also totalling 60 t/ha manure. Originally, the extra 20 t/ha manure treatment in year 1 (Table 3.2, plots 7 & 13) was not due to receive further manure additions in order to determine residual value compared to the other 20 t/ha treatments that received additional applications at this rate in years 2 and 3. However, nutrient concentrations measured in plant tissue for this treatment throughout year 1 and the observed yellowing of dry matter indicated low nutrient availability and residual value. Consequently, in year 2 this treatment was converted to manure plus urea

(20+25+20+(N)). In addition, the 60 t/ha manure treatment also received urea in year 2 to correct N deficiencies, improve crop yield and uptake of other nutrients.

The inorganic treatment received inorganic fertiliser every year. In year 1, the amount applied was designed to meet the requirements of a sorghum crop yielding 20 t DM/ha, assuming no losses such as immobilisation of nutrient and complete fertiliser efficiency. In year 2, the amount of N applied to this treatment was reduced due to appreciable amounts of NO_3 - N lost in subsurface water during year 1. Tissue analysis of plant material from the control treatment in year 1 indicated adequate K present to sustain yield so that the amount of K applied to the inorganic treatment was also reduced in year 2. In year 3 the amounts of N and P applied to the inorganic treatment were the same as those applied in year 2. However, in year 2 a measured decline in plant K over time, led to more K being applied to the inorganic treatment in year 3 compared to year 2.

Table 3.2 presents a summary of manure and inorganic fertiliser applications made over 3 years. Manure applications are presented as t dry manure.

Table 3.2: Manure, Effluent and Inorganic treatments in years 1, 2 and 3.

Plot number	**year 1**	**year 2** [ab]	**year 3** [b]
		Manure applied (t dry basis /ha)	
2,8	0 t/ha	0 t/ha	0 t/ha
6	0 t/ha	0 t/ha +E	0 t/ha
1,3	20 t/ha	25 t/ha	20 t/ha
4,12	20 t/ha	25 t/ha +E	20 t/ha
7,13	20 t/ha	25 t/ha + (120N)	20 t/ha + (120N)
5,11	60 t/ha	0 t/ha + (180N)	0 t/ha + (170N)
10,15	60 t/ha	0 t/ha + E + (180N)	0 t/ha + (170N)
9,14	Inorganic fertiliser 600N:60P:500K	Inorganic fertiliser 300N:60P:50K	Inorganic fertiliser 300N:60P:250K

a + E is where effluent was applied.
b Values within brackets indicate kg N/ha applied as urea per year.

A travelling irrigator was used to apply 20 mm of water from the on-farm storage dam at each irrigation over the 3 years. Irrigation was applied prior to the crops showing signs of moisture stress. In years 1 and 3, all treatments received dam water due to the unavailability of effluent for comparison. This allowed the plus effluent (+E) plots to be used as additional replicates. In year 2, in addition to dam water irrigations, 2.3 ML/ha of effluent was manually applied over summer with a pressurised flow through a fire hose. In the minus effluent plots (- E), extra dam water equivalent to the volume of effluent added to the +E plots was applied manually. Table 3.3 presents the average nutrient concentration of the manure and effluent at the time of application. Nutrient concentrations of manure are expressed for air dry manure.

Table 3.3: Average nutrient concentration from representative sub-samples of manure applied in year 1, 2 and 3, effluent (mg/L) in year 2, and dam water over years 1 and 2.

	Units	**N**	**P**	**S**	**K**	**Ca**	**Mg**	**Na**
Manure year 1	%	1.24	0.76	0.34	0.67	1.78	0.85	0.12
Manure year 2	%	1.65	0.81	0.38	0.86	1.85	0.80	0.22
Manure year 3	%	1.00	0.81	0.37	0.64	1.91	0.81	0.21
Effluent year 2	mg/L	1.08[a]	2.41	5.00	63.65	17.46	21.70	59.31
Dam water	mg/L	0.66[a]	0.11	0.93	3.58	7.76	5.51	32.36

a Represents the sum of NH_4-N and NO_3-N in mg/L.

Manure applied in years 1, 2 and 3 had similar nutrient concentrations. This is likely due to sampling from similar locations in the manure stockpile over 3 years and the fact that manure was derived from pens where cattle were fed similar rations. Effluent has a very low N concentration. This could be a result of volatilisation of NH_4 – N from the shallow storage facility during the summer months, and low stocking density of the feedyard area.

Crop management

The trial site was planted to successive crops of forage sorghum (*Sorghum bicolor* cv. Super-dan) and forage triticale (*Triticosecale spp.* cv. Madonna), grown in summer and winter, respectively, for 3 years. In each of the 3 years, sorghum was cut twice, whilst triticale was harvested only once.

Year 1 (Nov. 1997 – Oct. 1998)

Stockpiled manure was applied to the respective plots at rates of 0, 20, and 60 t DM/ha (Table 3.2). Single superphosphate (60 kg P/ha, 75 kg S/ha, 90 kg Ca/ha) was applied to the inorganic treatment at the same time as the manure was spread, along with urea (60 kg N/ha), and muriate of potash (50 kg K/ha). All plots were lightly rotary hoed to 50 mm depth immediately following manure and fertiliser applications to minimise loss of nitrogen by volatilisation, prior to sowing forage sorghum in November 1997 at 35.6 kg/ha. Split applications of muriate of potash and urea were made to the inorganic treatment throughout the growth of the sorghum crop. Applications, totalling 50% of allocated amounts of N (300 kg N/ha) and K (250 kg K/ha), were applied prior to the first sorghum harvest, with the last application made 8 days before harvest (Jan 1998). The remaining amount was applied in 2 applications to the ratoon (re-growth) sorghum crop, which was harvested in April, 1998. Following harvest of the sorghum crop and a light rotary hoeing, forage triticale was sown in April 1998 at a rate of 150 kg/ha, and harvested six months later. Inorganic fertiliser was not applied to any of the treatments throughout the triticale crop.

Year 2 (Oct 1998 - Oct 1999)

Stockpiled manure was reapplied at a rate of 25 t DM/ha only to those plots that received 20 t dry /ha of manure in year 1 (Table 3.2). An application rate of 20 t/ha was planned however the measured moisture content of the manure prior to spreading was overestimated. All plots were then immediately rotary hoed to 5 cm prior to planting forage sorghum at 35.6 kg/ha in October 1998. The inorganic treatment received single superphosphate (60 kg P/ha, 75 kg S/ha, 90 kg Ca/ha), urea (60 kg N/ha), and muriate of potash (50 kg K/ha) forty days after sowing. The plus effluent (+E) treatments received effluent at a rate of 2.3 ML/ha. Dam water was applied to the –E plots at the same time and rate as effluent. Leaf colour was used to identify nitrogen shortages, which resulted in 60kg N/ha being applied to the 20+25 t/ha + urea, 120 kg N/ha applied to the 60 t/ha manure treatments and the inorganic treatment prior to the first sorghum harvest. An additional 60 kg N/ha was applied to both the manure treatments and 120 kg N/ha to the inorganic treatment throughout the ratoon crop (see Table 3.2). Following the second sorghum harvest in March 1999, forage triticale was again planted in the same way as in year 1, and harvested in October 1999. As in year 1, no inorganic fertiliser was applied to any of the treatments during the triticale crop.

Year 3 (Oct 1999 – Nov 2000)

Stockpiled manure was again applied, at 20 t DM/ha to the plots that had received 20 and 25 t/ha of manure in the previous 2 years, respectively. Plots were then lightly rotary hoed and sorghum was sown at 35.6 kg/ha in November 2000. Nineteen days after sowing, the inorganic treatment received an application of single superphosphate (60 kg P/ha), urea (150 kg N/ha), and muriate of potash (125 kg K/ha); 60 kg N/ha as urea, was applied to 60 t/ha and 20+25+20 t/ha+urea treatments as in Year 2 (Table 3.2). After the first cut of sorghum, urea (150 kg N/ha) and muriate of potash (125 kg K/ha) were again applied to the inorganic treatment, and another 60 kg N/ha as urea was applied to the 60 t/ha and 20+25+20 t/ha+urea treatments. After the final sorghum harvest April 2000, triticale was sown in May 2000 at the rate of 150 kg/ha. No inorganic fertiliser was applied to triticale except in the 60 t/ha manure treatment which received 50 kg N/ha as urea. The rationale, progressive depletion of N by crops for this treatment resulted in triticale exhibiting symptoms of N deficiency.

Pest and weed management

Glyphosate at 1350 g active ingredient (a.i.)/ha (as Roundup CT Extra) was applied between the sorghum and triticale crop and Dicamba at 240 g a.i./ha (as Banvel 200) was applied to sorghum in year 2 to control a mixture of broadleaf weeds. Throughout the triticale crops, Omethoate at 580g/L (as Le-mat + wetter), fluroxypyr at 150 g a.i./ha (as Starane) and diclofop-methly at 375 g a.i./ha (as Hoegrass + crop oil) were used to control *Penthaleus major* (Blue oat mite), *Polygonum arenastrum* (wireweed), and *Lolium loliaceum* (ryegrass), respectively. In year 3, bromoxynil at 300 g a.i./ha (as Brominil) was applied to the triticale crop to control a mixture of broadleaf weeds.

Sample collection and analysis

It was anticipated that sampling would be conducted over 2 years. However, soil and sediment samples were collected for the 3 years due to some soil data not available for the 10 cm to the top of the B horizon sampling zone, at the end of year 2. The lack of these data prevented the computation of a nutrient balance at this time. In year 3, plant and water samples were collected and analysed as for years 1 and 2. Total nutrient exported by plant and water in year 3 and year 3 soil data have been used to calculate net loss and/or gain of nutrient for the entire three years.

Plants and manure

Crops were harvested to a height of 8 cm. The harvested material was weighed and a sub-sample taken to determine moisture content for calculating dry matter yield, and nutrient uptake. Sub samples of plant and manure (taken prior to land application) were dried at 80^oC for 48 hours, and ground to <2 mm. Sub samples taken from the ground material were stored in plastic air-tight jars pending analysis. An ARL3560 Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) was used to measure nutrient concentrations of plant and manure, after the samples had been digested using the sealed container digest procedure of Anderson and Henderson (1986). Plant and manure samples were also digested for total N by the Lindner and Harley (1942) method.

Water and Sediment

Water samples from both surface and subsurface lateral flows were collected from their respective sample containers below the tipping buckets and drums after rainfall events and frozen pending analysis. Recorded data from the tipping bucket instrumentation were matched with the water sample taken at the conclusion of the rainfall event in order to determine the mass of nutrient lost in both the surface and subsurface water for each event.

Unfiltered water samples were tested for pH and EC. Samples were filtered through Whatman No.42 ashless filter paper prior to elemental analysis. P, K, S, and Na were determined by ICP-AES, and, NO_3 – N and NH_4 – N by a Technicon auto analyserSediment samples, collected from runoff trays and runoff manifolds, were taken near the end of each crop rotation, dried at 40^{o}C, and sieved to remove litter and insects. Sediment samples were weighed, and digested using the procedure of Till *et al*. (1984) without the addition of potassium dichromate, to determine macro and micronutrients by the ICP-AES. C and N were determined by an Automatic Nitrogen and Carbon Analyser by Mass Spectrometry (ANCA-MS).

Soils

Soil samples were taken from each plot prior to treatment implementation. In years 1, 2, and 3 samples were collected using a 4 cm diameter core at the end of the sorghum and triticale crops, totalling 7 times over the 3 years. A string was used to map a diagonal transect (bottom left to top right) in each plot. At each of the sampling times cores were taken every two metres along the diagonal, with the first core taken at a different starting point along the transect so as not to corrupt sampling points over time. Ten cores per plot were bulked according to depth and horizon: 0 - 10 cm (0 - 10 cm), 10 cm to the top of the B horizon including all the A_2 horizon (10 – B horizon), and the top 10 cm of the B horizon (B horizon + 10 cm). Soils were dried at 40^{o}C, ground to <2 mm and then to <500 µm. Sub samples of each soil were taken and stored in plastic specimen jars at room temperature prior to analysis.

Nutrient analyses

Soil analyses included total NO_3^- - N and NH_4^+ - N (Adamsen *et al*., 1985), KCl - 40 extractable S (Blair *et al*., 1991), bicarbonate extractable P (Colwell 1965). The latter was determined colorimetrically (Murphy & Riley 1962) using a Technicon auto analyser. Cation and anion exchange capacities (Gilman 1979) were measured at the start and at the end of year 2. Total P, S, K and Na were determined on the initial soil sample, and at the end of year 3 using the procedure of Till *et al*. (1984), without the addition of potassium dichromate. pH and EC were measured in a 1:5 soil:water suspension which had been tumbled for an hour.

P sorption was determined from a 3 point isotherm using Rayment and Higginson's (1992) method on initial samples and on samples taken at the end of year 2, for two depths (0 - 10 cm and 10 cm – B horizon). Equilibrating solutions in a background of 0.01 M $CaCl_2$ were added to 5.0 g soil (<2 mm) to provide concentrations of P in solution of 0, 15 and 25 mg P/kg soil. The soils were equilibrated on an end-over-end shaker for 17 hrs at 25^{o}C. Solutions were then filtered through Whatman 42 filter paper, analysed on a Technicon auto analyser (Warrell & Moody 1984) using the colorimetric ascorbic acid/ammonium molybdate procedure of Murphy and Riley (1962). P sorbed was calculated by the initial P added minus the P remaining after equilibration in mg P/kg soil. P sorption isotherms were determined and used to calculate P sorbed at a solution concentration of 0.2 mg P/L, the value commonly assumed to be sufficient for plant growth (Beckwith 1965).

Soil samples ground to <500 µm were analysed for total carbon and nitrogen using an Automatic Nitrogen and Carbon Analyser by Mass Spectrometry (ANCA-MS) on all samples taken over 3 years.

3.2.3 Soil biology

Soil Microbial Biomass (SMB)

Baseline data for SMB were obtained in November 1997 prior to the imposition of treatments. Sampling thereafter, occurred immediately after each crop harvest (6 samplings over 2.5 years to November 2000). SMB was determined on fresh soil samples (0-10 cm depth) taken on the same day, but independent of, samples taken for nutrient analyses. Each plot was divided into three strata and one soil sample was taken at random within the stratum slightly to one side of the diagonal transect through the plot that was used for nutrient sampling. Soil was bulked into a single sample for each plot and sieved (2 mm mesh) to remove roots, stones and macrofauna. Soil moisture was adjusted to approximately 80 % field capacity and incubated at 25^0C for one week. SMB was measured using K_2SO_4 -extractable ninhydrin nitrogen released on fumigation (fumigation-extraction method, Joergensen and Brookes 1990).

Free-living Soil Nematodes

Free-living soil nematodes were sampled at Tullimba in April 1998 (0-10 cm) using the same sampling methods as for soil microbes and on the same day as microbial soil sampling. Extraction of nematodes from soil used the Whitehead and Hemming (1969) tray method and details of counting methods are available in Hunt (1998). Nematodes were not separated into feeding groups or species. Hence, data are for total abundance of nematodes.

Statistical Analyses

Treatment effects for nematode abundance were examined using AOV, with differences between treatments being identified using orthogonal contrasts. Repeated measures analysis of the SMB data, for the six samplings was used to examine treatment and time effects in all five manure or fertiliser treatments, with orthogonal contrasts identifying where differences occurred. The first two sampling periods were examined separately to the following four periods as urea additions to some of the plots after October 1998, added to the complexity of the design. Urea was added to two of the Manure 1 plots, thereby increasing the number of treatments. Also the urea additions to the 60t manure/ha confounded the treatment effects in these four plots.

3.2.4 Soil physical parameters

Measurement of unsaturated hydraulic conductivity

Unsaturated hydraulic conductivity was measured in-situ in April and November 1998, 1999 and 2000 after harvesting of the summer (sorghum) and winter (triticale) crop. The unsaturated hydraulic conductivity (K), hereafter was referred to as infiltration, was determined using a disc permeameter designed by Perroux and White (1988). Steady state infiltration was determined at four tensions (40,30,20,10 mm) and K was calculated using the method of Ankeny et al., (1991). The flow of water from the disc permeameter was controlled at a specific tension by different sized capillaries. Craze and Hamilton (1994) provided a useful generalised equation to calculate the size of the pore that will overcome a given tension:

Pore diameter (mm) = 3 / Soil Water tension

This means that capillaries of that diameter or smaller will be able to drain water from the infiltrometer. According to the theory pores of ≥ 0.75, 1.0, 1.5, and 3.0 mm will drain at 40, 30, 20, and 10 mm tension, respectively. By comparing the infiltration rates at increasing tensions, the relative contribution to water flow by various pore size classes can be evaluated. Faster infiltration means that pores are well connected within a pore size class.

Efforts were made to select a representative spot for measurement within the plot. Infiltration measurements were made at 4 locations within an area of approximately 4 m^2 in each plot. The wire length between the multiplexer and the infiltrometer restricted the area of measurement. Sites were prepared by trimming all vegetation to ground level where it was necessary, without disturbing the soil surface. Large stones were also removed from the surface. A 5 mm high brass ring was placed on the soil surface and filled with fine beach sand to act as a contact material. The sand was levelled within the ring. The disc permeameter was placed on the sand pad, set at 40 mm tension and allowed to come to steady state, which took about 10 to 15 minutes in the soil under study. The tension was then changed to 30 mm until steady state was reached. The same procedure was followed for the 20 and 10 mm tensions. An automated recording system using pressure transducers to measure the rate of flow, which was logged to a computer, was used. K was calculated at each tension from this output. The data was taken to Microsoft Excel, where output data was plotted against time. From the graph the last few minutes of steady state for each tension were selected. Using this data, the slope for each tension was calculated and these slopes represented the steady state flow at each tension in mm/min. This data was then used to calculate K for each tension using the method of Ankeny et al., (1991).

Aggregate stability

Following the measurement of infiltration all the sand was removed from the pad area. Plastic cores having diameter of 8.5 cm and 10 cm deep were inserted into each infiltrometer location and were left in the soil for 24 hours to allow drainage to minimise soil structural damage. Four cores per plot were collected and these divided into 0-5 cm and 5-10 cm lengths. Samples were bulked and large clods were broken gently by hand and air-dried. The air-dried samples were broken down to pass through a 4 mm sieve by gently crushing the soil on a board with 4 mm small ridges on the side to maintain a gap between the board and the roller. The samples were sieved to < 4 mm and large rock fragments and plant material, especially roots, were removed.

After sieving, the soil samples were then split, using a soil sample splitter and five sub-samples of approximately 30 g were weighed out into separate airtight plastic containers. These samples were then used for wet aggregate stability, dry aggregate stability, total carbon, liable carbon and particle size analysis.

Immersion wetting

Wet sieving was undertaken by placing a 30 g soil sample on the top of the a stacks of five sieves of 2000 μm, 1000 μm, 500 μm, 250 μm and 125 μm size with a diameter of 100 mm. A further 125 μm sieve was used as a lid. The sample was placed on the top sieve (2000 μm) and then the stack was gently lowered into a cylinder of water. It was immersed in the water for 30 seconds before being sieved for ten minutes (amplitude of 17 mm at 29 cycles/min). The method imparts an arbitrary degree of mechanical disruption. At the end of 10 minutes, the sieves were removed from the water, drained and each sieve placed on a plastic container and oven dried at 40^0C for 24 hours and weighed. The weight of the fraction that passed through the smallest sieve (i.e. < 125 μm fraction) was determined by subtracting the weight of soil retained on all the sieves from the original sample. The wet sieving technique was used as a measure of the ability of aggregates to remain stable after wetting. Only one sample was wet sieved from each plot because according to Whitebread (1996) there was no need of duplication with this technique.

Dry aggregate size distribution

The soil aggregate size distribution was measured using a dry sieving technique (Blair, 2000). A 30 g soil sample was placed on the 2000 μm mesh sieve of the set of sieves used for wet sieving. The soil was sieved through the set of sieves for 40 seconds with minimum energy input, to get as close as possible to the dry aggregate size distribution of the soil prior to wet sieving. The top sieve was removed and the same procedure was repeated for each sieve size. The amount of soil remaining on each sieve size was weighed.

Mean weight diameter (MWD), percentage of aggregates >250 μm and <125 μm were calculated for both wet and dry sieving after Kemper and Rosenau (1986). MWD is a weighted average of soil mass in each aggregate size fraction and is an index of aggregate size distribution in each treatment.

Determination of total carbon

The total carbon in each sample was determined using an Automatic Nitrogen and carbon Analyser by Mass Spectrometry (ANCA-MS). This instrument is usually used for the determination of ^{15}N and ^{13}C in plant and soil samples but can also determined % N and % C on weighed samples. The basic principle of operation of the ANCA-MS has been described in detail Barrie and Prosser (1996). Essentially, the sample is subjected to flash combustion in a Carlo-Erba (NA 1500) Dumas-type combustion unit during which all carbon is converted to CO_2 which is then measured by thermal conductivity detector in a mass spectrometer (Europa Scientific Stable Isotope Analyser).

Each 500 μm sieved sample, containing approximately 350 μg carbon, was weighed into tin capsules (8 * 5 mm). These tins were rolled to give them a ball shape. These balls were place in a sample chamber within the instrument for analysis.

Labile carbon by $KMnO_4$ oxidation

The original method for labile carbon measurement was proposed by Loginow et al. (1987) and relied on using three different concentrations of the oxidising agent to oxidise increasing proportions of the soil C within a fixed time interval. After investigation by Lefroy et al. (1993), it was found that the use of a single $KMnO_4$ concentration (333 mM) can provide sufficient characterisation of the labile C to define the state of soil systems. The total carbon (C_T) measured by combustion and the amount of oxidising agent consumed by $KMnO_4$ are used to calculate two fractions of organic carbon; one which is oxidised by $KMnO_4$ (labile carbon, C_L) and second which is not oxidised by the $KMnO_4$ (non labile carbon, C_{NL})

Samples of soil containing 15 mg C were weighed into 30 mL plastic screw top centrifuge tubes and 25 mL of 333 mM $KMnO_4$ added to each vial. Blank samples, containing no soil and samples of standard soil were analysed in each run. The centrifuge tubes were tightly sealed and tumbled for one hour at 12 rpm, on a tumbler with a radius of 15 cm. The tubes were centrifuged for 5 minutes at 2000 rpm (RCF = 815 g) and the supernatant liquid diluted to 1:250 with deionised water. The samples, as well as the standards, were well mixed on a vortex mixer. The absorbance of the diluted samples and standards were read on a split beam spectrophotometer at 565 nm. The range of standards, 300 to 333 mM, was chosen to adequately cover the sample range. All steps in the extraction procedure were carried out at 25 ^{0}C.

The change in the concentration of $KMnO_4$ is used to estimate the amount of C oxidised assuming 1 mM MnO_4^- is consumed (MnVII→MnII) in the oxidation of 0.75 mM, or 9 mg of C. The results were expressed as mg C/g soil.

Soil moisture

Continuous measurements of soil moisture were made with an EnviroSCAN multisensor capacitance probe installed in each plot. The capacitance sensors were placed at 10, 30, 50 and 80 cm depths. Soil water readings from each of the 64 sensors (15 plots x 4 sensors) were recorded at 10 min intervals in summer and at 30 min intervals during winter, when changes in soil water were slower.

Soil moisture retention curve

Soil samples were collected at the end of the second and third years to examine the differences in moisture retention in the various treatments at different tensions. The tensions used were -10, -30, -100, -300 and -1500 KPa. Available water content was calculated by the difference between the moisture at 10 and 1500 KPa (Rivers and Shipp, 1972).

The pressure desorption procedure (U.S. Salinity Laboratory Staff, 1954) was used. A metal core (4 cm high and 7.5 cm diameter) was driven into the soil and then carefully removed. Each core was cut from the base with a sharp knife to level it and the core stored in a metal container fitted with a lid. From each plot four full cores (0-4 cm) and four half cores (0-2 cm) were collected and transported to the laboratory and stored in a cold room. Three cores from each category were used for measurement of moisture retention and the fourth one was kept as a spare. Full soil cores were used for -10 and -30 KPa tensions and half soil cores were used for -100 and -300 KPa. Three porous ceramic pressure plates were used which each plate accommodating 8 samples. Each replication from each plot went onto a different plate to eliminate the effect of plate.

The pressure plates were wetted overnight to fully saturated them with water. The next day a vacuum extractor was used to remove all the air from the plates and the surplus water was sucked from the surface of the plate. A thick suspension of Alkolite was spread on the plate to ensure good contact between the soil and the plate and soil cores were carefully placed onto the plates. Water was added slowly to gently saturate the soil. This took about 5 to 6 hours. When the surface of the soil became shiny it indicated that they were fully saturated. The plates were then placed in the pressure chamber. For -10 KPa the pressure was set at 100 cm high water column. All three outlet tubes from the plates were placed in a plastic container. The containers were checked and water emptied daily. No water in the container meant that soil was at equilibrium, and this took about 6 to 8 days

At this time each core was weighed to determine the moisture content. As the same samples were used for the -30 KPa measurement they were transferred to another set of ceramic plates, which were prepared as described above. For -30 KPa a mercury column was used to measure the imposed pressure. A similar, procedure was adopted for -100 and -300 KPa measurements.

Disturbed soil sample was used for the -1500KPa measurement. Soil sample was sieved through a < 2mm sieve and metal rings were used to handle the sample on the plate. The samples were wetted overnight and at equilibrium the samples were removed from the plate and oven dried for 24 hours at 105°C. Volumetric water contents were calculated using the bulk density after removing the stones. The soil weight was also corrected for stones.

Soil strength

Resistance to penetration was measured after the harvest of triticale in October 1999 and after the harvest of triticale in November 2000. A Rimik CP 20 cone penetrometer was used (Basal diameter of 12 mm, 60° cone) with an ultrasonic depth gauge. Penetration was measured in 5 mm increments to 30 cm depth. In the first measurement (October.1999) twenty measurements were taken while in the second measurement (November. 2000) only ten measurements were taken from each plot. Soil moisture was measured by gravimetric method. Three soil samples were collected from each plot at 0-10, 10-20 and 20-30 cm depth.

Soil bulk density

Soil bulk density was measured according to the procedure (4A3a) given in the Soil Survey Laboratory Methods Manual (1996). A metal core with a diameter 10 cm and 8 cm high was used to collect the soil samples. The first measurement was made at the end of year 2. Four cores were collected from each plot. After removing the cores from the ground any protruding soil was trimmed with sharp knife to the level of the ends of core. Cores were covered with a metal core cover and tightly fastened with electrical tape so that shattering of the soil could be avoided.

The cores were transported to laboratory and weighed. These cores after removing the electrical tape were put into oven at 105 °C until the weight was constant and then placed in a desiccator to cool. The cores were weighed and emptied in plastic bags and stored for stone separation. The volume of each core was calculated by measuring the diameter and height of each core. The presence of stones in soil poses a serious problem in soil moisture and bulk density measurement (Relnhart, 1961). For stones separation soil was wet sieved through a 2 mm sieve. The stones retained on the sieve were oven dried and their weight recorded. A graduated cylinder was used to measure the volume of stones by the difference in the level of water in cylinder. The weight of stones was subtracted from the sample weight to obtain the soil weight. Similarly stone volume was subtracted from core volume to obtain soil volume. These volumes and weights without stones were used to calculate bulk density. At the end of year 3, 8 cores were collected to minimise the sampling variability. The bulk density was calculated with stones and this was compared with the + stones data in the year 2 samples (Figure 31).
Statistical analysis

The sums of squares of treatments in year 2 were partitioned using orthogonal contrasts. In year 2, effluent did not have a significant effect thus replicates for the same manure treatments were pooled. Pairwise multiple comparisons were made on treatment means for dry matter yield, tissue nutrient concentration and nutrient removal data using Tukey's test at 95% confidence limits using the Splus 4.5 statistical package (Mathsoft). CEC, Total C and P and sediment data were subject to similar analysis. Individual analysis per crop per year were carried out and not compared between years due to changes in climatic conditions and length of growing season confounding treatment effects. Since treatments were different in each year, between year differences were not compared. NO_3 – N, bicarbonate P, and KCl –

S, were modelled using a piecewise linear model with transition points and branches. Each of the branches has the equation

y = B0 + B1(t- delta) + sqrt((t-delta)^2 + gamma)

where, t is time, delta is the time at which intervention (end of year 1) occurred and gamma is a parameter that gives a smooth transition as the response changes shape at delta. Each branch is constrained to join its previous branch, ie. B0 is constrained so to be the value predicted by the previous branch equation for time where branches change over. Confidence intervals (CI) were fitted to the branches to determine differences between; effluent and no effluent in year 2, and the manure plus urea treatment (20+25+20+N t/ha) compared to manure only in years 2 and 3. Soil nutrient concentrations measured at the end of each crop were plotted against depth. Confidence intervals derived from the piecewise linear model per sampling period for each treatment at each depth are indicated.

3.3 Work Area 3 – Field Trials at Beef City Feedlot

3.3.1 Site Location

The cooperating commercial feedlot is located near Oakey on the Darling Downs, in south east Queensland at latitude 27°32' S and longitude 151°36' E. The feedlot site has an elevation of 410 metres ASL.

3.3.2 Site Description

The feedlot has been operation since 1974. At present it has a capacity of 27 000 head with an average stocking density of 12 m^2 per Standard Cattle Unit (SCU). Most cattle within the feedlot are kept on feed for a period of up to 150 days. The pens are arranged with concrete feed troughs on the high side, with a slope of about 2-3% away from the troughs. The drain slopes are typically 1%. The established controlled drainage area of the feedlot consists primarily of pens as shown in Table 3.4.

Table 3.4: Land uses within the Controlled Drainage Area.

Land Use	Area (ha)
Pen Area	38.19
Work Alleys/Drains	3.13
Roads	6.90
Grassed and cropped area inside Controlled Drainage Area (CDA)	7.60
Area of Settling Pond	2.43
Area of Holding Ponds	5.89
Total	64.14

3.3.3 Duration of Project

The feedlot established the trial site in 1988. It was established to examine the effects of varying manure application rates on crop production areas. This project superimposed controlled areas (plots) within this area in April 1997. The small plots were installed with the aim of examining the effects of manure application on crop growth, soil properties, rainfall runoff, and nutrient movement in the soil-plant system. These plots were used for experimentation purposes from November 1997 to December 2000.

3.3.4 Climate

This area is in the north of a transitional zone separating the summer dominant rainfall belt of northern Australia and the winter dominant rainfall belt of southern Australia. The distance from the sea (about 200 km) and its lack of protection from southerly air streams gives its climate a "continental" type influence. The climate can be described as subtropical.

The Bureau of Meteorology daily rainfall station nearest to the site is on a property about 2 km to the north of the feedlot. This station is Mt Irving (Station No 041072). The mean annual rainfall for this site is 621 mm while the mean rainfall for the nearby townships of Oakey and Pittsworth are 678 mm and 696 mm respectively

3.3.5 Farm Crop Management Practices

The farm associated with the feedlot has a total area of 730 ha. Within this, two areas totalling 363 ha are utilised for irrigation crop production with clean water, wastewater and manure applications occurring. The remainder of the property is managed as a dryland farm.

The soils at the site are well suited for irrigated crop production and, as such, continuous cropping is practiced. Crops are produced for silage, with corn, forage sorghum, triticale and barley most commonly grown. The cropping program is focused on maximum utilisation of irrigation waters (especially wastewater) and captured rainfall. Crop production is aimed to provide maximum fodder for the feedlot. Typically, dry matter production is consistently high, which means that nutrient and salt removal from the system is significant. Conservation farming practices (such as strip cropping and stubble mulching) are used by management to minimise erosion and maximise soil water storage.

3.3.6 Trial Site

In 1988 the feedlot initiated a trial site to study the effects of varying manure application rates. The trial consisted of 7 strips each about 400 metres long and 12.25 metres wide (one strip was only 6.1 metres in width). The layout of the trial area and plots, and the varying manure application treatments are shown in Figure 9.

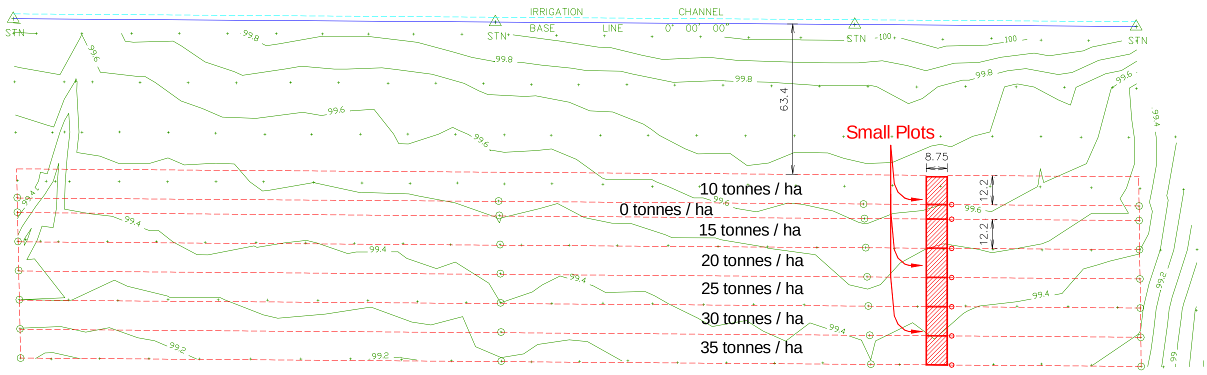

Figure 9: Layout of Plots.

From 1988 to 1996 the manure application rates were determined using gross amounts of wet manure applied by truck weight. In the years 1997 to 2000 additional measurements were taken using replicated catch trays located in each strip to determine dry matter application rates. The treatments are described in Table 3.5.

Table 3.5: Manure (t DM/ha) and Wastewater Treatments in the Trial Area.

Year	Strip1	Strip 2	Strip 3	Strip 4	Strip 5	Strip6	Strip 7	Winter Crop	Summer Crop
1988	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	NH_3 + E	-	Maize
1989	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	NH_3 + E	-	Maize
1990	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	NH_3 + E	-	Maize
1991	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	10 M +E	-	Maize
1992	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	10 M +E	-	Maize
1993	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	35 M +E	-	Maize
1994	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	35 M +E	-	Maize
1995	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	35 M +E	-	Maize
1996	-	-	-	-	-	-	-	Triticale	Fallow
1997	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	35 M +E	Triticale	Fallow
1998	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	35 M +E	Fallow	Maize
1999	10 M + E	0 M + E	15 M + E	20 M + E	25 M + E	30 M +E	35 M +E	Fallow	Maize
Total M	120	0	180	240	300	360	265	-	-

Note: No true control existed in the trial area with all strips receiving some manure and / or wastewater throughout the trial. However, given that applications of 10 t/ha of manure as well as wastewater application is the common waste application rate it was possible to make comparisons of relative changes in the other treatments. Strip 7 had a variable history and as such comparisons between its state and the other treatments were difficult. The data indicate that Strip 6 had received the most manure.

3.3.7 Small Plots Design

In 1997, small plots were installed in the trial area. These plots allowed six areas of 100 m^2 and one of 50 m^2 to be separated from the remaining strip area for the collection of surface runoff quantity and intense sampling of soil and crop. Figure 9 shows the location of the small plots within the trial area. The plots were located in an area of relatively uniform slope (0.2-0.4%), which was required to assist in runoff collection and also storm-water management around the site.

As shown in Figure 10, the construction of the small plots included the installation of metal guttering to collect surface runoff and conveyor belt to prevent sub-surface flow. Tanks were installed at the end of each plot within which the tipping bucket instrumentation was housed. Bilge pumps and sample collection bottles were also installed in these tanks.

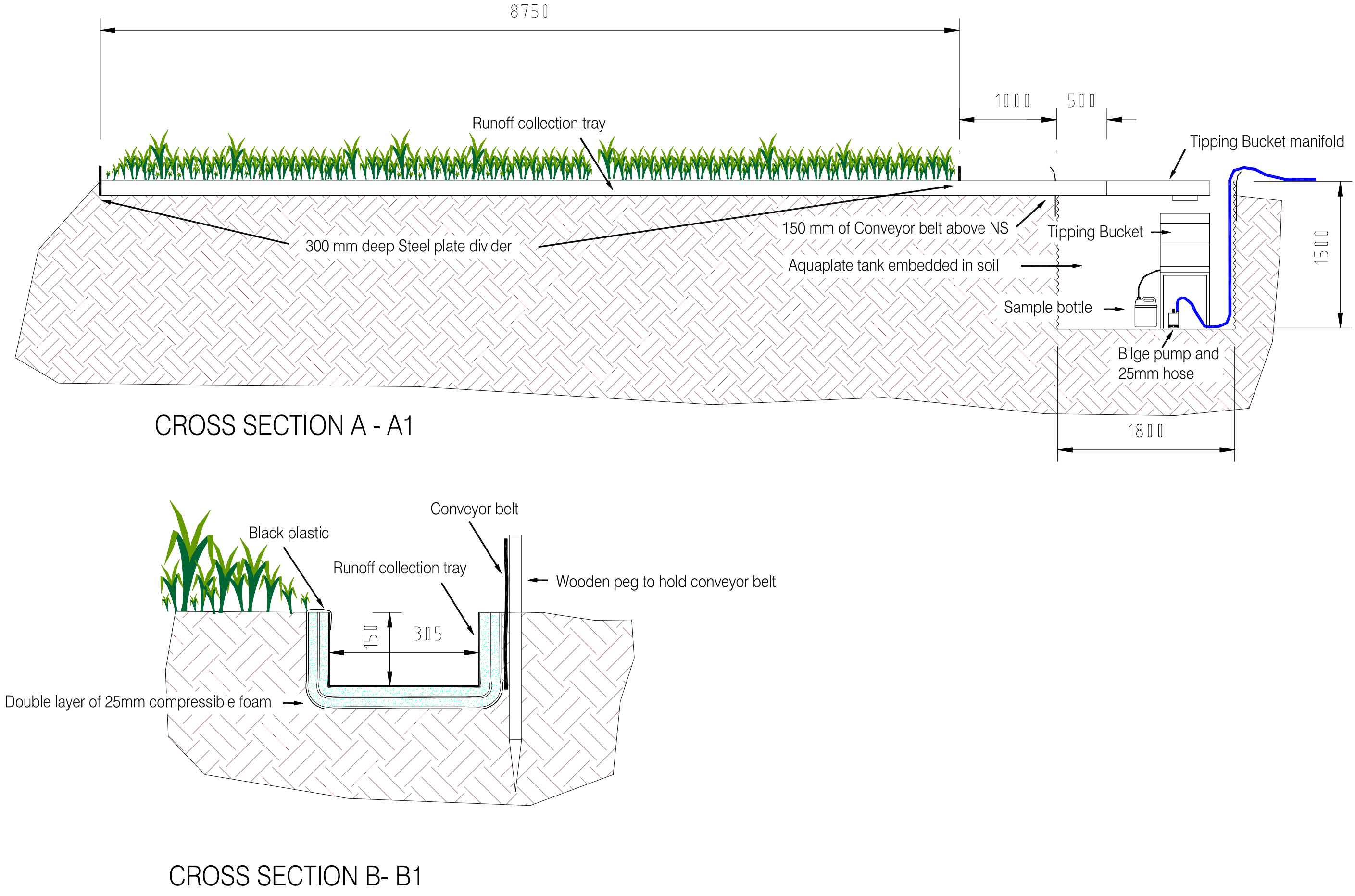

Figure 10: Layout of small plots

3.3.8 Crop Yield and Nutrient Concentrations

Crop samples were collected from the small plots from 1997 to 2000. Each sampling consisted of the collection of three randomly located 1 m^2 quadrant samples from within the plots. Samples were not taken within 1 metre of the plot edge as these areas exhibited some soil disturbance and 'edge effects'.

Plant populations varied across the plots as a result of planting method. In some areas of plots the crop had to be hand sown because mechanical planters could not access the area. For this reason, row, plant, and tiller numbers were measured for each collected quadrant. The collection of these data allowed yields across the plots to be normalised according to comparative plant population.

Plant samples were analysed for total mineral concentration.

3.3.9 Soil Properties

The soils at the site are typically a deep black-earth (ug5a - Northcote, 1975; Vertisol – Isbell, 1996). These heavy clays exhibit strong cracking during dry conditions and high levels of self mulching. Table 3.6 shows a typical analysis for the soil profile in the vicinity of the small plots. The soil at the plots is typically alkaline and very fertile with elevated levels of N and P.

Table 3.6: Results of the soil analyses conducted in the vicinity of the small plots.

Analysis	Unit	Soil depth (cm)			Method
		0-10	10-40	40-70	
pH		8.3	8.5	8.6	1:5 Soil/Water
Nitrogen (Nitrate)	N mg/kg	35	40	73	Aqueous extract
Phosphorus	P mg/kg	>150	88	17	Bicarbonate extract
Phosphorus	P mg/kg	66	10	2	Bray
Potassium	K mg/kg	2000	570	410	Ammonium acetate
Sulfur	S mg/kg	31.7	43.8	68.8	KCl-40
Calcium	Ca mg/kg	6900	6900	6300	Ammonium acetate
Magnesium	Mg mg/kg	3100	3700	4200	Ammonium acetate
Copper	Cu mg/kg	1.2	1.2	1.4	DPTA extract
Zinc	Zn mg/kg	6.1	0.9	0.5	DPTA extract
Manganese	Mn mg/kg	3	2	2	DPTA extract
Iron	Fe mg/kg	17	14	14	DPTA extract
Boron	B mg/kg	2.4	2.0	3.6	$CaCl_2$ extract
Organic Matter	%	2.2	1.2	2.9	Walkley-Black
Conductivity	dS/m	0.40	0.49	0.62	1:5 Soil/Water
Sodium	Na mg/kg	750	860	1100	Ammonium acetate
Sodium	Na mg/kg	900	1097	1352	Mehlich III
Chloride	Cl mg/kg	182	354	278	Aqueous extract
Cation Exchange	meq/100g	68.7	70.5	72.3	
Exchange Sodium	meq/100g	3.3	3.7	4.8	
Exchange Potassium	meq/100g	5.1	1.5	1.1	
Exchange Calcium	meq/100g	34.5	34.5	31.5	
Exchange Magnesium	meq/100g	25.8	30.8	35.0	
Ca/Mg ratio		1.3	1.1	0.9	
Exchange Sodium	meq/100g	3.9	4.8	5.9	Mehlich III

Soil samples were collected from the plot areas each year at the time of crop harvest. Three replicate profile cores were collected from the same locations as the random crop samples were collected within the plots. The cores were split into the samples representing the depths 0-10, 10-40, 40-70, 70-100 cm or 1-10, 10-30, 30-50, 50-100, 100-150 cm. Each of the samples was sent to a laboratory for complete soil analysis (as shown in Table 3.6).

Soil bulk density data were collected directly through the use of bulk density rings and indirectly through cone penetrometer measurements. Surface soil samples (0-100cm) were also collected for assessment of microbiological characteristics.

3.3.10 Manure and Wastewater Application

Manure was applied each year between April and June. Manure was supplied by the farm from the feedlot stockpile. Manure from the stockpile had been stored in a compacted anaerobic environment for some 1-2 years and was applied using trucks. At the start of the trial (1988) application rates were crudely determined by weighing truck loads, measuring truck speed and application area. During the trial manure application rates and manure characteristics were determined by positioning 3×0.1 m^2 trays in each strip. Manure gathered from the trays was weighed, dried and analysed.

Wastewater was applied uniformly across all strips via the lateral move irrigator. Wastewater was applied, generally, as a mix of bore water and feedlot wastewater in a ratio of about 3:1. The amount applied to the crops was determined by the farm manager at the site. At the time the lateral move irrigator crossed the small plots three replicate samples were collected and then frozen until they were presented to the laboratory.

Rainfall and Runoff Sampling

The design of the small plots included tipping bucket pluviometers that allowed runoff quantities to be measured. The bucket on these devices discharged over a slotted siphon that enabled the collection of water samples. Relatively few samples were collected.

During the initial stages of the project the quantity of sediment contained in the runoff was also determined through the collection of samples from the guttering and manifold above the tipping bucket. The collection of sediment samples was later abandoned as it was found that farm practices (such as ploughing) caused significant amounts of manure and sediment to enter the guttering, which grossly affected the results.

3.3.11 Soil Biology

Soil sampling

Soil sampling (0-10 cm) was carried out once each year in autumn in March 1999 and May 2000. The manure treatments had been applied each year since 1988. For both SMB samplings, the manure had been applied in the previous April. Hence, for the sampling in March 1999, manure had been spread 11 months before while for the May 2000 sampling, manure had been applied 5 weeks prior to sampling. The plots were also irrigated with wastewater, in addition to the manure.

Soil was sampled from sub-plots (8.25 m x 12 m for the manured treatments; 8.25 m x 6 m for the control plot) contained within the main plots (450 m x 12 m). A bulked soil sample was taken for each treatment and sieved (2 mm mesh) to remove roots, stones and macrofauna.

Soil Microbial Biomass (SMB)

In March 1999, a maize crop was growing, while in the May 2000 sampling, the maize crop had been harvested. Soil moisture was adjusted to approximately 80 % field capacity and incubated at 25^0C for one week. SMB was measured using K_2SO_4 -extractable ninhydrin nitrogen released on fumigation (fumigation-extraction method, Joergensen and Brookes 1990).

Soil Organic Carbon (SOC)

Based on a study of 115 non-calcareous UK soils, ranging in SOC from 1 to 40%, Ball (1964) recommended a temperature/time regime of 400^oC/24 hr when loss-on-ignition (LOI 400) in a muffle furnace is used as an indicator of SOC. We have calibrated LOI 400 against dry-combustion (Baird and Tatlock Instrument) and wet-oxidation (Vickery *et al*. 1995) methods using 50 New England (NSW) soils. The resulting equation used for this study was:

$$\mathbf{TOC = 0.514 * LOI\ (400) - 0.727;\ r^2=0.94.}$$

Statistical Analyses

Linear regression was used to evaluate the relationships between SMB and SOC.

3.4 Work Area 4 - Building Data Sets for the Development of Guidelines on Manure and Effluent Use

Paul Southcott undertook a substantial amount of work on the collection of data from commercial feedlots on soil and crop qualities from areas receiving manure and effluent. The work undertaken on the soil - crop survey has been collated and is to be presented in a paper that is in preparation. A comparative study of models used for effluent irrigation or waste application was undertaken.

3.5 Work Area 5 - Technology Transfer

During the year research findings have been presented in various forms. These papers, workshops and field days are summarised in Table 3.7.

Table 3.7: Presentations of project results

Date	***Activities***	***Attendance* (not including speakers)**
Formal Oral Presentations		
CRC Travelling Road Show 14, 15 and 16 March 2000	Dalby, Quirindi and Yanco	46
University Presentation at Rangers Valley for CRC 19 September 1999	Presentation of MLA results	25
Obtaining the Best use of Feedlot Manure and Effluent	Field Day at Tullimba	350
Papers		
Recycled Organics Conference (Coolum) 22 – 25 November 1999		
Lott, S., Blair, G., Klepper K., MacLeod, D., Murray, S., Wilkes J. (1997) Obtaining the best Use of Our Organic Fertilisers. In *'Proceedings of Production and Environmental Monitoring Workshop*.' 9-11 December 1997. University of New England, Armidale. Australia pp. 121-130.		
Klepper, K., Blair, G., MacLeod, D., Lott S., Murray S. (1998) Phosphorus dynamics in the soil-plant system following the addition of beef feedlot manure. In *'Proceedings of National Soils Conference – Environmental benefits of soil management'* 27-29 April 1998 Brisbane. pp. 115-119		
Lott, S., Klepper, K., Ahmad, R., Blair, G., Petrov, R. (1999) Australia – You're Standing In It. *'Conference Proceedings*.' Royal Pines Resort, Queensland, Australia		
Miller, B., Klepper K., Parker D., Lott S., Robinson C., Sweeten J., Blair, G. (1999) Application of Feedlot Manure and Effluent to Forage Sorghum. Presentation made at '1999 ASAE/CSAE Annual International Meeting' Toronto, Ontario Canada.		
Lott, S., Klepper, K., Davis, J., Ahmad, R., Blair, G. (1999) Safe Utilisation of Manures, Effluent and Biosolids. In *'Proceedings of Production and Environmental Monitoring Workshop*.' 17-19 March 1999. University of New England, Armidale. Australia (PEM05).		
Klepper, K., Blair, G., Ahmad R., Lott, S. (2000) The Impact of Feedlot Manure and Effluent on Nutrient Cycling and Crop Productivity in a High Rainfall Zone in Australia. In *Proceedings of the Eighth International Symposium on Animal, Agricultural and Food Processing Wastes.'* Oct. 2000, Des Moines, Iowa pp. 602-609		
Ahmad R., Lott, S. (2000) The Impact of Feedlot Manure and Effluent on Nutrient Cycling and Crop Productivity in a High Rainfall Zone in Australia. In *Proceedings of the Eighth International Symposium on Animal, Agricultural and Food Processing Wastes.'* Oct. 2000, Des Moines, Iowa pp. 602-609		

4. Results and Discussion

4.1 Work Area 1 - Database of Crop and Soils Data from Land Receiving Feedlot Wastes

A study tour to review overseas research work was undertaken in October/November 1998. Over 40 contacts were made with professionals working in agricultural waste management. An exchange of data occurred with researchers at the West Texas A & M University.

4.2 Work Area 2 - Nutrient and Salt Cycles from Manure and Effluent Application, Tullimba feedlot

4.2.1 Dry Matter Yield

Effluent applications did not significantly affect dry matter yield in Year 1 2 for the control and manure treatments. In year 1 increased application rates of manure resulted in increased ($p<0.05$) dry matter yields in each harvest and in each crop(Table 4.1). A yield increase was also noted ($P<0.10$) between the control, and both the 20 t/ha manure treatment and inorganic treatment for the first sorghum harvest only. A decrease in dry matter yield between sorghum harvests 1 and 2, was evident in the control and the 20 t/ha manure treatment, however, was not observed in the 60 t/ha manure treatment or the inorganic treatment. This may be attributed to nutrient removal, or nutrient imbalance. Plant response to inorganic fertiliser application to sorghum was greater for harvest 2 than harvest 1, however dry matter yields over year 1 did not differ significantly from the highest manure (60 t/ha) treatment.

In year 2, all treatments recorded similar dry matter yields at each harvest ($P<0.05$) apart from the control which produced lower yields for all harvests and the inorganic treatment in the first sorghum harvest (Table 4.1). Additional N fertiliser applied as urea to the 20+25 t/ha manure treatment did not significantly increase dry matter yield compared to manure alone, however, at each harvest it did produce an extra 6.9 t dry matter for the whole year. A higher yield was recorded in the 60 t/ha manure treatment which received urea, compared to the control at each harvest. The highest manure treatment recorded a higher total dry matter yield at the end of Year 1 compared to Year 2, however the 20 + 25 t/ha manure treatments did the reverse (Table 4.1) which may be attributed to the fresh manure application.

In year 3 there was again a very significant increase in yield in the manure treatments over the control. Highest sorghum yields were recorded in the inorganic and the treatment which had received annual applications of manure at 20 or 25t/ha which was supplemented with N in years 2 and 3 (Table 4.1)

Table 4.1: Dry Matter Yield (kg/ha) of Forage Sorghum and Triticale for Year 1, 2 and 3.

	Treatment (manure application t DM/ha)				
Year 1	0	20	20	60	Inorganic
Year 2	0	25	25 (N)	0 (N)	Inorganic
Year 3	0	20	20 (N)	0 (N)	Inorganic
Year 1					
Sorghum #1	3003a	5261a	5261a	8329b	5910ab
Sorghum #2	1722a	2313a	2313a	7647b	8340b
Triticale	2059a	3332a	3332a	7211b	9532b

	Treatment (manure application t DM/ha)				
YEAR 1 TOTAL	6784	10906	10906	23187	23782
			Year 2		
Sorghum #1	532a	5007b	6467b	4204ab	2367a
Sorghum #2	627a	6630b	10172b	7904b	8057b
Triticale	2826a	6807b	8707b	7770b	6809b
YEAR 2 TOTAL	3985	18444	25346	19878	18481
			Year 3		
Sorghum #1	443a	3957b	5456b	4640b	5055b
Sorghum #2	236a	1462b	4663b	3203bc	5225c
Triticale	2642a	5462b	6593b	6216c	6064c
YEAR 3 TOTAL	3141a	10881b	16810c	14060c	16350c
GRAND TOTAL	***14042***	***40232***	***552964***	***57493***	***57358***

a - Numbers followed by the same letter in a row are not significantly different (P=0.05).

Total dry matter production over the 3 years exceeded 50t/ha (Figure 11) in the inorganic treatment and that which received 60t/ha of manure in year 1 and supplemental N in years 2 and 3.

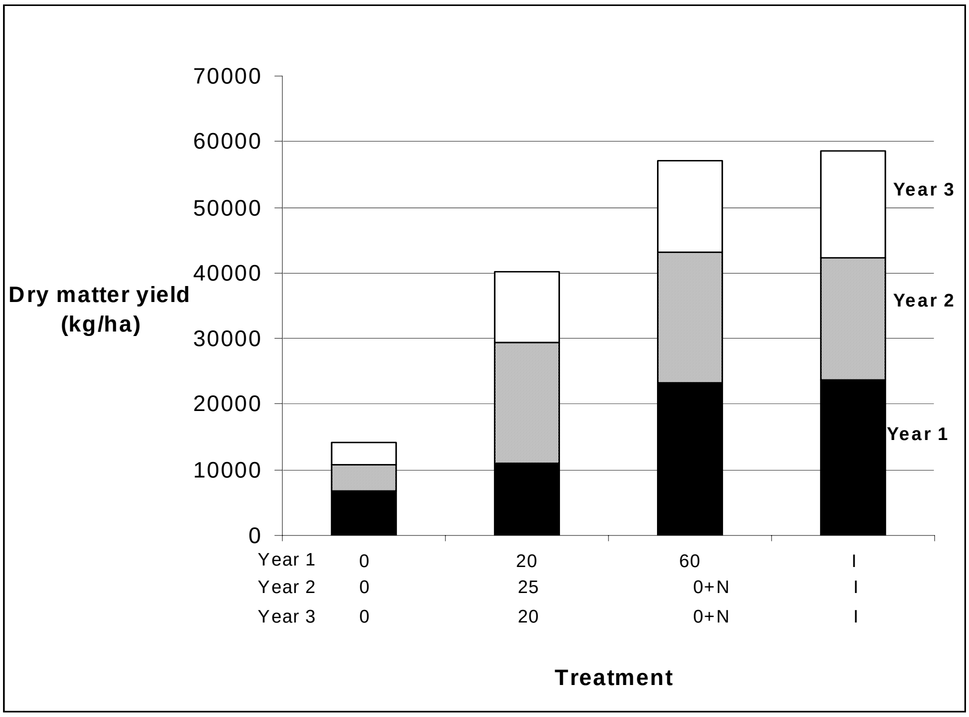

Figure 11: Cumulative annual dry matter production (kg/ha) as affected by manure and inorganic fertiliser application.

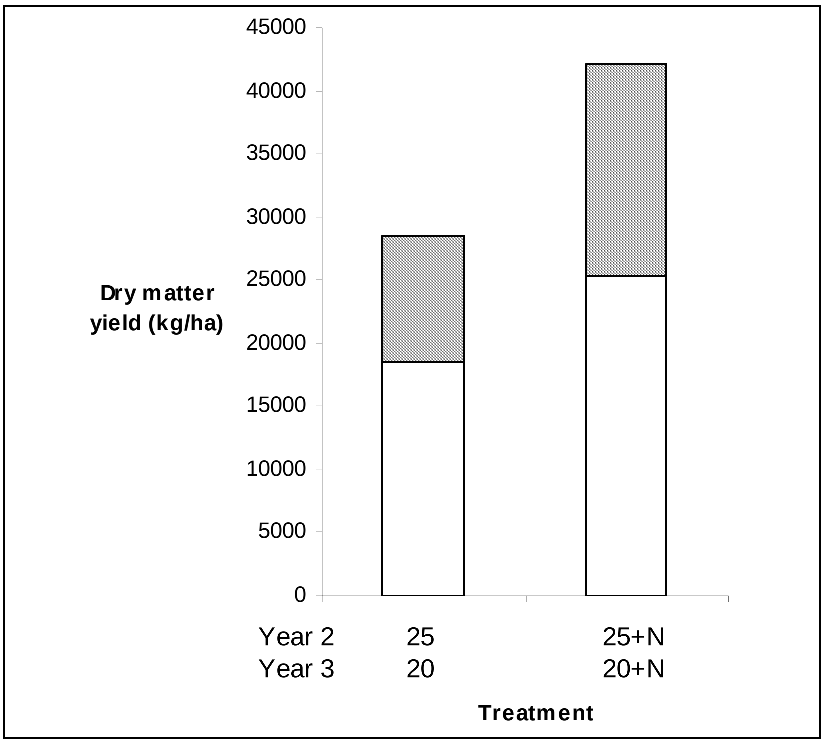

Figure 12: Response to N applied to the low manure rate treatment in years 2 and 3

Application of inorganic N to the manure and inorganic treatments in years 2 and 3 resulted in a large increase in yield (Figure 12) and large differences in agronomic use efficiency (Table 4.2) with the highest efficiency when N was applied to the treatment which received 20-25 t/ha (+N).

Table 4.2: Agronomic use efficiency of N applied in years 2 and 3.

	Treatment (Year 1, 2, 3)			
	20+25+20	20+25(N)+20(N)	60+0(N)+0(N)	Inorganic
Dry matter yield years 2+3 (kg/ha)	29323	42058	33937	33577
N applied years 2+3 (kg/ha)	0	290	300	440
N agronomic efficiency (kg DM/kg N)		145	113	76

4.2.2 Plant Nutrient Removal

In all years, plant tissue concentrations of N, P, K, and S generally increased with increasing manure application, however they did not exceed those considered to be toxic by Reuter and Robinson (1986). This, combined with increasing dry matter yields resulted in an increasing amount of nutrient exported in crop as manure application rate increased (Figure 13, and Figure 14). Tissue concentrations of N and K declined over the three harvests in all treatments in each year, and P and S concentrations increased.

Export (in kg/ha and as a % of applied nutrient) of N, P, K and S in harvested plant material was highest in the 60 t/ha treatment (Table 4.). Export of K exceeded that added in all treatments.

Table 4.3: Total Crop Removal of Nutrient (kg/ha) with Brackets ( ) Indicating Percent of Applied Nutrient Recovered by Forage Sorghum and Triticale in Year 1, 2 and 3.

Treatments	**(Manure application rate t DM/ha)**				
Year 1	0	20	20	60	Inorganic
Year 2	0	25	25+N	0+N	Inorganic
Year 3	0	20	20+N	0+N	Inorganic
N	115	337(39)	505(46)	558(51)	765(64)
P	27	113(22)	159(31)	191(42)	117(65)
K	306	941(197)	1153(241)	1342(334)	1445(181)
S	15	46(19)	59(25)	65(32)	76(35)

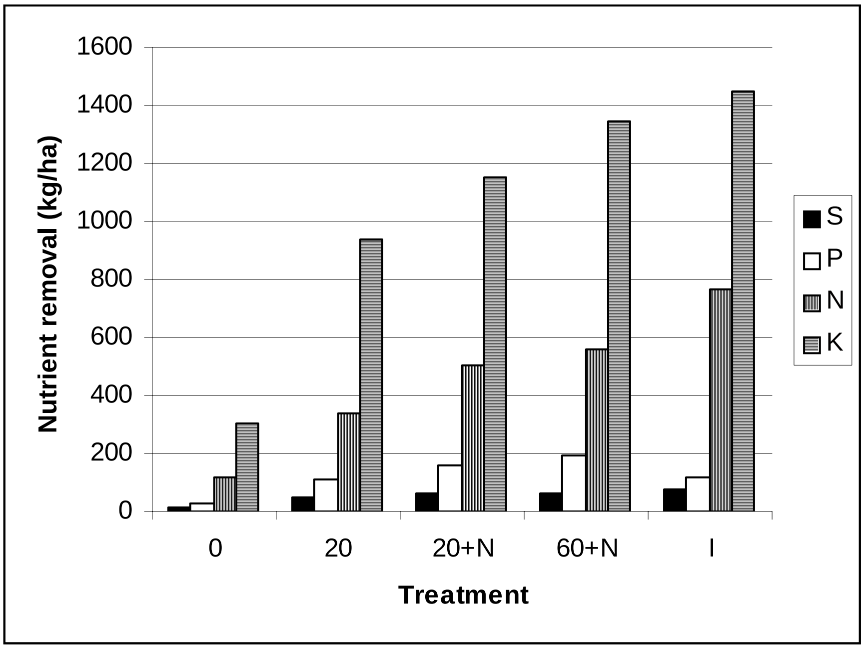

Figure 13: Total removal of S, P, N and K in harvested plant material (kg/ha).

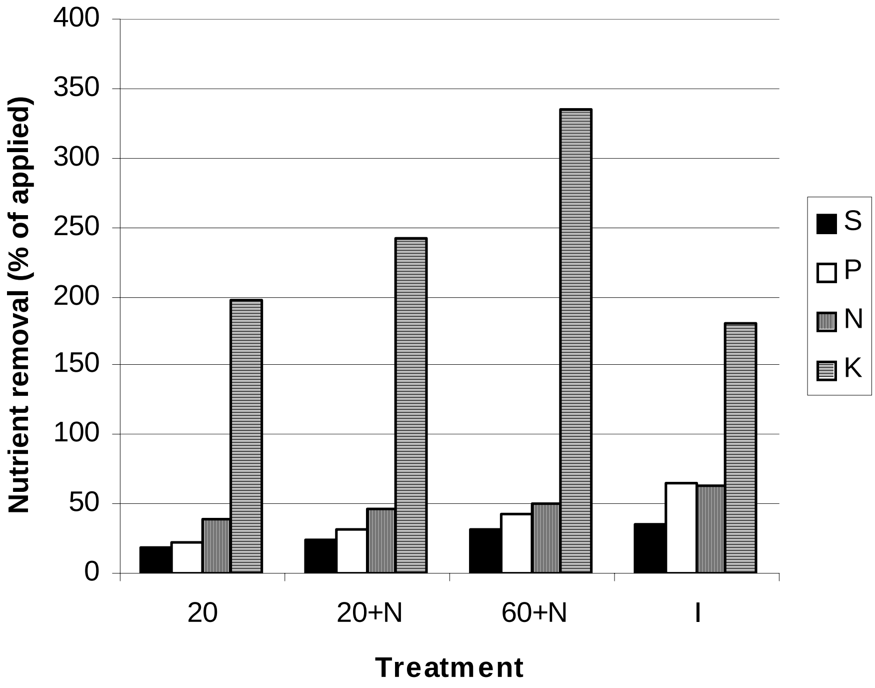

Figure 14: Removal of S, P, N and K in harvested plant material (% of applied).

Large amounts of nutrients were removed in the harvested plant material (Figure 13) Maximum amounts of N, K and S were removed from the inorganic treatment with total removal amounting to 765 kgN/ha, 1445 kgK/ha and 76 kgS/ha. Maximum amounts of P (191 kg/ha) was removed in the treatment that received 60t manure/ha in year 1 and N in the latter 2 years. Removal of K in harvested plant material greatly exceeded that applied in all treatments with the greatest loss in the 60 (+N) kg/ka treatment (Figure 14).

4.2.3 Soil Chemical Fertility

With manure continually decomposing and undergoing mineralisation, understanding soil nutrient availability over time is essential in determining when potential losses to the environment may occur. The following section presents the soil nutrient concentrations for years 1, 2 and 3. to show soil concentrations prior to the initiation of the experiment (initial), (a) after the second sorghum harvest, year 1, and (b) after the triticale crop in year 1, for three treatments: control, 60t/ha manure, and the inorganic treatment. The 20 t/ha manure treatment in year 1 is not shown due to it having similar concentrations to that of the control treatment. In year 2 this treatment, which received more manure (20+25 t/ha), has been included for after the second sorghum harvest in year 2 (c), and after the triticale crop in year 2 (d). Soil samples from 10 - B horizon were not available at the end of year 2 due to sampling problems. Year 3 data are presented for all treatments at (e) after the second sorghum harvest in year 3, and (f) after the triticale harvest in year 3. The midpoint of each sampling depth is shown on the y-axis of the figures. 95% confidence limits are shown where significant differences were found between treatments. No limits are shown where differences are not significant. Confidence intervals apply to each treatment and each data point, but limits were not calculated for the initial soil concentration values. Again there were no significant differences ($P<0.05$) between plus and minus effluent applications, nor were

there differences between manure plus urea (20+25+20(N) t/ha manure) compared to manure alone (20+25+20 t/ha manure). Where no significant differences occurred these treatments were used as additional replicates.
Soil nutrient concentrations

Ammonium – N

Initially, in the top 10 cm the NH_4 – N concentration did not exceed 5 mg/kg, and was even less at depth (<2 mg/kg). After 3 years of continual cropping concentration of NH_4 – N in the top 10 cm declined in all treatments to concentrations not exceeding 3 mg/kg and close to zero at depth. However, the inorganic treatment recorded a NH_4 – N concentration of 14 mg/kg in the surface soil following the sorghum crop in the first year, although the concentration was equivalent to the control after the following triticale crop. This high value is likely due to the 600 kg N/ha applied throughout the sorghum growing season.

Nitrate - N

In year 1, the concentration of NO_3 - N in the soil profile after both the sorghum and triticale crops was similar between the control and the 60 t/ha manure application (Table 15a and b). At neither sampling time did the concentration of nitrate in either treatment exceed that of the initial concentration, indicating that crop uptake was effective in removing NO_3 - N from the soil. In the 20 t/ha manure treatment the soil NO_3-N concentration was similar to that of the control treatment after both sorghum and triticale (not shown). However, in the inorganic treatment elevated levels were recorded in the surface horizon, and at depth, after sorghum (Figure 15a) but not at the end of the triticale crop (Figure 15b). In year 2, soil NO_3 – N concentrations after the sorghum crop (Figure 15c) for all treatments were below that of the initial soil concentration. The surface soil contained higher concentrations than at depth in all treatments, the highest being 14 mg/kg. After the triticale crop no significant differences were measured between treatments with soil NO_3 – N concentrations not exceeding 3 mg/kg in any treatment (Figure 15d).

The soil NO_3 – N concentration in the topsoil after sorghum was harvested in year 3 was higher compared to at the end of year 2 in all treatments, with the 20+25+20 t/ha manure treatment recording the highest concentration of 14 mg/kg NO_3 – N. This concentration was not significantly different from any treatment except the control, which recorded a soil NO_3 – N of 5 mg/kg (Figure 15e). As in year 2, NO_3 – N concentrations in surface soil for all treatments declined throughout the triticale crop to below that of the initial soil concentration (Figure 15f).

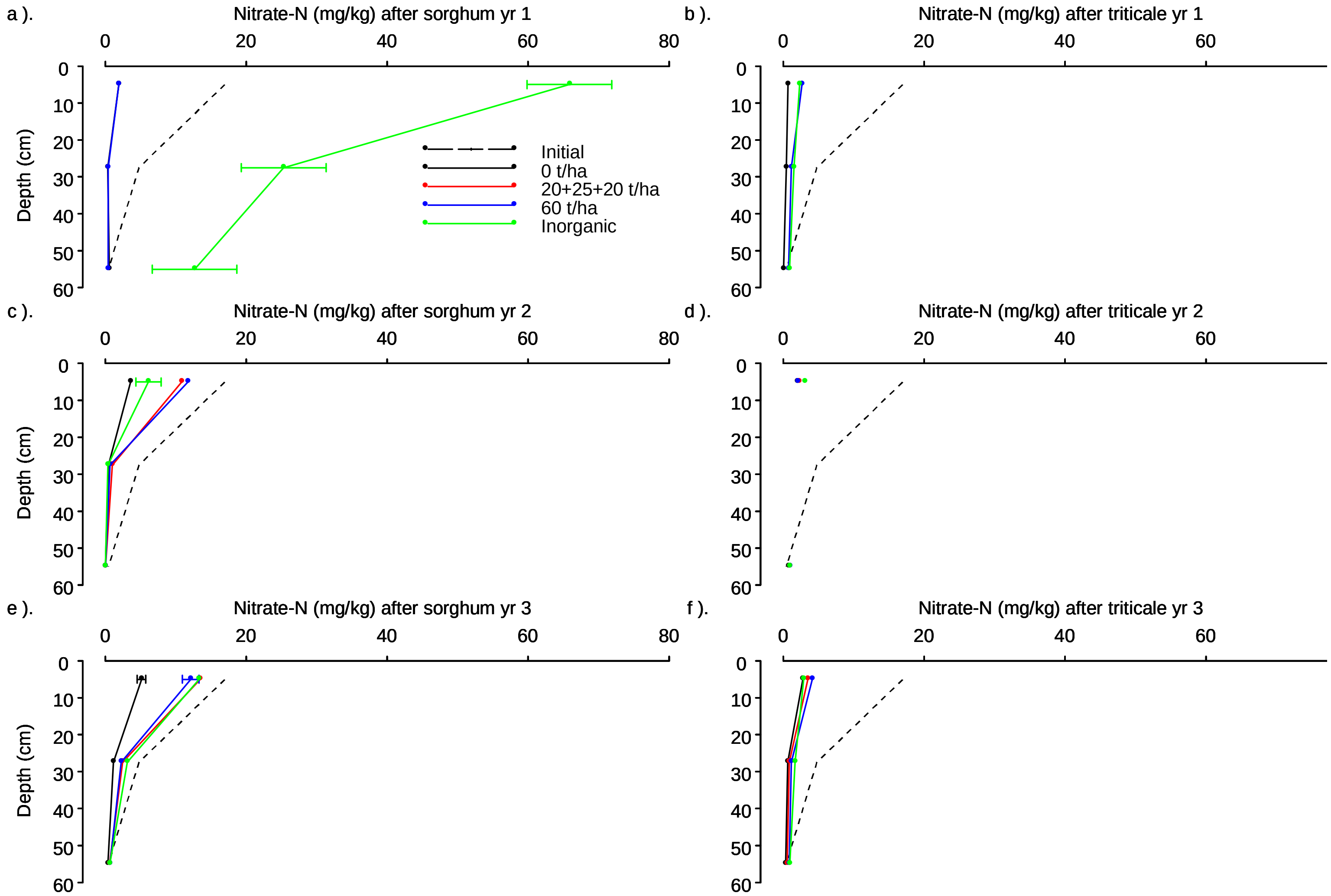

Figure 15: Nitrate -N concentration (mg/kg) in the soil profile over time for each treatment.

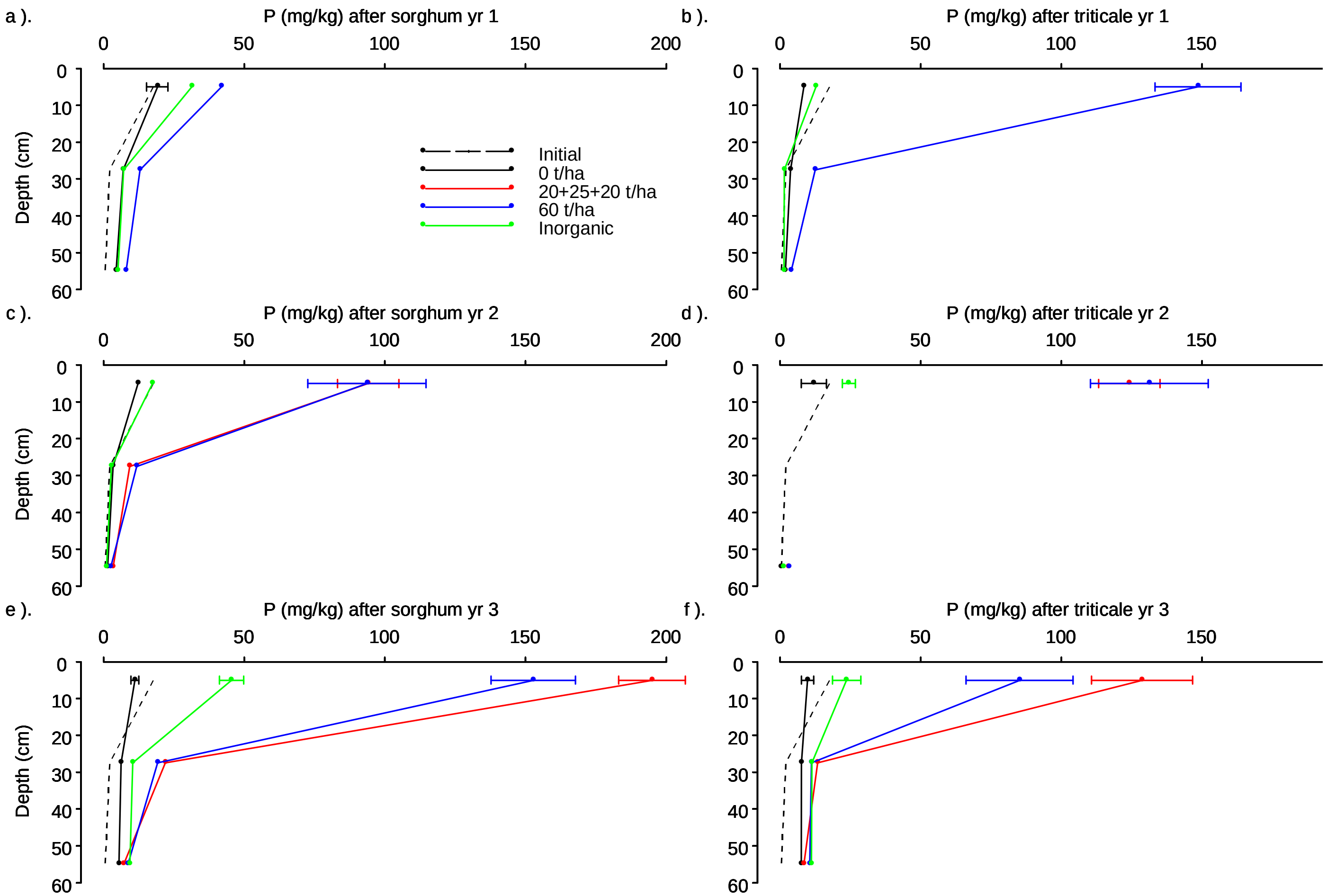

Figure 16: Bicarbonate P concentration (mg/kg) in the soil profile over time for each treatment.

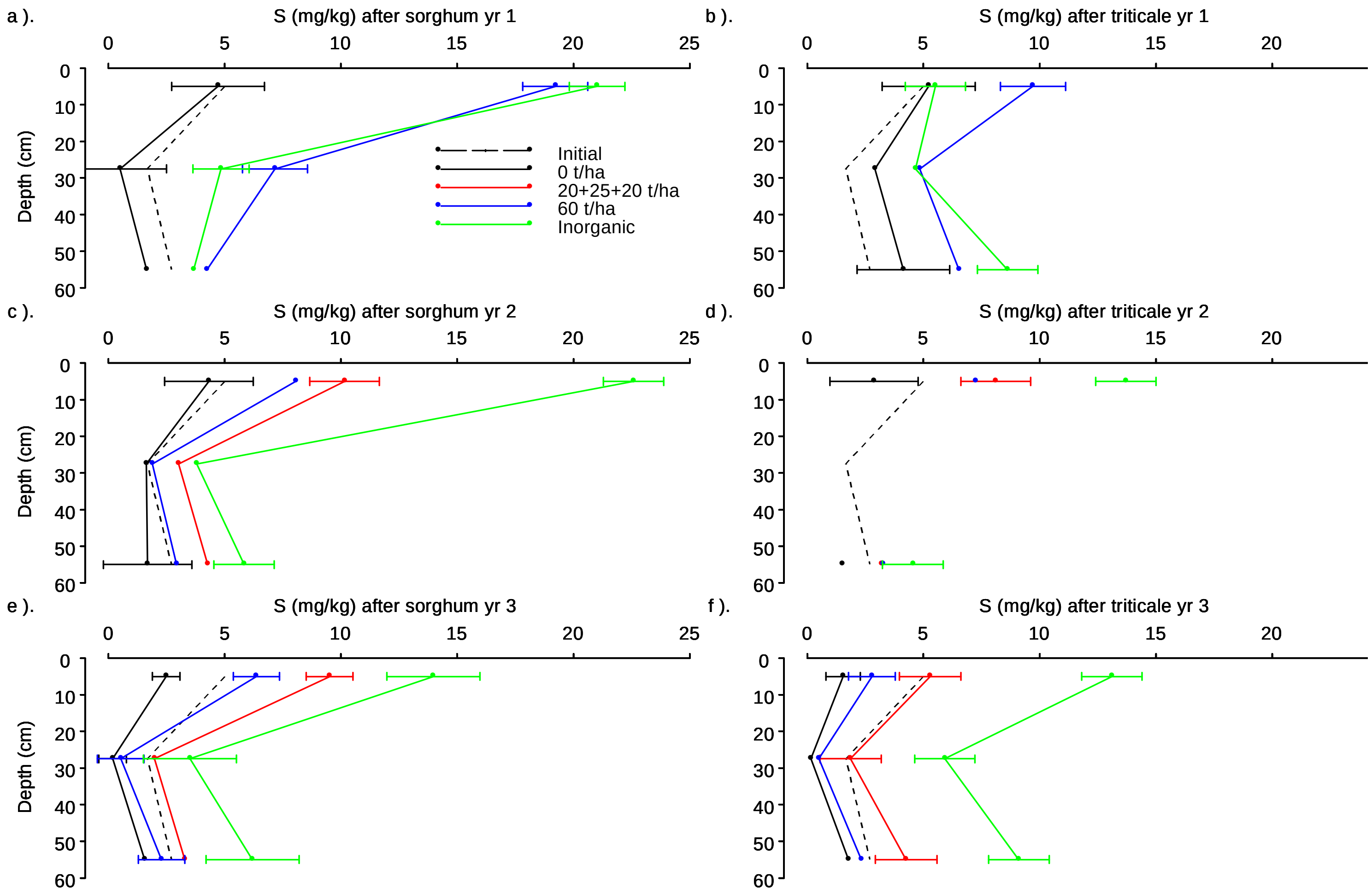

Figure 17: Available S (KCl - 40) concentration (mg/kg) in the soil profile over time for each treatment.

Bicarbonate P

The phosphorus concentration in the 60 t/ha manure treatment exceeded that of the initial soil concentration in the topsoil after the sorghum crop in year 1 (Figure 16a). The highest P concentration (42 mg P/kg) was recorded in the 60 t/ha manure treatment, with the control treatment significantly lower (19 mg P/kg) in the top 10 cm. Following the triticale harvest, the concentration of P in the control and inorganic treatments was similar to that of the initial value. However, substantial mineralisation and relatively low plant uptake resulted in the 60 t/ha manure treatment having a bicarbonate P concentration eight times that of the initial concentration (Figure 16b).

After the sorghum crop in year 2 the bicarbonate P concentration in the surface horizon of the 60 t/ha manure treatment decreased by approximately 50 mg P/kg. However, the P concentration in the surface soil in the 20+25 t/ha manure treatment increased from 40 mg P/kg recorded at the end of year 1 to 94 mg P/kg. Following the triticale crop in year 2, the P concentrations in both manure treatments increased, by approximately 40 mg P/kg (Figure 16c and d).

In year 3, all treatments were significantly different in the top 10 cm only, with the 20+25+20 t/ha manure treatment recording the highest value (Figure e and f). After the sorghum crop in year 3, soil P concentrations in the surface soil had increased from the end of year 2 by 71 and 22 mg/kg in the 20+25+20 t/ha and 60 t/ha manure treatments, respectively, as a result of the fresh application of manure and the amount of mineralised P exceeding plant uptake. The inorganic treatment also increased by 21 mg P/kg. However, after the triticale harvest soil P concentrations declined in all treatments with the 20+25+20 t/ha and 60 t/ha manure treatments decreasing by 66 and 68 mg P/kg, respectively (Figure 16f).

Sulfur

In year 1 the concentration of S in the surface horizons increased from the initial concentrations in both the inorganic and 60 t/ha manure treatment after the sorghum crop, which had received 80kg S/ha as SSP and 207 kg S/ha as manure, respectively (Figure 17a). Crop uptake, which was similar between the treatments and possible leaching of S resulted in lower concentrations after the triticale crop (Figure 17b) with the inorganic treatment having surface S concentrations lower than the 60 t/ha manure treatment, and similar to the initial values. Similarly, mineralisation in the control over the winter period resulted in the S concentrations higher at the completion of the triticale crop than initially.

At depth (>25 cm) there was no difference between the inorganic and the 60 t/ha manure treatment throughout year 1. However, the concentration of S in the B horizon for these treatments increased from the initial value by 6 and 4 mg S/kg, respectively, at the end of year 1.

In year 2, the concentration of S in the surface horizon following the sorghum crop was highest for the inorganic treatment, which received 75 kg S/ha, 40 days after sowing (Figure 17c). The 20+25 t/ha treatment showed an increased S concentration, though not significantly different compared to the 60 t/ha manure treatment, at all depths. A decrease in S concentration in all treatments was recorded after the triticale crop in year 2, with the largest decrease (23 to 13 mg/kg) occurring in the inorganic treatment.

In year 3, after the sorghum crop all treatments were significantly different from each other in the top 10 cm, with the inorganic treatment having the highest concentration at 14 mg S/kg

(Figure 17e). At depth (>30 cm) after the sorghum crop, the inorganic treatment recorded a similar concentration to the 20+25+20 t/ha manure treatment, but was higher than the 60 t/ha manure treatment which was below the initial soil S concentration. After the triticale crop at the end of year 3, all treatments showed a decrease in soil S concentration in the top 10 cm (Figure 17f). The inorganic treatment was significantly higher than the 20+25+20 t/ha manure treatment at all depths. Movement of S down the profile was evident in the inorganic treatment and may explain the decrease of 2 mg/kg in the surface soil.

Cation exchange capacity (CEC) and exchangeable cations

There were no significant differences between treatments in the CEC determined initially and after harvest of the triticale crop in year 2 (Table 4.4). There was a trend (P<0.10) for CEC to be lower in the inorganic treatment than in the manure treatments at the end of year 2 in both 0 – 10 cm and 10 cm – B horizon depths. Manure appeared to increase CEC of the topsoil over time, with increases of 22 to 24% recorded at the end of two years. The manure applications did not affect CEC at depth (10 cm - B horizon).

Table 4.4: Cation Exchange capacity in $cmol_c$/kg measured initially and at the end of year 2.

Manure application rate	0 - 10 cm		10 cm – B horizon	
	Initial	End of year 2	Initial	End of year 2
0 t/ha	5.19	5.43	5.69	5.57
20+25 t/ha	5.12	6.26	5.72	5.66
60 t/ha	4.87	6.05	5.54	5.85
Inorganic	4.72	4.73	4.41	4.57

No significant differences (P<0.05) were found between treatments for both depths in any year.

Exchangeable cations were measured at the beginning of the experiment and at the completion of each crop for 2 years for both a) 0 - 10 cm depth and b) 10 cm – B horizon (Figure 18 to Figure 21). The x-axis denotes the number of days since treatment implementation when soil sampling occurred; 0 - initially, 140 - after sorghum in year 1, 331 - after triticale in year 1, 490 - after sorghum year 2 and 700 - after triticale in year 2.

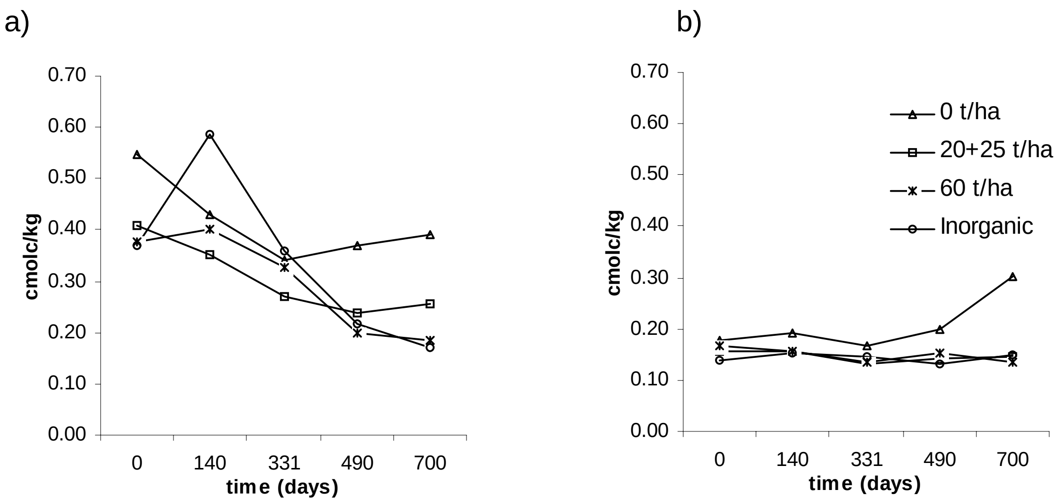

Figure 18: Exchangeable potassium in $cmol_c$/kg over time a) 0 - 10 cm b) 10 cm – B horizon.

Figure 18 indicates that all treatments declined in exchangeable K in the top 10 cm of the profile over 2 years. Initial values (time 0) varied between treatments, with the control plots sharing the highest values (Figure 18a). The inorganic treatment had the highest exchangeable K after the first sorghum crop, however at the end of 2 years continual cropping the control treatment was double that of the inorganic and highest manure treatment. At depth there was no difference between treatments, apart from the control treatment increasing over year 2, reaching a maximum of 0.31 $cmol_c$/kg K (Figure 18b).

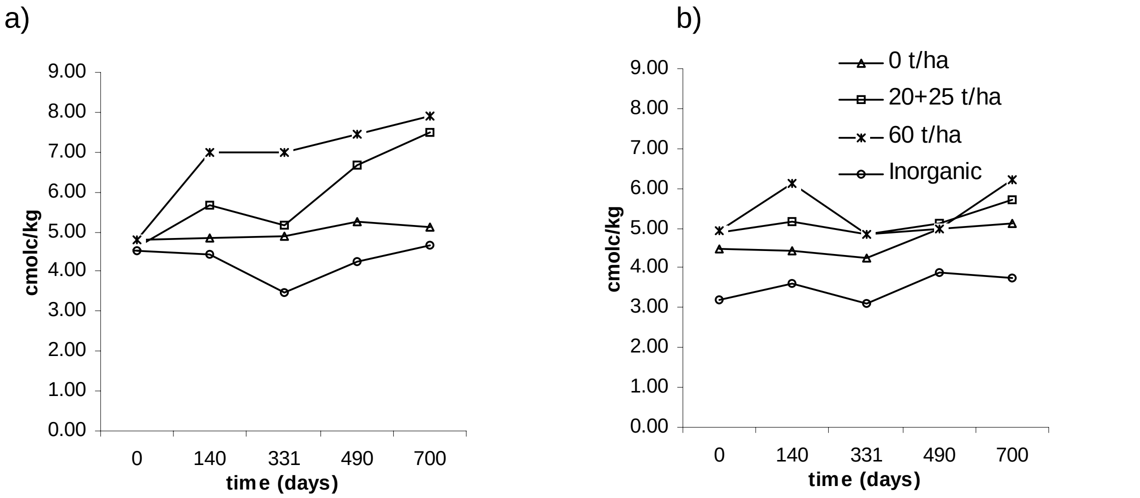

Figure 19: Exchangeable calcium in $cmol_c$/kg over time a) 0 - 10 cm b) 10 cm – B horizon.

In the top 10 cm, exchangeable Ca reached a maximum in the manure treatments at the end of year 2 (Figure 19a). The control and inorganic treatments remained relatively stable over the 2 years. The 60 t/ha manure treatment recorded the highest exchangeable Ca value (6.3 $cmol_c$/kg) at depth.

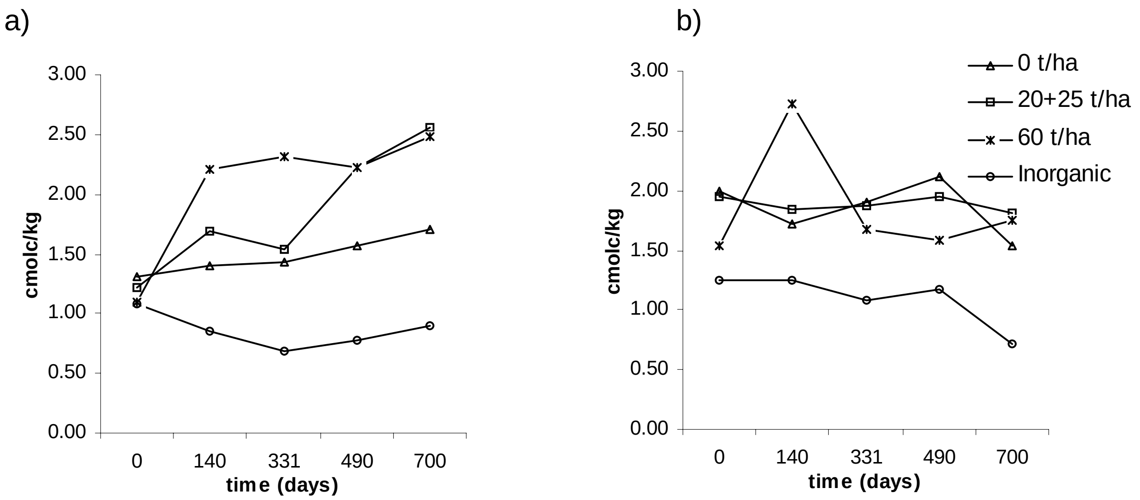

Figure 20: Exchangeable magnesium in $cmol_c$/kg over time a) 0 - 10 cm b) 10 cm – B horizon.

Like exchangeable Ca, exchangeable Mg increased following the second application of manure to the 20+25 t/ha treatments (Figure 20a). Highest exchangeable Mg values were recorded in both manure treatments, followed by the control and the inorganic treatment. At depth (Figure 20b), in the highest manure treatment, a rapid flush of Mg after the sorghum crop in year 1 resulted in exchangeable Mg reaching a maximum in the soil profile. Exchangeable Mg was depleted in the inorganic treatment throughout the soil profile.

a) b)

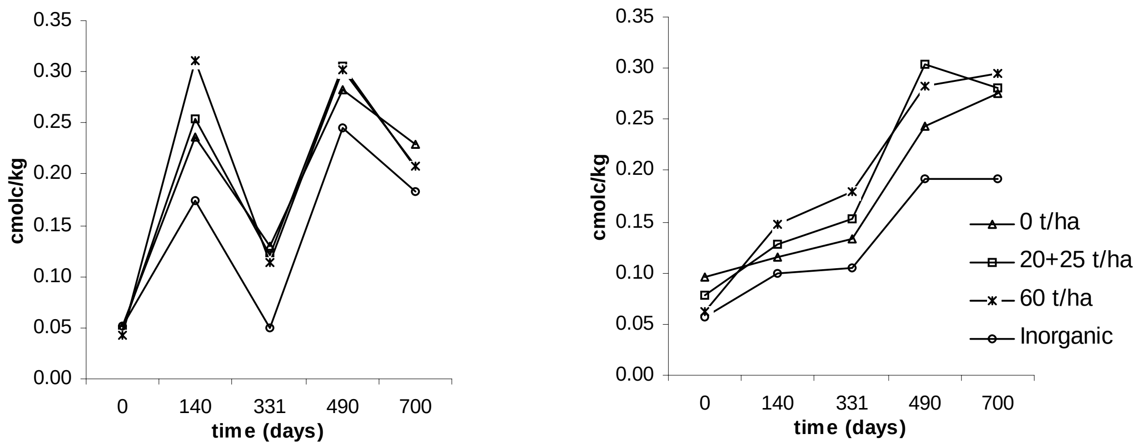

Figure 21: Exchangeable sodium in cmol$_c$/kg over time a) 0 - 10 cm b) 10 cm – B horizon.

Exchangeable Na was slightly higher at depth compared to the surface soil prior to initiation of the experiment (Figure 21). In the top 10 cm of the soil profile exchangeable Na in all treatments followed an annual pattern with increases during summer in year 1 (day 1 - 140) and in year 2 (day 331 - 490), when sorghum was growing and evaporation rates were high, whilst levels decreased during winter when triticale was grown and evaporation rates were lower. Exchangeable Na values were approximately double after the triticale harvest in year 2 compared to the corresponding time in year 1 for all treatments. At depth, there was a steady increase in exchangeable Na in all treatments.

Electrical conductivity.

a) b)

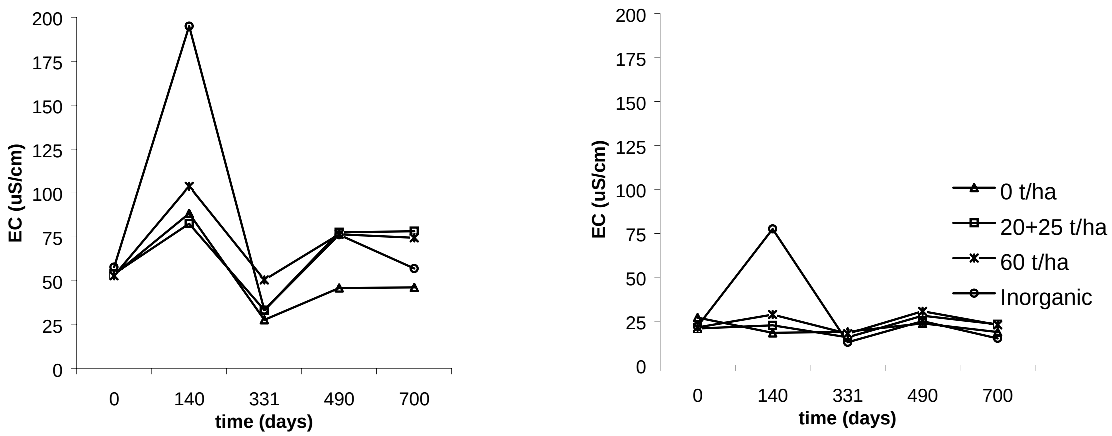

Figure 22: Electrical conductivity in μS/cm over time a) 0 - 10 cm b) 10 - B horizon.

The electrical conductivity (EC) measured at the beginning of the experiment in the top 10 cm was 53 μS/cm. After year 1 sorghum, EC measured at day 140 had increased in all treatments ranging from 83 in the 20 t/ha manure treatment to 195 μS/cm in the inorganic treatment (Figure 22a). This increase corresponds to the increase at this time observed for exchangeable Na (Figure 22a). At the end of year 1 (day 331) all treatments recorded EC values below that initially recorded, also reflecting the decrease in exchangeable Na at this time. At the end of year 2 (day 700), EC in the manure treatments were all higher than the control. A similar pattern as observed in the surface soil was found at depth although variation between treatments was not as great (Figure 22b). The peak observed in the inorganic treatment in the surface soil at day 140 was reflected at depth, values increasing from 22 to 78 μS/cm. In year 2 there were no large differences noted between treatments, with the manure treatments ranging from 21 to 30 μS/cm over the 2 years, compared to 27 to 19 μS/cm in the control.

pH $_{(CaCl2)}$

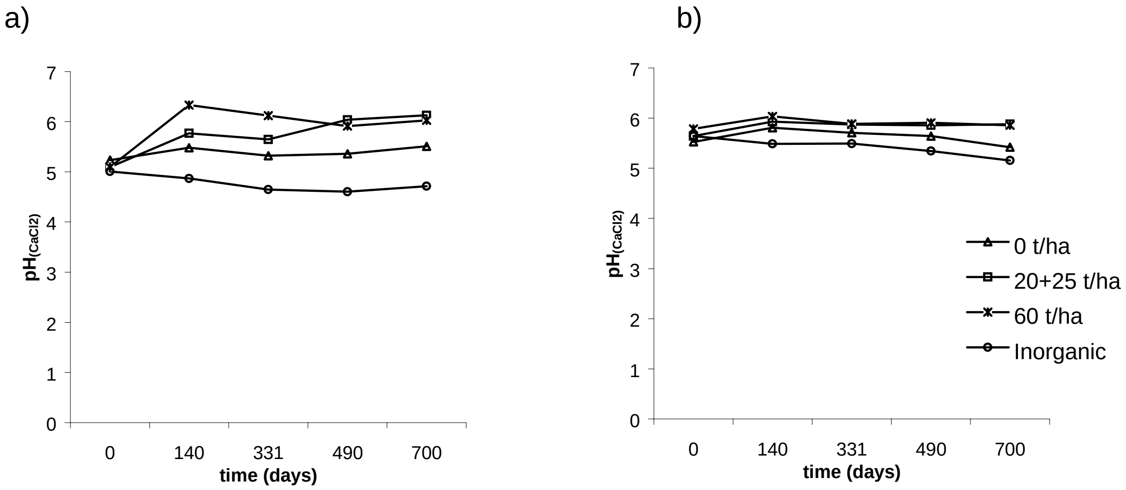

Figure 23: pH$_{(CaCl2)}$ over time a) 0 - 10 cm b) 10 - B horizon.

At the end of 2 years, the pH$_{(CaCl2)}$ of the top 10 cm of soil in the plots that received manure increased from 5.0 to 6.0 in contrast to the control treatment which remained relatively constant (5.2 – 5.5) (Figure 23a). The inorganic treatment, however, showed a slight decrease of 0.3 pH units at the end of 2 years. At depth (Figure 23b), slight decreases were observed for the control and inorganic treatments, while manure treatments remained constant, after 2 years of cropping.

Concentration of Nutrients in Surface and Subsurface Water

Average concentration of nutrients in surface and subsurface water were plotted for each of the treatments against elapsed time (Figure 24 and Figure 25). Effluent applications did not appear to significantly affect concentration of nutrients in either surface and subsurface water, nor did the application of urea to the 20+25 t/ha manure treatment in year 2. These treatments were used as additional replicates, respectively. Equipment for measuring surface and subsurface water flow was absent in the inorganic treatment, for year 1 throughout the sorghum crop, up to day 140. Tick marks on the x-axis indicate time in days after treatment initiation of soil sampling after each crop.

Concentration of NO_3 – N in waterways based on ANZECC (1992) guidelines for recreation (primary contact) waters is indicated by a dashed black line on both Figure 24b and Figure 25b. Total phosphorus concentration indicated by the guideline for aquatic ecosystems is also indicated in the relevant figures.'

Surface concentration

Concentration of NH_4 – N and NO_3 – N in surface water over 2 years was generally highest in the manure treatments (Figure 24a). During the triticale crop in year 2 the maximum concentration of NH_4 – N (12.5 mg/L) occurred in a low rainfall event from the 60 t/ha manure treatment, with the 20+25 t/ha treatment having half this concentration. Concentration of NO_3 – N in surface runoff from all treatments followed a similar trend, except for the highest manure treatment which reached a concentration of 17.0 mg/L, 100 days after sowing triticale in year 1 (Figure 24b). Over 2 years concentration of NO_3 – N in surface water exceeded the permissible limit of 10 mg/L as defined by ANZECC (1992) three times, however this concentration would not be equivalent to that entering streams (discussed in section 3.4.2). Two out of the three times occurred in between crop rotations when ground cover was absent and rainfall exceeded 59 mm.

Total P in rivers is said to damage aquatic ecosystems when its concentration reaches 0.1 mg/L (ANZECC 1992). In every surface runoff event over the 2 years the manure treatments exceeded this limit, whilst the control and inorganic treatment exceeded it 86% and 97% of the time, respectively (Figure 24c), however, the concentration would fall prior to reaching streams.

Potassium concentrations in surface runoff did not indicate differences between treatments over the 2 years, although higher concentrations were noted in summer compared to winter (Figure 24d). K concentrations peaked in a rainfall event exceeding 80 mm, two days after the first sorghum harvest in year 1. This increase in concentration in all treatments was also apparent in year 2 after the first and second sorghum harvest.

In year 1, the 60 t/ha manure treatment recorded the highest S concentration. However, in year 2 the inorganic treatment, which received equivalent amounts of S as single superphosphate in year 2 as in year 1, recorded consistently higher S concentrations compared to other treatments (Figure 24e). Like P, S concentration in surface runoff from the 20+25 t/ha treatment was higher in year 2 compared to year 1. In year 2, the 20+25 t/ha and 60 t/ha manure treatments recorded similar P and S concentrations in surface runoff (Figure 24c and e).

High Na concentrations were recorded in the control treatment after 84 mm of rainfall during the ratoon crop of sorghum year 1 (Figure 24f). Shortly after the triticale was sown in year 1 Na concentration reached a maximum (192 mg/L) in the 60 t/ha manure treatment, whilst all other treatments recorded a Na concentration of around 4 mg/L. In year 2, Na concentration was similar between all treatments, with concentration not exceeding 100 mg/L.

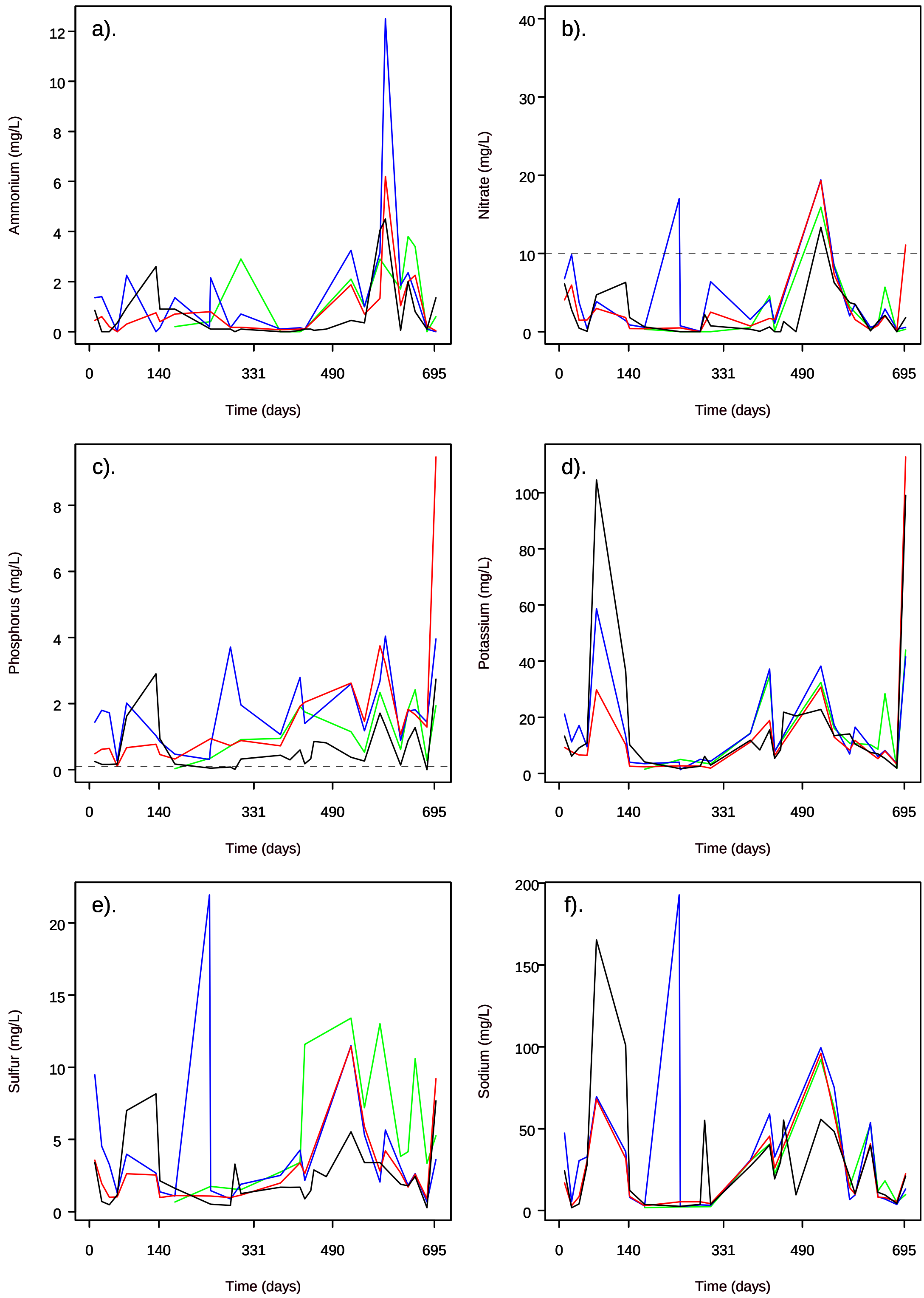

Figure 24: Average concentration of nutrient (mg/L) contained in surface water over time. (black = 0t/ha; red = 20+25 t/ha manure; blue = 60 t/ha manure; green = inorganic)

Subsurface water

The concentration of NH_4 - N recorded in subsurface water reached a maximum in the inorganic treatment at 1.0 mg/L after a 49 mm rainfall event 30 days after the first sorghum harvest in year 2 (Figure 25a). Prior to this rainfall event the highest manure treatment recorded half this concentration after 60 mm of rainfall, 10 days after the harvest. Concentration of NH_4 – N was relatively consistent over the 2 years among the other treatments. Ten days after sowing triticale in year 1, the inorganic treatment recorded the highest level of NO_3 – N in subsurface water (89.0 mg/L) amongst treatments over the 2 years (Figure 25b). In year 1 and 2, concentration of NO_3 – N in all treatments was similar for individual events, with peaks occurring soon after sowing times. As for surface water concentrations, the maximum limit according to ANZECC (1992) for recreational waters was exceeded. All treatments exceeded this concentration but the control treatment generally recorded lower concentrations, and less frequently exceeded the limit. At the time of peak concentration in surface water (5 days after sowing triticale in year 2) the concentration of NO_3 – N in subsurface water ranged between 24 – 32 mg/L.

In year 1, the lowest manure application rate did not often exceed the permissible concentration of P in groundwater (Figure 25c). However, in year 2 following a manure application, it did not record a concentration below it. Conversely, the highest manure application rate recorded the highest P concentration at 1.6 mg/L after 78 mm of rainfall, but it averaged a P concentration of only 0.3 mg/L in year 2.

Over the 2 years the control treatment recorded consistently higher concentrations of K in subsurface water compared to other treatments, possibly as a result of poor crop growth, hence lower uptake by roots. The lowest manure rate (20 t/ha) recorded the lowest K levels in subsurface water in year 1, but in year 2 the highest manure treatment (60 t/ha) showed the lowest K levels (Figure 25d). The concentration of 15.9 mg K/L recorded in the inorganic treatment at the end of the experiment may be due to sample contamination or a large flush after 86 mm of rainfall.

In general S concentration in subsurface water ranged between 2 and 18 mg/L for all treatments 92% of the time over 2 years (Figure 25e). Highest S concentrations in year 1 were recorded in between crop rotations by the 60 t/ha manure treatment (33.0 mg/L) after 88 mm of rainfall. However, in year 2 maximum S concentration (22.1 mg/L) occurred in the inorganic treatment during the triticale crop.

Unlike the surface Na concentration where treatments had similar concentrations over time, subsurface Na levels were consistently higher in the 60 t/ha manure treatment. Peak Na concentration reaching 200 mg Na/L occurred in the same treatment (60 t/ha) and time as that for S.

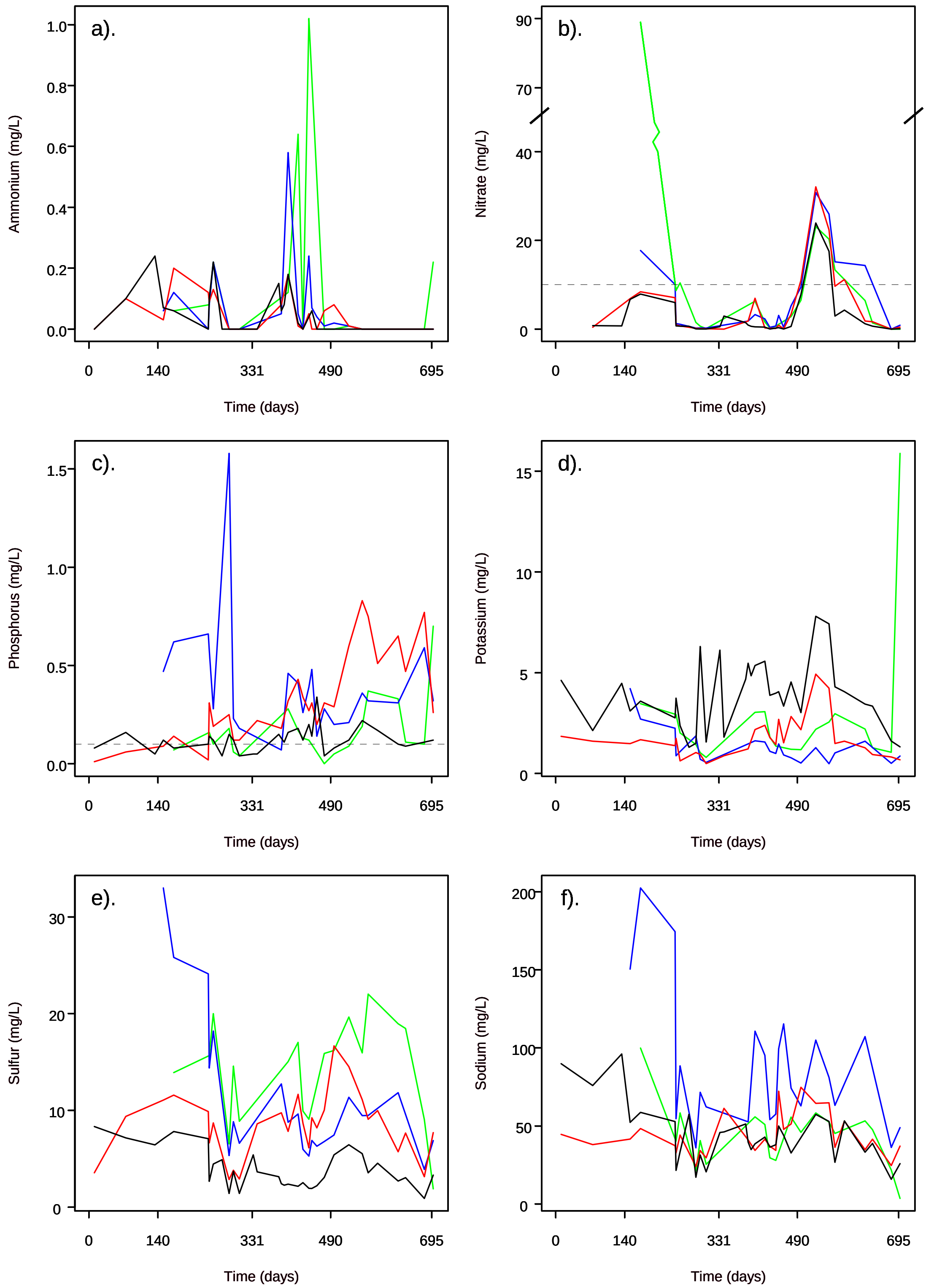

Figure 25: Average concentration of nutrient (mg/L) contained in subsurface water over time. (black = 0t/ha; red = 20+25 t/ha manure; blue = 60 t/ha manure; green = inorganic)

Total P and P sorption

Total P measured in the top 10 cm of the soil profile exhibited considerable plot variation within plots. Prior to the experiment beginning, the inorganic plots contained less kg P/ha than other plots (Table 4.5). However, the two replicates in this treatment showed wide variation (278 and 435 kg P/ha). At the end of year 3 the control, the inorganic and 60 t/ha manure treatments recorded similar amounts of P, with the control having decreased over time. Increases were noted between manure treatments with the 20+25+20 (+/-N) t/ha manure treatment increasing the most, 146 kg P/ha, by the end of 3 years. At depth all treatments increased in total P but not above the increase noted in the control.

Table 4.5: Total phosphorus (kg/ha) for two depths, initially and at the end of years 2 and 3. Numbers in brackets ( ) indicate increases or decreases compared to initial soil P content.

Treatment	Initial	Year 2	Year 3
		0 - 10 cm	
0 t/ha	499a	480a (-19)	408a (-91)
20+25+20(N) t/ha	565a	727b (162)	711b (146)
60 t/ha	494a	695b (201)	555ab (61)
Inorganic	356a	352a (-4)	402a (46)
		10 cm – B horizon	
0 t/ha	642a	na	764a (122)
20+25+20(N) t/ha	646a	na	766a (120)
60 t/ha	726a	na	819a (93)
Inorganic	652a	na	649a (-3)

[a] Numbers followed by the same letter in a column for each depth are not significantly different ($p<0.05$).

Figure 26 and Figure 27 show the initial P sorption capacity of the soil at two depths and at the end of year 2. The steepness of the phosphorus sorption curves is indicative of the required P additions to achieve a certain soil solution concentration and the soil's ability to replenish P in the soil solution as plant roots deplete the supply.

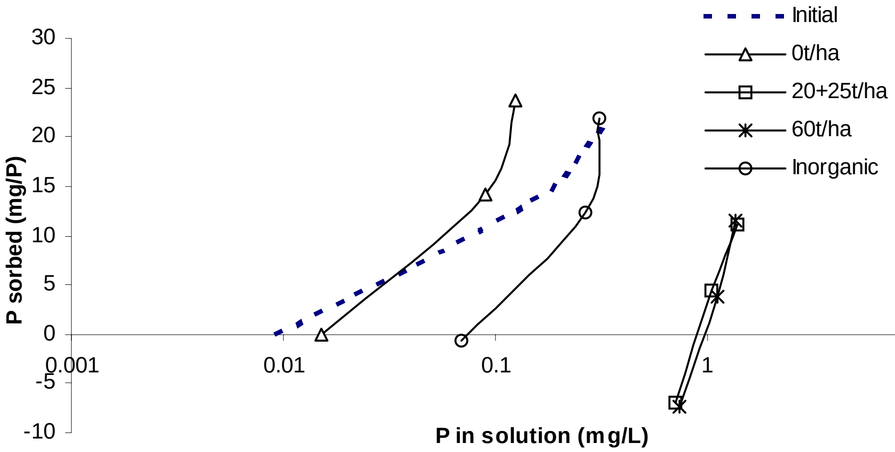

Figure 26: P sorption curves for all treatments (0 - 10 cm) at the end of year 2.

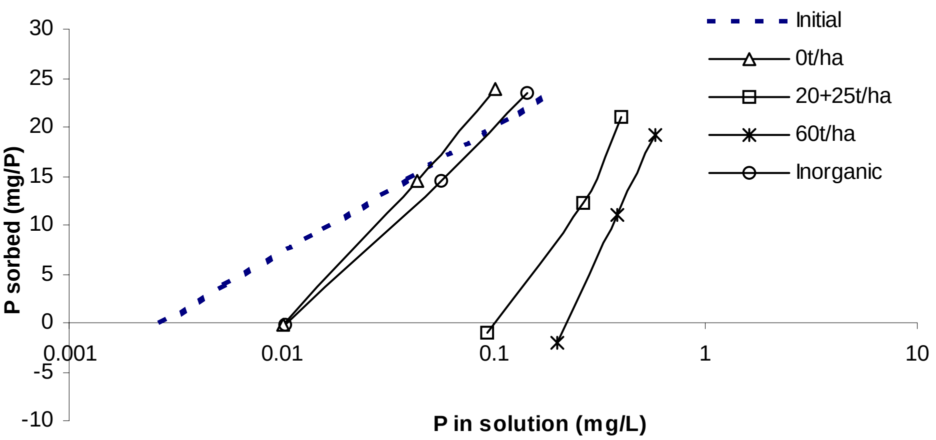

Figure 27: P sorption curves for all treatments (10 cm – B horizon) at the end of year 2.

P sorption decreased for the manure and inorganic treatments in the top 10 cm (Figure 26). The decrease was greater in the manure treatments compared to the inorganic treatment presumably due to greater additions of P in the manure treatments. In these treatments, the isotherms were displaced to the right along the x-axis resulting in higher solution equilibria values for a given addition of P. At depth (Figure 27) P sorption showed similar treatment effects to that observed in the top 10 cm. As manure application increased isotherms shifted along the axis as before. Compared to the topsoil desorption is much less.

Table 4: 6shows the equations of the sorption curves derived from Figure 26 and Figure 27. The amount of phosphorus sorbed at an equilibrium concentration of 0.2 mg/L for the two depths were calculated prior to the experiment and at the end of year 2 for all treatments.

Table 4: 6 Equations of the sorption curve and P sorbed at a solution concentration of 0.2 mg/L in the initial soil and in soil at the end of year 2, for two depths.

Treatment	Equation	r^2	P sorbed (mg/kg) at 0.2 mg/L in the soil solution
	0 - 10 cm		
Initial	y = 65.67x + 0.80	0.95	13.9
0 t/ha	y = 213.69x – 3.80	0.99	38.9
20+25 t/ha	y = 25.98x – 24.39	0.98	-19.2
60 t/ha	y = 30.51x – 29.95	0.99	-23.9
Inorganic	y = 85.44x – 7.15	0.93	9.9
	10 cm - B horizon		
Initial	y = 113.54x + 4.21	0.80	26.9
0 t/ha	y = 247.95x – 0.14	0.92	49.5
20+25 t/ha	y = 71.79x – 7.40	0.99	7.0
60 t/ha	y = 56.64x – 12.55	0.98	-1.2
Inorganic	y = 166.10x + 0.86	0.91	34.1

In the topsoil manure treatments exhibited negative P sorption at 0.2 mg/L in the soil solution showing that desorption occurred (Table 4: 6). In the control treatment at both depths sorption at 0.2 mg/L was approximately double compared to initial sorption levels, possibly due to depletion of sorbed P on cropping and thus increase in amount of sorption of mineralised P. In the top 10 cm of soil the inorganic fertiliser treatment decreased P sorption at soil solution concentration of 0.2 mg/L but at depth P sorption increased, compared to initial soil values. The changes in P sorption are consistent with the changes in bicarbonate P.

4.2.4 Soil Biological Fertility

Soil Microbial Biomass

A mean baseline value of 408 ($\pm$ 16.5 SEM) μg microbial carbon/g DM soil for SMB was obtained over the 15 plots prior to the imposition of fertiliser treatments.

Manure effects

Figure 28 shows SMB data from the control and the manure treatments at Tullimba over the 3 periods of sampling after the manurial treatments had been imposed. SMB increased by a factor of 1.5 in the 60 T/ha manurial treatment (P<0.05) over the levels in control soil in the 5 months after the initial application of manure. Eleven months after manure application, significant residual effects were still evident with SMB still higher (P<0.05) than the control values by a factor of 1.4. However, any residual effects had disappeared by 16 months after manure application, with SMB values for the 60 T/ha treatment declining to levels which were not significantly different to control levels. This trend was confirmed by repeated measures analysis. However, after October 1998, the manure effects were confounded as urea had been applied during the life of the summer crop and urea was found to depress microbial biomass in the inorganic treatment (see below). Table 2 shows the significant orthogonal contrasts for these AOV's.

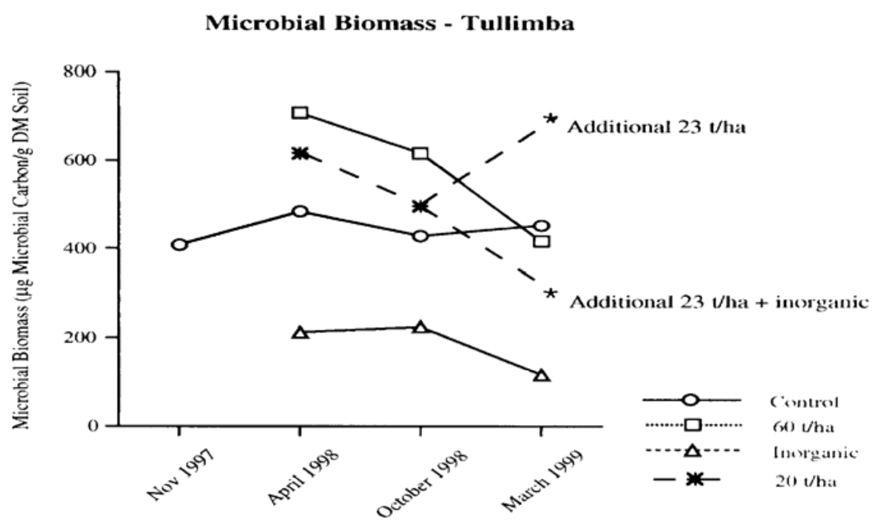

Figure 28: Soil Microbial Biomass for 4 sampling periods

Means for SMB were higher with lower levels of manure application (20 T/ha) but they were not significantly different to the control level in the April 1998 and October 1998 samplings (Figure 28). SMB in March 1999 had not increased to levels significantly higher than the control levels even after a second application of manure (23 T/ha) in October 1998.

Table 4.7: Means for SMB at Tullimba in manure and inorganic treatments for 3 sampling periods. (Within sampling periods, significant treatment effects (orthogonal contrasts) are indicated by dissimilar letters).

Sampling date	Control	20 t/ha manure	20 t/ha manure (+N)	60 t/ha manure (N added in 1999)	Inorganic
April 1998	481[a]	616[ab]		707[b]	208[c]
October 1998	425[a]	492[a]	615[b]	615[b]	223[c]
March 1999	449ab	649a	307b	413bc	115c

Inorganic fertiliser effects

In each sampling period, SMB values in soil treated solely with inorganic fertiliser declined to 30 per cent of the level of the control soil (Figure 28). The application of 23 T manure/ha in October 1998 as an additional treatment, may have reduced the adverse effect of the urea, as, although this treatment (20+23 T manure/ha) had lower mean values of microbial biomass than the control soil, this was not a significant (Figure 28). However, when the value for the biomass in this treatment (20+23 T manure/ha) was compared with biomass values of the same manure treatment but with urea applied over the growing season, there was a significant ($P<0.05$) depression of biomass in the latter treatment.

Free-living Nematodes

Responses of free-living soil nematodes to the manure and inorganic fertiliser treatments are shown in Table 4.8. Nematode numbers were significantly higher in the 60 T manure/ha treatment ($P<0.001$) than in the control treatment. Numbers in the control and 20 T manure/ha treatment were not significantly different. The addition of inorganic nitrogenous fertiliser increased numbers significantly above control values ($P<0.001$).

Table 4.8: Means for abundance of free-living soil nematodes (millions/ m^2) at Tullimba in manure and inorganic treatments in April 1998. Significant treatment effects (orthogonal contrasts) are indicated by dissimilar letters).

Treatment	Control	20t/ha Manure	60 t/ha Manure	Inorganic
Nematode abundance	0.846[a]	1.803[a]	6.085[b]	8.130[b]

Here "soil health" is viewed in the functional sense, where changes in soil biota are considered in relation to their essential roles in the soil ecosystem, the most important of which is the degradation of organic residues in manure and the release of contained nutrients. This may be impaired if organic wastes contain toxic products. For example, SMB in soils contaminated with heavy metals such as chromium or arsenic, may be less efficient in converting organic substrates into microbial biomass and need to use more energy for maintenance (Bardgett and Saggar 1994).

Soil microbes release nutrients from manures in a slow-release fashion. This is beneficial to the soil ecosystem as leaching of nutrients will be reduced. Soil microbes act as both a source of nutrients within the soil ecosystem, and as a sink of nutrients whereby nutrients are retained in topsoil where most biological activity is located, and are not so readily leached beyond the root zone. Microbes also act as indicators of soil health as they are sensitive to changes in the soil environment.

SMB increased as manure additions to soil increased. This result is similar to other studies that have examined effects on soil microbes of additions of organic amendments to cropping soil (Dick 1992; Fauci and Dick 1994; Gupta 1994, Paul and Beauchamp 1996). The treatments at the feedlot had received yearly applications of manure since 1988 that represented, in 2000, cumulative applications of over 110 and 385 t/ha at the lowest and highest manure levels respectively. Historically the cumulative applications would have been higher than this since the whole area had been manured at the rate of 10 kg/ha for many years prior to the treatments being imposed.

Manure additions have several effects on cropping soils. The additional carbon and nutrients supply energy and minerals for microbial growth. Increased levels of organic matter have beneficial effects on soil micro-climate and soil structure, both of which favour the development of higher levels of microbial populations in soil; soil moisture levels are conserved and water can infiltrate into soil more easily.

Other research has shown that manure applications increase microbial populations that decline gradually if fresh manure is not re-applied (Marshall 1977). Dick (1992) in his review of agricultural practices on soil microbes, concedes that, generally, fertiliser regimes that increase soil organic carbon, will ultimately increase soil microbial activity.

Manure additions to cropping soil in this project, increased levels of soil microbial biomass in heavily manured soils. Using SMB as one indicator of soil health, the manure additions at levels used in this project, appear to have little adverse effect on functional soil health.

4.2.5 Soil physical fertility

Many physical attributes in soils are influenced by soil organic matter and soil structure. All data of physical parameters were analysed but no significant effect of effluent or nitrogen was found on these parameters, therefore these treatments were used as additional replicates.

4.2.6 Soil Carbon

Total soil carbon (0-5 cm)

The upper 0-5 cm is more crucial with respect to different physical parameters and because of this data from the 0-5 and 5-10 cm layers are presented separately.

The application of 60 t/ha manure increased the total soil carbon in 0-5 cm depth from 25.00 mg/kg to 30.83 mg/kg about 5 months after manure application (Table 4.9). This treatment was significantly higher than the 20 t/ha manure and inorganic fertiliser treatments after the harvest of the first sorghum crop in year 1. After the harvest of the first triticale crop in year 1 there was no significant differences between treatments.

After the harvest of second sorghum crop in year 2 the 60 t/ha manure and inorganic fertiliser treatments had significantly higher total carbon as compared to 20+25 t/ha manure and control treatments. The total carbon after the second triticale crop in year 2 was highest in the 60t/ha treatment but this was not significantly different from the 20+25 t/ha manure and inorganic fertiliser treatments but was significantly higher than the control.

After the sorghum crop in year 3 the 20+25+20 t/ha manure treatment had the highest total carbon (29.44 mg/kg) but this was not statistically different from the 60 t/ha manure treatment but was significantly higher than the inorganic fertiliser and control treatment.

In the final soil sampling after the harvest of triticale in year 3 both the manure treatments and the inorganic fertiliser treatment had significantly higher total C than the control.

When the total C concentration in the uncultivated reference site was compared with the last soil sampling there was a reduction of 33, 2, 5 and 12 % in control, 20+25+20 t/ha, 60 t/ha manure and inorganic fertiliser treatments, respectively.

Table 4.9: Effect of feedlot manure on soil total carbon (mg/g) in the 0-5 cm soil layer during years 1, 2 and 3.

Treatments	**(Manure application rate t DM/ha)**			
Year 1	0	20	60	Inorganic
Year 2	0	25	0+N	Inorganic
Year 3	0	20	0+N+N	Inorganic
			Year 1	
Sorghum	15.74	16.63	20.75	15.51 ns
Triticale	17.20 ab	20.40 b	19.53 ab	15.55 a
			Year 2	
Sorghum	14.67 a	15.03 a	19.20 b	16.15 ab
Triticale	14.22 a	17.70 ab	19.80 b	14.66 ab
			Year 3	
Sorghum	18.06	22.39	22.83	19.51 ns
Triticale	14.32	19.35	19	20.23 ns

Numbers followed by the same letter in a row are not significantly different (P < 0.05)
ns (Non significant at P< 0.05)

Labile carbon (0-5 cm)

The labile carbon is the fraction of total carbon that can be readily oxidized. The labile carbon in the uncultivated reference soil at 0-5 cm depth was 5.39 mg/kg. After the harvest of the first sorghum crop in year 1 the maximum labile C concentration was found in the 60 t/ha manure treatment and this was significantly higher than the control and 20 t/ha manure treatments (Table 4.10). Both the manure treatments and the inorganic fertiliser treatment had similar labile C concentrations and these were higher than the control after the triticale crop in year 1.

The labile carbon concentration after the sorghum crop in year 2 was highest in the 60 t/ha manure treatment. At the end of second year there was a higher concentration of labile carbon in the manure and inorganic fertiliser treatments than in the control but the differences were not statistically significant. Both the manure treatments had a significantly higher concentration of labile C than the control and inorganic fertiliser treatments after the sorghum crop in year 3.

At the end of the experimental period both the manure treatments and the inorganic fertiliser treatment had similar labile carbon concentrations and these were higher than the control treatment. The differences between the reference site and the final values of the labile carbon were evaluated for the different treatments. A reduction of 33% was found in the control treatment. There an increase of 4, 3 and 9 % was found in the 20+20+20 t/ha, 60 t/ha manure treatment and inorganic fertiliser treatment in the upper 0-5 cm of soil.

Table 4.10: Effect of feedlot manure on soil labile carbon (mg/g) in the 0-5 cm layer during years 1, 2 and 3.

Treatments	(Manure application rate t DM/ha)			
Year 1	0	20	60	Inorganic
Year 2	0	25	0+N	Inorganic
Year 3	0	20+N	0+N+N	Inorganic
			Year 1	
Sorghum	2.83 a	2.99 a	4.39 b	2.70 a
Triticale	3.55 ab	4.63 b	4.68 b	3.23 a
			Year 2	
Sorghum	2.67 a	2.97 a	4.22 b	2.97 a
Triticale	3.93	3.57	4.25	2.83 ns
			Year 3	
Sorghum	3.51	4.85	4.92	3.77 ns
Triticale	2.86	4.39	4.39	4.11 ns

Numbers followed by the same letter in a row are not significantly different (P < 0.05)
ns (Non significant at P < 0.05)

Total carbon (5-10 cm)

The reference site had a concentration of 14.9 mg/kg total carbon at 5-10 cm. After the sorghum crop in year 1 all the treatments had similar total C concentrations (Table 4.11). In the second sampling after the harvest of triticale crop in year 1, both the manure treatments had the highest concentration of total carbon and the lowest carbon concentration was in the inorganic fertiliser treatment.

In year 2 after the harvest of the sorghum crop the maximum total C concentration was in the 60 t/ha manure treatment but this was similar to the inorganic fertiliser and higher than 20+25 t/ha manure and control treatments. At the end of year 2 the 60 t/ha manure treatment had the highest total C concentration.

After the harvest of the sorghum in year 3 there was an increase in total carbon in all treatments compared to the previous sampling and no significant differences were recorded between treatments in this year. All the treatments were found statistically similar during the third year. The total carbon concentration that was initially present at the reference site and the total carbon at the last soil sampling were used to determine changes in total C at 5-10cm depth. It was found that there was a reduction of 4% in the control treatment while there was an increase of 30, 28 and 36 % in 20+25+20 t/ha, 60 t/ha manure and in inorganic fertiliser treatments, respectively. This suggests that there was decomposition of plant roots and stubble and/or leaching of manure carbon into the lower depth.

Table 4.11: Effect of feedlot manure on soil total carbon (mg/g) in the 5-10 cm soil layer during years 1, 2 and 3.

Treatments	(Manure application rate t DM/ha)			
Year 1	0	20	60	Inorganic
Year 2	0	25	0+N	Inorganic
Year 3	0	20	0+N+N	Inorganic
			Year 1	
Sorghum	15.74	16.63	20.75	15.51 ns
Triticale	17.20 ab	20.40 b	19.53 ab	15.55 a
			Year 2	
Sorghum	14.67 a	15.03 a	19.20 b	16.15 ab
Triticale	14.22 a	17.70 ab	19.80 b	14.66 ab

Treatments	(Manure application rate t DM/ha)			
		Year 3		
Sorghum	18.06	22.39	22.83	19.51 ns
Triticale	14.32	19.35	19.00	20.23 ns

Number followed by the same letter in a row are not significantly different (P < 0.05)
ns (Non significant at P < 0.05)

Labile carbon (5-10 cm)

The reference site had a labile C concentration of 2.49 mg/kg. At the sampling after the sorghum crop in year 1 the maximum labile carbon concentration was found in the 60 t/ha manure treatment (Table 4.12). At the end of the first year the highest concentration of labile carbon was found in the manure treatments.

Soil samples taken after sorghum in year 2 showed that the maximum concentration of labile carbon was again in the 60 t/ha manure treatment. In the next soil sampling taken after harvest of the triticale crop in year 2 all the treatments had similar labile C concentrations. In the two soil samplings taken in year 3 there were no significant differences between treatments. However, there was an improvement in labile carbon concentration in all the treatments at 5-10 cm depth. The percentage increase over the reference was 15, 76, 76 and 65 % in the control, 20+25+20 t/ha, 60t/ha manure and an inorganic fertiliser treatment, respectively.

Table 4.12: Effect of feedlot manure on soil labile carbon (mg/g) in the 5-10 cm layer during years 1, 2 and 3.

Treatments	(Manure application rate t DM/ha)			
Year 1	0	20	60	Inorganic
Year 2	0	25	0+N	Inorganic
Year 3	0	20+N	0+N	Inorganic
		Year 1		
Sorghum	2.83 a	2.99 a	4.39 b	2.70 a
Triticale	3.55 ab	4.63 b	4.68 b	3.23 a
		Year 2		
Sorghum	2.67 a	2.97 a	4.22 b	2.97 a
Triticale	3.93	3.57	4.25	2.83 ns
		Year 3		
Sorghum	3.51	4.85	4.92	3.77 ns
Triticale	2.86	4.39	4.39	4.11 ns

Numbers followed by the same letter in a row are not significantly different (P < 0.05)
ns (Non significant at P< 0.05)

4.2.7 Aggregate stability

Table 4.13: Soil physical parameters throughout the experiment

	Year 1		Year 2		Year 3	
Sampled after	**Sorghum**	**Triticale**	**Sorghum**	**Triticale**	**Sorghum**	**Triticale**
MWD 0-5cm	1.2	1.7	1.6	1.2	1.2	1.1
MWD 5-10cm	1.2	1.7	1.6	1.2	1.3	1.2
%<125μm at 0-5 cm depth	17.4	9.7	11.6	14.0	14.0	
% <125μm at 5-10 cm depth	16.9	10.7	11.3	14.9	13.3	
%>250μm at 0- 5 cm depth	70.1	82.7	79.4	75.5	74.2	
%>250μm at 5-10 cm depth	70.8	81.5	79.5	73.0	74.8	

There was no significant effect of treatment on mean weight diameter (MWD) of aggregates, following immersion wetting, in the top 10cm of soil up until the end of the sorghum crop in year 3 (
Table **4.13**). The MWDs were all in excess of 1.1, indicating stable aggregates. Similarly the % of aggregates >250μm (macro-aggregates) remaining after immersion wetting was high in all treatments, which contributed to the high MWD. The % of aggregates <125μm remaining after immersion wetting (
Table **4.13**) was normal for this type of soil.

This data indicates that the soil at the experimental site is a stable one, and, the five high yielding crops and the addition of manure and inorganic nutrients has not resulted in deterioration of the soil structure. A major contributor to this has been the minimal use of cultivation between crops.

4.2.8 Soil moisture

There was an increase in the available water content in all the treatments over the control (Figure 29) at the measurement made at the end of year 2. The maximum increase was observed where 60 t DM/ha manure was applied in the first year. The available water contents in control, inorganic, 20+25+20 and 60t DM/ha were 0.197, 0.224, 0.222 and 0.247 g/cm^3, respectively.

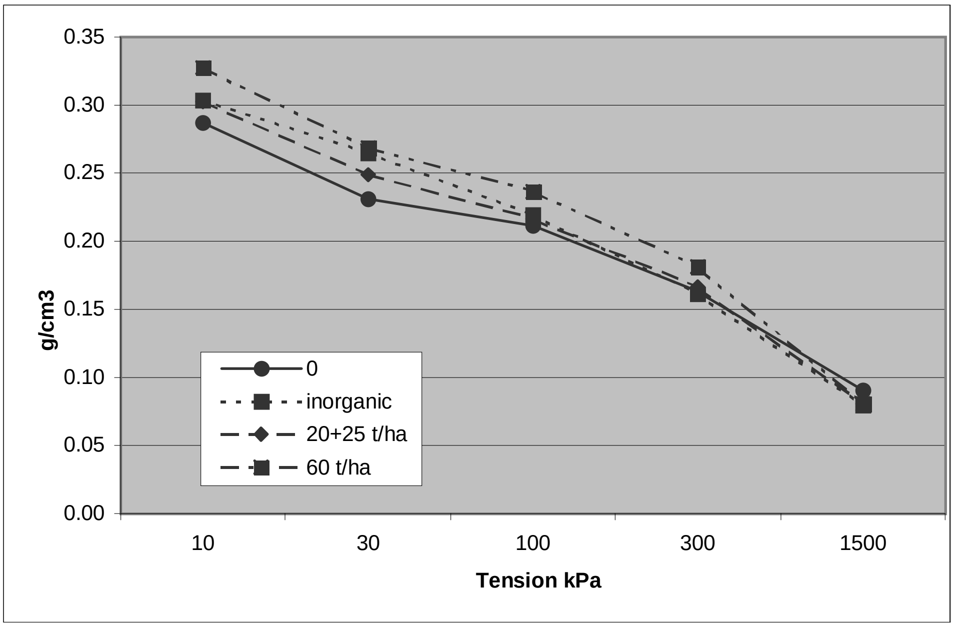

Figure 29: Effect of manure on the moisture retention after two years

Soil water storage and movement are influenced by soil properties, climate and management factors. These factors cannot be studies independently under the field conditions because of their interdependent effects on soil water content. Some of these factors, such an application of manure and other organic material, can greatly change the movement of water within the soil and its storage capacity. Until recently to measure these changes researchers mostly depended on intermittent measurement of soil water by various techniques. By these methods it was not possible to differentiate between different components of rainfall while the crop was growing.

In this study changes in soil water and the amount of surface runoff and subsurface drainage were monitored on a continuing basis. Data was collected throughout the experimental period and a sample of this is presented in Figure 30 where data from the 60 t/ha and 0 t/ha treatments are compared for a period of 186 days. This period commences 502 days after manure application and the growth of two crops of sorghum and one crop of triticale. The data set covers the whole growing period of the triticale crop in year 2. It starts on day 465 (April 10,1999) and ends on day 651 days (October 13, 1999). This period was selected to demonstrate the data as major rainfall and runoff events occurred at this time. The figures clearly indicated that application of manure reduced the amount of runoff and increased the moisture stored in the soil. The 60 t/ha manure treatment loss only a small amount of water in surface and subsurface flow and major proportion of rain water entered into the soil or was taken up by the crop. In the 0 t/ha (control) treatment a major portion of rainfall was lost in surface flow and sub-surface drainage. It is clear that the 0 t/ha manure treatment was only wet at the surface for a short period of time due to the higher amount of surface runoff. Water entered the soil profile better in the 60 t/ha treatment because it had a better infiltration rate and denser crop stand.

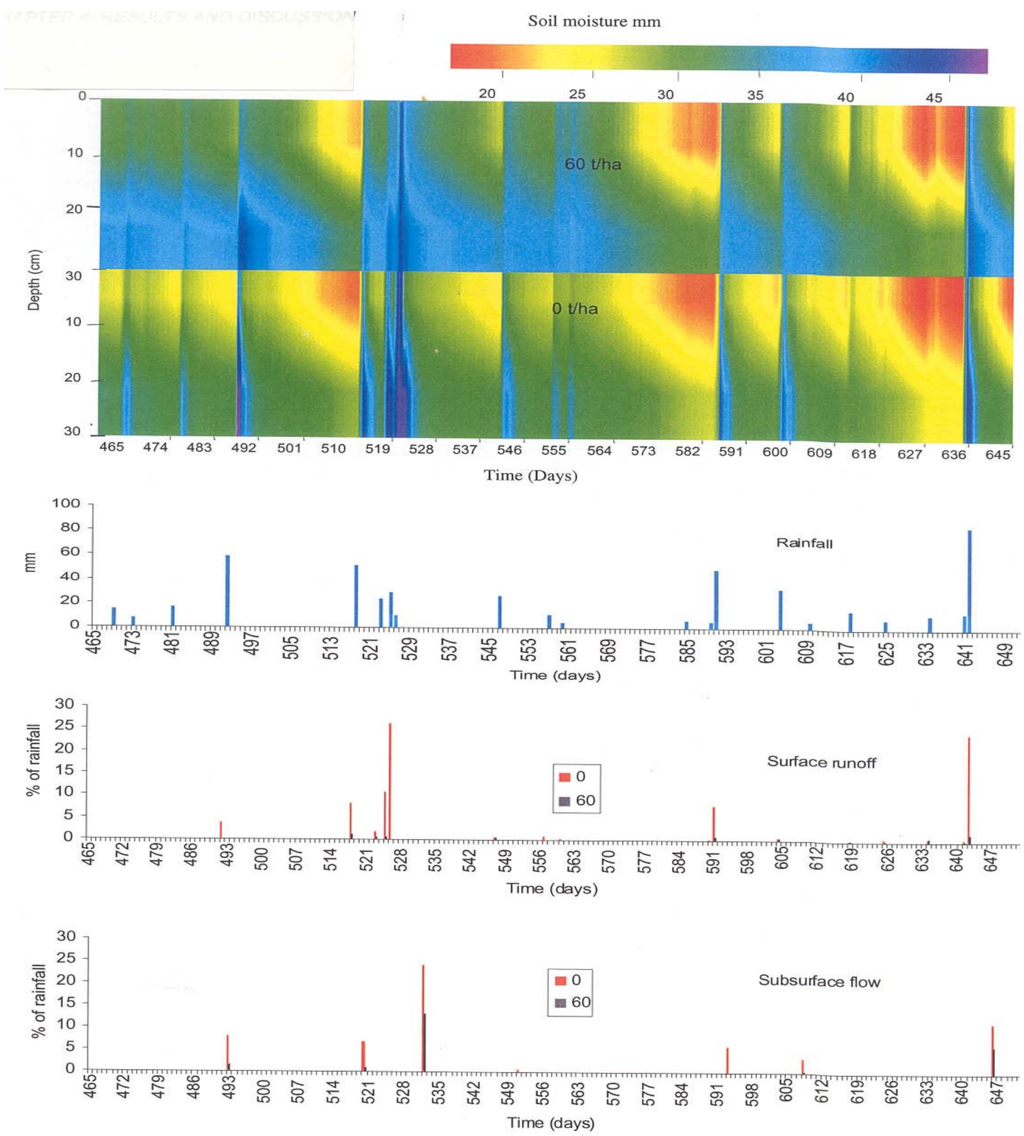

Figure 30: Effect of feedlot manure on soil water, surface runoff and sub-surface flow.

4.2.9 Soil Bulk density (BD)

Soil bulk density was measured at the end of years 2 and 3. In the first measurement, stones were separated from soil to determine BD without stones. Figure 31 shows that maximum BD was in the 0 t/ha manure treatment and this was significantly higher than the other treatments. When stones were removed and bulk density recalculated there was a reduction in BD which differed in magnitude in the various treatments. The maximum reduction was in the 20+25 t/ha manure treatment. The 0 t/ha treatment had a highest soil BD.

In year 3 there were no significant differences in BD between treatments but the control treatment tended to have the highest BD.

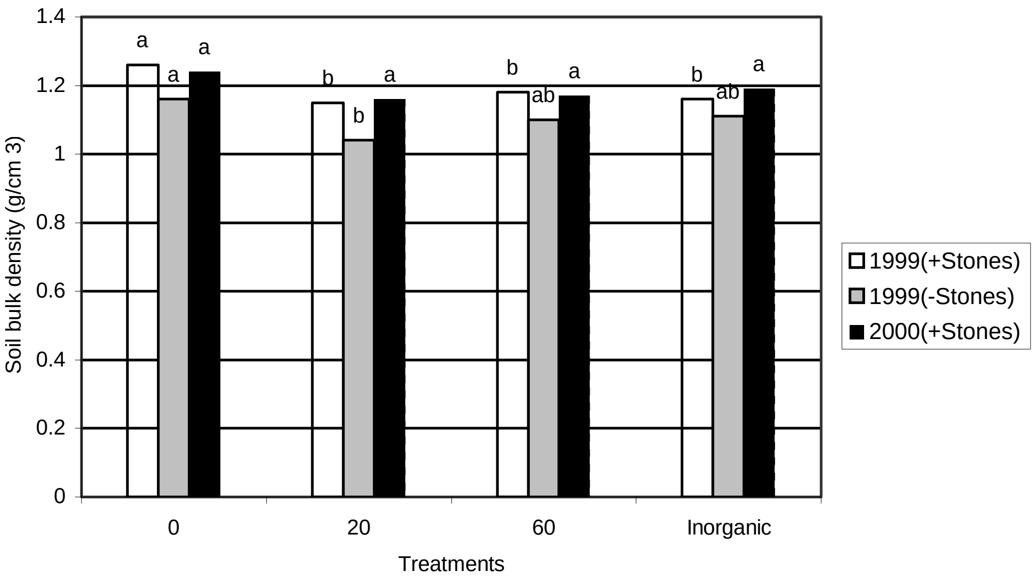

Figure 31: Effect of feedlot manure on soil bulk density (g/cm3) at 2 sampling times

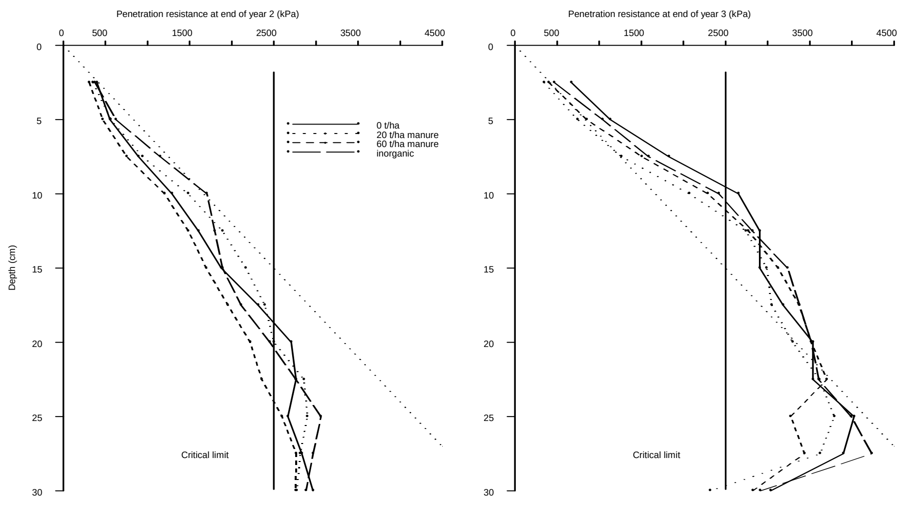

Figure 32: Effect of Feedlot manure on penetration resistance of soil (KPa)

4.2.10 Soil strength

The penetration resistance was measured two times during the experimental period. The first measurement was made at the end of year 2 and the second measurement was made at the end of year 3. There was large variation in the amount of stones within and between plots that caused problems during measurement. The results in Figure 32 are plotted as the mean of 2.5 cm depth intervals and there were no major differences between treatments. The measurements taken at the end of second year were generally lower as compared to the third year measurements. This was due to the difference in moisture content at the time of measurement (Table 4.14). At the first measurement time all the treatment exceeded 2500 KPa, the critical level where plant root growth is severely restricted (Taylor et al. 1966; Reeves et al. 1984), from the 18 cm to 30 cm depth (Figure 32). At the second measurement time all the treatments exceed the critical level below 10 cm.

Table 4.14: Water contents (%) in various treatments at measurement time

Treatments	**(Manure application rate t DM/ha)**			
Year 1	0	20	60	Inorganic
Year 2	0	25	0+N	Inorganic
Year 3	0	20+N	0+N+N	Inorganic
			Year 2	
0-10 cm	25	26	24	22
10-20 cm	19	18	19	17
20-30 cm	17	15	15	15
			Year 3	
0-10 cm	17	18	19	18
10-20 cm	16	15	16	14
20-30 cm	15	13	14	13

4.2.11 Water Infiltration

Water infiltration is a key factor that controls the surface runoff of water. Water infiltration was measured after the harvest of each crop. In the case of sorghum this was after the second cut. The results (Table 4.15) after sorghum in year 1 showed that treatments were different from each other at 40 and 30 mm but not at 20 and 10 mm tension. Manure application at 60 t/ha increased water infiltration at all the tensions with little difference between the 20 t/ha manure, control and inorganic fertiliser treatments. No significant differences were measured after the harvest of triticale in year 1. After the sorghum crop in year 2 treatments were significantly different only at 10 mm tension. The maximum rates was recorded in the 60 t/ha manure treatment and the minimum was recorded in the control treatment. The water infiltration results measured after the harvest of triticale in year 2 showed that there were no significant differences between treatments at any tension. The infiltration rate at 10 mm remained at higher values in manure treated plots as compared to inorganic fertiliser and control treatments.

After the harvest of sorghum in year 3 the water infiltration rate at 10 mm tension was significantly lower in the control than in the other treatments. In the final measurement made after the harvest of triticale in year 3 treatments there were significant differences between treatments at all tensions with the lowest infiltration rate in the control at all tensions. Overall manure resulted in an improvement in the water infiltration rate and this was reflected by the lower surface runoff from the manure treated plots as compared to control and inorganic fertiliser treatments.

Table 4.15: Effect of feedlot manure on water infiltration rate at 10 mm tension (mm/hr) during years 1, 2 and 3.

Treatments	(Manure application rate t DM/ha)			
Year1	0	20	60	Inorganic
Year2	0	25+N	0+N	Inorganic
Year3	0	20+N	0+N+N	Inorganic
Year 1 Sorghum	291.8	273.6	370.3	269.5 ns
Year 1 Triticale	155	237.4	236.7	131.4 ns
Year 2 Sorghum	175.1 a	238.8 ab	340.2 b	188.5 ab
Year 2 Triticale	145.9	252.6	233	137.5 ns
Year 3 Sorghum	162.4 a	246.9 b	283.7 b	265.0 b
Year 3 Triticale	119.4 a	284.7 b	339.3 b	331.0 b

Numbers followed by the same letter in a row are not significantly different (P< 0.05)
ns (Non significant at P< 0.05)

4.2.12 Runoff

Cumulative Surface Runoff

The amount and quality of surface runoff plays an important role in the management and utilization of manure as an agricultural input for crop production. The cumulative surface runoff over three years of the experimental period is presented in Figure 33. The results show that the highest amount of surface runoff was from the control treatment followed by the inorganic fertiliser treatment. The behaviour of 20+25+20 t/ha manure treatment showed that as the manure application in this treatment increased with time the difference in surface runoff between this treatment and the inorganic fertiliser increased. The lowest amount of cumulative surface runoff was in 60 t/ha manure treatment.

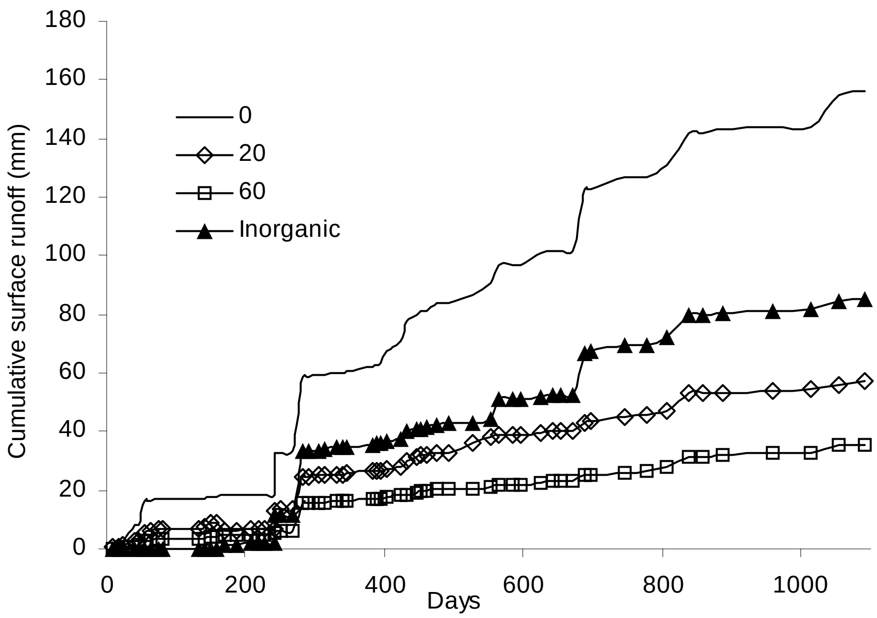

Figure 33: Effect of feedlot manure on the cumulative surface runoff (mm) of water

Cumulative subsurface runoff

The amount of subsurface runoff gives an indication of the soil moisture retention capacity and speed of water uptake by the crop. The cumulative subsurface runoff from different treatments is presented in the Figure 34. The results show that there was a minimum amount of subsurface runoff in the 60 t/ha manure treatment as compared to the other treatments. The 20+25+20 t/ha manure treatment had the same amount of subsurface runoff as the control and inorganic fertiliser treatments. The most likely reason for this is that one of the replications of this treatment had a high amount of stones (20%) in the upper surface and the depth to the B horizon was also small as compared to the other plots. It is likely that these two factors resulted in an extraordinary subsurface flow although surface flow was normal.

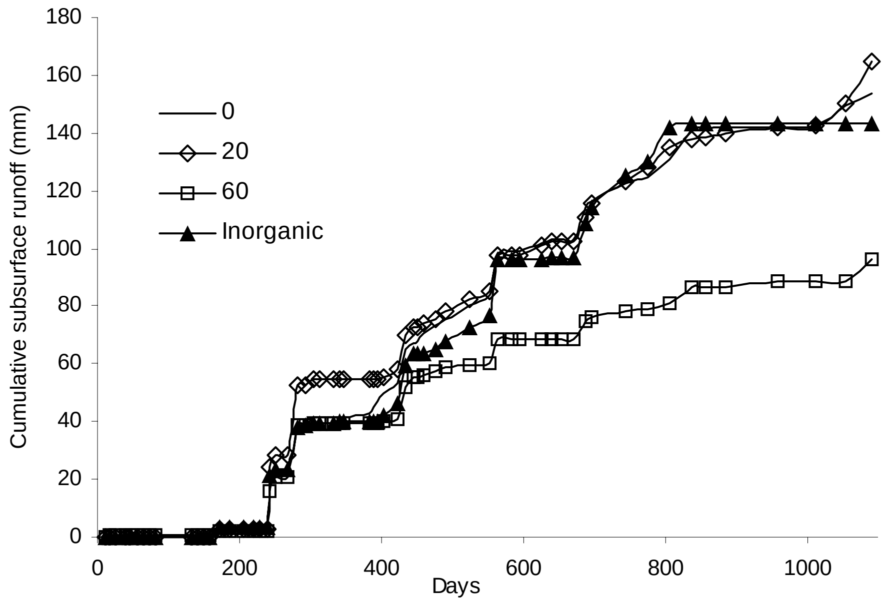

Figure 34: Effect of feedlot manure on the cumulative subsurface runoff (mm)

The distribution of surface runoff events

The number of surface runoff events in the different treatments has been classified (Table 4.16) into six categories. The maximum number of runoff events fell under the 0-0.5% category. The maximum number of events in this category was in the 60 t/ha manure treatment. In the second category (0.5-1.0 %) the lowest number of events was recorded in the 60 t/ha manure treatment. In the third category (1.0-5.0%) only one event occurred in the 60t /ha manure treatment while 22 events were recorded in the control treatment. In fifth and sixth categories no event occurred in manure treatments and all in control and inorganic fertiliser treatment.

Table 4.16: Number of runoff events classified according to loss expressed as % of incident rainfall

Loss as % of incident rainfall	**(Manure application rate t DM/ha)**			
	0	20	60	Inorganic
	0	25+N	0+N	Inorganic
	0	20+N	0+N+N	Inorganic
0.0-0.5	133	147	161	51
0.5-1.0	6	7	3	6
1.0-5.0	22	10	1	6
5.0-10.0	2	2	1	2
10.0-20.0	1	0	0	1
20.0-30.0	2	0	0	1

4.2.13 Nutrient losses in surface runoff, subsurface flow and sediment

In year 3 the loss of N, P, K and S in water as surface runoff and subsurface flow was higher in the 20 t/ha manure (-N) treatment compared to the other manure treatments (Table 4.17). The same trend was found in the total loss of nutrients in water flows over the 3 years. The next highest losses were in the inorganic treatment. The substantially lower loss of nutrients in the 20 (+N) treatment indicated that manure should be supplemented with inorganic N to prevent the loss of nutrients to the environment and to obtain a maximum nutrient capture by the crop and consequently higher crop production. The loss of nutrients from the inorganic fertiliser was high due to high solubility of the fertiliser. Increasing the splits in application could reduce these losses.

Table 4.17: Nutrients removed by surface runoff and subsurface flow (kg/ha)

Nutrient	**Loss**	0	20	20	60	Inorganic
		0	25	25+N	60+N	Inorganic
		0	20	20+N	60+N	Inorganic
NH_4-N	Surface	0.26	0.31	0.13	0.14	0.18
	Sub-surface	0.13	0.08	0.05	0.05	0.17
	Total	0.39	0.38	0.18	0.18	0.35
NO_3-N	Surface	1.30	2.06	0.50	0.47	2.61
	Sub-surface	5.24	16.41	4.15	3.20	12.42
	Total	6.54	18.47	4.65	3.67	15.02
P	Surface	0.32	1.85	0.29	0.91	0.51
	Sub-surface	0.26	1.99	0.16	0.57	0.42
	Total	0.57	3.84	0.45	1.48	0.93
S	Surface	1.71	2.55	0.49	0.68	3.38
	Sub-surface	4.19	17.22	7.24	7.33	15.79
	Total	5.91	19.77	7.73	8.02	19.17
K	Surface	10.24	7.64	3.01	3.65	5.35
	Sub-surface	5.98	6.52	1.63	1.27	4.96
	Total	16.22	14.16	4.64	4.92	10.31
Na	Surface	23.39	16.93	5.21	5.92	8.21
	Sub-surface	47.22	87.12	35.53	47.27	43.08
	Total	70.60	104.05	40.74	53.19	51.29

The loss of nutrient through sediment was negligible due to low sediment loss in all treatments (Table 4.18). Total N and K loss in sediment amounted to about 1 kg/ha while the loss of other nutrients was very small. The low slope (2 to 4 %), generally gentle rainfall and relay cropping all contributed to this low loss.

Table 4.18: Nutrients lost in sediment (kg/ha)

Nutrient	(Manure application rate t DM/ha)				
	0	20	20	60	Inorganic
	0	25	25+N	60+N	Inorganic
	0	20	20+N	60+N	Inorganic
N	0.94	0.94	0.86	1.03	0.61
P	0.15	0.19	0.17	0.21	0.11
K	1.18	1.01	0.77	0.94	0.60
S	0.08	0.09	0.08	0.02	0.11

The total loss of nutrients in both water and sediment was lowest in the 60 t/ha treatment and much higher in the 20 t/ha manure without N treatment than in the 20 t/ha manure with N treatment (Table 4.19).

Table 4.19: Total nutrient removal by surface runoff, subsurface flow and sediment (kg/ha)

Nutrient	(Manure application rate t DM/ha)				
	0	20	20	60	Inorganic
	0	25	25+N	60+N	Inorganic
	0	20	20+N	60+N	Inorganic
N	7.94	19.94	8.86	5.03	15.61
P	1.15	4.19	1.17	2.21	1.11
K	16.18	15.01	7.77	5.94	10.60
S	6.08	20.09	12.08	8.11	19.06

4.3 Work Area 3 – Field trials at Beef City Feedlot

4.3.1 Crop Yields

During 1997 to 2000 three crops were grown on the trial area. These were a winter crop of triticale in 1997 and summer maize crops in 1998 and 1999. Each of these crops were sampled in order to determine the dry matter yield and plant nutrient concentration. The data from this sampling is presented in the following sections.

Average dry matter yields for each treatment were determined by crushing, drying, and weighing the plant matter collected from the quadrats. The average dry matter yield for the 1997 triticale crop was about 8 t/ha across the treatments. The maximum yield was 10.0 t/ha on the 25 t/ha manure treatment and the lowest was 6.9 t/ha from the 0 t/ha manure treatment. A plot of yield against increasing manure treatment is shown in Figure 35.

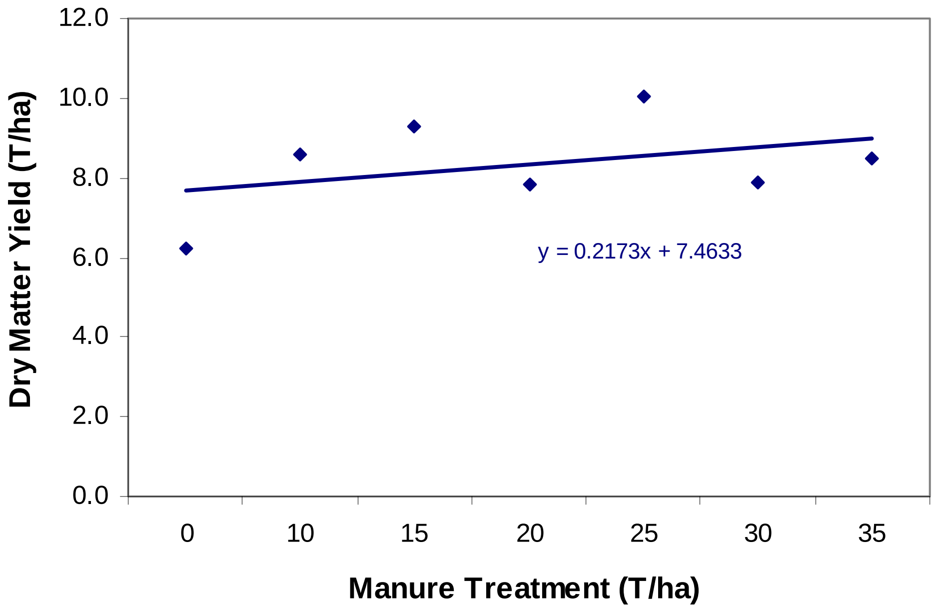

Figure 35: Mean yield for the 1997 triticale crop grown at the feedlot manure trial site.

The above figure shows that there is a slight trend of increasing yield with increasing manure application however this line is influenced by the high yield obtained from the 25 t/ha treatment and the low yield of the 0 t/ha treatment. Comparing all treatments shows no significant difference between yield and manure application rates.

The results from the maize crops show some positive correlations between manure application rates and dry matter yield. The 1998 crop data show a distinct difference between the 0 to 20 t/ha and the 25 to 35 t/ha manure treatments. The average dry matter yield for these collective treatments was 22.9 and 37.2 t/ha respectively. The average dry matter yield for this crop across all treatments was 29.0 t/ha.

The maize crop grown in the 1999/2000 summer produced very similar yields across all treatments. The average dry matter yield of 30.5 t/ha for this growing season was similar to the 1998 crop, however across the treatments the dry matter yields only ranged from 28.0 t/ha (15 t/ha manure) to 33.0 t/ha (35 t/ha manure). The dry matter yields for both the 1998 and 1999 maize crops are shown in Figure 36.

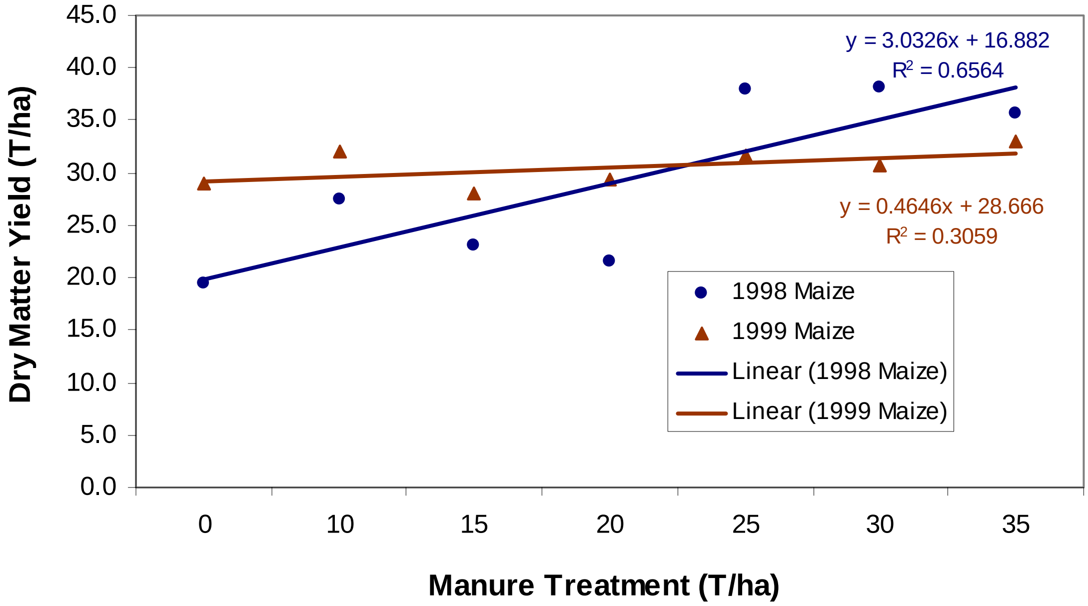

Figure 36: Mean yields for the 1998 and 1999 maize crops grown at the feedlot small plots.

4.3.2 Nutrient Concentration

The results of the crop analysis that was undertaken during the trial has shown that there is some correlation between crop nutrient concentrations and increasing manure application rates. shows the relation between mean plant tissue concentration of phosphorus and increasing manure treatment for the 1997 triticale crop.

A noticeable difference is found between the plant phosphorus concentrations from the 0 to 15 t/ha manure treatments and the 20 to 35 t/ha manure treatments. The average plant phosphorus concentration across the three lower manure application treatments was found to be 0.21 %, while the remaining four higher manure application treatments averaged 0.25 %. As such, a general positive correlation was found in plant tissue concentration of phosphorus in the 1997 triticale crop and increasing manure application.

The plant nutrient analysis of the maize crops show some differing trends compared to the earlier triticale crop. As shown in Figure 38, the 1998 maize crop did exhibit a slight increase in plant tissue phosphorus concentration with increasing manure application rate. It is noted however, that this correlation was not as distinct as the one exhibited by the triticale crop.

The results from the 1999 maize crop show a differing trend. Low phosphorus concentrations in the plant tissue harvested from the 30 and 35 t/ha treatment plots create an apparent negative correlation between P plant tissue concentration and increasing manure treatment. Comparisons of the other treatment plots show little difference in plant tissue P concentrations as shown in Figure 38. This may be the result of ‘dilution’ of nutrient as a function of increased dry matter yield.

While trends suggest various relationships between plant nutrient concentration and soil nutrient levels no significant differences occur with the nutrients, N and P. Significant relationships did occur between other nutrient concentrations or soil nutrient levels including S and Zn.

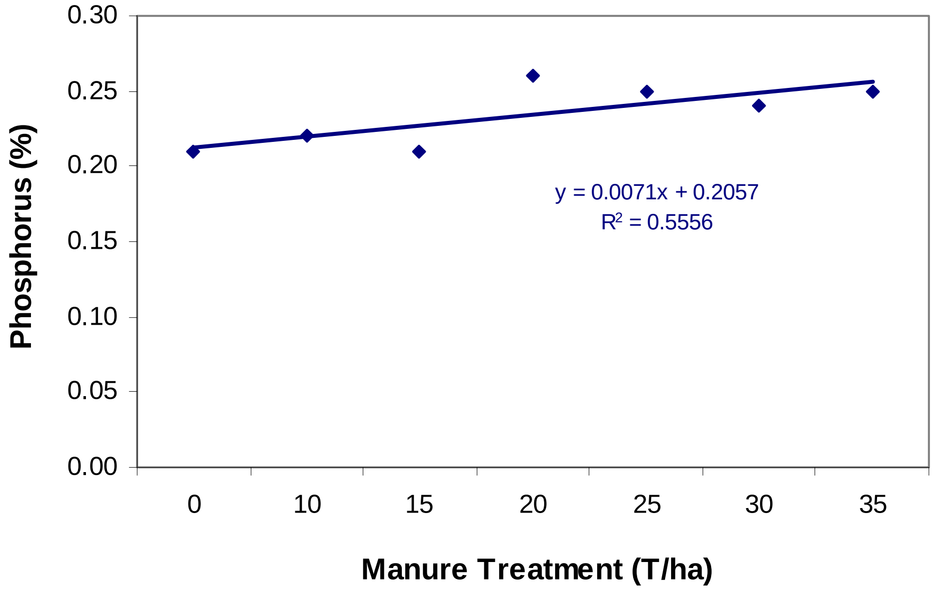

Figure 37: Mean plant tissue concentration of phosphorus for the 1997 triticale grown at the feedlot trial site.

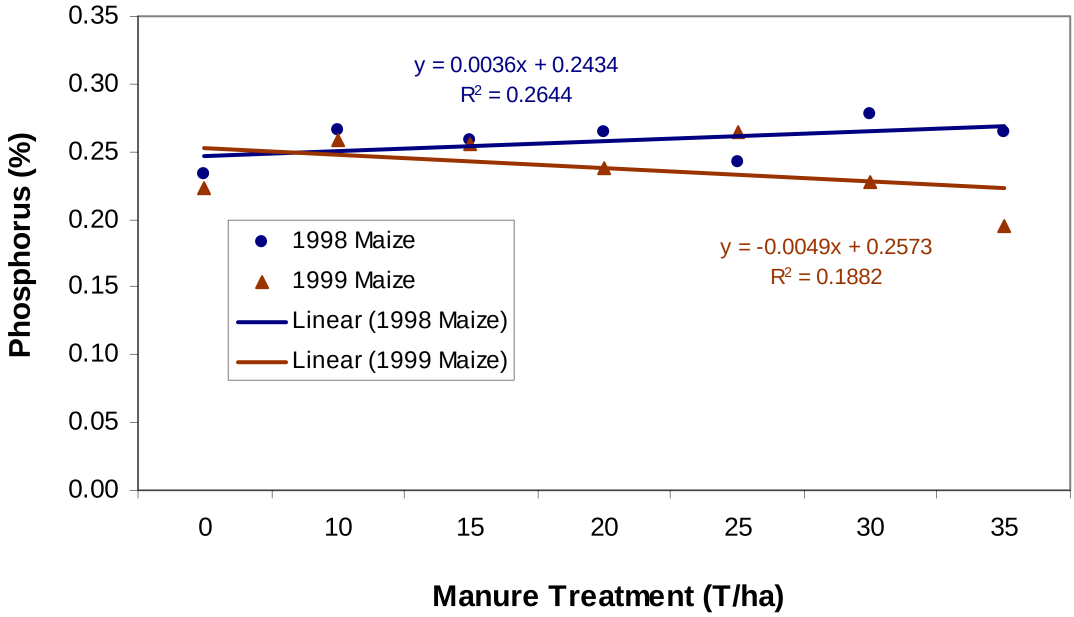

Figure 38: Mean plant tissue concentration of phosphorus for the 1999 and 2000 maize grown at the feedlot small plots.

4.3.3 Soil

Physical

The physical characteristics of the soils at the site have been reported in detail by Murdoch (1999). The results showed, generally, that surface soil bulk densities decreased slightly with manure application rate. However these positive effects did not exist in the deeper soil. The application of high rates of (ie. ~35 t/ha) manure resulted in up to five passes of the manure spreading trucks over a given area. Sub-soil bulk densities generally increased with the rate of manure application. These resulted in increased compactive forces associated with the multiple passes of the trucks. Surface tillage and the self mulching characteristics of the soil quite obviously alleviated surface compaction resulting from the spreading operations.

Chemical

Various soil analyses were undertaken over the trial period to determine the long term changes to soil chemistry. The results of some of these analyses and the trends that were observed over the trial period are presented in this section. Soil samples were collected in 1998. Unfortunately the data were found to be erroneous.

The soil organic matter (SOM) levels were determined through the trial period from 1992 to 2000. The data from 1992 show that the SOM levels in the top 150 mm of the soil profiles across the trial site were between 6 to 8 %. At the final sampling in 2000 it was found that SOM levels had decreased to within 2 to 3.5 % across the site.

As shown in **Figure 39**, the higher manure treatments of 20 to 35 t/ha had the effect of maintaining SOM levels in the surface soils, compared to that of the 10 and 15 t/ha treatments. This is most evident in the period of 1995 to 1999 where the SOM levels of the 10 and 15 t/ha treatments were reduced from around 5 to 6 % to below 3 %. In this same period, the 25 and 30 t/ha treatments experienced a minor decrease in SOM levels of approximately 0.7 %. Likewise the decrease in SOM in the 20 and 35 t/ha treatments was only 0.9 %.

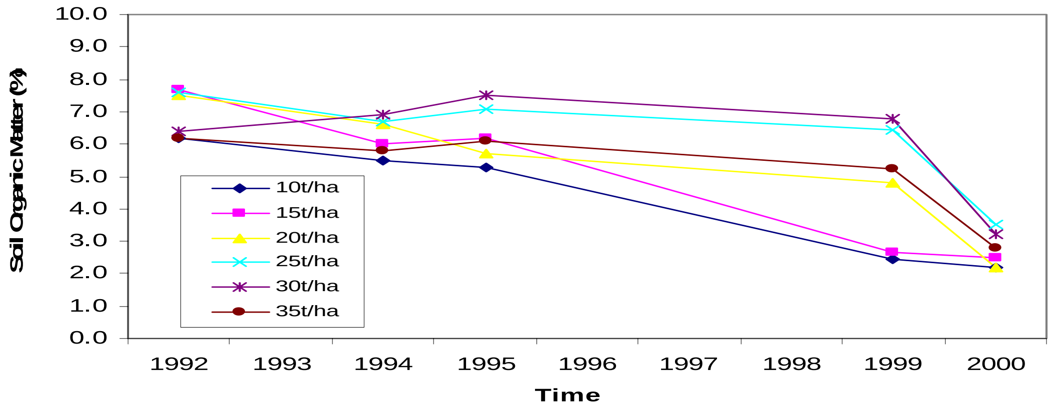

Figure 39: Mean concentration of soil organic matter (%) found in the black earth (0 - 150 mm) of the trial site under six different manure treatments.

The total organic carbon levels declined in the top 10 cm of soil for all treatments receiving less than “25 t/ha” of manure. Carbon levels in the 10-30 cm depth have declined by as much as 3% in the last 12 years. So while heavy rates of OM applications through manure spreading can maintain surface soil carbon levels, increased mineralisation of OM in irrigated agri-ecosystems as a result of increased moisture contents and tillage will reduce carbon concentrations in the soil over time. The data show that the rate of mineralisation is linked to manure application rate. The highest manure application rate, while with the highest surface soil carbon concentration, has the greatest microbial population yet it has the least amount of labile carbon. This is shown in Figure 40.

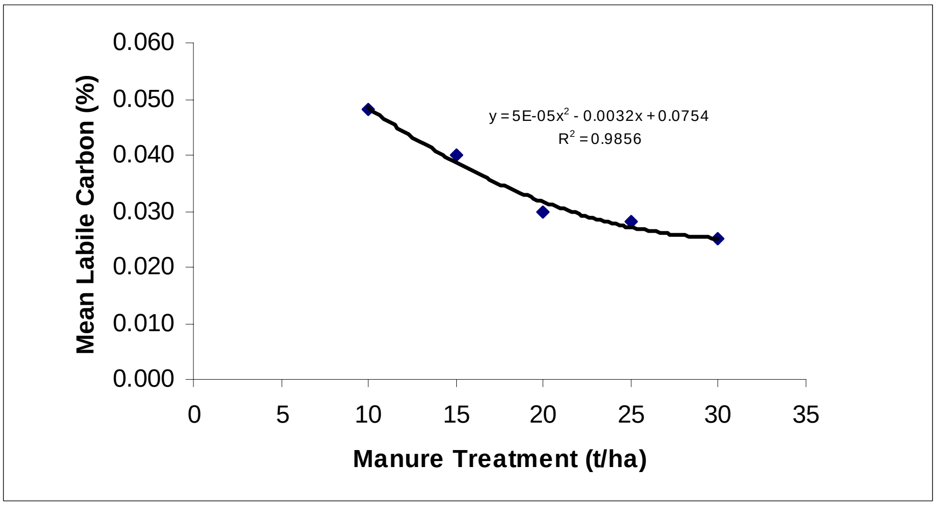

Figure 40: The mean concentration of labile carbon present (%) in ‘Feedlot B’ black earth (0-10 cm) under increasing rates of manure application.

Figure 41and Figure 42show the changes in sodium levels of the surface soils over the trial period. The data show that in general there has been an increase in sodium levels over the trial period. This increase is greater in then surface soils (Figure 41) compared to the 150 to 300 mm profile (Figure 42). The data show that all treatment areas exhibit similar trends. This is because the primary source of sodium is from feedlot wastewater, which was applied equally across the treatment areas. The salinity threshold (EC_{se}) for maize is 1.8 dS/m (Peverill *et al*., 1999). Wastewater irrigation has lead to the soil becoming saline under the higher rates (>25t/ha) of manure application. If soil salinity increases beyond the level of 1.8 dS/m it is expected that a 7.4% reduction in dry matter yield will occur for every 1 dS/m increase in soil electrical conductivity (Peverill *et al*., 1999). If salinity increases to 5.2 dS/m only 75% of potential yield may be achieved. If this level of salinity was to increase to 8.8 dS/m then the potential yield may be reduced by 50%.

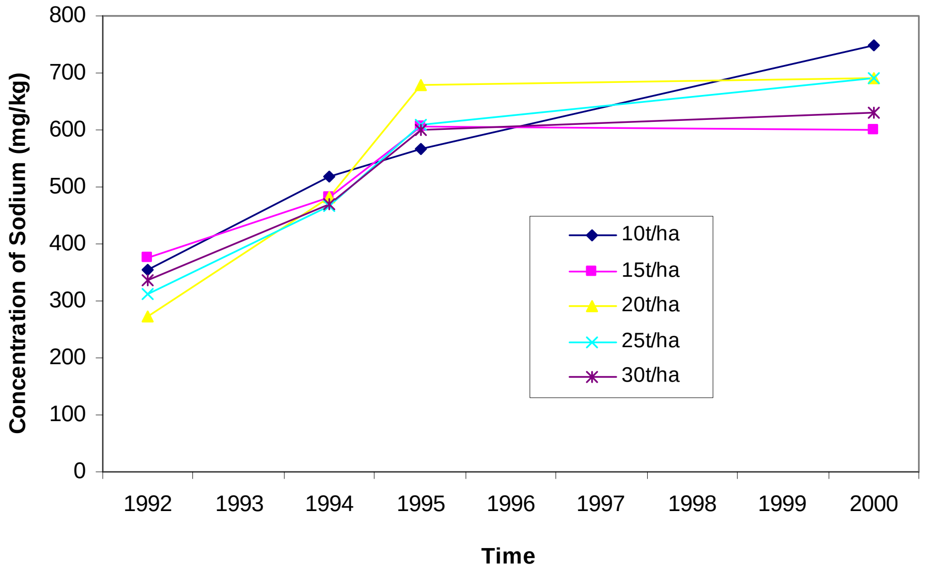

Figure 41: Sodium concentrations found in the black earth (0 - 150 mm) of the trial site under five different manure treatments.

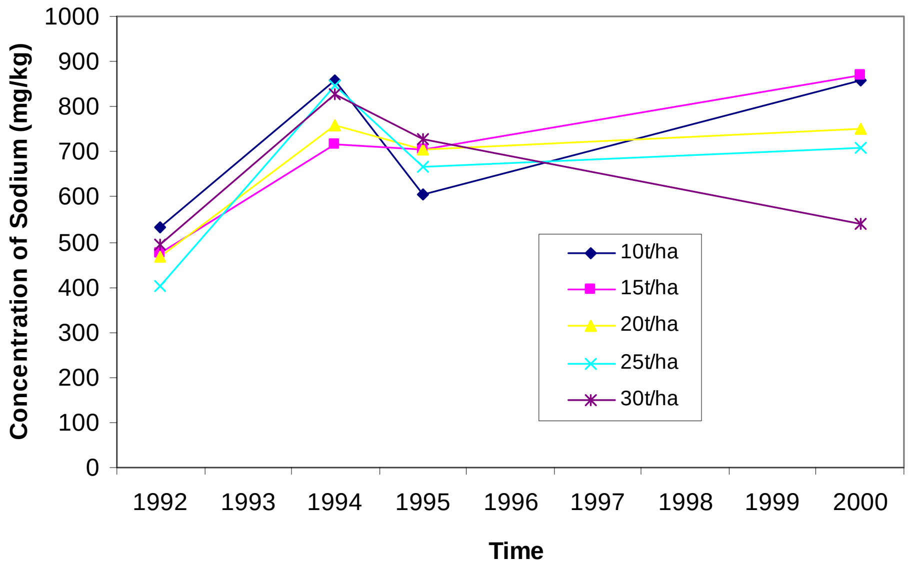

Figure 42: Sodium concentrations found in the black earth (150 - 300 mm) of the trial site under five different manure treatments.

The native soils at this site are strongly buffered as a result of its mineralogy. The addition of manure adds to the buffering capacity of the soil. This limits the affects of further large additions of nutrient etc. However, the presence of significant quantities of ions in the soil solution can give rise to salinity. The reduced yield in the 1999 maize crop at high manure application rates is most likely to be a result of increased salinity caused by the manure and the addition of ions in both the manure and wastewater. The soil EC_{se} in 1999 was higher than 1998 as a result of 'salt' buildup in surface soils following wastewater irrigation during dry seasons. It is noted that the EC_{se} of the soil is in most cases above 2 dS/m and at a level that could potentially reduce crop yields.

The additions of manure and effluent increased soil electrical conductivity with time. Conductance is increased through ions of N and P as well as other salts such as Na and K. The amount of Na added to the soil equates to about 350-500 kg/ha/yr. This is not removed in either crop harvest and very little is lost through leaching. Because sodium is not removed, levels of Na have steadily increased in the soil. While the increase in Na can be mitigated through the addition of gypsum the exchange capacity of the soil is such that the application rates will be massive. Soil electrical conductivity increased with depth in the profile. Subsoil sodicity together with deep soil compaction will result in severely limited percolation below the root zone.

The methods of determining soil phosphorus has varied over the duration of the trial. The most complete set of historical data is from the period 1992 to 1995 where soil P was determined using the Bray 1 method. Soil P was also determined with this method in 2000. Figure 43 shows the amount of phosphorus in the soils sampled from the 15 t/ha treatment plot over the trial period.

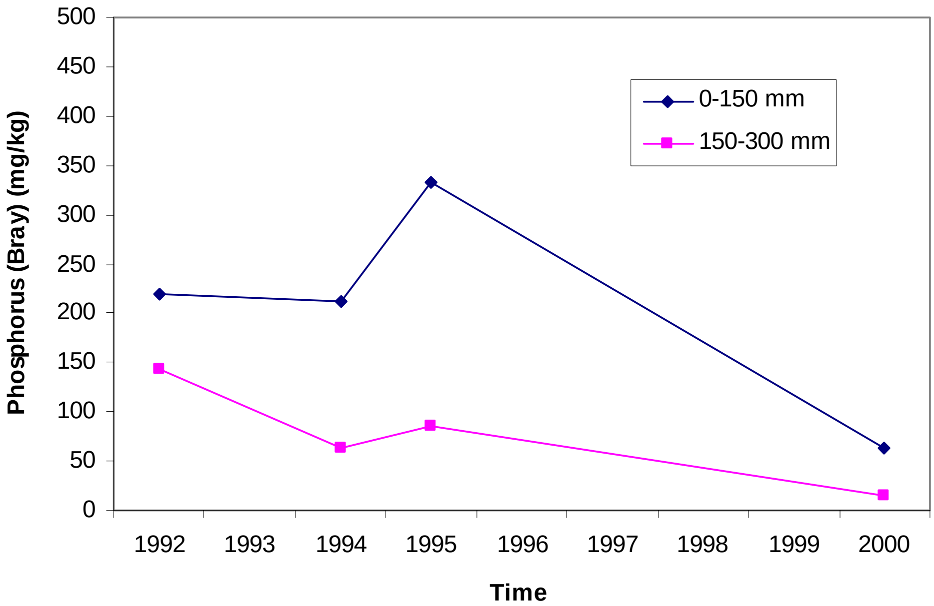

Figure 43: Phosphorus (Bray 1) levels for 15 t/ha treatment at two depths from 1992 to 2000.

These data show that the amount of immediately available soil P has reduced with time. In contrast to this are data for total P (TP), which shows TP to be increasing.

4.3.4 Soil Microbial Biomass

During the trial period surface soil samples were collected from the small plot areas for the purpose of determining soil microbial populations. This was done in order to study the cumulative effects of manure application on soil microbial mass (SMB).

In both years, there was a positive relationship (Figure 44) between SMB and levels of SOC (1999:$P<0.05$; $r^2=0.742$; 2000: $P<0.01$; $r^2=0.893$). Both the microbial biomass and organic carbon levels increased linearly with increasing manure additions to the cropping soil.

Significant microbial dysfunction due to high levels of manure addition would have been reflected by substantial curvilinearity in the relationships, but this was not evident.

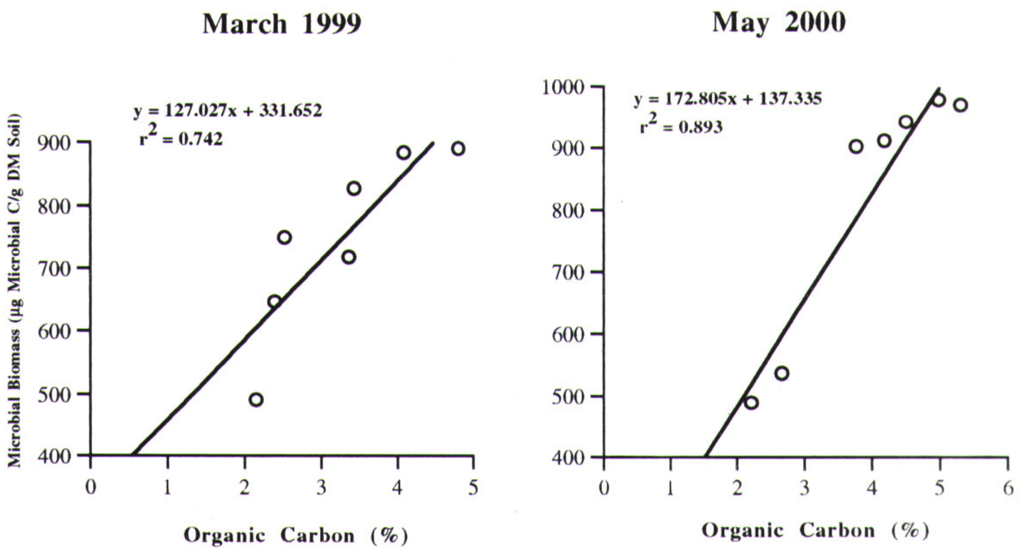

Figure 44: Relationships between soil microbial biomass and soil organic carbon in the feedlot soil in the autumn of 1999 and 2000.

It was also determined that the long term application of manure at the trial site had no adverse effect on the build up of SMB.

4.3.5 Manure and Wastewater Application

The feedlot had only crudely measured the amount of manure that was applied to each strip over the years 1988 to 1997. The direct measurement of the manure application rates showed that the application rates across the strips were higher than originally thought. The comparative application rate data for the treatments are presented below in Table 4.20.

Table 4.20: Proposed versus actual manure application rates in each of the treatment areas 1997-2000.

Treatment	Proposed manure application rate (t DM/ha)	Actual average manure application rate (t DM/ha)
Plot 1	10	12.7
Plot 2	0	0
Plot 3	15	15.7
Plot 4	20	21.2
Plot 5	25	29.1
Plot 6	30	38.7
Plot 7	35	51.7

Average data for all of the manure chemical analyses are presented in Table 4.21. The moisture and mineral analysis show that the moisture content and nitrogen concentration of the manure is highly variable. These vary as a function of the age of manure and the position in the stockpile from which the manure is drawn. Exposure of the manure to the environment results, in volatilisation of nitrogen, and either dry or wet manure.

Table 4.21: Average chemical analysis results for manure collected during the period of study.

Parameter	Average	Standard deviation
Moisture content (%)	21.6	21.5
N (%)	2.42	0.44
P (%)	1.04	0.07
S (%)	0.87	0.14
K (%)	2.96	0.24
Ca (%)	2.12	0.14
Mg (%)	.093	0.06
Na (%)	0.45	0.18
Zn (µg/g)	467.7	137.8
Cu (µg/g)	44.5	6.18

The amount of wastewater applied to the crop varied from year to year depending on available supply, dilution with bore water and crop demand. The triticale and 1998 and 1999 maize crops received 65, 220 and190 mm of wastewater irrigation respectively. The average analysis of the applied wastewater for the study is shown in Table 4.22.

Table 4.22: Average wastewater characteristics for the feedlot between the period 1998-2000.

Parameter	Unit	Average	Standard Deviation
Electrical Conductivity (EC)	µS/cm	1732	855
PH		8.43	0.02
Total Dissolved Solids (TDS)	mg/L	1700	404
Total Solids (TS)	mg/L	2250	507
Total Suspended Solids (TSS)	mg/L	550	312
Volatile Solids (VS)	mg/L	1022	287
Nitrate ($N\text{-}NO_3$)	mg/L	4.67	3.24
Ammonium ($N\text{-}NH_4$)	mg/L	128	17.0
Total Kjeldahl Nitrogen (TKN)	mg/L	133	20.2
Phosphate (PO_4)	mg/L	17.2	5.35
Total Phosphorus (TP)	mg/L	98.1	20.3
Sulphate (SO_4)	mg/L	8.82	1.70
Sodium (Na)	mg/L	136	48.2
Calcium (Ca)	mg/L	16.3	1.2
Potassium (K)	mg/L	226	98.8
Magnesium (Mg)	mg/L	30.5	10.1
Sodium Adsorption Ratio (SAR)		4.6	1.2
Chloride (Cl)	mg/L	555	226
Copper (Cu)	mg/L	0	0
Zinc (ZN)	mg/L	0.14	0.04
Manganese (Mn)	mg/L	0.06	0.01
Iron (Fe)	mg/L	0.70	0.19

4.3.6 Environment

Rainfall/Runoff

Rainfall was measured at a pluviometer at the site of the plots and 1.5 km away from the feedlot's weather station. The plots were also located about 1 km from the Mt Irving station.

Figure 45 shows the historical annual rainfall data from 1988 to 2000 for the Mt Irving station. This figure also shows the annual rainfall totals recorded at the site from 1998 to 2000.

In these years all of the seasons could be described as dry. Rainfall totals were increased with a few large rainfall events. Below average rainfall was received during the trial period from 1997 to 2000. (The data also show that a prolonged drought was experienced from 1990 to 1994). Extremely dry conditions were experienced in late 1999 and 2000, which lead to no runoff occurring within this period. As such, little effluent was generated at the feedlot, thereby reducing the amount of wastewater irrigation.

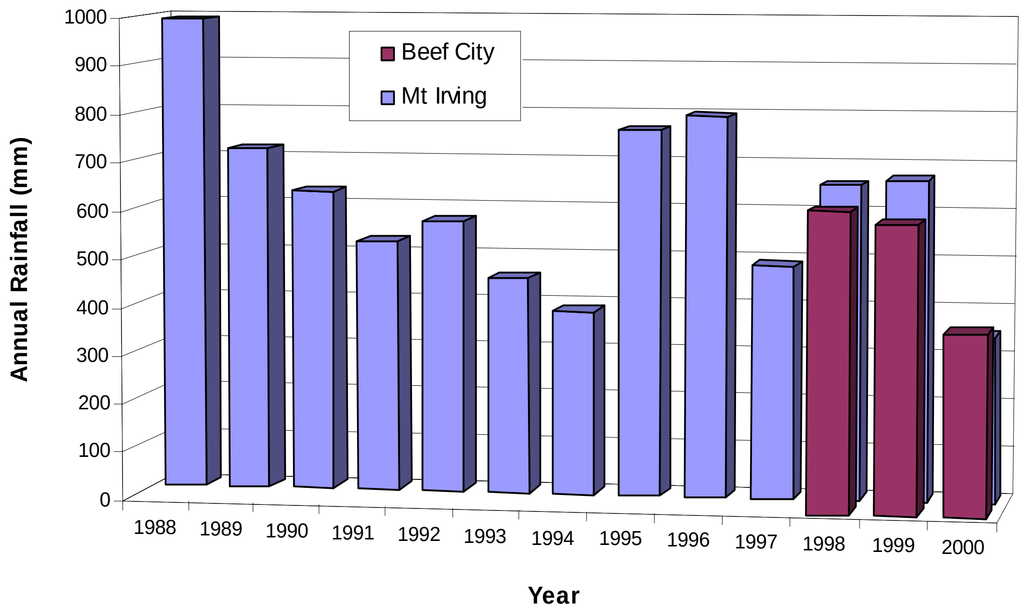

Figure 45: Annual Rainfall (1988 to 2000).

Significant rainfall events for the study period are presented in Table 4.23. These data show that only 5 runoff events were recorded in the period November 1997 to December 2000. Data were lost for several key events for some plots due to clogging of pumps with crop debris. This caused failure of the pumps, which in turn resulted in flooding of the pits and submersion of sensors. The limited data available show that runoff volumes are generally low. Only one exception is noted being a significant runoff event that resulted from rainfall that followed irrigation of the crop. No significant differences occurred in the quantity of plot rainfall runoff as a function of treatment. Visual inspection of the plots following rainfall events indicated a slight trend of reduced runoff with increasing manure application rate (based on depth of runoff held in each collection pit following these events).

Table 4.23: Significant rainfall events and runoff depths for the years 1998-2000

Year	Start Event	End Event	Rainfall events >25mm	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7
1998	28 Jan	31 Jan	48	-	-	-	-	-	-	-
1998	9 Feb	11 Feb	36.8	1.6	6.9	3.3	2.3	2.6	2.0	0.6
1998	21 Apr	21 Apr	37.5	-	-	-	-	-	-	-
1998	2 May	5 May	57	0.9	3.3	1.5	1.5	1.5	1.0	0.7
1998	27 Jun	27 Jun	50	-	-	-	-	-	-	-
1998	6 Jul	6 Jul	50	0.0	1.8	0.7	0.5	0.7	0.3	0.3
1998	26 Jul	26 Jul	40	-	-	-	-	-	-	-
1998	10 Aug	10 Aug	65.5	nd	nd	nd	nd	nd	nd	nd
1998	13 Aug	13 Aug	44	nd	nd	nd	nd	nd	nd	nd

Year	Start Event	End Event	Rainfall events >25mm	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7
1998	22 Oct	23 Oct	55	1.5	1.4	2.1	nd	0.2	1.9	0.8
1999	9 Jan	12 Jan	29	21.5	19.8	4.4	4.0	nd	5.9	5.7
1999	8 Feb	9 Feb	85	nd	nd	nd	nd	nd	nd	nd
1999	1 Mar	5 Mar	70	nd	nd	nd	nd	nd	nd	nd
1999	1 Jul	1 Jul	30	-	-	-	-	-	-	-
1999	22 Jul	22 Jul	29	-	-	-	-	-	-	-
1999	6 Nov	8 Nov	43	-	-	-	-	-	-	-
1999	10 Dec	10 Dec	45	-	-	-	-	-	-	-
1999	17 Dec	17 Dec	28	-	-	-	-	-	-	-
1999	27 Dec	27 Dec	39	-	-	-	-	-	-	-
2000	18 Jan	18 Jan	38	-	-	-	-	-	-	-
2000	28 Jan	28 Jan	37	-	-	-	-	-	-	-
2000	14 Feb	15 Feb	33	-	-	-	-	-	-	-
2000	11 Jun	12 Jun	34	-	-	-	-	-	-	-

- No runoff
nd Data lost

The above data show that the summer and winter rainfalls over the trial period were varied. The rainfall over the summer of 1998/99 was typified by small events. An exception to this was two very large single events that were experienced in early February and early March. The summer rainfall experienced over the summer of 1999/2000 was generally moderate and uniformly spread. This pattern while atypical provided an ideal supply of rain over the maize silage crop growth period. The winters of 1999 and 2000 were generally dry.

4.3.7 Sediment

Sediment samples were collected from the gutters. Masses of sediment collected from the events on August 10 and 13 showed dry masses that ranged from 3 to 17 kg (DB). No relationship existed between sediment mass and treatment. Most sediment collected from gutters was attributed to tillage throwing soil into the gutter, soil sloughing off the edge of the plot into the gutter, rainfall splash of soil into the gutter and, under fallow conditions, wind blown deposition. The collected data on sediment loss (kg/ha) were considered non-representative and were set aside. The gutters also captured large numbers of insects and crop residues (wind blown leaf and straw). The character of the sediment was such that the sediment was considered to be both unrelated to actual sediment transport off the plots by rainfall-runoff and “contaminated” and as such was set aside.

4.4 Work Area 4 - Building Data Sets for the Development of Guidelines on Manure and Effluent Use

The MEDLI model proved to be the most ‘useful’ model with respect to this study of modelling effluent irrigation. This is due to the fact that the model is structured to allow some specific consideration of effluent irrigation scenarios. However, the model is inflexible in the sense that it does not allow consideration of management inputs over time usual to waste utilisation areas (eg. changes in cropping regimes such as the use of a rotation, addition of manures, inorganic fertilisers or ameliorants such as lime and gypsum). Therefore, the model will in the first instance provide a conservative result, but, it also has the potential to provide a worst case outcome because no allowance is made for management changes to the soil-crop system (as would occur in real practice) in response to adverse changes.

4.5 Work Area 5 – Technology Transfer

Technology transfer activities are presented in Table 3.7

5. SUCCESS IN ACHIEVING OBJECTIVES

This study aimed to identify the effects of manure and effluent within the soil-plant-water system. The field studies, conducted in very different environments, have led to the following conclusions and development of best management practices for industry.

Objective 1. To broadly define the upper and lower limits of nutrient and salt concentration in crops commonly grown in feedlots and receiving manure and effluent and provide these data for use in guidelines and design methods.

This objective was not achieved as the range of nutrient concentrations recorded in the field trials were not toxic. It is recommended that the comprehensive data contained in Reuter and Robinson (1997),"Plant Analysis-An interpretation Manual" be used to set these limits.

Objective 2. To describe criteria that express limits of high/excess levels of nutrient and salt in soils receiving feedlot wastes and provide data for use in guidelines and design methods.

Because of the diversity of soils used in reuse areas this was an unrealistic objective. For example in some soils bicarbonate extractable phosphorus concentrations may exceed 200 ppm in their native state whereas this concentration may result in significant in other soils.

Objective 3. To fully define the nutrient and salt cycles in waste utilisation areas by obtaining closure of the mass balance of the key components of the cycles.

3a. Assessment of the best agronomic practices for achieving maximum crop growth whilst minimising loss of nutrients.

Annual manure applications of 20 - 25 kg/ha and a single large manure application of 60 kg/ha increased crop dry matter yields. However, slow mineralisation of manure and prevalence of factors enhancing volatilisation, particularly gentrification, resulted in these rates supplying insufficient N, thus impeding uptake of other nutrients, and reducing potential for maximum crop growth. Supplementing annual manure applications with urea increased DM yield in the years 2 and 3 compared to manure only. In addition, manure applied at a 60 kg/ha in year 1, supplemented with urea in years 2 and 3 produced similar DM yields to the manure treatment receiving annual manure applications plus urea and the inorganic fertiliser treatment. Manure applications also increased the available water capacity of soils which may have indirectly affected yields.

Maximising crop yield maximised nutrient removal. Export of K in plant harvests was in excess of the K applied. This may lead to K deficient crops and consequently K fertiliser may need to be applied. Balancing nutrient requirements by plants enhances recovery of nutrient derived from manure applications. The rate of removal of nutrients is a function of dry matter production and nutrient concentration in plant tissue, both of which are affected by fertiliser, soil type, and the time of fertiliser application. Furthermore, as yields fluctuate widely over a range of conditions, while nutrient concentrations fluctuate less, yield is commonly the major determinant of nutrient removal. Silage crops (corn and sorghum) have a long growing season and produce high dry matter yields. Harvesting regularly for silage production removes substantial quantities of nutrients from the site, especially K.

The recovery of nutrients by crops was lower in manure amended soils compared to treatments receiving inorganic fertiliser only. Subsequent cropping rotations benefited from the residual value of the manure. In the 60 kg/ha manure treatment the residual nutrient enabled crop yields to be maintained in years 2 and 3, compared to the 20+25+20 kg/ha manure and inorganic fertiliser treatments, although extra urea was still needed. Application of 60 kg/ha manure applied once every 3 years produced higher yields and greater nutrient recovery compared to annual applications. Equilibrium in the soil-plant system may be achieved where relatively high manure application rates supplemented with inorganic fertiliser (N and K) are matched with a corresponding high crop removal rate.

3b. Monitoring of soil chemical changes, and quantify nutrient exports and nutrient accumulation derived from different rates and times of manure application to land areas.

Manure applied annually at 20 - 25 kg/ha and once at 60 kg/ha increased available P and S, CEC, TC and pH at the end of 3 years. This compares to the addition of inorganic fertiliser that increased available P and S to a much lesser degree and had little or no effect on other measured parameters compared to manure amended soil. In soils with low buffering capacity cattle manure applied annually or in a large application are likely to accumulate available P in the topsoil irrespective of crop removal. In a pot trial using "Tullimba" soil, bicarbonate P increased from 19 to 311 mg P/kg following the addition of 182 t DM/ha manure. This compares to a black earth from the darling downs in Qld that increased from 262 to 301 kg P/ha (Klepper 1997). Annual manure applications with and without urea applications in the second and third year increase available P, compared to the single large application of 60 kg/ha. Supplementing crops with urea utilised soil nutrient pools derived from 60 kg/ha manure by maximising yield and uptake of P. Over time and with continuous cropping, soil available P stores will decline without the addition of P in manure or fertiliser. Additionally, in these soils loss of P in water is related to concentration of available P in soil. There is evidence that manure applied either annually or in one 1` application decreased P sorption. Isotherms showed manure decreased the P sorbed at an equilibrium solution concentration of 0.2 mg/L.

The slope of the isotherms (hence the buffering capacity) did not; appreciably after 2 years of manure application, suggesting the shift of the isotherm along the x-axis primarily due to additions of P rather than the blocking of retention sites by organic anions derived from the manure. Future annual manure applications may shift the isotherm further consequently increased adsorption and decreasing the amount of P required to achieve a given increase in solution P and he increasing potential P loss to the greater environment. While similar crop yields were achieved with combination of manure and urea compared to inorganic fertiliser over 2 years, soil ameliorating quality of manure were superior to those obtained from inorganic fertiliser applications. This was evident increased organic carbon, and CEC of the soil which would increase the retention of cations derived from manure applications. These ameliorating qualities along with the undecomposed nutrient reserve manure treatments will benefit future cropping rotations while maintaining soil integrity.

3c. Determination of rates of manure applications likely to cause excessive levels of nutrient waterways.

Manure applications produced the highest levels of nutrients in surface and subsurface flows in between crop rotations. Over 2 years, all treatments exceeded the levels of NO3 - N and P defined in ANZE water quality guidelines as being detrimental to water health, although this concentration would be diluted in streams. Furthermore, entrapment and sorption prior to this runoff water reaching water bodies would reduce these concentrations of nutrients in solution. In practice, a buffer strip between the land re area and watercourses would assist with lowering the nutrient concentration of surface and subsurface runoff. An active plant production system, along with increased water retention in manure treated soil reduced the nutrient load leaving the system, except for P. The decrease in P sorption and additional inputs in year 2 to the manure treatment receiving annual applications resulted in more P lost in surf and subsurface water in year 2, compared to the 60 kg/ha manure treatment which lost very little in year

Surface runoff from agricultural land is commonly accompanied by sediment transport. Manure solids may also be lost directly via runoff, with or without sediment loss, although low slope, continual crop cover and shallow incorporation of manure following application reduce loss of nutrients and maximise uptake of nutrients by crops. Similarly, land classes suitable for manure and effluent application preclude application of manure and effluent to sites prone to erosion.

Although effluent was unavailable during part of the time of the experiment, when it was applied in year 2 no effect was observed. Given the amount of nutrients especially P and K in manure compared effluent, little effect on soil stability and nutrient concentration of runoff might be expected. Furthermore the SAR and EC of effluent indicate no salinity or sodicity problems.

Objective 4. To balance the inputs and outputs of the soil-plant system receiving feedlot manure and effluent to define safe levels of waste application and acceptable levels of nutrient and loss from the system.

After 3 years, manure and inorganic fertiliser treatments recorded gains in P, S, and Na, and, a loss of N contained in the soil. The apparent gain in K indicated by the final K content of the soil at the end of 3 years is inconsistent with the K exported being greater than that applied and the progressive decrease exchangeable K. It is suspected that the analytical procedure used to determine total soil K is in error.

In quantifying the distribution of nutrients derived from manure and effluent within components of the plant system, it is important to consider such factors as waste characteristics, the rate of mineralisation nutrients in manures to ionic forms, and nutrient mobility. Large crop export of nutrient minimum leaching and sediment removal of nutrient derived from manure additions. Repeated manure applications may only be sustained through an understanding of the residual value of manure, crop nutrition and means of removal and losses associated with such additions to the soil-plant system.

Objective 5. To draw together, research data and data from other sources, via simple models, the development of BMP's and design methods for sizing land areas for feedlot manure effluent application.

The MEDLI model proved to be the most 'useful' model with respect to this study of modelling effluent irrigation. This is due to the fact that the model is structured to allow some specific consideration of effluent irrigation scenarios. However, the model is inflexible in the sense that it does not allow consideration of management inputs over time usual to waste utilisation areas (eg. changes in cropping regimes such as the use of a rotation, addition of manures, inorganic fertilisers or ameliorants such as lime and gypsum). Therefore, the model will in the first instance provide a conservative result, but, it also has the potential to provide a worst case outcome because no allowance is made for management changes to the soil-crop system (as would occur in real practice) in response to adverse changes.

The results from the Tullimba field trial indicate that manure that is surface spread should be incorporated to a shallow depth and then sown with forage crops immediately after. This reduces loss of nutrient by sediment and in water flows. Australian climatic conditions often permit summer and winter crop production. To maximise nutrient recovery and export via crop harvests continuous cropping of forage crops should be employed. Continual cropping ensures maximum benefit through reducing nutrient build up in the soil and losses via volatilisation and water flows. It is important to export the crop material away from the manure and effluent reuse area. The material may be sold off-farm or used for silage in the rations. Manure applications to the reuse area must be postponed if annual soil tests indicate excessive levels of nutrient content in the soil. Continued cropping supplemented with inorganic fertiliser will reduce these levels over time.

The application rate of manure to land areas is site specific. Factors such as method of handling, storage of manure and effluent and the resulting chemical composition, land spreading operation, soil fertility and nutrient buffering capacity, and climatic conditions will determine the rate of nutrient availability to plants. Manure sub-samples taken at the time of application for chemical analysis indicate additions of nutrients. Generally, manure applications require subsequent inorganic N additions to balance the nutritive requirements of crops. Crop tissue analysis allows timely application of inorganic fertiliser assisting in avoiding potential deficiencies or induced toxicities that reduce dry matter yields. Forage crops producing high yields result in a large export of nutrients which can be in excess of nutrient additions. In particular, the export of K from forage crops is greater than that from grain crops (Tisdale et a/., 1995) so that K may become deficient in manure amended soil and need supplementing with inorganic K. In addition to plant tissue analysis, monitoring inputs and exports of nutrient along with changes in soil fertility will be fundamental in maintaining plant nutrient requirements.

Australian soils are generally very low in P, although not the black earths of the Darling Downs, which play host to 2/3 of Australian feedlot establishments. These soils have a high buffering capacity, and most of the P applied as manure precipitates with Ca (Klepper, 1997). The high buffering capacity of black earth soils allows for high application rates of manure, whilst maintaining high plant yields and avoiding significant losses of P to the environment. For soils subject to long-term manure applications addition of inorganic N fertiliser may be required to maximise plant yields and hence P exported and the build up of excessive levels in the soil. When calculating permissible nutrient loadings, there is a need to take into account initial P status and P buffering capacity of the soil and changes in P sorption on adding manure.

The lower the fertility of the soil, the greater the value of manure. In the "Tullimba" soil applying 60 kg/ha or less per 3 or 4 years compared to current industry practice of annual applications of 20 - 25 t/ha has some advantages. It limits the amount of cultivations thus reducing deep and shallow soil compaction stemming from manure spreading operations and minimises disturbance of the soil structure. In addition, the combination of residual nutrient from further decomposition of manure with inorganic fertiliser in order to balance crop nutritive requirements allows depletion of nutrients derived from manure and thus reduction of pollution potential. If manure is applied annually, plants will take up the rapid flush of readily mineralisable nutrients derived from manure and not source residual nutrients released from manure over time. Manure is usually traded, freighted and spread at tonnage rates, and the moisture content of the manure has a large impact on the cost of applied nutrients. Aside from moisture variation of manure from year to year the monetary savings achieved by applying manure once over 3 to 4 years comes about via less cultivations and labour associated with manure and cultivation operations. Consequently, applying inorganic fertiliser between manure applications made every 3 to 4 years compared to spreading manure annually provides both environmental and economic benefits.

Monitoring and detailing of crop removal of nutrients and soil fertility status as required by current legislation leads to increasing the overall efficiency and ecological sustainability of manure and effluent application to land. This short-term study provided evidence that provided best management practices are implemented feedlot manure should not lead to unmanageable and unacceptable levels of soil and watercourse contamination.

6. IMPACT ON MEAT AND LIVESTOCK INDUSTRIES - NOW AND IN FIVE YEARS TIME

This research has demonstrated that feedlot manure can be safely used to produce large quantities of forage. The nutrients contained in the manure and effluent are a valuable resource that, when balanced with inorganic nutrients to meet plant demand, can earn additional income for the feedlot. This information should be incorporated into BMP'S for the industry and when this is done there should be an immediate impact on the industry. Provided in the suite of recommendations made from this research then the industry should continue to benefit beyond five years.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Feedlot manure is a valuable resource, which when used properly can generate feed for the feedlot and earn additional income. The results from the project are complete but unfortunately the trial was conducted only over 3 years. Longer term measurements would have provided the industry with clearer guidelines to cover long term use of manure and effluent.

7.2 Recommendations

(a) It is essential to measure the nutrient composition of each batch of manure before application.

(b) Soil analysis of the disposal area should be undertaken prior to application. P sorption capacity ne' to be measured to avoid P loading and samples should be analysed down the profile.

(c) The rate of application should consider

(i) potential plant production,
(ii) risk of surface nutrient loss (rainfall, slope, infiltration rate
(iii) The soils capacity to retain nutrients,

(d) 4) Manure should be applied as close as possible to planting of the crop to minimise risks of loss to environment. Manure should be well composted to reduce the risk of pathogen contamination of soil.

(e) 5) If analysis of the manure indicates a low concentration of a particular nutrient then a starter application of that nutrient should be made to maximise the utilisation of the other nutrients in manure. If the analysis shows a gross deficiency then top-dress applications may need to be made

(f) 6) Crops should be sown at very high seeding rates to establish ground cover and a nutrient sink quickly as possible.

(g) 7) The N status of the crop should be monitored by coloured charts, or a SPAD meter and supplemental additions of N made as required to maximise the utilisation of the other nutrients in the manure.

(h) 8) Relay cropping should be practiced to provide a nutrient sink. Cultivation should be avoided between crops to maintain soil surface characteristics favourable for infiltration.

(i) 9) Large infrequent applications are preferable than smaller annual additions as the need for reg incorporation, which destroys soil structure, is reduced.

(j) 10) Real time monitoring of soil moisture with an Enviroscan should be encouraged to optimise moisture conditions for plant growth and reduce the risk of nutrient loss in surface runoff subsurface flow.

(k) 11) The yield and nutrient content of harvested forage must be monitored to avoid nutrient overload or depletion. This method of measurement is more sensitive than total soil analysis.

7.3 Future Research

The possible effects of long-term effluent applications to land areas with and without manure addition requires greater definition. Changes in the soil chemistry such as ratio of exchangeable cations in the and potential nutrient leaching to the greater environment resulting from effluent additions n investigation.

Nutrients from manure additions that are not recovered by crops require partitioning in order to gain understanding of the rate of availability. By quantifying changes in the amounts of available and unavailable forms of nutrient over time, the rate of turnover of nutrients in subsequent cropping rotation may be assessed. The rate of decomposition will vary depending on locality subject to climatic and conditions.

Potentially, a manure application rate less than 60 kg/ha and greater than 20 kg/ha, applied once every 3 years may provide the physical and chemical benefits of 60 kg/ha, but reduce the quantity of P lost in water flows following application. At the same time an intermediate rate applied once every 3 to 4 years may avoid the problem observed with annual manure applications of increases in available P over time. In addition, the application of urea in year 1 may increase crop yield and P export, further reducing pollution potential following application.

Literature pertaining to the effect of manure on soil pH is conflicting. Whether manure increases or decreases pH for a variety of soil types requires further investigation, in particular for the black earths of the Darling Downs. In these soils P buffering capacity is attributed to precipitation of P with Ca, which is abundant in black earths. A decrease in pH would solubilise Ca phosphate and could lead to excessive high levels of P in plant available form.

The efficiency of a grassed buffer strip located between the manure and effluent reuse area and waterways which is harvested occasionally, in lowering nutrient concentration of surface runoff and subsurface water from the reuse area needs investigation. Considering that manure decreases the soils capacity to sorb nutrients which may allow loss by water flow, a buffer strip not receiving manure additions that sorbs organic and inorganic ions and entraps sediment bound P may prove successful in further reducing P lost from the site.

8. BIBLIOGRAPHY

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9. APPENDICIES

Appendix 1.
Klepper K (2001). The Safe Utilisation of Beef Feedlot Manure and Effluent for Forage Production on a Duplex Soil in Northern NSW, Australia. PhD Thesis, University of New England, Armidale, Australia.

Appendix 2.
Ahmad R (2001). Impact of Addition of Feedlot Manure and Effluent on Crop Yield, Soil Physical Fertility and Hydrology. PhD Thesis, University of New England, Armidale, Australia.